Life-Cycle of Engineering Systems:
Emphasis on Sustainable Civil Infrastructure

Editors
Jaap Bakker, Dan M. Frangopol
and Klaas van Breugel



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Emphasis on Sustainable Civil Infrastructure

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Preface

Nowadays, the analysis, design, construction, inspection, monitoring, repair, maintenance and optimal management of infrastructures require the consideration of the life-cycle of systems under uncertainty. The objective of the International Association for Life-Cycle Civil Engineering (IALCCE, http://www.ialcce.org), founded in 2006, is to promote international cooperation in the field of life-cycle civil engineering for the purpose of enhancing the welfare of society. Its mission is to become the premier international organization for the advancement of the state-of-the-art in the field of life-cycle civil engineering. IALCCE encompasses all aspects of life-cycle assessment, design, maintenance, rehabilitation and monitoring of civil engineering systems. The First International Symposium on Life-Cycle Civil Engineering (IALCCE'08) was held inVarenna, Lake Como, Italy (June 10–14, 2008), the Second International Symposium on Life-Cycle Civil Engineering (IALCCE2010) was held in Taipei, Taiwan (October 27–30, 2010), the Third International Symposium on Life-Cycle Civil Engineering (IALCCE2012) was held in Vienna, Austria (October 3–6, 2012) and the Fourth International Symposium on Life-Cycle Civil Engineering (IALCCE2014) was held in Tokyo, Japan (November 16–19, 2014). The Fifth International Symposium on Life-Cycle Civil Engineering (IALCCE2016) has been organized on behalf of the IALCCE under the auspices of Infraquest, a collaboration between the Dutch Rijkswaterstaat, TNO and the Delft University of Technology in Delft, the Netherlands. The interest of the international civil engineering community in areas covered by the IALCCE has been confirmed by the significant response to the IALCCE2016 call for papers. More than 400 abstracts from 48 countries were received by the Symposium Secretariat, and approximately 75% of them were selected for publication. Contributions presented at IALCCE2016 include state-of-the-art as well as emerging and innovative applications related to key aspects of the life-cycle civil engineering field.

All major aspects of life-cycle engineering are addressed, with special focus on structural damage processes, life-cycle design, inspection, monitoring, assessment, maintenance and rehabilitation, life-cycle cost of structures and infrastructures, life-cycle performance of special structures, and life-cycle oriented computational tools.

The theme of IALCCE2016 is "Civil Engineering from a life-cycle perspective". The symposium will devote special attention to meet the following four objectives: (a) better control of asset performance over the life-cycle; (b) better value over the life-cycle; (c) improved control of asset-related risks; and (d) reducing the environmental impact to society.

Life-Cycle of Engineering Systems: Emphasis on sustainable civil infrastructure contains the papers presented at the Fifth International Symposium on Life-Cycle Civil Engineering. It consists of a book of extended abstracts and a USB card with 333 full papers, including the Fazlur R. Khan lecture and 9 keynote lectures.

The aim of the editors is to provide a valuable source for anyone interested in life-cycle of civil infrastructure systems, including students, researchers and practitioners from all areas of engineering and industry.

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Carbon choices: Bringing CO_2 into life-cycle decision-making

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ABSTRACT: Only recently has the evaluation of the embodied carbon of building materials and construction processes been possible. Practical and timely embodied and operational carbon accounting is an evolving science, with life cycle thinking being the key to organizing the information and bringing clarity to decision making processes. This paper considers the state of environmental life cycle analysis (LCA) within the United States from a structural engineer's perspective. It includes recent information from the concrete, steel, masonry, and timber industries; efforts to collect, disseminate, or manage life cycle data; and the results of three case studies on its use. The paper also proposes guidelines for considering environmental LCA data for triple-bottom-line decision making. Aligning with the principles behind a USA LCA Practice Guide for Low Carbon Construction that is under development, a multi-step process is suggested with LCA evaluations within the design, procurement, and as-built milestones of a project.

1 OVERVIEW

The environmental impacts of our infrastructure choices are regularly considered, but only recently has life cycle analysis (LCA) of our building materials and construction processes become credibly possible. While LCA often asks and reports data from a variety of environmental impacts, the Global Warming Potential (GWP) (often dominated by and measured as the CO_2 impacts) is frequently the easiest of these impacts to articulate to the general public and is arguably one of the variables of greatest importance to track today.

There are more potent chemicals that impact GWP, such as methane CH_4, but the concentration build-up of CO_2 (carbon) is driving global warming concerns. Other important variables for reporting GWP include embodied energy consumption which can bring with it the scientific and social implications of energy policies around the globe. Energy that is not used to make steel, for example, can be directed to other societal needs, or conserved and not expended at all. Because embodied energy and embodied carbon often go hand in hand, and because excess CO_2 is driving global warming concerns, the focus of this paper is restricted to the embodied carbon impacts of building choices.

Practical and timely embodied and operational carbon footprint accounting is still an evolving science, with variability in the industry on when and how to best use this information. Life cycle thinking, though, is the key to organizing how this information gets used and to bringing clarity to its value in decision-making processes.

This paper presents the state of environmental LCA within the United States from a structural engineer's perspective and provides an overview of some of the most significant topics being considered in this rapidly growing field of study. As an abbreviated summary of who is doing what, it includes updates on recent information releases by the USA concrete, steel, masonry, and timber industries and efforts by Green Building rating systems, LCA software providers, and other industry organizations to collect, disseminate, and/or otherwise manage this data.

With the need for credible and actionable LCA information as part of a project's decision-making process, this paper also proposes an organization for when, and to what level of detail, environmental LCA data should be considered. The outline of a multi-step process is suggested, with LCA evaluations included as part of the design, procurement, and as-built milestones of a project's delivery.

2 HISTORY OF ENVIRONMENTAL LCA IN THE UNITED STATES

Environmentally-focused LCA took a major step forward in the 1990s, when the International Organization for Standardization (ISO) defined its ISO 14044 series, providing a general LCA approach. ISO 14044 defines LCA as the "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle." LCA methods have also been formalized by the British Standards Institute's PAS 2050, the World Resources Institute Protocols, and ISO 14067 (Skone, 2013).

Most recently, the Athena Sustainable Materials Institute defined LCA as "a scientific method for measuring the environmental footprint of materials,

products and services over their entire lifetime" (Athena SMI, 2016).

For clarity of discussion in this paper, life cycle costing (LCC) is a life cycle approach (typically cradle-to-grave) which considers the direct monetary costs related to a product or service. LCA is similar, but the quantified data is typically direct environmental impacts, such as global warming potential, ozone depletion, land/water acidification, eutrophication, tropospheric ozone, and non-renewable energy use (U.S. Green Building Council, 2013).

While there is considerable activity around the topic—most of it well intentioned and with the ultimate hope of reducing the speed of global warming—there is not consensus on how to best use LCA principles and data. The green rating systems also do not yet provide consistent guidance for how LCA should be fully executed within their standards. Many practitioners who attempt to track carbon emissions for upcoming or completed projects also find the data sometimes inaccessible or inconsistent, or the processes by which to evaluate the data difficult to implement.

LCA is an evolving field, and it would be misleading to imply that all involved parties have the same objectives. Yet there are more common themes and activities than differences, with its impact on the future of the design and construction industry just beginning to be realized. It has the potential to transform many of our design and decision-making processes. As the impacts from global warming increase, LCA evaluations become a measure by which to answer public comments with credible scientific and quantified data in ways not previously possible.

There are several LCA terminologies that are useful to understand. Product Category Rules (PCRs) are guidelines that define industry-specific measurements agreed to for the purpose of producing an Environmental Product Declaration (EPD). PCRs provide the structure needed to report the results of EPDs and are typically developed with the input of industry trade organizations for which the PCR covers (Carbon Leadership Forum, 2015).

An EPD declares the environmental impacts of a product over its expected life, similar to a food nutrition label. An EPD should be third-party verified and made public upon completion. An EPD and the respective PCR should, at a minimum, be compliant with ISO 14025 and 21930 and be posted in their entirety.

Herein lies one of today's fundamental challenges with LCAs. The industry- and material-specific PCRs are often not cross-compatible, as they do not always use the same boundary conditions or consider variables in the same way. Even LCA experts knowledgeable about the differences cannot always make practical apples-to-apples comparisons. As an example, it is difficult to directly evaluate timber land use issues against steel and concrete environmental impacts.

Attempting a whole-building LCA with today's data, while imperfect, can be done through a strategy

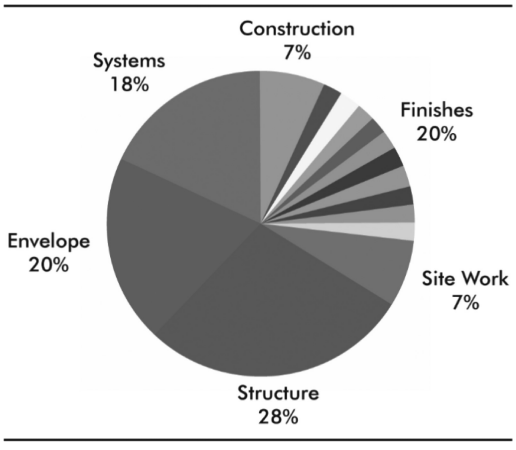


Figure 1. Percentage breakdown of embodied carbon within a 25-story hotel.

of reducing the number of variables considered and focusing on only the most significant influences as a means of getting closer to more comparable results. Such focus also begins to bring clarity to data comparisons within the design and decision-making processes. While LCA often requests and reports data from multiple impact categories, looking at the GWP, typically defined as the embodied CO_2 of a design, is perhaps the most understood and meaningful of these variables.

Thus, LCAs which focus on GWP, and which consider the relative impact of system choices and optimization studies within the same collection of materials, are some of the most meaningful LCA studies to date. Within the building industry, prior LCA studies by MKA and others have also shown that the structure is typically the single largest component of the embodied-carbon footprint for new construction projects (see Figure 1). Given the limited number of materials and industries that produce the structural frame for buildings, and with LCA focusing on optimizing those materials and reducing their production carbon footprints, the structure becomes a high-value investment of time and energy for current LCA discussions and comparisons.

In one recent MKA case study of a 25-story hotel, reducing the structural embodied-carbon footprint of the hotel by 50% identified 2500 metric tons of carbon for reduction, equaling approximately 6 years of operations carbon for the building. By considering both embodied and operational carbon impacts, tradeoffs could be considered within the design process to achieve best value from a global warming perspective over the life of the project.

3 MATERIAL UPDATES

LCA evaluations only work if the industries evaluated engage in the process and come forward with

meaningful and transparent data sets. Some industries are more progressive than others, and this can certainly be a loaded topic for debate. Public pressure to be seen as part of the global warming solution, combined with inter-material competition, is helping push PCR and EPD information forward.

A solid case for data transparency over time comes from the watchful eyes of competing industries and their identification of false or misleading claims by others, or from collaborative efforts between two material supply industries. With time, information from large, commodity-based material suppliers becomes hard to hide. There is thus much hope that the field of available LCA data will continue to grow and improve.

Following are updates on some of the most recent activities in the primary structural material supply industries of concrete, masonry, timber, and steel.

3.1 *Concrete*

Within a building, few materials can achieve the same function as concrete. It is often the largest volume of material and the largest carbon footprint of any single building element. Because of this, concrete can present the best opportunity for optimization and reduction in the embodied-carbon footprint of a project.

Calcium carbonate (limestone), or $CaCO_3$, comprises 70% of the base material used to make Portland cement. When heated, $CaCO_3$ reduces to Calcium Oxide CaO and Carbon Dioxide CO_2, with the CO_2 off-gas equaling approximately 0.5 kg of CO_2 for every kg of Portland cement created. An economic way to substantially alter this production process has not been commercially developed, although promising alternatives to Portland cement are in the experimental and early product development stages. Until such alternatives gain more industry-wide traction, optimization has come partly through energy efficiency gains of 16% in USA cement plants brought about by operational changes (Boyd & Zhang, 2011).

Most concrete CO_2 optimization processes come from paying attention to cement sourcing and corresponding plant efficiency, combined with cement replacement or reduction strategies at the ready-mix plant.

Complementary cementing materials (or CCMs) directly reduce cement content requirements but can impact the performance of the concrete in ways that are not always beneficial to a project's needs. Up to 100% cement-replacement concrete is possible with CCMs, but it is not always practical nor suitable for all locations in a building. This is especially true where strength gain delays impact formwork stripping schedules. Tertiary CCM mix blends that include both fly-ash and either silica fume or slag, in addition to Portland cement, have shown good results in more advanced mix designs, achieving some of the lowest CO_2 mix design footprints. CCMs are an important part of the discussion, but their use needs to be carefully considered.

LCA evaluations of the ready-mix industry by MKA and others have led to "rediscovery" of another

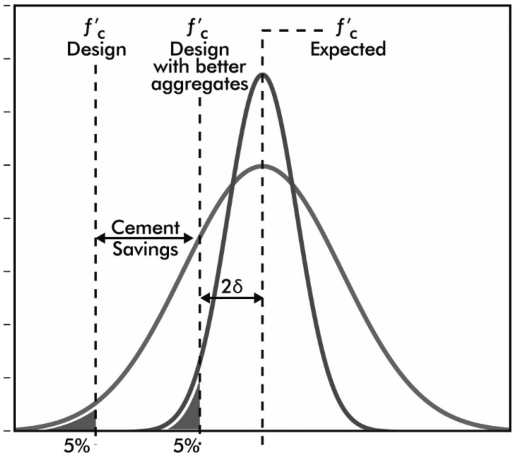


Figure 2. Concrete mix optimization through aggregate and quality control improvements.

critical location for optimizing concrete: batch plant quality control and material consistency, especially regarding the quality and consistency of the aggregate supply. This can change the cement requirements to reliably achieve certain concrete strengths by up to 50%.

This finding has recently led the Los Angeles market into some fundamental changes. After a number of mix design comparisons among the USA West Coast cities of Seattle, San Francisco, and Los Angeles, it was found that the Los Angeles mixes for the same concrete strengths used considerably more cement.

With further research, the reasoning for this anomaly came from an inconsistent and poor-quality regional aggregate supply and batch plant quality control. Recently, though, Los Angeles and other Southern California markets have started importing much of their high-strength concrete aggregates from the Northwest, where quarries are able to deliver consistent, quartz-based rock at a more competitive price.

In addition to several improved material advantages from the better aggregate with less cement, including improved modulus of elasticity, shrinkage and heat of hydration control, LCA studies found barge-shipping carbon footprint impacts are small compared to the CO_2 savings achieved through using less cement.

On a national level, the National Ready Mixed Concrete Association (NRMCA) has shown significant leadership in advancing the use of LCA within the USA. NRMCA continues to take a mature view of the issues, leading many in the construction industry to make their production processes more efficient and potentially more profitable, while addressing global warming impacts head-on. NRMCA has helped generate both concrete PCRs and industry-average EPDs for use within the USA. This ability to provide mix-specific EPDs is not far from becoming available on a much wider scale, with several suppliers in the San Francisco and Seattle markets already taking this leap.

3.2 *Masonry*

In conjunction with ASTM, the masonry industry, led by the National Concrete Masonry Society (NCMA), generated its own PCR, officially issued in December 2014. This PCR has been defined to cover a wide range of manufactured concrete units, including concrete masonry units (CMU), segmental retaining wall units, and other unitized products made by manufacturing equipment with the help of mechanical vibration and compaction.

There are currently two ASTM-verified EPDs that use the USA-based ASTM masonry PCR. These EPDs, published by Air Vol Block and Angelus Block in August 2015 and March 2015, respectively, cover a total of 27 mix designs that can be used in 30 different unit configurations. Angelus Block released the first version of their internally verified EPD in November 2013. This EPD was later re-released as the March 2015 ASTM-verified EPD (Angelus Block Co., Inc., 2015).

New technologies aimed at decreasing the environmental impacts of the concrete and masonry industries are also emerging.

3.3 *Timber*

The USA timber industry follows the PCR produced by FPInnovations (FPI), first published in November 2011. FPInnovations is a Canadian not-for-profit research and development group that supports the global competitiveness of the Canadian forest sector. The PCR applies to a variety of timber products in North America, including softwood lumber, softwood plywood, oriented strand board, glued-laminated timbers, laminated veneer lumber, wood I-joists, redwood decking, medium-density fiberboard, and particleboard (FPInnovations, 2011).

EPDs for these products can be accessed through the American Wood Council (AWC) or the Canadian Wood Council (CWC). The current documents, valid for 5 years, were issued between April and November 2013. The EPDs include aggregated data from multiple manufacturers across North America, and their scope is limited to "cradle-to-gate." This is because of the variety of product options following the timber manufacturing process, so the "gate-to-grave" phase of their life cycle is not considered.

Timber EPDs do not yet adequately measure the potentially negative impacts of the tree-harvesting process on carbon storage naturally supplied by forests, such as the amount of carbon released from soil disruption or the carbon sequestered from the trees continuing to grow. Trees naturally sequester carbon from the air, and when they are cut down, the forest carbon-storage capacity is reduced.

While not yet referenced within timber EPDs, recent studies have investigated this topic and how the rate and quantity of trees harvested for timber production affect a forest's capacity for carbon storage. While this science is still evolving, several studies provide much-needed early guidance on this topic.

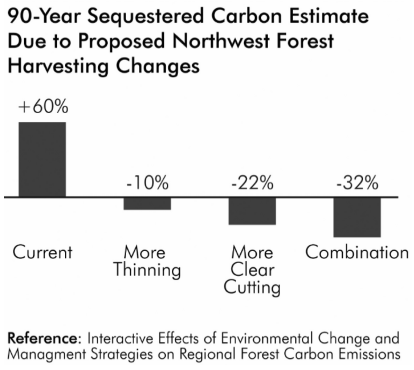


Figure 3. Carbon sequestration estimates.

As an example, looking at the embodied carbon of a 2×4 and ignoring land use issues, an argument can be made that the sequestered carbon for two different 2×4s is the same. However, if the boundary is expanded to include the forest ecosystem and disrupted land use implications from harvesting, the sequestered carbon impacts can vary significantly based upon the harvesting practice and rotation cycle.

Comparing an 80-year rotation versus a 40-year rotation in a mixed Douglas fir/western hemlock vegetation (of medium site productivity), every board foot of lumber that comes from the forest on an 80-year rotation has been reported to represent 32% more carbon storage than a board foot of lumber that comes from a forest on a 40-year rotation (Harmon et al. 2009).

Similarly, when looking at sequestered carbon based upon harvest practice intensity, a recent Oregon State University study showed that current harvest practices resulted in a 60% increase in sequestered carbon over a 90-year duration (including modeling assumptions for forest fires and other impacts), compared to a 32% reduction in sequestered carbon from a proposed increase in thinning and clear-cutting that was being studied (Hudiburg et al. 2013) (see Figure 3).

The first version of FPI's PCR for the North American wood industry calls for GWP estimation to account for biogenic and fossil fuel emissions captured by wood products but "does not include adding or subtracting changes in soil carbon during forest growth up through harvest." This accounting method applies only to the product itself and not the forest system from which it is harvested. The PCR indicates that the producer of timber products is not responsible for tracking forest carbon stocks in a given region (FPInnovations, 2011).

The second version of FPI's PCR was published in June 2015 and, similar to its predecessor, calls for GWP to "reflect CO_2 from air captured in the forest and retained in the product." In the new PCR, some guidance is provided to track greenhouse gas (GHG) emissions occurring as a result of deforestation from harvesting operations, though they are to be documented separately in the report (FPInnovations,

2015). The AWC/CWC EPDs do not yet reflect this most current PCR or the forest carbon-sequestration issues noted above.

Another example of recent guidance for addressing carbon-sequestration issues within a forest can be found in Microsoft's Nisqually Carbon Project. As part of a carbon-offset program, Microsoft purchased 2.1 square kilometers (520 acres) of private forest land for the purpose of allowing the forests to grow for 80 years prior to cutting, instead of the current rotation of cutting every 40 years. For this project's site-specific study, the carbon sequestered after 40 years will double over its starting condition from 55,750 metric tons of CO_2 per square kilometer (223 metric tons per acre) to 111,500 metric tons of CO_2 per square kilometer (446 metric tons per acre) when still un-cut at 80 years. If the forests were harvested and re-planted at the start of the project, the baseline estimate was that 42,250 metric tons of CO_2 per square kilometer (169 metric tons per acre) would have been sequestered over the same time period, a reduction of 13,500 tons per square kilometer (54 metric tons per acre) (Natural Capital Partners, 2016) (Nisqually Land Trust, 2016). A non-trivial challenge is that timber cut rates need to be maintained at a sustainable level in order to have material available on an annual basis into the future, and for forestry jobs to stay viable for the long term. The Hudiburg study was based upon an annual cut rate of 2.2% per year for in-production forests, to represent current forest practices in the Pacific Northwest, which is close to a 40-year return period harvesting cycle (Hudiburg et al. 2013).

Timber is clearly a low-carbon potential alternative in the right building construction applications, especially when it is FSC-certified timber that is harvested using sustainable practices. Its carbon accounting, though, needs to include forest-scale sequestered carbon impacts.

If renewable fiber grown material is to significantly increase in production from current building volumes, considering faster-growing plant stock that can sustain harvest rates more frequent than 40 to 80 years needs further research. While the industry is still only a fraction of the size and scale of current soft-wood forestry operations, bamboo likely holds the most significant promise for this, as it is one of the fastest-growing plants in the world (Farrelly, 1984).

Alternative fiber grown materials for construction applications is an area of further research that will likely expand with time.

3.4 *Steel*

Steel is unique in what it does for building designs, and it often is used in combination with other materials as an indispensable part of the building construction process. Like concrete, steel is integral to our industry and will not go away in any foreseeable future. The steel supply industry's approach to LCA, though, is varied. It ranges from progressive LCA advancements from several Europe-headquartered companies to a wait-and-see attitude from many USA suppliers to avoidance of the topic from some suppliers in Asia, most specifically in China. The world's steel supply also includes two starkly different production processes, without a consensus on how to handle LCA data. To date, the industry is collectively resisting efforts to specifically identify the mills from which material is produced. This is partially because of inventory control and tracking limitations, but also because of the differences in creation processes; many steel suppliers have both blast furnaces and electric arc furnaces within their plant portfolio. Limited but useful information is available through the World Steel Association, including their current thoughts on LCA (World Steel Association, n.d.). Blast-furnace smelting is used in plants that use iron oxide ore, coking coal, and other basic mined elements to make steel products. Steel that requires high material and dimensional quality control, such as sheet and plates, typically comes from a blast furnace (car bodies, steel coil, light-gauge metal studs, decking products, and more). In addition to the high energy demands needed to create molten pig iron and its steel derivatives, the chemical reaction required to produce first-generation steel is generally described as $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$ (Trabucco et al. 2015).

The high CO_2 off-gas from the reaction with iron oxide and the burning of coking coal are significant contributors to global steel manufacturing CO_2 emissions, making recycled steel an important part of lowering the material's CO_2 footprint. The total energy required to make 1 metric ton of liquid steel using a blast furnace/basic oxygen furnace is approximately 22,040 MJ/metric ton (19 million BTU/ton). The total energy required to make 1 metric ton of liquid steel in an electric arc furnace is about 7.424 MJ/metric ton (6.4 million BTU/ton) (including electrical energy, burners, and other chemical energy) (EPRI, 1997). Blast furnaces exist around the world and are heavily used in China and Russia, where coal-fired energy production and natural gas are most economically available. China is the leading world supplier by volume of steel, especially sheet steel product, and largely is a blast-furnace production supplier.

Structural rolled shapes and rebar production, however, are often not made from virgin material, especially when sourced from Europe or the USA. Because of the high-volume but lower-characteristic material demands, much of this material is from second- or third-generation recycled steel, melted and re-cast from an electric arc furnace.

Electric arc furnaces are most prominent in disposable-economy world markets, such as the USA and parts of Europe, where scrap steel is readily available. Rolled steel shapes, such as those produced by Arcelor Mittal in Luxembourg, or rebar such as that made by Nuccor in the USA, are from electric arc furnaces, with recycled steel often 80 to 95% of the feed stock.

Electric arc furnace steel has a CO_2 footprint that is mostly a function of the cleanliness of the electrical

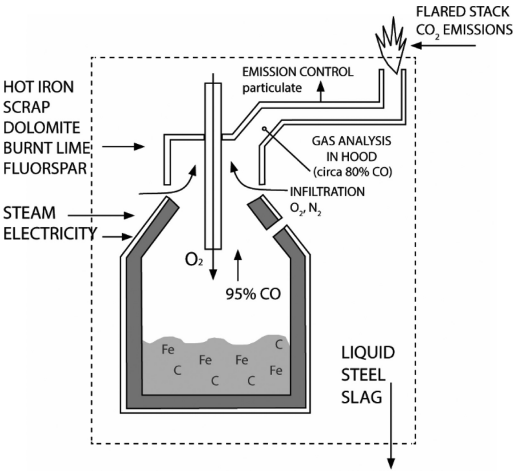


Figure 4. Arc furnace.

grid supplying the mill, with a secondary heating process prior to rolling that is often from burning natural gas (methane CH_4). In places such as Seattle's Nuccor plant, where the input feed stock is 80 to 90% recycled product and the electrical grid is almost 100% hydroelectric, the steel produced is some of the lowest-carbon-footprint steel available. The same can be said for certain plants within Europe and South America, where the electrical grid is nuclear, hydro, or renewable. When the electric arc furnace gets its power from natural gas or coal, there is a significant increase in the material's CO_2 footprint, though less than from a blast furnace (Figure 4).

When engaging in a "low-to-no" carbon building design competition in Sweden, one of the conclusions MKA reached was that it is more CO_2-optimized to use building steel products from a mill utilizing an electric arc furnace with a low CO_2 footprint electrical grid than any comparative building geometry considered.

Using industry average data for early LCA project studies combined with mill-specific sourcing requests at the procurement stage for approximately 90% by volume of the project's steel stage has produced our most accurate structural frame GWP LCA efforts to date. The plant-specific data request should consider the recycled content percentage of the steel materials and either plant-specific EPD information or a basic understanding of the electrical grid and natural gas usage at the location of the plant producing the material in addition to the plant's operating efficiency (MJ/metric ton (BTU/ton) of steel produced) (Carma, 2016). It can be generally assumed that building steel products with a recycled content exceeding 80% come from an electric arc furnace.

4 PROPOSED LCA PROCEDURE FOR THE DESIGN AND CONSTRUCTION INDUSTRY

LCA has the potential to transform the design and construction industry decision-making process. There is much activity around the topic, but it is not yet organized to achieve that potential. As noted earlier, many LCA modeling approaches focus on a one-time building review. They capture a snapshot during design but lack the detail of what actually gets built. Other modeling approaches look back when a project is done and capture final built data, but do not impact decisions made during design. These later LCA case studies can be informative for future project considerations and more generalized decision making, but they do not inform design decisions regarding how to best bring LCA into current project decision-making.

To bring value to the design process, LCA information needs to be available during design to establish a baseline project, be easily tracked and evaluated during optimization efforts, and be available and actionable during a project's procurement and construction process.

The best approach we have found to date is multi-phase LCA modeling, similar to and often in parallel with a project's cost estimating effort, with an increasing level of accuracy and refinement. Our experience with early design optimization recommends first choosing materials best suited for the intended purpose that also meet the project's owner and architectural intents. Optimized designs based upon engineering first principles that maintain a "big idea" and can then carry through to organize the project are key. Once the base project approach is defined, project-specific LCA can be meaningfully incorporated to further perfect the design.

4.1 *Phase 1: Design-phase LCA*

MKA has had the most success with design-level LCA, starting no sooner than the end of Schematic Design and using industry-average data from Thinkstep's GaBi database embedded within Revit's LCA "Tally" module, or from the Athena Impact Estimator. Having a Revit model with LCA input embedded directly, with accuracy increasing as the quality of the design and model increases, is, in MKA's experience, the most useful approach to invest in through the duration of a project. That model, if transferred to the contractor with appropriate qualifications, can also become the baseline for later procurement and construction-phase LCA efforts, using the multi-phase LCA process outlined in this paper. As Athena continues to refine its software, given its prominence in the USA LCA community, the differences between Tally and Athena IE could converge into even more useful LCA modeling tools.

Schematic design-level LCA modeling can most easily be described as a Level of Development (LOD) 200 BIM model LCA (BIM Forum, 2013).

The schematic LCA model should be refined at the end of Design Development, with an LOD 300 BIM model LCA, and at the end of Construction Documents, with an LOD 350 or LOD 400 BIM model. In these later stages, LCA identifies where optimization trends occur, and the impacts of design decisions can be tracked over the course of the project.

This iterative approach also increases attention to project "quantity control" earlier in the design process. That step alone is a significant value-added client service. In addition to early LCA input, it allows more accurate and detailed cost estimating by preconstruction estimators and more reliable comparative system evaluations.

4.2 *Phase II: Procurement LCA*

Phase II LCA efforts should include reaching out to the primary material supply subcontractors during the bidding process for LCA information that will be considered in the procurement efforts of the project. Next to design optimization, this is one of the project's most important efforts toward achieving a lower carbon footprint. A point-of-sale review means requesting project-specific EPDs, often as part of the project specifications, for the most significant project consumptive materials. It also requires up-to-date quantities from the design team. This combination of the design team providing CD-level material quantity estimates and the vendors making their own independent material estimates, in addition to quality LCA evaluations, provides a useful check and balance during the project's procurement phase.

With an industry-average Phase I LCA in place, there is a consistent benchmark to reference for tracking project progress, good or bad, as specific material suppliers are considered. While LCA reviews by MKA have focused solely on the structure frame, a shell-and-core review that considers the building façade and MEP systems, when applicable, would be important next steps. Ultimately, whole-building LCA evaluations are the goal, but in most cases, the industry is not there yet.

It is important to continue beyond the initial Phase I design LCA models. The LCA footprint of large-volume and energy-intensive items, such as steel or concrete, can vary widely depending upon the source and production, influencing final LCA results by 50% or more.

4.3 *Phase III: Construction-phase LCA*

Design is theoretical; construction is when things really happen. Without construction follow-through to validate assumptions and predictions made during design, most LCA efforts are of little consequence. If proper information is assembled in the Phase I and II efforts defined above, and assuming there is a continuity of LCA information flow from the design team to the construction team, much of the Phase III LCA is collecting EPDs and monitoring consumption of material volumes. Having the LCA tied closely to the cost estimating efforts by the contractor is critical. Cost estimates and cost tracking procedures are well-established within the construction industry. LCA, as proposed above, is the same iterative process with a change of variables.

Construction also includes a number of variables not tracked during a design LCA which ultimately affect any whole-building LCA. Energy usage during construction, waste management, cut-and-fill soil balancing of a site, recycling, and/or re-use of materials and forming systems are a few of the significant variables to further consider with a Phase III LCA. Construction and demolition waste constitutes about 40% of the total solid waste stream in the USA and about 25% of the total waste stream in the European Union (U.S. Green Building Council, 2016).

Attempting to measure every kilogram of CO_2 released during construction is a futile and non-informative effort. Like economics, the Phase III LCA should track the most significant of the project carbon sinks. It should be accurate enough to identify trends for an overall accounting of the final project, and would ideally include a statistical margin-of-error estimate for the data collected.

5 SUMMARY

MKA's project-specific LCA efforts were initially developed out of frustration over not being able to account for the environmental impacts of our structural choices or the environmental value of design optimization, cornerstones of our approach to design. It has since become a point of MKA's leadership in sustainable design, but it remains only one part of a larger goal of whole-building life cycle analysis as a transformative way to produce more thoughtful and sustainable designs.

The goal of this paper is to consolidate several years of structural frame LCA study and provide an abbreviated overview of the state of LCA practice in the USA.

Several key findings have been highlighted along the way, including most fundamentally that optimized load paths and efficient material usage in a design are crucial. Similarly, looking at where materials come from and how they are produced has a major influence on the LCA findings. These often have a much bigger influence on the overall LCA embodied carbon footprint of a project's design than the choice of a particular building frame material.

Finally, this paper has attempted to bring clarity to how LCA can be meaningfully adopted within the design, procurement, and construction processes in use today, to bring a more responsible and accountable measuring of the environmental impacts of our design and construction choices.

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Reliability-based maintenance of complex structures for life-cycle performance

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ABSTRACT

The PDEM (probability density evolution method) has been well established as an effective method for the response and reliability analyses of complex engineering systems including large structural systems. However, its application to deteriorating systems in which inspections of the system parameters require updating needs some extension. The proper updating is based fundamentally on the Bayesian approach.

Determining the appropriate maintenance strategy with occasional inspection and repair at the right time to ensure satisfactory performance and minimize cost over the life of a structure is central to life-cycle management. In this process, maintaining a required level of reliability throughout its life-cycle is essential; hence, the analysis of time-dependent reliability plays an important role.

This study presents an approach based on the PDEM for time-dependent reliability analysis of deteriorating complex structures with inspection. The probability information between inspection intervals is preserved, as required in the basic PDEM; however, at the instants of inspections *the probabilistic information of the source of randomness changes because the Bayesian updating changes the probability density function (PDF) of the basic random variables*. Therefore, incorporating these changes into the probability density evolution process of a structure with inspection, the basic PDEM needs to be revised and extended; such an extension involving the Bayesian approach is proposed here.

The extension is denoted as the Bayesian updated PDEM or BU-PDEM for short. The rationale of the extension is formally established, and the numerical procedure for its implementation is described and illustrated with three numerical examples. The results for each of the examples are summarized in the following.

Example 1: *A Truss Structure*
The first example is a ten-bar truss shown in Fig. 1. Three cases for the truss were considered as follows:

Case 1 – With no inspection.

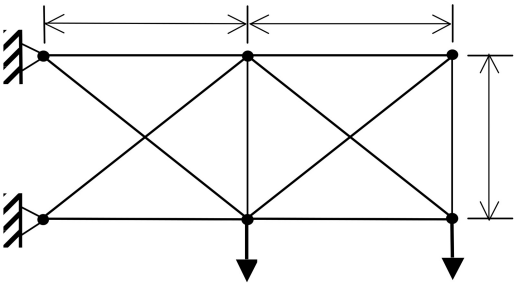


Figure 1. Ten-bar truss structure.

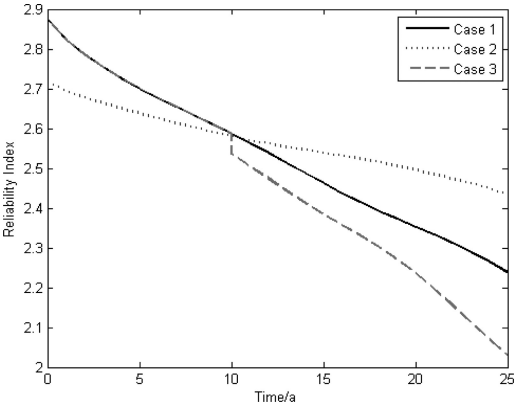


Figure 2. Comparison of reliability indices of the three cases.

Case 2 – With inspection at $t_1 = 0$ only.
Case 3 – With inspection only at $t = 10a$

The reliability analyses for each of the three cases were performed with the BU-PDEM. The final results for all the three cases are summarized in Fig. 2, showing a comparison of the respective reliability indices of the three cases.

From Fig. 2, it is clear that updating the structural parameters based on the results from the inspection

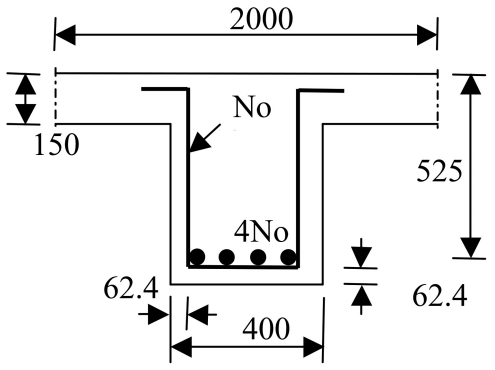


Figure 3. Reinforced concrete T-section beam.

Table 1. Sample values of *loads* observed during inspection.

Time	Samples/kN.m					
$t=0$	198. 5	198.2	157.0	185.2	180.3	211.0
	231.3	232.1	157.0	189.2	146.5	149.4
	186.1	252.4	160.0	200.5	178.2	232.5
$t=6$a	153.0	180.9	195.4	212.1	226.6	182.3
$t=12$a	132.8	155.2	145.2	295.0	159.3	211.5
$t=18$a	168.0	208.1	150.0	132.2	131.7	192.3
$t=24$a	157.9	157.4	206.7	170.9	168.2	212.7

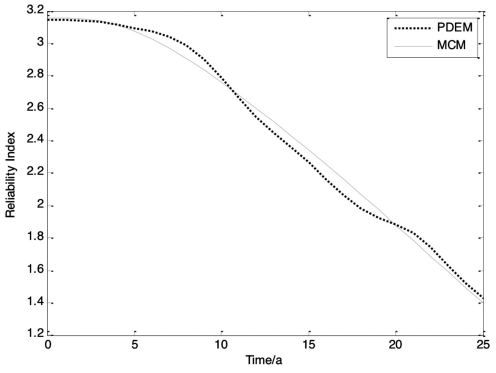


Figure 4. Time dependent reliability index.

has significant influence on the reliability indices of the structure.

Example 2: *T-section reinforced concrete beam*

Two cases were considered for the T-section beam as follows:

Case 1—Without inspection
Case 2—With inspection of live loads at 6-year Intervals

In Case 1, results obtained with the PDEM and a large sample (10^7) Monte Carlo simulation are shown in Fig. 4, verifying the accuracy of the PDEM.

In Case 2, results of the inspections of the loadings on the beam are summarized in Table 1.

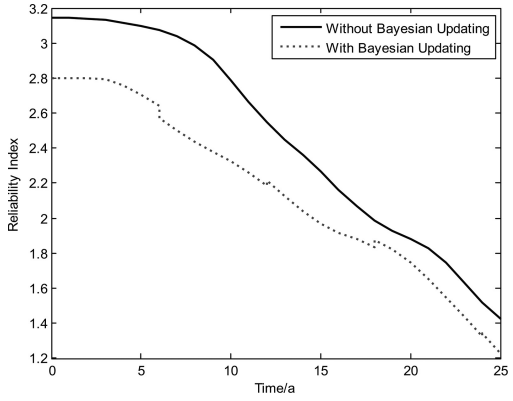


Figure 5. Comparison of reliability indices with and without Bayesian updating.

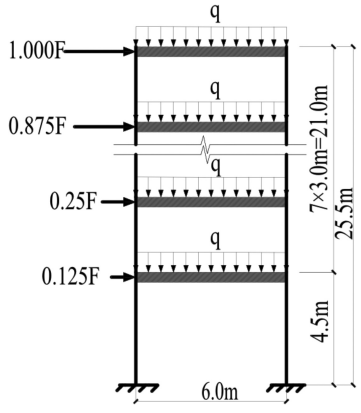


Figure 6. Steel frame building.

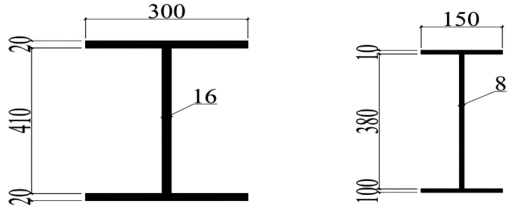


Figure 7. Cross sections of members (mm).

Fig. 5 shows the reliability indices for Cases 1 and 2, indicating clearly the significant effects of inspections and updating.

Example 3: *An 8-story steel frame building*
In this example, the 8-story building is subjected to the El Centro earthquake ground motions. Inspections of damages were assumed after the earthquake and the system parameters were updated based on the inspection results.

Two cases were considered as follows:

Case 1 – *Without inspection*
Case 2 – *With inspections after the earthquake*

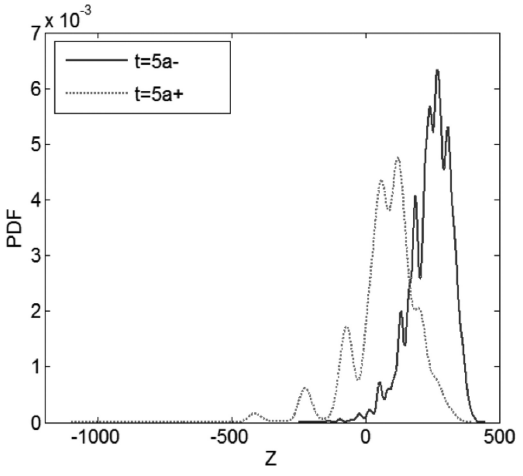


Figure 8. PDFs before and after earthquake.

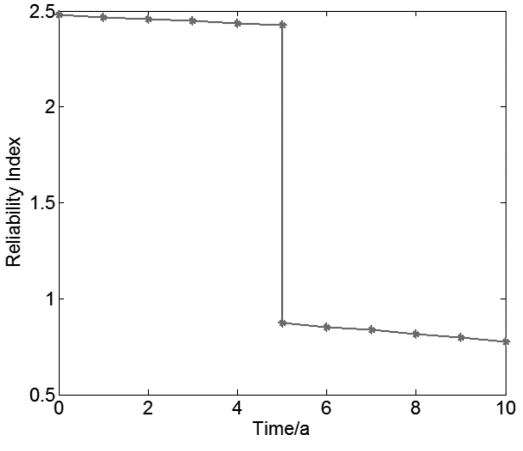


Figure 9. Time-variant reliability index.

Table 2. Inspection with 25 samples of D Samples ($\times 10^5$).

0.544	0.573	0.533	0.536	0.569
0.537	0.570	0.586	0.603	0.616
0.615	0.546	0.581	0.563	0.603
0.572	0.525	0.547	0.538	0.640
0.551	0.592	0.564	0.596	0.547

In Case 1, applying the PDEM, the PDFs of the performance function of the building before and after the earthquake, occurring at time $t = 5$a, are shown in Fig. 8. And the result of the time-variant reliability index is illustrated in Fig. 9. As expected, there is a sharp change before and after the earthquake.

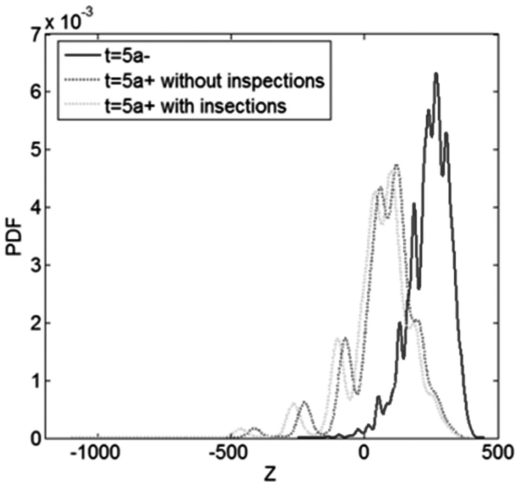


Figure 10. PDFs before and after earthquake, with and without inspection.

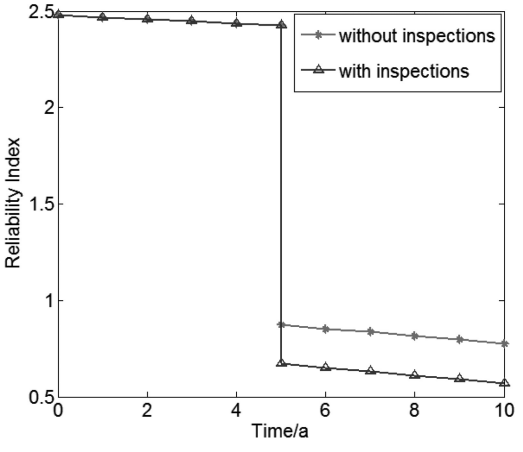


Figure 11. Time-variant reliability index.

Case 2: With inspections after earthquake

Table 2 shows the 25 samples of the observed damage factor D from the inspection.

Through the BU-PDEM, the PDFs of the performance function before and after the earthquake are shown in Fig. 10. And results of the time-variant reliability index in the time interval [0,10a] are illustrated in Fig. 11, together with the comparison with Case 1 (without inspection). It is easy to see that the results of inspection significantly affect the time-dependent reliability of the structure.

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Providing a second service life for bridges

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1 INTRODUCTION

1.1 *Editorial remarks*

Current structural engineering often results in invasive intervention on existing bridges including even replacement of bridges. This unsatisfactory situation leading to heavy socio-economic burden, is not due to missing know-how in the domain of structural engineering.

There are too many standards and codes, reluctance because of liability issues and a general thinking still driven by new construction. These factors explain why most structural engineers are over-conservative and lack of motivation and curiosity for innovation and progress in existing structures and life-cycle engineering. In addition, the system of pay of engineering performance and in general relatively low fees in many countries do not offer any incentive to apply novel engineering approaches and new technologies with the goal of no or only non-invasive intervention on existing structures.

Obviously, this situation has to be challenged and changed radically as public expenditure for infrastructure (including civil structures like bridges) should be invested into improvement and extension of existing infrastructure creating real added value.

This change needs to rely on scientific research oriented towards effective life-cycle engineering applications. The purpose of research in engineering domains is not only to produce peer-reviewed papers but to implement new knowledge into practice. Application is the best peer-review of research.

1.2 *General approach*

With respect to civil structures like bridges, the basic idea behind our research and application activities is to (1) accurately determine in-situ structural behaviour in order to be able to perform a more precise and realistic verification of structural and fatigue safety, as well as (2) the targeted use of advanced materials for the improvement of structural behaviour and resistance of bridges and other structures.

The ultimate goal is to limit construction intervention to a strict minimum while providing a future long service life for structures.

We call this approach examination engineering (short: Examineering). "Examineering" thus also means leaving common "assessment and retrofitting" methods.

1.3 *Objective of this keynote lecture*

The objective of this keynote lecture is to highlight two novel structural engineering approaches with the goal to significantly extend the service life of existing bridges, actually to provide a second service life to bridges, even of more than 100 years of age:

- A novel approach is suggested for structural and fatigue safety verification using directly data from in-situ long term structural monitoring to determine updated action effects.
- If interventions are necessary, their objective must be to effectively improve the structure (not only to repair or retrofit it). A new technology is presented to improve concrete bridges using Ultra-High Performance Fibre Reinforced Cement-based composite materials (UHPFRC).

General aspects of maintenance, management and life-cycle performance of structures and in particular of bridges are also be presented explicitly and "between the lines" as "food for thoughts".

2 ABOUT LIFE CYCLE ANALYSES

The successful improvement of existing structures is a major challenge for structural engineers. Figure 1 presents two different strategies of bridge maintenance from a user's or owner's point of view. The traffic demand is continuously increasing in both cases.

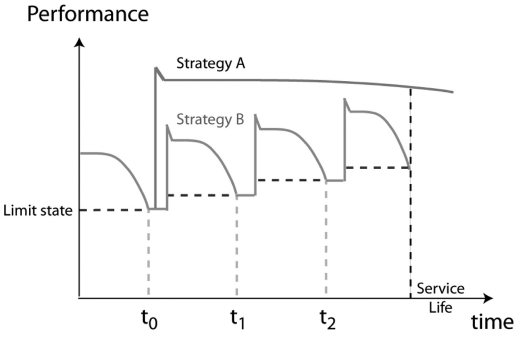


Figure 1. Evolution with time of the demand and supply for two different maintenance strategies.

During the planned service life of the structure Strategy B usually induces multiple interventions for rehabilitation with periods of traffic disruptions. Depending on the size of the structure and the extent of the interventions to be realised, these periods of traffic disruption can extend up to several months each with significant consequences in terms of traffic disturbance, as well as user and environmental costs.

On the contrary, Strategy A aims at both decreasing the time spent for the rehabilitation works, and increasing the durability to an extent that will make the rehabilitated structure fulfil all requirements of functionality, serviceability and resistance, for the planned service life, with only minor preventative maintenance.

Obviously, Strategy A is highly desirable. It ought to be the objective of any rehabilitation intervention. Strategy A may however only be achieved by means of novel engineering approaches and technologies like the ones presented in the previous chapters. Real improvement thus goes through engineering innovation.

Nevertheless, theoretical life-cycle analyses are often based on the implicit assumption that intervention methods will stay the same over the coming decades. Strategy B is still considered by many researchers as being "state-of-the-art" or inherent to civil structures. These researchers do not account for novel technologies that may improve significantly existing structures after interventions.

Also, many approaches in the domain of life-cycle management need Strategy B or similar as a basic hypothesis. Strategy A would virtually make life-cycle considerations obsolete.

The assumptions of many life-cycle analyses may thus turn out to be unrealistic since novel engineering approaches and technologies will finally be introduced leading to a real improvement in the maintenance and management of structures. Progress cannot be stopped.

Consequently, a fundamental change in paradigm, i.e., a change from Strategy B to Strategy A, is thus needed to seriously tackle the question of infrastructure management. Does this imply that research efforts need to be made in the domain of material and structural engineering rather than in the domain of life-cycle costing and management?

3 CONCLUSIONS

Structures like bridges have more than one design life. There are no "old" bridges; there are only bridges that provide adequate performance (or not).

Novel structural engineering methods and technologies are nowadays available to provide a second service life for existing structures.

Structural and fatigue safety of bridges shall be verified using data from in-situ long term structural monitoring to update traffic action effects. More realistic and precise data on structural behaviour allow for extending significantly the service life of fatigue prone structures.

If strengthening interventions are necessary, their objective must be to effectively improve the structure. The novel UHPFRC technology allows to improve structures like bridges. This technology is applied in Switzerland for more than 10 years because it is cost-effective while it significantly extends the service life, and it may be expected that it reduces maintenance of the improved bridges.

A fundamental change in paradigm, i.e., a change from the conventional strategy of multiple interventions to a strategy of a one-time intervention leading to a significant improvement of the structure after the intervention, is needed to seriously tackle the question of infrastructure management.

Remarks: The "philosophy" proposed in this keynote lecture is in agreement with the principles of sustainable development in terms of cost effectiveness (economy), economical use of resources and compatible social impact of transportation infrastructure.

Providing a second service life finally means giving value to bridges as well as appreciating the art of structural engineering and the identity of structural engineers.

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Integrated life cycle design and assessment of concrete structures – contribution to sustainability and resiliency in a changing world

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ABSTRACT: The world is changing. Humanity faces increasing frequency of natural disasters and increasing economic and social problems and challenges. The building stock should be more adapted to the new situation and changing conditions for sustainable functioning in the future. It should be more resilient. A significant part of present buildings makes use of concrete structures. Concrete is, due to its specific material properties, the most used material in the world after water. Due to optimization of production technology and design techniques, concrete is gradually becoming a building material appropriate and advantageous for resilient and sustainable structures. Thus the more sophisticated use of advanced concrete structures represents a significant potential for further improvement of sustainable and resilient built environment.

1 INTRODUCTION

1.1 *Changing world*

The world faces increasing number of natural disasters and increasing economic and social problems and challenges. Due to rising and aging human population, these effects threaten more people. Climate change-related effects like floods, storms, hurricanes, tornados, heat and cold waves, extreme dry weather and fires are more and more frequent. According to an analysis by WMO (World Meteorological Organisation), the 2011–2015 was the warmest five-year period in records, with many extreme weather events influenced by climate change (WMO 2015). The probability of a natural disaster is now nearly five times higher as it was in the 1970s, because of the increasing risks due to climate change – Figure 1.

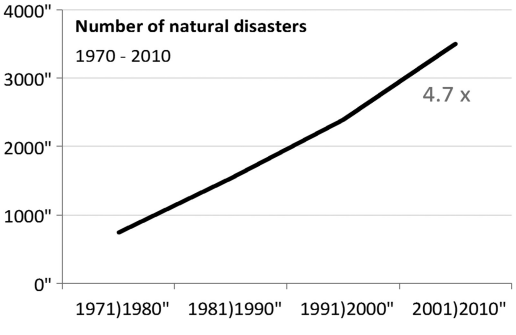


Figure 1. Increasing number of natural disasters in four last decades – since 1970 to 2010.

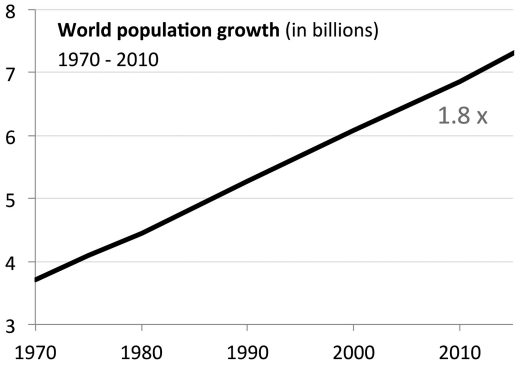


Figure 2. World population growth in four last decades – since 1970 to 2010.

In the same period of 40 years 1970–2010 the world population increased from 3.7 to 6.8 billions, it represents 1.8 times increase, see Figure 2.

As the population and number of natural disasters grow, so does the impact of natural disasters on humans is increasing – see intersection in the Figure 3. Continuously growing intersection leads to costlier and deadlier disasters (Nishenko & Barton 1997) around the world.

One recent example: In the last year 2015 a massive earthquake with magnitude 7.8 devastated Nepal, killing more than 8,800 people, damaged or destroyed nearly 900,000 buildings, created avalanches in the Himalayas, and left almost 1 million children out of school (Huber 2015).

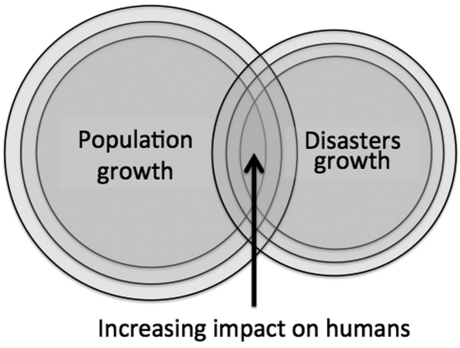


Figure 3. Increasing impact on growing population with increasing number of natural disasters. Intersection is growing in faster manner.

At the same time, human population faces accelerating number of extreme social phenomena, like social unrest, instability of states, wars and increasing number of man-made disasters like terrorist attacks (e.g. WTC New York terrorist attack September 11th, 2001; current increasing number of terrorist attacks in Europe and Middle East, etc.). As a consequence of natural and man-made disasters and socio-economic situation, human migration increases. This all results in enormous economy impacts and causes extensive humanitarian crises, influencing a quality of human life on the Earth.

Considering above mentioned situation and development trends, it is necessary to evaluate and modify existing principles and methods of structural design, corresponding techniques of construction and operation of structures. The principle goal is to enhance structures and entire built environment to be more resilient in the situation of changing natural and socio-economic conditions in the world.

1.2 *Sustainability*

The 2005 World Summit on Social Development identified sustainable development goals, such as economic development, social development and environmental protection (UN 2005). Sustainability is based on socially derived goals, combining social equity, economic viability and environmental integrity (Curwell et al. 2005). Application of sustainability principles into various human activities became a common and necessary practice. This was supported by implementation of the new knowledge and latest research results in the filed of sustainability into curricula at universities and schools, focused on the construction practice.

With respect to the general principles of sustainability, the three essential pillars should be considered in the whole life cycle of buildings:

- environmental integrity,
- economic efficiency, viability and feasibility
- social equity and well-being.

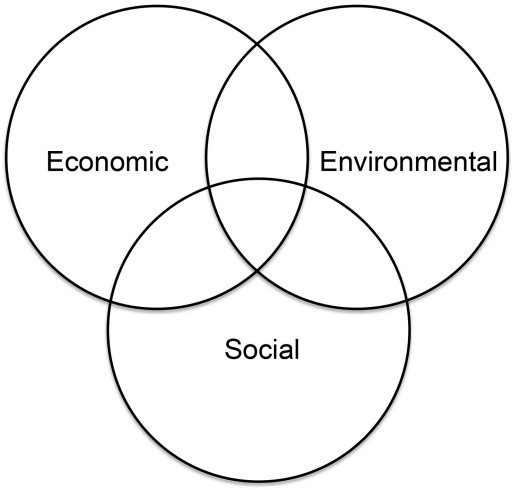


Figure 4. Three pillars of sustainability and their mutual interaction.

The Figure 4 shows three pillars of sustainability – environmental, economic and social and their mutual interactions as a basic conceptual approach to integrated design.

1.3 *Resiliency*

Increasing number of natural disasters requires increasing focus to resilience of structures. Nowadays there exist many concepts and specific definitions of resilience (Hassler & Kohler 2014). Focusing to design of structures, resilience is in general the capacity to adapt the system to changing conditions and to maintain or regain functionality and vitality in the stage of stress or disturbance (Resilient Design Institute 2015). It is the capacity to recover after a disturbance or interruption. It refers to the capacity to continuous reconstruction (Hamel & Valikangas 2003). According to the Resilient Design Institute (2015) "resilient design is the intentional design of buildings, landscapes, communities, and regions in order to respond to natural and man-made disasters and disturbances, as well as longterm changes resulting from climate change, including sea level rise, increased frequency of heat waves, and regional drought". Pickett et al. (2014) apply the concept of resilience to cities as a key concept for operationalizing of sustainability.

Considering increasing number of natural and man-made disasters in the changing world it is essential and urgent to modify principles of structural design and construction technology for development and maintenance of buildings and all built environment in order to be more resilient. Of course the reduction of environmental impacts (especially global warming) is urgently needed to slow down the process of climate change. Only structures with reduced environmental impacts and in the same time with high level of resiliency can be sustainable in the changing environmental as well as social situation of the forthcoming era.



Figure 5. Floods in the Czech Republic, due to heavy rains in August 2002. Collapse of residential buildings in the Prague centre.



Figure 6. Floods in the Czech Republic 2013, due to heavy rains. Flooded old Hostivar area in Prague.

1.4 *Regional specifics*

In general, the process of design and construction of structures varies in different countries and regions. They are more or less determined by regional specifics due to different material basis, energy mix, different climate conditions, different technology (based on the local labor cost, tradition in organization of work and different climate conditions) and differences in cultural traditions. Regional specifics should be considered when collecting the embodied environmental data of different materials. The type of material sources, mining technologies, transport means, transport distance and technology of production have a significant influence on the final unit embodied values.

Considering resiliency, especially of buildings, the climate conditions and potential impacts and looses are essential for the design of sustainable structures/buildings. In different regions there are different major risks of natural disasters. The world's greatest earthquake zones are the circum-Pacific seismic belt and central Asia. Hurricanes are most common in the Pacific, however, hurricane Katrina in 2005 occurred in the South Atlantic. The world's deadliest floods were several times in Asia. However, also very damaging floods strucked Europe several times in last decades, see Figure 5 and 6.

With respect to some prognosis of climate changes in Europe, there could be expected increasing number of heavy rains (followed by floods) and more frequent heat waves in the future.

1.5 *Concrete and environment*

It is well known that concrete is after water the most used material in the world. The production of concrete in the industrialized world annually amounts to 1.5–3 tone per capita (Fib 2013). World cement production has been 12 times increased in the second half of the last century (Hajek et al. 2011). Davidovits (1987 and 1994) showed that cement industry production in the year 1987 was about 5% of world CO_2 emissions. Considering continuing increase of

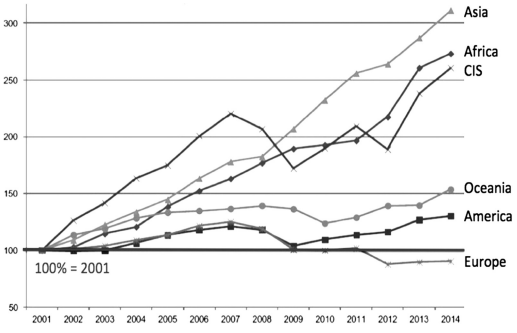


Figure 7. World cement production by region – evolution 2001–2014 (based on the source Cembureau 2015).

cement production it is estimated that nowadays about 7–8% of global CO_2 emissions is connected with cement industry. The Figure 7 shows a development of cement production in world regions presented by The European Cement Association – Cembureau (2015). From the Figure 7 it is evident that the production of cement significantly grew in developing countries in Asia, Africa and CIS (Commonwealth of Independent States – some former Soviet Republics) and slightly grew in America and Oceania. The European production in 2014 was even lower, compared to 2001. China with 56.5% kept dominant position of total world cement production in 2014.

As a consequence of economy growth, especially in emerging countries, the demand for construction materials, including cement and concrete, is increasing. According to WWF (2008) the cement production in industrialized and developing countries in 2050 was estimated to be almost 5 times higher then in 1990 despite the need for reduction of total CO_2 emissions (!).

Besides their impacts on climate change, the concrete structures at the end of life represent also a large source of solid waste. Recycling can significantly reduce the amount of landfilled demolition concrete waste. The use of recycled concrete as an aggregate for new concrete mixes has a significant potential to reduce the pressure on landfilling sites and to save

resources of natural aggregates. However, the recycling process still brings several question marks and tasks for further research related to the new concrete quality guarantees (Pavlu et al. 2014).

Another significant impacts of concrete structures production and demolition on the environment are associated with transportation.

The above-listed environmental impacts of use of concrete are significant. On the other hand, it is important to note, that current development of concrete as a material, concrete production technologies and development in design of concrete constructions during last twenty years lead to improvements of technical parameters and at the same time to reduction of environmental impacts per functional unit. Newly introduced types of concrete have (due to mix optimization) significantly better characteristics from the perspective of strength, mechanical resistance, durability and resistance to extreme loads. The use of new high performance concrete (HPC) enables construction of more sustainable and resilient structures.

Considering the above-specified global situation it is highly important to focus the research efforts on an implementation of improved technologies and construction techniques to further reduction of the environmental impacts and increase performance of concrete structures. Since the consumption of concrete is expected to continue to rise also in the future, the concrete industry should take some kind of action (Sakai & Noguchi 2012). The progress is more important in emerging countries and regions with the highest forecasted cement production.

2 INTEGRATED LIFE CYCLE ASSESSMENT OF CONCRETE STRUCTURES

2.1 *General framework for ILCA*

The general framework for Integrated Life Cycle Assessment (ILCA) of Concrete Structures is defined in a fib report of TG3.7 prepared and published by fib (Fédération internationale du béton/International Federation for Structural Concrete) Commission 3 (Fib 2013, convener P. Hajek). It is a complex approach implementing all relevant and significant requirements on concrete structures into one single design process.

The integrated approach ILCA presented on Figure 8 integrates material, component, and structure design and considers selected relevant criterions from a wide range of sustainability criterions sorted in environmental, economic and social areas and considering the entire life cycle of the construction.

Complex integrated approach is based on simultaneous and interactive consideration of various requirements at various scales (material, component, entire structure) over life cycle phases throughout the entire life of the structure:

- sustainability requirements (environmental criteria, economic criteria and social criteria);

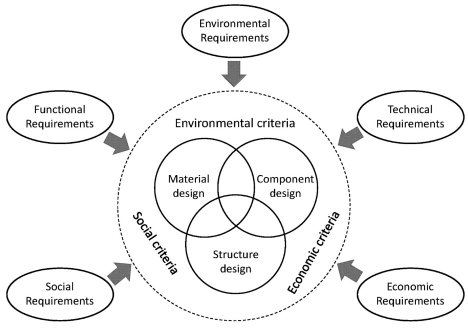


Figure 8. Basic principle of integrated design approach ILCA implementing all sustainability criteria in one single design process.

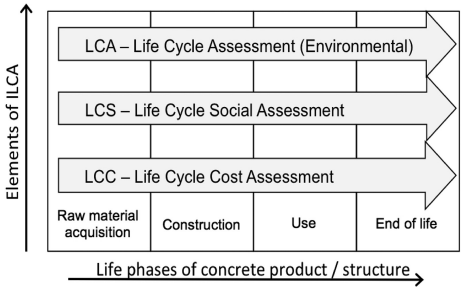


Figure 9. Elements of ILCA for evaluation of total impact of concrete structure covering three process streams – environmental (LCA), social (LCS) and economic (LCC).

- technical and functional requirements (technical performance, functional performance, durability).

The assessment methodology is based on the three traditional pillars of sustainability:

- Environmental aspects: e.g. effects on climate change, resource use, local air quality, biodiversity, raw material use and waste production;
- Social aspects: e.g. occupants' health and interior microclimate, security and safety, social and cultural issues;
- Economic aspects: e.g. life cycle costing, support for local economy, externalities.

Concrete is used in a wide variety of structures (buildings, bridges, roads, dams etc.), each designed with a specific kind of functionality and life span in mind. A complex approach to ILCA process that can be applied to different types of concrete structures is described in Fib 2013 report (Figure 9).

In this process regional specifics play the key importance, because concrete is typically produced from regionally available materials using regionally available techniques and transport systems – see also chapter 1.4.

2.2 *Total life cycle impact assessment*

The total impact of a product is according to EN ISO 14040 considered throughout its whole life (from

cradle to grave), from raw material acquisition through production, use and disposal. The global character of todays' supply chains and environmental impacts and complexity of relations among the elements of the built environment require use of multicriterion evaluation methodology.

Total life cycle impact of each impact category I_{tot} is in general expressed as follows

$$I_{tot} = \sum I_i \tag{1}$$

where I_i is partial impact of impact category corresponding to particular life phase.

With respect to the uncertainty of the impact caused in individual phases of the whole life cycle of the structure, the total impact can be for the most cases of structures expressed as a sum of partial impacts as follows (Hajek 2001):

$$I_{tot} = \sum p_i \; I_i \tag{2}$$

where p_i represents probability factor.

Analogically to (1) and (2), the total impacts for the three main groups of sustainability criteria can be expressed in the following forms:

$$E_{tot} = \sum E_i \text{ and } E_{tot} = \sum p_{E,i} E_i \tag{3}$$

$$C_{tot} = \sum C_i \text{ and } C_{tot} = \sum p_{C,i} C_i \tag{4}$$

$$S_{tot} = \sum S_i \text{ and } S_{tot} = \sum p_{S,i} S_i \tag{5}$$

where $E_{tot}, C_{tot}, S_{tot}$ are total environmental, economic and social impacts respectively, E_i, C_i, S_i are partial impacts corresponding to particular life phase and $p_{E,i}, p_{C,i}, p_{S,i}$ are corresponding probability factors.

The evaluation of performance quality is based on a complex consideration of a set of relevant and significant criteria for a specific scope and system boundaries of impact assessment. This usually leads to application of multiparametric assessment tools comprising weighting procedures. The partial impact could be thus calculated using following equation:

$$I_i = \sum w_j \; Q_j \tag{6}$$

where $\{w_j\} = (w_1 \ldots w_m)^{\mathrm{T}}$ is the vector of weights representing importance of individual criteria, m is the number of essential criteria, $\{Q_j\} = (Q_1 \ldots Q_m)^{\mathrm{T}}$ is the vector of embodied values for particular criteria.

The equation (2) could be in application on building or civil engineering strucure expressed in a more specific form as:

$$I_{tot} = I_{in} + \sum p_{op} I_{op} + \sum p_m I_m + \sum p_f I_{rep} + \sum p_{ren} I_{ren} + \\ + I_{dem} + I_{rec} \tag{7}$$

where I_{in} represents the initial impact associated with the production of primary building materials and components and with the design and construction phases. I_{op}, I_m, I_{rep} and I_{ren} are operation, maintenance, repair and modernization/renovation impacts respectively. Factors p_{op}, p_m, p_f and p_{ren} are corresponding probabilities of operation level, maintenance, failure and modernization/renovation respectively. I_{dem} is impact associated with the demolition of the structure and I_{rec} represents impact associated with recycling and/or disposal of waste.

Probability of modernization and renovation is dependent on the level of degradation of structure and on probability of impacts caused by disasters.

$$p_{ren} = f(degr, p_{dis,n}, p_{dis,m}) \tag{8}$$

where $degr$ is representing level of degradation, $p_{dis,n}$ is probability of natural disaster and $p_{dis,m}$ is probability of man-made (soci-economic) disaster.

2.3 *Life cycle resilience*

The problem of prediction of durability and resilience of structures is in the specification of probability factors for the assessment system. In the case described by equation (7) probability factors p_{op}, p_m, p_f and p_{ren} should be considered and predicted based on a scenario for future development of natural or socio-economic changes.

Due to disturbance caused by natural or human-induced impact (e.g. flood, fire, earthquake, terorist atack etc.) the quality level of performance of structure is effected and could drop down under required (or even bearable) performance values. Change could be caused also by change of reqirements on structure performance (e.g. given in standards). The probability factors $p_{dis,n}$ and $p_{dis,m}$ needed for evaluation of p_{ren} using eq. (8) should be determined based on scenario of natural and socio-economic developments for specific situation.

Based on the general definition, resilience is the capacity to adapt the system to changing conditions and to maintain or regain the functionality. In the Figures 10, 11 and 12 there are three scenarios showing different cases of performance development within lifetime of the structure.

Scenario A (Figure 10) represents development of functionality (level of performance) without any disaster event during lifetime of the structure – "non-disaster" case. Due to changes/degradation of functional properties in the time, the level (quality) of performance could fall down the required performance

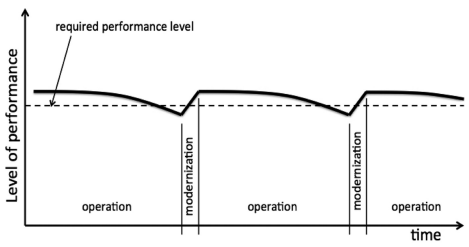


Figure 10. Scenario A – standard (non-disaster) development of functionality (performance level) within lifetime of the structure.

level. In this situation it is necessary to decide about the future use/operation of the structure. There are two basic possibilities:

(a) stop the operation and demolish the structure;
(b) modernization/renovation of structure and thus prolong its operation with required level of performance. This process is usually repeating several times within entire lifetime of the structure.

Modernisation and renovation of existing structures and prolongation of their operation is considered to be preferred concept from the viewpoints of sustainability.

Figure 11 presents Scenario B with disruption of function of the structure caused by disaster. As a consequence of disaster and associated direct impacts to a structure, the level of performance drops down below required performance level. After shock, caused by disaster, decision should be taken about the future use and operation of the structure. Again there are several possibilities:

(a) stop the operation and demolish the structure;
(b) modernisation/renovation of structure to the performance level before disturbance by disaster;
(c) modernization to the higher level of quality following developments of requirements. Scenario C in the Figure 12 presents this case, where performance requirements were increased during operation of structure.

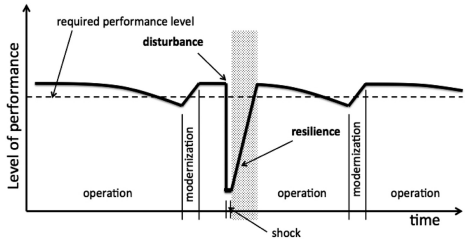


Figure 11. Scenario B – resilience after disturbance of structure by disaster and shock. The level of performance is recovered to the level before disaster.

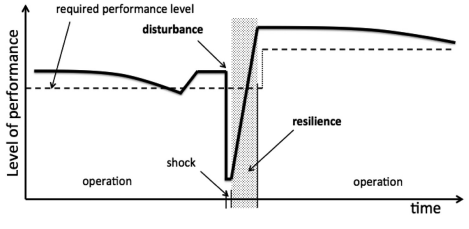


Figure 12. Scenario C – resilience after disturbance of structure by disaster and shock. The level of performance is recovered to the higher level following developments in standard requirements.

3 SUSTAINABLE AND RESILIENT CONCRETE STRUCTURES – PRINCIPLES

New situations in natural and socio-economic environment require new technical solutions for construction of new and reconstruction and modernization of existing buildings. These solutions should be optimized considering multi objective character of the problem. Time dependent degradation of materials and risk of system disturbance within life cycle of building should be taken in to account.

3.1 *Advantages of concrete structures from sustainability and resiliency viewpoints*

The main advantages of concrete for new structures and reconstructions are: (i) thermal mass (stabilizing indoor environment), (ii) acoustic properties (improving air-born sound insulation), (iii) fire resistance, (iv) long term durability, (v) structural safety, including high resistance to natural hazards, (vi) maintainability and (vii) flexibility. With respect to specifics of concrete presented as a strong and durable material it is possible to design and construct robust structures with high level of resiliency when faced to the exceptional natural or man-made disaster shocks. High structural safety and reliability, and higher fire resistance of concrete (compared to other materials) results in a high resistance to extreme conditions during natural disasters (floods, storms, winds, hurricanes, tornados, fires, earthquakes, etc.) and terrorist attacks.

Concrete in comparison to other materials (timber, steel etc.) enables longer service life of buildings. Concrete structures are usually more resistant to various climatic conditions, they have a good capability of withstanding wear, and they do not easily subject to degradation processes. This consequently results in lower operating and maintenance cost.

3.2 *Optimization of concrete mixture*

Utilizing new composite materials with significantly enhanced physical characteristics allows for realistic assumptions of achieving substantial improvement of material and energy savings. Some examples from abroad show that HPC can be used for optimized shapes of RC (reinforced concrete) elements, which can now be very thin (wall thickness of 30 mm and less) due to their mechanical parameters. Nowadays, use of concretes with compressive strength around 100 MPa is not exceptional, also ultra high performance concrete (UHPC) with compressive strength over 150 MPa is already used for some specific construction elements in construction of building and infrastructure. These kinds of materials enable design with reduced material consumption (and thus with lower environmental impacts) and with improved reliability and durability. Due to higher durability UHPC could be used also for special elements for external skin of buildings (Figure 13) or street furniture (Figure 14).



Figure 13. External facade panels from textile reinforced UHPC – realization Skanska, Malmö, Sweden.

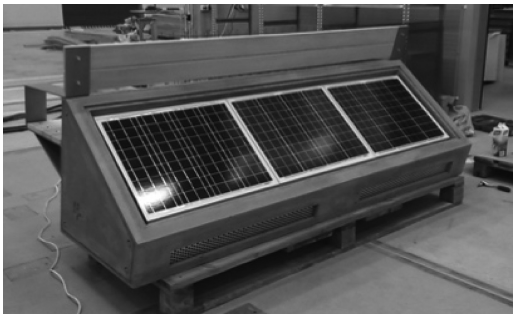


Figure 14. UHPC application – prototype of solar bench CapaSitty made from UHPC at University Centre for Energy Efficient Buildings, ČVUT (photograph by T. Vlach).



Figure 15. Ribbed floor panel with shell fillers from recycled plastics developed at ČVUT, realization ŽPSV a.s.

3.3 *Shape optimization*

Shape optimization enables lightened cross-sections and lower weight of resulting elements imposes lower load on supporting structures. Application of HPC enables additional savings due to even larger reduction of cross section dimensions. Cross section shape can be created using moulds, various types of lightening elements (Figure 15) or light-weight concrete. Mentioned techniques can lead to material savings from 30 to 70% (Hajek 2001).



Figure 16. Hybrid floor made of thin UHPC slab glued to timber beams. Testing at CTU FCE Experimental Centre.

3.4 *Effective structural concepts*

More efficient structures from sustainability and resiliency viewpoints could be obtained by combination of different materials and structural principles.

The composite structures based on HPC and wood represent the beneficial alternative to the timber floor structures (Figure 16). The timber structures have problems to achieve sufficient stiffness; the lack of mass causes troubles with acoustics; inflammability of wood limits the use from the perspective of fire safety. Combination of concrete and timber elements can lead to advantageous structural and environmental solutions.

With reduced thickness of structures there emerged a problem with traditional steel reinforcement of concrete. For corrosion protection, the steel needs a minimum concrete cover layer (specified in codes – usually 15 mm or more), which adds otherwise unnecessary layer and mass. This barrier in design of the traditional reinforced concrete lead to introduction of alternative reinforcements (Laiblova et al. 2014). Textile reinforced concrete (TRC) is used for very thin plate or shell elements (thickness 12 to 25 mm). This concept is mostly used for shells with particular shapes, for strengthening of structural elements or for thin façade panels. In the Figure 7 there is a façade in Malmö, Sweden made from TRC panels (13 mm thick TRC plate is fixed to steel bearing frame).

Lightening of building components can be applied also to structural elements. The team at ČVUT designed a structural system from HPC, which can be easily integrated into the thickness of building envelope of energy efficient buildings. Subtle RC structures become a great advantage in the form of slender load-bearing wall or subtle RC frame. Figure 17 shows prototype of concrete structural subtle frame for construction of houses in passive energy standard built at the University Centre for Energy Efficient Buildings of ČVUT in Buštěhrad, the Czech Republic. The concept considers combination of light



Figure 17. Prototype of HPC subtle RC frame for residential buildings under construction in UCEEB research centre, CZ.

subtle concrete load bearing frame and envelope, partitions, roof structure from timber elements and other renewable bio based materials.

4 CONCLUSION

Only resilient societies can be sustainable in the changing world and resilient built environment is needed to support them. Due to optimization of production technology and design techniques, concrete is gradually becoming a building material appropriate and advantageous for construction of sustainable and resilient buildings. Especially optimized concrete structures using new types of concrete and advanced technologies can significantly contribute to needed reduction of global environmental impacts. Mechanical properties of new types of concrete such as high compressive strength, durability, water tightness etc. create conditions for designing subtle structures that lead to saving up to 70% of material in comparison with ordinary concrete, and consequently to reduction of embodied CO_2 emissions. In the same time such structures could be more resilient in the situation of changing environmental as well as social conditions.

The results of performed research and developments show that the high quality of mechanical and environmental performance of new silicate composites creates the potential for wider application of HPC in building construction focused on sustainability issues. Some of principles are demonstrated on results of research with experimental verification performed by authors and the team at the CTU in Prague, Faculty of Civil Engineering and University Centre for Energy Efficient Buildings (presented in Figures 13, 14, 15, 16 and 17).

ACKNOWLEDGEMENTS

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Life Cycle Management to increase social value at renovations and replacements

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ABSTRACT

Asset managers of civil infrastructures are faced with increasing complexity in their networks, due to increasing societal and technical demands, ageing infrastructure and limited budgets. A safe and reliable infrastructure, managed from a multi-perspective life-cycle view, is of vital importance for a sustainable and competitive society. Life Cycle Management (LCM) opts to create an optimal value for society over the life cycle of infrastructure. The fact that many civil assets come to the end of their technical or functional lifespan stimulates the development and implementation of LCM.

This paper focuses on the renovation and replacement program of civil infrastructures of the Dutch public asset manager Rijkswaterstaat. In the paper, we distinguish 6 main challenges for asset managers: (1) making reliable prognoses for assets; (2) broadening towards a network approach as an opportunity for redesign; (3) developing innovations for increasing requirements and budget restrictions; (4) realizing adaptive networks to cope with future challenges; (5) combining functionalities to increase added value; and (6) maximizing value for society by playing with complexity.

Essential at these six challenges is the interaction with other actors, such as other asset managers, stakeholders, and service providers. Asset managers are recommended to start timely with programs of renovation and replacement, and to develop their organizational competences to meet with the challenges in a way that our networks are fit for future needs.

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Developments in the management of flood defences and hydraulic infrastructures in The Netherlands

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ABSTRACT

Large parts of the Netherlands are at risk coastal and river floods. These flood prone areas are protected by a system of flood defences with a length of almost 3800 km. The management, maintenance and reinforcement of the dikes, dunes, and storm surge barriers requires continuous attention and knowledge development. In addition, several other types of hydraulic infrastructures are present in the country, such as sluices and gates for purposes of navigation and water management. In many cases, large parts of these infrastructures are ageing and need to changed or upgraded to account for new (safety) standards and requirements related to reliability and availability. In addition, demands on these infrastructures are changing, e.g. due to expected sea level rise, more stringent standards and/or more intense use.

This article highlights recent developments in the flood risk management in the Netherlands and approaches for asset and life cycle management for flood defences and hydraulic infrastructures. The functioning of these infrastructures is of great importance for the country as large parts of it are prone to flooding, and the adequate functioning of several hydraulic structures is vital for safety and other functionalities. The recent transition of the flood management policy toward more risk-based is summarized, resulting in new safety standards for flood defences in the form of tolerable failure probabilities. Using a risk-based framework, challenges in reliability assessment and management are discussed, such as the dynamic nature of loads, resistances and reliability requirements over time. Finally, various case studies are discussed to present advances and challenges in various subfields. Examples illustrate the utilization of risk-based approaches in the evaluation of innovative dike reinforcements and nature based solutions in flood management. In a third case life cycle cost analysis is demonstrated to be used to optimize the management and future proof reinforcement of large structures.

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Developing realistic deterioration models

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ABSTRACT

For management of long-term reliability of infrastructure mathematical models are required to predict the capacity $R = R(t)$ for $t > 0$), and hence the probability of failure $p_f(t) = \text{Prob}[R(t) < S(t)]$ where S is a relevant stress resultant. The challenge for deteriorating (corroding) structural systems is how to determine a reasonable function for R(t) given that at design time only $R(0)$ is available.

The present paper provides an overview of recent developments in the building of sound models for corrosion as a function of time, principally for steels, in various natural environments, focusing on one practically important special case – the corrosion of steels in marine environments. Earlier models are reviewed briefly but most attention is given to a model with scientific backing and that has been calibrated to coherent and homogeneous field data. Both mass loss (average corrosion over large areas) and pitting or very localized corrosion are considered, as is the role of microbiological corrosion. The model applies also to stainless steels, aluminium, copper-nickel alloys, and cast irons. Several example applications are then discussed. Caution is required in possible relationship(s) between the longer-term corrosion of actual structures and short-term field or laboratory corrosion tests and also in applying results from laboratory or electrochemical tests.

A piece of structural steel exposed to a marine environment (immersion, tidal, splash, coastal atmosphere) and inland (with or without chloride deposition) usually will corrode in an approximately 'uniform' manner that can be represented as a loss of thickness of the exposed surface layer. When surface deposits, other well-developed rusts, barnacles, etc. are present, there is likely to be 'pitting' corrosion (Figure 1) and sometimes, in cracks, there may be crevice corrosion. These are the most common. For structural engineers the most important is so-called 'uniform' corrosion, which is not strictly uniform but for most structural engineering applications may be idealized as such with little error. The net remaining section properties such as cross-section area or remaining elastic or plastic section moduli are all easily estimated once the corrosion loss is estimated. For containment systems (pipelines, tanks, ships, etc.) pitting is of much interest.

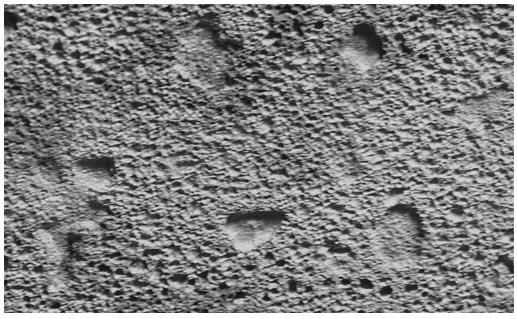


Figure 1. Corrosion of structural steels showing typical pitting, after 4 years immersion exposure.

The simplest, most common, model for corrosion is the 'corrosion rate', values of which abound in various practical reference books or compendia, based on a wide variety of sources. Mostly the quoted values for these rates do not mention the period over which they were measured, and often provide little or no information about the prevailing environmental conditions. Unfortunately, a fixed corrosion rate is misleading for all but very short observation periods. This is illustrated in Figure 2 for mild steel exposed to 4 different exposure environments in the Tropics. All show curvilinear corrosion trends.

The trends in Figure 2 have been assumed by many researchers to be representable by the so-called 'power-law':

$$c(t) = At^B \tag{1}$$

where c(t) is the corrosion loss as a function of time t and A and B are constants obtained by fitting to the data. Of course, the special case $B = 1$ yields a linear function in which A is the corrosion rate.

Interestingly, when inconsistencies between data and Eqn. (1) have been noted, they tend to be dismissed as caused by errors in the data or by natural variability. It also has been noted that the length of the data set in time affects the values of A and B. This suggests Eqn. (1) is not a robust model. Also, the implicit assumption that it applies *ad infinitum* needs critical examination. Others have proposed various empirical variations of Eqn. (1), some noting that long-term

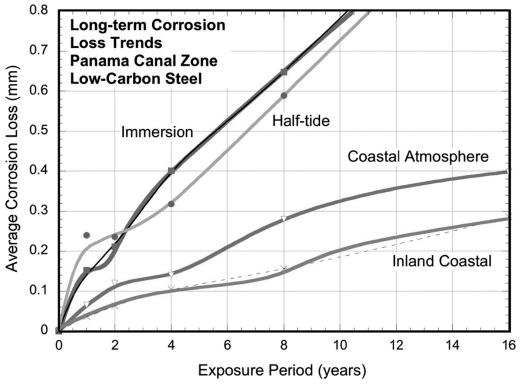


Figure 2. Corrosion loss curves for low carbon steel exposed to 4 different environments.

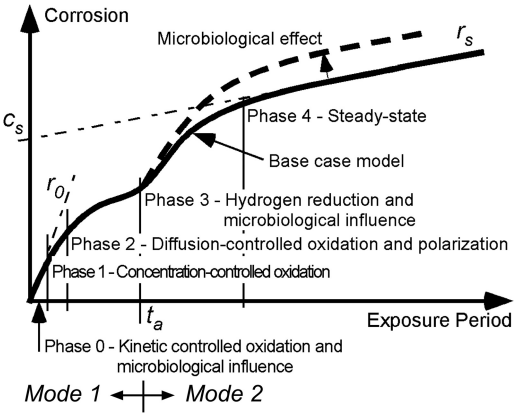


Figure 3. Bimodal model showing the two modes, the phases representing different corrosion rate controlling mechanisms (phase 0 not shown) and some of the parameters used to describe the model. The main effect of microbiological influence on corrosion loss is shown also (broken line).

corrosion tends to a linear trend, or that it ceases to increase after some time, that is that corrosion ceases. Mostly they have been claimed to be engineering (i.e. empirical) models rather than science-based models, working from whatever data are available. In many cases this is from assorted collections of observations of corrosion on, for example, different ships at different points in time and with very little if any control over the environmental conditions. As a result, the standard deviations in the data sets typically are very high. Fundamentally, indiscriminately putting together data from disparate sources is not acceptable for deriving meaningful statistics.

Working directly from well-controlled long-term data such as in Fig. 2 but also many other homogeneous data sets obtained from planned experiments and mainly available in the open literature, the so-called bimodal model shown in Figure 3 was proposed some time ago, initially for mild and low alloy steels in natural coastal seawater immersion conditions. Subsequently it has been demonstrated to apply for steels exposed in tidal, splash and coastal marine atmospheric conditions, to cast iron (a ferrous metal) in tidal and immersion conditions and in buried in (wet) soils. It follows that the bimodal model is not the result of some aberration in data.

The sequential phases in Fig. 3. are associated with a different mechanism controlling the rate of corrosion (Melchers & Jeffrey 2008) (Table 1).

The rate-limiting step for mode 1 (phases 0-2) usually is oxygen diffusion towards the metal surface, while for mode 2 (phases 3–4) it is hydrogen diffusion away from the metal surface (Melchers & Jeffrey 2008). The most important observation is that the corrosion processes controlling the behaviour in the early period are not those that control the corrosion process in the long-term.

Mode 2 of the bi-modal model (Figure 3) is predominantly under anaerobic conditions. This can be seen also for corrosion pitting (Figure 4) after t_a is reached.

The mechanisms involved in pitting corrosion have been established. Mathematical modelling (e.g. Sharland & Tasker 1988) has shown that chlorides are not

Table 1. Phases and mechanisms in bi-modal model.

Phase	Rate controlling mechanism(s)	Reaction
0	Mainly anodic reaction	$Fe \rightarrow Fe^{2+} + 2e^-$
1	Oxygen diffusion from surrounding water	$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$
2	Oxygen diffusion through rusts	ditto
3	Hydrogen diffusion through rusts	$2H_2O + 2e^- \rightarrow H_2 \uparrow + 2OH^-$
4	Steady-state hydrogen diffusion	ditto

necessarily part of the corrosion reactions, although they may be necessary for charge neutrality considerations. This at first appears a surprising result as 'everyone knows' that chlorides are aggressive in corrosion of steels. However, care is required.

Already in 1908 Brauns & Schwenk reported that steels corroded to a very similar degree irrespective of the type and concentration of (the various) salt solutions in which they were immersed. In 1968 Dora Brasher (1967) argued that in the stagnant solutions used by Brauns & Schwenk oxygen controls the rate of the (admittedly slow) reactions and that the chlorides and other halides were of little importance. She postulated that under these conditions the oxides that form on the metal surface are sufficiently protective. Mercer & Lumbard (1995) showed convincingly using rotating mild steel tubular samples in natural and in artificial seawater that the effect of chlorides reduces dramatically as the rate of rotation decreases. Figure 5 gives a schematic view of their results.

The reason chlorides are so often implicated in severe corrosion is that in many practical cases the waters are not stagnant but constantly moving, by wave

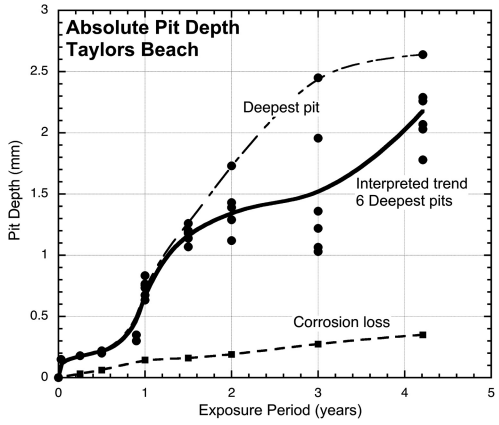


Figure 4. Trend in deepest and 6 deepest pits (Melchers 2004).

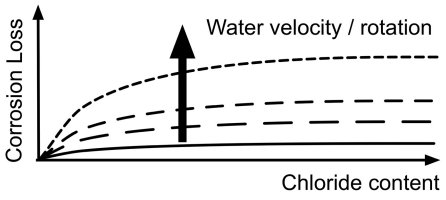


Figure 5. Schematic representation of insensitivity of corrosion to chloride content under near-stagnant conditions, and also insensitivity to elevated chloride contents (based on data reported by Mercer & Lumbard, 1995).

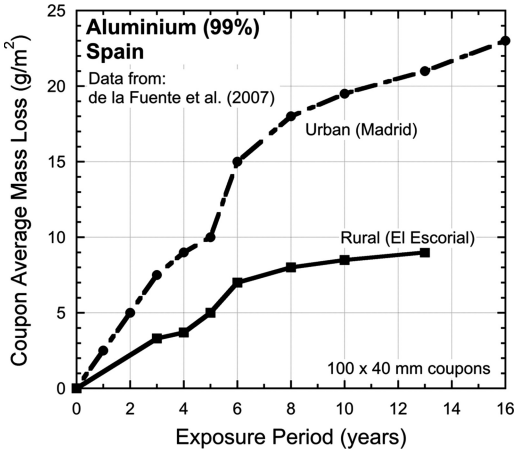


Figure 6. Corrosion Loss for 99% pure aluminium in two different exposure environments (Melchers 2014b).

or wind action. This is important for short-term corrosion but, for long-term corrosion, the corrosion products soon provide a protective layer and then the effect of water velocity or turbulence becomes much less relevant. It is sometimes forgotten that chlorides are hygroscopic, thereby tending to increase the percentage of time steel surfaces exposed to the atmosphere remain wet, thus causing increased corrosion.

These basic research findings also explain why in longer-term exposures, corrosion of steel was found not to be strongly dependent on the salinity of seawater but rather on the hardness of the water. Soft fresh waters can be very corrosive, despite their obvious lack of chlorides.

Some types of corrosion can involve bacteria, or more generally prokaryotes (which includes Bacteria and Archaea). It is now known that the SRB (or more generally the SRP) are ubiquitous in nature and can be found in many locations where conditions for the metabolism of microorganisms are suitable (Little & Lee 2007). For SRP this means primarily an anoxic environment. Other requirements include suitable locations or shelter, an environment (e.g. temperature range) suited to the species of interest, one or more energy sources (such as a flow of electrons) and suitable macro- and micro-nutrients. The macronutrients include sulphates, phosphates, nitrates or inorganic nitrogen sources and organic carbon. An important micronutrient is ferrous iron (Fe), typically lacking in seawater, but, in the case of steel or ferrous metal corrosion, supplied by the corrosion process.

A number of other species have been implicated in the MIC of steels, including the iron oxidizers (IOP), the iron reducers (IRP) and corresponding manganese species. These groupings are very broad-brush. Modern DNA analysis typically reveals many different microorganisms, many (most) not previously investigated in any detail and therefore without understanding of their possible effect on corrosion. Our experience is that for engineering investigations DNA analysis must be considered to be premature at this time. However, other avenues are available. In particular, standard in-situ culturing methods such as provided by BART® kits can provide insight as to the presence of a range of bacterial types, some long associated with the corrosion of steels.

For infrastructure of aluminium alloys and copper alloys (but not pure copper) the bimodal trend applies also (e.g. Figures 6,7) (Melchers 2014) and aluminium alloys (2015a, b).

Turning now to practical examples, a phenomenon called Accelerated low water corrosion (ALWC) sometimes just below the low tide level for steel piling in seawater harbours (Figure 8). It was first noted in the 1980s for steel sheet piling in some UK harbours. There were many potential factors involved but the primary cause has now been isolated as MIC under high nutrient loadings (Melchers & Jeffrey 2012).

The argument had to rely on the idea that there must be elements of uncertainty involved. These include the notion that corrosion does not always progress at exactly the same rate, that local variations in DIN concentration may be involved, such as resulting from water velocity effects, and that sunlight and shading and port operations may be factors. Local pollution is inevitable in ports. These probabilistic aspects are not always fully appreciated by theoretical corrosion researchers and microbiologists.

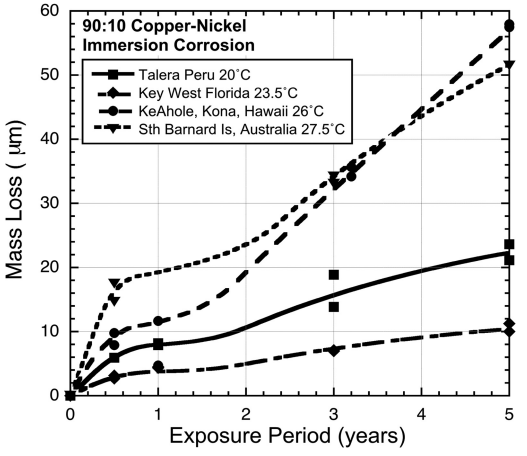


Figure 7. Corrosion (mass) loss of 90:10 Cu-Ni alloy in immersion conditions (Melchers 2015b).

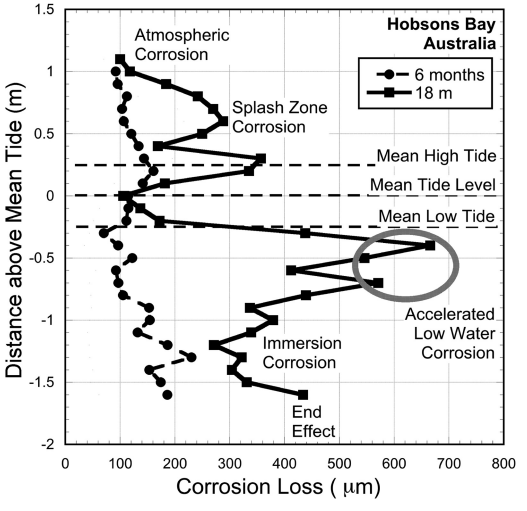


Figure 8. Corrosion profiles for steel piling at 6 and 18 months exposure in polluted seawater.

A rather similar severe corrosion effect has been observed for the corrosion of mooring chains used for FPSOs (floating production storage and offloading) vessels (Lee et al. 2015).

Also ALWC has been noted for cast iron bridge piers, some now around 100 years or more old. Cast iron corrodes very little in the atmosphere, even in marine atmospheres but is prone to corrosion under immersion and tidal conditions. Data from longer-term field trials in tropical conditions show corrosion loss and pit depth to have a bimodal behaviour (Melchers 2013). An investigation of the corrosion of cast iron piers for 4 railway bridges all in brackish but tidal seawater conditions in Queensland, Australia showed evidence of ALWC, more severe for the waters with higher DIN concentrations. These were related directly to upstream agricultural and pastoral fertilizer practices (Melchers et al. 2015).

The corrosion of cast iron in soils is of particular interest for water supply pipelines, since cast iron was the material of choice at the time major water supply and water reticulation networks were introduced into larger cities in the mid-late 1800s. Typically the major issue in the UK, Australia and some parts of the US is exterior corrosion in soils.

Several research projects were commenced already in the early 1900s, with perhaps the most famous being the US National Bureau of Standards project that involved some 120 different soils across the US and many different ferrous metals and combinations, including several cast irons (Romanov 1957). Although, as noted earlier, already in the 1930s MIC was suspected as being involved, the NBS program did not specifically investigate it. Several recent surveys conclude that it is still not possible to make robust predictions of the likely corrosion to be expected in soils, even if a range of soil properties, such as those recorded in the NBS study, are known.

The Australian water utilities, joined by UK and US partners, commenced a new study of the prediction of the likelihood of failure of larger cast iron water mains and one part of that project is the prediction of corrosion, both corrosion loss and pitting. Because of the incompleteness of the existing data bases a new protocol for soil testing was adopted. Actual water pipes (not samples) were exhumed from various locations in different water supply networks. The data showed that the development of pitting depth in soils follows a bimodal trend for the first few years (decades) (Petersen & Melchers 2012, 2014, 2015).

In contrast all earlier efforts to relate soil properties to corrosion and pitting have been based either on a 'corrosion rate' or the power law, perhaps based on Romanoff (1957) claim that the power law best fitted the trends he reported.

Care is required for the corrosion of chromium (Cr) – bearing and stainless (i.e. Cr-Ni) steels in marine immersion, tidal and coastal atmospheric exposures. Stainless steels rely on the greater corrosiveness of Cr compared to Fe to form Cr oxides that are very protective, forming the so-called passive layer on the metal surface. Thus scratches of the passive film exposing new Cr that then immediately oxidizes to create new passive film. This implies that oxygen must be available for the protective films to reform. If for some reason oxygen access is inhibited, corrosion will be as severe if not more so than for ordinary mild steel. An example of such severe localized corrosion occurs when marine organisms have settled on the metal surface, giving deep penetration even though the rest of the surface is only very mildly and almost uniformly corrosion pitted. Repassivation of the metal surface was not possible and severe localized corrosion occurred.

The bimodal pattern can be observed also in laboratory results reported by Mercer & Lumbard (1995) for mass loss corrosion of steels at controlled higher

temperature freshwater exposures (Melchers & Chernov 2010).

Taken together, the results reviewed herein, for a variety of metals, a variety of environmental exposure conditions, each with different possible longer-term patterns, support the notion that the bimodal behaviour is not some artifice but rather is of a fundamental nature.

For engineers dealing with long-term corrosion effects and attempting to predict likely future corrosion the distinction between modes 1 and 2 is important since in mode 2 there is much less emphasis on the role of oxygen. Two aspects follow immediately for practical applications: (i) that care must be taken in extrapolating short-term observations (i.e. before t_a) to the long term (i.e. after t_a), and (ii) that whatever may be used to inhibit corrosion before t_a must be assessed separately for effectiveness after t_a.

Electrochemical testing is sometimes used in practical situations for estimating the rate of corrosion loss and for estimating the likely future rate of corrosion. Mostly this follows the use of electrochemical testing in the laboratory, and it is seen as a quick and relatively easy way of obtaining corrosion loss results and sometimes information about pitting corrosion. Typically the metal of interest is connected to a (usually) direct current power source to drive the reaction at the anode faster by forcing out the electrons. To complete the circuit and to isolate the anode, it is connected by a conducting wire to another, larger, piece of metal, often stainless steel or platinum that acts as the cathode. This experimental format in itself makes direct comparison to natural corrosion behaviour problematic since in most practical cases the anodes and the cathodes are on the same piece of metal. To try to simulate natural corrosion conditions electrochemists sometimes use 'open-circuit' conditions in which the power source is disconnected. This also assumes that the corrosion process is controlled by the anodic (metal dissolution) reaction. Such a scenario may be the case immediately after first exposure but in practice this lasts only a short time and soon oxygen diffusion (concentration control) takes over. This means the corrosion process is controlled by a cathodic reaction. Further, even though textbooks seldom mention it, in electrochemical testing it is common to employ rotating electrodes or artificial magnetic stirring of he electrolyte to destroy the diffusion layer immediately next to the corroding metal and thereby increase the rate of the electrochemical reactions. This is not consistent with the protective nature of the corrosion products in practice and with phases 1-4 of the bimodal model.

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Life cycle structural integrity management of offshore steel structures

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ABSTRACT

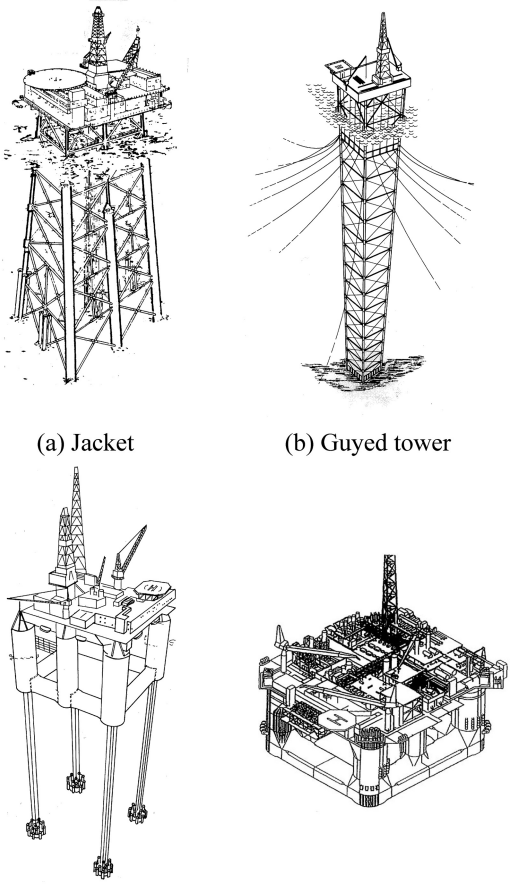
General The continuous innovation to deal with new serviceability requirements and demanding environments as well the inherent potential of risk of fires and explosions, have led to an industry which has been in forefront of development of design and analysis methodology for safety assessment.

Different types of structures are required in the exploitation of subsea oil and gas resources (Figure 1). The significant latent energy associated with hydrocarbons flowing through, or stored in production platforms, obviously represents a significant hazard.

The focus in this paper is on structural integrity management during the life cycle – design, fabrication, installation and operation (Figure 2). The various types of marine structures experience different failure modes which ultimately can lead to fatalities, pollution or property loss. Structures supported on the seafloor can experience failure of the structure, foundation or soil, while buoyant structures can experience capsizing or sinking, hull or mooring system failure.

Current practice is implemented in offshore codes, e.g. by API (1993–97), ISO (19900, 2013) and NORSOK N-001(2012) as well as by many classification societies, and reviewed by Chakrabarti (ed., 2005). The most advanced codes are characterized by:

– design criteria formulated in terms of serviceability and safety limit states
– semi-probabilistic methods for ultimate strength design which have been calibrated by reliability or risk analysis methodology
– fatigue design checks depending upon consequences of failure (damage-tolerance) and access for inspection
– explicit accidental collapse design criteria to achieve damage-tolerance for the system
– considerations of loads that include payload; wave, current and wind loads, ice (for arctic structures), earthquake loads (e.g. for bottom supported structures, tethers in tension-leg platforms etc.), as well as accidental loads such as e.g. fires, explosions and ship impacts
– global and local structural analysis by finite element methods for ultimate strength and fatigue design checks



(a) Jacket (b) Guyed tower

(c) TLP (d) Semi-submersible

Figure 1. Example production facilities.

– nonlinear analyses to demonstrate damage tolerance in view of inspection planning and progressive failure due to accidental damage
– life cycle feature, with strong link between design, and inspection, monitoring, maintenance and repair (IMMR)

Moreover, reassessment of design is required during operation, for instance, because of planned change of

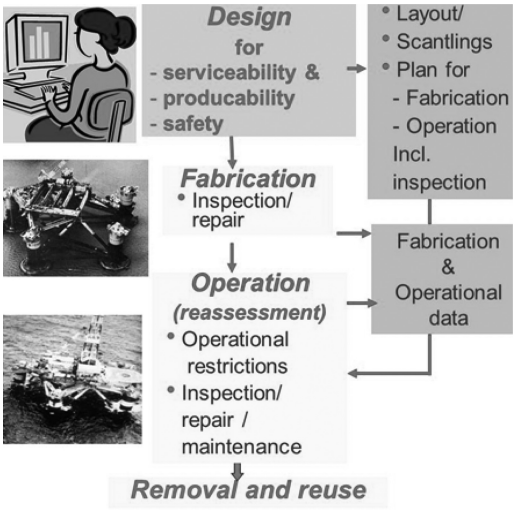


Figure 2. Life cycle phases of offshore structures.

Table 1. Cause of structural failures and risk reduction measures.

Cause	Risk Reduction Measure
Less than adequate safety margin to cover "normal" inherent uncertainties.	– Increase safety factors or margins in ULS, FLS; – Improve inspection of the structure (FLS)[1)]
Gross error or omission during: – design (d) – fabrication (f) – operation (o)	– Improve skills, competence, self-checking (for d, f, o) – QA/QC of engineering process (for d) Direct design for damage tolerance (ALS) – and provide adequate damage condition (for f, o) – Inspection/repair of the structure (for f, o)[2)]
Unknown phenomena	– Research & Development

[1)]Measure by Structural Reliability Analysis
[2)]Measure by Risk Assessment

platform function and, hence, the need to increase payload or accidents or damages, Basically, the reassessment involves the same assessments as carried out during initial design, however, with performance data available for the specific structure.

Experiences The current structural integrity management philosophy has to be based on experiences. The detailed inquiries made after catastrophic accidents are particularly useful (Moan, 2009a–b; Vinnem, 2014; WOAD, –). In the paper the Ranger I, Alexander Kielland, Ocean Ranger, Piper Alpha and P-36 accidents are addressed both from a technical physical (TPY) point of view as well as a human and organizational (HOF) point of view. HOF (gross errors or omissions) in design, fabrication or operation, is the root causes of accidents.

In a TPY perspective failures occur due to:

– overload failures – often caused by accidental loads or abnormal occurrence of environmental loads
– fatigue failure/rupture
– corrosion

Degradation due to corrosion and fatigue crack growth would normally develop slowly to failure. However, fatigue can cause catastrophic accidents if the fatigue life is not sufficient to make IMMR effective or if there is lack of robustness, as in the case of the Ranger I and Alexander Kielland platforms.

Cracks are for instance always present at welds. The development of cracks depends on their initial size (normally a fraction of a mm), uncertainties in the stresses driving the crack, fatigue resistance and the inspection method used to detect the crack. Due to the very nature (small size) of initial (fabrication) defects, an abnormal size of such defects often have been the cause of fatigue cracks. Extensive experiences regarding cracks in North Sea jacket and semisubmersible platforms have been reported by Vårdal and Moan (1997, 2016). The service experiences show that cracks have been caused by e.g.:

– not carrying out proper fatigue design checks and inspections and possible repairs
– abnormal initial defect size, e.g. due to wet electrodes
– abnormal crack propagation e.g. due to corrosion fatigue effects
– fatigue caused by overprotection or loss of protection
– abnormal local geometry (e.g. eccentricities) due to bad design or fabrication detailing (as-built structure deviating from design). Hence it is always important to refer to the as-built condition of the structure when planning and executing inspections
– error in load (stress) analysis (environmental conditions, method, stress concentration factor)

The experiences with mooring (chain) is that the annual failure rate is of the order of 0.01 per line, which may be one to two orders of magnitude larger than the notional failure probabilities obtained by assuming "normal uncertainties" and not accounting for "gross errors", as discussed above. Failures of mooring lines are hence often caused by "abnormal strength" and inaccurate modelling of hydrodynamic loads, while failures of load-bearing hull structures are often caused by accidental loads due to operational errors (Stiff, 2014; Smedley and Petruska, 2014).

Safety Management Approach In Table 1 the causes of failures are categorized and the corresponding measures to control the accident potential are listed. In general, the measures include design criteria, quality assurance and control (QA/QC) relating to the engineering process as well as the hardware and operational procedures.

Primarily, gross errors and their effects should be avoided by adequate competence, skills, attitude and

self-checking of those who do the design, fabrication or operation in the first place; and by exercising "self-checking" of their work. In addition, quality assurance and control (QA/QC) should be implemented in all stages of design, fabrication and operation.

The quality assurance and control of the engineering process have to address two different situations, which require different type of attention (Moan, 2004; Bea, 2005), namely:

- detect, control and mitigate errors and omissions made in connection with technology that is known in the engineering community as such. With the increasing use of computers in the design, construction, and operation of oil and gas structures, software errors are of particular concern
- identify possible unknown phenomena, e.g. associated with load, response and resistance, and clarify the basis for accounting for such phenomena in design; especially for novel concepts

As mentioned above, operational errors typically result in fires or explosions or other accidental actions. Such events may also be controlled by appropriate measures such as detecting the gas/oil leakage and activating valve shut in; extinguishing of a fire by a deluge system activated automatically etc. These actions are often denoted "Event Control".

Despite the efforts made to avoid error-induced accidental actions or abnormal resistance, they cannot be completely eliminated. For this reason the trend is to base regulations on the following general safety principles:

- Structural integrity to withstand environmental and operational loading throughout its lifecycle
- Prevent occurrence of and protect against accidental events
- Tolerate at least one failure or operational error without resulting in a major hazard or damage to structure
- Provide measures to detect, control and mitigate hazards at an early time to avoid accident escalation.

Accidental Collapse Limit State (ALS requirements are motivated by the design philosophy that "small damages, which inevitably occur, e.g. due to ship impacts, fires and explosions, and other accidental loads, as well as abnormal environmental hazards, should not cause disproportionate consequences".

In addition to accidental loads caused by operational errors, "damages" implied by fabrication errors need to be considered. Such damages e.g. relating to fatigue, which depends on very local structural features and IMMR, need to be specified by judgement.

The introduction of the quantitative robustness check in terms of ALS, was possible because FEMs had been developed for accomplishing the necessary nonlinear structural analysis to estimate the damage and the strength of the damaged structure (NORSOK N-001). The structural integrity criterion in Norsok N-001 is a two-step procedure. First, the initial damage due to accidental actions with an annual exceedance probability of 10^{-4} is estimated by a nonlinear analysis or damage is specified e.g. in terms of a failure of a slender member. The second step is to demonstrate that the damaged structure resists relevant functional and environmental loads an annual exceedance probability of 10^{-2} or a lower probability depending on the correlation between the accidental event and the environmental condition – without global failure. Further details about the background and practicing of the ALS criterion is described by Moan (2009a), Storheim and Amdahl (2014), Vinnem (2014) and Czjuko, et al. (2015) including that the assumed annual target probability of total loss for each type of hazard is 10^{-5}.

Inspection, Monitoring, Maintenance and Repair (IMMR) should address all kinds of damages, i.e. corrosion and cracks, as well as conditions that could lead to damages. The occurrence of accidental damage due to fires/explosions and ship impacts should on one hand be controlled by surveillance of hydrocarbon leaks and ship traffic but on the other hand the damage once it has happened, easy to identify. The main challenge is the integrity management in view of cracks that abnormal fabrication induced cracks are relatively small and might escape NDT examinations.

In general, therefore, it becomes important to ensure that there is ample time between visible (detectable) crack and fracture. A general remedy to ensure this feature is to limit the stress level by designing for fatigue by a large FDF or to ensure ultimate strength after member failure.

Structural Reliability Analysis relating to ULS and FLS criteria The offshore industry early recognized that the lifecycle structural management takes place under uncertainty and adopted risk and reliability methods to make more rational decisions, see e.g. Marshall (1969) and the overview of early developments by Cornell (1995) and Moan (1995) in conjunction with the ISO effort to harmonize codes for offshore structures (ISO 19900 suit of standards). Significant developments of structural reliability methodology, including Bayesian updating techniques to update the reliability measure based in inspection results, have taken place since the 1980's, as outlined e.g. by Itagaki et al. (1983), Madsen (1985), Lotsberg and Kirkemo (1989), Shinozuka and Deodatis (1989), Jiao and Moan (1990), Faber et al. (1992), Lotsberg et al. (2013) and the reviews by Yang (1994) and Moan (1994).

SRM is applied to determine the failure probability considering fundamental variability, as well as uncertainties due to lack of knowledge in loads, load effects and resistance. The state of art methods for calculating the failure probability are numerical First Order and Second Order Reliability as well as Monte Carlo simulation methods (e.g. Madsen et al., 1986; Melchers, 1999).

The reliability estimates critically depend on the assessment of uncertainties in structural loads and strength, as indicated above and exemplified subsequently. It is important that authoritative values of the uncertainties are applied in reliability analyses.

Table 2. Safety criteria for structural design.

Limit states	Description	Remarks
Ultimate (ULS)	– Overall "rigid body" Instability – Ultimate strength of structure, mooring or possible foundation	Different for bottom – supported, or buoyant structures. Component design check of strength
Fatigue (FLS)	– Failure of welded joints	Component design check depending on residual system strength (see Table 4)
Accidental collapse (ALS)	– Ultimate capacity[1)] of damaged structure with "credible" damage	System design check

[1)]Capacity to resist "rigid body" instability or total structural failure.

Moreover, the probabilities obtained by SRM in general should not be considered as actuarial values. because human errors are not explicitly considered in the SRM. Hence the probabilities should be considered notional.

Yet, SRM is useful in ensuring that the ultimate strength and fatigue design criteria (Table 2) are consistent with a certain target probability of failure level.

Calibration of semi-probabilistic ULS design criteria have been carried out by e.g. Fjeld (1977), Lloyd and Karsan (1988) and Moan (1988). See also overviews by Moan (1995) and Wisch (2014).

Since SRM provides notional failure probabilities a comparison with experienced failure probabilities is not a consistent approach. Anyway the probabilities of overload failures due to the uncertainties accounted for.

Fatigue is an important consideration for structures in areas with more or less continuous storm loading (such as the North Sea) and especially for dynamically sensitive structures.

Fatigue crack growth is primarily a local phenomenon. Fatigue strength is commonly described by SN-curves. Fracture mechanics analysis of fatigue strength has been adopted to assess more accurately the different stages of crack growth including calculation of residual fatigue life beyond what is defined as fatigue failure in conjunction with SN-curves. (Lotsberg, 2016; Moan, 2007). However, it is important to ensure that the fracture mechanics model is consistent with the SN-approach with respect to fatigue failure (e.g. Ayala-Uraga and Moan, 2007).

Recently DNVGL (2015) issued a comprehensive guidance for use of probabilistic methods for inspection planning with respect to fatigue cracks in jacket structures, semisubmersibles and floating production vessels. The approach is rather general may be used also for inspection planning of other structures subjected to significant dynamic loading such as jackups.

Fatigue failures (in terms of observed cracks, cracks through thickness etc.) the failure rate has sometimes been high, especially in old designs, with inadequate design practice, and comparisons could in principle be made. Yet the SRM gives a notional probability.

Hence, comparisons of the observed frequency with the estimated probability give measure for the capability of the analyses to describe the actual failure potential.

The failure detection frequency is also a trigger for extended assessment and inspection. This approach has been extensively used for jackets and semisubmersibles (Vårdal and Moan, 2016).

An example of applying the effect of inspection on the reliability level is shown in Figure 3 where the reliability index β is displayed as a function of time based on prediction of the effect of inspection at the design stage and based on the outcome of actual inspections. The latter obviously is more efficient in increasing the reliability index β. It is seen from Figure 3 that a reliability level of $\beta \approx 2.0$ and 3.0 is maintained in the first 20 years with no inspection and an NDE inspection method with mean detectable crack size of 1.5 mm and no detection of crack every 5th year

The updating methodology is useful in connection with extension of service life for structures with joints governed by the fatigue criterion (Vårdal et al., 2000).

So far reference has been made to the reliability of components. The importance of a systems reliability approach as well as the complexity of implementing it for offshore structures that can fail in a sequence of overload or fatigue failures of components, is discussed in the paper. The challenges are partly linked to the modelling of structural failure process, and partly the uncertainty modelling of components considering correlation (Dalane, 1993; De, 1989; Karamchandani et al., 1993; Moses and Liu, 1992; Shetty, 1992; and Wu and Moan, 1989).

However, for some structural systems, like jackets accurate estimates of the systems failure probability under extreme sea loading can be achieved in many cases by considering a single system failure mode. This is because environmental load uncertainties dominate and the extreme loads in various components are highly correlated (De, 1989; Wu and Moan, 1989).

A first, simple approximation to the failure probability, P_{fSYS}, of a jacket system consisting of discrete elements, considering both overload as well as fatigue failure followed by overload failure modes, may be expressed as:

$$P_{fSYS} = P[FSYS] \approx P[FSYS(U)] + \sum_{j=1}^{n} P[F_j] \cdot P[FSYS(U) \mid F_j] + \ldots\ldots \quad (1)$$

where $FSYS(U)$ is a pure overload system failure readily calculated by efficient methods for framed structures (Skallerud and Amdahl, 2002) and F_j the

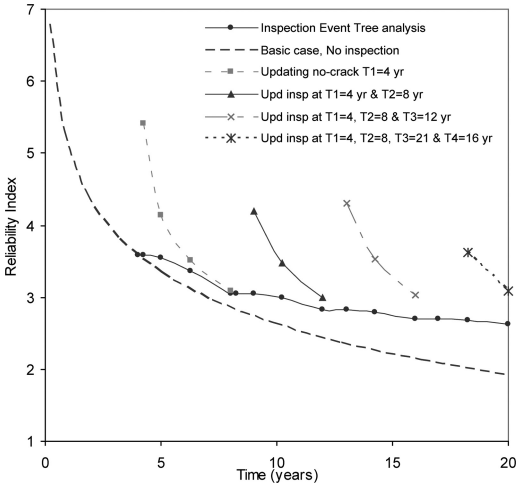


Figure 3. Reliability index as a function of time and inspection strategy. Inspection Event Tree analysis is based on prediction at the design stage. The other curves are based on inspections with known outcome during the service life (Ayala-Uraga and Moan, 2002).

Table 3. Fatigue design factor, FDF to multiply with the planned service life to obtain the design fatigue life: NPD-NORSOK/API and (reliability analysis).

	Access for inspection and repair		
		Accessible (inspection according to generic scheme is carried out)	
Classification of structural components based on damage consequence[1)]	No access or in the splash zone	Below splash zone	Above splash zone or internal
Substantial consequences	10/10 (10)	3/5 (4)	2/5 (3)
Without substantial consequences (i.e. satisfaction of ALS req.)	3/5 (4)	2/2 (2)	1/2 (1)

[1)]NPD(1984)-NORSOK N-001(2002) – general requirements while; API(Karsan,2005); and reliability estimates (Moan et al. (1993a), Moan et al. (1999) and Moan (2002).
[2)]The consequences are substantial if the Accidental Collapse Limit State (ALS) criterion is not satisfied in case of a failure of the relevant welded joint considered in the fatigue check.

fatigue failure of component j. It is noted that the first term then covers all pure overload failure sequences. For a statically determinate system $P[FSYS(U)|F_j]$ is 1.0, since failure of each component implies system failure. The validity of Equation (1) is discussed in the paper.

The formulation expressed by Equation (1) is particularly applicable for structures with clearly defined components such as members and joints on jackets, jack-ups, drilling semi-submersibles (with braces) (Moan, 2004) while cracks in monocoque structures like ship hulls are more challenging to deal with.

There is an important link between fatigue and ALS design criteria and inspection, by the fact that the acceptable fatigue failure probability should depend on the consequences – i.e. potential progressive failure, see Table 3.

Structural reliability methods may be applied to estimate the reliability of mooring systems. However, currently there is a significant mismatch between reliability estimates and observed failure rates, partly due to lack of refined models accounting for local bending effects on individual chain links, excessive corrosion rate and partly because of gross defects caused in the fabrication and operation (Smedley and Petruska, 2014; Stiff, 2014).

In applying SRM the selection of target level for the notional probability of failure obtained is crucial in the decision making (e.g. Moan, 1998; 2014).

A main issue is that target levels for notional failure probabilities relating to SRM should be clearly distinguished from actuarial failure probabilities relating to risk assessment considering human factor effects also. It also implies that the target level for failure probabilities estimated by the SRM should be assumed to be a fraction of the actuarial target probability level (e.g. Jordaan and Maes, 1991).

Moreover, rather that setting an overall target level it is more practical to establish target levels for each hazard separately, see e.g. Moan (1983, 1994) and Cornell (1995).

Table 3 shows fatigue acceptance criteria established by NPD/NORSOK in Norway and API (Karsan, 2005 – essentially for jackets), respectively. By accounting for the effect of inspection (Moan et al., 1993a) and using a simplified system approach by considering each term in the sum in Equation (1) for jacket structures (Moan et al., 1999), fatigue design criteria have been derived and compared with codified criteria in Table 3.

Reliability-based Inspection Planning with respect to Crack Control IMMR during operation needs to address structural damage but also other operational and hardware aspects, especially event control relating to fires/explosions, ship impacts that can result in damages or failures. Herein the focus is on *crack control*.

The main life cycle efforts to prevent that cracks develop into failures, include:

- adequate design with respect to
  - fatigue design
  - residual fatigue life
  - ultimate reserve strength (to overload)
- adequate inspection, or
- adequate monitoring of leak, when relevant

Achieving robust offshore structures by applying ALS criteria is an important issue. In the present context a damage condition for an ALS check associated with abnormal cracks is envisaged (Moan, 2009a).

Table 4. Crack control measures.

Type of structure	Type of joint	FDF[1)]	Residual fatigue life	Ultimate reserve strength	Inspection method
Jacket	Tubular joint	2–10	Some-Sign.	Normally	NDE, U[2]
Semi-Subm.	Plated brace	1–3	Some	By ALS[4)]	LBB[3)]
		1–3	Some	Limited	NDE
	Plated col.-p.				LBB
					NDE
TLP	Tether	10	Small	By ALS	IM[5)]
	Plated col.-p.	1–3	Some	Limited	LBB
					NDE
Ship	Plated longt.	1–3	Sign.	None	Close Visual

[1)]FDF – Fatigue Design Factor – by which the service life is to be multiplied with to achieve the design fatigue life.
[2)]NDE – Non Destructive Examination Method; U – underwater.
[3)]LBB – Leak before break monitoring.
[4)]ALS – Accidental Collapse Limit State.
[5)]IM – Instrumental monitoring (by "an intelligent rat").

Table 4 shows qualitatively which role different safety measures play regarding crack control for different types of structures.

The objective of inspections here is to detect cracks. An inspection plan involves:

- prioritizing which locations are to be inspected
- selecting inspection method (visual inspection, Magnet Particle Inspection, Eddy Current) depending upon the damage of concern
- scheduling inspections
- establishing a repair strategy (size of damage to be repaired, repair method and time aspects of repair)
- assessment methodology for crack detections

Typically major inspections of offshore structures (special surveys, renewal surveys) are carried out every 4–5th year, while intermediate and annual inspections normally are less extensive. The inspection history of a given structure is actively incorporated in planning future activities. The inspection and repair history is important for a rational condition assessment procedure of the relevant structure and other, especially "sister" structures.

Further refinement of the inspection planning has been made by introducing probabilistic methods as (Moan, 2008; DNVGL, 2015) as outlined in the paper.

Permanent repairs are made by grinding to remove small cracks, cut out and butt welding a new section, re-welding, adding or removing scantlings, brackets, stiffeners, lugs or collar plates.

Inspection, monitoring and repair measures can contribute to the safety only when there is a certain damage tolerance. This implies that there is an interrelation between design criteria (fatigue life, damage tolerance) and the inspection and repair criteria. Fatigue design criteria, hence, are taken to depend upon inspection and failure consequences as shown by Table 3.

However, during operation the situation is different. Modification of the design and hence the scantlings is very expensive, and the most relevant measure to influence safety is the inspection and repair. The following section briefly describes how fatigue design and inspection plans (based on an assumed inspection method) can be established by reliability analysis to ensure an acceptable safety level.

As mentioned above, design and inspection criteria (Table 3) relating to fatigue crack growth, are based on generic information. Inspections during operation of the specific structure yields more information – that can be used in planning future inspections. Reliability methods can serve as tools for the decision making under uncertainty relating to fatigue crack growth – to maintain an acceptable safety level, by updating the reliability estimate. In particular the reliability estimate aims at considering the systems reliability. Such procedures were developed for structures consisting of slender member where the fatigue problem was located in tubular joints and the member overload failure can readily be represented by nonlinear finite element models (Kirkemo, 1988; Moan et al., 1999).

It is emphasized that RBI of structures is generally based on considerations of normal variability and uncertainties, i.e. by applying conventional structural reliability analysis methods. Such methods are also applied to establish the acceptance criteria in Table 3. In addition, possible gross errors needs to be taken into account.

Concluding Remarks In conclusion, it is found that the failure probability implied by current ultimate and fatigue limit state criteria is small and virtually do not show up in accident statistics. Yet structural reliability methods are needed to rationally deal with the normal uncertainties in loads and resistances that define ULS and FLS design checks, to ensure that these criteria comply with an intended failure probability.

The main cause of accidents is human and organizational errors and omissions. To achieve an acceptable safety level, therefore, requires QA and QC of the engineering process; inspection, monitoring and repair of the structure; as well as design for structural robustness. In this paper, particular emphasis is placed on the accidental limit state design check related to accidental loads and abnormal strength. The philosophy behind this robustness criterion is described. In view of the aging of offshore structures, crack growth and rupture are particularly addressed. It is shown how fatigue and robustness design criteria, as well as inspection strategy can be combined for different types of offshore structures, to yield an acceptable safety level.

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Railroad infrastructure management enabled by structural health monitoring

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ABSTRACT

To increase overall profitability, add capacity to rail operations, and comply with new federal regulations on bridge safety, North American railroads are exploring means to improve the management of their bridge net-works. Current maintenance, repair, and replacement (MRR) decisions are informed by bridge inspections and ratings, which recommend observing the response of bridges under trains. However, an objective relationship between bridge responses, bridge service state condition, and impact to railroad operations has yet to be established. Better determining the consequences of MRR decisions will allow railroads to effectively allocate their limited resources. This paper develops an approach for consequence-based management of bridge networks, employing fragility curves to relate service condition limit-states to bridge displacement. The operational costs associated with these service conditions can be used to estimate the total costs of a given MRR policy. This framework provides a consistent approach for the prioritization of railroad bridge MRR decisions.

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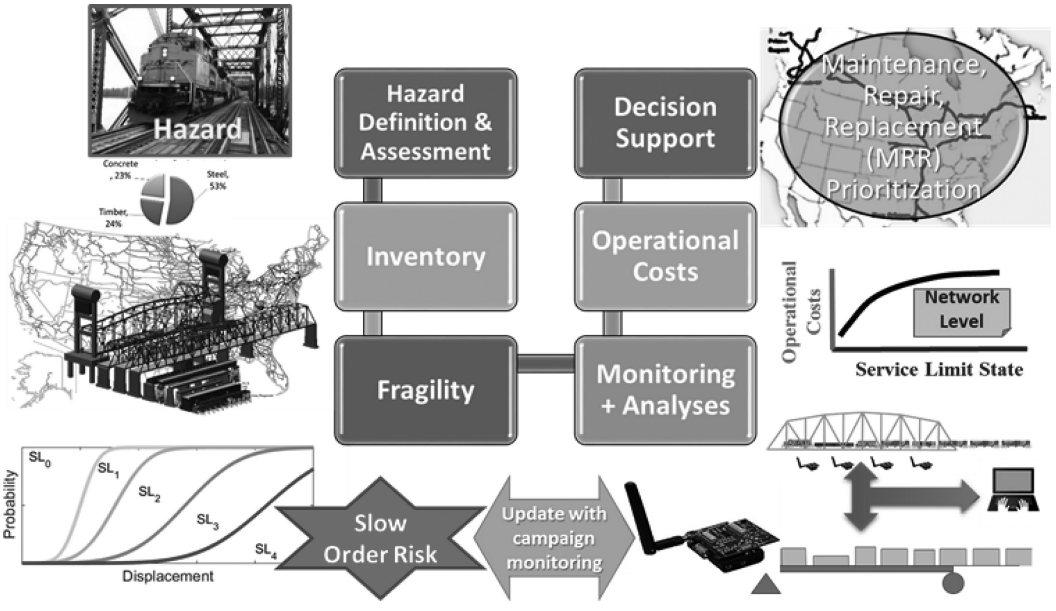


Figure 1. Framework for consequence-based management of railroad bridge infrastructure.

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Innovation of construction materials for more durable structures with less maintenance fee

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ABSTRACT

In Japan, infrastructural development began in the 1950s in step with rapid economic growth. However, most structures built around that time are expected to become decrepit in the near future after more than a half century from the original construction. Japan has already had a huge stock of infrastructure that needs maintaining in an efficient and appropriate way. In order to do this, it is important to address various issues found in each stage of the Plan-Do-Check-Act (PDCA) cycle for structural management, which consists of new construction, inspection, evaluation, rehabilitation, renewal, and reconstruction (Figure 1).

Since Japan is surrounded by the sea with mountain ranges running through the central area of its land, most of the infrastructure is located in coastal areas. Because of this, the service life of the infrastructure in Japan is often decided by the status of corrosion in steel used in steel and concrete structures.

Considering the critical role that materials such as steel play in determining structural life, it is important and efficient to focus on problems caused by materials that compose structures. The materials industry has been active for innovating various kinds of construction materials, and some of the main problems, such as metal corrosion, seem to be solved by applying new materials and technologies at each step of the PDCA cycle for structural management. Such efforts have produced positive outcomes including prolonged structural life and reduced maintenance cost.

The main materials used for structures are concrete and steel, and thus technological development to ensure longer life of these materials is very important for improvement in the new construction stage of the PDCA cycle. This paper will present examples of research and development efforts in this area with a special focus on the service life of construction materials. The ingress of chloride ion is an important factor to consider in preventing corrosion of concrete members in a marine environment. Fundamental data on the ingress of chloride ion to concrete were obtained through the 30-year exposure test using the Marine Engineering Research Facility (MERF, Figure 2), which is located about 250 m seaward from the coast line along the Pacific Ocean in Shizuoka

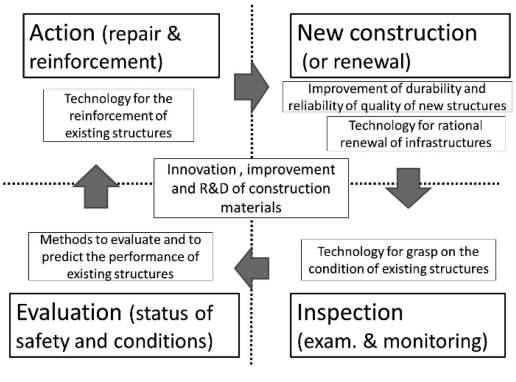


Figure 1. PDCA cycle for structural managemnt and the R&D in construction materials.



Figure 2. Marine Engineering Research Facility (MERF).

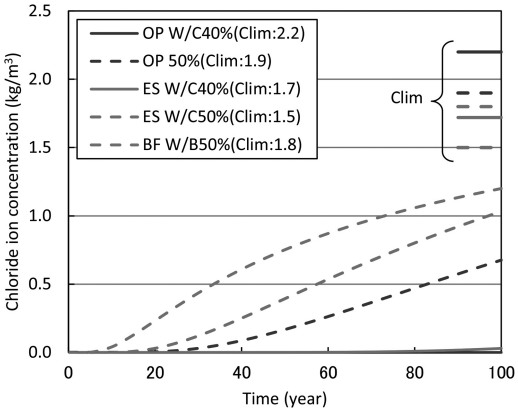


Figure 3. Prediction of chloride ion concentrations on the second deck with limit values for corrosion in reinforcement (Cover depth: 70 mm).

Prefecture of Japan. When the chloride ion reaches to the reinforcement position and the concentration of chloride ion exceeds the limit value for corrosion, the reinforcement will begin to corrode. Therefore, the life of reinforced concrete will become longer if we can extend the time until the time that chloride ion reach to the position.

Figure 3 shows the prediction of chloride ion concentrations on the second deck of MERF, 70 mm inward the surface, with limit values for corrosion in reinforcement. The results found that even after 100 years, chloride ion concentrations are likely to be lower than the limit values for corrosion in reinforcement. This suggests that if thick cover concrete is used, reinforcements would be kept in a good condition for many years. The results also suggest that if the corrosive environment becomes as severe as, or even severer than, the environment on the third deck of MERF, some anticorrosive methods would be required. This paper also introduces the protective effect of surface coating as an example of such kinds of anticorrosive method.

The other option is to introduce non-corrosive materials instead of conventional materials. More specifically, a new structural material called FRP and the Life-Cycle Cost Assessment (LCCA) will be presented in this paper. Three examples, two bridges and one hydraulic gate (Figure 4), of the applications of FRP are introduced and LCCA of those applications comparing the alternatives are also described. The results of LCCA of FRP bridge showed that FRP bridge tends to be more economically viable in the long term, and is clearly superior in a long-term scenario involving harsh environmental conditions. The results of LCCA of FRP hydraulic gate showed that even the initial costs of the FRP gates would be only marginally higher overall, because of the low installation cost in the example case. And the LCCA of the corresponding steel gates was 60% higher than the FRP gates after 50 years.

In the inspection and evaluation stages of the PDCA cycle, innovative materials, such as sensor materials, are expected to help to reduce maintenance effort



Figure 4. Example of FRP gates (Hibi, Hideki et al (2009)).

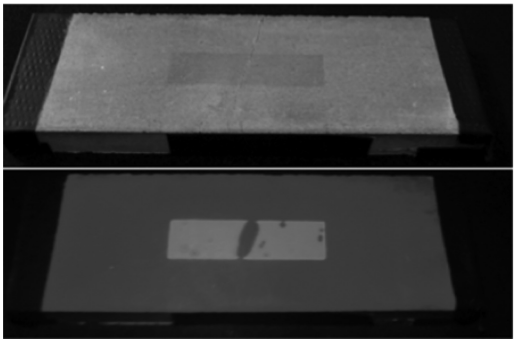


Figure 5. Luminescent crack sensitive paint on a cracked mortar test piece under room light (top) and black light (bottom; wavelength = 405 nm), (Hyakutake T. et al. (in submission)).

and cost. This paper will present research on sensor materials conducted by the Public Works Research Institute (PWRI), although LCCA for these materials has not been possible yet. Numerous studies have been conducted on degradation inspection using advanced functional materials. And when a specific degradation site is undetectable, visualization methods using paint or sheet type sensor materials are highly promising because they are easily applicable to wider surface area and also capable of making degradation visible in 2D by "color change" or "luminescence". To address these challenges, PWRI has been developing advanced crack sensor paint (Figure 5), which can detect microcracks by luminescence. The paint responded to a 0.1 mm wide crack by luminescent quenching, and the crack became clearly visible to naked eyes even under room light.

In relation to the action stage of the PDCA cycle, this paper will focus on asphalt pavement materials. In Japan, asphalt pavement is widely used for road surface. This type of pavement is less mechanically durable than concrete pavement, and thus requires maintenance (mainly re-surfacing) at relatively short intervals. Considering sustainability, it is important to improve its Life-Cycle Cost (LCC), as well as solve

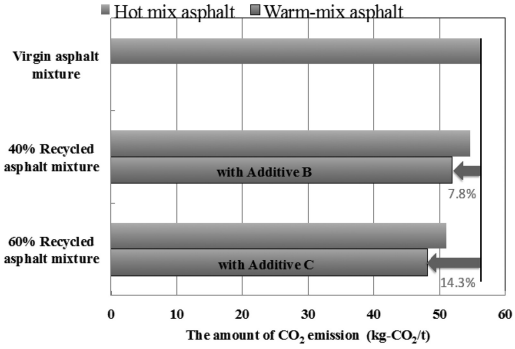


Figure 6. CO_2 emissions from warm-mix recycled asphalt mixtures.

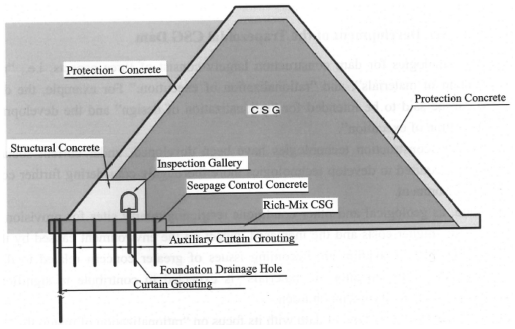


Figure 7. Standard cross section of the trapezoidal CSG dam.

relevant environmental issues, by innovating materials for pavement.

About 60% of CO_2 emissions from regular re-surfacing construction are reported to originate in manufacturing re-surfacing materials. If new materials are developed to produce asphalt mixtures by heating at lower temperatures than usual, less CO_2 emissions will be emitted. This type is called warm mixture in contrast to usual hot mixture. The application of warm-mix techniques is also required to be applied to recycled asphalt production in Japan, because the proportion of recycled asphalt mixtures to the overall asphalt shipment has exceeded 80 % in recent years. Base on the situation above, new warm-mix additives have been developed by PWRI, which produce micro-bubbles in asphalt binder and can be applied to recycled asphalt mixture. This paper introduces the reduction rates of CO_2 emissions for the developed warm-mix asphalt mixtures were presented on the basis of the CO_2 emission unit. The application of the warm-mix technology to the recycled asphalt mixture was found effective in reducing CO_2 emissions (Figure 6).

This paper also introduces Cemented Sand and Gravel, or CSG, materials as an example of new materials that are effective and locally available, for example, near a construction site. CSG is made by mixing cement and water with materials available within easy reach of construction sites using simple facilities developed by PWRI and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japanese Government, and Japan Dam Engineering Center edited a technical manual for its application (Japan Dam Engineering Center, 2012). The materials are minimally processed by just removing or crushing oversized pieces of gravel, as necessary, without additional procedures such as sorting, grading and washing. The CGS construction method is used to build structures by spreading and leveling CSG by bulldozers and compacting it with vibration rollers. In the action stage of PDCA cycle, the development of materials like this is also efficient to reduce the LCC.

The characteristics of the trapezoidal CSG dam can be summarized as bellow from the viewpoint of:

(1) Rationalization of Materials
Allowing widening the range of choice of materials by using lower quality materials because the trapezoidal CSG dam requires less strength and less material strength will be required;

(2) Rationalization of Design
Allowing dam sites selection to be more flexible because the trapezoidal CSG dam can lower the requirements of strength of materials for dam bodies, and also for the rock foundation;

(3) Rationalization of Execution
The trapezoidal CSG dam requires only extremely simple material manufacturing facilities. It also enables faster construction of works by employing continuous mixing facility.

Thus, the trapezoidal CSG dam, which was developed primarily aiming for “rationalization of materials,” will also contribute to “rationalization of design” and “rationalization of execution”. Figure 7 shows the standard cross section of the trapezoidal CSG dam.

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MINI-SYMPOSIA

MS1: Life-cycle performance of structural systems under multiple hazards

Organizers: F. Biondini & D.M. Frangopol



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Climate change, hurricanes, and the performance of coastal bridges

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ABSTRACT

Recent large scale hurricanes and their associated damage to bridges have demonstrated the need to include such extreme events in the design and performance assessment of coastal bridges. Coastal zones are vulnerable to accelerated sea level rise (SLR) due to anthropogenic changes in the climate. As a result, the structures and infrastructure systems located within these zones become increasingly vulnerable to damage. Flood plains and the effect of hurricanes may be magnified due to sea level rise and other climate change effects. This paper investigates the performance of coastal bridges under climate change effect with an emphasis on sea level rise and hurricanes.

The emission of greenhouse gases (GHGs) induces climate changes including increase in global temperatures and sea level rise, among others. The intensity of hurricanes is attributed to climate change by some researchers, while others attribute the variation of the intensity of hurricanes to oscillatory climate patterns. Due to the current debate over the correlation of the intensity of hurricanes to climate change, this paper incorporates only the SLR aspect of climate change. Tunnels and low lying coastal infrastructure have a higher potential for submergence as a direct result of SLR. Additionally, the effects of hurricanes are magnified by SLR as potential flood plains are expanded and the surge damage is increased.

Simply-supported low-clearance coastal bridges are subjected to extreme hydraulic forces during hurricanes. These forces may be sufficient to dislodge the superstructure from the supports. Adaptation measures can be applied to structures and infrastructure systems to mitigate the negative impacts of climate change. In the case of coastal bridges and their vulnerability to climate change, adaptation measures include retrofitting the bridge to either reduce the hydraulic forces acting on it or by providing additional capacity to withstand these forces. A quantitative assessment of the site-specific climate change effects on the performance of a typical coastal bridge located in a hurricane prone region in New Jersey is performed. Adaptation measures are to performed to reduce the probability of failure due to deck unseating and help mitigate the effect of climate change on coastal infrastructure.

ACKNOWLEDGMENTS

The support from grants from (a) the National Science Foundation (NSF) Award CMMI-1537926, (b) the U.S. Federal Highway Administration (FHWA) Cooperative Agreement Award DTFH61-07-H-00040, and (c) the U.S. Office of Naval Research (ONR) Awards N00014-08-1-0188, N00014-12-1-0023 and N00014-16-1-2299 is gratefully acknowledged. Opinions presented in this paper are those of the authors and do not necessarily reflect the views of the sponsoring organizations.

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Degradation uncertainties and life-cycle performance of a structure

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ABSTRACT

Structures are initially designed/constructed using a capacity-based approach, i.e. maximum forces caused by natural and man-made hazards are determined for anticipated magnitude of events, and then structural components are sized to provide sufficient capacities to resist these forces without affecting their defined performance functions. However, the structural materials, such as concrete, reinforcing steel, structural steel, deteriorate or degrade during a structure's life-cycle (e.g., corrosion in structural and reinforcing steel), caused by adverse environmental demands (e.g., earthquake, flood). These effects are generally not considered during the initial design of a structure, designed in accordance with the prescriptive capacity-based requirements of the national industry codes. Design or safety factors are used to ensure satisfactory performance for the structures. In general, the capacity-based approach to structural design has served the industry and the public well in the past. However, this approach fails to recognize uncertainties in material strengths and degradation effects, and the probability of occurrence of natural and man-made events. This may cause the strength demand to exceed the capacity of a structure, thus resulting in failure of a structure to perform its intended function during its life-cycle. Thus, the capacity-based approach does not quantify risk to the owner and the society.

The recent trend has been to quantify material degradation of a structure over its life-cycle, and use it to develop an inspection and maintenance strategy (Frangopol et al. 2012). Additionally, the building industry has recognized the need to change the prescriptive requirements to those based on performance. However, these requirements are limited to material performance and do not address the risk of a facility to the public. The nuclear regulatory agency has taken a lead in this area, and has changed the regulatory requirements to make them risk-informed performance-based for new reactor facilities and the proposed high-level waste disposal facility at Yucca Mountain, NV, USA (ASCE 2005). Recent studies by Shah (2010, 2012) reported on how increased concrete strength and corrosion of reinforcing steel, based on specified mean values and uncertainties in corrosion parameters would impact the time-dependent failure probability of a typical shear wall structure in a nuclear facility.

The study described in this paper extends the studies described above (Shah, 2010, 2012), and uses a stochastic method using a Monte Carlo simulation technique to examine sensitivity of a concrete shear wall performance to uncertainties in degradation parameters and reinforcing steel strength. The degradation parameters examined include pitting corrosion and modeling errors. Additionally, sensitivity studies are performed to address the effects of number of iterations in Monte Carlo simulation, the distribution types assumed for the reinforcing steel strength, and variation in logarithmic standard deviation used to develop the shear wall fragility curve.

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Influence of the exposure scenario on corrosion damage and life-cycle seismic performance of RC structures

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ABSTRACT

The level of environmental aggressiveness and the exposure scenario may have a significant impact on the seismic performance of reinforced concrete (RC) structures (Akiyama *et al.* 2011, 2012, Biondini *et al.* 2011, 2014). Design for durability should consider in a quantitative way the effects of the local damage of materials and components on the overall structural performance, particularly when continuous deterioration interacts with seismic hazard. However, this need is not explicitly addressed in seismic design codes, guidelines and standards (e.g., CEN-EN 1998-1 2004).

For RC structures exposed to corrosion, durability requirements are usually related to the quality of the materials and to the compliance of technical prescriptions such as the minimum cover depth (CEN-EN 1992-1 2004, fib 2006). To overcome this drawback, the assessment of the life-cycle seismic performance of RC structures should be based on general methodologies able to reproduce the diffusion process of aggressive agents, such as chlorides, and the effects of the mechanical damage induced by diffusion on the overall system performance under uncertainty (Biondini *et al*. 2004, 2006).

A probabilistic approach to life-cycle seismic assessment of RC structures is presented and applied to investigate the influence of the environmental aggressiveness and exposure scenario under chloride-induced corrosion. Chloride ingress is modelled at cross-sectional level based on the Fick's laws and is described by two-dimensional concentration maps. The effects of corrosion, including the mass loss of the reinforcing steel bars, the reduction of steel ductility, and the deterioration of concrete, are described through damage indices. The seismic capacity of the deteriorating structure is evaluated over the structural lifetime by means of time-variant non-linear static (pushover) analyses under a seismic lateral load distribution. The uncertainties are taken into account by Monte Carlo simulation.

The proposed approach is applied to the life-cycle seismic assessment of a three-storey RC frame under different exposure scenarios. A parametric analysis is performed by varying both the concentration level and the spatial distribution of chlorides on the external surface of the structural members. The results show the important role of the environmental aggressiveness and exposure severity on the life-cycle seismic performance of corroding RC structures.

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Life-cycle structural assessment of industrial heritage buildings

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ABSTRACT

Industrial buildings may have a significant architectural, historical, technological or social value and represent an important part of the cultural heritage of a country (Sýkora & Holický 2014). Historic industrial buildings frequently exhibit a significant decay of structural safety over time due to the detrimental effects of aging and deterioration of materials and components. Consequently, they may not fulfil the safety requirements of present codes of practice and rehabilitation and upgrades are necessary to ensure their proper conservation and effective reuse (Walljes & Ball 1997).

The industrial complex of cast iron foundries located in Multedo (Genoa, Italy) was established in 1917 and represents a remarkable example of industrial archaeology. The factory, built near the sea shore, is not in use since many years and its buildings, mostly made by reinforced concrete structures, are severely damaged by deterioration processes mainly related to chloride-induced corrosion of the steel reinforcement (Serafini 2011).

The feasibility of a reuse of the industrial complex has been investigated through experimental tests and numerical analyses based on a general methodology for life-cycle assessment of concrete structures under diffusive attack from aggressive agents and reinforcement corrosion (Biondini *et al*. 2004). The investigation allowed to assess the state of conservation of the structures, predict the evolution over time of the structural performance, and identify potential retrofitting strategies (Biondini *et al.* 2012).

The investigation has been supported by the results of an extensive experimental campaign. Special attention has been paid to the study of existing documentation, definition of in-situ and laboratory tests, and calibration of numerical models for the assessment of the actual damage state of the structural members. Structural analyses have been performed to check the safety requirements over time by taking into account the detrimental effects of environmental aggressiveness and related corrosion processes.

Details about the experimental activity and the results of mechanical and chemical testing are reported elsewhere (Bertolini 2012, Maselli 2012, Rosati 2012). This paper summarises the main results of the life-cycle assessment, including the chloride diffusion process, the effects of reinforcing steel corrosion, the time-variant loss of structural performance and the consequent reduction of structural safety. The results highlight the importance of a life-cycle approach to structural assessment and rehabilitation of industrial heritage buildings.

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Evaluating the seismic behavior of precast concrete connections in the life-cycle of concrete structures

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ABSTRACT

In the process of designing a typical structure, it is assumed that the structure is able to dissipate the seismic energy through inelastic behavior. In order to make sure that the mentioned assumption is valid for a concrete structure, the role of connections especially in concrete structures are of paramount importance. Therefore, using precast concrete in construction enhances the quality of members and minimizes the whole life-cycle impact on the environment when compared with other construction methods. The advantages of using this method has made researchers pay more attention to the way precast concrete connections behave under dynamic loadings.

In this paper, a finite element model for precast concrete connections is presented and verified based on the existing experimental results. To this end, connections are modelled completely using the software Abaqus, and a new simplified model (including beams, columns and springs) is proposed. The simplified model could be utilized in simulating more complicated structures. Afterwards, the efficiency and robustness of the proposed model are demonstrated by comparing the results of the modelling with those of the experiment. Finally, the seismic behavior of precast connections is compared with the seismic behavior of monolithic ones. This investigation includes various dynamic properties such as time-history response, damping, hysteresis curves, pushover curves, and stiffness.

The results show that precast concrete connections are considerably ductile and capable of withstanding high loadings. Precast concrete connections also provide more damping than monolithic concrete connections. This could result in a much more desirable response to dynamic loadings due to earthquakes. It will enable designers to make an accurate estimate of the real capacity associated with connections and frames so as to avoid dangerous overestimation or uneconomical underestimation of their capacity.

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Multi-hazard life-cycle performance of tall buildings under seismic and wind loads

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ABSTRACT

The current trend in designing important civil structures and infrastructures is to adopt life-cycle cast analysis (LCCA) approach. LCCA is aimed at predicting monetary losses over the structure's lifetime and is an useful tool for decision makers as it accounts for all sources of expense, structural deterioration, uncertainties in load and structural modeling and multiple-hazard occurrence. This paper presents a unified framework for LCCA of tall buildings subjected to wind and seismic loads. Due to the slenderness of tall buildings, they are mainly prone to serviceability problems and non-structural damage, provided that a proper design against lateral forces maintains the structure in the linear range.

In this paper a framework for LCCA of tall buildings subjected to wind and seismic loads is presented. The following assumptions are adopted: 1) the structure is restored to its original condition after damage occurrence; 2) maintenance costs are neglected as they vary slightly between different design solutions; 3) multiple hazards never occur simultaneously; 4) structure has linear behaviour under both wind and seismic load. Under these hypotheses, the expected value of normalized life-cycle cost of a non-structural element due to wind (w) and earthquake (e) over a time period t (design life or remaining life of a retrofitted structure) can be expressed as follows (Wen & Kang 2001):

$$E\left(\frac{C-C_0}{C_0}\right)=\frac{1-e^{-\lambda t}}{\lambda}\sum_{j=1}^{k}\left[c_j\left(\nu_w P_j^w+\nu_e P_j^e\right)\right] \qquad (1)$$

where $c_j = C_j/C_0$ is is the ratio of the intervention cost for the jth damage state relative to the initial construction cost C_0; λ is the discount rate per year; ν_w and ν_e are the mean rates of occurrence of hazards, P_j^w and P_j^e are the probabilities of exceeding the jth damage state given the occurrence of hazards; k is the number of damage states under consideration. Wind and seismic hazard curves for the specific site of the building are used to compute the probability of exceeding a damage threshold exploiting the total probability theorem.

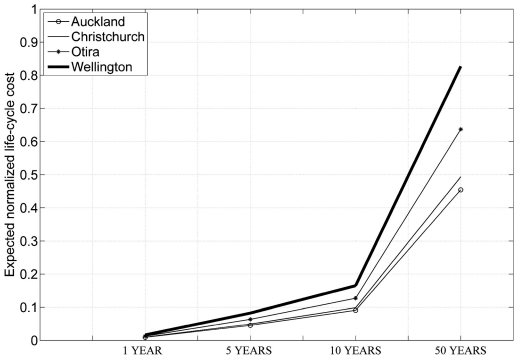


Figure 1. Dependency of expected normalized life-cycle cost on lifetime.

Numerical analyses, carried out on a benchmark 76-story building subjected to an ensemble of seismic accelerograms and to wind forces measured in the wind tunnel, allow the estimation of the relative influence of the two hazards on the expected lifetime costs. Wind and seismic hazard curves are computed for four different cities of New Zeeland, based on literature data. Results show that in order to have a correct estimate of the life-cycle cost of a building it is not possible to neglect expenses related to repair of non-structural components which are of the same order of magnitude of initial costs. Results also show that wind load produces higher costs related to drift-dependent damages then seismic load. The life-cycle cost increases with the duration of life-cycle and is strictly dependent on the hazards characteristics of the site (Figure 1).

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Risk quantification for life-cycle management of infrastructure considering the effect of maintenance behavior

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ABSTRACT

Maintenance strategy of civil infrastructure has been discussed from the viewpoint of optimization in terms of efficiency, such as reduction of LCC. It is also essential, however, to prevent severe accidents, such as collapse of bridges or tunnels. In the discussion of efficiency, risk is quantified by the expected cost or state (Liu & Frangopol 2006). However, even if the expectation is small, that is, structures are in good condition in average, the probability of occurrence of accidents can be high when a fraction of them are in a poor condition. This type of risk is often referred to as a tail risk. In actual situation, fatal accidents are prevented by maintenance activities. Therefore, the effect of maintenance behavior on the reduction of tail risk should be taken into consideration.

The objectives of this study is to propose the risk measure to quantify the riskiness of the state of infrastructure from the viewpoint of avoiding rare but severe events, considering the effect of maintenance behavior.

First, probabilistic characteristic of risk is investigated by numerical simulation model. One-way RC slabs in marine environment shown in Akiyama et al. (2010) are employed as target structures. Maintenance actions, inspection, prioritization, and repair, are also considered in order to reveal its effect on risk. The simulations show that probabilistic characteristic of tail risk can be affected by maintenance behavior. It means that the mean value of risk may not be an appropriate measure of risk quantification.

Variance, Value at Risk (VaR), Conditional VaR (CVaR) and Entropic VaR (EVaR), are compared in terms of quantification of the tail risk of numerical simulation of maintenance. EVaR and CVaR are more appropriate risk measures to quantify the tail risk under the effect of maintenance behavior.

However, those risk measures do not have a property of time-consistency. They are not applicable for multi-period problems because, even if the optimal maintenance policy is designed to minimize those risk measures, it is possible that that policy is rejected in the decisions at some time in the future.

This problem can be averted utilizing a scheme called iterated risk measures (Hardy & Wirch 2004), which utilize an ordinary single-period risk measure, such as CVaR and EVaR, recursively. This paper proposes to use such iterated risk measures as a tool to evaluate the risk and discusses the performance of the iterated risk measure.

It is also pointed that the computation cost to calculate iterated risk measure rigorously in Markov Decision Process increases exponentially when it is applied to multi-period dynamic problem. To reduce the amount of computation, we developed a scheme that utilizes a re-sampling method and clustering approach. Its clustering approach decreases the number of scenarios and tail part is simulated elaborately by utilizing re-sampling.

The presented scheme is applied to the numerical simulation of infrastructures under maintenance behavior. The results (e.g. Figure.1) show that the iterated risk measure can select an appropriate maintenance policy for the multi-period dynamic problems, avoiding rare and severe events.

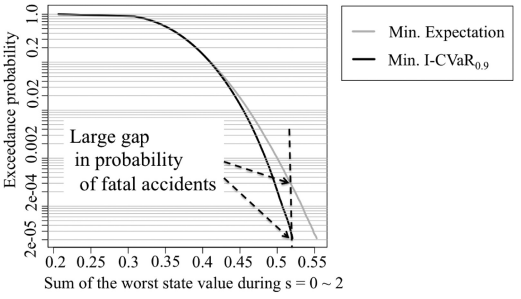


Figure 1. Exceedance probability of sum of the worst state value during the concerned period.

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Overall collapse and reliability analysis of RC structures under stochastic seismic excitations

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ABSTRACT

Collapse simulation and risk assessment of reinforced concrete (RC) structures are of great significance to promote life safety. The present work aims at suggesting a multi-scale stochastic response analysis approach towards the reliability against collapse for the large complex RC structures subjected to random strong ground motions.

The parametric uncertainties of seismic inputs are quantified based on the physical random function model with a superposition method of narrow-band harmonic wave groups.

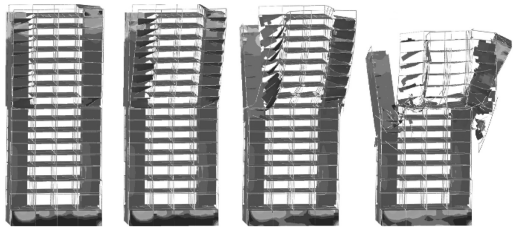
The micro-mechanical approach based stochastic damage model (SDM) of concrete makes it feasible to capture the uncertainty relation between micro- and macro-scales of concrete and is available for the accurate simulation of overall collapse process of complex RC structures.

To attain the statistics of expected structural responses and address the uncertainty propagation in a nonlinear stochastic dynamic system, the probability density evolution method (PDEM) provides a new perspective. With PDEM the instantaneous probability density function (PDF) and its evolution of any structural response can be easily obtained.

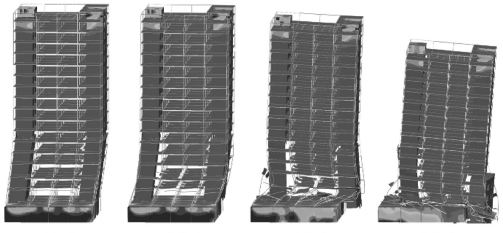
As to evaluating the collapse risk of RC structures, a new dynamic instability based structural collapse criterion is proposed to constitute a structural collapse descriptor, which is particularly useful for quantitative collapse detections during the stochastic collapse analyses. And with which the structural collapse probability can be evaluated via PDEM.

To illustrate the above proposed methodology, the stochastic seismic collapse analysis of a prototype high-rise building structure is carried out. In which the fiber beam-column element and the multi-layer shell element are widely adopted during the modeling to balance the accuracy and the efficiency.

Numerical results indicate that the randomness rooted from the ground motion records affect prominently on the seismic response of RC structures, and even lead to entirely different collapse modes (Fig. 1). Thus it should be properly deliberated during the collapse prediction to promote the structural safety as well as the hazard-resilience.



(a) Sample 1



(b) Sample 2

Figure 1. Typical collapse processes and failure modes of a structure under four simulated ground motion excitations.

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Evaluation of the response of RCC dams to earthquakes with different frequency contents

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ABSTRACT

The stage of preliminary analysis of a dam has the challenge of finding the optimal and initial section with which you can move to the detail-design stage and even to design stages with nonlinear material characteristics. The design begins with the definition of geometric data; in many cases knowing the height of the dam is easier to define the remaining parameters as geometric relationships with respect to height. The next step is to review the stability of the dam's cross section before turning and sliding under operating conditions and seismic conditions. Once it is determined that the section is stable we proceed to the analysis of stresses and strains in order to obtain the usual conditions efforts (loads of operation), unusual conditions (base operation earthquake SBO) and extreme conditions (maximum credible earthquake SMC). Finally we proceed to obtain the strength of the required RCC mixture.

A dam is a structure containing at least 8 geometric parameters and a mechanical parameter, the stiffness contrast (SC), which is the ratio of the shear modulus of the dam and the shear modulus of the foundation (ground or rock).

Given these parameters, the number of geometric possibilities to analyze are greatly increased and the ability to perform all of these analyzes is further reduced to face the barriers of computational time. For this reason a methodology to reduce the options of study has been developed with an adaptation of the square-cube law first described in the book Two New Sciences: Discorsi e Dimostrazioni Matematiche, intorno e due nuove scienze (Galileo Galilei, 1638); this law allows to know the acting stress of a whatever geometry whenever you save the aspect ratio with a base geometry.

In this paper is developed the analysis of two main load conditions; the first is the usual load condition where operating loads of the dam are present. The second condition corresponds to the seismic condition. The initial number of cases results in 8448 for operation condition and 25344 for unusual condition, the methodology for the reduction of case studies is discussed and the application of the two adaptations formulas from quadratic-cubic equation is described.

$$\sigma_2 = \left(\frac{h_2}{h_1}\right)\sigma_1$$

$$\Delta t_2 = \Delta t_1 \left(\frac{\beta_2}{h_1}\right)\left(\frac{h_2}{\beta_1}\right)$$

The second purpose of this paper is to present an example of the methodology developed for the analysis of RCC concrete dams. The model studied includes the rock mass environment and the stiffness contrast. The example is developed for four seismic excitations where the accelerograms have the same maximum acceleration but containing different frequency content. The analysis is performed dynamically using the step by step method using finite elements.

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MS2: Vibration-based health monitoring, damage identification and residual lifetime estimation

Organizers: E. Reynders, G. Lombaert, E. Chatzi & C. Papadimitriou



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A comparison of two Kalman-type filters for robust extrapolation of offshore wind turbine support structure response

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ABSTRACT

With strict targets in place for the reduction of the levelized cost-of-energy of offshore wind, a diverse range of possible cost reduction schemes is being investigated. Among them are the life-time extension of offshore wind turbines/farms, and the accompanying investigation into the fatigue life of offshore wind support structures. Fatigue life predictions are based on processed historical metocean data applied to a numerical model of the offshore turbine in aeroelastic simulations where different operating conditions are taken into account.

The true accumulated fatigue damage during the operating life of the turbine will differ from the predicted damage due to metocean conditions deviating from those assumed, errors in the numerical model (e.g. foundation stiffness), various turbine faults (e.g. blade pitch errors), etc. There is thus a need for monitoring systems capable of tracking accumulated fatigue damage at all critical locations in a support structure based on actual observations. Since the critical locations are mostly located underneath the water line, some form of downward extrapolation of the response measured above the sea level is required. Given that the first natural frequency of installed turbines can deviate from the design value with up to 10%, it is not sufficient to base this extrapolation on the numerical model only.

Instead, algorithms capable of jointly estimating the states (displacements/velocities) and input forces can be used. Response prediction on the basis of jointly estimated states and input was first proposed in Lourens, Papadimitriou, Gillijns, Reynders, de Roeck, & Lombaert 2012, where additionally it was shown that the identification of a set of (equivalent) forces can to some extent compensate for inaccuracies in the extrapolated response due to modeling errors. The concept was later applied to an offshore wind turbine lattice support structure by Van der Male & Lourens (2015), where the capability to compensate for modelling errors was again illustrated using a numerical example.

The algorithm used in Van der male & Lourens (2015) suffers, however, from an important drawback, namely that the state estimates are affected by spurious low-frequency components in situations where displacement and/or strain data are not available. A number of related methods has since been suggested, one of them being the Dual Kalman filter (Azam, Chatzi, & Papadimitriou 2015). For a state-of-the-art review, the reader is referred to Azam, Chatzi, Papadimitriou, & Smyth 2015.

In this contribution, a comparison is made between two of those promising Kalman-type filters capable of robustly extrapolating the response of a wind turbine support structure, namely the recently proposed Dual Kalman filter (DKF) and the Gillijns and De Moore filter (GDF). The support structure under consideration is modelled with three-dimensional beam elements and soil-structure interaction is taken into account by means of vertically oriented linear spring elements on the basis of the jacket. Synthetic measurement data is generated by subjecting the full-order finite element model under consideration to a pair of environmental loads: a thrust force due to wind acting on the rotor disc and a wave load acting on the lattice structure. The response extrapolation is performed using noise-polluted measurement data and a reduced-order numerical model, assuming large modelling uncertainties and no prior knowledge of the input forces. Finally, a critical assessment of both filters is presented, with the focus on tuning of the filter parameters and requirements on the available data.

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A discontinuous class of filtering methods for the identification of non-smooth dynamical systems

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ABSTRACT

Engineering problems often arise in relation to phenomena such as plasticity, friction or impact. A common factor in these aforementioned cases lies in that the behavior of the system may vary substantially depending on the realization of its states. Mathematically, this can be attributed to the fact that for the corresponding models the corresponding state-space equations of the system or their derivatives are discontinuous.

This discontinuity in turn affects the observability and identifiability properties of such systems, which is a major topic within the context of system identification and structural health monitoring. A notable effect lies in response intervals during which one or more parameters of the system may be unidentifiable, i.e., their value may not be inferred on the basis of the measured signals regardless of the efficiency of the identification algorithm used, while the same parameters may become identifiable in a subsequent time window.

As a direct consequence, online system identification algorithms, such as the popularly employed Kalman filter methods, are also affected by the discontinuous nature of the system. In this work, the authors introduce an enhancement to the widely adopted Extended Kalman Filter in order to account for dynamic systems comprising discontinuous governing equations. The corresponding effect on the observability and identifiability properties of the systems will further be assessed. This enhanced variant is in this work referred to as the Discontinuous Extended Kalman Filter. An illustrative example is offered for demonstrating the robustness of the Discontinuous Extended Kalman Filter for physical problems involving discontinuous behavior.

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A new method for structural damage detection and localization based on modal shapes

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ABSTRACT

This paper presents a new method for structural damage detection and localization using changes in mode shapes. This method, named Mode Shape Damage Index *(MSDI)*, is based on comparison of normalised modal shape vectors determined in undamaged and damaged state of the structure (Duvnjak 2015). The validity of the proposed method was demonstrated using numerical models (shell elements). Different damage scenarios were simulated by reducing the modulus of elasticity of selected finite elements in numerical models to 80 % and 50 %. In this stage, nine damage cases were investigated whilst changing three different boundary conditions.

Methodology of new method for structural damage detection and localization based on modal shapes consists of four stages:

- stage 1: mass normalized mode shape,
- stage 2: trace of MAC matrix,
- stage 3: modification of MAC matrix,
- stage 4: mode shape damage index.

Proposed MSDI method utilized coefficients related to global behaviour of the structure. When a structural stiffness matrix is changed (damage induced) original modal shape vectors are changed as well. In order to emphasize difference between two sets of vectors their value is squared and multiplied with corresponding element from modified MAC matrix. Finally, all sets of modified mode shape vectors are summarized thereby representing coefficients for damage detection.

This method only considers modal shapes that are almost identical and excluding dissimilar modal shapes. Theoretically, if there are no damages in between two stages stiffness of structure will not be changed. Therefore, if there is no change in stiffness modified MSDI index is equal to zero.

It was found that the Modal Shape Damage Index method is robust and effective to accurately locate single and multiple damages on plate-like structures.

Three numerical examples of plate like structures are presented to demonstrate effectiveness of the proposed method: clamped plate (Fig. 1), simply supported plate over one and two spans. The peak values of MSDI indicate the location of the damage in the plate (Fig. 2).

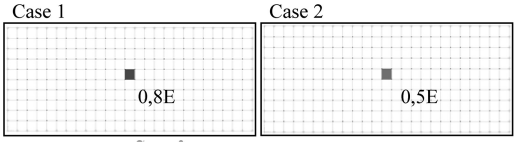


Figure 1. Damage cases for plate with all edges clamped.

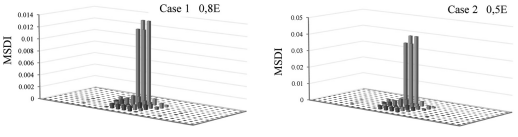


Figure 2. Plot of damage for clamped plate case 1 and case 2.

The results indicate that proposed method is successful in not only predicting the location of damage but also in determining the severity of damage to some extent. One of the important characteristics of proposed method that it is capable to detect damages adjacent to plate supports. Disadvantage of the method is that damage location affects the severity of damage that is being detected. It is shown that structural damage on plate like structures is related to the change of modal shape and also natural frequencies. The reason for using natural frequencies in structural damage assessment is that natural frequencies are easy to determine with relatively high accuracy.

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An application of Gram-Schmidt process on structural modal parameters identification

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ABSTRACT

Identifying the modal parameters of an existing structure system based on field tests is essential in confirming the construction quality, validating or improving analytical finite element structural models, or conducting damage assessment.

This study would present a wavelet-based method and an orthogonalization-based approach, respectively, for identifying the modal parameters and correcting the identified mode shapes of a structure. A discrete wavelet transform would apply to the measured responses of a structure. Consequently, the discrete equations of motion could be reconstructed in wavelet domain. The coefficients in the discrete equation of motion could be determined by a conventional least-squares approach. Then, the natural frequencies, damping ratios, and mode shapes of the structure could be calculated from these coefficients. Next, applied the given mass properties and Gram-Schmidt process on the identified mode shapes to reduce the error of the identified model shapes.

Numerically simulated responses of a five-story shear building (Fig. 1 and Fig. 2) under earthquake would be used to validate the proposed approach. The effects of noise on the ability to identify the dynamic characteristics would also be investigated.

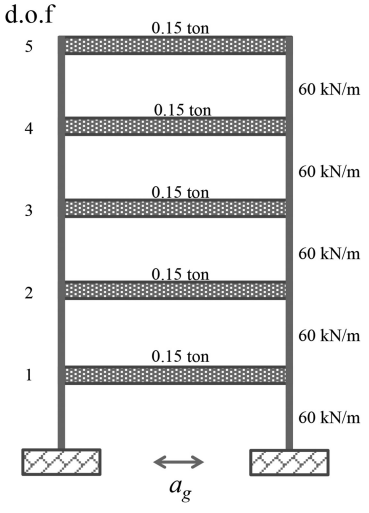


Figure 1. Schematic diagram of a five-story shear building.

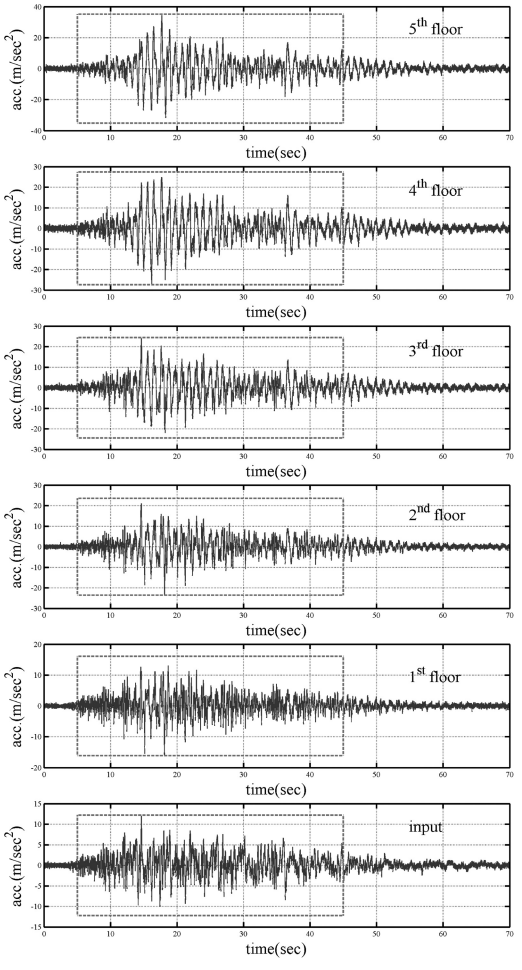


Figure 2. Input and simulated responses of numerical model.

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An experimental investigation on the health monitoring of the new City Hall building in Bucharest based on real-time data transmission

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ABSTRACT

In Romania, the National Institute for Research and Development URBAN-INCERC manages, maintains and operates for more than 40 years the National Strong Motion Network for Constructions. At present, the network consists of 55 accelerometers, located in 45 localities in Romania. A plan for real-time transmission of the recorded seismic data, based on a protocol signed with the Romanian Special Telecommunication Service, was developed, such that, starting from November 15th, 2015, the network has 32 seismic stations with real-time data transmission, four in Bucharest and 28 distributed throughout the country. Real-time data transmission is provided both for stations located in free field-type conditions and for monitored building structures.

The paper emphasizes the need for extensive seismic instrumentation of important buildings in Romania, so that information on the behavior of various structural categories becomes available within short time after the occurrence of an earthquake. The aforementioned ideas are illustrated by a case study showing vibration measurements performed on the location of the City Hall building in Bucharest, and the determination of various characteristics based on seismic and non-seismic vibration records. A proposal is made for a complementarity-based integration of the infrastructure of URBAN-INCERC with homologue Romanian and European infrastructures, to maximize the efficiency of post-earthquake damage assessment and intervention.



Figure 1. Present situation of the URBAN-INCERC network and types of deployed instruments.



Figure 2. City Hall building in Bucharest.

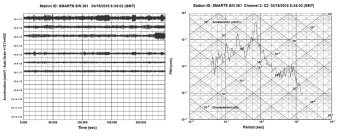


Figure 3. Acceleration time histories recorded by two triaxial sensors located on the 4th floor and on the roof of the new City Hall building and the corresponding response spectrum.

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An information theoretic framework for optimal experimental design

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ABSTRACT

An information theoretic framework for model-based optimal experimental design is presented. The model involves a number of uncertain parameters to be inferred using experimental data. Bayesian inference is used to update the model parameter uncertainties. The model also involves design variables, which affect its behavior. These design variables can, among others, be related to sensor locations or excitation characteristics. The optimal design problem is viewed as an optimization problem with respect to the design variables. For that, we need a measure of the "goodness" of a specific set of design variables.

This depends on the goal for which we perform the experiment. Common goals include optimal model parameter inference and optimal future model predictions. In this work we focus on model parameter inference. The choice of the measure of "goodness" of a specific set of design variables is rooted in information theory, and is the expected Kullback-Leibler divergence between the prior and posterior pdf of the uncertain model parameters in the Bayesian framework of uncertainty management. This is equivalent to maximizing the information gain for the model parameters, which happened due to the observation of the data which depend on the design variables. In this way we seek designs which will yield data that are most informative for model parameter inference.

In general, the objective function has to be estimated by a Monte Carlo sum, which means that its evaluation requires a large number of model runs. Asymptotic approximations are introduced in order to significantly reduce the number of the required model evaluations. The asymptotic approximations involve the approximation of the posterior pdf with a multivariate Gaussian distribution, and the Laplace approximation of one of the integrals involved in the objective function. These asymptotic approximations significantly simplify the form of the objective function, and therefore the computational cost.

The optimization of the objective function with respect to the design variables is performed using stochastic optimization methods such as CMA-ES to avoid premature convergence to local optimal usually manifested in optimal experimental design problems.

The framework is demonstrated using applications from mechanics and structural dynamics. Specifically, two optimal sensor placement problems are solved: 1) estimation of uncertain magnitude and location of a single load applied on a simply supported beam, 2) modal identification.

The framework, which also relies in the Bayesian theory of uncertainties, is able to take into account prior knowledge about the model parameters, through the prior pdf. This proves to be a very important aspect, especially in unidentifiable cases where the number of parameters is greater than the number of sensors (measurements). In these cases, already existing information about the parameters can be incorporated into suitable informative Gaussian priors and aid the procedure, and eventually enable optimal designs to be found even for number of sensors less than the number of parameters to be identified from the experiment.

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Assessment of vibration intensity as a condition and safety indicator for short-span bridges

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ABSTRACT

Over the years, there have been numerous efforts by researchers in quantifying structural performance and damage from vibration measurements. Curves proposed by several authors (Koch 1953, Steffens 1974) attempt to relate acceleration spectrums to damage level, which were determined based on experimental surveys conducted on buildings. The technique is focused on the use of vibration intensity, which is a function of acceleration amplitude and frequency, as a parameter to discern damage. Recently, some Codes have adopted vibration intensity criteria for evaluating damage, such as the Brazilian Code for non-destructive testing ABNT-NBR-15307 (2005), which reproduces Koch's criteria for any kind of structure, including bridges. It states that vibration intensity is an empiric parameter used to estimate damage levels in structures, and can be expressed in units known as *vibrars* in the following way:

$$V = 10\log\left(160\pi^4 a^2 f^3\right) \quad (1)$$

a = the vibration amplitude in centimeters;
f = the frequency in Hertz.

According to the Brazilian Code, there exists an empirical relationship between the values of *V* and the level of structural damage, as indicated in Table 1.

The present work investigates the use of *vibrars* and maximum peak-to-peak accelerations as parameters of damage and performance evaluation in existing bridges and also as a way to predict long-term performance during the initial design stage. To achieve this, a database of the most common Brazilian bridge types was analyzed, whose structural design and dynamic parameters are known. Measured traffic data and material properties were integrated into calibrated FEA models and a fatigue assessment was conducted.

A damage index compiled by Kim et al. (2005) was used to assess damage based on dynamic property variation and the general structural condition of the bridges, observed during detailed inspections. Measured vibration was subsequently assessed against the damage index and an additional reliability index to assess the bridges' fatigue safety. This resulted in a clear correlation between maximum peak-to-peak accelerations and the indices; however, vibration intensity, measured in *vibrars* as suggested by ABNT-NBR-15307 (2005), did not produce good correlation with the indices. Not only worse correlation was observed in the case of *vibrars*, but also a tendency of damage decreasing with increasing *vibrars*, which is not reasonable.

As a final result, from the observed correlations, limits of maximum peak-to-peak acceleration are proposed to be considered in existing and newly designed bridges to certify an acceptable long-term condition and safety against fatigue effects.

Table 1. Damage & vibration level according to ABNT (2005).

V	Damage Level
10–30	None
30–40	Small
40–50	Severe
50–60	Failure

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Comparison of optimal sensor placement algorithms via implementation on an innovative timber structure

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ABSTRACT

This research work aims at deriving an optimal sensor configuration for the modal identification of an innovative timber structure. Currently an extensive modal identification campaign is carried out on a post-tensioned timber frame, developed at ETH Zürich. Investigations with respect to the optimal placement of sensors for modal identification are undertaken, based on an a-priori numerical model of the structure. The goal of the optimal placement of sensors is to extract the maximum possible information, while minimizing the amount of deployed sensors. Several different optimal placement methods are tested to this task and the results are compared and discussed. The implemented methods include the effective independence method (EFI) (Kammer 1991), the modal kinetic energy method (MKE) (Salama, Rose, & Garba 1987, Papadopoulos & Garcia 1998, Kammer 1991) and the information entropy method (IEI)(Papadimitriou 2004). Additionally, a modified version of the IEI method, incorporating a prediction error correlation term is introduced (Papadimitriou & Lombaert 2012). This addition alleviates sensor clustering around a single location, which often occurs if the modal input data is generated from a finite element model of a dense mesh of possible sensor positions. Furthermore, a modified version of the algorithm is implemented, which accounts for the use of multiaxial sensors in place of uni-axial sensors in a number of practical applications. The performance of the different methods is evaluated using the information entropy index (IEI), which serves as an indicator of the information content generated by a particular sensor configuration. It can be concluded, that to obtain an optimal sensor setup, prediction error correlation effects should be considered in order to avoid sensor clustering, and the multiaxiality of sensors should be taken into account during the optimization process (Figure 1).

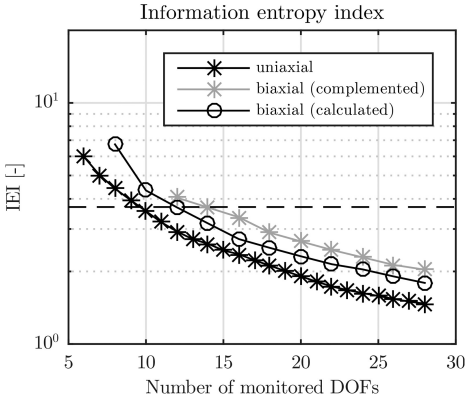


Figure 1. Considering bi-axial sensors with the IEI method.

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Compressed sensing strategy for BIGDATA in output-only system identification

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ABSTRACT

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This paper presents an output-only system identification method that is capable of processing new types of data such as BIGDATA, mobile sensor data, and others. Fixed sensor networks dominate those implemented for system identification (SID) and structural health monitoring (SHM). The rapid growth of smartphones has amplified the amount of digital data available and meanwhile, novel data collection techniques have been developed to provide more informative data. In the near future, new types of SHM data sets, not strictly those from a fixed sensor network, could be expected to become abundant in quantity and sufficient in quality, to the extent that they would provide a preferable alternative. Mobile sensor data and BIGDATA can be classified as dynamic sensor network (DSN) data and can be considered exactly with the truncated physical state-space model (TPM). This paper provides equations necessary to identify modal properties using data from this class. A compressed sensing SID strategy for BIGDATA is presented and applied to ambient accelerations recorded at the Golden Gate Bridge. The compressed data contain dense spatial information in a compact size and provide accurate modal estimates.

In order to realize the true benefits of these new data formats, data processing methods must be developed with consideration of these potential peculiarities. In SHM, BIGDATA is defined as a very large data set, obtained using very many sensors; an amount that would be prohibitive with today's equipment, e.g., thousands. Recent studies have estimated the computational costs required to analyze BIGDATA in full, as one large data set (Matarazzo et al. 2015), and concluded that current SHM procedures are inadequate. Merely, loading the data into the computational software workspace could become a challenge.

Observations from multiple sensor groups may be integrated into one concise data matrix with spatial discontinuities. The offline dynamic sensor network (DSN) data set would include measurements from substantially more sensing nodes than a fixed sensor data set of the same size. The result is that DSN data are capable of condensing dense spatial information into a compact size. The compressed sensing BIGDATA DSN strategy is applied to acceleration measurements obtained from the Golden Gate Bridge (Pakzad et al. 2008).

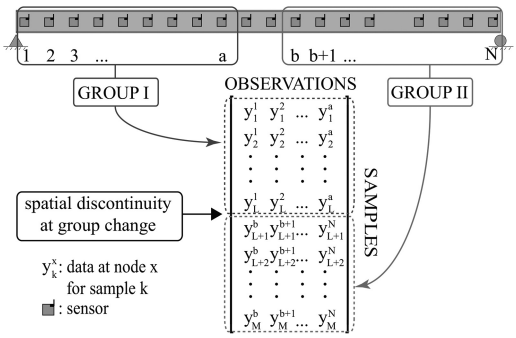


Figure 1. Schematic for processing BIGDATA from a simple beam structure by integrating two sensing groups into a DSN data matrix with a spatial discontinuity at $k = L + 1$.

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Damage assessment of real buildings

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ABSTRACT

Although a great deal is known about where earthquakes are likely to occur, there is currently no reliable way to predict the time when an event will occur in any specific location. However, the damages caused by them can be greatly reduced with proper structural design using safer seismic code. In this regard, dynamic behavior of structures under earthquakes should be considered in the process of design. In order to realize the dynamic behavior of structural systems, we can determine the dynamic models and parameters by system identification techniques. Fortunately, the strong motion data recorded by accelerographs, which were installed under the Taiwan Strong-Motion Instrumented Program (TSMIP) since 1993, has accumulated to a remarkable amount. In addition to updating the structural parameters for better response prediction, system identification techniques made possible to monitor the current state or damage state of the structures. The parameters of the structures are identified and referred to the associated baseline states. The current state of a structure condition relative to a baseline state is compared and the degree of damage is determined.

In the implementation of the recursive hybrid genetic algorithm in the time domain, numerical integration is essential for solving the differential equation in the time domain. This integration procedure may result in a huge amount of computational time since it is required to apply so many times as long as the evolutionary process is proceeded. In order to accelerate the identification process, a Frequency-Domain recursive hybrid Genetic Algorithm is developed. The time history of the measurement is divided into a series of time intervals, and then the model of equivalent linear system is employed to identify the modal parameters of the system for each time interval. The differential equation can be transformed into the frequency domain by Fourier transform and the response in the frequency domain can be solved by algebraic equations instead of differentials equations. The process of exploring this new algorithm is similar to that of recursive hybrid genetic algorithm in the time-domain, by using the simulated MDOF system considering the effect of noise contamination. Finally, this new identification strategy is also applied to the identification of the real buildings. The structure identified will be the Civil-Environment building of Chung-Shin University, which experience moderate damage under the struck of the Chi-Chi earthquake. The parameters of this structure are identified using the response records of the structure under the attack of earthquakes of different intensities. The other building identified will be the building of Taitung Fire department, which experienced severe damage during the earthquake, occurred on April 1, 2006. By monitoring the variation of the identified parameters, the damage assessment of these structures will be performed and the damage states of these structures will be evaluated. Therefore, by employing the maximum softening index, Approximate Story Damage Index and Modal Assurance Criterion, we can determine the damage states of these buildings.

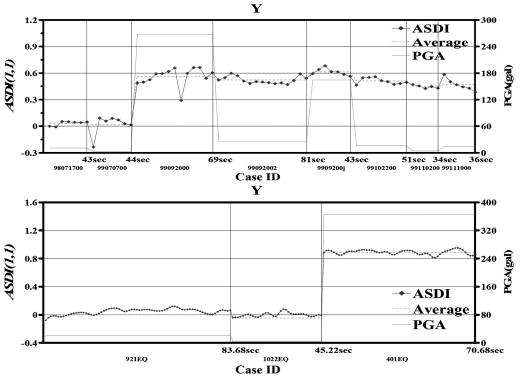


Figure 1. Variation of ASDI(1,1) index in the transverse direction for the two buildings.

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Damage identification on bridges using ambient vibration testing

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ABSTRACT

Structural health monitoring (SHM) has been increasingly used due to the advances in sensing technology and data analysis using machine learning, facilitating the shift from time-based to condition-based maintenance. This work is an effort which has applied SHM to the Sydney Harbour Bridge and will complement the current biennial bridge routine inspection.

In SHM applications, there are two common approaches to monitor the integrity of structures: measured-input test and the ambient vibration test (AVT). In the first technique, the structure is excited with artificial exciters such as large inertial shakers, drop weights and underground blast or explosion. In this method, both input and output signals are employed to identify possible structural damage. This technique often requires disruption of traffic and human activities for structures under in-service condition. In contrast, AVT is an output-only dynamic test where the structure is excited by natural or randomly varying environmental excitations such as traffics, winds, waves or human movements. In this approach, structural integrity assessment is performed based on output-only response measurement data without any knowledge of the input driving forces.

In this study, we propose a method to detect and assess damage using AVT. Frequency domain decomposition (FDD) technique (Brincker, et al., 2000) is used to fuse and extract useful damage sensitive features from ambient vibration measurement of multiple sensors. Then random projection (Johnson & Lindenstrauss, 1984) is utilized for dimensionality reduction on the extracted feature data. After that, anomalies and failure patterns of bridge components are learned in the lower dimensional projected space using one-class SVM (Schölkopf, et al., 1999). The learned models will be used to generate real-time health scores for bridge components.

Figure 1 shows the decision values of the test data collected from a specimen using the proposed method. It shows that the technique not only successfully separated between data corresponding with small damage (damage 1) and data corresponding with bigger damage, but also captured the progression of damage. Damage 3 data instances had more negative decision values compared those from damage 2 data. This shows high feasibility of the proposed method in damage detection and assessment in SHM.

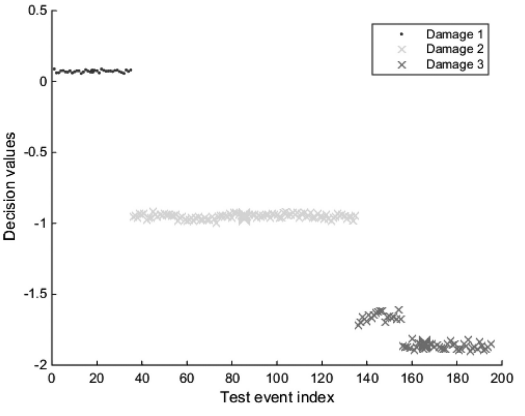


Figure 1. Decision values objects in test data.

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Damage localization in beam-like structures under moving load by empirical mode decomposition

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ABSTRACT

Structural health monitoring (SHM) is one of the major issue discussed within recent years. Structures usually encounter many natural and non-natural disasters during their lifetime, which cause many damages to them. The disasters may sometimes lead to financial losses and physical, and even irrecoverable injuries. Regardless, the important question is how much and where damages are. Therefore, SHM is one of the important issues that play a crucial role in improving safety and health of structures. Several damage de-tection methods have been proposed. Some of these methods when have been applying for structures, faced with a failure. The reason is low sensitivity of response system to damage location and low accuracy of measured response of structure by sensors. The using of signal processing tools for SHM have been affected several researches in the last three decades. Because of proper estimation and low cost, Signal processing methods have been developed. The main purpose of these methods, determining of the changes in physical properties of damaged structure and the changes as modal parameters which is measurable. Modal parameters include: natural frequency, mode shape, and damping ratio.

In this paper, a new damage localization method is proposed based on empirical mode decomposition (EMD) and derivation of intrinsic mode function (IMFs) of measured displacements of beam under moving load. The static responses (displacement) of some joints are measured when a moving load with specific velocity is traveling on the beam. Intrinsic mode functions of displacement are evaluated using EMD. The derivation of IMFs are obtained and damage location is determined by comparing of IMFs derivation graphs of damaged and undamaged data. A finite element model of two spans continues beam is created to consider the efficiency and accuracy of proposed method. The variation of beam deformation in 6 joints are obtained from finite element analysis when the moving load is traveling on the beam. The damage location in 2 scenarios are localized. The results demonstrate the second IMF derivation can be localize the damage with acceptable accuracy

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Monitoring dynamic stiffness that predicts concrete structure degradation

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ABSTRACT

This paper presents a series of laboratory experiments on a scaled reinforced concrete bridge deck as well as results of a pilot project on an existing bridge. The ultimate goal is to develop a structural health monitoring system based on evaluation of the dynamic bending stiffness which would be derived from easy to use measurement devices. The experiments are aimed at measuring the deflection for static load, and the dynamic response due to a moving mass, representing a traffic load. The two types of applied sensors are accelerometers and linear variable differential transducer (LVDT). Lab results include dynamic response from uncracked, partial cracked and fully cracked conditions, which influenced the dynamic stiffness. Changes of stiffness therefor is to be believed to be a parameter for crack conditions. The concept has been applied to an existing bridge to prove its value. In this research a series of laboratory measurements has been done on the scaled concrete bridge while carrying static and moving loads. Monitoring the change of the bending stiffness of the beam has been done by using LVDTs and accelerometers. The results have been summarized in Table 1.

As it can be seen in the experiments no. 3 till 10 by increasing the damage level the difference between the obtained EI values from respectively LVDTs and accelerometers is increasing. The reason might be the nonlinear behavior of the concrete beam by increasing cracking level. The *EI* by LVDT has been determined via an elastic deformation equation of the beam directly, while the EI values calculated from the accelerometer data are obtained via the frequency equation. Therefore, it can be concluded that at least for structures that are not fully damaged, the bending stiffness can be determined by LVDT measurements.

Also by repeating impact tests on the beam with various damage conditions, an overview of the changes in natural frequencies has been acquired for the first five modes. The results show that the frequency shift due to cracking is increasing by increasing the mode number.

The effects of the mass and velocity have been investigated. The outcomes have been compared with the model to confirm that for very small P/G the moving mass can be considered as the constant moving load. Further, the mid-span displacement is decreasing by increasing the velocity.

Regarding the field measurements, the resulting train weights and bending stiffness values determined with each passing train are all within the right order of magnitude. The highest deviation from the average of the 18 measured trains is 15%. More accurate results can be obtained when having all the installed LVDTs working. This may be required for having a more robust system for taking periodic measurements or over short time span. When taking continuous measurements over a longer time span having a deviation of 15% may yield enough accuracy. Here finding a trend is more important.

Table 1. Calculated bending stiffness of concrete beams.

Experiment No.	EI (Nmm^2) LVDT	EI (Nmm^2) Accelerometer	damage level
2	2.1E+11	–	0
3	–	2.1E+11	0
4	1.3E+11	–	1
5	–	1.9E+11	1
6	0.6E+11	–	2
7	–	1.5E+11	2
8	0.2E+11	–	3
9	–	1.3E+11	3
10	2.0E+11	–	0
11	1.28E+11	–	2*
12	0.80E+11	–	3*

Damage level 2* & 3* are not exactly the same as 2 & 3 since the beam has been replaced after experiment no. 10

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Effective virtual sensing scheme for fatigue assessment of monopile offshore wind turbines

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ABSTRACT

Fatigue assessment of offshore wind turbines (OWT's) is of utmost importance due to their continuous subjection to cyclic loads caused by wind and wave excitations. Fatigue assessment includes estimation of the remaining lifetime and accumulated fatigue damage. In order to do so, the complete distribution of stresses along the structure with main emphasis at the fatigue hot-spots is to be known. This is not always the case and especially for OWT's on monopile foundations where most of the fatigue hot-spots are located beneath the water level, prohibiting sensors due to unfavorable installation, maintenance and cost (Iliopoulos et al. 2016).

Moreover, what distinguishes OWT's from other civil structures is the strong variations of their dynamics under different environmental and operating conditions (EOC).

To accommodate for the EOC and tackle the issue of limited measurement capacity of the structure, a robust, reliable and inexpensive modal expansion technique is utilized for response prediction and accurate fatigue assessment. The method intelligently extrapolates a limited set of measured data to generate virtual strain measurements in conjunction with a tuned finite element modal model (Figure 1).

Two distinctive contributions in the strain response time history and subsequently in the fatigue spectra can be identified. The low-frequent, near static which is related to variations in the thrust loading of the turbine, e.g. due to gusts and the higher frequent dynamic contributions related to additional sources of vibrations such as turbulence, rotor harmonics and wave loadings. For each frequency band and each operating case, the optimal sensor and mode settings are chosen in order to be adaptively incorporated to generate the entire time strain history as a superposition of the near-static and dynamic contributions.

The paper presents the results of the validation of the proposed virtual sensing technique for a representative set of EOC over a long period of measurements as well as results for a day during summer storm.

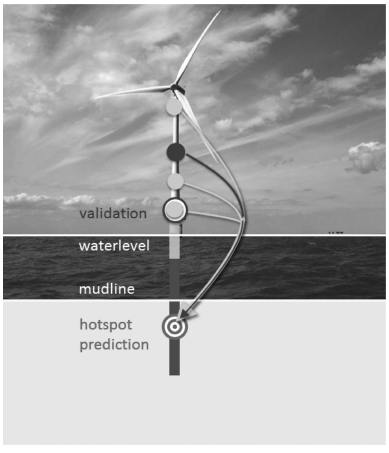


Figure 1. The concept of modal expansion for virtual sensing in a schematic representation for OWTs on monopile foundation. In yellow are the acceleration measurement levels and in purple the strain measurement levels.

ACKNOWLEDGEMENTS

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Evaluation of wind turbine seismic behaviour during life cycle functioning based on numerical FEA

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ABSTRACT

The enhancement of wind turbines construction has revealed some design and building difficulties because care need to be taken when dealing with some particularities of these structures, especially in regions with high seismic hazard.

This paper presents a case study of a 70 meters tall wind turbine located in Iasi region, near Vrancea region from Romania, the epicenter of major tectonic earthquakes relevant for the Eastern Europe, considering 4 different types of supports conditions.

FE simulations and seismic analysis within elastic linear domain were performed in SAP2000 finite element computational environment. Time History analyses were performed using accelerograms recorded in Iasi sites for 1986 and 1990 Vrancea's earthquakes (INFP http://www.infp.ro/en/) (Figure 1 and Figure 2).

The purpose of these analyses is to evaluate the maximum responses of this type of structures under the action of earthquakes. Also the results from the FE analysis are compared in terms of maximum responses that may occur during the lifetime of a wind turbine located in Iasi region.

Time History Analysis results showed that soils flexibility interferes with the displacement and acceleration responses. Usually, smaller displacements are recorded for a rigid base model than for flexible ones which can be misleading in terms of safety requirements. When considering a rigid support, the performance of the wind turbine during earthquakes can be significantly affected, having potential of high devastating effects. Therefore, considering soil structure interaction in analyzing a wind turbine plays an essential role in design and lifetime cycle functioning.

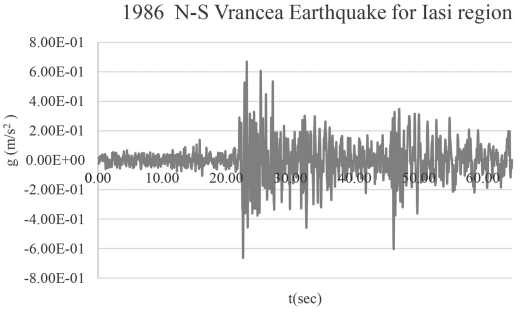


Figure 1. N-S 1986 Vrancea's earthquake acccelerogram, Iasi region record.

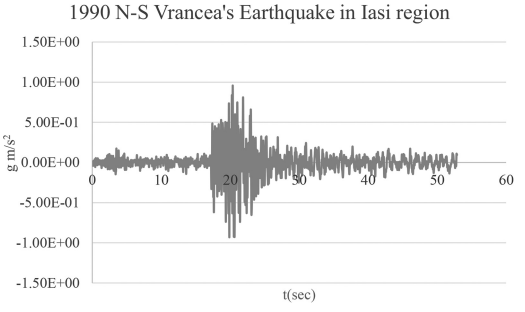


Figure 2. N-S 1990 Vrancea's earthquake acccelerogram, Iasi region record.

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Modal strain identification from low-amplitude FBG data using an improved wavelength detection algorithm

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ABSTRACT

Vibration-based damage identification of existing infrastructure currently suffers from the low sensitivity of natural frequencies to certain types of damage while the sensitivity to environmental influences may be sufficiently high to completely mask the effect of severe damage. Modal strains and curvatures are much more sensitive to local damage, but the direct monitoring of these quantities in a dense grid is not possible with current measurement techniques due to the very small strain levels occurring during ambient, or operational excitation.

The development of the Fiber-optic Bragg Grating strain sensors is a groundbreaking invention that allows to measure dynamic strains with high accuracy even when the excitation amplitude is low. However, the ability to determine the Bragg wavelength shift with high resolution and accuracy is essential in order to use the capabilities of the FBG sensors in their full extend. The conventional Maximum peak Detection Algorithm (MDA) can yield inaccurate results especially for low signal to noise ratio (SNR) and when the wavelength resolution is limited. To overcome these problems, a novel Fast Phase Correlation (FPC) shift detection algorithm, which computes the wavelength shift in the reflected spectrum of a FBG sensor was recently developed [1].

In the current paper, the performance of the novel FPC algorithm with an extensive experimental modal analysis test that was conducted at the Structural Mechanics Laboratory of KU Leuven, is discussed. A steel beam of type IPE 100 was used for the experiments. The beam was instrumented with a chain of multiplexed FBG sensors, at the top and the bottom flange of the beam, and excited with a shaker located at one of its ends (figure 1). The raw wavelength FBG data were processed into strain values using both the FPC and the MDA optic algorithms. Subsequently, the strain time series were used for the identification of the modal characteristics of the beam (i.e. eigenfrequencies and modal strains) using both Stochastic Subspace Identification [2] and Combined deterministic-stochastic Subspace Identification (CSI) [3]. The obtained modal characteristics from both optic algorithms are compared between them and further with results from a finite element model built in ANSYS and results from a conventional experimental modal analysis in which accelerometers that were attached at the top flange of the beam (figure 2) were used as sensors.

The before mentioned comparisons were obtained-for dynamic tests excited with periodic random signals of various bandwidths and force RMS values.

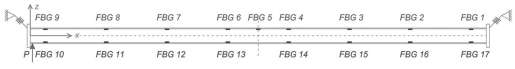


Figure 1. FBGs setup – Front view.

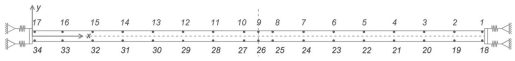


Figure 2. Accelerometer – Top view.

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Modelling damage for successful detection-localization of damage

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ABSTRACT

The efficiency of any damage detection and localization technique depends on the care with which the damage is modeled. Usually, to simulate a damage, we reduce either the Young modulus or the cross sectional area of the elements housing the damage. Certain authors suggest more realistic damage models that help locate more precisely the damage in the structure. These models range from very simple to more complex damage models. Here is particularly considered the flexibility variation method. The objective of this work is to compare different damage models concerning their efficiencies in detecting and localizing not just one damage but a few, whether they be very distinct or close.

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ResoCable® – a quick in-situ non-destructive test method for external prestressed tendons and stay cables

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ABSTRACT

In Germany the use of external tendons is mandatory since 1998 for prestressed concrete bridges with box-type construction in the area of responsibility of the Federation as standard building method. In order to assess the current state of the built-in external tendons and stay cables, various non-destructive testing methods are available with which damage or a decrease in the prestressing force can be detected. All currently existing techniques are so time-consuming that a routine use in situ is not economically feasible. The extent of a routine measurement cannot primarily have the aim to determine the absolute change of the tension force referring to the initial state, especially since the initial state is not known in most cases. Rather, the measurement should provide clear indicators that the condition of the tendon is located inside or outside of the confidence interval.

Therefore, a rapid in-situ test has been developed which proceeds only by the following conditions: The initial tension force is not known; the free tendon length is not determined exactly and creep and shrinkage is not of particular interest. Assuming these conditions, it is sufficient to measure only the frequency of the tendons and not make further in-depth considerations. For the pure determination of the frequency, these points are not necessary and above all the time required for these measurements is a few minutes. If you draw the periodic tests in a database, you get a picture of the changes that have occurred in the meantime. In order to classify the results, a classification of the changes has to be done. To this intention, all the frequencies of all tendon sections are normalized to the respective very first value of each section. This allows that all the tendons of the same superstructure can be compared.

The measurement time is a few minutes. By connecting to a database, the measurements can be checked on site for accuracy and in the case of damage further investigations can be initiated directly. In addition to external prestressed concrete bridges, stay cable bridges and other guyed cable structures now also wind energy plants are analysed. The newest type of hybrid towers (figure 2) consists of a lower part with externally prestressed reinforced concrete segments and an upper steel part. Here the influence of the number of vibrational interaction of the tower is of particular interest, which has a significant impact on the state of the external tendons.



Figure 1. External prestressed bridge and measuring instrument.



Figure 2. External prestressed wind energy plant.

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Verification of joint input-state estimation by means of a full scale experiment on a footbridge

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ABSTRACT

Knowledge of the dynamic loads acting on a structure and its dynamic response is important for many engineering applications. Monitoring the dynamic loads allows comparing the design loads to the actual solicitation of the structure. The response of the structure, which for example consists of strains or accelerations, can be used to check if serviceability limit states are exceeded, or to monitor the condition of the structure. In many cases, the forces applied to the structure cannot be directly measured. In addition, the response cannot be measured at all physical locations, due to practical and economical considerations. If the forces and/or the response cannot be directly obtained from measurements, system inversion techniques can be used for estimating the unmeasured quantities, hereby using a limited set of response measurements and a dynamic model of the structure.

This paper presents a verification of a state-of-the-art joint input-state estimation algorithm (Gillijns and De Moor 2007, Maes et al. 2016) using data obtained from in situ experiments on a footbridge (figure 1). A dynamic model of the footbridge is based on a detailed finite element model that is calibrated using a set of experimental modal characteristics. The joint input-state estimation algorithm is used for the identification of two impact, harmonic, and swept sine forces applied to the bridge deck. In addition to these forces, unknown stochastic forces, such as wind loads, are acting on the structure. These forces, as well as measurement errors, give rise to uncertainty in the estimated forces and system states. Quantification of the uncertainty requires determination of the power spectral density of the unknown stochastic excitation, which is identified from the structural response under ambient loading. The verification involves comparing the estimated forces with the actual, measured forces. Although a good overall agreement is obtained between the estimated and measured forces, modeling errors prohibit a proper distinction between multiple forces applied to the structure for the case of harmonic and swept sine excitation.



Figure 1. The lightweight footbridge in Ninove, Belgium, crossing the Dender river.

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Vibration-based damage severity estimation basing on a non-model damage feature

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ABSTRACT

Civil engineering structures during their life-cycle are subjected to degradation and may suffer damage due to natural or man-made events.

Information given by efficient damage identification algorithms using streams of data recorded on the structure by a network of sensors can greatly reduce the cost of structural maintenance while improving safety. Data-driven methods are attractive for adoption in automated monitoring systems but generally limited to detection and localization of damage. Model-based methods may allow a deeper knowledge about the health of the structure, allowing the damage severity estimation, but are hardly compatible with real time on line damage identification algorithms. The possibility to use a data driven method to estimate the magnitude of damage can thus greatly enhance the effectiveness of an on line damage identification system. In this paper is investigated the feasibility of the Interpolation Damage Detection Method (IDDM), previously proposed as a damage localization algorithm (Limongelli 2010), to estimate the magnitude of damage in a structure monitored by a network of accelerometers. The investigation is carried out with reference to the finite element model of the Shimotsui-Seto suspension bridge (Domaneschi et al. 2015a) subjected to seismic excitation. In a previous paper (see Martinelli et al. 2016) the possibility to identify the severity of damage was investigated with reference to single damage scenarios, herein the investigation is extended to multiple damage scenarios. The finite element model was used to simulate several damage scenarios with one, two or three damaged locations. Damage was simulated through a reduction of the elastic modulus of the material in selected structural elements. The response of the structure both in the undamaged and in several damaged configurations was computed and used for the application of the damage identification algorithm. For each damage scenario several damage levels are modeled and the correlation between the damage feature and the severity of damage is investigated. In order to study the sensitivity of the values of the damage index to both the severity and the location of damage have been considered damage scenarios corresponding to increasing reductions of stiffness, from 10% to 90%, with increments of 10%, at four locations along the bridge deck.

The investigation gives two main results (see Figure 1): (i) whatever the damage scenario, single or multiple, the damage parameter monotonically increases with damage (ii) the value of the damage parameter corresponding to a given loss of stiffness depends on the location where the damage occurs but is not sensibly influenced by damages at other locations.

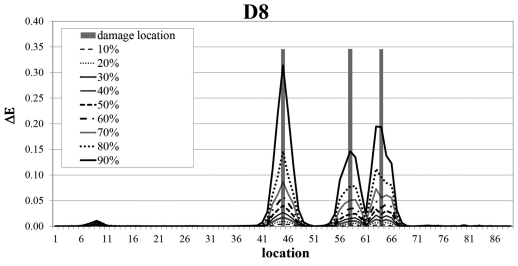


Figure 1. Damage at mid-span, at one-third and at one-quarter of the central span length.

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Wind turbine blade damage detection and localization via spatiotemporal Kalman filtering

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ABSTRACT

Damage detection and localization remains among the most important and active research problems in vibration-based Structural Health Monitoring (Farrar & Worden 2012). Practical limitations call for a balance between the extraction of reliable structural response information and the density of the deployed sensor network (Laflamme et al. 2016). Focusing on strain, the translation of strain recordings acquired from dynamic response, into effective information revealing potential damage, requires efficient post-processing schemes. In dealing with this task, one can proceed by repeatedly applying Kriging for every time instant (Laflamme et al. 2016). Yet, this is not a recommended strategy, since it does not consider the dynamics of the process, while it is characterized by increased computational cost.

An alternative strategy pertains to the simultaneous modeling of the process in space and time. To this end, we apply a space-time Kalman filter (STKF) (Wikle & Cressie 1999) for characterizing the strain intensity field of a wind turbine blade and we explore its effectiveness in damage detection and localization. The STKF scheme decomposes the monitored physical quantity into a spatial and a temporal component, with the former corresponding to a spatially colored, temporally white process and the latter to a purely dynamic one, parameterized though a set of orthogonal functions. Such a decomposition allows for a direct implementation of the original KF, according to which the spatiotemporal process is estimated by the sum of a spatial component that pertains to simple Kriging, and a temporal component that essentially pertains to a time varying linear combination of the orthogonal functions, the coefficients of which form the unknown state vector that needs to be estimated. The encouraging results, both in terms of estimation quality (Fig. 1) and computational efficiency (Tab. 1), necessitate further investigation into this direction.

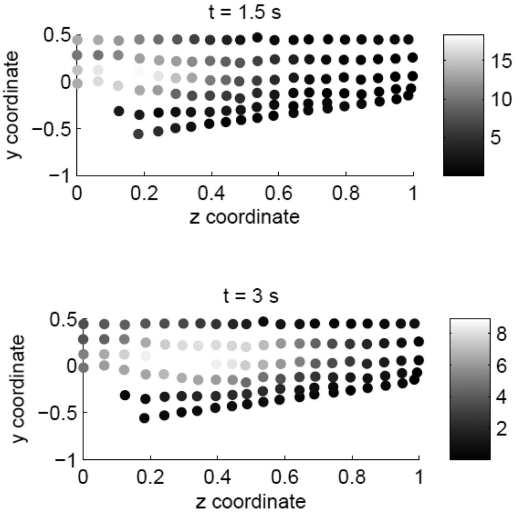


Figure 1. Strain percentage differences of estimated STKFs in the healthy and damage cases for two time instants.

Table 1. Estimation times in s for the STKF and the conventional Kriging model.

Model	Healthy Case	Damage Case
STKF	0.09	0.12
Kriging	9.76	9.96

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MS3: Life-cycle performance assessment of civil engineering systems

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A multi-objective optimization approach for sustainable pavement management

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ABSTRACT

A comprehensive and modular multi-objective optimization (MOO)-based pavement management decision support system (DSS) for enhancing the sustainability of the pavement management policies and practices was developed. The methodological framework of the DSS comprises three main modules: (1) a MOO module; (2) a comprehensive and integrated pavement life cycle costs-life cycle assessment (LCC-LCA) module that covers the whole pavement's life cycle, from the extraction and production of materials to construction and maintenance, transportation of materials, work-zone traffic management, usage and end-of-life; and (3) a decision-support module, which relies on the membership function concept in the fuzzy set theory (Zimmormann 1996).

The DSS provides a platform that enables environmental and road user-related objectives to be jointly optimized with the traditional economic objective (i.e., minimization of highway agency costs (HAC)), by employing a bi-objective optimization procedure to generate a set of potentially optimal pavement maintenance and rehabilitation (M&R) strategies for a road pavement section while satisfying multiple constraints.

The results from the application of the DSS to a case study consisting of determining the optimal M&R strategy for a one-way flexible pavement section of a typical Interstate highway in Virginia, USA, revealed the existence of conflict between the LCHAC and life cycle road user costs (LCRUC) and between LCHAC and life cycle climate change score (LCCCsc), whereby an increase in one of the objectives leads to a decrease in the other (Fig. 1). Furthermore, a complementary analysis scenario was performed in which the most structurally robust M&R activity initially available for selection was replaced by an equivalent recycling-based M&R activity. The results of this analysis showed that reductions in all four considered metrics can be achieved by moving from the current Virginia Department of Transportation's (VDOT's) pavement M&R practice to the recycling-based best optimal compromise solution.

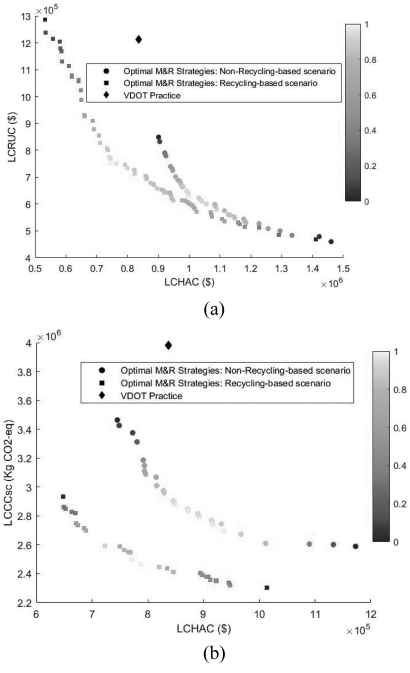


Figure 1. Pareto optimal sets of solutions in the objective space for both scenarios, along with the M&R strategy defined by VDOT: (a) Min. LCHAC vs. Min. LCRUC; and, (b) Min. LCHAC vs. Min. LCCCsc.

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Analytical solutions for cohesive concrete cracking due to non-uniform corrosion of the steel reinforcements

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ABSTRACT

The serviceability and durability of concrete structures may be seriously affected by the corrosion of steel reinforcement in structures that are exposed to aggressive environments, such as bridges, buildings, and marine structures. Reinforcement corrosion consumes original steel rebar, generates much lighter rust products, and creates expansive layer at the interface between the reinforcement and the surrounding concrete cover. As corrosion progresses, the expansive displacement at the interface generated by accumulating rust products causes tensile stress within the concrete cover, leading to splitting cracks in the concrete.

Many investigations have been undertaken during the last two decades regarding the influence of reinforcement corrosion and concrete cracking on the performance of reinforced concrete structures. Andrade *et al*. (1993) investigated the cracking evolution of the concrete induced from reinforcements corrosion. Liu & Weyers (1998) presented a model for estimating the time to cracking of concrete cover based on the experiments on various specimen dimensions and corrosion rates. Bhargava *et al*. (2006) proposed analysis model for calculation of the rebar weight loss due to corrosion, and the prediction of the concrete cracking time. Most of the investigations conducted were focused upon uniform corrosion of the reinforcements(Tamer & Khaled, 2007; Kapi *et al*. 2006; Will & Clark, 2000; Chen & Xiao, 2012). However, corrosion of the reinforcements initiates practically at the nearest point from the concrete outer surface (Jang & Oh, 2010). As to this point, various contour lines of steel corrosion had been put forward, such as stress distribution curve in foundation soil adopted (Xia & Ren, 2006), ellipse curve (Mou *et al*. 2006; Li & Ge, 2003). Normally, the non-uniform corrosion model contour are more complex and concrete stress produced by the rust expansion is difficult to use simple analytical solutions.

This paper presented analytical solutions for cohesive concrete cracking evolution due to non-uniform corrosion of the steel reinforcements. The corrosion contour line of the steel reinforcements is assumed as fan-shaped, and meanwhile the shape of expanded rust products is assumed accumulating rectangularly in the interface region between rebar and concrete. Based on cumulative rust products geometric analysis, the depth of rectangular can be found out while the rebar eroding, the depth is then regarded as the settlement in foundation soil, the rust products pressure acting onto the concrete cover can easily be obtained. Accordingly, the stress distribution at any point in concrete cover would be formulated. Furthermore, the proposed analytical solutions are validated by comparing with the experimental results carried out by Liu & Weyers (1998).

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Assessment of the structural behavior of corrosion-affected RC beams: Experimental study and modeling

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ABSTRACT

Structural performance of deteriorated reinforced concrete (RC) members under corrosion depends mainly on the magnitude and location of steel corrosion. Finite element (FE) analysis has been employed to evaluate the potential effects of steel corrosion on the structural performance of aging RC members. These numerical studies used constitutive models in the FE analysis which could consider the effect of steel corrosion on the mechanical properties of rebar and the surrounding concrete. However, as reported in Coronelli & Gambarova (2004), a main challenge in numerical simulation is caused by the difficulty in assessing the non-uniform steel corrosion in the RC structure. The important matters for FE numerical analysis are how to accurately estimate the location and the level of steel corrosion and how to adequately represent damages as the input data into the FE models (Akiyama & Frangopol 2014).

The two main objectives of this paper are to: (1) experimentally investigate the effects of spatial variability associated with steel corrosion on the structural behavior of a corroded RC beam and (2) establish a FE numerical method to assess the structural performance of corroded RC beams. The spatial variability associated with steel weight loss along the longitudinal rebar is quantified using X-ray and digital image processing techniques. In the FE modeling, to examine the effect of the distribution of rebar cross-sectional area over the RC beam on the computational result, both non-uniform and uniform cross-sectional area of rebar have been employed. When considering the non-uniform cross-sectional area, the spatial variability associated with reduced cross-sectional area of rebar was modeled by varying cross-sectional area in each steel truss element

To verify the validation of the FE model presented in this paper, the flexural responses of the simulated beams with different inputs of rebar cross-sectional area are compared to that of the test beam as shown in Figure 1. It should be noted that the FE model using the varied cross-sectional area of rebar (FE_{var}) provides a better agreement with the experimental result than that using the uniform cross-sectional area of rebar (FE_{ave}).

The difference between these two flexural responses is small because the standard deviation associated with steel weight loss over the longitudinal rebar is not large. However, corroded specimen could have very localized steel weight loss. In this case, it is impossible to assume the uniform cross-sectional area of longitudinal rebar over the RC beam.

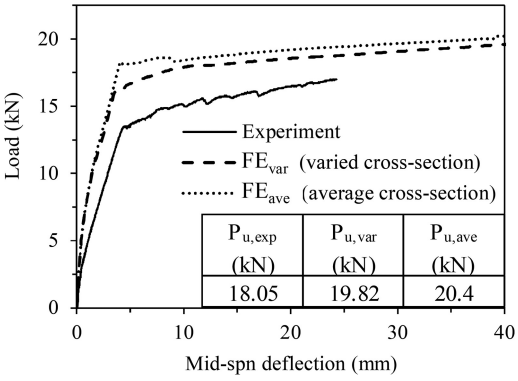


Figure 1. Experimental versus FE numerical results for flexural responses of a RC beam.

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Bayesian inference for the assessment of the carbonation front in RC structures

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ABSTRACT

In 2014 it was reported that, for the first time in human history, the averaged concentration of carbon dioxide in the atmosphere reached 400ppm and is increasing by almost 2 ppm per year (NASA 2014). Penetration of the carbonation front depends on the concentration of CO_2 in the atmosphere and the exposure of reinforced concrete (RC) structures results in the carbonation of concrete accompanied by a cutback in pH values of the pore solution, which can cause corrosion of reinforcing steel (Parrot 1987, Yoon *et al.* 2007).

Diffusion-controlled damage processes have been widely investigated over the last decade and efficient methodologies for life-cycle assessment of corroding RC structures under uncertainty have been proposed (Biondini et al. 2006, Biondini and Frangopol 2008). However, further research is needed to establish feasible and computationally affordable probabilistic models for service life prediction of corroding RC structures owing to carbonation (Liang et al. 2013).

This paper presents a probabilistic procedure for updating the prediction of the carbonation front in RC structures considering a Bayesian approach that combines the Model Code carbonation model (fib 2010) with information from field tests. Bayesian estimation methods handles the parameters of the probabilistic distributions as random variables and can effectively combine theoretical predictions and monitoring-based data. Priors and posteriors distributions are compared to adjust the distribution parameters (Gelman 2004, Hamada et al. 2008). In this way, the uncertainties related to predictions can be decreased by the use of information from visual inspections, field test, and/or monitoring.

In the proposed approach, Bayesian estimation is applied to update the prediction of the carbonation front in RC structures. A Markov Chain Monte Carlo (MCMC) sampling method is used for computing the posterior probability density functions based on monitoring data from both the structure and local environment. The Metropolis-Hastings (MH) algorithm is considered for the sampling process and a point-in-time approach is adopted to perform a reliability analysis over the structural lifetime. The methodology is illustrated through the application to the prediction of the carbonation front for an existing RC bridge in Brazil. The results show the importance of Bayesian updating to predict more accurately the evolution in time of the carbonation front under uncertainty. This allows to better support the planning of maintenance actions and rehabilitation interventions and to improve the life-cycle risk management of structures with limited information.

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Analysis of deviation correction of concrete piers with transverse and longitudinal displacement

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ABSTRACT

The piers with excessive deviation need to be corrected by installing lifting equipment and applied jacking force. Pier tilt caused by the horizontal thrust can be simply corrected by applying a reverse-direction horizontal thrust. Too large piers' deviation, including piers vertical and horizontal misalignment, may easily lead to the cracking of the concrete piers, decrease the bridge piers affect stability and cause the operational safety issues.

This bridge is a 5×16 m reinforced concrete curved slab bridge, shown in Figure 1. The 1st and 2nd span are circle curved line, the other spans are straight line. The type of piers is double-column pier with the 5.4 m column-center spacing.

The construction process of deviation correction includes: the lifting of the continuous girders, which can cause the force release of surface friction on the top of piers and the retrievable rebound of piers. In the construction process, beam lifting is a key process that involves the tensile stresses of key parts of concrete girders, tension and compression stresses of key parts of piers, the stability of the pier, and the local stresses of main beams under the jacks.

In this paper, the actual situation of continuous beam bridge pushing correction is simulated and analyzed, the use of ANSYS analysis of the jack at the top of the pier arrangement to achieve the main beam jacking key processes, analyzes a variety of conditions.

A solid model of the whole concrete girders is established by ANSYS, shown in Figure 2. This solid model has 30174 elements and 10272 nodes. The stress analysis of the 3rd girder under the effect of 1cm uplift by jacks is performed.

Under the effect of the uplift of the girder near the 3rd pier the girders of main girders induce the stress redistribution, and the supporting forces of the 3rd pier increases.

The 3rd pier considering its actual geometric deviation is modeled and established by ANSYS to investigate the stress distribution of 3rd pier under the effect of the 1cm uplift. The deviations of the longitudinal and lateral displacements are both increase. The deformation and tensile stresses at the top of the 3rd pier beams are analyzed.

The key part of main girder is established by ANSYS to analyze the local stresses of main girder under the effects of uplifting jacks. Local area of the main beam anchor hole stress is larger, but the area is very small, small stress elsewhere.



Figure 1. The in-situ picture of this bridge.

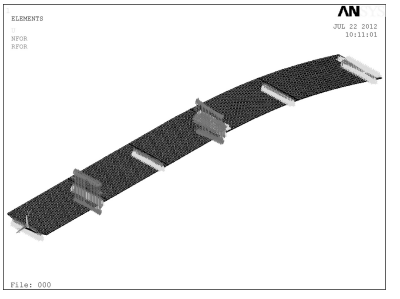


Figure 2. Solid model of the whole bridge.

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Effect of RAP on the mechanical properties of registered asphalt mixtures in Flanders

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ABSTRACT

The service life of a construction, and accordingly the number of maintenance interventions during a certain analysis period, has a significant influence on the life cycle environmental impact. Hence, a short service life of bituminous road pavements can counteract the environmental gain of using reclaimed asphalt pavement (RAP) instead of virgin raw materials. Numerous case specific laboratory researches investigated the influence of RAP on the performances of asphalt mixtures. Some contradiction is found in literature, but several studies agrees that mixtures with RAP have a higher dynamic modulus and are hence stiffer, have a lower thermal cracking resistance, and have an improved rutting resistance (Colbert & You 2012, Li et al. 2008). In the scope of life cycle environmental assessment it is more important to know the performances of asphalt mixtures with the identical composition as used on the road. These are mixtures with various rates of RAP and with a composition which is already optimized in order to counteract possible effects of the RAP.

Asphalt mixtures for base courses designed with the fundamental method are subjected to a series of lab tests (i.e., rutting, stiffness and fatigue resistance) prior to acceptance for use on public roads in Flanders, according to SB250 v2.2 and following versions. In the current contribution, these test results were collected and statistically analyzed for a total of 65 different hot asphalt mixtures with RAP content ranging from 0 up to 63%.

The strongest, statistical significant correlations were found for rutting and fatigue resistance in relation to the percentage of RAP. The mixtures with RAP have an increased resistance to rutting and an increased resistance to fatigue compared to mixtures without RAP. Nevertheless, it is important to note that the variance of the results is very large, as seen in Figure 1. For the same percentage of RAP in the mixture, the results for rutting, stiffness and fatigue varies for one mixture to another. This means that there are other parameters, besides RAP, which have an effect on the performance characteristics e.g., granulometry and binder characteristics.

The relation between the recycling rate and the binder content or binder type was analyzed, but no significant trends were observed.

Finally, the effect of the service life on the life cycle environmental impact is investigated with a LCA case study. For this particular case, it was found that the service life of the base course with 20% RAP should decrease with at least 8.2 years before the environmental impact of the base course with RAP is higher compared to the base course without RAP.

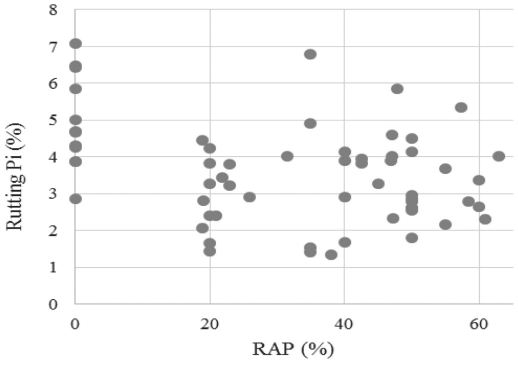


Figure 1. Graphical analysis of test results for rutting.

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Effects of the spatial variability of saturated permeability on slope safety factor

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ABSTRACT

As the global climate changes, more and more landslides are caused by concentrated heavy rainfall in weathered residual soil slopes (Fredlund & Xing. 1994). With the process of rainfall infiltration, the moisture content of the soil increase and the pore-water pressure become less negative or even positive (Rahardjo et al. 2011). As a result, the strength of soil would less than the acting stress developed by rainfall intiltration that would trigger the landslide.

However, since Griffiths & Fenton analyzed the process of steady seepage using stochastic finite element method in 1993, many scholars carried out a series of research on this problem by the application of random field. Gui et al. (2000) analyzed the seepage and stability of dam by using the permeability coefficient random field. Cho (2014) generated the permeability coefficient random field by using K-L method to study its effect on the stability of the infinite long slope, considering the case of one-dimensional seepage.

In the present paper, based on the random field theory and unsaturated seepage theory, the process of rainfall infiltration in a hypothetical specific slope is simulated and the influence of the spatial variability of the soil saturated permeability coefficient and the rainfall intensity on the slope safety factor is studied. According to the analysis, the safety factor of the slops decreases gradually with the increase of rainfall intensity while considering the spatial variability of soil saturated permeability. When the rainfall intensity is equal to the permeability coefficient, the slope safety factor reaches the lowest. The slope safety factor is no longer influenced by the increase of rainfall intensity. Therefore, the critical rainfall intensity is $I = K_s$.

In addition, the slope safety factor is affected by the vertical fluctuation scale of saturated permeability. During the rainfall, the slope safety factor decreases as the vertical fluctuation scale increases, and remains lower than deterministic analysis. When the rainfall stopped, the slope safety factor tends to recover more slowly with larger value of vertical fluctuation scale. These circumstances indicate that the results obtained from analysis considering the vertical fluctuation of saturated permeability of oil are worse than those ignoring the spatial variation of the saturated permeability of soil.

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Life-cycle optimization of FRP-strengthening interventions for RC bridge superstructures

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ABSTRACT

Bridges, as critical nodes in transportation networks, play an important role in the overall performance of transportation infrastructure. Confronted with a huge backlog of deficient bridges, the allocation and application of resources must be optimized. This requires effective and innovative maintenance actions at the most appropriate times in the service life of bridges.

The current paper presents a systematic method for the optimization of fiber reinforced polymer (FRP) strengthening interventions for reinforced concrete (RC) bridge superstructures considering two conflicting objectives: life-cycle performance and strengthening cost. The methodology is able to seek optimal strengthening times of different structural components of RC bridge superstructures in the form of Pareto fronts that can directly facilitate the scheduling and design of FRP-strengthening interventions. Cumulative-time failure probabilities from time-dependent reliability analysis are used as an indicator of life-cycle performance. Compared with previous studies, the use of time-dependent reliability analysis considers the characteristics of structural deterioration process and preserves the framework of reliability analysis. By virtue of efficient sampling algorithms, cumulative-time failure probabilities can be computed directly during the optimization process. In addition, a component-wise bookkeeping technique compatible with parallel computing is employed to further improve the computational efficiency. This new method is illustrated on a RC bridge superstructure subjected to chloride-induced corrosion. The Pareto front obtained is presented in Figure 1, where the four solutions A, B, C and D are described in the paper.

The method developed herein is the first of its kind to optimize FRP-strengthening interventions from life-cycle and reliability perspectives. Features of the proposed method and conclusions from the exemplified analysis can be summarized as follows: (a) the proposed method can accommodate different types of deterioration as long as realistic deterioration models are available; (b) the use of cumulative-time failure probabilities enables a realistic consideration of the variation of deterioration rate due to FRP strengthening; (c) the Pareto front obtained is dependent on the corrosion process and the system model of RC bridge superstructures.

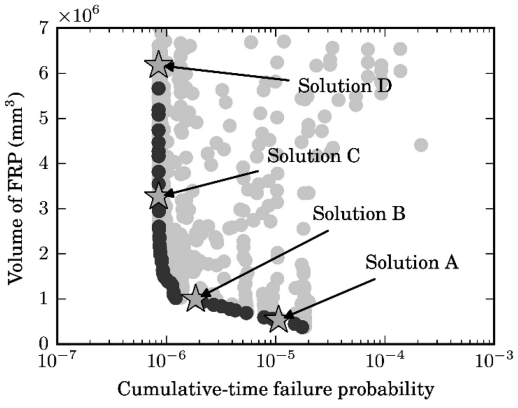


Figure 1. Bi-objective optimization and the associated Pareto front.

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Life-cycle reliability assessment of corroded bridges under multiple hazards

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ABSTRACT

The performance of reinforced concrete (RC) structures under various mechanical and/or environmental stressors such as seismic ground motions, traffic loads, and chloride attack is deteriorating (Akiyama & Frangopol 2014). Many environmental factors affect the long-term structural performance. However, their effects are difficult to predict because they vary in time and space. In addition, uncertainties associated with the estimation of steel corrosion and deterioration of structural performance are involved. Because of the presence of uncertainties, it is necessary that long-term structural performance be treated based on probability concepts and methods.

This paper presents a probabilistic framework for the life-cycle reliability assessment of existing bridges under multiple hazards. Figure 1 shows the updating process of the life-cycle reliability of corroded RC bridge structures under multiple hazards. In this paper, the life-cycle reliability of a bridge girder under traffic and airborne chloride hazards is compared with that of a bridge pier under seismic and airborne chloride hazards. By comparing the life-cycle reliabilities among bridge components under multiple hazards it is possible to prioritize maintenance actions.

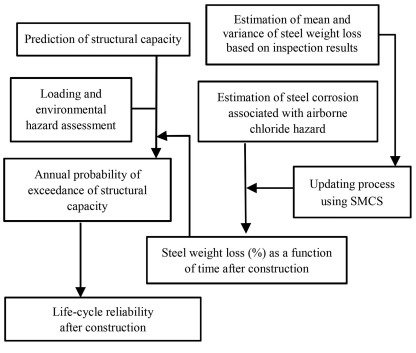


Figure 1. Flowchart for updating of the life-cycle reliability of corroded RC bridge structures under multiple hazards.

When assessing the life-cycle reliability of existing bridge girders and piers, observational data from inspections could be used to estimate the current material corrosion level. In this paper, the mean and variance associated with steel weight loss are estimated. The parameters to estimate the steel weight loss incorporating the spatial corrosion distribution are derived from experimental results to visualize the steel corrosion in RC members by X-ray technology. The random variables associated with the prediction of time-variant steel weight loss are updated by using Sequential Monte Carlo Simulation (SMCS). The life-cycle reliability of two bridge components under various hazards and inspection results are discussed in an illustrative example.

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Point-based POMDP solvers for life-cycle cost minimization of deteriorating structures

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ABSTRACT

Optimized maintenance of operating aging infrastructures is of paramount importance to ensure safe and cost effective operation during their original design lifetime and even beyond that. Modern answers to the problem should focus on automated planning and decision making techniques taking advantage of informative but uncertain data that become available during the structural life-cycle. In this paper such a solution framework is presented, based on partially observable Markov decision processes (POMDPs), that surpasses the limitations of all other current approaches, which are very briefly categorized in that they do not work simultaneously in a stochastic domain, taking both data and their uncertainty into consideration, satisfying long-term objectives. To address all these mainly mathematical and modeling restrictions, POMDPs move away from conventional optimization approaches and tackle the problem in a hidden Markov model domain equipped with control actions and Bayesian principles. Therefore, the evolution of the system is described by stochastic processes, real-time observation data update the system state estimations, and all possible future actions, about where, when and what type of inspection and repair should be performed, are taken into account in order to optimize the long-term life-cycle objectives.

As a consequence of their advanced mathematical attributes, POMDP models are unfortunately hard to solve. In recent years, however, significant breakthroughs have been achieved, mainly due to the introduction of point-based value iteration algorithms. In this work, several POMDP point-based methods are examined, with various characteristics in the selection of the belief space points/subset and the value function update procedures. To investigate the strengths and limitations of the various solution methods for structural maintenance problems of deteriorating infrastructure, a realistic nonstationary example is selected, concerning corrosion of reinforcing bars of concrete structures in a spatial stochastic context. Algorithmic concepts, numerical features and comparative results are showed, analyzed and discussed, and valuable conclusions are derived, regarding the efficiency of several existing point-based value iteration solvers in structural maintenance problems, and possible ways forward towards dedicated point-based solvers for very large infrastructure problems.

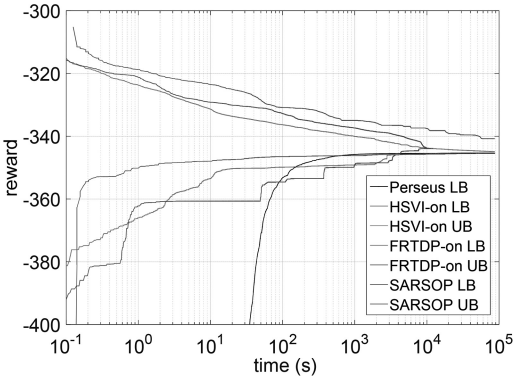


Figure 1. Value function bounds estimation in time.

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Risk-informed performance assessment and updating of fatigue-sensitive structures at component and system level

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ABSTRACT

Fatigue can affect structural performance and ultimately can cause structural failure. Inspection events, such as non-destructive inspections, are used to estimate the performance of structural details that are prone to fatigue. Based on the inspection results, performance of the inspected and uninspected details can be updated using Bayesian techniques. Overall, fatigue performance assessment and updating using inspection events are of vital importance to ensure structural safety and functionality during the service life of deteriorating structures (Frangopol 2011).

A probabilistic approach is needed to account for the uncertainties associated with structural deterioration under fatigue (Kwon and Frangopol 2012). Additionally, there are uncertainties associated with inspection events considering human factors and inspection quality. In this paper, a risk-based performance indicator combining the probability of structural failure with the consequences associated with the failure is computed for fatigue-sensitive structures considering uncertainties. Regarding the consequence evaluation, the rating functions, considering social, economic, and environmental metrics, can serve as useful tools in decision making. Relevant studies associated with risk-informed performance assessment of structural systems under fatigue are needed (SSC 2000; Dong and Frangopol 2015) and these aspects are addressed in this paper.

The information associated with inspection events can be used to update structural performance. Considering correlation among random variables associated with the performance function considered, the inspection results can be used to update fatigue reliability and risk of inspected and uninspected details (Moan 2005; Chen *et al.* 2011). Most previous studies focused on the reliability-based fatigue performance updating at a component level. In this paper, the risk, as a performance indicator, is used to evaluate and update structural performance at both component and system level.

This paper, based on the approach presented in Dong and Frangopol (2016), briefly summarizes the methodology for risk-informed performance assessment and updating of fatigue-sensitive details considering uncertainties and correlation effects. The risk ranking of structural systems associated with multiple fatigue-sensitive details at a system level is also computed. Overall, Bayesian approach can be used to update the reliability and risk of inspected and uninspected fatigue-sensitive details at both component and system level, ultimately aiding the risk-informed decision making process.

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Urban infrastructure in connection to sustainability issues

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ABSTRACT

The development of cities to sustainable, CO_2-neutral areas with reduced energy and resource consumption and resilient urban structures are of high importance.

Sustainability issues in general have been an issue in Europe for quite a while. The European commission introduced various initiatives, guidelines and strategies with the goal to reduce energy, material and waste consumption and additionally CO_2-emissions.

Much research has been done on issues of sustainability and energy efficiency in the building sector in general.

The area of urban infrastructure is a wide area and a strict differentiation between buildings (in Germany Hochbau) and underground infrastructures (Tiefbau) is not unambiguously possible. Urban infrastructure under consideration of sustainable issues has not been in focus yet. Many but not all findings from the surface construction can be adopted for underground infrastructure. For instance, some main differences can be found in life expectancy from environmental and economic perspective, the availability and flexibility of subsurface systems, the system boundaries, functional unit and relevant environmental impacts.

These special features of underground infrastructure and their differences to building sector will be discussed in the paper.

As interdisciplinary approach is essential to forward looking developments, we explore in this paper the connections between urban infrastructure and sustainability issues from various perspectives. The state of art on infrastructure projects is shown through literature research and already realized projects. Work is collected concerning theoretical concepts and practical research of all life cycle phases from production, construction, use, renewal and dismantling.

In the past most infrastructure projects in Europe have been awarded according to the EMAT principle (with EMAT being an abbreviation for **E**conomically **M**ost **A**dvantageous **T**ender). In the course of such tendering phases sustainability issues are normally not considered – at least not beyond the already existing regulations and requirements like the environmental impact assessment. Such mandatory assessments are part of the typical planning process but do not provide a methodology for weighing different aspects and provide no input besides strictly environmental issues. Additionally, such impact assessments are often criticized as being arbitrary since the underlying regulations do not define specific constraints for the assessment procedure. For instance, the regulation defines "targets of protection" but does give no advice in regard to how or how much these targets need to be protected.

In the paper the authors show the different aspects and criteria that are possibly influencing a sustainability assessment of underground infrastructure in general and of road tunnels in special. Some already done basic research is presented. In terms of additional research the simple amount of criteria – as well as the holistic expertise that their assessment would require – is indicating the need for specific knowledge that is currently lacking in these fields of expertise.

For enabling decision makers to rank competing alternatives properly and to develop comprehensive assessments of tunnels, hubs and utility pipes specific target areas and accompanying scales for the criteria and their indicators are needed.

One of the main obstacles for the future implementation of sustainability issues and their assessment during the tendering process seem to be the uncertainties about the lawfulness of such procedures in regard to our current contractual framework. Open questions do exist in terms of the compatibility with the EMAT-concept and its realization within the boundaries of national and international regulations.

Based on the aforementioned approach the authors will show the need for research on these issues and present a possible road map for further development. Currently, underground infrastructure provides a lot of open questions in regard to sustainability assessments, ranging from a comprehensive and quantified criteria catalogue to open legal questions.

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Use of Bayesian updating of time-dependent performance indicators for prediction of structural lifetime and critical inspection points in time

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ABSTRACT

A comprehensive life-cycle performance assessment of structures and infrastructures requires the definition of Performance Indicators (PI), which provide an easier and time-efficient assessment procedure. While structures are subjected to time-dependent degradation processes which require considerations of uncertainties, the evolution of PI can be simulated and forecasted with appropriate statistical model in combination with available inspection and monitoring information. An innovative Bayesian framework for making use of the available historical data and incorporation of additional information from inspection and monitoring in a so-called Stepwise Changing Rate Updating Method (SCRUM) is developed in this paper to predict the future PI. First, an estimation of the statistical properties of the PI as well as its changing rate is made, and then further inspection and monitoring allows for incorporating additional information in the Bayesian updating framework for performance prediction. A time-dependent weight factor is defined and implemented in order to account for the decreasing influence of previous changing rates on the predicted PI.

A case study on a box gird bridge with dataset obtained from field tests is elaborated. The main objectives is to examine the applicability of the proposed method on the expected lifetime prediction as well as to investigate the main model parameters, namely β (the order term of the polynomial function that fitting the observations), weight factor, number of observations n_1 and inspection intervals Δt_{pred}, which have major influences on the predicting performance of the model. Results are shown in Figures 1–2 and Tables 1–2.

As proven by field test data, the SCRUM methodology is promising for the lifetime prediction and inspection interval determination of civil structures. The advantage is that neither an underlying mechanical nor dynamic model is needed, which makes it an easy applicable tool which only uses Monte Carlo simulations to fulfill its task. Only data should be put in and a few parameters, such as the β value, PI_{limit} and target failure probability that are derived from past and present performance assessment results should be set in order to perform the predictions. The primary application is the determination of the lifetime of the structure, given a clear definition of the lifetime and the failure probability limit. However, it should be noted that the SCRUM has limited accuracy for processes with larger fluctuations and/or seasonal trends.

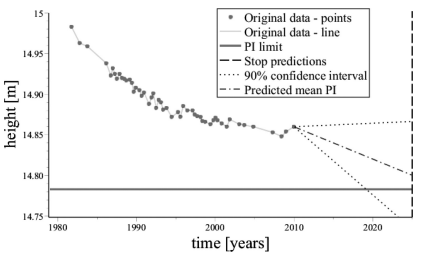


Figure 1. Lifetime prediction.

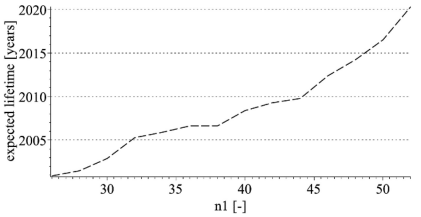


Figure 2. Influence of n_1 on the expected lifetime.

Table 1. Influence of β on the expected lifetime.

β	Expected lifetime	Weight on the last observation
0	2020.3	0.0196
0.454	2023.1	0.0604
0.75	2027.5	0.1155
1	2037.8	0.1851
1.25	2089.4	0.2730

Table 2. Influence of inspection intervals.

Δt_{pred} [*year*]	Expected lifetime [*year*]
5	2013.5
6	2011.2
6.25	2011.8
6.5	2005.5
7	2007.1
8	2000.5
9	1995.1
10	1995.1

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Structural optimization for advanced life-cycle engineering solutions

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ABSTRACT

Optimization of systems can be performed for most components within the tall building. For the mechanical systems this optimization may be related to the efficiency of systems. For the exterior wall systems, optimization may relate to absorbing energy while controlling heat gain. For the structure, material is selectively distributed throughout the building resulting in an efficient use of material will minimizing embodied carbon. The design of the structure is usually optimized to achieve the maximum stiffness of the building, which is typically measured by the compliance of the lateral system, or by the tip displacement of the building itself. Therefore, the resulting design is the stiffest structure that can be obtained for the volume fraction of material considered and satisfies the performance requirements under gravity and lateral loads (wind and seismic).

Conceptually, the frame systems for the towers mimic plant behavior where trunks carry water vertically to branches and leaves, with active movements from the ground to the top. For this structure the principles are the same, only forces replace water and active flow from the ground is replaced with resistive forces originating in the superstructure, the seismic mass of floor framing systems, or winds applied to each floor diagram passing into the braced frame down to the foundations. Shear and bending moments increase as these forces near the ground and so does the density of the structure. The structure could have multiple purposes and would be resilient, capable of acting elastically with minimum damage in strong earthquakes with optimal performance for wind and frequent seismic events.

Optimization techniques can be used effectively for components of building systems to increase efficiency and resiliency. Cantilevered trusses systems have been found to be use materials more efficiently when the mathematical principles of Michell are applied. Optimization can also be introduced into outrigger systems where lateral loads are resisted by a combination of a central core wall and mega-columns linked by walls. Material placement that considers force flows and boundary conditions (ie. openings in concrete) can also be optimized for best placement of materials.

Bridges, spanning horizontally, also can benefit from the same principles of optimization. Truss system geometry reveals forms similar to tall buildings and it designs have been found to save substantial material even when compared to trusses such as the Warren Truss which have been traditionally used and have been considered quite efficient.

The principles of structural optimization hold great promise in defining innovative building and bridge structures for the future. Historically optimization technics have been used in the aeronautical, automobile, and mechanical industries but recent trends have shown opportunities in the building and bridge fields. Additional developments are required to link design of components/systems with the behaviorally analysis that are currently available. In addition, new concepts of placing materials are required in lieu of traditional discrete structural members. This can be achieved by advanced placement techniques of concrete where continuous pours of materials defined by three-dimensional modeling/forming systems may be used.

Perhaps in the future, concrete structures could be eroded, systematically removing material where not required for imposed loads or conceptually aligning with the concept that the strongly remains when a material is subjected to eroding environmental conditions. The key to creating efficient structures of the future is to recognize behavior. For instance, braced frames for tall buildings are most efficient in resisting lateral loads for wind but are non-ductile for extreme seismic events. This ductility can be accomplished through seismic fuses or links designed to yield or perhaps in the future slide, dissipating energy without material inelasticity.

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Reliability of corrosion detection in reinforced concrete structures – impact of the half-cell potential evaluation

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ABSTRACT

In reinforced concrete structures the half-cell potential measurement (HCP) is an effective inspection method to detect on-going corrosion non-destructively (RILEM 2003, ASTM C876-09, 2009, SIA Merkblatt 2006, 2013, DGZfP Merkblatt B3 2014). Generally, corroding areas can be assumed mostly at the more negative potential values in combination with a pronounced potential gradient. But the HCP data can also be treated statistically by means of cumulative probability plot. For implementing the half-cell potential measurement data in the probabilistic service life prediction the knowledge about its inspection accuracy is essential. The reliability of qualitative NDE is expressed with the statistical parameter Probability of Detection (POD) curve in dependence of the defect size, here the anode area. The evaluation of POD-curves according to the so called Hit/Miss Model is based on the comparison of a defined condition (corrosion, no corrosion) with the inspection results (corrosion indicated, no corrosion indicated). The correspondent outcome is classified whether the defect is detected "hit" or not "miss". Hereby, POD-curves are generated based on numerical simulation of potential fields (Keßler 2015) considering a grid size of $15 \times 15\,cm^2$; homogenous moisture condition, 100 Ωm and 400 Ω m, and heterogeneous moisture condition by combining both data sets in one data set (100 + 400 Ωm). Various potential fields are simulated to obtain the required number of hit/miss data. Threshold potentials are defined where the gradient changes in the cumulative distribution: $E_{th,100} = -265\,mV_{SCE}$; $E_{th,400} = -240\,mV_{SCE}$; $E_{th,100/400} = -265\,mV_{SCE}$. The Probability of Detection curves, Figure 1, of HCP show a good reliability. The detectability of an anode area of $5\,cm^2$ is 95% for 100 Ωm and still 85% for 400 Ωm. Under mixed moisture condition the Probability of Detection decreases to 70%.

When considering homogenous moisture condition statistical evaluation of HCP is acceptable. But under mixed moisture condition the POD-curves indicate bad corrosion detection reliability. For a statistical treatment of HCP data under mixed moisture condition the parallel measurement of concrete resistivity would be beneficial. Due to the fact that the concrete resistivity and the half-cell potentials are spatially dependent, random fields can be used to describe them and the resulting corrosion probability.

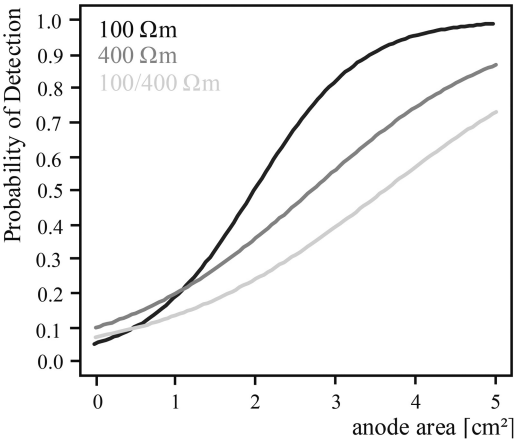


Figure 1. POD of HCP based on threshold potentials resulting from cumulative probability evaluation.

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MS4: Life cycle engineering for hydraulic structures, levees, and other water related infrastructure

Organizers: F. den Heijer, H. Yokota & M. Hoffmann



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A framework for life-cycle management of public infrastructure

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ABSTRACT

Within the programme Risk and Opportunity Based Asset Management for Critical Infrastructures (ROBAMCI) a framework has been developed for life-cycle management of public infrastructure. Compared to for instance life-cycle management for industrial applications, public infrastructures offer some specific challenges, which this framework aims to capture. The framework is set up in three parts: 'Concept & process', which aims to structure questions in accordance with common literature on life-cycle management, while considering specific challenges in the field of public infrastructure. An example of this is that often different parties with different responsibilities are involved in the life-cycle of an asset, and that assets of one party are part of the network of another. Also the role of external factors such as public opinion is taken into account. The second part of the framework is on 'Dealing with data and information'. In this part a model is being developed which enables assessing the quality of information used for decisions in different stages and on different levels (e.g. strategic, tactical and operational decisions). This is of specific importance as literature shows that especially the transition (of information) between different phases and parties in the life-cycle of an asset is often problematic. Insight in the quality of information can help improve this transition. The last part of the framework is on 'Supporting quantitative tools', where the goal is to develop generic tools for quantitative analysis of life-cycle strategies for different types of public infrastructure. These can be coupled to specific physical models for different types of assets. Using these tools, decision makers can quantitatively determine the performance, cost and risk of their specific life-cycle strategy for their specific type of asset, while using generic techniques for probabilistic analysis, deterioration models, economic analysis and optimization.

The conceptual part of the framework has been applied to various case studies in the ROBAMCI project, for instance on coastal nourishment strategies, replacement strategies of hydraulic structures and long-term benefits of structural health monitoring for flood defences. It has proven to be a useful aid in structuring questions, with the development of the information quality models, and the generic toolbox for quantitative analysis of strategies this will be further enhanced. Within the ROBAMCI project the framework will be further developed and refined using practical case studies.

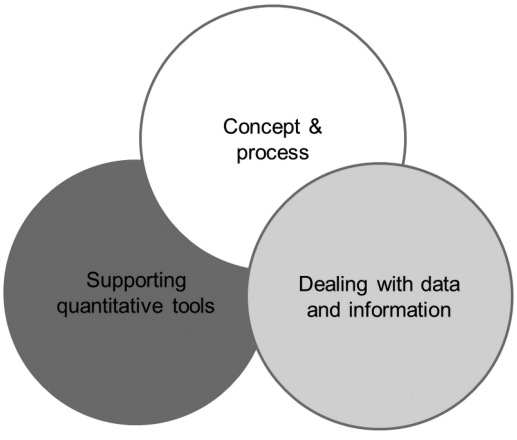


Figure 1. Basic set-up of the framework: consisting of three parts.

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A simple estimation method of the probability distribution of residual deformation of gravity type quay walls considering the variation of earthquake ground motion

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ABSTRACT

In the earthquake resistant design for gravity type quay walls, the residual deformation is the target of the performance verification. The evaluation of the residual deformation of the quay wall cannot be conducted analytically because the deformation is caused by shear deformations of foundation soil layers and so on. Two-dimensional finite element earthquake response analysis considering non-linear characteristics and the effects of liquefactions of soil layers must be used for the evaluation of the residual deformation of the quay wall. The Monte Calro simulation technique is usually used to calculate a failure probability of a structure for the case, but there is a problem on the computational load for the kind of analysis.

This study aims at proposing a simple estimation method of probability distribution of residual deformations of gravity type quay walls considering the variation in earthquake ground motion. Earthquake ground motions can be evaluated by source effects, path effects and site effects. We evaluate probabilistic characteristics of site effects by using strong motion records. The variations of site effects are shown in Figure 1. The logarithmic mean is shown as a thick line and the logarithmic mean plus or minus logarithmic standard deviation is shown as dotted lines. We then conducted two-dimensional finite element earthquake response analysis by using 136 seismic input motions which reflect the variations in the site effects and obtained the probability distribution of residual displacement of gravity type quay walls. The probability distribution of residual displacement was found to be approximated by the logarithmic normal distribution as shown in Figure 2. Next, we evaluated the mean and the standard variation of the site amplification factor for the simple estimation method of residual displacement. We conduct two-dimensional finite element earthquake response analysis by using 3 input motions: mean site amplification factor (λ), mean plus standard variation (ζ) and λ minus ζ. We proposed a simple estimation method by the linear approximation of the 3 residual displacement. As shown in Figure 2, the 3 point approximation well evaluates the probability distribution of residual displacement.

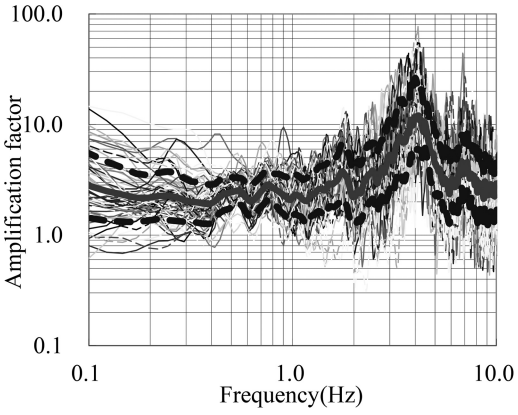


Figure 1. Variation of site amplification factors.

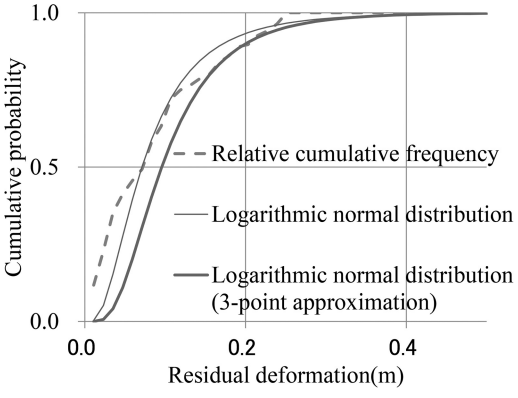


Figure 2. Comparison of cumulative distribution of residual deformation (3-point approximation: λ, λ plus and minus ζ).

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A system approach for replacement strategy of hydraulic structures

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ABSTRACT

Many of the Dutch movable hydraulic structures are are designed and built between 1930 and 1960, based on the then-current standards and regulations, and are approaching their end of lifetime. Also signs of ageing become apparent, regulations get more and more strict and functional requirements have often increased over time due to climate change and socio-economic developments.

Therefore Rijkswaterstaat wants to ensure that these hydraulic structures (and it's operation) always comply to an adequate performance level. This by setting up a systematic approach for replacing hydraulic structures based on their cost-effectiveness and future uncertainties.

To provide answers regarding this method a probabilistic performance framework has been set up. This framework links the performance of the object (IJmuiden Pumping Station) with the performance of the system (Noordzeekanaal & Amsterdam-Rijnkanaal) and defines, analyses and considers different measures for the object and so-called 'adaptation' pathways, providing insight in the most cost effective solutions considering future uncertainties.

Goal of this study is to improve the efficiency of functional requirements and long term investments of hydraulic structures. Therefore a method analysing costs and benefits of strategies in a holistic approach at a system level taking into account the uncertainties in future development has been made. This approach should lead to transparent information about long term costs and risks of strategies. The goal of this case study is to find out if this approach is viable and whether it could lead to a more efficient use of available resources (budget).

In the case study several options for the renewal of pumping stations in order to keep the water system functioning were identified. Also uncertainty in future (climate) scenarios were taken into account in the calculation of strategy costs and risks for different scenarios. Furthermore the societal costs of each scenario were taken into account. Last the expected damage is calculated based on water levels and frequency. With this approach it is possible to compare the long term expected costs (including the risk) of different strategies.

With some constraints, the applied approach to the replacement task for the structures' function within the system was found possible, as well as a step towards a risk based approach.

Through this integrated approach it is possible to optimize (government) spending by taking calculated risks that are socially acceptable and financially bearable.

This case shows that the level of the risk is pivotal in finding the optimum. This leads to the conclusion that risk-based analysis should be the basis for both performance requirements as well as long term strategies in such systems.

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Actual developments, treatment options and future waterway asset management implementation for the waterway Danube

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ABSTRACT

The river Danube from Germany to the Black Sea plays an important role as part of the pan-European transport network. In order to manage a dynamic river providing continuous and reliable fairway conditions a holistic waterway asset management approach and software (WAMS) has been developed in Austria since 2012. This WAMS tool is already capable of calculating fairway availability for 350 km including all fords based on past actual water levels and riverbed surveys for the last decade until now. In addition, systematic analysis and planning of individual dredging measures as most common treatment for fords in low water periods up to budgeting for any target condition have been implemented as well. In this paper we focus on the concepts for further developments of this WAMS including an assessment of dredging and dumping impact, full sedimentation and erosion management capabilities as well as impact and condition assessment of river engineering measures. Furthermore, we will provide an approach to optimize timing of all measures regarding fairway availability together with a short outlook how transport analysis, utilization and traffic management based on transponder data could be included.

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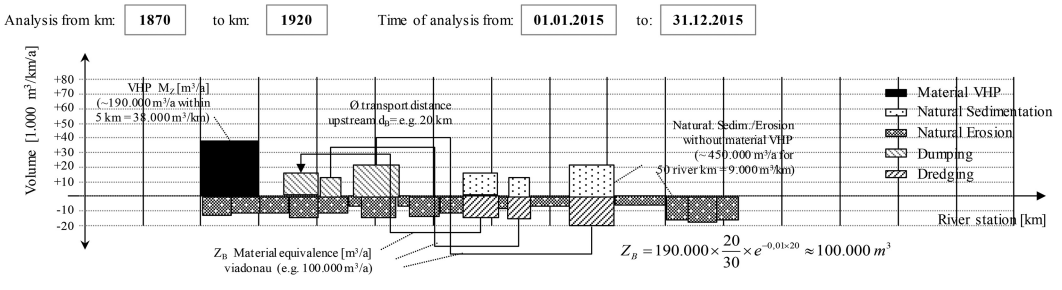


Figure 1. Concept for an overview and volume balancing in sediment management with natural erosion tendencies, dumping of additional material below a main power plant (VHP), dredging in sedimentation areas and dumping upstream with mass equivalence.

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Towards a new approach to estimate the functional end of life time of hydraulic infrastructures

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ABSTRACT

For centuries, engineers around the world have focused on regulating water systems in order to facilitate a number of important societal functions. This resulted in extensive, interlinked water infrastructure networks that provide protection against flooding, sufficient freshwater supply and a thriving navigation network. Due to either technical wear and/or malfunctioning, or by changing functional requirements resulting from climate change and/or societal developments, hydraulic structures reach at some point the end of their lifetime, making replacement or renovation likely. The fact that hydraulic structures operate in a complex water network, fulfil many functions and the fact that many stakeholders are involved, makes the redesign of these infrastructural assets a complex task.

To cope with these challenges in the Netherlands Rijkswaterstaat, as part of the Dutch Ministry of Infrastructure and Environment, has developed an integrative framework for long term planning of the replacement and renovation of the major hydraulic structures. The framework comprises a set of methods, tools and process improvements. One of the methods still in development consists of a new, more sophisticated, approach to estimate the end of technical and functional lifetime of hydraulic structures.

There is a need to have a better prognosis about the timing of replacement work in order to budget the necessary funds and planning capacity for these projects and to better understand the implications of uncertainties, such as uncertainties in climate change and social development, in these decisions. This forecasting can be done by estimating the remaining service life of individual hydraulic structures, which can be assessed in a number of different ways.

At its simplest, an indication of when a structure must be replaced can be derived by adding the design lifetime (80 or 100 years) to the year of construction. This 'basic' approach enables a rapid assessment of the remaining useful life of a hydraulic structure. However, it dramatically simplifies reality and pays little attention to the fact that, in reality, the age at which a hydraulic structure reaches its end of lifetime is highly uncertain (Bernardini et al., 2014; Van Vuren et al., 2015).

In this paper, we introduce a new approach to estimate the functional end of life of hydraulic structures. The timeframes for 'functional end of lifetime' are estimated using a scenario analysis. The development of the novel approach is still in progress and no final version is available yet. This paper focuses on the proof of concept and presents preliminary results. We demonstrated how estimates of the functional end of life can be derived for two types of hydraulic structures in the Netherlands, viz. bridges and ship locks. The novel approach sets requirements with respect to the availability of information about the hydraulic structures (characteristics, functional performance requirements) and the functioning of the water network in the present and future situation.

The proposed new approach for estimating the end of functional end of lifetime of hydraulic structures is promising, but needs further development. The proof of concept in this paper shows that the approach for the assessment of functional end of lifetime provides a potentially better substantiated estimation of the end of a structure's functional lifetime compared to the traditional estimation.

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Asset management of the subsurface: A new way to manage subsurface functions?

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ABSTRACT

The pressure in urban areas increases by demographic and climate change. To enable healthy, adaptive and livable urban areas different strategies are needed. One of the strategies is to make better use of subsurface space and its functions. Asset management of the Subsurface (AMS) can contribute to this. It can be used 1) to use the subsurface in a sustainable way within urban spatial planning (using its benefits, avoiding problems) and 2) to manage and maintain the (urban) subsurface and its functions.

AMS is based on "traditional" asset management methods, but it does not only take the "standard" assets in the subsurface (e.g. sewer system, underground parking garage, cables) into account. AMS also considers the services that the subsurface, including groundwater, has to offer as an asset (ecosystem services).

The basis for AMS is, similar to traditional asset management, the balance of the requested performance of functions of the subsurface with risks and costs/value. As the subsurface is a slow-responding system, aspects such as irreversibility and scarcity of subsurface functions are important. In addition, multifunctional use of space adds value.

For AMS, four main adjustments on the "traditional" asset management are needed:

1) From maintaining objects to maintaining functions. Municipality is responsible for maintaining and managing essential functions for the public. These functions can be obtained both by deploying anthropogenic or natural assets, or a mix of them.
2) Consider the system instead of separate functions: different functions (anthropogenic & natural) in the subsurface system can coexist, compete for underground space, or interfere with each other, leading to positive or negative effects.
3) Private versus public asset management: for subsurface functions different stakeholders are involved concerning who manages the functions and who benefits from this. This demands consideration of the distribution of costs and benefits of the management of subsurface assets and good interaction with stakeholders.
4) From lifecycle to land cycle: where assets have a specific life time and are considered from construction to disposal, functions of the subsurface are just there, when maintained well, for "eternity". Therefore they should be considered using a land cycle in which they perform their role.

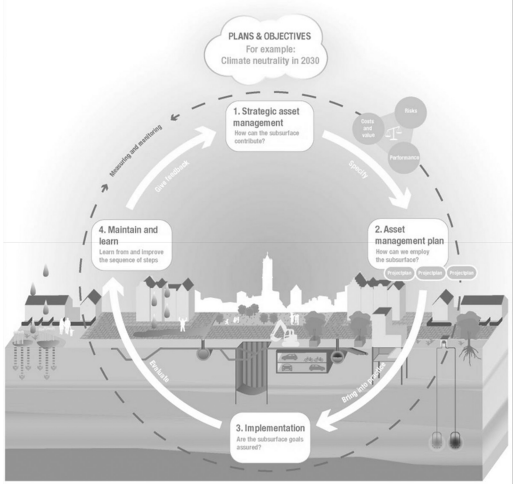


Figure 1. The AMS method.

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Design of RC caissons for breakwater against repeated impact load due to collision of concrete blocks

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ABSTRACT

In breakwaters, the outer walls of the caisson sometimes show local failure in repeated collision of the wave-dissipating blocks, as shown in Figure 1. Local failure induces flow-out of the filling in the caisson, reducing the self-weight of the caisson. This failure of the outer wall destabilizes the caisson against sliding and harbor calmness. The design and verification method of the caisson and preventive measures against such incidental impact loads, not yet established, need to be developed. In the near future, storm tides and super typhoons engendered by global warming put forward the need to enhance the stability of breakwaters so that they will be able to withstand such extremes of weather.

The authors have investigated the structural response of RC walls subjected to repeated impact loads through an experimental program (Iwanami et al. 2010, Kawabata et al. 2011). The preventive measures of a RC wall against repeated impact loads also have been investigated.

When incidental large waves act on the wave-dissipating block as well as RC caisson, the block moves with the waves and collides against the RC walls. This collision takes place repeatedly during storm waves. The damage process can be divided into 3 steps (Figure 2): (1) cracking of caisson wall by several collisions of the block, (2) cover concrete of RC wall is spalled and exposed re-bars are damaged by collisions and (3) local failure very similar to punching-shear failure occurs by further repeated collisions. At step 3, filling materials can flow out through the hole so that the stability of the caisson is significantly compromised. Consequently, the damaged caisson can be slid by additional wave forces, reducing the protective ability of the facility, such as harbor calmness.

In this paper, a design method for the outer RC wall of caisson against repeated impact loads is proposed, with a summary of the previous studies. This paper also deals with the advantageous conditions of the preventive measures from the viewpoint of life-cycle cost (LCC) reduction. Life-cycle cost analysis has been performed and as it turned out increasing the reinforcement ratio of slab provided the best result, followed by thickening slab and use of FRC. These calculations contributed to proposal of a scheme to select the preventive measures for the caisson RC wall.



Figure 1. Local failure of RC wall of caisson after typhoon.

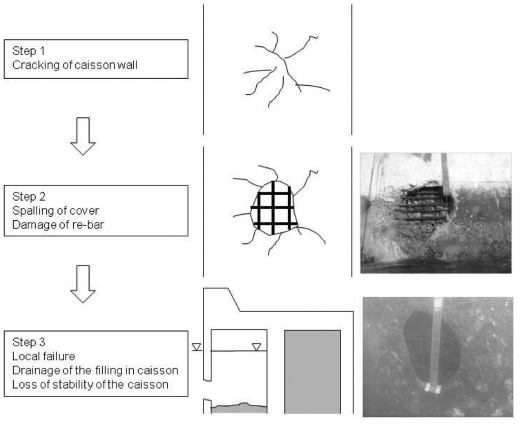


Figure 2. Damage process of RC walls subjected to repeated collision of concrete blocks.

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Innovative design for floating structures on Tonle Sap Lake in Cambodia

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ABSTRACT

The Tonle Sap Lake in Cambodia is the largest freshwater lake in Southeast Asia, which contains an exceptional large variety of interconnected eco-regions with a high degree of biodiversity; the Lake is an ecological hotspot and was designated as a UNESCO biosphere reserve in 1997. Currently, about 1.2 million people are living in the greater Tonle Sap region (CNMC & NEDECO 1998). Due to pollution and the environmental deterioration, the inhabitants and species there are facing critical conditions. In order to improve the living conditions of the local villagers, stand-alone floating structures functioning as medical aid, research center and educational center are designed in sustainable and eco-friendly purposes.

Half-boat and half-building floating structures are designed as a regular hexagonal base with a single storey structure made of wooden offcuts, available from a nearby sawmill, and locally grown bamboo. The formation of hexagonal base is beneficial for wind resistance and structural stability. Regular hexagonal platform has less splice length so as to be more feasible to unite. Additionally, the hexagon makes several stand-alone structures assemble easily when much more activity space rooms are required. In terms of structural materials, the combination of bamboo and wood are affordable for the locals and fit to the tropical climate since they not only ventilate to the inner room but also demonstrates natural aesthetics in parallel stripe lines. For the convenience and feasibility of the construction, space truss will be adopted for the global structure with replaceable wooden elements in sake of convenient maintenance in the future. The arrayed plastic barrel tanks framed with wooden trusses (Riise & Adeyemi 2015) are applied for the base of the structure. In order to reach an appropriate draft depth, the number of the barrel tanks is designed to be adjustable.

For the environmental friendliness, sewage and run-off systems (Czapiewska 2013) and solar panels are employed following the design of the structures. Sewage systems of waste water are systematically connected with the two different conductive tubes, one tube to the underneath container filled with algae and another one to the Lake after adequate treatment. By the way, run-off rainwater from the roof is collected through gutter with filter to a clean water container that can supply for daily consumption. In terms of energy system, solar panels are mounted on the roof for power supplying of the building.

Innovative designs presented in the paper provide an alternative solution to improve the conditions of both the environment of Tonle Sap Lake and local villager's wellbeing.

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An integrated approach for the life cycle management of water reservoirs

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ABSTRACT

This proposed method for asset lifecycle management is based on a three step approach: (1) ageing modelling, (2) risk-based prioritization of maintenance actions and (3) long term simulations for lifecycle cost evolution considering CAPEX, OPEX and risk. It is applied to water storage reservoirs owned by Northumbrian Water Ltd. (NWL) to provide advanced analytics which are used to make better informed decisions in the context of Reliability-centred Maintenance (RCM). Gaining new capabilities in the digitizing of the ageing of water retaining civil works and their related risks were a key step in adopting a more predictive maintenance approach and to find the right balance between performance, risk and costs.

– **Concrete ageing model**: according to the environment condition of the reservoirs, building of P-F curves of the concrete and identifying typical damages for each level of deterioration condition;

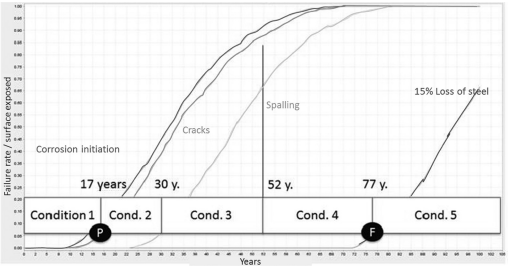


Figure 1. Ageing law carbonation induced corrosion of reinforced concrete.

		Failure probability				
		1	P 2	3	4	F 5
Defect observed	Crack	*Minor to major*	*Severe*	N/A	N/A	N/A
	Spalling	*None*	*Minor*	*Major*	*Severe*	N/A
	Corrosion	-	Rebar exposed *minor to major*, Rust staining *minor*	Rebar exposed *severe* Rust staining *major to severe*	[5% - 15%] loss of steel (cf. photo)	[5% - 15%] loss of steel (cf. photo)

Figure 2. From P-F Curves to level of deterioration condition.

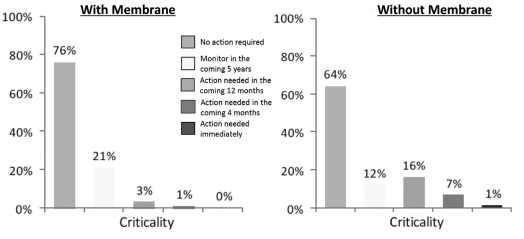


Figure 3. Risk profile of the reservoir.

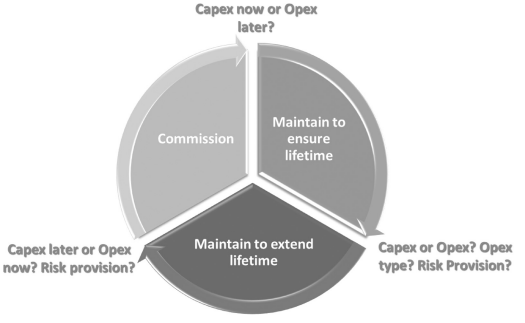


Figure 4. Life cycle management decision cycle.

– **Risk Analysis**: linking information from the ageing analysis to the field information from inspection report in order to assess failure probability of the reservoir and assessing severity for each identified risk. It provides an action plan prioritization
– **Life cycle cost model**: breaking down the reservoirs portfolio, linking information from the ageing analysis to maintenance practices in order to model the life cycle cost and decide on a maintenance strategy that will optimise performance targets under budget and regulatory constraints

The integrated approach of lifecycle management ensures that maintenance guidelines and budget forecasting are suitable from short to long term.

It guarantees the right alignment between corporate objectives, knowledge capture and field observation for life cycle management decision making.

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Lifecycle optimization of portfolios of hydraulic structures

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1 INTRODUCTION

Developed economies possess a vast portfolio of infrastructure. A major portion of this infrastructure was built during the 1950's and 1960's when these economies showed rapid growth. This is true for "dry" (road, railroad) infrastructure and for "wet" infrastrastructure (figure 1).

In this paper, we will show two cases where decision had to be made on major investment in hydraulic infrastructure. We will show that the analysis of lifecycle cost is a suitable way of supporting decision-making of this kind.

2 DECISION SUPPORT BY LIFECYCLE COSTING

We show two real-life cases where lifecycle costing was applied to a portfolio of hydraulic structures. In both case we showed that savings up to 30 % were possible in the long-term cost of asset management. These savings are achieved when:

- The functions of the water system are taken as the starting point
- It is accepted that the same functions may require a different design of the infrastructure than is currently present
- Several renewal strategies are considered. A strategy consisting of combinations of renovation, replacement or removal of old infrastructure

In the paper, the application of the method is show for discharge facilities along the Dutch coast and for a system of weirs in the lower Rhine.



Figure 1. oversized container vessel entering an 80 year old ship lock (photo by first author, May 2014).

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Remaining lifetime concept for existing hydraulic structures

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ABSTRACT

Hydraulic structures are long-living infrastructure assets which have to some extent a high risk potential. Waterway structures in Germany have an average lifespan of 70 years already, about 25% of the structures have already passed their theoretical service life of 100 years. By aging and degradation, but also by changes with time security concepts and proof formats in standards and codes existing structures must be evaluated within a static verification.

The verification according codes which are provided for the design of new structures is not satisfying because the safety cannot be proofed. The application of these "new structure" standards leads to a computationally not given bearing capacity, which does not correspond to reality. In addition, limited resources prohibit to meet the safety standard ever for new structures during a cycle of use, and thus to negate the aging.

A method has been developed to determine the reliability as time-dependent safety for the remaining lifetime. This method, called remaining lifetime concept, is based on the design concept of the Eurocodes which is a reliability-based design procedure. Main issue of the methodology is an adaption of the reliability index β and furthermore on-site investigations to clarify action and resistance values of the structure. The reliability is chosen in that way that the intended safety for the design lifetime is retained for the remaining lifetime which is conform to Eurocode.

For example, the remaining lifetime has been optimized to a residual lifetime $T_{RN} = 30$ years. On-site measurements of relevant actions, such as groundwater levels and water levels, but also soil properties and material testings of concrete and steel properties allow updated base variables (means, standard deviations) so as to fit the uncertainties. No failure up to the valuation date leads to a transfer of the structures' overall reliability according the Eurocodes to the remaining lifetime. Thus the equivalent reliability index β can be adapted for the remaining lifetime, see figure 1, and for verifications within a semi-probabilistic design concepts partial safety factors for actions and resistances can be modified. Conversely in case the required reliability is given and the base variables are precised the remaining lifetime of a hydraulic structure can be calculated in retrospect.

The actions water pressure and self-weight and the resistance concrete strength are described by their determination in the codes. Then, modified partial safety factors are derived on the method of the remaining lifetime concept.

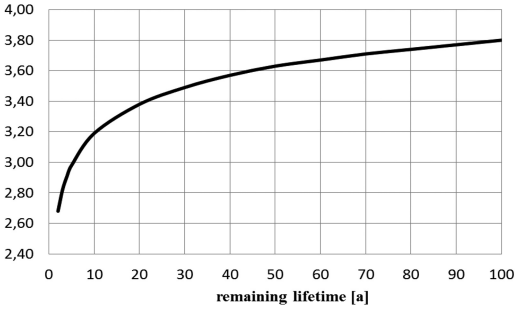


Figure 1. Equivalent reliability index for hydraulic structures.

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Risk-based maintenance management system for waterway infrastructures in Germany

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ABSTRACT

The Federal Waterways Engineering and Research Institute (Bundesanstalt für Wasserbau, BAW) is developing an asset management system (called EMS-WSV) to support decision making processes, involved in waterways infrastructure management. The management system is based on the actual condition of the facilities. As a result, immediate repair works, renewal actions or measures are needed within the next years to pro-long their lifetime and suitability for further usage. Limited budgets as well as reduced staff resources have led to low renewal rate and maintenance backlog. Hence, main tasks include not only the limitation of the continuous degradation as well as the maintenance backlog, but also to increase the renewal rate and improve the service capacities of waterway infrastructures.

To achieve these objectives, parameters which reflect the urgency of action are to be determined. Classic parameters are the economic importance of a waterway or features, such as the condition or the age of a building. However, these parameters are not sufficient to establish a priority order of actions to be undertaken. Therefore, risk analyses are integrated into the maintenance management system EMS-WSV.

The focus of this project will elaborate on the consequences of a possible infrastructure breakdown. As previously described, a significant risk is associated with the current maintenance strategy of the infrastructures themselves through construction failure.

One of the first steps developing such a method is to design a basic procedure. An essential part of this procedure is dedicated to the investigation of possible damages caused by construction failures. Reference scenarios were developed to show possible failure modes, and ex-ante damage analyses were performed to determine the extent of damage for a particular scenario.

The determined or calculated ratios of the sample system were put together in an overview (Table 1).

Table 1. Characteristics of the sample system.

Characteristic	Expression	
Age of weir	Year of construction	1925
Condition	Rating from database	4,0
HQ_{100}	m^3s^{-1}	2100
(n-1)-condition fulfilled	0 = no, 1 = yes	0
Possibility to lock	0 = no, 1 = yes	0
Flow rate (acc.to Beffa)	ms^{-1}	9,99
Drain height (acc.to Beffa)	m	0,61
Specific energy level	m	5,69
Affected people	number	320
Flooded industrial areas	Total km^2	0,08
Flooded residential areas	Total km^2	0,07
Damaged houses	€	10500000
Flooded agriculture area	Total km^2	2,34
Bypass	0 = no, 1 = yes	0

As a result, a risk assessment can be made. Using the determined characteristics, a performance measurement system will be developed to compare waterway infrastructures with respect to their risk factor.

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Sensitivity analysis on repair prioritization for mooring facilities

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ABSTRACT

It is essential to establish life-cycle management strategies in order to ensure function and performance requirements of structures. Conventionally, the maintenance strategy has been designed by considering only deterioration condition of the facility. However, it is not an effective maintenance strategy that the facility with low benefit is prioritized in the repair process under the budgetary restrictions. Accordingly, it is required to establish the maintenance strategy for infrastructure considering both the repair costs and benefits. This paper discusses the prioritization procedure of repair for mooring facilities and the most efficient annual budget based on the net present value (NPV). A total of 10 mooring facilities in three ports were investigated as a model case.

Deterioration progress of the facilities was predicted by using the Markov-chain model. For the simplicity, the transition probability in this study is assumed to be identical in each state. The overall deterioration state of each facility is quantified by using the overall deterioration point (Sato et al. 2011). Based on the findings of the transition probability of mooring facilities (Yokota et al. 2013), the transition probability was varied to follow the nog-normal distribution for the prediction of deterioration progress.

Repair costs and benefits of each facility were calculated with current standard unit costs and with only considering the effect of the cost for substitute transportation. Then, the net present values (NPV) of each facility during the planned service life of 50 years were calculated in consideration of the repair costs and the benefits.

An index, Repair Optimization Index (ROI), for determination of the repair prioritization is newly proposed. This index represents the contributions on the repair cost and the benefit of each facility. The ROI ($\alpha \times \beta$) can be calculated as the products of α and β for each facility; α represents the contributions on the repair cost and β represents the contributions of the annual benefit. The NPV becomes large when the repair of facility with the high value of the ROI is prioritized.

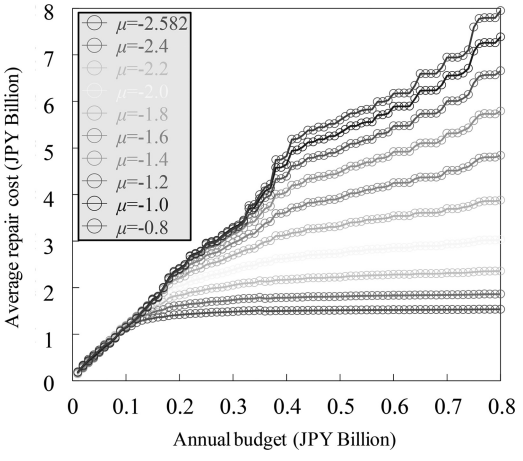


Figure 1. Average repair cost under the budget capping.

Figure 1 shows the average repair cost for each annual budget based on those optimized strategies with varying μ from -0.8 to -2.582 (μ is a parameter to shape the log-normal distribution; the smaller, the slower the deterioration speed). The average repair cost stops increasing at the certain annual budget when μ is small ($\mu < -2.2$). It can be concluded that the suitable annual budget for each port can be estimated from the average NPV depending on the transition probability (deterioration speed).

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Styles of public asset management in Dutch regional water management

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ABSTRACT

Modern infrastructural asset management within the public domain has to deal with many challenges. It has to deal with more and more uncertainties, climatic as well as socio-economical. Furthermore, demands from politicians and society on the functioning of these assets are growing as well. Bad performance of intensively used networks is less and less tolerated, while available budgets are reduced. Finally, more and more stakeholders have to be taken into account while planning and implementing asset management. Regular asset management focuses on the lifecycle of assets, and puts investments in assets in their life-cycle perspective. It considers the performance of assets within the context of their risks and costs. But as in infrastructure asset management goals often are derived from the public interest, this narrow focus of regular asset management can hamper an integrated and holistic view on public interests. Thus, a broadened integrated focus – from different public interests – is needed to realize the desired (public) values: public asset management.

Dutch regional water managers have to deal with these trends, especially when it comes to their contribution to the transition towards sustainable energy. To deal with them they need to extend their regular approach of asset management, focused on exploitation and current functions of assets, to a more broadened, public orientated style of asset management in which opportunities for sustainable energy production are capitalized. Hereto, four styles of public asset management can be discerned, depending on task orientation and strategy: monofunctional, integrated, accommodating and learning asset management. This article answers the question which factors explain the selection of a specific style by Dutch water boards and how this might contribute to adding more public value to the management of their assets.

Keywords: public asset management, public value, water management, energy transition, organizational style, organizational drivers

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Structural health monitoring in strategies for life-cycle management of dikes: A case study in the north of the Netherlands

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ABSTRACT

In recent years there has been an increasing focus on life-cycle and asset management as a means of managing systems of ageing infrastructure. To accurately assess performance, structural health monitoring (SHM) can be an important means. In the past years, structural health monitoring of dikes has become increasingly popular, but up to now a structured method for assessing the cost-efficiency of SHM is not readily available.

In this project a tool was developed which enables assessing the costs and benefits of SHM as part of life-cycle management strategies. The tool was based on experiences at the Ommelanderzeedijk, an old sea dike in the north of the Netherlands that didn't pass its last safety assessment. Water board Noorderzijlvest has applied several monitoring techniques over the past years, such as piezometric head monitoring and temperature measurements as well as full-scale tests. These experiments have provided a variety of valuable information, which has led to a more effective design for the upcoming reinforcement. This case focuses on assessing the benefits of monitoring of the phreatic level in the dike body. The phreatic level is generally represented by scenarios which represent different but possible positions of the phreatic line, each scenario has its own scenario probability. By using Bayesian updating, measurement information is added to the discrete probability distribution of scenario probabilities, resulting in updated scenario probabilities. Thus, the information can be used to update the estimate of the failure probability and possibly exclude certain scenarios. Figure 1 illustrates the possible effects of monitoring on the reinforcement strategy. In the dashed case the dike is much stronger than expected, resulting in a large postponement of the reinforcement. This results in a reduction of Net Present Value. In the dotted scenario the performance is lower than expected, resulting in an early reinforcement, which means higher costs. However, if no monitoring would be carried out, the risk would be at an unacceptable level for quite some time as the solid line would be followed. So in both cases monitoring provides benefits.

The tool enables calculation of Net Present Value for different strategies with and without monitoring, and where monitoring projects can by carried out in different stages of the life-cycle. Although in the actual case the benefits of monitoring were enormous, the tool shows that this can vary greatly depending on the case and that the amount of risk one needs to take in order to obtain information is pivotal in this analysis.

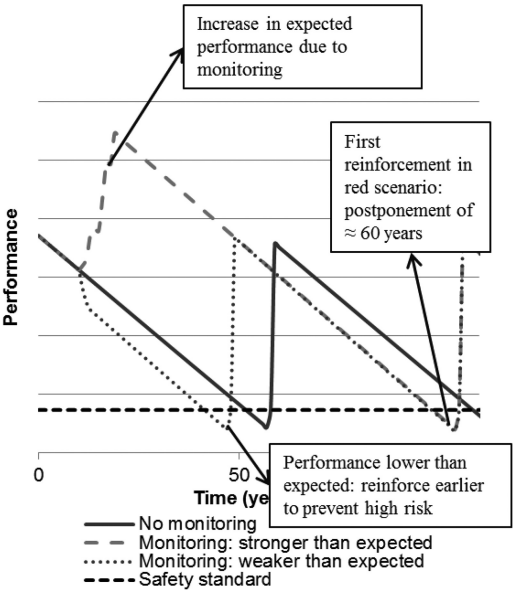


Figure 1. Influence of monitoring and reinforcement on performance.



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MS5: Building information models (BIM) for the lifecycle

Organizers: J. Bakker, A. Adriaanse, B. Mommers & M. de Jonge



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A Dutch concept library (CB-NL) to support BIM for the life cycle

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ABSTRACT

The use of Building Information Models (BIM) and the digital exchange of information in the construction industry is growing rapidly. Objects and their information are being exchanged throughout the supply chain and throughout the lifecycle. When exchanging information, problems occur. Information is defined and interpreted differently by the different parties. Automated exchange of information in the industry is therefore not possible. The Dutch Building Information Council, a sector wide national cooperation between partners in the total building sector, took the initiative to develop a Dutch Concept library (CB-NL)[1]: "one language for the building sector". Based on the concept of "distributed libraries", the library is mapped to other international and national libraries and classification systems. The CB-NL is an open standard.

When exchanging information, problems can occur. One problem is that information is defined, described and interpreted differently by different parties. This makes the uniform interpretation and automated exchange of information within the industry impossible. The goal of the CB-NL is to define a common language for the Dutch Industry. (Bakker and Mommers, 2014)

This library is, in fact, an ontology, which defines concepts and semantic relations between these concepts. The library primarily consists of:

- Terms for concepts;
- Semantic definitions: subtyping relations and defining properties;

Concepts are ideas, which do not already exist in reality (similar to words in a dictionary). By contrast, instances (for example a building at a specific location) do exist in reality.

The CB-NL creates a neutral reference for others to relate to. Other so called "context ontologies" used in the sector can map their concepts to the CB-NL. (Figure 1).

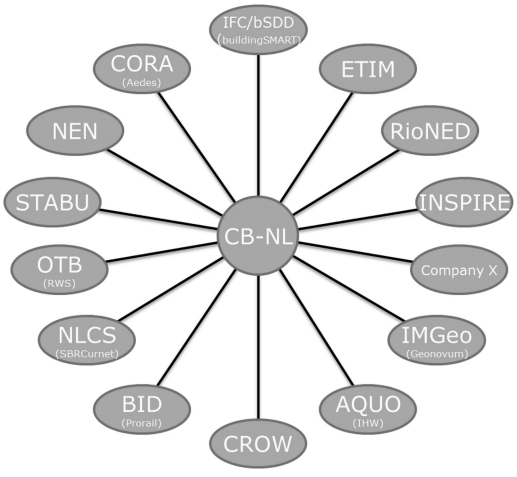


Figure 1. Mapping of context ontologies to the CB-NL.

Mapping ontologies to one single concept library is more efficient than mapping all ontologies to each other. The mapping of these ontologies will result in a system of distributed libraries, all directly or indirectly connected (Nederveen et al., 2013). Many national and international standards are mapped to the CB-NL by now. This paper describes the CB-NL and covers some practical experiences.

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[1] CB-NL website: www.cbnl.org; CB-NL viewer: http://viewer.cbnl.org

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A research review on building information modelling in infrastructure projects

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ABSTRACT

Rapid advances in building information modelling (BIM) offer new opportunities for improving construction processes in the architecture, engineering and construction (AEC) industry. While BIM is increasingly diffused in building construction, transportation is left behind. In today's infrastructure projects traditional two- and three-dimensional computer aided design (CAD) systems are predominant. Nonetheless, there is increasing pressure in this sector of the industry for replacing dated surface modelling technologies with novel solid modelling BIM systems.

In Norway several major governmental clients, like the national road and railroad authorities, increasingly demand BIM. BIM will become mandatory in large public Norwegian infrastructure projects in 2016. This makes the Norwegian infrastructure sector a global pioneer in this area of BIM use. The initiative is driven by sustainability, cost, time, environmental, and quality considerations. However, BIM implementation in infrastructure is all but easy. Beyond the need to change the way the industry does business, BIM and GIS integration remains challenging. The transition from designing based on geometric points, lines and surface data towards using parametric objects is nontrivial.

Against this background the article presents a review of literature compiling the latest research on BIM being applied in infrastructure design. The goal was to develop a state-of-the art overview of BIM research in infrastructure as well as to identify areas for further research. The framework chosen to systematize the literature review in this article is depicted in Table 1. The findings of this study provide useful information for the infrastructure industry practitioners considering implementing BIM technology in their projects. Based on a systematic review of journal publications on Building Information Modelling in transportation and infrastructure, this article has provided an overview of the nature and the scope of the research conducted in this domain to date.

Our analysis shows how the body of literature on horizontal BIM is to date incompletely developed.

Table 1. Principal BIM research axes (adapted from Yalcinkaya & Singh, 2015).

Factor	Factor lables
F1	Implementation and adoption
F2	Energy management
F3	Academy and industry training
F4	Information exchange and interoperability
F5	Safety management
F6	Urban/building space design and analysis
F7	Construction and project management
F8	Design codes and code compliance
F9	As-is, as-built data
F10	Promotion and technology development
F11	Maintaining and managing facilities
F12	Architectural design process

Our main intent in this article has been to draw attention to transportation and infrastructure BIM as an interesting area for further research and we have provided several limitations in literature which present research avenues worthwhile pursuing. These are: academy and industry training; safety management; construction project management; design codes and code compliance; as-is, as built data; promotion and technology development; maintaining and managing facilities. Moreover, there is need for further work into BIM's strategic potential for infrastructure projects and further application areas of BIM beyond those mentioned here. This, in conjunction with the exiting potential of BIM for transforming the transportation and infrastructure construction industry, leads us to conclude that BIM deserves more research attention in this area.

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BIM role in enabling sustainability and better asset performance over the life-cycle (comparative context)

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ABSTRACT

The Building Information Modeling (BIM) creates new opportunities for advanced collaboration and project coordination to develop building design solutions-documentation and construction processes. By comparing global BIM development with local context, this paper outlines the benefits, enablers and barriers associated with its role in Kosovo, to makes suggestions about how BIM issues may be addressed towards sustainable development of Architectural, Engineering and Construction (AEC) industry and better asset performance over the life-cycle.

There are many definitions of BIM, but it is simply the means by which everyone can understand a building through the use of a digital model, an asset in digital form the enables those who interact with the building to optimize their actions, resulting in a greater whole life value for the asset (NSB, 2015).

The concept of BIM theoretically emerged and developed in the late 1970s, grew rapidly after that because of the increasing attention paid to construction teams and firms that found merits in using BIM in order to integrate the process of the construction projects and managing assets. The term BIM was firstly used in 2002 to describe virtual design, construction and facilities management (Eastman et al., 2011). But, the paper highlights as well the advantages maturity of BIM, particularly the increased utility and speed, enhanced fault finding in all construction phases.

Theoretically and practically BIM developments in Kosovo are between level 0-1 compared with global context so far. A need for sustainability and development of BIM is emphasized in syllables, industry and facility maintenance. The aim of this research is identifying the role of BIM in sustainability and performance, as well as making recommendations for process implementation. In this context the research questions to be addressed are: how can identify the BIM interrelation role with sustainability? which is the role of BIM in relation to asset performance over life-cycle? how can be identified recommendations for BIM implementation in Kosovo?

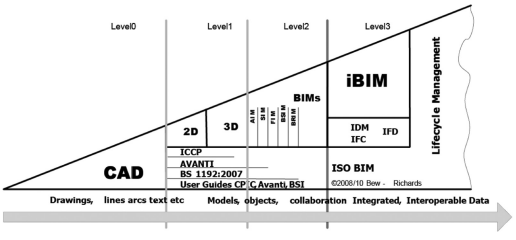


Figure 1. BIM maturity model (source: Bew-Richards 2008/10).

(Alwan et at. 2015) discussed that this process revealed a number of challenges faced by the construction sector, including: the need to improve the strategic vision with regard to sustainability within the industry, local and national government; resistance to the implementation of new, more efficient technologies; and inefficient logistics and communication methods inhibiting the adoption of new technologies to improve efficiencies. However, when these challenges could overcome, BIM as a new information technology promises a new level of collaborative engineering knowledge management, designed to facilitate sustainability and asset performance issues in life-cycle of AEC industry of Kosovo.

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Data clouds for product life-cycle management

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ABSTRACT

This paper addresses removing barriers for sharing information in order to facilitate Product Life-cycle Management (PLM), which is used to optimize the life-cycle of products within the civil engineering sector. The PLM concept holds the promise of integrated information produced throughout a product's life-cycle – for everyone in an organization and at every managerial and technical level – along with key suppliers and customers to use it. In practice, however, civil engineering data is hard to share in a controlled manner between different parties and different phases. As such, a solution is needed to create, retrieve, use, and store coherent data about civil engineering systems in a way that multiple sources from different parties can coexist and be used in cohesion.

This is where the concept of Data Clouds comes in. A Data Cloud is a coherent set of information that can be used by different software from different suppliers unbound by the location where the information is stored. A Data Cloud can be a single autonomous set of information or a collection of different sets which link information into a coherent whole. A Data Cloud can describe a civil engineering product throughout its life-cycle while different parts (subsets) of the data are managed by different stakeholders in the supply chain, with different software from different suppliers. Information in a Data Cloud is retrievable via the Internet and can be (re)used by different parties to add data about a civil engineering product, contributing to one big 'cloud' of data that covers parts of or even the whole range of the PLM concept.

We suggest that Semantic Web technology is particularly suitable to realise Data Clouds. This technology meets the required conditions for both managing civil engineering data (flexible, scalable, yet remaining coherent and consistent) and sharing such data (vendor-neutral, enabler for integration). Successful implementations in the field show that the suggested data solution is not just a good choice theoretically, but has also been proven to already be effective in practice.

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The use of BIM for deconstruction and reuse: Literature review and future needs

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ABSTRACT

The objective of this paper is to provide insights in the use of BIM for deconstruction and reuse of building materials and components. The paper reviews the literature in the light of the research question: "How does BIM support deconstruction and reuse decision making?" A three-step approach was used. First we conducted a background research on deconstruction and reuse (step 1), which delivered input for a decision making framework developed in step 2. The third step included an in-depth review of selected papers on BIM supported reuse decision making.

In the first step of this study (background research), the relations between the building life cycle and the materials life cycle are explored.

Focussing on end-of-life decision making, in the second step of this study, a decision making framework is presented that distinguishes different levels of reuse. The three-staged decision framework is tailored to modular building structures with different modules having different life cycles. Furthermore it distinguishes between demolition and deconstruction in the light of intended reuse. The purpose of the decision framework is to clarify to building owners, contractors, component manufacturers, building designers and consulting engineers when various reuse options should be investigated. It models the decision making process for entire buildings or parts of buildings.

In the third part of this study, an in-depth review was carried out on BIM related papers on deconstruction and reuse. Different uses of BIM are identified and grouped according to the decision framework developed in step 2 of this study. An obvious instrumental use of BIM is providing data for decision support models. Information is extracted from the BIM database and transferred to other software tools for further analysis. BIM databases are also used to store relevant information for future deconstruction and reuse. The use of BIM in combination with other digital technologies, such as RFID and sensors, is generally recognized in the literature for gathering and storing of component life cycle information. Related to deconstruction and reuse, different BIM uses are identified: tracking and tracing of materials, monitoring of components physical condition, reverse manufacturing and reverse logistics, technical analysis of in-situ components, 'fitness for a subsequent use' analysis, on-line auctioning of in-situ components, planning deconstruction projects.

The use of BIM, in combination with other digital technologies, looks promising. However there are some issues that need to be investigated for adoption of BIM for deconstruction and reuse purposes on a larger scale. Further research is needed into the way different stakeholders are involved in decision making. The alignment of their interests, motives, attitudes and competences towards gathering, analysing, using and sharing of building information for supporting reuse of building components is crucial, but not addressed in the literature reviewed. To the best of our knowledge, research on this field is limited. Recognising that empirical work is yet to be conducted, more extensive comparative research into reuse decision making with BIM in different collaborative arrangements encountered in professional practice is needed.

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Government's perspective on BIM and sustainability in transport infrastructure in Europe and China

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ABSTRACT

A recent development in transport infrastructure has been the linkage of BIM and sustainability (by terms such as Green BIM). Sustainability is a common goal in current transport infrastructure projects and BIM is a commonly used technology. It is stated that there is a strong relationship between BIM usage and sustainability, but there is not much known about this relationship, especially in transport infrastructure. This paper reports on an exploratory study on the relationship between BIM and sustainability in transport infrastructure in the perspective of government. In this study, a comparison is made between the political situation in Europe and China. The existing state of the transport infrastructure construction policies in terms of sustainability and BIM strategies and how they change and develop over China and Europe will be explored. The views from practitioners will be collected via semi-structured interviews for validating. A special focus will be laid on the pull and push policy analysis. It is concluded in Europe there is currently not so much activity in new transport infrastructure projects, but more in maintenance and renovation. There is a growing interest for life-cycle approaches. In China there are a lot of activities in new transport infrastructure projects as a result of the fast economic growth. But also the interest for sustainability has recently grown dramatically. The paper will contribute to our understanding of the role Green BIM plays in the design, construction and maintenance of transport infrastructure and ways in which Green BIM are interpreted by transport infrastructure participants.

The paper has the following main conclusions:

(1) First and foremost, in Europe there is currently not so much activity in new transport infrastructure projects, but more in maintenance and renovation. There is a growing interest for life-cycle sustainability approaches with the use of BIM. In China there are a lot of activities in new transport infrastructure projects as a result of the fast economic growth. But also the interest for sustainability and BIM has recently grown dramatically.

(2) The European countries set a good example to transition BIM and sustainability to a strategic framework. It creates a uniform environment for nationwide responsibility of sustainability and acceptance of BIM. Sustainability has and BIM requirement would then come under legal jurisdictions. It would provide users from transport infrastructure sector an official approval of their BIM implementation for sustainability. A more uniform and better coordinated mechanism of BIM development spreads across the country in the case of a strong public sector support. However, at the moment the linkage between BIM and sustainability in European transport infrastructure is still not obvious.

(3) A fast moving construction sector and significant investment in transport infrastructure coupled with strong government support give China a good position to adopt BIM quickly. But China's government policies for BIM are still lack systematic planning and a detailed roadmap development in BIM implementation guide. Many policies and programs have been adopted to increase efficiency. The most influential appear to be R&D projects and industry participation encouragement at the national level.

(4) Currently China is faced with balancing economic growth and the environment. Policy has focused primarily on increasing the energy efficiency by BIM, which leads to cost savings. Less attention has been devoted to changing sustainability aspects in transport infrastructure.

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Life-cycle cost calculations supported by building information modelling software – unrealised potential

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ABSTRACT

Use of Life-cycle cost (LCC) for is highly a relevant method for comparing different building projects or different solutions within a building. LCC requires increased information compared to traditional building cost calculations. Use of building information modelling (BIM) based software should therefore lead to highly increase or LCC calculations in every projects. However, this is not the case regarding LCC and BIM. This study will explore this situation and attempt to answer the following research question: *"Why is BIM-based LCC not applied more often?"*

Integrated design and Delivery Solutions (IDDS, 2013) illustrated in figure 1. is used as framework to cover a holistic approach. The study is based on interview with stakeholders from public builder/ facility management, contractor/property developer and consulting engineering company to cover integrated processes and collaborating people in IDDS. A Norwegian BIM-based for software, ISY Calcus, is used as reference for covering interoperable technology in IDDS.

There exists standards and sustainability rating systems (e.g. BREEAM, LEED, DGNB, CASBEE and others) covering integrate processes. The level of specification are not detailed enough to secure reliable implementations in BIM-based software. Lack of joint price databases is another barrier. Transparent process and established practices can compensate. Despite agreement about importance of LLC is use of LCC as decision criteria very limited. This imply that use of LCC is missing an important driver for change. Use of LCC require multi-disciplinary competence among all involved in the design and decision process. LCC calculations require input of more information than traditional cost calculations. Use of BIM-based technology can act as an enabler for combing LCC calculations with traditional cost calculations and environmental calculations e.g. CO_2 based on BIM file as joint source of information.

This study identify a gap between the integrated processes, collaborating people and interoperable technology, illustrated in figure 2 as superior reason for limited use of BIM-based LCC calculations.

Increased use of LCC calculations would benefit more from increased integration rather than development of separate factors (circles or "silos"). Functionality in BIM-based software is not a delimiting factor. Even if all perspectives become developed, more detailed or advanced, this is no guarantee for increased use. IDDS has proven to be useful for understanding factors for increased use of BIM-based LCC calculations. Outcome of this study can contribute to better alignment of resources to support increased use of BIM-based LCC calculation in all projects.

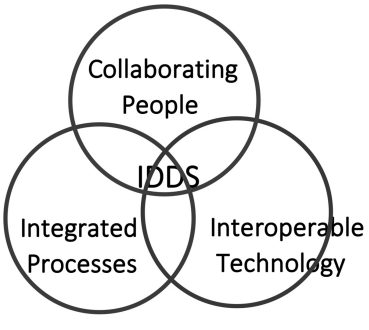


Figure 1. The three aspects of IDDS (2013); figure simplified by the author.

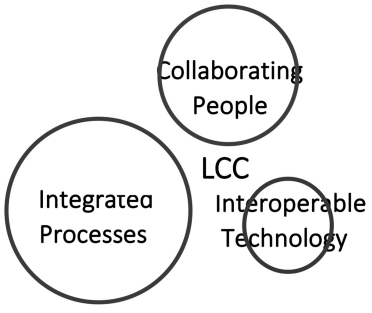


Figure 2. The current aspects of BIM based LCC calculations.

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A hybrid linked data approach to support asset management

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ABSTRACT

National Road Authorities (NRAs) face many challenges when managing their road assets. As a result, NRAs are changing their way of managing their assets. This paper focuses on the changes needed in information management for asset management.

Currently, asset information is acquired, managed and processed in very disparate ways. From political, economic and technical perspectives assets are dealt with differently by diverse expert groups within NRAs and their supply chains. Often, information in NRAs' systems is not interlinked; not current; contradictory; incorrect; unclear; incomplete; non-uniform; and non-semantic. These issues increase risks of inappropriate decision making, high information management costs and contractual disputes.

The research question dealt with in this paper is whether the use of a linked data approach for the technical specification of information standards is a feasible and expedient objective for NRAs, based on the experiences in national and international standardization initiatives.

To answer this research question, we first elaborate on the linked data approach.

We observe that several national and international initiatives are moving towards a technical specification using the linked data approach. The basic assumption in these initiatives is that, to improve the information management of NRAs in an economically viable manner, the standardisation solution for the technical specification lies in representing civil infrastructure assets as semantically enhanced Linked Data. The paper elaborates on the data, process and business facets of the linked data approach.

Two relevant international initiatives in this field are the V-Con project (V-Con 2016) and the CEDR 2015 BIM call CEDR 2015). These initiatives use a hybrid, semantically enhanced linked data approach. The linked data approach originates from the World Wide Web Consortium and can be used for modelling, storing, linking and retrieving data, including road data; integrating existing software applications and giving rise to new innovative software functionalities. It is called a 'hybrid' approach because it also incorporates and reuses existing non-linked data information standards originating from the worlds of Building Information Modelling, Geospatial Information Systems and Systems Engineering.

The hybrid linked data approach has many benefits over existing standard approaches, as explained in the paper. These benefits originate from the scientific foundation in logic and the existing W3C free and open standards and supporting tooling. The hybrid approach ensures that existing standardization investments do not become obsolete but can be aligned to the new linked data approach.

The linked data approach described in this paper offers a great opportunity for improved communication and data sharing in information management for asset management. However, final conclusions on the feasibility and expedience for NRAs cannot be drawn yet. As many national and international initiatives are following this approach, we expect to be able to draw final conclusions on our research question in the near future.

ACKNOWLEDGEMENT

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The possibility of using BIM for nonlinear life-cycle analysis of concrete structures

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ABSTRACT

In the recent years the issue of BIM is gaining increased attention and there is a growing number of practical applications of BIM. The basis of BIM is Industry Foundation Classes (IFC), 2013, published as International Standard ISO 16739: 2013. IFC constitute an open data format for data exchange between different types of software applications throughout the entire structural life-cycle. Authors created within the international project SE-Lab an application for data conversion to structural analysis (Structural Analysis View MVD). The structural data are converted from IFC standard to ATENA software input format, which is suitable for the non-linear FEM analysis of concrete and reinforced concrete structures. The functionality of ATENA solution core has been extended in order to solve some of previously unsupported load types which are part of the IFC standards. Integration of the NLFEA with stochastic and degradation modeling allows to assess life-cycle reliability of civil engineering structures or structural elements.

The presented paper describes an unified approach in modeling advanced behavior of structures directly using the information from an IFC based BIM model (Figure 1). Suitable filtering tools are first applied on the BIM model to eliminate any redundant information. The geometrical information as well as the information about reinforcement, material properties, loads and boundary conditions is used to automatically construct the numerical model with as little user intervention as possible. The numerical model is then used for nonlinear analyses, which can be used to evaluate various design scenarios or limit states. In the presented validation problems two design scenarios were evaluated and tested: ultimate limit state in terms of failure load and failure mechanism and service limit state of deformation, crack location and crack width.

The presented approach is part of the ongoing research and development effort of the authors in applying advanced numerical models and simulations in design and life-cycle assessment of safety critical structures.

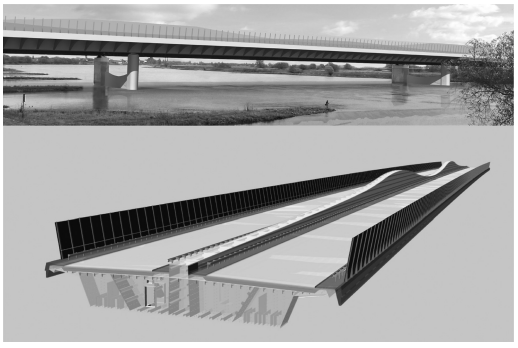


Figure 1. Visualization (top) and IFC model (bottom) of bridge Wittenberge, one of the validation problems in SE-Lab project.

The support for spatial variability analysis was developed within the project No. P105-14-10930S "SPADD – Spatial variability degradation and damage in reliability analysis of concrete structures".

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Towards more integrated information management solutions for lifecycle asset management for integrated infrastructure projects

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ABSTRACT

One of the big challenges for current asset management is to properly command lifecycle project information to enable asset managers having an integrated view of their engineering assets. During the lifecycle of an infrastructure project, there will produce extremely large amount of information. In the traditional way, the information exchanging and sharing processes are always fragmented. It is general that lifecycle information from different project phases is not efficiently delivered to support asset management works.

This paper tries to find an optimal solution for more integrated asset information management. We start from a brief and state-of-art overview of current information integration approaches for asset management purpose. Three main kinds of approaches are reviewed: (1) BIM and IFC based approach, (2) the Semantic Web based approach and (3) the information retrieval based approach. A comparison between different approaches is then given based on our understanding of the principle of asset information management. Finally, we conclude that an information retrieval tool using artificial intelligence techniques is needed for more integrated asset information management. This paper is a preparation for future developments of a smart information retrieval prototype. The prototype is supposed to be tested on real projects, which will be conducted with collaboration with Rijkswaterstaat (the Dutch Ministry of Infrastructure and Environment) in the Netherlands.

Keywords: Lifecycle asset management, Information integration, BIM, Semantic Web, Artificial Intelligence.

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Standardization of condition assessment methodologies for structures

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ABSTRACT

Governments are tending to use asset management increasingly as the main method for dealing with their as-sets: for public space in general and infrastructure in particular as well as real estate. The basic requirement in asset management is reliable information regarding the assets: it is vital to know what you have got and what state it is in.

It is therefore that in 2011, CEN/TC 319 'Maintenance' created a new working group, WG 11 'Condition assessment methodologies for structures'. The aim of this working group is produce Technical Specification (TS) on methodologies for condition assessment. The TS will describe an objective inspection method, which is usable for the determination of the technical condition of objects in a uniform way. Starting point for WG 11was the Dutch standard for 'Condition assessment of buildings and infrastructural objects', NEN 2767. This standard is now common practice in building sector and starting to find its way in infrastructure, but for the moment predominantly for bridges, tunnels and viaducts.

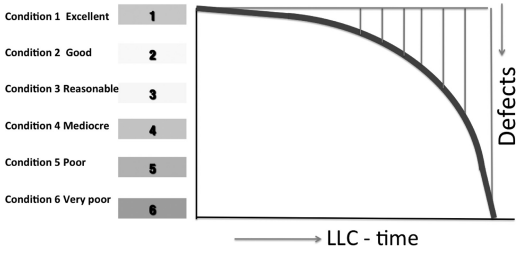


Figure 1. Condition rating based on defects assessment.

By applying NEN 2767, a method of defining the technical state of objects or object parts, the condition can be expressed in a condition score ranking. This condition score is based on three parameters: the severity, extent and intensity of the defect. This will lead to:

- uniformity in both assessment and results;
- greater objectivity;
- similarity in definitions.

As a result of this, all parties involved in the process of condition assessments benefit:

- less communication failures;
- improved long-term maintenance planning and control;
- improved maintenance budget planning.

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BIM in the 'New International Airport in Mexico City' project

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ABSTRACT

Engineering an international airport with multiple disciplines is a complex project which demands good information sharing to support the decision process during the whole life-cycle of the airport.

This information will have a variety of formats like visualizations, quantities, drawings, reports or analyses and must be based on a single source to keep the output consistent.

NACO (Netherlands Airport Consultants), a company of Royal HaskoningDHV, is a global provider of airport planning, airport design and airport engineering services and uses the latest BIM technology to execute complex projects in time, in budget and with the highest quality.

In the New International Airport in Mexico City project BIM is used by the Master Engineer to execute the project within a year.

The master engineering for this project is done by three companies, two from Mexico and one from the Netherlands; together they form a joint venture TASANA (TAdco, SAcmag, NAco).

During the project engineers from different areas of the world were working on the project at the same time. This should be done well organized on an engineering point of view due to the amount of interfaces between these objects. But also from an information management point of view, due to the need for each other's designs to create a consistent design.

The main questions to be answered are:

- How to provide an intensive and flexible cooperation?
- How to produce over 10.000 documents in the short time frame (one year)?
- How to ensure a uniform design, both in technical content and visually?
- How to keep control over these documents?

So not only the engineers had a challenge to overcome within this project. The challenge for the information management team was to create a way of working which was acceptable and feasible for all the involved parties.

Before BIM was implemented in this project, commitment was needed of all the involved parties because BIM is not a standard way of working yet in building and infrastructure projects.

The way how BIM is executed in this project, a BIM Execution Plan (BEP) is developed. This document is written by all teams that are a part of the BIM process and is critical for the success of the BIM execution in the project.

To create the BEP, a structured procedure is used that is developed by the Computer Integrated Construction Research Program at the Pennsylvania State University as a buildingSMART alliance Project (CIC 2010).

The turnaround time for this master engineer project was one year. Could this project be done without BIM? The answer is NO. Concurrent Engineering and working with one single source is crucial to deliver quality within a limited time frame.

But it can be even better if there are (international) BIM standards for the whole life cycle of buildings and infrastructure. This means that during the engineering phase, information can be created that can be reused in the construction and maintenance phases.

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TRIMS: A risk-based information model to manage object data

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ABSTRACT

TRIMS means Tauw Risk-based Information Management System. It is an information model, developed in a Relatics platform, to organize and structure object data.

For an assetmanager it is important to get a clear picture of the total amounts of assets he has to maintain. To organize the maintenance of a large amount of assets with a limited amount of budget it is important to prioritize the assets: which assets need maintenance first and for what reason. A method to prioritize assets is FMECA (Failure Mode Effect and Critically Analysis). Applying this method to available assets results in a risk analysis, which can be used to risk-based prioritize assets.

TRIMS is used to perform a risk-analysis, based on the FMECA method. The result is a maintenance & budget plan and it provides a total overview of the assets that need to be managed.

What makes TRIMS unique is that the user can define the outcome. TRIMS is complementary to the working process and therefore the information model is built to be flexible. This concerns both the requirements for in- and output.

TRIMS is developed around four important pillars: knowledge, track and trace, verification and visualization and presentation. TRIMS is used to organize and structure information about assets. This can include information, both technical and practical, from documents (analogue and digital), but also information from experts (field and object related). To validate the gathered information, it is important that the sources of the information are traceable. Requirements to the output data are also implemented in the information model. The verification of the products is therefore an active part of both work process and information model. Most important is that the output is workable and practical, hence it is made attractive to use. Therefor data can be enriched by adding inspection results or new data to improve the quality of the risk analysis. and the visualization and presentation of the object data is an important part of the information model. TRIMS uses strong points of other existing systems such as ArcGIS (GIM) to present the data.

Applying a risk-based approach to prioritize maintenance on assets creates a well-underlined maintenance & budget plan. As a result savings can be done to the expenses on maintenance.

The combination of knowledge about process, assets and an information model that can enrich data of assets and ensures data is traceable and visual is rare. The development of TRIMS shows that it is important to build systems that support our working process and not the other way around. Important is to think in possibilities *and* constraints to ensure a practical and workable output.

TRIMS is applied in projects to organize and prioritize assets for the Department of Waterways and Public transport, Waterboards and Regional authorities.

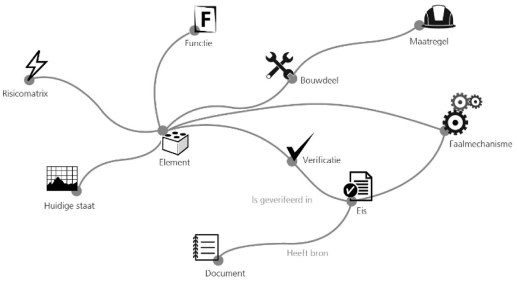


Figure 1. Schematization of the relations in TRIMS.

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BIM supporting economic optimization of seismic retrofit of existing structures

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ABSTRACT

The life-cycle cost (LCC) analysis of buildings prone to seismic risk is a critical issue in structural engineering. During the lifecycle, facilities are prone to economic losses due to ordinary and exceptional events. Generally, designers are unable to estimate these costs due to the related uncertainties. Knowing the expected economic losses and structural performance of a facility may support the planning of retrofit strategies aimed at preventing, or at least limiting, the damages. This purpose can be achieved by defining seismic retrofit strategies and analysing the increased structural capacity and the consequent reduction of the expected loss.

The procedure adopted in this work for estimating the economic losses of a building is based on the well-consolidated methodology developed by the Pacific Earthquake Engineering Research (PEER) (Aslani & Miranda 2005).

The final scope is to identify the most cost-effective strengthening strategies and strengthening levels (i.e. the strengthening interventions associated with a given safety level) for existing structures during their lifetime.

Procedures for the assessment of economic losses are widespread in the research community, but practitioners very rarely implement them because they are too difficult to be applied. The BIM methodologies can improve the feasibility of these procedures by dealing with the large amount of data referred to the damage and cost analyses of the structural and non structural components.

The integration of economic loss assessment methodologies in BIM models provides a quick procedure that can support designer who want to optimize the seismic retrofit strategy.

The framework proposed in this work is synthesized in Figure 1.

Within this context, this paper aims to show how to create a framework to assess the economic expected seismic loss of an existing building by means of BIM-based methodologies, and then design and optimize seismic retrofit operations from an economic point of view.

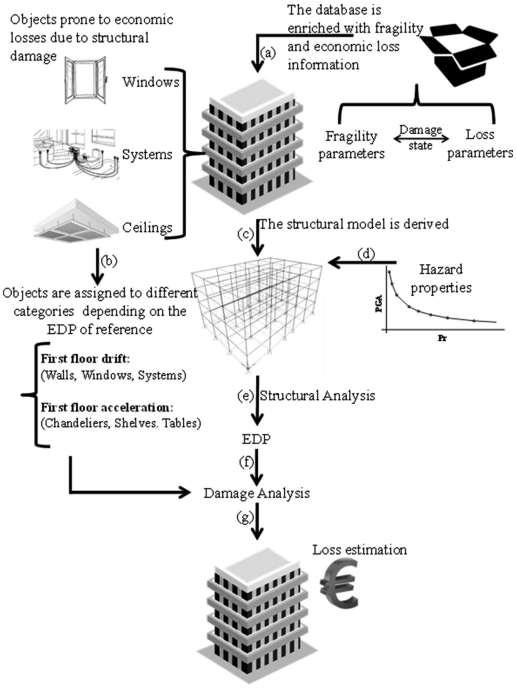


Figure 1. Scheme of the flow of information.

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MS6: Issues and challenges in real-world applications of structural health monitoring

Organizers: C.W. Kim, Á. Cunha, L. Sun & P.J. McGetrick



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A fundamental investigation to survey the state of RC bridge decks with vertical acceleration given by FWD test

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ABSTRACT

In Japan, the deterioration of RC bridge decks is one of the most important problems in maintenance of road bridges. In order to achieve the efficient maintenance of road bridges, it is important to recognize the state of decks. Main existing methods to check the state of decks are visual check and loading test with heavy vehicles. We can easily check the damages on surface of decks but we can't estimate the mechanical property of decks. And we can check the mechanical property with loading test with high cost and hard work.

Then we have tried to develop the simple testing method to survey the mechanical property of bridge decks. In the past researches, we developed the simple evaluation method with FWD system and we use the deflection of decks to evaluate the state of decks. In this research, we try to survey the detail of damage state of bridge decks with vertical acceleration given by FWD test.

In this research, we used the small FWD system (Figure 1) to make the impact and to measure displacements of bridge decks. We also used the servo type acceleration sensors in order to measure the acceleration of the decks. The specimen decks of existing bridge are without fatigue damages because of execute exchange of decks.



Figure 1. FWD test.

To analyze the measured acceleration data with FFT method, we can get the distribution spectrum (Figure 2 and 3). The aspect ratio of both panel is 1:2. The panel 7 is outer area and the panel 12 is inner area of tested bridge. In these panels, the natural frequency are not same. Then the authors discussed with these phenomena and other factors as aspect ratio, magnitude of impact, arrangement of sensors, and so on.

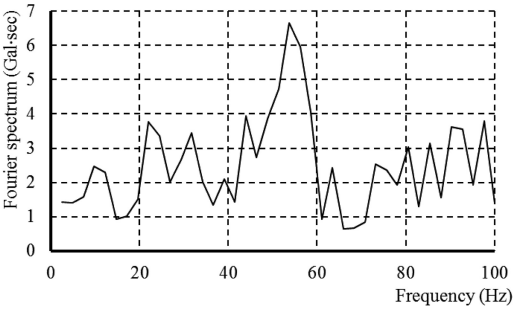


Figure 2. Fourier Spectrum given by FWD test (Panel 7).

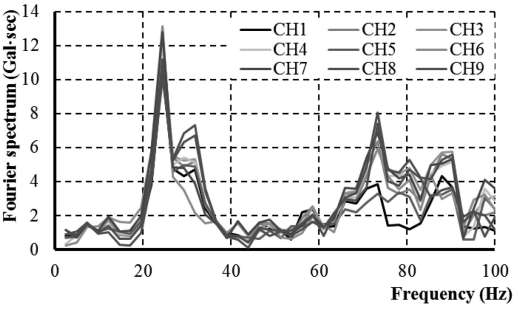


Figure 3. Fourier Spectrum given by FWD test (Panel 12).

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A novel damage indicator from a multivariate linear system model

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ABSTRACT

Management of aging civil infrastructures is a crucial technical issue. Techniques of structural health monitoring (SHM) based on ambient vibration measurements have been attracting bridge owners because of its efficacy in terms of inspection. Changes in structural integrity of bridges engender changes in their modal properties such as natural frequencies, damping ratios and mode shapes that are identifiable from vibration data utilizing linear system models (e.g. Kim *et al*. 2012). This study proposes an unsupervised damage detection method using a damage indicator (DI) automatically estimated by a set of multivariate autoregressive (MAR) models from ambient vibration of bridges. The DI evaluates a stochastic distance between a set of the reference samples obtained from a healthy bridge and an unknown test sample utilizing Mahalanobis distance (MD) (Taguchi & Rajesh 2000). The expectation of DI will be 1 for a healthy bridge whereas a damaged bridge is supposed to provide larger DIs. A statistical hypothesis testing based on a probability distribution of the DI was performed for damage detection.

A field experiment on a real steel truss bridge under a passing vehicle was conducted so as to investigate efficacy of the proposed DI for damage detection. The truss members of the bridge were artificially severed. The damage scenarios are shown in Figure 1 and Table 1. One of the experimental results of the DIs and the statistics related to the hypothesis test are summarized in Figure 2, where each of the damage scenarios provides its sample mean located above the critical value whereas the each of cross validation (CV) samples provides its sample mean below the critical value. This observation demonstrated the proposed DI enables to detect damage of the three different damage patterns clearly by means of the hypothesis test. It is noteworthy that the proposed DI successfully identified even small damage such as damage scenario DMG1.

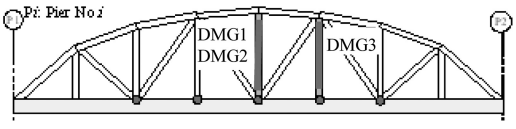


Figure 1. Damage locations.

Table 1. Damage scenarios.

Scenario	Description
INT	Intact bridge
DMG1	Half cut in vertical member at midspan
DMG2	Full cut in vertical member at midspan
RCV	Recovery of the cut member
DMG3	Full cut in vertical member at 5/8th-span

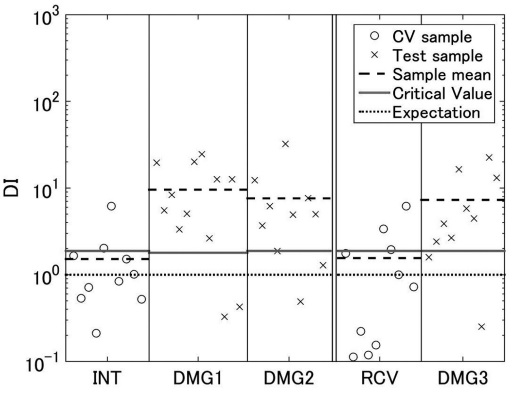


Figure 2. DIs and test statistics.

Efficacy of the proposed DI was also confirmed by comparison with previous investigations (Kim *et al*. 2013) using the same experimental data, which is discussed in the full paper.

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Bridge condition assessment from long-term monitoring by means of Bayesian hypothesis test

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ABSTRACT

Many vibration-based bridge health monitoring (BHM) techniques have been proposed to identify the hidden information of structural integrity in the vibration data and to diagnose bridge structures, and have been successfully applied under constant environments such as laboratories. Focusing on real world applications, however, bridge structures are subject to changing environmental and operational conditions that affect measured vibration data, and the signals from these effects lurk in the measured vibration data and disguise themselves as structural responses. A crucial issue, therefore, is how to reduce or consider those environmental and operational effects in the framework of the BHM.

A Bayesian approach (Kim *et al.*, 2015) utilizing the Kalman filter and Bayesian hypothesis test is applied to investigate long-term monitoring data of an in-service bridge in this study. The data were measured at a seven-span plate-Gerber bridge. This study considers time-varying temperature and vehicle weights measured by a BWIM system as environmental and operational factors respectively. All data was taken from a healthy bridge, since no damage and deterioration was reported during the monitoring period from August 2008 to July 2014 considered in this study. Those observed and predicted damage indicators (DI_{ob} and DI_{pr}) from August 2008 to August 2009 are shown in Figure 1 as an example in which DI_{pr} is predicted by means of the Kalman filter considering time-varying temperature and vehicle weights on the bridge. Utilizing the residual (DI_{ob}-DI_{pr}) (the r in Figure 1), the Bayesian hypothesis test was conducted utilizing the Bayes factor (Sankararaman and Mahadevan, 2011) that is the ratio of the likelihood of alternative hypothesis to the hypothesis of the null hypothesis.

Observations through the study demonstrated that, in the Bayesian hypothesis testing utilizing data from the healthy bridge, the damage probability of the bridge was judged as no damage as shown in Figure 2 since the Bayes factors were less than 1 for all examined data.

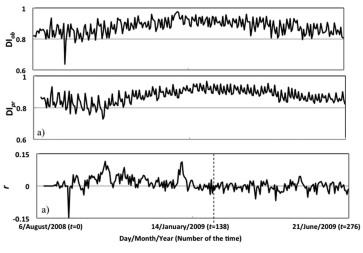


Figure 1. Observed damage indicator (DI_{ob}), predicted damage indicator (DI_{pr}) and residual (r) of DI_{ob} and DI_{pr} identified from accelerations.

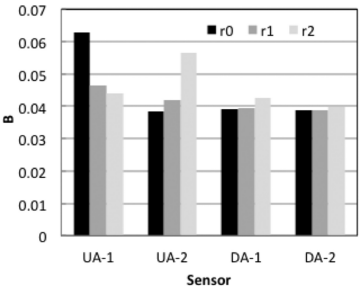


Figure 2. Bayes factors (B) estimated from accelerations of four sensors named UA-1, UA-2, DA-1 and DA-2 utilizing data from October 2008 to March 2009 (r0), October 2009 to March 2010 (r1) and October 2013 to March 2014 (r2).

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Damping and frequency of a sag cable attached with a pre-tensioned Shape Memory Alloy wire

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ABSTRACT

Stay cable vibration mechanism and mitigation is a major concern for bridge engineering community. This study proposed and tested a system of a stay cable transversely attached with a tensioned Shape Memory Alloy (SMA) wire. Cyclic tension loading test of pre-tensioned 0.5 mm diameter SMA wire was firstly conducted. The effective modulus and energy dissipation per unit volume were derived from the tested hysteretic loops of pre-tensioned SMA wire. The pre-strain effects on the effective modulus and energy dissipation of SMA wire was discussed based on the test results. Then vibration mitigation experiment of a model stay cable transversely attached with a tensioned SMA wire was conducted. The strain level of SMA wire was calculated from the stay cable force increment. Both the 1st and the 2nd in-plane vibration mode were tested in the experiment. The effects of the SMA wire installation location and pre-strain on frequency and damping ratio of the model-cable-SMA-wire system were discussed. The test results confirmed there was an optimal pre-strain of SMA wire for the maximum mode damping larger than 0.50%. A preliminary linearized theoretical study was also carried out to further explore the dynamics of model-cable-SMA-wire system. The comparison results showed good accordance of theoretical frequency and damping to the tested. The study confirmed great potential application of pre-strained SMA wire as cross-ties for stay cable vibration mitigation.

Keywords: stay cable; SMA; pre-strain; damping; frequency

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Deflection based monitoring as a bridge damage indicator

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ABSTRACT

Bridge condition is assessed primarily through the use of visual inspections. This is an approach that lacks consistency and reliability due to the subjectivity of inspections. Catastrophic occurrences like the Interstate 34 Bridge in Minneapolis in 2007 (Azarbayejani et al., 2009) may be prevented by using more reliable bridge inspection methods. Premature bridge repair may also be prevented with adequate bridge monitoring.

This paper investigates the use of a damage indicator based on the deflection responses at a number of points along a bridge. As a vehicle crosses a bridge, the deflection at the point directly underneath an axle is recorded. This enables a moving-reference deflection response to be created. The mean moving reference response of a batch of similar vehicles may then be used to create a damage indicator. The root mean squared difference between the mean moving reference of a batch of vehicles crossing a healthy bridge and a batch crossing a damaged bridge is the damage indicator used in this paper.

This indicator has been shown to increase with damage. This damage indicator is location-specific. Examining Figure 1, it can be seen that there exists multiple solutions of damage severity and location for any damage indicator magnitude. For any one location of damage, the indicator increases with damage severity. The method is shown to be most effective for detecting higher levels of damage in and around the centre region of the bridge.

In off-centre locations the method alone is less effective. The damage indicator is also compared to an indicator proposed by OBrien et al. (2015), based on a moving force identification algorithm. The two damaged indicators are shown to provide similar but not identical results. They are both poor at predicting the location of damage but for any one area of damage, the damage indicators increase with an increase in damage severity. The damage indicator based on the deflection responses alone has an advantage in that it is more computationally efficient than the MFI damage indicator.

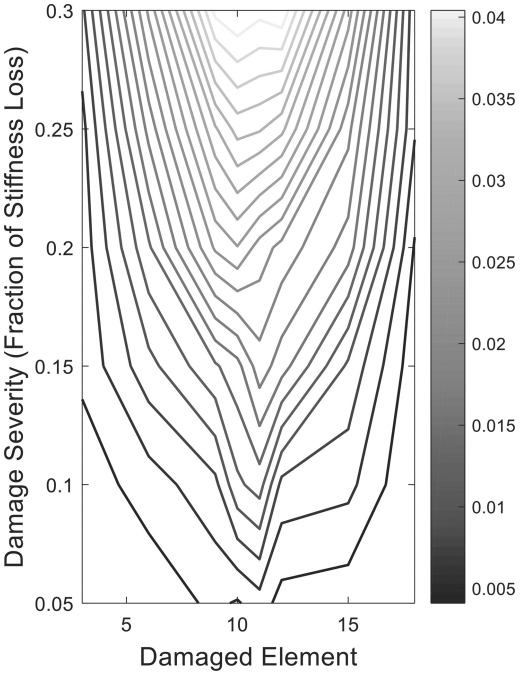


Figure 1. Contours of damage indicator based on moving-reference deflection response

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Experimental validation of spectro-temporal compressive sensing for vibration monitoring using wireless sensor networks

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ABSTRACT

Modal characteristics of structures such as modal shapes, natural frequencies and damping factors are often adopted within a vibration based monitoring framework for extraction of condition or damage indicators. The inference of the modal properties of the system is commonly carried out via data sets acquired from tethered monitoring solutions. The recently surfaced Wireless Sensor Networks (WSNs) however, offer a cheaper and more easily deployable alternative to a wired-based system allowing for a more attractive solution to long-term deployments.

This work presents an extension of previous work of the authoring team (Klis & Chatzi 2016), addressing the issue of heavy transmission costs, which prohibit the usage of WSNs in vibration monitoring. An enhanced Compressive Sensing (CS) scheme is presented, exploiting the spectro-temporal information contained in measured signals for the purpose of signal reconstruction. The proposed approach enables signal recovery from partially transmitted measurements, which in turns allows for reliable identification of the structure's modal characteristics.

The validation of the method is carried out on an experiment setup of a 4-storey steel frame structure tested in using a laboratory shaking table. The extracted data serve for feeding the proposed data compression framework and the System Identification (SI) routines. The quality of the proposed methods is confirmed in the stabilization diagrams provided in Figure 1, derived for both the complete–reference and partially transmitted recovered signals. The recovered signals are obtained via transmission of only 12 % of the complete–reference time series. Additionally, a comparison of the identified modal parameters is provided Table 1, revealing a very good agreement. The results of the proposed approach appear highly promising towards the effective handling of active problems in WSN deployments, such as the reduction of the transmission costs and the extension of node functionality and sustainability.

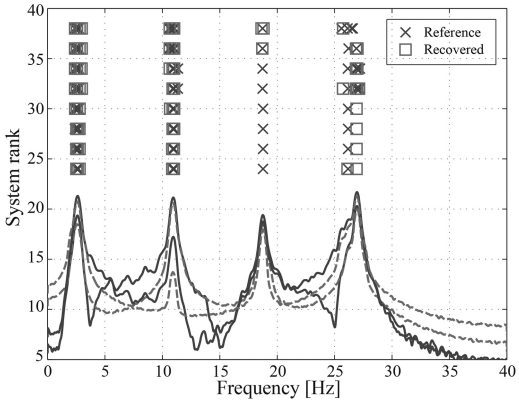


Figure 1. Stabilization chart at $m_{avr} = 0.12, \in_l = 3.5$.

Table 1. Identification results.

Mode	$m_{avr} = 1.0$	$m_{avr} = 0.12$	MAC
1	2.71 [Hz]	2.56 [Hz]	0.98
2	11.03 [Hz]	11.00 [Hz]	0.96
3	18.72 [Hz]	18.71 [Hz]	0.92
4	26.90 [Hz]	26.99 [Hz]	0.99

REFERENCE

Klis, R. & E. Chatzi (2016). Vibration monitoring via spectrotemporal compressive sensing for wireless sensor networks. *Life-Cycle of Structural Systems, Special Issue of Structure and Infrastructure Engineering, in press.*

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Fatigue life assessment of three offshore wind turbines

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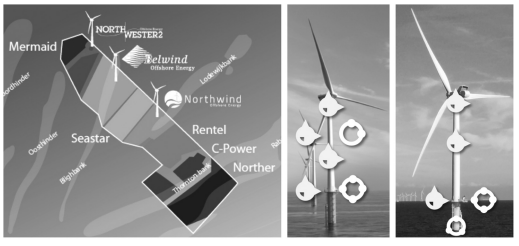
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ABSTRACT

Offshore wind is developing in Europe at a rapid pace, with ever growing turbine sizes and greater distances to shore the demand for structural monitoring of the foundations has become more relevant than ever. In particular the monopile foundation, which represented over 75% of the total installed capacity in 2014, has been pushed in terms of weight and diameter. The monopile foundation, in essence a single pile driven into the seabed, is subjected to both static and cyclic bending moments, the latter caused by waves, wind and the turbine's rotor dynamics. As such the structure is vulnerable to fatigue and fatigue life is a known design driver for many of the installed monopiles (Bhattacharya 2014, Gengenbach et al. 2015).

However, in design many uncertainties in hydrodynamic loading and turbine (thrust) loading and uncertainties in soil conditions mean that the actual fatigue progression in offshore monopile foundations might differ from design.

This paper is part of an ongoing research collaboration between the Vrije Universiteit Brussels, OWI-lab and Parkwind, the owner of the Belwind and Northwind offshore wind farms outside the Belgian coast.The main goal of this research collaboration is to develop and field-test a broad structural health monitoring strategy for offshore wind turbines that can support wind farm owners and developers in the near future. The results from a fatigue monitoring campaign can serve as a support tool for cost-effective inspection and end-of-life decision for the wind farm owner. By better understanding how fatigue is progressing for the different turbines within the farm, the owner is better aware of turbines that might run up to their expected lifetime and turbines that can be considered for lifetime extension. In addition a monitoring campaign allows to put actual results against design assumptions. In collaboration with designers and regulatory bodies this can result in improved design codes in the near feature.



(a) (b) (c)

Figure 1. (a) Position of the two monitored wind farms within the Belgian zone for offshore wind energy (b) Belwind V90 turbine (c) Northwind V112 Turbine with indication of accelerometers (yellow) and optical fiber strain gauges locations (white).

In this contribution we will focus on the measurements obtained thus far from three instrumented wind turbines in the Belwind and Northwind farms, Figure 1. At the start of the research project in 2012 one turbine at Belwind, a farm consisting of 55 Vestas V90 turbines on monopiles, was equipped with LVDTs and force transducers to monitor the condition of the grouted connection, accelerometers for dynamic analysis, corrosion sensors in the monopile and since 2014 optical fiber Bragg gratings (FBGs) to monitor strain and consequently loads. At the more recent Northwind wind farm, 72 Vestas V112 on monopiles, two turbines were equipped with an optimized setup in 2014. The three equipped turbines are currently continuously monitored.

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Health monitoring of real structures by distributed optical fiber

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ABSTRACT

Two different existing structures monitored with distributed optical fiber sensors, are described in this paper. The principal Structural Health Monitoring (SHM) results of a valuable hospital rehabilitation (Sant Pau Hospital) and the enlargement of a prestressed concrete bridge (Sarajevo bridge), Figure 1, are presented. The results are obtained using a novel Distributed Optical Fiber Sensor system (DOFSs) based on an Optical Backscattered Reflectometry (OBR) technique. The versatility and easy installation of DOFSs compared with traditional monitoring systems is an important characteristic to consider its application in monitoring real world structures. The DOFS used in this study provide continuous (in space) strain data along the optical fiber with high spatial resolution in order of centimeters. Also and because the structural surfaces generally are roughness, the procedure to attach the optical fiber to two monitored structures are described. This is an important aspect because the influence in strain transfer between the DOFS and the surface is one of the principal parameters that should be considered in the application of the OBR technique.

Numerous works presenting information regarding the study of the potential of these sensors have been published in the last decade (Rodríguez et al. 2015 a,b; Palmieri & Schenato 2013) but very few showcase their application to real world structures.

One of the various advantages of this technology is the easy installation to real life structures and the variety of them that can be instrumented with it. In both studied instrumentations the used fiber is based on a type of fiber optic in which the wavelength is established and compatible with a commercial data acquisition system. Each section of optical fiber has a maximum length of 50 meters and the union between the fiber and structural element (concrete/masonry) was performed using a two-component type epoxy adhesive. A coating of a polymer (polyimide) was used to protect the fiber against scratches and environmental attack.



Figure 1. Sarajevo bridge.

Due to their particularities, each one of these structures underwent changes in their structural behavior without, nevertheless, ceasing to serve their purpose, i.e. accommodating patients in the case of the Sant Pau Hospital and the passage of vehicles and pedestrians in the case of Sarajevo bridge thanks to the application of these sensors.

With the results obtained in this work, the OBR theory associated with DOFS proved its reliability in SHM of civil engineering applications and continues to showcase the promising future of monitoring systems based on this technology.

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Monitoring and model updating of an FRP pedestrian truss bridge

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ABSTRACT

Fiber Reinforced Polymer (FRP) is a new structural material for bridges as it has strength comparable to that of steel but better performance in corrosive environment. On the other hand FRP bridges are usually more easily vibrated than steel bridges since the elastic modulus of FRP is smaller than that of steel. Another weak point of FRP is its larger variance of material properties than structural steel. The elastic modulus, for example, assumed in design stage usually differs from the elastic modulus of the real bridge constructed following the design, which sometimes leads to different structural behaviors comparing to those predicted from the FE analysis in the design. Therefore it is worth to investigate ways to estimate material properties of FRP bridges without conducting material tests for every bridge. This study is intended to estimate elastic modulus of a real FRP pedestrian bridge shown in Figure 1 by means of vibration measurements and the FE model update.

Accelerations of a pedestrian FRP bridge were measured under pedestrian walking as well as a drop test to investigate dynamic characteristic of the bridge. Mode shapes, natural frequencies and damping constants of the bridge were identified from the accelerations by means of the multivariate autoregressive (AR) model (Kim *et al*. 2012).

The FE model update of the bridge was conducted by means of the cross-entropy (CE) method (e.g. McGetrick *et al*.). The Fe model of the bridge is shown in Figure 1. Natural frequencies and mode shapes for the first two modes were the target variables considered in the cost function for the optimization of the FE model update. It is noteworthy that every connection of the truss members was reinforced with a stainless steel member. Therefore in the model update the elastic modulus of the reinforced members was estimated by assuming the reinforced member as a composite member from stainless steel and FRP. Table 1 shows identified natural frequencies, eigen frequencies from FE model considering elatstic modulus in design and eigen frequencies from the FE model update as well as those elastic modulus. Observations demonstrated that the vibration-based FE model update could provide a way to estimated mechanical properties of FRP bridges.

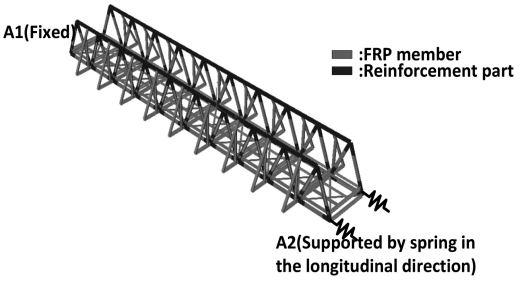


Figure 1. FRP pedestrian truss bridge.

Table 1. Comparison of bending mode frequencies.

	1st bending mode (Hz)	2nd bending mode (Hz)	Elasticity of FRP (GPa)
Identified from experiment	8.30	16.09	N.A.
Before FE model update	9.43	17.13	23.0
After FE model update	8.30	16.09	20.2

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Performance analysis of long-span cable-stayed bridge based on long-term monitoring data

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ABSTRACT

Vibration-based structural health monitoring (SHM) utilizes variation of modal parameters as indicators to assess structural conditions. However, it was widely recognized by many researches that bridges' modal parameters can suffer a considerable variation with the normal change of such environmental or operational factors as temperature, wind and traffic loadings, which would lead to an unsuccessful structural evaluation. So it is quite necessary to investigate the correlations between these environmental or operational factors and structural modal parameters to "normalize" the environmental/operational condition. Based on the 5-year long-term monitoring data recorded by the Structural Health Monitoring Systems (SHMS) of Donghai Bridge (DHB) and Shanghai Yangtze River Bridge (SYRB), both of which are long-span cable-stayed bridges (CSB) with center spans longer than 400 m in Shanghai, China, this paper studied the modal frequencies' variation during the bridges' operational stage, as affected by temperature and traffics. The spectral analysis showed that the variation of modal frequencies possessed some long-period components such as 1 year, 1 week, 1 day, 12 hours and so on. Focused on the first vertical bending mode and the first lateral bending mode of DHB, this paper inferred the reasons for periodic characteristics of modal frequencies' variation, and compared the relative importance of temperature and traffics on each dominating cycle by the regression analysis. In addition, traffic loading monitoring method was also investigated. The incorporation of video monitoring technology into SHMS was recommended to bridge the gap between traffic load monitoring and structural response monitoring. Taking full advantage of the complementary capabilities found in video camera, inductive loop and Weigh-In-Motion (WIM) system, a comprehensive solution for traffic monitoring can provide sufficient and accurate information. The study herein can advance the understanding on the bridge's behavior and benefit the monitoring and maintenance of long-span bridges.

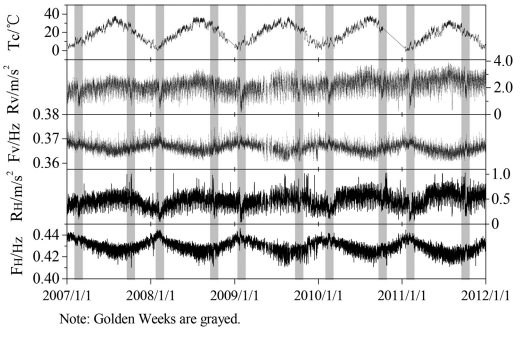


Figure 1. Time histories of temp., RMS and freq. of Donghai Bridge.

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Radar interferometry as a tool for structural health monitoring: Current situation and perspectives of the technique for the next decade

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ABSTRACT

The development of Interferometric radar sensors for the monitoring of Civil Engineering structures dates back to the 90's. The effectiveness of the working principle has been demonstrated and specific instrumentation, comprehensive of basic processing and analyzing tools are nowadays available from the market. Different case studies on measuring the vibration characteristics of civil structures have been presented, and published papers are available in journals from both radar and SHM communities.

The first use of an interferometric radar to measure the dynamic response of a structure dates back to 1999 (Farrar et al. 1999), when off-the-shelf electronic and microwave components measured the displacement response of target surfaces belonging to a bridge during forced vibration tests. In the following years, various experiments were carried out developing an apparatus initially not user friendly and based on costly and bulky microwave laboratory hardware (Pieraccini et al. 2003). Later on, papers dealing with ambient vibration testing of structures using specific radar systems, devoted to this application, were published about bridges (Gentile & Bernardini 2008), cables, wind turbines, towers (Luzi et al. 2013), and buildings (Negulescu et al. 2013). A radar interferometer is able to provide displacement samples of any structure with submillimetre accuracy and from large ranges, with the limitation that only the component along the line of sight can be measured.

Recently some papers tried to propose advanced sensors, taking profit from the present on the shelf microwave sensors, aiming not only at improving performances and capabilities of interferometric radar but also at proposing instrumentation with reduced costs. Currently no original novel system has been definitely commercialized, and expected improvements have been only achieved in theoretical or trivial examples. In this paper, the authors summarize the main technical features of the available radar sensors, how they are linked to the final performances of the system in terms of spatial and temporal resolution, and discuss the possible improvements achievable using an updated technology.

Based on the state of the art, a crucial aspect for the design of an "optimal" new sensor stems from the different experimental conditions, i.e. the range, the size and characteristics of Civil Engineering structures, which strongly affects the measurement requirements as well as and the engineers' expectations. For this reason the development of advanced systems able to provide an optimum configuration of the proposed technology demands a strong interaction with the user communities.

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Structural health monitoring and damage detection of an arch bridge using a minimum mean square error estimator

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ABSTRACT

The Infante D. Henrique Bridge, a concrete arch bridge in the city of Porto (Fig. 1), is equipped with a monitoring system continuously recording structural vibrations. The vibration characteristics are extracted from the measurements using automatic output-only identification. Statistical deviation of the natural frequencies of the structure can be used as an indication of damage. The variable environmental and operational conditions have also an effect on these features. A minimum mean square error estimation algorithm was used to eliminate the environmental influences from the data (Fig. 2). The measurement of the environmental variables (e.g. temperature) is not necessary. Damage detection was made using an extreme value statistics control chart. During two years, no damage emerged, which was in agreement with the damage detection results.

In order to study an early detection of damage, natural frequency shifts were computed using numerical models of the undamaged and damaged structure with realistic damage scenarios (Fig. 1). The computed frequency shifts were then added to the experimental values to simulate damage.

For damage scenario *D*2, the EVS control chart for the first principal component scores of the residuals is plotted in Figure 3. It clearly shows an abrupt and permanent change in the data. Occasional false alarms emerged.

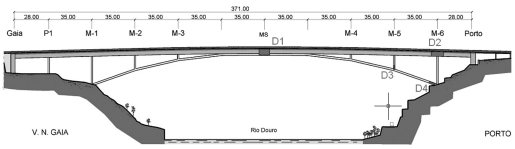


Figure 1. Location and extent of the simulated damage scenarios *D*1–*D*4.

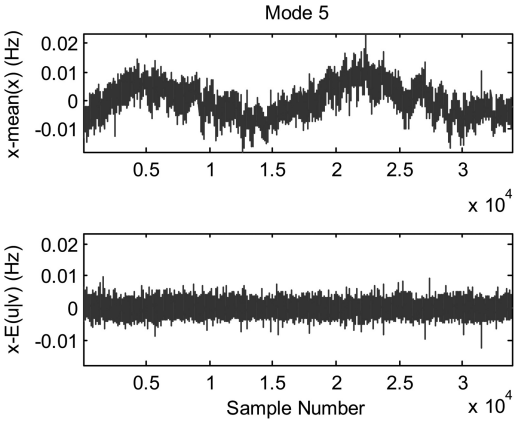


Figure 2. Residuals of the natural frequency of mode 5. Top: data mean subtracted; bottom: conditional mean subtracted.

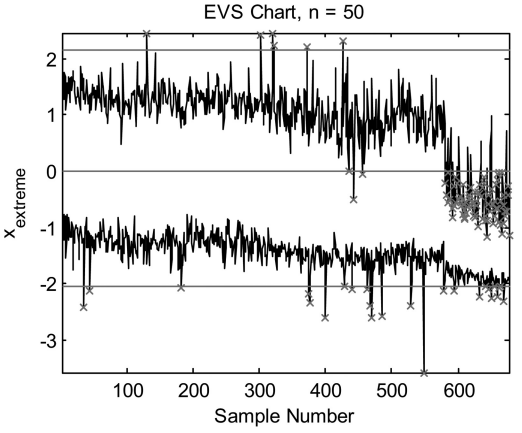


Figure 3. EVS chart of the first PC scores of the residual with damage *D*2.

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Substructural identification using input-output observations and neural network

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ABSTRACT

This study focuses on the system identification and damage detection of reinforced concrete bridges. The well-known autoregressive exogenous (ARX) algorithm is used to find a data set of autoregressive coefficients. Based on this data set, the eigenvalue realization algorithm (ERA) is used for the modal identification of the structures. ARX-ERA are used because the experiments includes the acquisition of output data, i.e. acceleration, based on a forced input, which is produced by an exciter. This provides more accurate modal results than output only methods. The innovation of this study is the use of these results in a new neural network framework that identifies the possible damaged elements and the type of damage. This is achieved using an improved version of the substructural identification method. Instead of a single submatrix scaling factor the new method further subdivides the element stiffness matrix in four additional submatrices according the force type: K_N axial force submatrix, $K_{My,Vz}$, $K_{Mz,Vy}$, K_T; each with its own submatrix scaling factor. The method is validated with experiments on different reinforced concrete bridges. The computational effort required is mitigated by the used of parallel computing on GPUs.



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MS7: Life-cycle maintenance technology and management system for concrete roads in severe chloride environment region

Organizers: S. Kimura & S. Miyazato



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Analytical study on structural performance of PC T-shape beam with various deterioration scenarios

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ABSTRACT

In the sustainable society, concrete structure should retain safety structural performance to the future. When pre-stressed concrete (PC) beam received the chloride attack, the failure of them may occur by steel bar corrosion.

In this study, for the purpose of investigating the structural performance decrease by the several deterioration, the loading test of full scale PC T-shape beam and the structural analysis to it were carried out. This PC beam that have 17.9 m length, 1.3 m width, and 1.0 m height was cut off from existing bridge in Hokuriku Expressway, Japan.

In this structural analysis, the several deterioration scenarios of PC beam were prepared. As these deteriorations, mass of the PC bar decrease, the pre-stressing force decrease, and the beam edge damaged by chloride attack were mainly assumed. The effects of deterioration on structural performance, such as the beam's failure mode and load-carrying capacity, were examined by structural analysis, based on the results of the experiment. The extent that mechanical properties have an effect on structural performance was clarified by the analysis.

One example of examinations is given. As the rate of mass reduction of the PC bars increases, their mechanical characteristics drop correspondingly, affecting the structural performance of the member. Parameter analysis was performed on the assumption that the three PC bars located in the lower center of the PC beam are corroded. In analysis cases as shown in Table 1, the rate of mass reduction due to corrosion was defined as three different values: 5%, 10% and 15%.

As the results, the relationships as shown in Figure 1 were obtained. The reduction in the maximum load was smaller in method B than in the other two methods. In the method A, when the mass of the PC bars was reduced 15%, the maximum load that could be carried by the beam was approximately 40%.

As the summaries of their numerical analysis of a PC T-shape beam, load-displacement curve of analysis was similar to experiment curve, when the section data and the measurement results such as compressive strength of concrete and pre-stressing stress of PC bars were used.

Table 1. Analysis cases.

	Rate of mass reduction (%)			
	0	5	10	15
A	T-0 (Elastic section)	T-1-A05 (Elastic section)	T-1-A10 (Elastic section)	T-1-A15 (Breaking)
B		T-1-B05 (Elastic section)	T-1-B10 (Elastic section)	T-1-B15 (Elastic section)
C		T-1-C05 (Elastic section)	T-1-C10 (Yielding-Breaking)	T-1-C15 (Breaking)

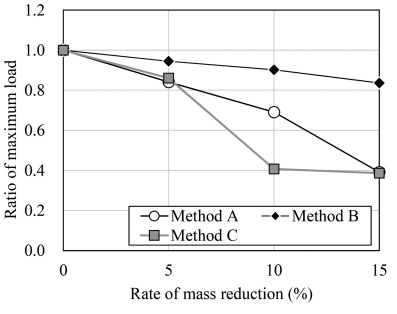


Figure 1. Relationship between reduction rate of mass and ratio of maximum load.

In the parametric analysis, the mechanical properties of PC bars and the pre-stressing stress had greater effects on the failure mode, maximum load, yield load, and the amount of deformation than any other mechanical properties. Based on the comparisons, it was confirmed that the crack occurrence load of beam significantly depended on pre-stressing stress of PC bars. And the maximum load was influenced by the mechanical properties estimated by the mass reduction of PC bars. Therefore, it is important to ascertain those mechanical properties accurately by inspecting the beam.

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Chloride ion penetration under two-dimensional freeze-thaw attack

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ABSTRACT

Concrete structures and members deteriorate and their performance will be degraded during the service life. In particular, frost damage due to freeze-thaw cycles causes deterioration of concrete structures in cold regions (Shashank et al, 2008). Also, chloride from deicing agents can penetrate into concrete and accelerate the deterioration due to frost damage in a freeze-thaw environment. Consequently, corrosion of reinforcing bars occurs in concrete members (Wang et al, 2014). Moreover, it has been reported that icing on the surface of concrete leads to acceleration of frost damage, which must consider the geometric conditions of the structure such as which concrete surfaces are exposed to snow cover and thaw water with chloride ion. In particular, parts of the concrete structure which have higher potential to be deteriorated by frost damage, such as bridge piers, would have chloride ion penetration two-dimensionally from the top and side surfaces of concrete. To simulate freeze-thaw environment on the surface of concrete structures considering the real environmental exposure, which shows severe damage in cold regions as mentioned earlier, it is necessary to prepare an experimental methodology to induce two- dimensional chloride ion penetration and icing behavior on the top and the side surfaces of concrete.

Freeze-thaw cycles of temperature history and immersion test were applied as shown in Figure 3 using 1, 3 or 5 wt% of NaCl solution in the bank on the top to simulate icing conditions. There were two test series for concrete specimens: freeze-thaw cycles for 6 days and immersion test for 1 day (Cycle 1) and immersion test for 7 days (Cycle 2). These were executed cyclically for 28, 56 and 84 days. As for mortar specimens, freeze-thaw cycles for 12 days and immersion test for 1 day were periodically-cycled till the freeze-thaw cycles reach 300 times.

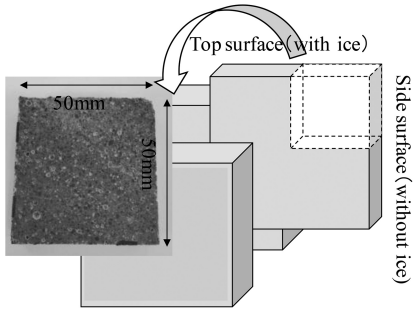


Figure 1. EPMA sample fabrication for mortar specimens.

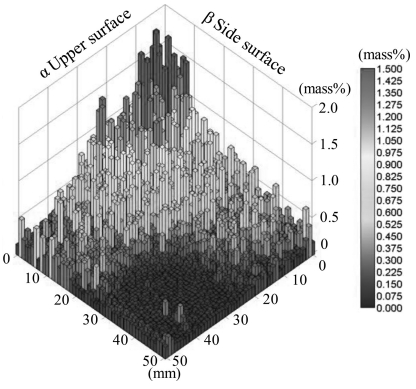


Figure 2. EPMA results on Cl ion concentration.

Chloride ion penetration behavior by Electron Probe Microscope Analyzer (EPMA) as shown in Figure 2.

As the results of two-dimensional experiments for freeze-thaw attack chloride ion penetration, chloride ions accumulated and the chloride penetration front remained at the surface layer when ice formed on the surface of concrete, and the corrosion initiating chloride threshold content with icing on the concrete surface should be set to 10% to 30% lower than that without icing. Also, considering permeability alteration in the Fick's law and increase of diffusion coefficient due to frost damage, the calculation results were improved.

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Cracking of cover-concrete by rebar corrosion in reinforced concrete

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ABSTRACT

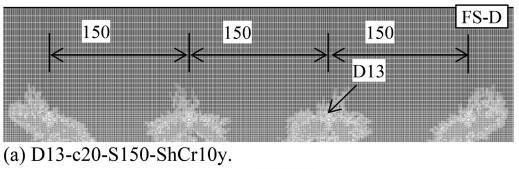
To grasp the properties of materials used in reinforced concrete (RC) structures, it is important to evaluate their structural performance. Corrosion of steel bars used to RC, in particular, lead to a lack of cohesion between the concrete and rebars, resulting in cracking and spalling of the cover-concrete. Cracking or spalling of cover-concrete reduces durability in terms of seismic performance, appearance-related serviceability, and functional safety of RC viaducts. Cracking and spalling also serve as effective indices for detecting rebar corrosion, and a number of studies relate the cracking mechanisms involved and the prediction of rebar corrosion.

The objective of this study is to evaluate the amount of rebar corrosion which results in cracking and spalling of cover-concrete. The field-portable rebar cross-section measurement system was developed for measuring the cross-section and area of rebars used in RC structures, and proved to be effective for measuring in-situ corrosion. Based on measured results, a cover-concrete push-out machine of was developed, simplifying experiments to determine the occurrence of cracking and spalling of cover-concrete by applying load as well as displacement to the rebar. The study examined the effect of rebar spacing, cover-concrete thickness, shrinkage and creep of concrete on crack shape and rebar-corrosion induced displacement.

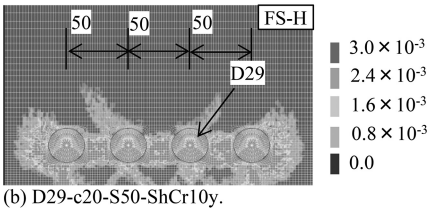
The finite element method (FEM) of RC for evaluating the cracking of cover-concrete has been conducted with considering the shrinkage and the creep of concrete. Figure 1 indicates the example of diagonal cracking with D13-c20-S150-ShCr10y and the horizontal cracks with D29-c20-S50-ShCr10y. The diagonal crack was initiated at the vicinity area of rebars, and propagated to the concrete surface. Even the cracks in Figure 1(b) were initiated at the rebar, however, these cracks were propagated horizontally. Finally, the horizontal cracks were connected with the crack propagated below at the edge of the rebar. The study identified the difference in cracking shapes as FS-D: diagonal cracks, and FS-H: horizontal cracks according to c and s.

The FEM evaluated that the space of rebars s will change the cracking shape even the ratio of cover-concrete thickness and the rebar diameter c/ϕ. This study focused on the expansion displacement d_{crack} of the rebar at the moment of cracking when the strain increased suddenly as load increased, and the expansion displacement $d_{spalling}$ of the rebar at the moment of spalling when the strain increased suddenly at second time. The values of d_{crack} and $d_{spalling}$ were affected by shrinkage and creep of concrete. The reduction of rebar radius (Δr) at the case of FS-D was expressed by a linear with the value of c/ϕ and the coefficient η.

In the case of FS-H identified by s and c, the signal of spalling, e.g. cracking, was not observed from the outside of the concrete. It means that the type of FS-H seems to be difficult to detect before spalling. In particular, when the corrosion of rebar happened in the case with $s = 50$-mm, the horizontal cracks propagated without the information on the surface of concrete, and it has a potential of inducing the spalling of cover-concrete in wide range.



(a) D13-c20-S150-ShCr10y.



(b) D29-c20-S50-ShCr10y.

Figure 1. Cracking of concrete-cover by corrosion.

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Evaluation of a stainless steel bar embedded in carbonation curing concrete

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ABSTRACT

Carbonation curing concrete which was made to intentionally absorb carbon dioxide in a process, has been developed to reduce carbon dioxide emissions. However, there is much concern about the corrosion of steel inside the concrete caused by the decrease in pH resulting from CO_2 absorption. Hence, the main target of carbon dioxide fixation is plane concrete which does not have any steel bar. If carbon dioxide can be fixed within the matrix of reinforced concrete, it can conduct more carbon dioxide reduction. In addition, carbonation curing concrete could be implemented in areas such as strip roads and handrails of bridges, and other vast applications. Based on the above backgrounds, this study evaluates corrosion resistance of stainless steel bars (SUS304, SUS316, SUS410) embedded in carbonation curing concrete.

After the specimen was exposed to an environment with 40°C, RH40%, and 20% CO_2 concentration until the carbonation depth was 30 mm, it was exposed to a chloride acceleration environment for 11 and 42 weeks. After that, the half-cell potential and the chloride ion concentration distribution in concrete were measured. The specimens were then split and the steel was observed. The results of the half-cell potential are shown in Figure 1. According to this figure, it can be confirmed that the longer the exposure periods, the more base the half-cell potential of both the carbon steel and stainless steel bars. In evaluating all the three types of stainless steel bars, it is observed that the half-cell potential of SUS410 is base in comparison to those of the other steels. Next Figure 2 shows the soluble chloride ion concentration. According to this figures, the chloride ion concentrations are 1) highest near the surface, 2) gradually lower at a position further from the surface in carbonation part (0–30 mm), and 3) elevated again at 40 mm in the no-carbonation part. This reason seems to be that in the case of carbonation curing concrete, the chloride ion cannot be fixed and it easily penetrates into greater depths. Hence, the chloride ion penetrated to the carbonation part easily moves forward to the no-carbonation part. Also by the reverse analytic with Fick's second law from the chloride ion penetration distribution in carbonation part of Figure 2, the apparent chloride ion diffusion coefficient is estimated at 0.58 cm^2/year.

As a result, the conclusions are as follows. 1) Anti-corrosion performance becomes good within the steels in order the order of SUS316 > SUS304 > SUS410. 2) It is difficult to fix chloride ions in the carbonation curing concrete. 3) The apparent chloride ion diffusion coefficient in the carbonation part was 0.58 cm^2/year, and this value was smaller than that obtained in the no-carbonation part.

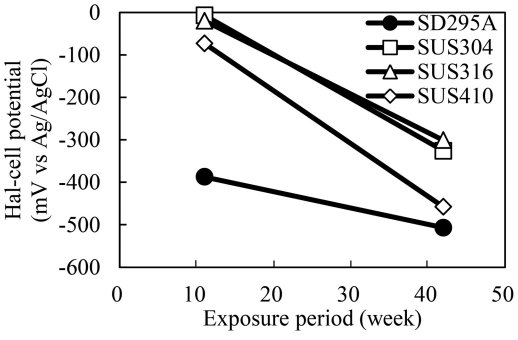


Figure 1. Hal-cell potential.

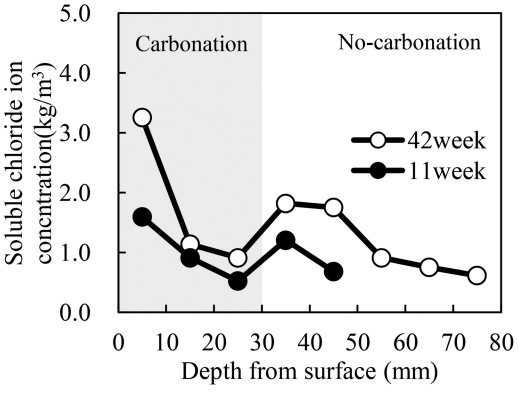


Figure 2. Chloride ion concentration.

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Examination of the validity of monitoring method for bridge damaged by chloride using UAV

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ABSTRACT

Visual inspection of the bridge is performed by that an inspection person strikes a bridge with a hammer on the special bridge inspection vehicle or scaffolding. This method is required in order to ensure inspection. But, this method is inefficient and high expense. The local government which turns into a subject of inspection, is in the situation where the budget of inspection cannot fully be secured from financial difficulties. This research shows that the effect and subject which carry out bridge inspection using UAV. Additionally, the monitoring methodology is developed in this research and the results of the actual proof experiment are reported. UAV is a small pilotless plane in which operation and photography are possible in remote control. Although the usual UAV hovers using GNSS, but the signal of GNSS cannot receive under a bridge easily. Therefore, UAV which does not use GNSS was used in this research. Normal digital cameras, all the circumference cameras and an infrared camera were used for the camera used for inspection. All the circumference cameras can photo a bridge from various directions by photography once. An infrared camera observes the wavelength which cannot be seen in viewing of man. The researches which investigated degradation of concrete were reported using the infrared camera. In this research, the crack of concrete, the rust of steel materials, and the situation of the bolt were able to be checked using a digital camera and all the circumference cameras. Since verification has not been completed yet, the inspection by an infrared camera needs to inquire continuously. Although the monitoring methodology was proposed in this research, it cannot check about all inspection items by the proposed method. Therefore, it is expected that this methodology will be utilized as primary screening for defining the priority of diagnosis and investigation of a bridge.



Figure 1. Observation by drone to main girder lower flange.

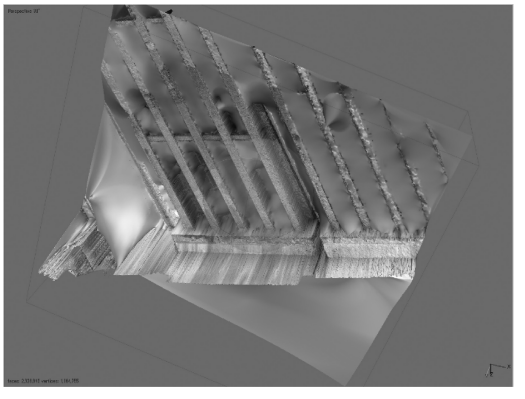


Figure 2. 3D model of N Bridge derived from drone.

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Forecast improvement of chloride profiles in road structures using LA-ICP-MS

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The road network of the ASFiNAG contains more than 5000 bridges. Most of them are made of reinforced or prestressed concrete. In Austria strong winters are obligate and therefore de-icing measures are used for thawing. These substances contain chloride, which are solved in water. Several elements of the bridges – especially the columns – are strongly exposed to the chloride attack. Additionally, more than half of the structures were built in the 1970's or 1980's. They are therefore many years exposed to this chemical attack leading to an enormous amount of retrofitting measures due to concrete degradation.

Let us assume that the initiation of corrosion starts at about 20 years and the reduction of the cross section takes place for another 5 years. That assumption indicate that after 20 years a small rehabilitation measure and after 25 years a large rehabilitation measure is necessary, which demands two times the cost. Thus, the maintenance costs of the structure due to chloride induced corrosion calculated per year is enormously higher (about 60%) when the initiation of corrosion is neglected for a few years.

Therefore, an accurate determination of the susceptibility to corrosion and a model that is able to predict the initiation of corrosion is mandatory for structural safety and cost savings.

The LA-ICP-MS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry) method applied in this paper leads to results that are more accurate, less laborious and better to assess the problem than in the traditional titrimetric methods. The advantages of the new and the traditional method are discussed and the results from both methods are compared. The presented method is a fast and reliable analysis strategy for determination of the chloride contend in existing concrete structures. It was shown, that the traditional titrimetric method lead to high deviations and to systematic errors in the results. Therefore, the proposed LA-ICP-MS approach helps to increase the reliability of the obtained results. The high depth resolution of the chloride profiles enables a more exact data assessment for forecast models and supports the prediction of critical developments even further.

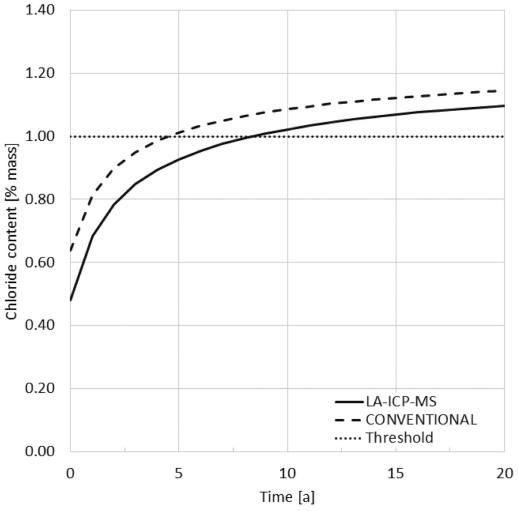


Figure 1. Example of the difference in the prediction of the chloride concentration at the rebar level over time using the LA-ICP-MS or the titrimetric method.

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Influence of bleeding on durability of horizontal steel bars in RC column specimen

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ABSTRACT

This study reports on the influence of bleeding on the durability of reinforced concrete, especially horizontally placed steel bars in RC column specimens cast from the height of 1.5 m. This was examined through the use of in-situ air permeability tests and electro-chemical tests. The airtightness in conjunction with moisture measurement has been reported as an indicator for the durability performance of cover concrete (Kawaai and Ujike, 2015). Because the presence of moisture in pore structure could modify the airtightness in terms of air permeability coefficients, the tests in conjunction with moisture measurements were crucial in determining the durability performances. This could be dependent on the pores modified by the bleeding water, which may have a large influence on the durability with respect to ingress of harmful substances and corrosion processes.

In addition to the height of casting i.e. 1.5 m, fine aggregate used in this study was copper slag aggregate with a specific gravity of 3.55 g/cm^3 which was intentional to cause excessive bleeding in fresh concrete. On the other hand, proper use of fly ash in concrete mixtures could lead to higher resistance against segregation thus suggesting that the integrity between steel bars and cover concrete and the durability may not be compromised. The objective of this study was to examine the corrosion resistance of horizontal steel bars in concrete mixtures with different bleeding rate owing to chloride attack induced by dry and wet cycles.

The results showed that the air permeability coefficients tended to be higher in the upper parts of concrete specimens compared to those in lower parts of the column specimen, which was dependent on the bleeding rate. The corrosion processes occurring in horizontal steel bars located at upper parts of the specimen were observed to be relatively severe in the concrete specimens tested. The microcell corrosion current density was dependent on the rate of oxygen permeability measured by cathodic polarization curve as shown in Figure 1. Lower total corrosion current density was clearly observed in the FACUS30 mixture which can be explained by the fact that the air permeability coefficients and the rate of oxygen permeability measured in the FA mixture were smaller and less varied in the segmented steel bars in column specimens. The results seemed to suggest that the durability of horizontal steel bars located in upper parts of column concrete specimens could be affected by the loss of integrity in horizontal steel bars/concrete interface and cover concrete with less resistance against the ingress of substances. They were confirmed by air permeability tests in conjunction with measurements of moisture content and oxygen permeability measured by cathodic polarization measurements in this study.

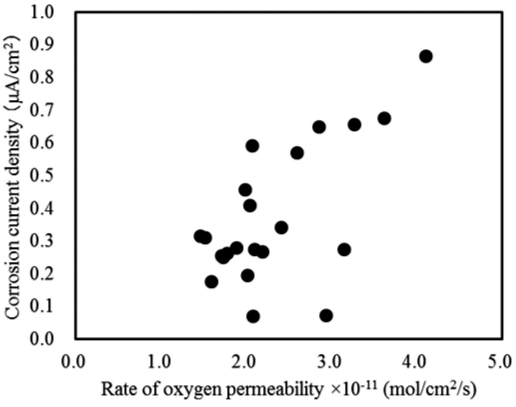


Figure 1. Rate of oxygen permeability and corrosion current density.

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Modelling the life-cycle of concrete gravity sewers subject to microbial corrosion

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ABSTRACT

Long term deterioration of concrete sewer infrastructure costs the wastewater industry billions of dollars per year globally raising serious questions about how best to prioritize remedial and replacement work in order to maintain the sustainability of wastewater infrastructure. It follows that predicting rates of corrosion and the resulting time to failure of existing reinforced concrete sewer systems is an important issue for wastewater utilities.

To gain a better understanding of the corrosion process inside working sewers, a 6 year in-situ study of sewer pipe corrosion was recently undertaken by the authors. In the study coupons cut from newly manufactured reinforced concrete sewer pipe ('new' coupons) and 70 year old sewer covers ('old' coupons) were placed in 6 gravity sewers throughout Australia operating under a wide range of internal environmental conditions. The use of the two coupon types enabled the corrosion process to be studied at the beginning of the pipe's service life and when corrosion was more advanced. New and old coupons were recovered at 6–8 month intervals for the first 3 years of the trial and annually thereafter. Recovered coupons were inspected for changes in surface morphology and surface pH. Photogrammetric analysis was then used to determine the depth of corrosion product covering each coupon and also the amount of sound concrete corroded away during the time of exposure.

The general pattern of mass loss experienced by new coupons was the same at all sites. Following installation in the sewer new coupons passed through an initial "induction period" lasting between 9 to 36 months during which no losses occurred despite a fall in surface pH. Once the surface pH had fallen to pH = ~6 new coupons began to experience mass loss of various degrees depending on local sewer conditions. Once mass loss commenced it increased in a linear manner over time at all sites (i.e. coupons at each site experienced a constant rate of corrosion). Old coupons bypassed the induction period and began experiencing mass loss almost immediately. Again mass loss increased in a linear manner over time. Rates of corrosion experienced by new and old coupons at any given site were found to be in close agreement despite differences in the mineralogy and pore structure for the two coupon types indicating that the rate of corrosion is dictated more by the specific local sewer conditions than pipe material properties.

By considering the fundamental physical and biological processes taking place a first pass corrosion model relating the rate of corrosion to sewer gas temperature, humidity and H_2S concentration was developed, (Equation 1):

$$C = A \times [H_2S]^{0.5} \times \frac{(0.1602H - 0.1355)}{(1 - 0.9770H)} \times e^{\left(-45000/RT\right)} \quad (1)$$

where C is the rate of corrosion (mm yr^{-1}), A is a constant (=207,750) determined empirically to obtain the best fit between the model and field data, $[H_2S]$ is the concentration of H_2S in the sewer gas phase (ppm), H is the relative humidity (expressed as a fraction of saturated), T is the absolute temperature (K) and R is the universal gas constant.

Predictions from Equation (1) were found to be in excellent agreement with the rates of corrosion observed at the study field sites indicating that a good estimate of the rate of corrosion (and hence the pipe service life) can be made if long term average sewer gas temperature, H_2S concentration and humidity conditions are known.

One important finding from this study is that corrosion behavior is very sensitive to sewer gas humidity. Low humidities were found to significantly depress corrosion rates even when H_2S levels were high. The field results also indicate that maintaining the surface pH of sewer walls above pH = 6 (by washing or application of a high pH coating) should prevent pipes from entering the active corrosion phase of the corrosion cycle where mass loss takes place.

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NMR study of salt transport in porous material during steady state wick action

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ABSTRACT

Chloride induced corrosion of steel bars has been an important issue in durability of concrete structures for decades. Chloride from sources such as see water or deicing salt can penetrate into the porous structure of concrete. When chloride concentration in the depth of embedded reinforced bars reaches to critical amount, it starts to damage the protective layer of steel and increase the speed of corrosion of reinforcement bars. To have an insight into salt transport in concrete we have focoused on wick action. Wick action is a situation that structure is permanently exposed to moisture with dissolved salt in one side and drying in open air in the other side. Continues capillary force brings ions faster and builds up high concentration in drying face. As soon as the concentration on drying face reaches to solubility limit ions start to precipitate and eventually crystalize. To Predict the ion profiles evaluation, a model based on advection – diffusion has been designed. A non Fickian's diffusion term based on a lattice gas model has been used. In this case the ion concentration stays limited to the solubility concentration C_s. It is assumed that conditions in wet and dry face stays constant (steady state) and the liquid-vapor interface stays stationary at the drying face. Also the concentration and velocity in inlet has been considered as constant values. In order to evaluate the model set of NMR experiment has been undertaken for sodium chloride transport in lime stone during wick action. The moisture and sodium ions profiles has been measured along the axis of a cylindrical sample within eight days. The Peclet number of the material was 16.9. However the overall comparison of model output and experimental results shows very good agreement on prediction of distribution front moving through the sample, but the ion loos due to precipitation is not predicted in the model.

To add the precipitation term to the initial model, the total concentration of ions which enters to the column (uC_0) has been compared with the slop of the total concentration versus time in the column, the difference is the precipitated part. The precipitation rate defined by Heaviside has been added to the initial model as a sink term. The final model shows very good agreement with the experiment (Fig. 1).

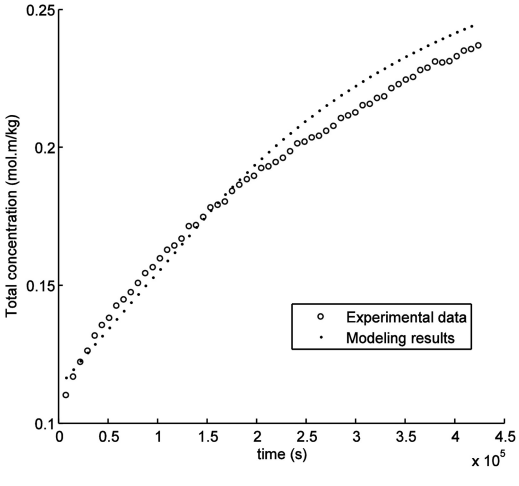


Figure 1. Experiment and model output comparison of the total concentration of sodium ions along the sample versus time.

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Research of tunnel appendage conservation monitoring with MEMS technology

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Atsushi Nishijo & Takashi Kunimi
Akebono Brake Industry Co. Ltd., Japan

Sadao Kimura
Kanazawa Institute of Technology, Japan

1 REQUIREMENT TO MONITORING SYSTEM

A time line is because a protection against disasters action plan from abnormal measure to traffic regulation, urgent check, maintenance, removal and traffic regulation release was related to grace time from abnormal measure to the fall and a time line is considered here, and it's made more certain that a main system possesses the function which stops crash suffering by the user's falling object. Or the system (1) will be a judgement index of the validity of the main system.

$$T1>T2 \quad (1)$$

Time and $T2$ until a target accompaniment falls down abnormal measure put traffic regulation into effect from abnormal measure and check it urgently for $T1$ here or, or a repair, time until correspondence of removal is performed and traffic regulation is released or time to prevent the user regulates urgent passing in the case when exigency is very high, and enters falling object falling plumb down, and passing is a time line.

About 100 illuminators are installed in 1,000 m of road tunnel, so the road management person managing an average of 500 m of 50 tunnel will watch an illuminator of 5,000. When I'm managing a increase lamp, ventilating installation, a cable rack and dissemination of information equipment by entrance illumination as an accompaniment in the tunnel and possess the same fall risk, actual condition becomes more numerous.

We aimed at a business sensor for cars and the communication know-how by this research as the way it was low in cost and to achieve these. A lot of highly precise sensors are installed in the present car focusing on vehicle posture control, and something which are high precision and high durability sensors are offered inexpensively. I also decided to aim at an inclination sensor and a vibration sensor by the MEMS (Micro Electro Mechanical Systems) technology which can be used and excel the reliability and a low price most and check the below as a basic experiment at the inside.



Figure 1. Equipment for experiment.

a) the abnormal measure ability
b) local application properties

And an experimental target is established most as an accompaniment in the tunnel, and when falling, I aim at an illuminator of the road tunnel a trouble makes the user space.

2 RESULT OF EXPERIMENT

The knowledge an experimental result gave is below.

a) I can think the natural frequency which can be put in the installation state of the tunnel illuminator is being vibrated by low frequency oscillation which is about 100 Hz and is caused by passing body of rolling stock than run vibration from a pavement face.
b) there is a possibility that it's possible to catch a natural frequency change by looseness in an attaching portion of a tunnel illuminator from the early stage stage for the vibration sensor used for an experiment.
c) the direction where a change in a mounting bolt is caught sensitively relatively and the insensible direction are judged from the measurement axial direction of a vibration sensor.

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Technical, ecological and economical assessment of welded joints for offshore wind energy plants

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ABSTRACT

Wind energy plants play a decisive role for renewal energy production. Especially offshore constructions imply an engineering challenge during the design and erection process. For a holistic assessment different aspects have to be analyzed. Therefore, in this paper aspects describing the technical performance are combined with ecologic and economic assessments. For the foundation structure of wind energy plants steel tubes with diameters from 219 mm up to 914 mm and three different welding methods are compared with regard to their ecologic and economic impacts.

The investigations show that a precise modelling of the single production steps is necessary to generate meaningful results. Concerning ecological impacts in the impact category global warming potential (GWP), for smaller diameters especially the weld seam preparation is important for the overall results, for larger diameters mainly the welding process of filler layers cause the highest environmental impacts and the highest costs. If the functional unit is chosen as shown in Figure 1 a good comparability of all tube diameters from 219 up to 914 mm can be found for the welding method MAG.

When comparing the results with data in the database ecoinvent 3.1 a difference of 350% arises by which the results calculated are higher compared to existing benchmarks. It can be assumed that the ecoinvent data are not integrating all necessary process steps which is explainable because for thinner plate thicknesses only the welding process itself is normally balanced and preparatory and subsequent works play a considerable minor role. Therefore, for offshore specific tube dimensions it is important to perform a comprehensive process step analysis and to considers all of them within the assessment.

The economic analyses show that especially labor costs are dominating the overall result with a share of 71 to 84%. The different process steps during the weld manufacturing lead to different shares depending on the tube diameter again. For higher diameters the welding of the filler and cap layers are responsible for over 70% of the accruing costs.

Regarding the technical performance of the welds analyzed particularly the fatigue behavior is investigated. In total 45 large scale fatigue tests have been conducted. Nominal stresses are established at the location of failure at the inside of the pipes. Concerning the fatigue strength (FAT class) $\Delta\sigma_c$ at $2 \cdot 10^6$ cycles. The evaluation of the results leads to a fatigue strength of approximately 78 MPa at $2 \cdot 10^6$ cycles for girth welded joints. Therefore, a classification of FAT 71 yields to an appropriate and sound estimation for fatigue design of tubular girth welds. Indications of a required reduction of fatigue strength for an increased wall thickness could not be determined for the tested specimens of position 1 and 2 with maximum wall thickness of 25.4 mm and 43.6 mm.

The holistic assessment on the detail level of single girth welds can help to provide information on the structural level. As a result, the assessment quality of a complete wind energy structure can be improved.

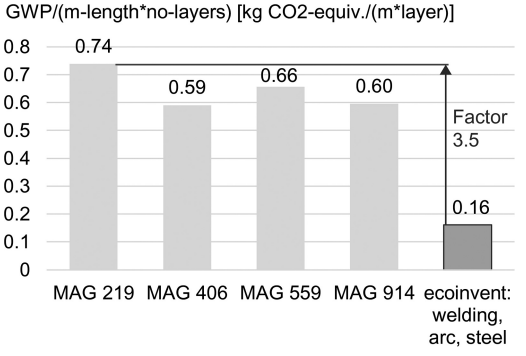


Figure 1. Comparision of calculated environmental impacts for four tube diameters with welding processes in the database ecoinvent, version 3.1.

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Wetting and drying cycles with NaCl solution in model microchannels to understand chloride ion transport in concrete

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ABSTRACT

Microchannels were used to study how chloride ions move under cyclic wetting and drying. Each channel was 500 μ m wide, 200 μ m deep and 180 mm long with an inlet and outlet. Sodium chloride (NaCl) solution was introduced to the channels and allowed to dry. Crystals precipitated at the inlets and outlets. Some channels were plugged by the precipitated crystals, thereby preventing evaporation (Fig. 1).

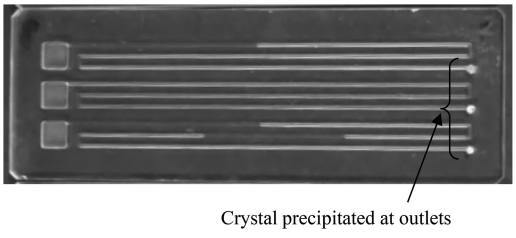


Figure 1. Precipitation of sodium chloride in micro channels.

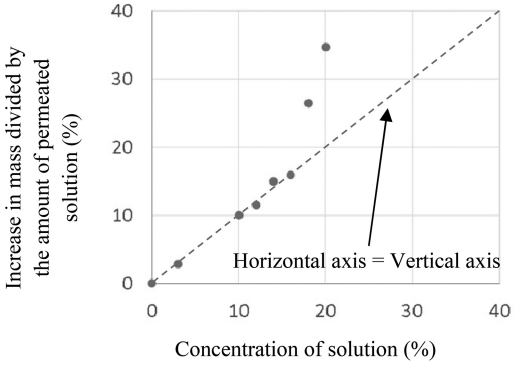


Figure 2. Mass increase of pumice as a function of solution concentration.

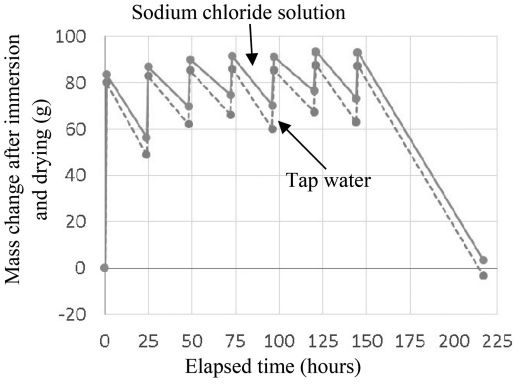


Figure 3. Mass change after immersion in tap water or sodium chloride solution and drying.

To investigate if plugging occurs in porous materials, pumices and hardened cement pastes (HCPs) were im-mersed in NaCl solution and dried. Pumices immersed in sodium chloride solutions of equal to or greater than 18% concentration increased their masses of precipitated salts more than the calculated amount. The pumice immersed in the solution having a 20% concentration was covered with thick layer of precipitated salt after drying, indicating that the salt blocked the evaporation of the solution remaining inside (Fig. 2). HCP specimen immersed in a sodium chloride solution showed less of an increase in mass following immersion and less of a decrease in mass following drying, compared to the HCP specimen immersed in tap water (Fig. 3), likely due to blocking of the pores by precipitated salts. The calculated concentration of the sodium chloride solution in HCP increased from 3% to 7.3% after 7 cycles of immersion and drying.

MS8: Construction in the context sustainable development

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Complete retrofitting solutions of precast concrete panel buildings using lightweight steel systems

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ABSTRACT

In an increasingly developing world, in which sustainability has become not only an option but rather a demand, building adaptation or retrofitting has become an activity that continues to make a significant contribution to the workload of the construction industry (Douglas 2006). Moreover, besides over-cladding of existing buildings, the over-roofing occupies a significant part in this modernization scheme (Lawson 2008). The paper presents an integrated refurbishing solution, which combines the idea of implementing highly industrialized over-roofing systems using cold-formed steel profiles with an integrated over-cladding system for complete renovation (see Figure 1) (Dubina et al. 2001, Di Lorenzo et al. 2010).

A structural analysis and design was performed on a common precast concrete panel block typology 744R. This type of structures, built in Romania in the 1960–1990 period, present a series of deficiencies, including lack of space and thermal discomfort.

The retrofitting solution includes two actions:

- building over-roofing in order to enlarge the habitable area;
- over-cladding, in order to improve the thermal performances of the building and to give an aesthetical design of the building.

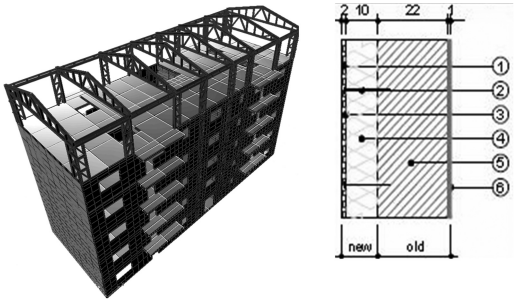


Figure 1. 3D view of representative common block typology 744R and example of uniform over-cladding (rock-wool).

In order to have an uniform finishing of the wall system, three solutions were analyzed, all of them adaptable to both the original concrete and the over-roofing steel structures: (i) polystyrene finished by plastering, (ii) rock-wool finished by decorative bricks and (iii) mineral wool included in sandwich panels.

The sustainability analysis of solutions rely on three pillars: safety and thermal comfort accounts for the social pillar, the integrated costs are directly linked to the economical pillar while the environmental impact represents the environmental pillar.

Considering the sustainability approach, for similar thermal pre-requisites ($R > 2.5$ m^{2}K/W), the third solution in sandwich panels proved the best performances in both environmental impact and price evaluation. This system is highly industrialized conducting to minimum man-power and loses on site.

In all three cases, the major environmental impact is due to the thermal insulation layers as compared to finishing layers and fixing components.

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Desire for quantitative information in a qualitative information context: Induction of sustainable development via decision making in real estate and construction

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ABSTRACT

Sustainable development has become the regulative goal in the EU and is about to be sanctioned. This means that real estate and construction activities shall induce sustainable development, if not – this has to be seen as risk on real estate. Sustainable construction and the contribution of construction to *sustainable development* are highlighted first. On this base, aspects are identified where the current concept of sustainable construction falls short in meeting the demands of sustainable development. Inducing sustainable development by real estate means to take into account construction activity and property investment. This means, to integrate quantitative and qualitative information. An interdisciplinary approach connects environmental sciences with construction sciences using a social scientific method. The ownership and tenancy conditions influence the adaption of conditions and conception of the real estate product. Given the practical context of real estate, the Brunsvician Lens serves as scientific method within case study research. This allows assessing a multi-disciplinary context. Processes are systematically linked to the identified demanding aspects for sustainable development. Both, real estate and construction result in a building, but hardly anybody is fluent in both languages. Therefore, a model based view is described to systematically link information flows, using existing control channels for information support. The model is in a further step developed as expert model for the separability of construction, to create databanks and to define relevant scarcities in the context of resource efficiency. This information can be used for a material pass. The material pass aims at management of material flow by environmental impact due to efficient material use. Material is described by a material related performance (resource performance). As tool for analysis, the material pass is able to reach environmental relevant material characteristics as well as functional information on construction. Components of a material pass are derived by analysis of organizational problems whilst documentation in planning and construction processes. The main challenge is, to link quantitative (material characteristics and data location) and qualitative (importance) information (Ott and Hausmann 2014). Objective is the development of a resource inventory of structures which is at the same time simple to understand but sufficient precise for everyday practice. Resource inventory should serve as basis for data collection, use and documentation.

Key findings are: A homogenous integration of the trifold demands of sustainable development needs the integration of information generated in construction management processes and information on real estate development and economics. Next, responsibility must be taken and given personally. Further, economic aspects need to include life cycle costs along the building life cycle to be able to assess sustainable development. This supports to keep an eye on technical quality. Then, regulation should use existing control channels to be efficient. Therefore, a model based view on information steps beyond the classic structures of real estate and construction as abbasis for strategic management in any real estate context.

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Development of a ranking algorithm for the green building attributes – A case of Indian cities

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ABSTRACT

The density of the buildings in Indian cities has become higher and higher due to the social and economic evolution. It will make a great impact on the ecological environment leading to the climatic changes, deteriorating weather conditions, depletion of resources, and lowering down of public hygiene. For sustainable building constructions, it is important to avoid construction methods which negatively affects the environment and results in increasing the pollution. Therefore, the green building becomes a significant factor. This study evaluates the green building attributes by entropy method and ranks them as per their impact on the environment. The ranking is performed by a procedure based on the Technique for Order Preference by Similarity to Ideal Solution. Based on the analysis, the study finds out five prominent attributes in green building rating system for India. These are indoor air quality; water recycles, and the cost of investment, daylight, and water pollution.

India is the seventh largest country in the world. It has a leading economy, and it is home to over one billion people living in various climatic zones. Rapid urbanization has resulted in environmental degradation caused by increased pressures on the limited land available, leading to a reduction in open spaces, increased air and water pollution, and problems of waste disposal and its management. Various climatic changes pose additional stresses on the environment. The green building has high-efficiency in the use and consumption of natural resources, water, energy, and materials that are used throughout building's life- cycle i.e. design, construction, operation, maintenance, renovation, and demolition. Green building practices can substantially reduce negative environmental impacts. So in this study the 24 significant green building attribute are shortlisted based on stakeholder's judgement and ranking is done. Ranking of the attribute has been done by Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), a ranking multi-criteria decision-making method (MCDM) based on their overall sustainable performance. This method considers three types of attributes as cost attributes, quantitative benefit attributes and qualitative benefit attributes.

RESULTS

The weight of 24 green attributes is calculated by entropy and result of 10 attributes is as shown in Table 1. Renewable energy got the highest weight followed by daylight, BIM, water efficient landscaping and Occupant's health and safety. However ranking by TOPSIS is indoor air quality, water recycle, cost of investment, daylight and water pollution.

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Economic, environmental and social cost-benefit analysis of road construction works

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ABSTRACT

Decisions, in particular by governments, are increasingly supported by support tools like social cost-benefit analysis (SCBA) (Damigos 2006). SCBAs have been proven to be an effective way to evaluate projects involving a large number of aspects that can be monetized (Mouter et al. 2013; Mouter et al. 2015). The application of SCBA as a sustainability assessment for maintenance decisions on infrastructural works are seldom found.

In this contribution a social cost-benefit analysis tool for asphalt structures on steel bridges is presented that enables decision makers to choose between different maintenance options. Asphalt structures on steel bridges require regular replacement. This causes hindrances for traffic flow and the can have environmental and health impacts due to material and energy use. The developed tool includes the calculation of direct costs, external costs such as environmental costs related to construction materials and processes, and external costs caused by reduced availability of the bridge during construction works. Material properties as well as maintenance cycles can be included in the assessment. The tool supports the selection of the combination of materials and processes with the least direct, social and environmental costs.

To illustrate the function of the tool, the Merwede Bridge in The Netherlands is analysed. A reference scenario is compared with an alternative scenario with other asphalt structures. The result of the comparison is shown in Figure 1. The figure reveals differences between the scenarios, between the layers and between the cost categories (direct economic, external environmental and external traffic hindrance costs).

The results show that replacement of materials with longer lifetimes can have economic as well as environmental and traffic benefits.

The developed tool is suitable for bridges on motorways in the Netherlands and can be used to choose the optimal pavement solution in case of maintenance decisions for specific steel bridges, but it can be expanded to other countries and applications. The dominance insights which are obtained with this tool can support further development and optimization for pavement solutions.

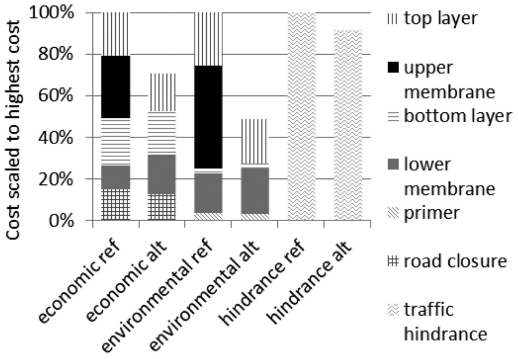


Figure 1. Comparison of economic, environmental and traffic hindrance costs for the reference (ref) and alternative (alt) asphalt structure. For each cost category the results are scaled to the scenario with the highest costs. Contribution of separate layers to the economic and environmental costs is also shown.

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Effect of transportation distance, energy mix and allocation of fly ash on the life-cycle assessment of concrete

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ABSTRACT

Comparative life-cycle assessment (LCA) of concrete containing fly ash was carried out and sensitivity analysis of the transportation, energy mix and allocation was conducted in order to ascertain the viability of competing options. The environmental effect of the concrete was measured using four impact categories, namely; Global Warming, Acidification, Water Depletion and Resource Depletion.

The environmental benefits of using fly ash stems from both the repurposing of a waste product, and the replacement of cement content in a given concrete mix design. O'Brien, Menache & O'Moore (2009) have shown that replacing cement with fly ash is environmentally beneficial from a greenhouse gas emissions perspective even when very large transportation distances are required. Traditionally, upstream energy, raw materials, and emissions are not included in this process, which is a common conservative assumption.

The distance that the fly ash has to travel, the energy grid mixture used in its processing and the allocation of the supplementary cementing materials (SCMs) affect its environmental impact. Electricity grid modelling is of special concern in LCA (Curran, Mann, & Norris, 2005), due to its ubiquity across industries and its potential for contributing significantly to environmental impact results. The electricity supply mix is dictated by a multitude of factors including available resources, economic market forces, and policy directives, all of which have the potential to change significantly over time. The Ontario energy landscape has changed dramatically, partly as a result of: i) the government mandate to shut down all coal burning power plants, ii) a change in nuclear power capacity, and iii) the growing importance of renewable energy technologies. This study examines the sensitivity of changing electricity grid mix in the province of Ontario from the year 2010 to 2014 and projected 2025 supply mix on LCA results.

This study also examines the effect of fly ash allocation by four approaches, subdivision method, system expansion method, mass allocation method and economic allocation method. This consideration is necessary because coal combustion is an example of a multifunctional process as it is a single process which produces both electricity and fly ash.

Key outcomes from this research are:

- Compared to the Baseline (no allocation) scenario, when the Disposal Avoidance Allocation approach is applied, the change in environmental performance is essentially negligible (∼0%).
- Changes in environmental performance of the overall concrete life cycle are more significant (∼5% and ∼10%, respectively) when the Baseline (no allocation) scenario, is compared to the Economic Allocation and Mass Allocation approaches. This study reveals that this is contradicts the assumption that the relative environmental impact of fly ash processes in concrete LCA is expected to be small.
- In this study electricity processes accounted for approximately 40-80% of the LCIA results in a given impact category and year.

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Effects of different reference study periods of various buildings on material input and global warming potential

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ABSTRACT

The new European standards EN 15978 (2012) for assessment of environmental performance of buildings and EN 15804 (2014) for environmental product declarations do not provide explicit data for the Reference Study Period (RSP) of buildings and Reference Service Life (RSL) of building products, which are influential parameters on life cycle assessment (LCA) results. Consequently, LCA studies of buildings are performed with arbitrary RSPs and RSLs, depending on the author's professional and geographical background. These discrepancies contributes to inconsistent LCA results in the building sector. Especially in building assessments time-related characteristics play a significant role, since components require maintenance, repair and replacement over the buildings use stage.

This study analyzes the EN standard 15978 (2012) concerning time-related characteristics and its scope of interpretation. On this normative base building LCAs are calculated focusing the building's use stage (module B) and the effects of different RSPs. Life cycle assessments of residential buildings of different sizes and construction materials according to the method of EN 15978 (2012) are performed over RSPs of 30, 50, 80 and 100 years. For the RSL of building products the specifications of the German Assessment System for Sustainable Building (BNB) (last updated in 2011) and the Guideline Sustainable Building (2001) are applied (BMUB 2011, BBR 2001). The buildings are analyzed with regard to the input of building material masses and the associated global warming potential (GWP) as one of the most researched indicators in LCA calculations. All construction material and technical equipment required over the RSP was considered. The results were assessed by the functional unit of one m^2 gross external area (GEA) and one m^2 GEA for one year of the RSP. LCA calculations were performed with the LCA-tool LEGEP that bases on the German open-source database Oekobau.dat 2011.

In summary the analysis show that the LCA results for a building depend on the RSP and the number of replacement of replaceable building components over the building's use stage. Generally speaking, the longer a building is used the less material input and the less GWP emissions over its functional unit of one m^2 of GEA for one year of the RSP are accrued. The impacts relate to the number of replacement of a building product within its RSP, which is determined by the RSL of the building product. In this respect, the influence of technical equipment does not change significantly over different RSPs. The results of the performed LCAs in this study point out the demand for clear specifications of time-related parameters to achieve comparability of building LCAs. In this context the normative handling of temporary buildings with short use stages should also be discussed.

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Efficiency assessment of various solutions for the thermal rehabilitation of multi-storey buildings

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ABSTRACT

The topic brings to the fore an important concern in Europe: increasing energy efficiency in construction sector by thermal rehabilitating the existing building stock as the existing building stock represents a significant potential for decarbonizing the atmosphere. The European residential buildings stock represents 75% of the total building heritage from which a substantial percentage was built before 1990, having serious energy performance problems.

In Romania, for the apartment blocks built between 1940 and 1989, the thermal transmittance of the vertical envelope elements ranges between 1.25 and 2.00 W/m^2K and the thermal transmittance of the horizontal envelope elements ranges between 0.90 and 1.80 W/m^2K, therefore they have a very poor energy performance compared to current requirements. Consequently, the thermal rehabilitation of the apartment blocks has gained momentum, especially due to the fact that these interventions are financed by national rehabilitation programs and also through "Renovating Romania" collaboration between Romanian Government and BPIE. Because the program provides only partial financial support, in many cases the thermal rehabilitation is regarding only the thermal renovation of the envelope elements, ignoring the building's services. In this context, the present paper presents the possibilities of thermal rehabilitating the buildings envelope so as to achieve a high level of energy efficiency considering only the envelope thermal rehabilitation, but also to maintain a significant level of financial efficiency. The case study is a multi-storey collective building with bearing structure of large precast concrete panels from Timisoara erected after the 770-IPCT standard project in 1978 and currently requires thermal rehabilitation. Seven thermal rehabilitation solutions are presented using mineral wool with different thickness for exterior walls and expanded polystyrene for floor above the basement and floor above last level. Also, the replacement of old windows and exterior doors is considered for some solutions.

It is noted that for a thickness of up to 200 mm of mineral wool for the exterior walls, a thickness of up to 300 mm of polystyrene for the terrace floor and a thickness of up to 250 mm of polystyrene for the floor over the basement floor, the energy performance is significantly increased and the financial investment is justified. For greater thicknesses of insulating layers, financial investment is not justified nor does the energy efficiency, as heat losses through building envelope represent a small percentage compared to the ventilation losses of the total heat losses.

The economic impact of all proposed thermal rehabilitation solutions is assessed through a life cycle cost evaluation.

As a final conclusion, the study demonstrates that from both energetic and financial point of view, excessive increase of the thermal insulation layer thickness, it is not efficient, if the thermal rehabilitation solutions do not consider the building's services.

ACKNOWLEDGEMENT

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LCA of different construction types depending on the building class

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ABSTRACT

The construction sector is one of the major sources of environmental pollution. As the energy and resource consumption during building operation is declining, the influence of the construction and end of life phases on the overall consumption during the life cycle of a building is increasing. Hence, finding an ecological construction while still meeting all structural and functional requirements is crucial for reducing the environmental impact. An increasing demand for high-rise wooden buildings (Brunner & Humm, 2012, Holzforschung München, 2010), indicates a trend towards ecological construction made of renewable materials. For multi-level timber buildings the German fire protection requirements are high and demand the use of several materials for fire protection (e.g. gypsum board). From this background the aim of this study was to determine which construction type is ecologically the most beneficial for residential buildings with respect to the building size. To answer this question, the primary energy (PE) demand and global warming potential (GWP) over the entire life cycle were calculated based on German LCA data for five sample buildings, each representing a different building class according to the German model building code (Bauministerkonferenz, 2012). A functionally equivalent component catalog with regards to structural design, fire, sound, heat and moisture protection was developed for a brick, sand-lime brick, reinforced concrete, wooden frame, solid wood and steel construction for each sample building. The interpretation was conducted considering the overall results, the influence of each component and of the fire protection measures depending on the construction type and the building class. The sensitivity of the results was analyzed regarding the functional unit, the considered LCA life span and the assumptions for the end of life stage.

The study shows that both timber construction types consume less non-renewable PE and cause a significantly lower GWP than the other designs, but with a narrowing gap in the higher building classes. In the building classes 1 to 3, the wooden designs cause about 50% of the non-renewable PE demand and 30% to 40% of the GWP of the other construction types, in building classes 4 and 5 60% to 70% and 50% respectively. The non-renewable PE demand of the solid and steel constructions are of the same order of magnitude. Regarding the GWP the steel construction achieves a reduction of 10% to 30% in comparison to the solid types. The biggest differences between the various construction designs are caused by the components floors, with an increasing influence with the building class, and exterior wall, with a decreasing influence. The fire protection measures are relevant, especially in the wooden construction types in building class 4 and 5 with a proportion of 15 to 20% of the total environmental impact. The sensitivity analyses confirm the favorable trends of the timber designs, especially in terms of GWP. The results of the steel construction react most sensitively with a disadvantageous tendency. According to the results of this research both wooden constructions are environmentally recommendable in each building class. Alternatively, the steel constructions show a certain potential, especially in terms of GWP. The influence of the building class on the ranking of the three groups of construction types – solid, timber and steel – according to their environmental impact is rather low.

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Life cycle assessment of mortars and concretes with recycled construction and demolition wastes

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ABSTRACT

The increasing demand for infrastructure and construction works generates high consumption of building materials, especially concrete. The high CO_2 emissions of cement and other environmental impacts of concrete life cycle has encouraged the development of more sustainable concretes. Among alternatives, there are cement and aggregates partial replacement for recycled construction and demolition wastes (CDW).

The aim of this study was to assess the environmental performance of the mortars of Gonçalves (2005) with 10% and 20% of their cement content replaced by grinded calcined-clay brick waste (GCCCBW) and the concretes of Amario (2015) with 40% of natural coarse aggregates replaced by recycled concrete aggregates, with 25 MPa, 45 MPa and 65 MPa.

The Life Cycle Assessment (LCA) approach, established by ISO 14.040 and 14.044 standards, was used. SimaPro® was utilized to perform the necessary calculations related to the environmental impacts of these products and the CML-IA was the chosen life cycle impact assessment methodology. The environmental impact categories analyzed were: global warming potential (GWP100), ozone layer depletion (ODP), photochemical oxidation (POCP), acidification (AP) and eutrophication (EP).

The outcomes showed that the durability advantages induced by the GCCCBW content led to average reductions in all environmental impact categories relative to the ordinary mortar (ORM) from 37%, when 10% of the cement content is replaced (CWM-1) to 81%, with 20% of cement replaced (CWM-2).

However, because the lower life expectations of recycled aggregate concretes (RAC), the substitution of 40% of the natural coarse aggregates by recycled concrete aggregates led to increases of about 30% in all the environmental impact categories, relative to natural aggregates concretes (NAC).

It can be concluded that, for the conditions adopted in this study, the use of grinded ceramic waste for partial substitution of cement is promising. Environmentally, the use of recycled concrete aggregate is not advantageous for structural purposes. However, it can present some benefits (because of the disposal space savings), if used for non-structural purposes, like road sub-basement.

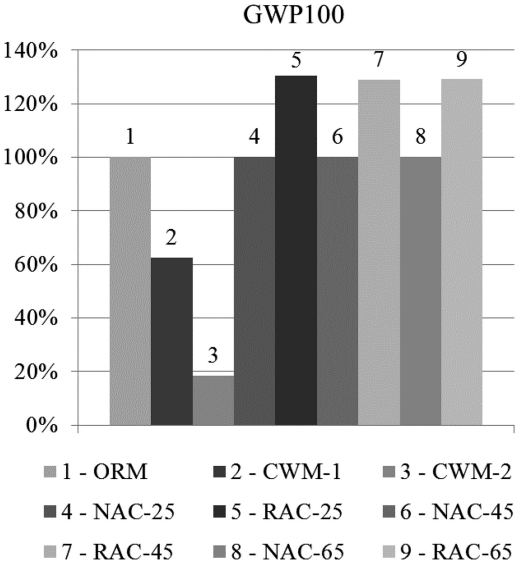


Figure 1. Relative global warming potential of mixtures with 1 MPa compressive strength at 28 days and 1 year life span.

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Life cycle engineering for roads (LCE4ROADS), the new sustainability certification system for roads from the LCE4ROADS FP7 project

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ABSTRACT

There are many initiatives in the market capable to assess some aspects of sustainability for roads (mainly environmental): the Americans: Greenroads Certification System, Envision Certification System and The Invest sustainability tool, Ceequal in UK as a Sustainability assessment, rating and awards scheme for civil engineering or many tools to evaluate CO2 and Carbon Footprint (the most important and already implemented: the Dutch CO2 Performance Ladder), but none capable to asses sustainability as a whole.

The EC by means of the Joint Research Centre (DG-JRC) is developing the Green Public Procurement Criteria (GPP) for design construction and maintenance of roads and considers systems like the ones mentioned, as useful for the pre-selection criteria for contractors and to ensure compliance of performance, so JRC considers this type of systems and methodologies as useful to support the GPP process.

This paper summarizes the new sustainability certification system for roads named "LCE4ROADS", under development as part of the FP7 LCE4ROADS project: "Life Cycle Engineering approach to develop a novel EU-harmonized sustainability certification system for cost-effective, safer and greener road infrastructures"

LCE4ROADS will integrate by a Life Cycle Engineering (LCE) approach, all the aspects of sustainability (Environmental, Economic, Social, Technical) to asses roads projects and works (both new construction and rehabilitation/maintenance) with the final goal of creating a holistic and EU-harmonized methodology to increase the sustainability of future and to be rehabilitated roads.

The certification system developed is based on current EN and ISO standards for sustainability in construction (EN15804) and LCA and LCC (ISO 14040-44 and ISO15686) and considers previous developments from other research projects like MIRAVEC, EVITA, COST 354 among others.

Key aspects at European level like the adaptation and resilience to Climate Change and the implementation of freight corridors (the so called TEN-T: Trans European Transport Network) will be considered in this new certification system.

With the goal of refining the certification system and the parameters and key performance indicators to be considered, it should be mentioned that LCE4ROADS has been already presented to different key stakeholders such as:

- National and Regional Road Authorities in six EU countries (France, The Netherlands, Spain, Germany, Sweden, Poland) and in Turkey (The Turkish Ministry of Transport (KGM) is partner of the FP7 Project).
- The European Commission (DG Research, DG Environment, DG JRC, and DG Move-Transport)
- Sectorial Platforms and Associations like the European Committee for Standardization (CEN), The European Road Federation (ERF), the Spanish Construction Technology Platform (mirror of the European ECTP) among others.

The US Federal Highway Administration (FHWA) is also interested in this topic and is working closely to the FP7 project team (the EC selected the project to collaborate with the most important transport research center in America).

The feedback received for future implementation from the key stakeholders has been taken into consideration to modify the scope of the certification system, the phases covered and the certification moments.

This system, together with a guide for application and a mullti-criteria software tool to be developed could be really useful for future procurement and GPP processes in Europe.

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From LCA to LCC in infrastructure: Reducing CO_2 emissions in infrastructure

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ABSTRACT

This paper shows the struggle of man with applying different construction materials to different types of civil structures. Especially the recent development is highlighted of using a new material, fibre reinforced polymer (FRP) as construction material in infrastructures. The question always is: how can we come to our goal on a cost effective way? Life cycle analysis is too limited and life cycle cost is nowadays a rather good comparison method to use. The challenge is how we optimize the use of materials, planet and costs.

What materials are concerned, the material fibre reinforced polymer (composite) from LCA is the highest in comparison to the traditional materials wood, steel and concrete. However, this is very dependent on the type of construction, parameters, structural demands and way of engineering. Note that FRP does not necessarily have the highest environmental impact! In infrastructure it is essential not only to look at Life Cycle Analysis but at Life Cycle Cost as well. As seen with the small bridges FRP bridges can be the best choice.

Although the LCA is a used form of "uniform-database", the LCA in 2015 is different than the LCA in 2011. In all discussions about LCA it is useful to have a scientifically proven uniform LCAdatabase at our disposal, which can be the foundation for every LCA-instrument like Dubocalc. Hopefully it is going to happen in 2016. A uniform database can be the foundation for environmental statements of materials and products in infrastructure. However, it's the difficulty with materials that there is a difference in the usage of LCA.

New materials and new products like FRP need a time to develop in order to become a generally accepted new product. For instance, there is an enormous difference in costs between 2011 and 2015.

Nowadays composite is more used and there are more suppliers. The other benefits of composite are helpful as well. The benefits are for instance: less maintenance, reduction of construction time, reducing nuisance and the fact that it needs less inspection. With every new project we will advise each time to make a new decision on which material to use.

For every material there is the cradle to cradle challenge: extension of the life cycle by reusing the released products and materials. Nowadays there is a positive development in looking for alternative ways to use materials in constructions. However, we need to be careful with this development, because there is the possibility that when we are only thinking of a durable planet when we are designing and building our constructions, there is the danger that we might get a lesser technical and economic lifespan as a consequence. We need a durable planet as well as a durable technical construction for the infrastructure in a liveable and accessible city.

The present challenge for engineers and deciders in projects is to find an optimum between structural possibilities, planet and cost. So the outcome of the study and practical experience of the Rotterdam small bridges can now be used in the further developments of the Rotterdam quay walls.

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Sensitivity of bridge life-cycle costs and sustainability measures to parameter uncertainty

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ABSTRACT

Sustainable performance of critical infrastructure like bridges under both service loads and extreme events is of growing importance to the society. This performance of a bridge throughout its life-time can be measured in terms of sustainability metrics like embodied energy and carbon dioxide (CO_2) emissions using a life-cycle sustainability analysis (LCS-A) framework, which quantifies life-cycle metrics of performance as an aggregate of various life stages such as the construction, maintenance, hazard exposure and demolition phases (Padgett & Tapia 2013).

To support this quantification of sustainable bridge performance, uncertainties in various input parameters should be acknowledged and accounted for in a risk based assessment. However, the significance of various sources of uncertainties in LCS-A input parameters across different phases of a bridge's life-cycle need to be evaluated for their impact on sustainability metric quantification. In order to address this, sensitivity analysis is carried out in this study to evaluate the effect of input parameter variations on the life-time sustainability measures of a bridge. This variation in input parameters may stem from either differences in problem and site definition, or uncertainty in assumed values of input model parameters. For example, the first set of variable parameters considered can include those that vary across a region, such as the bridge type, deterioration exposure condition, maintenance schedule, rerouting distance, and hazard exposure condition. Sources of uncertainties may, on the other hand, include variation in assumed downtime due to bridge damage, cost estimates for construction, repair, or demolition, or cost per unit volume of material (e.g. (embodied energy /m^3). For many such input parameters, a wide range of values have been reported in the literature (Alcorn 2003, Hammond & Jones 2008).

To account for effects of higher order interactions, a multi-level factorial design coupled with *n*-way analysis of variance (ANOVA), is adopted for the sensitivity analysis. The results of this study show that the maintenance interval, exposure condition for corrosion and the cost per unit volume of material are significant modeling parameters that affect estimation of life-cycle costs and emissions, and require care in definition for LCS-A or require future research to reduce uncertainties propagated in the analysis. The paper also emphasizes the role of maintenance in improving seismic performance of aging bridges and the importance of choosing an optimal maintenance interval to have both a reliable as well as sustainable bridge in a hazard prone region.

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The influence of databases on the Life Cycle Assessment (LCA) of building components – A comparison of databases using three different wall constructions

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ABSTRACT

Life Cycle Assessment (LCA) finds its application in many areas of today's building sector. As a part of building certification systems and environmental product declarations (EPDs) LCA is also used for optimizing product systems. One of its main strengths in this context is its holistic approach, since LCA includes all relevant environmental impacts along the whole life cycle of the product. This broad perspective is at the same time the main advantage and a big limitation.

Calculations of building LCAs are based on extensive databases that deliver datasets for building materials and processes. As there is a need for high quality and validity of these datasets they have to be reviewed thoroughly. Considering the various factors influencing a dataset and the growing influence of LCAs, the following questions arise:

1. Which differences can be found between the main databases for LCAs?
2. How significantly do these differences influence the result?
3. Is the selection of exterior wall types according to LCA results influenced by the selection of the database?

In this paper six databases are compared using the LCA calculation of three different wall constructions as a reference. As environmental indicators, renewable and non-renewable primary energy demand (PERT/PENRT) and Global Warming Potential (GWP_{100}) are chosen.

The results show a trend regarding the GWP. The concrete wall always has the highest, the solid wood always the lowest GWP. This result corresponds to previous studies (Takano et al., 2014; Yokoo, 2013). Besides this trend there are significant differences between the resulting values. Most strikingly, the concrete wall calculated with Ecoinvent does have a GWP up to 60% higher as the concrete wall calculated with the other databases. Within the results for the brick wall, Gabi shows the highest results; up to 130% higher as with the other databases. For the wood wall one major difference is obvious: some databases have negative results. On the other hand, the overall results for the PERT / PENRT do not show a trend.

As one of many levers affecting the results a major difference between ecoinvent and ökobaudat in the method of allocation is identified. As a conclusion the paper underlines the importance of such comparisons and recommends an increasing effort in making the background information of each dataset publicly available.

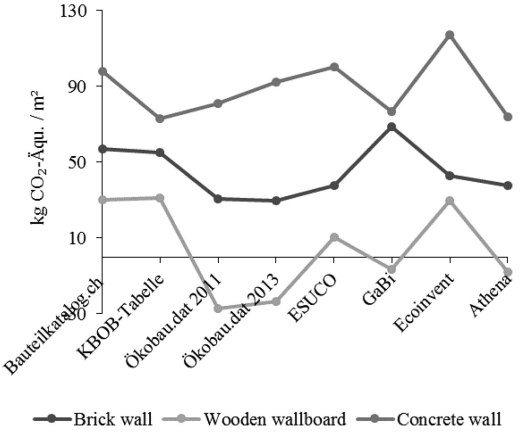


Figure 1. GWP from cradle to gate and EOL.

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Is a stronger building also greener? Influence of seismic design decisions on building life-cycle economic and environmental impacts

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ABSTRACT

This study responds to previously untested recommendations that designing a structure for higher seismic (and/or other forces) is a green design strategy. To do so, we consider the seismic performance and environmental impact of reinforced concrete frame buildings with varying strengths (with respect to the "R factor," a direct design modifier on structural strength), by quantifying CO_2 emissions (embodied carbon), related to seismic design decisions. The study considers eight commercial buildings designed for Los Angeles. The design of these modern four-story office space and perimeter frames is adopted from Haselton et al. (2011). We employ an approach developed in Welsh-Huggins and Liel (2016) to translate damaged components from seismic loss analysis into material volumes for post-earthquake repairs and quantify the subsequent embodied carbon impact.

The results suggest that larger structural members of stronger buildings (above-code designs) lead to higher upfront embodied carbon, whereas manufacturing of smaller structural members for weaker buildings produces less upfront embodied carbon. In terms of post-earthquake impacts, we quantify the expected annual embodied repair cost and embodied carbon from repair activities, based on the probability of exceedance of each hazard level and the dollar or CO_2 emission consequences of shaking intensities at each hazard level (Baker and Cornell 2003).

The results in Figure 1 demonstrate that stronger, above-code buildings have lower annual repair costs and embodied carbon than weaker code-compliant or below-code designs, suggesting that—in terms of annualized impacts—stronger buildings are in fact "greener." Deaggregating these results reveals that at lower hazard levels (*i.e.* more frequent events), stronger buildings experience lower drift and acceleration demands than code-compliant or below-code variants, leading to lower seismic losses and embodied carbon. However, at higher hazard levels, increased stiffness from lower fundamental periods of stronger buildings can increase the influence of nonstructural losses on repair embodied carbon, producing somewhat higher emissions. Certain details differ, but the overall trends are consistent between space and perimeter frames.

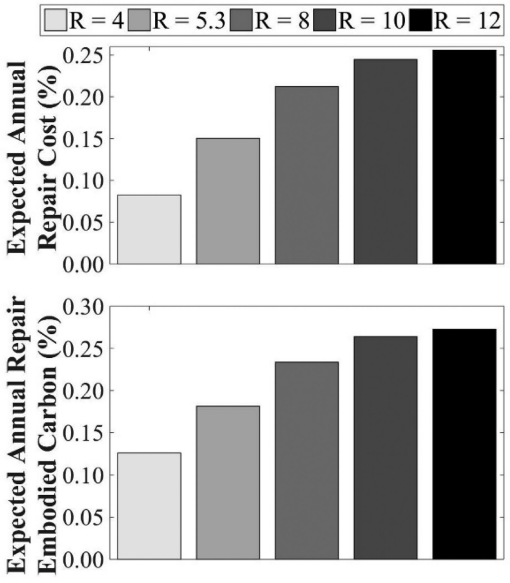


Figure 1. Expected annualized losses for space frames (normalized by replacement cost and replacement embodied carbon; not discounted to present value).

The findings from this study present important tradeoffs for designers to consider with respect to the prioritization of different metrics and their influences on the life-cycle costs of a potential new structure.

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MS9: Modeling time-dependent behavior and deterioration of concrete

Organizers: M. Alnagger, R. Wendner, G. DiLuzio & G. Cusatis



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Degradation modelling based renovation strategy for concrete facades

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ABSTRACT

A vast number of concrete buildings utilizing newly developed prefabrication techniques were built from 1960 to1979. Since then, the durability properties of the concrete building stock from this era have been found to be poor in regard to freeze-thaw action and the corrosion of the reinforcement. This building stock has now reached an age when many of the building components are due to be renovated. Because of the huge volume of this building stock, its renovation is also challenging in terms of resources. This paper combines in-depth studies on the propagation and effects of reinforcement corrosion with discussion on the different strategies of the maintenance of these structures. Studies on the rate and extent of reinforcement corrosion in concrete facade panels were conducted combining the analysis of specific experimental research material gathered from 12 visually corrosion damaged concrete buildings to statistical data gathered from standardized condition investigation reports from 947 buildings and long term corrosion rate measurements on two locations and quantitative weather data from the Finnish Meteorological Institution.

The options available for renovation projects can be divided into (SFS-EN 1504–9): a) do nothing & monitor, b) re-analyse & downgrade in function, c) prevent & reduce further degradation, d) repair & protect, e) replace with new or f) demolish. Another way of classifying the renovation options based on the level of intervention to the structure is (BY 41 2008): a) do nothing, b) preserving renovation, c) altering renovation, d) renewing of the structure, e) special methods.

Modelled average corrosion rate levels caused by the prevailing weather are 0.7–1.4 $\mu A/cm^2$ in inland and 1.0–1.8 $\mu A/cm^2$ in the coastal area. The study suggests that with an average corrosion rate the length of the propagation phase is 4 to 8 years in inland and 3 to 6 years in the coastal area (Fig. 1). This time period may, however, provide just the necessary latitude for the renovation budget. It also illustrates clearly the influence of the delaying of renovation, which will in eventually render lighter repair options not applicable due to increasing degradation.

The strategy for the maintenance and renovation of built assets is closely tied to the business strategy, financial situation and future prospects of the owner. Protective renovation options usually perform best when applied in the initiation phase whereas delaying intervention will force the use of repair/renew options. Furthermore, if the corrosion propagation phase is included in the service life of the structure to some extent it already forces the use of heavier repairs. The knowledge on active corrosion phase will enhance the capability of the owner to utilize the delaying options with more confidence. The choice of intervention must always be made by the owner. A confident choice can only be made based on sufficient assessments and investigations.

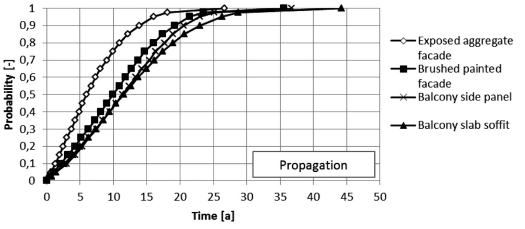


Figure 1. The length of the propagation phase in concrete facades and balconies based on a Monte Carlo simulation.

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Effects of environmental stressors and material properties on life-cycle durability of reinforced concrete structures

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ABSTRACT

The performance and serviceability of reinforced concrete (RC) structures vary during their operational life. This can be due to aging mechanisms, natural hazards or the increase of service loads over time. Therefore, it is important to estimate the extent of deterioration of structures over time and plan for essential maintenance and repair actions in future. Chloride penetration is one of the main reasons of deterioration of RC structure. Penetration of aggressive ions is particularly expected when RC structures are located in marine and tidal zones or when the structures are subjected to deicing salts. The chloride penetration normally results in corrosion initiation and propagation. Among all the models representing the ingress of chloride ions into concrete, the models that include the diffusion and convection terms are the dominant ones. Such models are also capable of taking into account the effects of both internal (e.g., concrete properties and diffusion characteristic), and external (e.g., ambient temperature and relative humidity) parameters.

A review of the existing literature indicates that the time-dependent effects of environmental stressors and material properties on the extent of chloride penetration are critical. In the current paper, the chloride penetration mechanism is introduced and the chloride concentration at different depths of RC structures is predicted through the finite-element models that capture the effects of temperature, humidity, carbonation, and exposure to chloride ions. For this purpose, heat transfer, moisture transport, carbonation process, and chloride penetration are modeled by a set of partial differential equations. The changes in the chloride profile are obtained under the variation of different parameters, including surface chloride, diffusion coefficient, temperature, and humidity. The variations are caused because of geographical location, seasonal change, and concrete mixture properties. By a detailed investigation of the observed variations, the current study is expected to help the engineers and decision makers improve the efficiency of maintenance and repair actions through a reliable prediction of the condition state of RC structures during the expected life cycle.

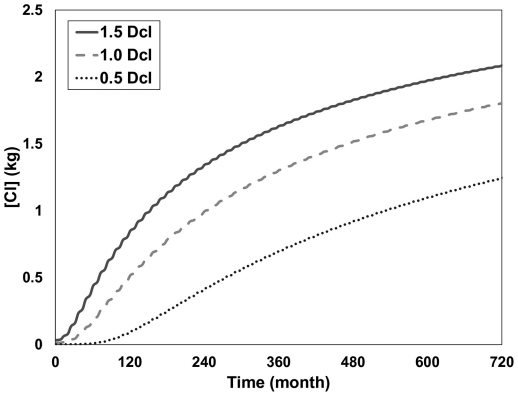


Figure 1. Effect of chloride diffusion coefficient on the chloride content at the rebar level.

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Finite element modeling of concrete cover cracking due to non-uniform corrosion of reinforcement

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ABSTRACT

Chloride-induced corrosion of the reinforcement is identified as the main cause of deterioration of reinforced concrete structures. Steel corrosion in reinforced concrete structures can lead to cracking of concrete cover due to accumulation of corrosion products. In this study, a finite element model is developed to study crack propagation in concrete as corrosion progresses, in which two neighboring longitudinal reinforcing bars are embedded in the concrete, and three basic parameters, such as the concrete cover thickness, the rebar diameter and the rebar spacing are considered in the model. Non-uniform radial displacement with a half ellipse shape is adopted to describe the expansion distribution of the corrosion products. The failure pattern and the corrosion pressure of cover concrete, and the critical corrosion level when the cover concrete cracks due to non-uniform corrosion expansion are studied based on the damaged plasticity model. The comparison of the simulation results with the available test results shows fairly good agreement. Moreover, the influences of concrete cover thickness, rebar diameter and rebar spacing, on the failure pattern and the corrosion level are examined.

Keywords: Chloride-induced corrosion; finite element method; non-uniform corrosion; concrete cover cracking;

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Markov chain modelling for life-cycle performance assessment of coastal flood defences

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ABSTRACT

Management and maintenance of coastal defence structures during the expected life cycle have become a real challenge for decision makers and engineers. Rising sea level and increase in hydraulic forces on coastal defences will result higher performance deterioration and structural failure rates. The deterioration process of coastal defence structures may be accelerated by sea level rise, which lead to a signifi-cant reduction in structure's resistance. Structural deterioration caused by erosion and settlement of coastal defences such as earth dykes has continuous increments. Therefore a stochastic modelling such as the Markov chain is an effective tool to evaluate the performance of the structure (Mehrabani and Chen 2016).

This paper presents a probabilistic method for predicting future performance deterioration of coastal flood defence structures based on deterioration curves estimated by expert judgement. The deterioration process of the structure related to the transition states is modelled according to Markov chain process, and a reliability-based approach is used to estimate the probability of structural failure.

Visual inspection data according to the Condition Assessment Manual (Environment Agency 2006) are used to obtain the condition grade of the coastal flood defences in order to develop transition probabilities through non-linear regression optimisation process. Figure 1 shows an example of a deterioration curve which is used for transition probability calculation. The Monte Carlo simulations are then used to evaluate the future performance of the structure on the basis of the estimated transition probabilities. Finally, a numerical example is given to demonstrate the applicability of the proposed method. Results show that the proposed method can provide an effective predictive model for available condition grading data. The proposed model also provides useful information on time-dependent probability of failure of the coastal flood defences.

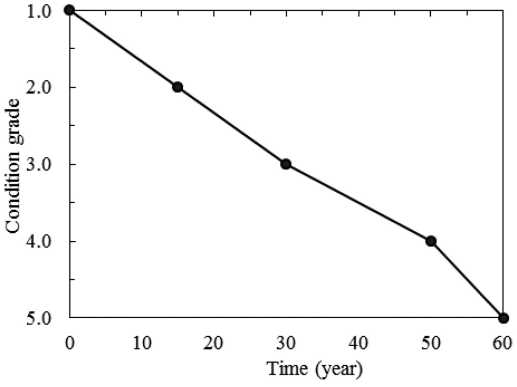


Figure 1. Deterioration curve for sea earth dykes within varying core material and medium rate deterioration (Halcrow Group 2013).

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Non-destructive measurements of ^{1}H, ^{23}Na and ^{35}Cl profiles in cementitious materials with NMR

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ABSTRACT

It is widely acknowledged that chloride-induced corrosion is one of the main degradation mechanisms in civil structures based on reinforced concrete. Gaining insight into the transport phenomena can improve the assessment of durability aspects of existing structures. At the moment there is lack of experimental data on this topic that can be used to validate or discredit the wide range of models available in literature. While such models might be correct, erroneous input is bound to lead to false predictions (i.e., the garbage in, garbage out principle). Nowadays there is a wide range of non-destructive techniques available. While most of these methods are able to detect chloride content non-destructively, none of them are able to measure moisture and ion transport simultaneously. For research a method that can measure combined moisture and ion profiles with high accuracy and high temporal and spatial resolution would be desired as to verify transport models. Using a specially designed Nuclear Magnetic Resonance (NMR) setup quasi-simultaneously the ^{1}H, ^{23}Na and ^{35}Cl content can be measured in cementitious materials. As the gyromagnetic ratio of the selected nuclei is too far apart to be combined into one insert we have opted to use the main field of a 1.5T whole body MRI system (Philips Intera). The sensitivity of the current setup is sufficient to monitor the intrusion of seawater in cementitious materials. The relaxation of ^{1}H, ^{23}Na and ^{35}Cl can be used to obtain pore-size information, and thereby information on the pore-ion concentration distribution during transport Moreover the setup has shown that by multi nuclei measurements more insight could be gained on interactions with the cement matrix during hydration of cement with a 4m NaCl soution. In Figure 1 we have plotted the total measured free ^{35}Cl as a function the total measured free ^{23}Na. Initially after the hydration starts, the ^{23}Na content immediately decreases, whereas the ^{35}Cl content remains almost constant. This shows an interaction with the cement paste where there is an exchange of ^{23}Na, and some other ion must come free. After some time the situation stabilizes and the $^{23}Na/^{35}Cl$ ratio becomes almost constant is constant while the ^{23}Na concentration decreases. This shows that there is a complex exchange of ions during the hydration, which can be studied by NMR

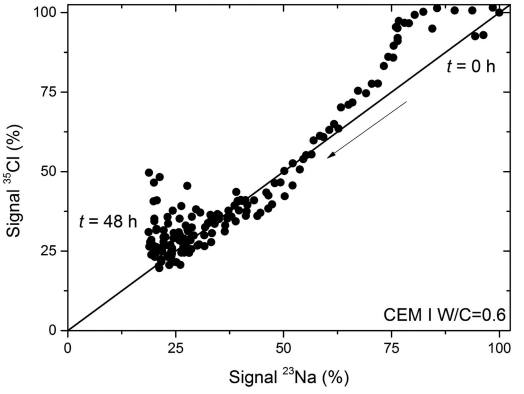


Figure 1. The total measured free ^{35}Cl as a function the total measured free ^{23}Na in a hydrating CEM I paste during the first 48 hours. Portland CEM I was made with a water-to-cement ratio of 0.6 using 4 m NaCl solution.

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Performance predictions based on coupled chemo-mechanical simulations

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ABSTRACT

Concrete structures represent a significant part of our infrastructure. Considering the full life-time of engineering structures, it is quintessential for a safe and sustainable design to predict, as accurately as possible, the technical life-time of these structures. As a result it is crucial to have knowledge about the long-term performance of the material. In particular, those phenomena that lead to deterioration and/or failure have to be understood and captured by suitable prediction models. However, also on the resistance side the accurate prediction of material properties such as compressive strength, tensile strength, and fracture energy is of significance. In the present paper we present an experimental campaign aiming at a full characterization of one chosen concrete mix. Apart from mechanical properties the creep and shrinkage behavior in sealed and unsealed conditions, loaded at different ages have been measured. Further measurements include the evolution of internal relative humidity and temperature under given environmental conditions. A comprehensive chemo-mechanical framework (Cusatis, Pelessone, and Mencarelli 2011, Di Luzio 2009) able to accurately capture cement hydration, water transport and heat transfer, is used to predict thermal strains, drying shrinkage, the evolution of material properties, and aging visco-elasticity. Additionally an evaluation of current design equations given by EC 2 concerning aging is carried out. The results show that the suggested aging laws are suitable for data obtained by the different concrete mixes. Furthermore an alternation of the aging rates of different kinds of tests are noticed and the suggested kink in the aging curve for tensile strength after 28 days is found to be nonexistent. Merely a change in the curing conditions would support such a behavior. The time shape curve for shrinkage given by European standards provides a good fit to the measured data and a final shrinkage value as well as the shrinkage half time can be predicted.

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Seismic life-cycle cost analysis of aging highway bridges under pitting and uniform corrosion: A comparative study

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ABSTRACT

The past decade has witnessed significant progress towards the seismic reliability based life-cycle cost analysis of deteriorating highway bridges. Among the different aging mechanisms affecting bridge components, corrosion deterioration from chloride attacks have been identified as a severe forms of structural degradation. Although a considerable amount of work exists on the chloride induced corrosion of bridges, the physics based modeling of this degradation mechanism has been rather simplistic. For instance, almost all studies on aging bridge reliability and life-cycle analysis assume a uniform area loss of steel due to corrosion. While this may be true for carbonation induced corrosion, chloride corrosion (for instance from marine environments or deicing salts) is typically localized and results in pits or crevices at small discrete areas. This non-uniform and highly localized deterioration mechanism is considered to be more dangerous than uniform corrosion because it is difficult to detect, predict and design against. Moreover, if these pits occur at critical locations within the structure during seismic shaking, such as in the plastic hinge regions of bridge columns, the probability of failure is likely to be significantly high.

This paper focuses on the development of a probabilistic model for pitting corrosion deterioration and assess the impact on the seismic vulnerability and life-cycle cost analysis of highway bridge structures. Time-dependent bridge fragility curves are developed to quantify the change in bridge failure probabilities and life-cycle cost estimates for the realistic pitting corrosion model compared to simplistic assumptions of uniform loss of steel area under chloride attacks. The proposed comparative assessment framework presented in this paper is demonstrated on a multi-span continuous steel girder bridge located in Central and Southeastern US under chloride induced corrosion degradation. The results underline the significance of considering the effect of pitting corrosion on seismic reliability within the framework of life-cycle evaluation.

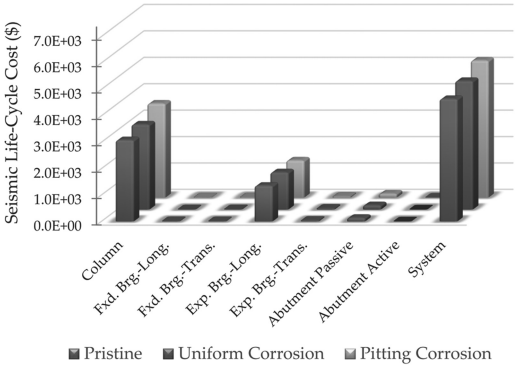


Figure 1. Seismic life-cycle cost analysis for the case study bridge struc-ture under pristine conditions (neglecting structural degradation, and under uniform and pitting corrosion condition.

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Time-variant reliability analysis incorporating multiple deterioration and live load models

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ABSTRACT

Bridge elements deteriorate with time due to exposure to different environmental attacks, distress mechanisms and live-loads effects. In order to optimize the time-variant life-cycle costs or to obtain realistic time-variant reliability profiles, time-variant load and resistance models are needed. This paper presents a comparison of time-dependent reliability profiles for bridge components obtained by using different deterioration mechanisms and live-load models.

To calculate the time-variant reliability of a bridge component, based on different load and resistance models, a shell algorithm is developed which calls a First-Order Reliability Method (FORM)-based program as an executable code. In this study, effects of five different resistance degradation models (based on reinforcing corrosion, sulfate attack, diffusion controlled degradation, traffic spray damage and load-carrying capability) and two separate live-load models (proposed by Nowak and Sivakumar, respectively) on the reliability profiles of a bridge component are investigated. Effects of these models on time-variant reliability profiles are compared.

In the comparison of degradation models, it is observed that the load-carrying capability deterioration model has the highest reliability in 60 years. However, it has the lowest reliability in the following 15 years. In the comparison of live-load models, the reliability using Sivakumar's model is observed to be slightly higher than the reliability using Nowak's model, although the reliability profiles are very close to each other. Consequently, through the application of five resistance degradation models and two separate live-load models in the algorithm, it is possible to calculate the time-variant reliability of a bridge member and to determine which distress mechanism may be the cause of the actual deterioration process. Another advantage of the algorithm is that the number of models implemented in the algorithm is not limited to the ones presented here. The user has the option of adding new models to the analysis and calculating the reliability-index profiles or the reliability profiles for a bridge member for different degradation functions using different live-load models.

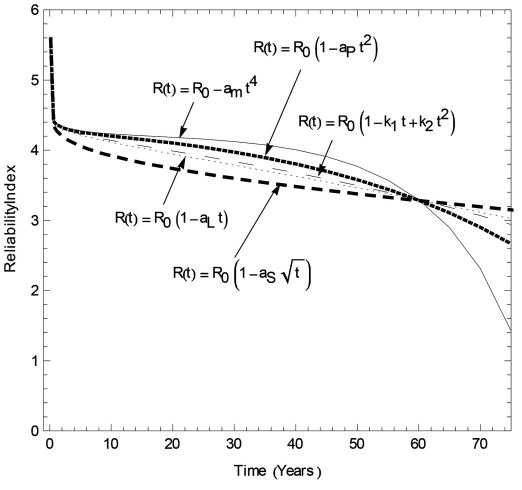


Figure 1. Reliability index profiles for five different deterioration models, using Nowak's live-load model, for a period of 75 years.

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Coupled transport-degradation behavior of reinforced concrete: State-of-the-art

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ABSTRACT

The transport-related degradation of concrete materials is a major factor for the premature deterioration of concrete structures in cold and marine environments. The huge costs of maintaining or replacing deteriorated structures, the implications of this on the environment and society, and the impetus to increase the sustainability of the constructed environments have created an urgent need for the development of durability design methods and service-life prediction models. This requires understanding the coupled transport-degradation behavior of concrete materials.

During service, structures are typically subjected to several physical and chemical deterioration factors. The physical factors include heating and cooling, as well as drying and wetting cycles. Chemical factors include attacks from i) deleterious chemicals such as acids, ii) aggressive ions such as chlorides and sulfates, and iii) fluids such as carbon dioxide, oxygen and water. Figure 1 presents the major factors that contribute to the deterioration of concrete structures, which include drying and wetting, freezing and thawing, and chloride attack. Drying and wetting, freezing and thawing and chloride attack can be described by moisture transport, heat transfer and chloride penetration, respectively. When these factors are combined with the mechanical loads, they accelerate the aging and deterioration of concrete materials and consequently impair the safety, serviceability and durability of concrete structures and shorten their service lives.

Predicting the durability of concrete structure is very complex task. The complexity arises from the difficulty in quantifying the extent of damage as a function of the structure age. This research will provide practical engineers with computational tools for developing construction materials, deterioration prevention measures, and maintenance and repair methods that will extend the service life of the buildings and infrastructures, thus reducing the adverse impacts of the concrete industry on the environment while sustaining the social and economic development of the society.

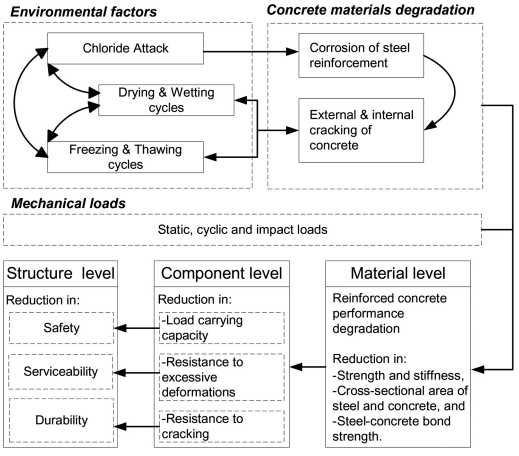


Figure 1. Concrete deterioration processes.

This paper presents a state-of-the-art and comprehensive literature review on the experimental and analytical research results on the transport-degradation behavior of concrete including the coupled transport processes, the coupled transport-deterioration processes. The paper also identifies areas for additional research. These include refining the transport models to account for the cracking, developing model-based simulation for the transport-degradation behavior and finally validating these simulations by experimental measurements and field data. This research will ultimately lead to the development of a degradation function that can be applied in computational tools for performance-based design of new structures or to predict the remaining service-life of existing structures.



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MS10: Assessment of structural capacity by proof loading

Organizers: Y. Yang, E. Lantsoght, A. de Boer & D. Hordijk



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Acoustic emission measurement in the proof loading of an existing bridge affected by ASR

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ABSTRACT

Assessment of the residual capacity of existing structures has being raised increasing attention in Europe. In the Netherlands, proof loading became an interesting option recently for the assessment of existing concrete slab bridges. On one hand, most of the concrete slab bridges are of short span, the design load is relatively small. Moderate load is needed for proof loading. On the other hand, these structures are often of rather complex material properties or boundary conditions, and they are considered to be vulnerable to shear failure. The available design expressions proposed by the present design codes or other theoretical models are not always capable to give an accurate estimation on the capacity of such structures. Consequently, applying proof load on the structures becomes an interesting option.

As one of the basic principles for proof loading, the structural safety should not be affected. Therefore, the assessment of possible additional damage caused by the proof loading becomes essential. In addition to the conventional approaches, Acoustic Emission (AE) measurement is considered to be an attractive alternative for the proof loading of existing structures.

Because of the complexity of existing concrete structures, reports of application of AE measurement on structural tests (proof loading) on existing structures is very limited in literature. This paper presents the AE measurement during the proof loading on an ASR (alkali silica reaction) affected existing bridge: the Zijlweg bridge in the Netherlands, see Figure 1. The major findings of the study are as follows:

The friction between the shoes of a worker and the deck surface would generate recognizable AE hits. Therefore during the proof loading, any unnecessary activities on the bridge deck should be forbidden.

The presence of cracks between the AE sensor and the signal source reduces the amplitude of the hit recorded by the sensor. Therefore the arrangement of the AE sensors should take into account the attenuation properties surrounding the sensor. An approach of determining the attenuation contour of a given AE sensor is suggested in the paper.

Because of the relatively large variation of the wave speed at different locations, accurate source location based on triangulation is not possible. Zonal location is therefore recommended. The cumulative signal strength rate is suggested as a robust indication of the locations of cracking activities that can be used in the zonal location approach. In the proof loading of Zijlweg bridge, the results of zonal location compared well with the expectation based on the moment distribution calculated with FEM.

In addition to the locations of cracking, the additional damage level of the cracking active area can be evaluated by a comprehensive scale based on the load ratio and the calm ratios. In the Zijlweg bridge proof loading, limited additional damage was reported by this approach, even though the peak load was higher than the highest safety level required by Eurocode. The conclusion was confirmed by the other measurement results.



Figure 1. Zijlweg bridge (viaduct) in the highway A59 in the province Brabant, the Netherlands.

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Assessment and failure test of a prestressed concrete bridge

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ABSTRACT

Tests have been carried out at service- and ultimate load levels of a 55 year-old prestressed concrete girder bridge. The bridge, located in Kiruna, Sweden, was continuous in five spans with a total length of 121.5 m. The overall aim of the study was to determinate the accuracy of assessment methods for existing structures and to provide procedures for optimized assessment.

Before the tests a 2D finite element (FE) analysis was performed to predict the behavior and load-carrying capacity of the bridge. In order to more accurately assess the bridge response a 3D FE model has now been developed. The actual loading history and material properties has been considered in the model. A Life Cycle Cost Assessment of the bridge has also been performed. Assessment, repair and strengthening of existing bridges are required in order to meet current and future demands on sustainability of existing infrastructure. For instance, a survey carried out within the project MAINLINE (2015) in twelve EU countries, indicated a need for strengthening of 1500 bridges, replacement of 4500 bridges and replacement of 3000 bridge decks. It is believed that for some of these structures replacement can be avoided if more accurate assessment methods are used, see e.g. Sustainable Bridges (2007).

An effective life cycle analysis is based on a reliable assessment that can mitigate uncertainties related to structural and loading parameters and deterioration mechanisms. In the past decade the monitoring concept has been developed to update models for bridge assessment, reducing the number of uncertainties, based on monitored data. Moreover, proof loading has been suggested and later implemented for reinforced concrete structures in ACI 437 (2013) as an approach to verify the reliability and reduce the uncertainties of existing bridges. Thus, test and monitoring of bridges in service-load levels is an accepted and well-known approach for assessment. With the aim to provide better understanding of the true structural behaviour, and also calibrate assessment methods and models, a limited amount of complete full-scale bridges have been tested to failure. Such tests are seldom performed due to high costs and lack of test objects. Only few destructive investigations have been reported for bridges or structural members of prestressed reinforced concrete, see e.g. Bagge (2014).

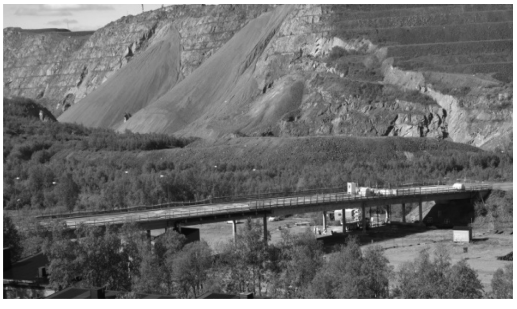


Figure 1. Kiruna Bridge with the LKAB iron mine in the background, Bagge (2014).

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Development of stop criteria for proof loading

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ABSTRACT

To determine the capacity of existing bridges, proof loading tests can be carried out. Proof loading of bridges is an option to study the capacity when crucial information about the structure is lacking. When proof loading, the question arises which maximum load should be attained during the experiment to prove sufficient capacity of the bridge, and which criteria, based on the measurements during the test, would indicate that the proof loading needs to be aborted before reaching the maximum desired load (the so-called stop criteria). In fact, these requirements are contradictory. On one hand, to demonstrate the structural capacity and to gain as much insights on the structural behaviour of the bridge as possible, the proof load should be as high as possible. On the other hand, to prevent irreparable damage, the maximum applied load is limited.

Diagnostic proof loading to low load levels to check the stiffness of a structure is possible, as well as proof load testing, in which a certain load level needs to be achieved to proof sufficient capacity. In proof loading, the maximum load to approve a bridge needs to be determined as well as the stop criteria. These criteria indicate when a proof load test needs to be aborted because permanent damage can be inflicted upon the structure, or because failure might be imminent. In The Netherlands, proof loading is studied for the assessment of existing bridges.

A literature review has identified the existing codes and guidelines for load testing: the German guideline, ACI 437.2M-13, the French guideline, the British guideline, the Manual for Bridge Rating through Load Testing and the Irish guideline NRA BA54:2014. Only the German guideline and ACI 437.2M-13, which is developed for buildings and cannot be used for bridges without adaptations, have clearly defined stop criteria as part of the provisions. The German guideline defines stop criteria based on strains in the concrete and steel, crack width and increase in crack width, and residual deflection. ACI 437.2M-13 defines stop criteria based on the comparison with calculated deflections, signs of shear or anchorage failure, residual deflection, the deviation from linearity index and the permanency ratio.

Three beams were sawn from a bridge, the Ruytenschildt Bridge, and five tests were carried out on these beams. The material properties and geometry were studied. Cyclic loading was applied to evaluate the stop criteria from the German guideline and ACI 437.2M-13. This analysis was carried out based on the loads at which the stop criteria are exceeded. Failure of the beams in shear and flexure occurs, see Figure 1. For flexure, the stop criteria for both methods are exceeded well before failure. For shear, the stop criteria are unsafe.

For the development of a Dutch guideline for proof loading, new stop criteria for shear are necessary. For flexure, the criteria for the residual deflection, the crack width and the deviation from linearity index should be revised so that the improved stop criteria are not too conservative for structures with existing cracks and possible yielding of the reinforcement. The crack width criterion is also important for the durability of the tested bridge. The stop criteria also need to take into account that during a proof load test, a minimum load level is kept.

The further development of the stop criteria for shear and flexure for the Dutch guideline for proof loading is subject of future research.

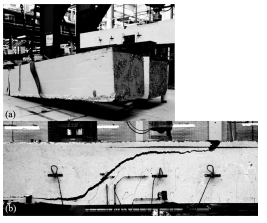


Figure 1. Observed failure modes: (a) RSB01F, flexure; (b) RSB03A: shear.

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Initial in-service response and lateral load distribution of a prestressed self-consolidating concrete bridge using field load tests

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ABSTRACT

Bridge A7957 is the first Missouri Department of Transportation (MoDOT) infrastructure in which self-consolidating concrete (SCC) and high-strength self-consolidating concrete (HS-SCC) were implemented. The objective of this research was to monitor the initial in-service behavior of the precast-prestressed concrete primary elements of Bridge A7957. An initial series of diagnostic load tests was conducted on the bridge's superstructure. Embedded sensors recorded strain variations at instrumented girder sections during different load configurations. Lateral distribution factors were computed from experimental data, finite element models (FEM), and using the AASHTO LRFD Bridge Design Specifications which resulted in conservative values. No significant difference was observed between the SCC and conventional concrete members' response during this first series of field load tests.

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Preparation in proof load test projects

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ABSTRACT

Good preparations are the starting point for a successful and safe proof load. Witteveen+Bos has extensively prepared the proof load test of concrete structures to ensure the proof load test is conducted as safe and practical as possible. The accessibility of the object, material parameters, but also the licenses and permits necessary during this project, play an important role. Availability, accessibility and the safety of road users are of great importance. During the proof load test a safety supervisor will supervise the work and intervene if necessary. With these preparations a safe and efficient working environment is created.

Calculation results are not consistent with the behavior of the concrete structure in situ. This points out that there is more strength available than demonstrated by calculation. Recent investigations performing proof load tests confirm that the actual strength of a structure can be determined. This leads to lower costs and contributes to sustainability goals of road authorities.

However, proof load tests may never cause additional risks in relation to the constructive safety of the structure, during the tests and during further use.

Multiple proof load tests are necessary to proof the reliability of the proof load test outcomes and to develop a extensive safety approach during the proof load tests so that a solid basis is provided.

To conduct proof load tests in a safe manner, during preparation of the proof load tests some calculations are carried out to determine the size and weight of proof load test and the load procedure. For these calculations, material parameters are necessary. These are often derived from existing files.

If these parameters are not available, then compressive strength of the concrete, quantity and quality of present reinforcement are determined on site. With these preparations proof load tests can be carried out safely without unacceptable risks.

As said, safety first. The constructive security during a proof load test may never be compromised, as well as safe working conditions.

A crane is necessary for applying the proof load test on the structure. This crane is positioned on embankments near the structure. In order to ensure the stability during the lifting, is a geotechnical review of the stability is necessary, so stability is ensured during lifting.

To be able to carry out the work, various measures have been undertaken in coordination with various parties. Examples of measures vary from traffic diversions (according to CROW 96b) on top of the object, work platforms, completely enclosed worksites, office facilities, power supplies and lighting to toilets and catering.

The approach described above contributes to a cost-effective method for conducting proof load tests in relation to time, safety, costs and results.

Using proof load tests for drafting a new guideline will lead to more realistic calculations of the end of life of concrete structures.

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Shear load testing of hollow core slabs

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ABSTRACT

As a result of bad quality sealing, moisture and deicing agents penetrated into pre-stressed hollow core slabs of the top floor in a freely exposed parking garage. Caused by corrosion the slabs showed especially heavy damage in the support regions near the joints. The theoretical shear bearing capacity according to the technical approval of these slabs was strongly questionable because of the damage. With the help of an experimental loading test in-situ the influence of the damage on the shear bearing capacity of the slabs with different damage-levels could be determined.

Because of the great amount of damaged slabs it was impossible to experimentally investigate all of the questionable slabs to determine the shear bearing safety. Therefor a limited number of slabs were cho-sen which represented a characteristic sample of the whole population of the damaged slabs. In total 5 characteristic slabs (two with heavy and three with medium damages) were tested and the results of these tests used as the basis for an overall evaluation of the shear bearing safety of all slabs of the City-Center. The experimental results allowed a secure evaluation on how many slabs had to be replaced or could be repaired.

For the experimental investigation of the shear bearing capacity of the hollow core slabs a combination of photogrammetry, Acoustic Emission Analysis and section-wise curvature measurement was used to determine the beginning shear damage on a very low level during the test. The comparison of the results of the different measuring techniques allowed a clear identification of the damage processes and increased the information quality about the bearing condition of the slabs during the experimental investigation significantly.

The loading tests proved a sufficient shear bearing safety of the medium damaged slabs. The results of the tests on five slabs could be transferred to the whole population of slabs because sufficient margins of safety were considered in the calculation of the aim test load. With the results of the loading tests it was concluded how many slabs had to be replaced and which could further be used.

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Some relevant experiences from proof load testing of concrete bridges

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ABSTRACT

In a proof load test, the load level in the load test necessary to guarantee a predefined safety level under real traffic conditions jointly with the load level where the test should stop are two of the main parameters to be defined.

The target proof load achieved should guarantee the normal operation of the bridge under the traffic action with a predefined (by the user) level of safety. Therefore, two important requirements arise concerning an accurate assessment of the bridge capacity by proof load testing:

- An accurate estimate of the actual traffic action in the bridge;
- A statistical definition of the traffic action, allowing the definition of the required safety level with a certain level of confidence.

Both requirements need the recording and analysis of several days or weeks of traffic measured in the bridge. Nowadays this can be effectively achieved by the use of Weigh-in-Motion (WIM) systems. Later on, the WIM data must be used to define the traffic action. Advanced and simplified extrapolation methods can be used to this end (Soriano et al. 2014, 2016).

An important element of proof load testing is an analysis of the uncertainty of the tests and its influence on the final result of the structure's evaluation. The notion of the measurements uncertainty is relatively well-known and often taken into consideration (JCGM 2010). This is not, however, the only reason for the uncertainty of the whole proof load testing. Each element of the measurement process, design of the structure's calculation model and comparative analysis of the measurement results and calculations brings an un-avoidable uncertainty. In case of dynamic load testing there is a Code describing possible reasons of uncertainty (ISO 2004). And in case of static load testing one of the uncertain elements is the correct estimation of the elastic and permanent values of the measured displacement. The possibilities of the estimation will be presented with the example of several bridge tests, when different speeds of stabilization of the measured displacements were observed. This is an important issue, as the incorrect sampling frequency during measurements could distort the final result of the measured deflections and, as a consequence, the bridge evaluation.

Incremental loading is applied for proof load testing until the bridge materials approach the elastic limit. Defining the load level where this limit is close to be reached is another element of the uncertainty of the whole proof load testing process. It is necessary not to damage the bridge. Acoustic emission has been identified and is presented as a useful technique in the follow-up of the loading process to stop the load increase before any damage can be inflicted to the bridge. It is presented in the case of a three span concrete bridge, made of prestressed precast beams (Olaszek et al. 2015).

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MS11: Reliability analysis of structural systems and reliability-based optimal design and assessment

Organizers: R. Steenbergen & R. Caspeele



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A bridge life-cycle cost optimization methodology

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ABSTRACT

A life-cycle cost optimization methodology for a set of bridges, regarding the desired quality level and the available budget, will be presented.

The methodology analyses multiple scenarios and evaluates the performance and cost consequences of implementing different types of interventions, in different periods of time. The cost estimation considers the direct and indirect costs of several types of maintenance or rehabilitation works and the deterioration of each bridge is predicted with Markov matrices, based on a condition state index, defined with a five level scale.

The optimization is performed through a genetic algorithm, where the cost and performance information are considered and the optimized intervention plan, over the desired analysis period, is identified. That process takes into consideration the life cycle cost minimization and the boundary constraints which could be fixed by the decision maker, either in terms of performance or cost.

The methodology was tested on set of 100 concrete road bridges and the results of its application will be presented (Figure 1), as well as some outcomes of its sensitive analysis.

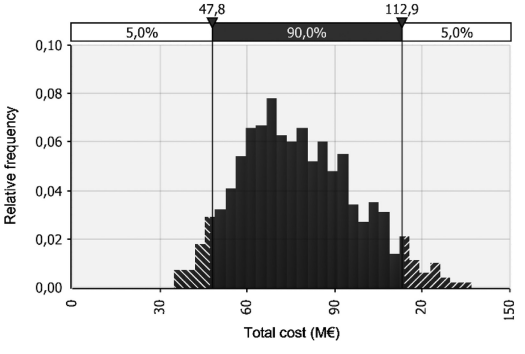


Figure 1. Optimized total costs for the considered set of bridges during 20 years.

A multi-objective analysis is also made, based on non-dominated Pareto fronts – the set of solutions that cannot be improved by enhancing one objective unless comprising another one. With that, the decision maker can analyse graphics with two main objective functions presented at the same time, for example the cost minimization and the performance maximization. Attending to the nature of the problem, data's uncertainty is considered and Monte Carlo simulation Method is used to present the results in a probabilistic manner.

Thus, the methodology is an approach to support bridge management decisions that could help to optimize the maintenance and rehabilitation interventions plan for a specific group of bridges, during a medium or long period of time, based on life cycle cost minimization.

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Analysis for cracking progress of concrete dam based on double scale variables damage-based cohesive crack model

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ABSTRACT

Concrete, as the most widely used construction material for infrastructures, is featured by its stochastic nonlinearities due to the random distribution of the multiple phases and defects. Existing researches indicate that the nonlinear behaviors of concrete is very complicated, especially in the cracking progress of concrete structure. In this paper we focus on the development of a class double scalar variables damage-based cohesive crack model (CCM), which is used in the numerical simulation of crack propagation of concrete dam under earthquake.

In the present work, a class of double scalar variables damage-cohesive crack model is proposed in the framework of thermodynamics, which is developed for simulating crack growth in concrete under mixed-mode fracture including tension-shear and compression-shear. On one hand, a tension-shear damage-based coupling traction-separation relationship is proposed for the tension-shear mixed-mode fracture. On the other hand, the Coulomb's law is utilized to consider the enhancement of shear strength due to compressive stress for the compression-shear mixed-mode fracture.

In general, the CCM is implemented as the cohesive zone element within the finite element framework. Using the interface finite element and the cohesive crack model, we try to the analysis for fracturing process of the Koyna dam, which is a typical overall pouring gravity dam. In order to embed the interface elements under the crack propagation path, the meshing of the concrete dams can be generated following numbers of steps. Firstly, we will generate the random point in the domain and boundary of dam. Secondly, we will decompose the domain by the delaunay triangulation scheme, as the figure 1 (a) shown. Lastly, we will embed the interface element along the edges of the triangle elements, as figure 1 (b).

The model is applied to the analysis for cracking progress of concrete dam under earthquake with different peak acceleration. We can get the conclusions as: The greater the peak acceleration is, the more cracks the dam have. Moreover, the greater the peak acceleration is, the more complex the crack progress is, which remains to be further studied.

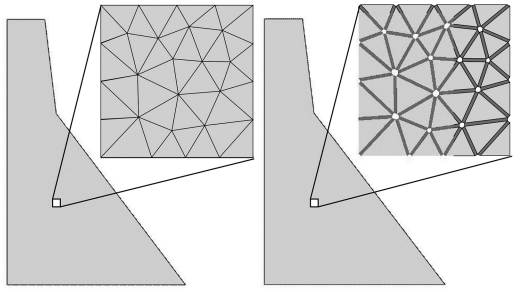


Figure 1. (top) and 1b (bottom). Meshing of dam (1a) the Delaunay triangulations (b) the interface elements and the triangle elements.

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Computationally efficient estimation of the probability density function for the load bearing capacity of concrete columns exposed to fire

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ABSTRACT

Fire is one of the most severe load conditions for structures, and it is generally accepted that the structural stability of (concrete) columns in case of fire exposure is of primary importance for the overall stability of the building. However, considering the low probability of a fully developed fire to occur and considering the large uncertainty with respect to the fire load and ventilation characteristics, it is at times questioned whether a significant fire rating of the structural elements makes sense economically.

In order to allow for a true Performance Based Design, the design should be based on considerations of risk and reliability. Consequently, the probability density function (PDF) which describes the load-bearing capacity of concrete columns during fire exposure has to be assessed. As second order effects can be very significant for columns, traditional probabilistic methods to determine the PDF become very computationally expensive. More precisely, for most current numerical calculation tools (e.g. Finite Element), the computational requirements are so high that traditional Monte Carlo simulations (MCS) become infeasible for any practical application.

Recently, a computationally very efficient method has been developed by Zhang (2013). The method is known as the (Fractional-Moment) Maximum Entropy Multiplicative Dimensional Reduction Method (ME-MDRM). At its very core, the method makes an unbiased estimation of the true probability density function describing the uncertain output by using the criterion of maximum entropy on a set of calculated model outputs. The method is further developed in the full paper and applied to assess the load bearing capacity of eccentrically loaded and fire exposed concrete columns.

As a first application of ME-MDRM to structural fire safety, consider a 300x300 mm concrete column with a height of 4 m, loaded with an eccentricity of 5 mm and exposed to a (prescribed) 60 minutes ISO 834 standard fire. The column is reinforced by 4Ø32 mm corner rebars with 500 MPa characteristic yield stress and a concrete cover of 25 mm. The characteristic concrete compressive strength is 55 MPa. Applying a nonlinear calculation tool based on the Direct Stiffness Method (as elaborated in the full paper), 10000 MCS have been performed and the obtained histogram for P_{max} is given in Figure 1, together with a lognormal approximation (LN) for which the parameters have been estimated using the MCS data. Alternatively, the ME-MDRM method is applied, requiring only 25 model evaluations, resulting in an independent estimation of the PDF. As illustrated by Figure 1, the ME-MDRM estimated PDF captures the shape of the observed histogram very well. Furthermore, the method has an excellent computational efficiency requiring only a very limited number of model evaluations.

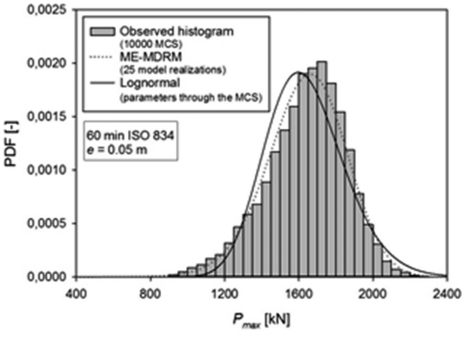


Figure 1. ME-MDRM result for PDF describing P_{max} at 60 minutes ISO834 for $e = 0.05$ m, and comparison with histogram of 10000 MCS, and a lognormal approximation (with parameters based on the MCS).

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Discussion on the probabilistic assessment of fatigue with respect to reference periods

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ABSTRACT

The paper covers the topic of time dependent reliability for fatigue assessment of engineering structures. Time dependency for cumulative degradation processes has to be handled differently than for failures caused by extreme impacts. Target reliability levels prescribed in codes are minimal levels of reliability with respect to a given time period, the so called reference period *RP*. In practical examples of fatigue assessment the consideration of the reference period is often found neglected, which leads to results not comparable with the target reliability levels given in codes.

For the design of structures EN 1990 (CEN 2013) prescribes $1.5 \leq \beta_{Target} \leq 3.8$ for $RP = 50$ years depending on the degree of inspectability, repairability and damage tolerance of the structure while for the assessment of existing structures ISO 13822 (ISO 2010) prescribes $2.3 \leq \beta_{Target} \leq 3.1$ depending on inspectability. Here, *RP* is the intended remaining working life.

For a case study, using a S–N curve and stochastic variables the cumulative failure probability $P_f(t)$ and the associated reliability index $\beta(t)$ have been derived for a time period of $[0, 100]$ years. Calculation of the probability $P_{f,RP}(t)$ that failure will happen in a time period equal to the reference period *RP* can be done using methods given in literature for reliability analysis as well as in the recently published update of the ISO 2394 (ISO 2015) code. Results of calculations conducted for the case study are shown in Fig. 1 with $P_{f,RP}(t)$ calculated for different reference periods *RP* as well as $P_{f,rem}$ for the remaining working life and the associated reliability indexes $\beta_{RP}(t)$ and $\beta_{rem}(t)$. Comparison of $P_{f,RP}(t)$ with $P_f(t)$ (or $\beta_{RP}(t)$ and $\beta(t)$) shows that neglecting the RP will result in wrong comparative values for the target reliability level as stipulated in codes or guidelines.

The discussed procedure employ fundamental and well-known methods of reliability analysis. However, in practical examples the reference period is often neglected or not accounted for properly, thus resulting in wrong comparative values for the target reliability level given in codes.

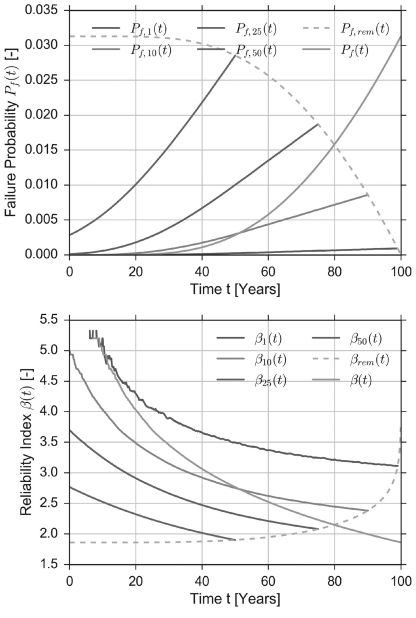


Figure 1. Calculation results. Failure probabilities $P_{f,RP}(t)$ for $RP = \{1, 10, 25, 50\}$ years and $P_{f,rem}(t)$ for the remaining service life compared to $P_f(t)$ on the top and the associated reliability indexes $\beta_{RP}(t)$, $\beta_{rem}(t)$ and $\beta(t)$ on the bottom.

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Influence of codal provisions on life-cycle cost estimates of highway bridges

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ABSTRACT

A history of damaging earthquakes in the Indian subcontinent over the past century has prompted noteworthy, albeit infrequent, upgrades in seismic codal provisions for highway bridge design. However, there is a marked absence of seismic vulnerability evaluation tools and financial loss assessment frameworks for highway bridges within the country. The present study addresses this need using seismic life-cycle cost estimation techniques which enables the combination of seismic fragility of bridges, regional hazard information and repair cost data. The paper traces the evolution of seismic codal provisions of highway bridges within India and subsequent impact on the seismic vulnerability and life-cycle cost estimates.

Four distinct highway bridge design cases are identified based on design force and reinforcement detailing specifications from different versions of bridge design codes. These design cases incorporate generational changes in bridge design principles and construction practices in India. Fragility curves are developed to assess the probability of exceeding a given level of structural damage conditioned on a chosen ground motion intensity measure. These fragility curves provide essential insights into the difference in performance of the identified bridge column designs from a statistical standpoint. Consequently, annual failure probability estimates are computed after convolving bridge fragility estimates with regional hazard curves, followed by lifetime seismic loss estimates using repair cost information. Results reveal a significant improvement in life cycle cost of highway bridges designed as per the latest seismic design and detailing provisions. Lifetime seismic loss of non-seismic designed bridge exceed more than 50% of its initial cost within the first three years of its service life while for seismic design case it is only 14.6 % of the initial cost at the end of its service life. The results shown in Figure 1 clearly indicates the importance of seismic provisions in the design of bridges.

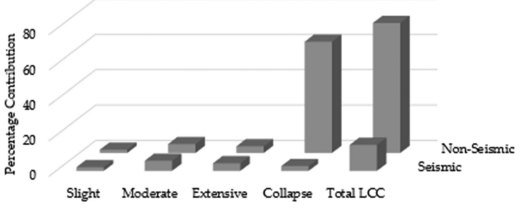


Figure 1. Percentage contribution of each damage state to seismic life-cycle cost for the case studied bridge for non-seismic and seismic design case.

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LCE-analysis of existing anticorrosive coated bridges based on the parameters ageing, remaining load bearing capacity & reliability as a basis for an adaptation of the future maintenance strategy

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ABSTRACT

The current steel bridge maintenance strategy of the Austrian Federal Railways assumes a full replacement of the corrosion protection every 30 years.

As two-thirds of the steel bridges within the Austrian Federal Railway Network have an approximate age of 70 years the development of a more targeted future coating strategy was aspired.

The key issue of the presented investigation was the assessment of probable corrosion processes getting effective once the corrosion protection has lost its functional capability. The consequences of these processes in terms of remaining load bearing capacity and reliability of the primary, secondary and tertiary load bearing system and residual lifetime were analysed and evaluated for several reference steel bridges along a defined railway section.

The major question to be answered was, whether this in-depth numerical simulation of effective corrosion processes would provide additional time frames for a more moderate long-term maintenance strategy (still complying with the relevant verifications) as an alternative to the current 30 year replacement period of the entire anticorrosive coating on existing bridges.

In the first stage a new methodological framework regarding the analysis of global and local remaining load bearing capacity and reliability was elaborated.

In the second stage the developed methodology was applied at three existing railway bridges by means of the following analysis concept:

A) Primary load bearing system

Analysis of the impact of two-dimensional (planar) corrosion over time; numerical simulation of effective corrosion until reaching the stage when not complying with the relevant verifications of the original structural design calculations

B) Tertiary load bearing system

Analysis of the impact of local corrosion over time on the integrity of single riveted joints; numerical simulation of effective corrosion until reaching the stage when not complying with a defined threshold for residual static component resistance

C) Secondary load bearing system

Analysis of the impact of local corrosion over time on the horizontal bracings for braking thrust in the abutment areas; numerical simulation of decreasing reliability and comparison with the minimum values according to ULS/SLS verifications

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Comparing the life-cycle cost of optimal bridge designs using a lifetime reliability-based approach

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ABSTRACT

Bridges, as an important component of infrastructure, are expected to have a long service life and high safety margin, but these requirements often entail an increase in the life-cycle cost. In this paper, several optimal designs of continuous post-tensioned concrete box-girder road bridges, considering initial cost, durability and structural safety as objectives, are obtained first. Cost evaluation is explained in Garcia-Segura et al. (2015). These bridges are subjected to chloride attacks in coastal environment. Then, a lifetime-reliability-based approach is used to evaluate the maintenance required to satisfy a reliability target during a specified time horizon. The differences among these designs would lead to alternative maintenance options. These maintenance options would in turn affect the life-cycle cost of bridges, which includes the bridge initial cost and the maintenance cost. The indirect maintenance cost due to the traffic disruptions during the maintenance action is included (Dong et al. 2013). The results provide the designers with different options from a life-cycle perspective in the early design stage.

The bridge considered has three continuous spans with a post-tensioned concrete (PSC) box-girder cross-section. The length of the main span is 44m, the external spans are 35.2m. The deck has a width of 11.8m. Figure 1 shows the bridge elevation. The design space of the PSC bridge is made up of a total of 34 variables, which define the cross-section geometry, the concrete, the reinforcing and post-tensioning steel of the bridge.

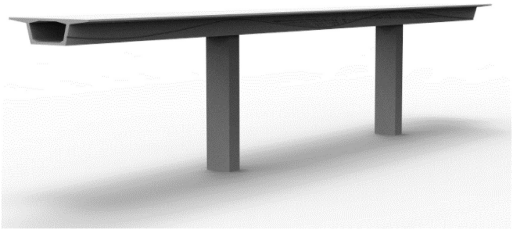


Figure 1. Bridge elevation.

Three bridge designs are studied. The first one represents the best cost solution of a PSC box-girder road bridge. The second one achieves a safer solution, but entails an increased cost. The last one improves the durability with an initial corrosion time around 50 years.

Four steps are followed to plan the required maintenance actions and the corresponding cost. Firstly, the degradation process is formulated. Bridge deterioration in coastal zones is mainly caused by chloride attacks. The chloride-induced corrosion reduces the reinforcing steel area. A numerical model is used to reflect the material degradation process. Secondly, the reduction in structural safety due to the corrosion process is evaluated based on reliability. Thirdly, a series of maintenance actions are scheduled to insure structural safety during a prescribed service life of 150 years. The objective is to take appropriate maintenance measures to keep the structural reliability above the threshold value and minimize the maintenance cost. Fourthly, the life-cycle cost, combining both the initial and the maintenance cost, is obtained by comparing the three bridge designs in the last phase.

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Numerical simulation of unprotected solid steel beams at elevated temperatures

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ABSTRACT

Large local buckling, Vierendeel bending failure mechanism and web-post buckling are the main critical drawbacks that may disrupt the integrity of the steel members, especially cellular steel beams (CSBs). The aim of this research is to investigate numerical behavior of naked steel beam at elevated temperature. It is expected that local buckling on naked steel beam will occurred due to extreme fire load applied with additional applied load on top of the steel beam. Traditionally prescriptive based approach does not consider several important factors that may affect the structural strength of the structural steel member. A new, reliable performance based approach will be use to predict the fire resistance performance of the naked steel beam. Validation process of naked steel beam will be perform between Compendium of UK Standard Fire Test Data (compiled by Tata Steel) against numerical analysis performed in this research.

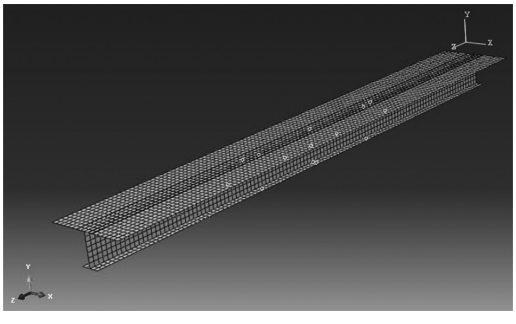


Figure 1. Sample of undeformed shape of naked steel beam attach together with cover slab on top of the beam.

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The use of nested sampling for prediction of infrastructure degradation under uncertainty

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ABSTRACT

Because of the competing demands for scarce resources (funds, manpower, etc) national road owners are required to monitor the condition and performance of infrastructure elements through an effective inspection and assessment regime as part of an overall asset management strategy, the primary aim being to keep the asset in service at minimum cost (BRIME 2001). A considerable amount of information is then already available through existing databases and other information sources. Various analyzes have been carried out to identify the different forms of deterioration affecting infrastructures, to investigate the parameters controlling their susceptibility to, and rate of, deterioration. This paper proposes such an approach by building a transition matrix directly from the condition scores. The Markov assumption is used stating that the condition of a facility at one inspection only depends on the condition at the previous inspection. With this assumption, the present score is the only one which is taken into account to determine the future of the facility. The objective is then to combine nested sampling with a Markov-based estimation of the condition rating of infrastructure elements to put some confidence bounds on Markov transition matrices, and ultimately on corresponding maintenance costs.

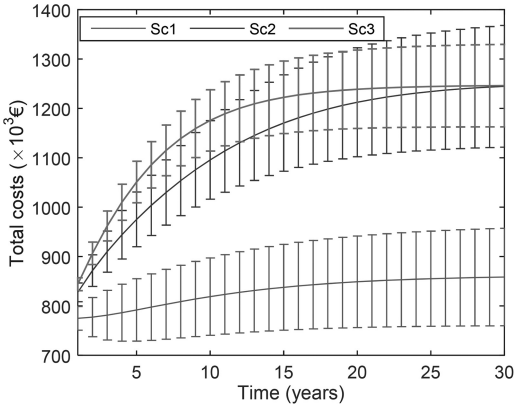


Figure 1. Prediction of maintenance costs for scenarios Sc1 (reference scenario), Sc2 and Sc3 with incremental additional observed in the database and assumed to be linked with climate change effect and/or traffic growth.

The objective in this paper is to combine nested sampling (Skilling 2004) with a Markov-based estimation of the condition rating of infrastructure elements to put some confidence bounds on Markov transition matrices, and ultimately on corresponding maintenance costs. The paper is organized as follows: first, the Nested sampling theory is introduced and exemplified with a basic case study. Second, the combination of the Nested sampling approach with a Markovian process is detailed. The proposed concepts are illustrated by considering some transitions observed on a virtual road highway infrastructure asset.

The method to determine the degradation process is formulated so that any infrastructure managers can determine their own deterioration processes based on the inventory and condition assessment of their stock. This approach is developed in the project RE-GEN (Risk assEssment of aGEing iNfrastructure) funded through the CEDR Transnational Road Research Programme Call 2013 “Ageing Infrastructure”.

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MS12: Integrative monitoring for the life-cycle performance of engineering structures

Organizers: A. Strauss & D.M. Frangopol



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Analysis of damage model of mechanical system under long-lasting dynamic load

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ABSTRACT

An identification in modeling a dynamic phenomena of mechanical system uses a main two elements: a mathematic model and its parameters that have to be determine.

A value of parameters can by determine with use an experimental modal analysis (Uhl & Mendrok 2005, Kulisiewicz 2005). An analysis of model can be reduced to analysis a function $F(x,\dot{x}) = k\dot{x} + cx$, where x – generalized displacement of points A and B of mechanical system.

Paper contains some examples of modeling a process of destruction the mechanical structure. A simple mechanical system described by 1-DOF model was used and computer analysis was conducted.

For analyzes element of true mechanical construction which can be tested on the stand. It is assumed that its dynamic properties can be established by analyzing movement of concentrated mass m for specially tested element in accepted physical configuration (Bocian et al. 2009) (Fig. 1a). If value of mass m is large enough in comparison with mass of spring dumping element only basic form of vibration are present which is presented on the model with one stage of freedom movement (Fig. 1.b).

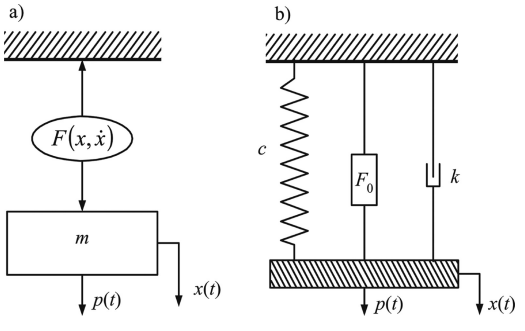


Figure 1. Schematic of analyzed system: a) schematic of physical system, b) schematic of analyzed model.

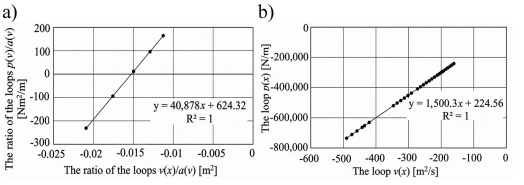


Figure 2. Graph showing linear regression: a) based on force balance equation – shape after damage, b) based on energy balance equation – shape after damage.

Equation identification of model takes the form:

$$m\ddot{x} + k\dot{x} + cx + \frac{1}{2}(\mathrm{Sgn}\, q + \mathrm{Sgn}|\, q\,|)\cdot \cdot (c_d x + k_d \dot{x}) = p(t) \tag{1}$$

Analyzes of this system were based on the Simulink software according to the equation (1) and specific data.

Using regression analyzes and field loop α before and after system damage we were looking for rigidity and dumping values (see Fig. 2).

Based on performed tests one can conclude, that this process analyzes of damaged system is possible to use for practical use, if change of parameters after damage is substantial.

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Determination of load lines for train crossings on a tied arch bridge

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ABSTRACT

The maintenance and expansion of the railway network represents a central task for transport planning in the future. In addition to the ultimate limit states, the aspects of resource conservation and sustainability are of growing importance for basic engineering. Therefore, as part of the *AiF-FOSTA* research project P978 "Integrated assessment of steel and composite railway bridges in accordance with sustainability criteria", the internal forces of a reference bridge are evaluated. The exact knowledge of stresses and strains in the different parts of steel bridges during the crossing of trains is of vital importance for fatigue analysis and to give an accurate estimation of their remaining lifetime. Currently, analytic methods can only give a very rough approximation of the deterioration during a life-cycle as they contain uncertainties and are very sensitive to local stiffness distribution.

In terms of durability and performance of steel structures, it is particularly necessary to consider the demands on hanger connections resulting from fatigue. Therefore, numeric simulations are conducted on a finite element model of the reference bridge, which gives an indication of the internal forces of the individual structural components of a tied arch bridge as they occur during the crossing of the different operational trains described in Eurocode 1 – Part 2 (EC1-2).

The calculations are carried out on a detailed FE model, which allows an extraordinarily accurate mapping of the stiffness of all parts of the construction as it is made up of shell elements. Within the modeling process special importance has been attached to an equitable balance between computational effort and an increase in accuracy.

The results point to a large impact of the design of the details on fatigue-related changes in stress, on the one hand, and on the other, they could depict construction-specific particularities of the influence lines. Comparative calculations with varied axle-stress distribution also provide information about the sensitivity of the results compared to the imposition of stress and axle distribution on the development of the stress resultants.

Dynamic influences are considered by static equivalent loads that are computed by multiplication of the static loads and the dynamic factors described in Appendix C of Eurocode 1 – Part 2 (EC1-2). A future comparison to a full-dynamic calculation will also give information about the impact of dynamic effects to the durability of tied arch bridges.

The more than 10,000 calculated diagrams will provide the basis for further investigations with the aim to achieve an optimized hanger connection design with improved durability, which can take a contribution to a significant reduction of the maintenance costs. They are also used for investigations that lead to practical guidelines for the simplified modeling of complex details.

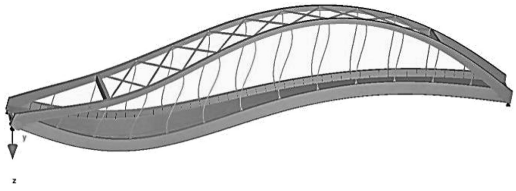


Figure 1. Model of the tied arch bridge and deflection during simulation.

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Drive-by bridge damage detection using road reaction force

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ABSTRACT

Bridge structures are subjected to continuous degradation, which requires a continuous screening to give an early warning if the bridge becomes unsafe. In recent years, many authors have shifted to instrumentation of passing vehicle rather than the bridge. This approach is referred to as 'drive-by' bridge inspection. This paper introduces a new method in the drive-by bridge concept by using the Bridge Displacement Profile Difference as a damage indicator. When a truck passes over a road with a bridge, the truck contact node will has a vertical displacement history equal to the road roughness highest plus the bridge displacement. If the rear contact node displacement history is subtracted from the frontal contact node displacement history when the rear node reaches the position if the contact node, the result will be the difference between the bridge displacement under the rear and contact node which is the Bridge Displacement History. The bridge displacement history is calculated using a Matlab algorithm which solves the truck equation of motion knowing the Road Reaction Force on the truck. The bridge is represented as 1D beam model, and 2D plate model. The study uses a half car model to simulate the instrumented truck. Damage is represented as local loss in structural stiffness. The solution for the Vehicle Bridge Interaction is performed using the LS-Dyna FEA program.

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Drive-by bridge inspection using inverse dynamics optimization algorithm

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ABSTRACT

Bridges are considered as an integrated part of any transportation network. They are under continuous degradation, therefore they require a continuous inspection. Recently, focus has shifted to the instrumen-tation of a passing vehicle rather than the bridge, known as 'drive-by' bridge inspection which has the potential to be more cost effective. This paper present a new innovative method of using the Inverse Dynamics Optimization Algorithm to identify bridge damage using data collected from an instrumented truck. The Inverse Dynamics Optimization algorithm has been first used to calculate the passing truck weight using measurement from bridge (B-WIM). This paper present a novel approaches of using the Inverse Dynamics Optimization Algorithm for a truck model instead of the bridge to back calculate the bridge Apparent Profile as a damage indicator. For the Apparent Profile term, when a vehicle passes over a certain profile without a bridge, it gets dynamically excited. Using the data which has been collected from the instrumented truck it is possible to 'back-calculate' the profile that causes that excitation. If the vehicle starts to pass over the same profile with a healthy bridge, the back-calculated profile will be contaminated by bridge displacement which is referred here as the 'Apparent Profile'. In short, the 'Apparent Profile' refers to the summation of a 'Road Profile Heights' and 'Bridge Displacement'. The study uses a half car model with four degrees of freedom. The solution for the Vehicle Bridge Interaction (VBI) is done using the LS-Dyna FEA program. A road roughness class 'A' is used to represent the road roughness heights.

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Durability of concrete structure with attached marine growth in tidal zone

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ABSTRACT

Many coastal and offshore structures are gradually affected by marine growth attachments. These organisms modify structural properties such as concrete covering and column size. Consequently, the increasing size of structures causes more wave loads which are not preferable in any civil design. Many researchers name these organisms as "bio fouling" and claim them as a potential threat in long run. However, justifying them as a threat for concrete structures is too early. Some researchers are convinced that certain groups of marine growth namely; barnacle, oyster, and biofilm have a surface coating ability. This effect can shield the concrete surface from harmful ions, such as chloride. Nevertheless, marine growths are considered as a natural phenomenon. The creatures always grow on structures in a long term. As a result, the counter measures have to be established. Providing that the marine growth helps strengthening the structures, it will be desirable to take into account the effect of marine growth in design and maintenance of concrete structures. Besides, maintenance costs for coastal and offshore structures are considerably expensive and sometimes maintenance works could be dangerous.

A short-term investigation of marine growth has been conducted for 39 days. The exposure site locates at Yokosuka port, south from Yokohama prefecture, Japan. The site contains abundances of inter-tidal species such as barnacles, oysters, blue mussels, and algae. A set of concrete specimens was deployed at the inter-tidal area, while the other set with same configurations was put in wet-dry tanks in the laboratory. Later on, these specimens were compared and discussed. This research mainly explored on four points. Firstly, the coating performance on concrete substrates by barnacle-like organisms and biofilm was investigated. Secondly, the effectiveness of concrete coating ability by sessile creatures such as barnacles, bivalve clams, and oysters was studied. Thirdly, the crack closing ability of attached materials secreted by oysters, barnacles, and some species of mussels was discussed. Finally, due to many constraints and limitations on site, the attempt of making an artificial marine growth for using in future research was attempted.

Chloride migration test and observation of marine growth behaviors on macro images were used as the study methods. Except from the wet-dry, wave, and sunlight, the results suggest that there are other factors, such as abrasion by sand and corrosion by acid secreted organisms, involving in the concrete deterioration during the study period. In addition, specimens with the attempt of biofilm removing obviously have higher chloride diffusion rates. The next finding is the amounts of sessile coating organisms on the concrete surface can clearly decrease the chloride diffusion coefficient values. On summary, results from this study support that some species in marine growth such as barnacles, oysters, and biofilms could be friendly to concrete and be able to improve durability of concrete structures.

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Benefits and future of the dynamical monitoring of structures

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ABSTRACT

For a few years; the dynamic monitoring of structures has shown its usefulness for diagnosis and maintenance optimization. Due to the recent advances in miniaturization and integration of sensors, a permanent, complete, and low-cost monitoring of all the structures can now be envisaged.

This paper aims to list the main uses and benefits that could be expected:

1 – Knowledge of the real structure

Most of the works (buildings, bridges, dams…) are designed according to rules including safety coefficients representing uncertainties on material characteristics, loads, execution…The monitoring of the structure ensures afterwards the reliability of the studies carried out for the design and gives information useful to calibrate future calculations.

2 – Survey of the structure

A building or civil engineering work is generally designed for a 50 years project life or more. During this period, the probability that an exceptional event occurs (fire, storm, earthquake…) isn't negligible. Often the question is whether the structure has suffered significant damage or not. A permanent monitoring provides an immediate answer: a significant modification of the dynamic characteristics reflects an evolution of its stiffness, and a probable occurrence of damage. A targeted action can therefore be launched to evaluate the damage extent. Conversely, a stable response means that the structure hasn't been hit.

This monitoring also detects unusual behavior: we have been informed about the increasing degradation of the junction between the mast of a wind turbine and its foundation. The same measurements have later shown the efficiency of the strengthening solution.

3 – The evolution of measurement systems

Thus far, we have mainly used instruments designed for geophysical uses. Today, due to the advances in electronics, smaller devices offer equivalent features. The cost, size and power requirements decrease strongly, and a systematic monitoring becomes possible.

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Inspection, structural health monitoring and maintenance of a cable-stayed bridge in Vienna, Austria

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ABSTRACT

Donaustadtbrücke is a cable-stayed bridge over the Danube in Vienna, Austria. The bridge was erected as a road bridge for public buses in 1994. The bridge had been designed for later upgrade to a metro bridge.

The inspection and maintenance concept included periodic visual inspection as well as periodic structural health monitoring activities like the measurement of the stay cable forces and of the dynamic characteristic of the bridge.

In 2008 the bridge was modified to a metro bridge for the extension of Vienna's underground railway line U2. This included the upgrade of the load-carrying capacity by doubling the number of stay cables. The construction works were accompanied by monitoring activities with a special focus on the old and new stay cables.

In 2013 and 2014 remarkable stay cable vibrations were observed at the longest stays, which led to interruptions of the traffic of the bridge. The stays and especially the stay anchorages were checked for damage by visual inspections and measurements. Based on the measurement of the dynamic characteristic of the stays and the bridge deck, stay cable vibration measures were developed and installed. Additionally, a permanent monitoring system was installed to monitor the most vibration-prone stays and the function of the vibration mitigation system.

In 2015 damage was detected at the hinged columns at the south abutment. Measurements were carried out to assess the reasons for this damage. Furthermore a principal inspection of the bridge was done in 2015, followed by maintenance works.

The paper and the presentation will cover all inspection, measurement and monitoring activities of the bridge.

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Numerical investigation of bridges with the aim of condition assessment in applying the Deformation Area Difference method (DAD-method) and selecting appropriate measurement techniques

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ABSTRACT

Condition assessment of existing bridges gains ever increasing importance today as bridges are getting older and the inflow of heavy traffic is constantly increasing. The further development of recognized techniques and the development of new methods for early and accurate detection of damage to the structure are made possible by means of innovative technological progress. In this contribution, the principles of Deformation Area Difference Method (DAD-Method) for condition assessment of bridges are presented. This method is based on the further processing of measured and computed deformation values. The application of the DAD-Method requires a precise recording of the deflection of a load-deflection test. On the basis of theoretical calculations, this method has allowed to identify as well as to localise damage to a structure. The DAD-Method is independent of a reference measurement and insensitive to global influences such as temperature fluctuations. For precise recording of deformations, the most modern measuring instruments and methods like photogram-metry, total stations, displacement sensors, strain gauges and levelling are compared to each other. In collaboration with the appropriate measurement technology, the localisation of damage in bridges becomes possible.

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Safety assurance of problematic concrete bridges by automated SHM: Case studies

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ABSTRACT

Structural Health Monitoring (SHM) is currently being more and more applied, all around the world, for the analysis of bridges and buildings. It greatly improves the knowledge available about structure's behavior and condition, both qualitatively and quantitatively, reducing uncertainties and increasing structural safety.

This paper shall present various recently designed and installed SHM systems. The diverse range of applications, designed in collaboration with structure owners and design engineers, includes concrete long-span box girder bridges and concrete viaducts. The systems are assigned to fulfil 4 major tasks such as monitoring of environmental loads (temperature, humidity), monitoring of the crack behavior, settlements, monitoring of strains, displacement and vibrations under rail and road traffic.

These case studies are excellent examples of ongoing monitoring activities, based on both static and dynamic approaches. As well as presenting the application of innovative monitoring techniques, the case studies demonstrate statistical models and data processing procedures that have been developed and applied in order to eliminate uncertainties and maximize the benefits gained from monitoring data.

All of these techniques have been used in the present study, and more importantly, have been applied to important concrete bridges that were in danger of settlements (Fig. 1) , deterioration (Fig. 2) or under modification of structural schemes.



Figure 1. Views of the monitored structures of the Hunter Expressway.

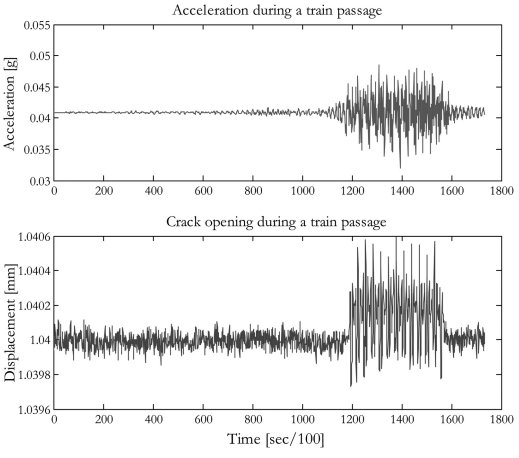


Figure 2. Train passage effects, in close view, on the accelerations and on the crack opening of the bridge.

Additionally, automated monitoring of structures does indeed have much to offer right throughout a bridge's life-cycle. Such systems can also be used, for example, to provide structural engineering or bridge usage data, or immediate notification of the reaching of predefined values of any measured variable. The examples of the use of such a system at various stages illustrate this – starting with a case study from the very start of a bridge's life.

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Sensor-enabled geogrids for stabilization and instrumentation of Earth structures

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ABSTRACT

Sensor-enabled geogrid (SEGG) technology has been introduced and developed by the authors in the past few years as a new category of geogrid products that possess embedded strain-sensing capability in addition to their conventional reinforcement/stabilization function in geotechnical and transportation applications. In this technology, the strain-sensing function of modified geogrids (i.e. SEGG products) stems from their tensoresistivity, which is the sensitivity of their electrical conductivity to tensile strain.

This paper reports the state of development of the SEGG technology and reports latest findings on both the in-isolation and in-soil tensoresistivity performance of SEGG specimens (e.g. see Figure 1). The authors' research study on the SEGG technology has so far yielded promising results showing its potential as a practical and cost-effective alternative to existing technologies for performance-monitoring of geotechnical structures. For instance, strain gauges typically require expensive data acquisition systems, which is an impediment to their widespread use in field projects. In comparison, the SEGG technology is amenable to measuring and monitoring strains in large numbers in geosynthetic layers (e.g. geogrid reinforcement), allowing for significantly larger numbers of data points including e.g. those at comparable locations within the structure. As a result, the SEGG technology helps to improve the accuracy and reliability of the measured performance data significantly.

Ongoing research on the SEGG technology includes more detailed study of their in-soil performance and addressing practical issues such as durability and protective measures for field installation before they can be pilot tested in field projects.

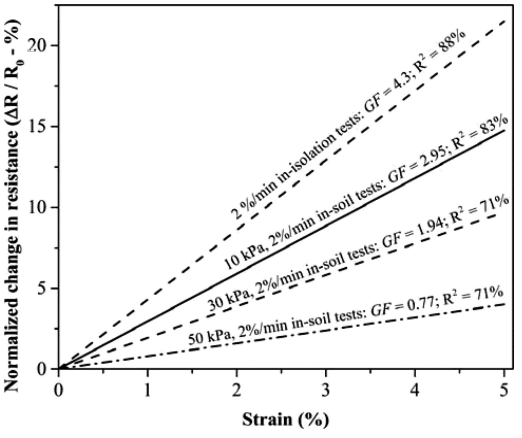


Figure 1. In-isolation (strain rates = 0.15, 2 and 10 %/min) and confined (confining pressures = 10, 30 and 50 kPa) normalized resistance of SEGG specimens as a function of strain.

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Subsequent sensor installation for corrosion monitoring of reinforced concrete structures

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1 INTRODUCTION

Durability prognosis of reinforced concrete structures especially if exposed to aggressive environmental impact, such as bridges, car parks, off-shore structures, needs permanent or from-time-to-time information on certain condition parameters of relevant structural members. A very important information is, where and to which depth corrosion inducing substances have been penetrated into concrete cover of reinforcement or if corrosion has already started to proceed. The availability of suited measurement devices for such purposes is very limited.

In this contribution, the development and testing towards prototype status of a new, compact, wireless and robust corrosion sensor is reported. This sensor can be integrated into the cover-layer of reinforced concrete structures. Due to the chosen compact geometry of the sensor it is possible to detect the progress of the depassivation front in staggered intervals of depth (e.g. due to carbonation or critical chloride concentration). The sensor can be applied both to new-built and to existing structures as well. For latter purpose a main problem which has to be solved is, how to install the sensor into boreholes without any defects of coupling by help of bonding and without influencing the corrosion inducing transport phenomena. Suited mortars and application methods for different mounting conditions have to be found and a quality assuring system to avoid the formation of voids during installation has to be developed.

The wireless sensor for corrosion monitoring is shown in Figure 1. The overall dimension amounts to 50 mm in height and 40 mm in diameter. Thus, the application of the sensor is possible even in complicated installation conditions. The sensor shell features four notches at a spacing of 10 mm which contain a tenuous iron wire as sensitive element. Due to the chosen geometry with its four wire layers it is possible to detect the progress of the depassivation front in staggered intervals of depth. The resistance of the wire is measured in constant intervals. In case of corrosive attacks, one or several of the wires depassivate and corrode on a short-term basis.

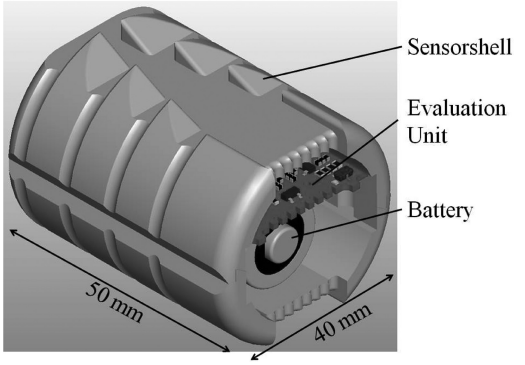


Figure 1. Sensor Prototype.

The sensor is applicable to new build structures. Then the sensor is fixed to the reinforcement before concrete is placed. There is a direct connection between the sensitive element of the sensor and the surrounding concrete, enabling accurate measurements. Beyond that a subsequent sensor installation is possible, which represents the majority of case of application. For this purpose the sensor can be installed within a bore hole (Ø 45–46 mm), which is filled up afterwards with a suited grouting mortar. In the full paper, the development and testing of the grouting material and the installation process in lab and in first field application is reported.

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The Netherlands changing for a European skid resistance measurement method

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ABSTRACT

Rijkswaterstaat, the Dutch National Road Agency (NRA), will change its existing skid resistance measurement method. Per 2017 the present longitudinal skid resistance method (RAW 72), originally developed by Rijkswaterstaat 60 years ago, will be replaced by measuring transversal skid resistance with the Sideway Force (SWF) method. This method is presently used in nine European countries and four countries outside Europe. Major consequence is that Rijkswaterstaat will have no longer its own measuring devices that are used for quality assurance and incidental measurements.

The paper starts with an overview of European harmonization attempts in the field of skid resistance measurements, the motivation for the change to the Sideway Force method and the decision process which has taken place. This included an exploration, a risk session and a pilot project of comparative measurements between the current RAW 72 method ant the SWF method.

Overall conclusion was that a change for the SWF method is possible. A business case report has been made with the advice for the Board of Rijkswaterstaat to make the change to the SWF method. In August 2014 the Board followed the advice and decided to make the change per 2017 for the main road network in the Netherlands.

The major part of the paper discusses the process which has been developed to ensure a robust and smooth transition. The main activities of this process are:

1. setting up a cooperation with the BASt for the quality assurance. Aim of this cooperation is:
   – approval and calibration of the Dutch SWF systems according to the existing German standard;
   – performance of control measurements with a BASt-device on the Dutch network during regular monitoring;
   – exchange of research activities;
2. European tendering for the annual network monitoring with SWF method of the complete road network;
3. carrying out a full scale trial campaign with the current Dutch device and SWF in 2016 to determine a conversion factor between the two methods and to define new threshold values for maintenance and contracts;
4. changing current contracts with road contractors;
5. performing specific measurements on selected topics (seasonal effects, curves and lower measurement speeds).

The implementation of the SWF method is progressing as planned. The full implementation remains therefore foreseen in 2017.

The skid resistance measurement method RAW 72 for use on the main road network will therefore terminate in 2017, consequences for the provincial and municipal roads have to be decided by those road administrations. RWS will withdraw its own measurement device and will terminate the ownership of the RAW 72 method.

BASt will watch over the quality control of measurement devices used on Dutch main road network and will perform on a regular basis control measurements. The annual monitoring campaign, the acceptance control of new surfaces and the assessment of warranty will all be measured by SWF. After two full years of operating production measurements, an evaluation will be held.

SPECIAL SESSIONS

SS1: Learning from excellent performance

Organizer: K. van Breugel



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Critical success factors for construction projects: A survey of Brazilian companies

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ABSTRACT

In the last decade, the Brazilian economic scenario was favorable to the construction sector, fostering its growth especially in large infrastructure projects such as the expansion and construction of airports, roads, stadiums, among others. However, many of these projects have gained notoriety for their poor management performance, leading to schedule delays, increased costs and quality gaps of the delivered works.

Due to the relevance of the construction sector for the economy, it is imperative to ensure that these projects have the expected performance (HWANG & LOW, 2011). Therefore, there is a need to identify any factors that might influence the likelihood of such projects be succeed.

In that respect, there is a line of study in the literature of project management that deals with the so-called "Critical Success Factors" (CSF), a term that was first used by Rockart (1982) to designate "critical elements" that influences success in any kind of project.

The identification and categorization of these elements can serve to guide managers in this area and also expand the academic understanding about the determinants of success in construction projects. So, considering this scenario, this work has as its main purpose to understand the influence of CSFs in the obtaining of success in construction projects.

The research was initiated analyzing the scientific literature on project management and identifying the CSFs associated with construction projects, as shown in table 1 and 2.

Considering the CSFs presented in Tables 1 and 2 a questionnaire based on Liket scale was built using CSFs as independent variables and a multidimensional success measure (efficiency, organizational learning customer satisfaction and "preparation to the future") was used as response variable.

Then a survey on Brazilian companies from construction sector was carried out obtaining 164 valid responses.

Table 1. Human and Organizational CSFs.

Human aspects	Organizational aspects
Proj. manager competence	Efficient communication
Proj. manager experience	Empowerment
Proj. manager leadership	Organizational structure
Proj. team integration	Change management
Proj. team flexibility	Top support management
Conflict treatment	Lessons learned

Table 2. Project management and Environmental CSFs.

Project management	Project environment
Project planning	Project size
Monitoring and control	Corruption
Clear objectives	Excessive bureaucracy
Requirements management	Stakeholders involvement
Risks identification	Safety conditions
Risks responses	
Risks control	
Incentive mechanisms	
Disincentive mechanisms	

The data was analyzed with the logistic regression technique and the main results shows that only few of the CSFs are significant to explain the success: 7 explain the success in the efficiency dimension, 5 in the organizational learning dimension, 4 in the customer satisfaction dimension and 5 in the "preparation to the future" dimension and each one has a different level of influence on construction projects success.

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Dynamic deformations of reinforced concrete beams during their total service-life

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ABSTRACT

The number of bridges which are monitored by Structural Health Monitoring systems is increasing rapidly (Salawu, 1997). The aim of such monitoring system is to provide an early warning system for malfunction or failure of a bridge by monitoring the deformations of the bridge over time (Priya & Inman, 2009). However, for such early warning system, it is required to understand potential changes in the deformations of the bridge. Dynamic tests of Reinforced Concrete (RC) beams have been conducted. During these tests, the deflections of the beams have been monitored during their total service-life.

Every test contained two RC beams. Both beams had a length of 1500 mm, a width of 100 mm, and a height of 150 mm. Both beams were reinforced with a single steel bar with a diameter of 12 mm. The beams were loaded in a four-point-bending configurations whereby bending cracks have been developed in the top section of the beams. To initiate corrosion of the reinforcing bar of one of the beams, the first beam was exposed to a chloride-solution for two days per week. The second beam, which acted as a reference, was exposed to tap water during the same period. The tests were conducted in a climate controlled room with an ambient temperature of T = 20° C (±2° C) and an ambient humidity of RH = 50% (±10%).

Small fluctuations in the deflections of the beam were observed during the tests. These deflections were caused by fluctuations in the ambient temperature. Wetting/drying cycles resulted in larger changes in the deflections of the beams. In the first 99% of the load cycles, the deflections of the beams increase slightly. During the last few thousand load cycles, larger deflections were observed. The development of the deflections of the chloride-exposed beams was similar to the development of the deflections of the beams exposed to tap water. The main difference between the chloride-exposed beams and the beams exposed to tap water is the number of load cycles until failure (Figure 1).

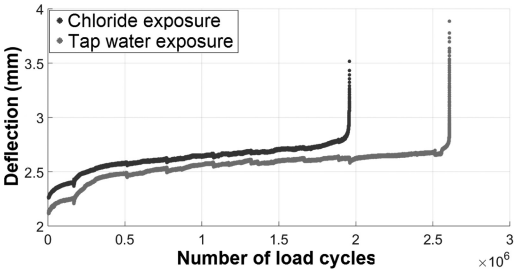


Figure 1. Deflections of a chloride-exposed beam and a beam exposed to tap water (Load = 12 kN). Flexural failure had occurred in both beams.

The Dutch environment contains far larger fluctuations in the ambient temperature and ambient humidity than they were performed under laboratory conditions (Miao, 2014). Therefore, the impact of environmental fluctuations on the deflections of concrete structures is larger in the Dutch environment than it was in the laboratory. Since damage-induced deformations can only be observed in the last few thousand load cycles and the probability of observing the damage-induced deformations is limited, it was concluded that deformations of concrete bridges cannot be used as early warning systems.

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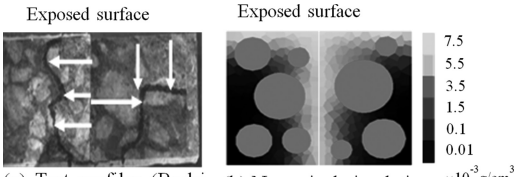
Lattice-based simulation of water and chloride transport in cracked-unsaturated concrete on mesolevel

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ABSTRACT

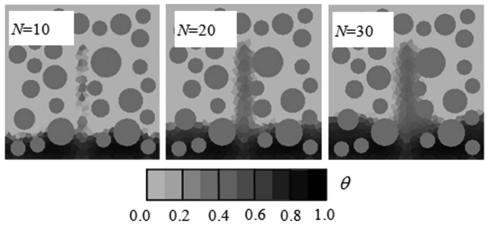
It is widely recognized that chloride-induced corrosion of reinforcing steel is one of the most common causes for the deterioration of reinforced concrete structures, especially under the cracked-unsaturated state. In terms of the characteristic of internal structure of concrete, numerical analysis of mass transport in concrete by mesoscale method, in which concrete is described as a three-phase composite consisting of the coarse aggregate, hardened cement mortar and the interfacial transition zone (ITZ) between aggregate and mortar, not only may enhance understanding of the non-homogeneous characteristic of concrete but also can represent influence of material composition and cracking on transport properties. Generally speaking, mesoscale numerical simulations, coupled with correlation theory and experiment results, are considered to be an extremely important tool for successfully predicting material mechanical property and mass transport process by means of computational materials science.

Recently, there have been many studies on the mesoscale modeling of water and chloride transport in saturated/unsaturated or sound/cracked concrete. In this paper, the partial differential equations of water and chloride transport are solved by the Galerkin weighted residual method and the Crank-Nicholson method. Compared with the available findings from the literature, the transport coefficients of water and chloride through a single crack treated as a parallel-plate configuration are developed and validated (see Figure 1). The numerical prediction of water and chloride ingress into cracked-unsaturated concrete subjected to drying-wetting (D/W) cycles was conducted by coupling of above-mentioned models, and the D/W cycles were investigated to visually present the water and free chloride content distribution by lattice-based numerical simulation (as shown in Figure 2). It indicates that the water and chloride content distribution and penetration depth increase with an increase of cyclic times.

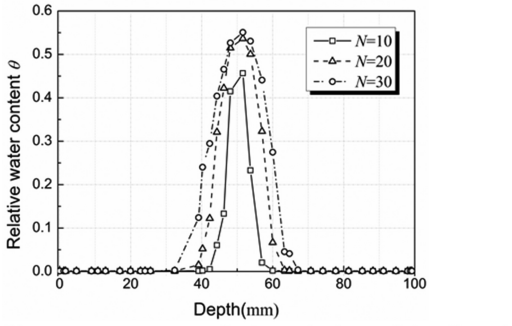


(a) Test profiles (Rodriguez and Hooton 2003) (b) Numerical simulation

Figure 1. Chloride ingress profile in cracked concrete.



(a) Water content distribution



(b) Water content perpendicular to single parallel-wall crack

Figure 2. Water content distribution in cracked concrete after different D/W cycles.

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Deterministic *versus* probabilistic approach of the factor method for the service life prediction of ceramic claddings

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ABSTRACT

Buildings and their components constitute an extremely important asset of contemporary societies. Service life prediction allows adopting more rational and sustainable solutions for their management. In recent decades, the possibility of incorporating data on the service life of materials and components during the design and construction phase has been thoroughly analyzed (Soronis, 1996) and currently there are several methodologies available for the service life prediction of buildings and their elements. Among the different methods developed, the factor method (FM) is considered a general framework for the evaluation of building components' service life in the specific conditions of use (Daniotti et al., 2008). The factor method allies simplicity to flexibility, despite its known limitations, in particular, when it is seen as a purely deterministic tool. Also, this method usually ignores the degradation condition or the pattern of loss of performance over time of the elements under analysis.

This study addresses the service life prediction of ceramic tiling systems. For that purpose, 186 ceramic claddings are analyzed in real life use conditions, based on visual inspections. The factor method is then applied as a service life prediction method. To overcome the limitations of the method, in this study the results obtained are validated by comparison with real data, observed during the fieldwork. Two approaches are proposed: i) a deterministic one, in which the durability factors are quantified by an absolute value, resulting from an iterative analysis, minimizing the deviations between the observed values and the values predicted by the factor method; and ii) a probabilistic one, in which a probability distribution is adjusted to each durability factor, leading to an estimated service life also given by a probability distribution, based on the assumption that a probabilistic approach may be more appropriate to model the variance of real-life phenomena, such as the degradation of ceramic claddings.

The most relevant parameters in the degradation of ceramic claddings are also identified in this paper: i) the type of surface; ii) the colour of the façade; iii) the size of the tiles; iv) the type of substrate; v) the presence of peripheral joints; vi) the presence of peripheral protection; vii) the façade orientation; viii) the distance from the sea; ix) the exposure to wind-rain action; x) the exposure to damp; and xi) the ease of inspection. Other relevant durability factors cannot be evaluated since the claddings degradation condition are evaluated based on visual inspections only.

The application of the deterministic approach of the FM leads to an average estimated service life of 50 years, with a standard deviation of 9 years. Using the graphical method, an average estimated service life of 54 years is obtained, with a standard deviation of 18 years. In the stochastic approach, the durability factors are translated into probability distributions, so that the estimated service life of each case study within the sample is given by a probability distribution. To demonstrate the applicability of this approach, this model is applied to three case studies. The proposed methods lead to similar results. The three ceramic claddings analyzed are used to illustrate the applicability of the stochastic approach of the FM. Furthermore, the application of this approach may be extended to the whole sample.

This study provides crucial information to support the decision-making process in the construction cluster, namely in the definition of maintenance and rehabilitation plans and in the definition of insurance guarantees.

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Long-term performance of marine structures in The Netherlands – Validation of predictive models for chloride ingress

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ABSTRACT

In the late nineties an international research team has developed a conceptual and numerical tool for service life prediction of concrete structures. This has resulted in the DURACRETE model, particularly used for predicting chloride transport in concrete and chloride-induced corrosion. Model parameters were defined on the basis of a large number of available data on chloride profiles and theoretical considerations. After the launching of the DURACRETE model a commission was installed in The Netherlands with the aim to further validate this model by comparing the chloride profiles in existing marine structures with profiles predicted with the DURACRETE model. Structures were chosen of different age, different exposure conditions and different mixture compositions.

Six structures were selected for field investigations which were thought representative for a larger group of structures: 1) The Pier at Scheveningen is a bridge-type structure, with a promenade deck composed of precast cross beams and precast slabs, supported by precast piles; 2) The Haringvliet sluices, composed of in-situ cast piers and precast bridge elements; 3, 4, 5) Three quay walls, located in Rotterdam harbor; 6) The Eastern Scheldt Storm Surge Barrier. A cross section of this barrier is shown in figure 1, with an indication of the test areas. The barrier was built in the 1970s and consists of 65 piers, horizontally connected by threshold beams on the sea bed and upper beams extending from sea level to about +8 m. Beams were cast in a plant nearby as elements of about 20 m length, two of which were cast together on site to form one span. The main structure was designed for a service life of 200 years, whereas the bridge superstructure was designed for 50 years. sheltered by an overhanging part of the driveway.

In this paper it will be shown that numerical models, like DURACRETE model, can describe chloride profiles sufficiently accurate for supporting decision making processes concerning required density of the concrete and thickness of the concrete cover in order to ensure a predefined service life of marine structures exposed to moderate climate conditions. By adjusting only two parameters a good correlation was established between predictions and observed chloride profiles in the examined structures. This points to a high degree of robustness of the model, even though there appeared scope for refinement of the model. Further refinement of the model, however, should keep step with the accuracy with which other factor that affect the service life are under control. From this research project is could be concluded that the performance of real structures could be predicted reasonable good with the DURACRETE model.

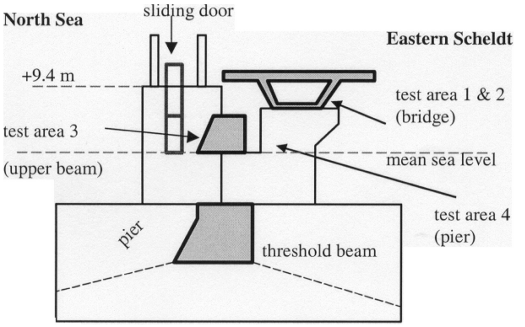


Figure 1. Cross section of Eastern Scheldt Storm Surge Barrier.

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SS2: Durable materials for longevity of ageing concrete infrastructure

Organizers: H. Jonkers & K. van Breugel



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Self-healing of corrosion damage in reinforced concrete through the application of polymeric nano-materials: Brief review of recent studies

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ABSTRACT

Establishing a novel and feasible technology for corrosion control in civil structures, through utilising a cross-border research, has been the objective of our recent research within self-healing & nano-materials application. With this regard and in view of novelty and originality, the application of tailor-made, polymeric nano-architectures for self-healing of corrosion damage (Fig. 1a–e) was recently studied.

Tailor-made polymeric nano-composites for simultaneous corrosion protection and improved bulk matrix properties, including self-healing mechanisms is a novel approach. Our recent studies on (hybrid) core-shell particles e.g. PEO_{113}-b-polystyrene $(PS)_{218}$ micelles (50 nm size), Fig. 1f), revealed that in their presence (0.024 wt.% per cement weight), the porosity of the micelle-modified matrix was reduced two times, water permeability was reduced with six orders of magnitude; a more uniform distribution of C-S-H and enhanced mechanical properties, but un-disturbed water balance was evident from nano-indentation tests. From corrosion view point, stabilized (kinetically frozen) PEO_{113}-b-PS_{760} vesicles (200 nm size), "empty" and $Ca(OH)_2$ containing ones, were studied. Increased corrosion resistance was recorded in the presence of Ca-containing vesicles. The mechanism was hypothesized to be related to increased barrier effects and Ca-core release, triggered by: initial Cl-induced restructuring of the PEO-based "shell", followed by diffusion limitations and osmotic pressure effects at the interface of the vesicles' outer membranes. Consequently, the steel/cement paste interface (Fig. 1a–c) and the steel surface (Fig. 1e) of vesicles-modified matrix showed no corrosion product accumulation, but rather "healed", Ca-rich interface (Fig. 1c) in contrast to the vesicle-free specimens (Fig. 1b,d). These global mechanical, microstructural and electrochemical properties indirectly proved a plausible self-healing process. The exact chemical, physicochemical and electrochemical mechanisms were further revealed by specific electrochemical tests. Cyclic Voltammetry justified the self-healing effect over time, supported by results from electron microscopy and X-ray analysis of steel surfaces and steel | cement paste interfaces. This paper will briefly review main outcomes from the above recent research on the application of vesicles and hybrid nano-architectures for corrosion control in reinforced cement-based materials.

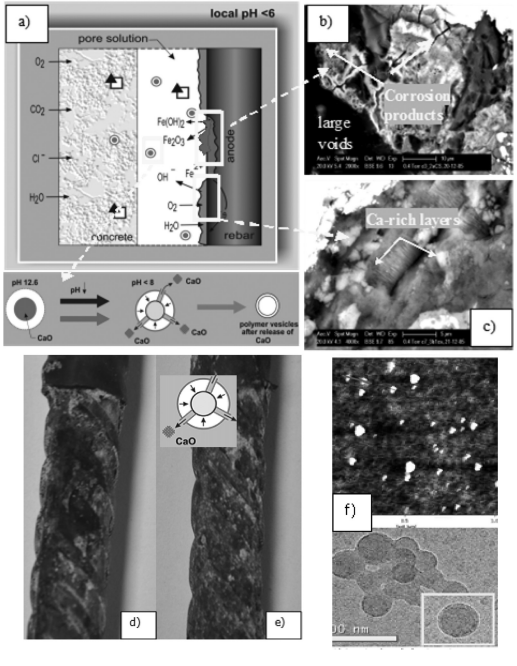


Figure 1. (a) Schematic of Cl-induced corrosion in reinforced concrete and controlled-release active substance; (b) corroding interface; (c) healed interface; (f) AFM (liquid cell) and TEM of PEO-b-PS nano-particles.

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Ageing of materials in civil structures

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ABSTRACT

The ageing of materials in civil engineering structures is a natural phenomenon. Corrosion of steel in concrete structures and fatigue of steel are examples of daily observed deterioration processes in structures now infrastructure becomes aged. The challenge for the nearby future is to keep the structures reliable at a high level of performance while the structure itself ages without having to spend huge amounts of money.

For lifetime optimization, service life prediction, time-variant reliability and life cycle cost, time is a dominant factor. Engineering on these performances of a structures requires reliable predictions of how a structure functions in time. In time the materials used in the structure will change due to ageing. The origin of these changes are primary from the natural change in materials. A material will age even when it is not used at all. Other factors will influence the ageing process. The environment and its use of the material will influence the ageing process and can lead to enhancement of the rate of ageing.

To improve the forecast of life time of structures knowledge of ageing is required. This knowledge can be gained with fundamental research on the chemistry, life science, physics, electromagnetism, mechanics, mathematics and design in respect to ageing. This research requires a multidisciplinary and multi-level scale approach. The Delft Centre of Materials initiated the Ageing Centre at the Delft University of Technology. Its goal is to investigate and model ageing phenomena at fundamental materials level and to make ageing predictable at the level of materials, devices, structures and systems.

This paper presents the framework that will be used by the Ageing Centre with which the balance can be made between the required performance and the require efforts to maintain this performance. The frame-work also shows how knowledge of the materials gained from inspections and tests are used to make reliable predictions of material changes and how this can be used for life cycle engineering of civil structures.

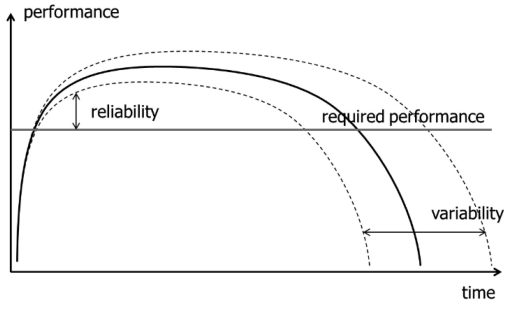


Figure 1. Life cycle engineering based on the performance of a structure.

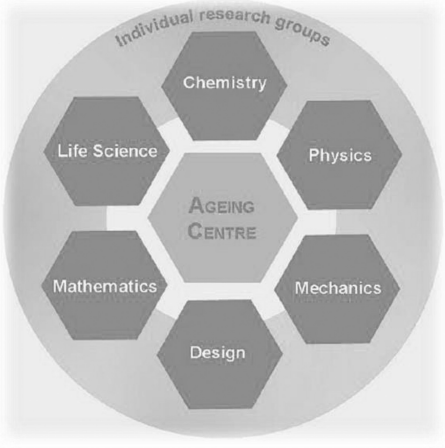


Figure 2. Multidisciplinary approach for research on ageing o materials, structures and systems.

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Comparison for permeability resistance between concrete and mortar

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ABSTRACT

Mortar using for repairing on reinforced concrete structures. The substances such as carbon dioxide and chloride ion will be penetrated into the concrete or mortar. However, it is existing the interfacial transition zone while the aggregate interface and paste in the concrete. In this study, using a mortar obtained by removing the coarse aggregate from concrete, it was carried out a comparison of resistance of permeability between concrete and mortar. As a result, it decreases the permeability resistance by the water cement ratio is increased in ordinary Portland cement and blast furnace slag cement by carbonation resistant. The permeability resistance of concrete tends to decrease significantly compare to mortar by the interfacial transition zone. On the other hand, in case of the salt resistant, it is not clear the effect of interfacial transition zone. Thus, it becomes formed pores like water reservoir to the lower surface aggregates by bleeding.

1 CONCLUSIONS

The results obtained in this study a comparison of the mass transfer resistance of mortar and concrete is as follows.

(1) The presence of coarse aggregate is different from the effect on the material permeability on water cement ratio.
(2) The difference between the substance permeability of the mortar and concrete is assumed to be the effect of the interfacial transition zone. And it has the different tendencies depending on the type of cement.
(3) The presence of coarse aggregate, that prevent the moisture rise due to bleeding, then the interfacial transition zone is generated.
(4) The presence of the interfacial transition zone is affected the pore gap and the great influence on the mass transfer.

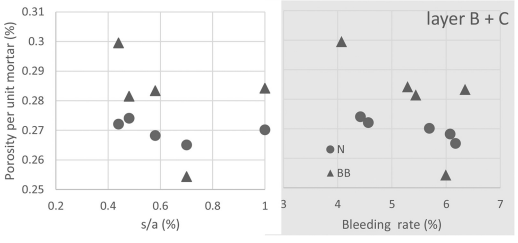


Figure 1. Relationship between s/a or bleeding ratio and porosity per unit mortar.

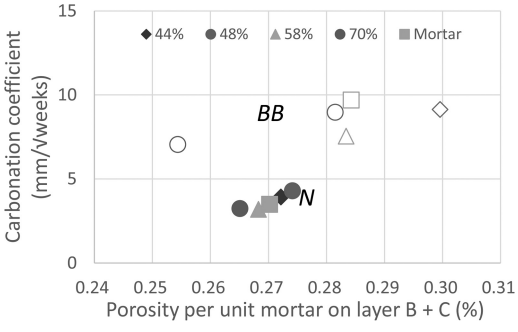


Figure 2. Relationship between porosity per unit mortar and Carbonation coefficient.

(5) Carbonation and moisture movement is seen to be highly dependent on the interfacial transition zone and the pore characteristics. Meanwhile chloride ion penetration, it is difficult to understand the only pore properties.

In the future works, for the improvement of the lower surface aggregate, we want to consider the following method.

a. Use of aggregate with reaction activity
b. Use of ultra-fine powder that was aimed at fine powder effect
c. Enhancement of the interface by reaction with C-S-H Nano-particles.

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Durability design of reinforced concrete structures with stainless steel reinforcement

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ABSTRACT

In the design of reinforced concrete structures exposed to aggressive chloride bearing environments, the use of stainless steel reinforcement can allow achieving the durability target. Usually the choice of the stainless steel grade is based on expert opinion or practical codes developed by public institutions or producers, instead of performance-based approaches which would allow to quantify the service life of a structures. However, unfortunately, in some of the nowadays available performance-based approaches, especially the Model Code for Service life design proposed by the *fib*, designers fail in finding any specific indication for stainless steel bars [Lollini et al. 2015]. For instance, the *fib* model does not provide any suggestion about the critical chloride threshold of these types of bars, Cl_{th}. Unfortunately, the determination of this parameter is not an easy task, since it is influenced by many parameters (exposure conditions, steel composition, surface conditions, etc.) [Lambert et al. 1991, Thomas 1996]. Hence, there is the need to develop an experimental test that allow the evaluation of Cl_{th} for the specific grade of stainless steel and that can be used as a compliance test within this approach.

To use any test result as an input parameters for performance-based design approach some requirements, i.e. the possibility to account the factors which can affect Cl_{th}, as for instance its dependence on the exposure environment, the role of the steel-concrete interface and its variability, should be satisfied. In this work, an experimental testing procedure was studied, developed and applied to reinforcing bars of austenitic-ferritic stainless steel type 1.4362. The test procedure to evaluate the probability density function of Cl_{th} is based on tests in concrete with mixed-in chlorides and potentiostatic polarization of steel to be carried out on ten replicate specimens.

Figure 1 shows the results obtained at different amounts of admixed chlorides on the stainless steel of types 1.4362 with the proposed methodology. For the amount of admixed chlorides at which the test is carried out, the number of specimens where corrosion occurred is reported. Being the test carried out at different amount of admixed chloride contents, by fitting the number of specimens out of ten that failed during the tests with the different admixed chloride content, the probability distribution function of Cl_{th} could be determined. Obviously, the results of this test are valid only for the specific material and the test conditions. To extend the use of this result as input parameter in performance-based design models, corrective factors, which take into account the effect of different parameters, e.g. the exposure conditions and the type of concrete, are discussed in the paper.

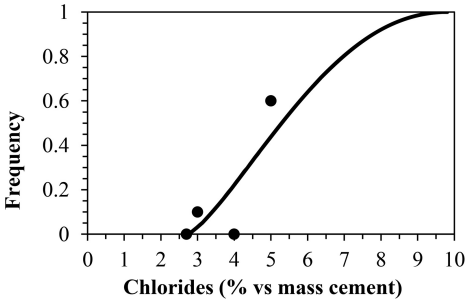


Figure 1. Cumulative distribution function of the stainless steel of types 1.4362.

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Effect of prevention for chloride ion using both of CA_2 and expansive admixture to low heat Portland cement

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INTRODUCTION

Salt damage is one of the serious causes of deterioration in reinforced concrete. Recently, $CaO \cdot 2Al_2O_3$ (CA_2) which react with calcium hydroxide from cement hydration and makes hydrocalumite. Its reaction is shown in formula (1). This hydrocalumite immobilize chloride ion as Friedel's salt. Its reaction is shown in formula (2). Thus, the soluble chloride ion is reduce. Finally, concrete using CA_2 has high resistance for salt damage.

In this research, we made and tested concrete using low heat Portland cement, CA_2 and expansive ad-mixture for shrinkage prevention. Table 1 shows the mix proportion of concrete. Using these concrete, we checked the resistance for chloride ion by immersed test in salt water. As a result of Fig. 1, we find that the concrete addition of CA_2 and expansive admixture is different between LPC and OPC. So, we assumed that the hydration product and hydration speed in LPC and the OPC are different due to the difference in chemical composition content. We made cement pastes with the addition of CA_2 and expansive admixture to the LPC and the OPC to measure the hydration product. Fig. 1 shows the specimen dimensions and experimental outline. Specimens were sealed curing. Specimen

Table 1. Mix proportion of concrete.

	Cement type	W/B (%)	s/a (%)	Unit Weight [kg/m^3] W	C	CA_2	Ex	S	G
L	LPC	50	48	163	326	–	–	876	974
L(0-20)					306	–	20		
L(10-10)					306	10	10		
L(10-20)					296	10	20		
L(15-15)					296	15	15		
L(30-0)					296	30	–		
L(30-20)					276	30	20		
N	OPC				326	–	–	873	971
N(10-0)					316	10	–		
N(10-10)					306	10	10		
N(15-15)					296	15	15		

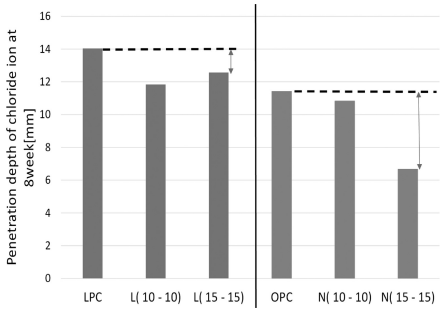


Figure 1. Penetration depth of chloride ion.

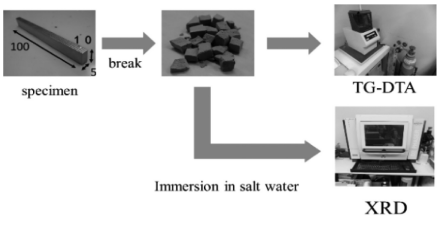


Figure 2. Outline of chemical test.

were crushed in every test age, for the purpose of confirming the hydration products, like monosulfate, ettringite, hydrocalumite, calcium hydroxide. Hydration products were measured by X-Ray diffraction (XRD). Further, for the purpose of measuring the amount of calcium hydroxide, Thermogravimetric-Differential Thermal Analysis (TG-DTA). When the addition of CA_2 and expansive admixture to the OPC and LPC, we confirms that the hydration product is different. In the case of adding OPC+CA_2+Ex, hydration products which has potential to immobilize the chloride ion are hydrocalumite and hydration product of the based on carbonate. In the case of LPC+CA_2+Ex, monosulfate was produced. We think that the ability which immobilize the chloride ion is different in each. This is the reason why the difference occurs in the penetration depth of chloride ions in the LPC and the OPC.

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Mechanical and microscopic properties of hybrid fibers reinforced self-compacting concrete

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ABSTRACT

As a high-performance building material with excellent construction performance, self-compacting concrete (SCC) has been widely applied to various structures worldwide. The research and application of fiber reinforced self-compacting concrete (FRSCC) is one of the effective methods in improving its basic mechanical properties, raising dimensional stability, increasing crack resistance, toughness and permeability resistance.

At present, researches on properties of fibers in concrete mainly focus on polypropylene and steel fibers. This study aims to research the influences of SCC mixed with hybrid carbon and cellulose fibers on its compressive strength, splitting tensile strength and microscopic properties.

Based on the test results obtained from this investigation, the following conclusions can be made:

1) The adding of carbon fibers impairs the compressive strength of concrete. When the content of 6 mm carbon fibers is 3.4 kg/m^3, 28d compressive strength can reduce by 21.82% in comparison with reference concrete; carbon fiber can improve the splitting tensile strength of concrete to the extent, namely if 6 mm carbon fiber is mixed, with its content up to 3.4 kg/m^3, 28d splitting tensile strength will increase by 72.5%; in case of the same content, 28d splitting tensile strength of concrete with 2 mm carbon fibers is lower than that with 6mm carbon fibers.
2) The incorporation of cellulose fibers can impair the compressive strength of concrete. When the content of carbon fibers is 2.0 kg/m^3, 28d compressive strength of concrete will reduce by 14.1%; while the incorporation of cellulose fibers can improve the splitting tensile strength of concrete, namely the splitting tensile strength of concrete will increase by 25.77% when the content is 2.0 kg/m^3.
3) During the orthogonal test on hybrid fibers reinforced concrete, the order of influences on the compressive strength is: content of carbon fiber > length of carbon fiber > content of cellulose fiber; the order of influences on the splitting tensile strength is: content of carbon fiber > length of carbon fiber > content of cellulose fiber, both of which indicate that content and length of carbon fiber have great influences on the mechanical properties of concrete.
4) The close bonding of cellulose fiber with cement matrix without large cracks on the interface can ensure that cellulose fiber acts simultaneously with the cement matrix in the process of concrete withstanding any external force; both carbon and cellulosic fibers suffer from a tensile failure with irregular fracture surfaces, indicating that both carbon fiber and cellulose fiber play their functions sufficiently.
5) Figure 1 shows there is a large gap between carbon fiber and cement matrix, which indicates that the bonding force between carbon fiber and cement matrix is weaker than that between cellulose fiber and cement matrix. It can be also observed that there are a large number of bubbles existing on carbon fibers, mostly arising from the fact that the incorporation of carbon fiber into the specimens will bring in a lot of hardly-removed air, which results in and the increase of cellular air vents on the specimen surface and the reduction of compaction rate, such effect will be more obvious with the increase of curing time and the evaporation of water from the concrete.



Figure 1. Carbon fiber in concrete.

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Multiple self-repair of concrete cracks by encapsulated methyl methacrylate

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ABSTRACT

In order to obtain more durable and sustainable concrete structures, nowadays, many researchers attempt to provide concrete with self-healing properties. In this way, crack appearance triggers a mechanism causing crack repair and thus the ingress of aggressive ions via the cracks is prevented.

One of the investigated self-healing approaches makes use of encapsulated polymeric healing agents. Upon crack formation, the embedded capsules break and the (components of the) healing agent is/are released towards the crack where it/they will polymerize and cause autonomous crack repair. However, it is important that the chosen healing agent results in a permanent barrier against the ingress of aggressive substances and thus that multiple crack healing actions can take place. Therefore, the use of a healing agent causing a crack repair which is stronger than the original matrix is suggested. In this way, later cracks will appear at another location were intact capsules are still available to cause a next self-repair action.

From previous research (Van Tittelboom et al., 2011) it was shown that methyl methacrylate (MMA) seems to be a suitable agent to fulfill the above mentioned requirements. It is a multi-component healing agent which is relatively insensitive to the mix ratio and which is characterized by a very low viscosity allowing it to fill the crack completely. Even more important, poly(methyl methacrylate) (PMMA) is able to create a bond with the cementitious matrix which is stronger than the cohesion within the original material. In the afore mentioned study, a two-component MMA based healing agent was used to obtain self-healing of concrete cracks. One component consisted of the monomer MMA, the initiator and a thickening agent and the second component consisted of the MMA monomer, an activator and a thickening agent. However, it was noted that the component of the healing agent containing the initiator already hardened inside the capsules. The other component of the healing agent seemed to remain stable. Therefore, in this study it was investigated whether the component containing the initiator, which hardened inside the capsules, could be altered to make this a successful healing agent for multiple self-repair of concrete cracks.

Three approaches were investigated. In the first approach it was tried to add a certain amount of inhibitor to the BPO compound in order to prevent early hardening. In the second approach the composition of the compound containing the BPO initiator was altered and the MMA was replaced by a solvent. In the last approach it was tried to change the two-compound healing agent to a one-compound healing agent and mix the BPO initiator into the cementitious matrix directly. The influence of adding initiator to the cementitious matrix on the fresh and hardened mortar properties was investigated and the most optimal initiator concentration was selected. In further research, the self-healing efficiency using the most successful approach(es) will then need to be investigated.

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Study on estimation technique of hydration on concrete in the mold by electrical resistance value

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ABSTRACT

Concrete structures are required to build a strength and durability. Moreover, it is also required to economically construct. Therefore, construction management is important. In construction management, we have some test the quality of the concrete at the time of acceptance. Even passes through the test, initial defects such as cold joint occurs. Therefore, it is important to monitor the hydration in the mold. However it is difficult to check the state of concrete in the mold. Then, we focused on the electrical resistance as a method to check hardening concrete for in the non-destructive test. It has been reported that the electric resistance of the hardening concrete has a correlation with compressive strength at remolding time and carbonation ratio. However, it is not measured in the fresh concrete. So, we measured the electrical resistance of fresh concrete in the mold. As a result, the behavior of the electric resistance is very similar to the results of heat of cement hydration measured by the conduction calorimeter. Moreover, the behavior of the electric resistance was correlated with the setting time. Thus, it can be monitored the hydration on concrete from fresh to harden in the mold by using the electrical resistance.

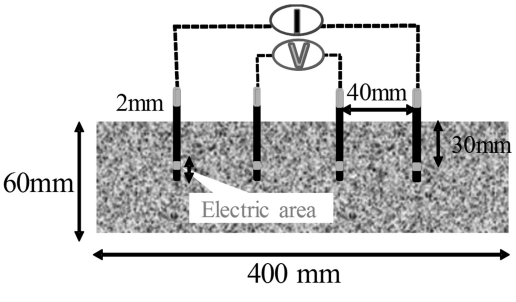


Figure 1. Outline of measurement method for electrical resistance using four-probe.

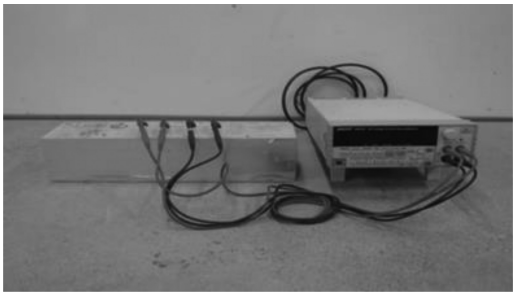


Photo 1. Electrical resistance using four-probe.

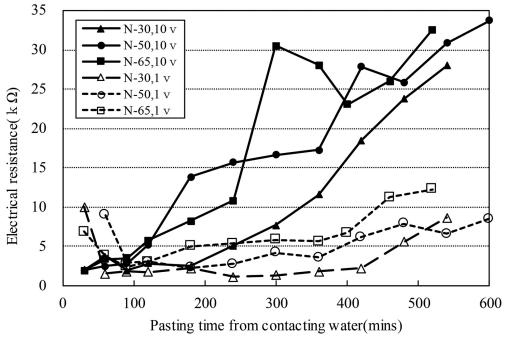


Figure 2. Measurement of electrical resistance in concrete.

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Climate change effect on deterioration of concrete structures in Finland

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ABSTRACT

The main reasons for facade degradation in the Finnish climate are freeze-thaw weathering of concrete and carbonation induced corrosion of reinforcement. A common denominator in every mechanism is water in varying forms. It can either work as a passage for harmful substances, e.g. chlorides, cause damage by its phase changes (freeze-thaw) or cause dissolution of substances in concrete. It has been shown before that future climate conditions in Finland are likely to get worse in terms of durability of structures exposed to climate. E.g. precipitation during the winter season is going to increase while the form of precipitation is going to be increasingly water and sleet. At the same time, the conditions for drying are going to get worse. In this study changes in the amount of freeze-thaw cycles, precipitation and carbonation rate due to the climate change were studied and their effect on deterioration of existing buildings was analysed.

As a result it was found that the climate change seems to have harmful effect on climatic factors critical to concrete degradation such as amount of wind-driven rain (WDR). The amount of freeze-thaw cycles after rain events will decrease significantly at coastal area and moderately at inland by 2100. However, successful air-entrainment is still needed for eligible service-life. While increasing amount of rain reduces carbonation rate the increase of CO_2 level has higher opposite effect. Thus the initiation phase of reinforcement corrosion is likely to be faster at future climate.

According to the study WDR is and will be focused mainly at southern directions at both studied locations. The amount of WDR is significantly higher at coastal area as a consequence of higher wind speed during the rain events (Figs 1 & 2). Together with remarkably increasing amounts of rain and sleet also the freeze-thaw conditions might get harder by the end of century, at least at inland.

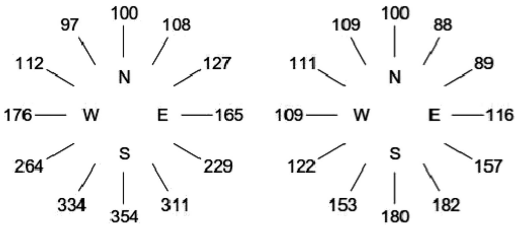


Figure 1. Relative amount of WDR at present climate from different wind directions compared to the north direction on coastal area (left) and inland (right).

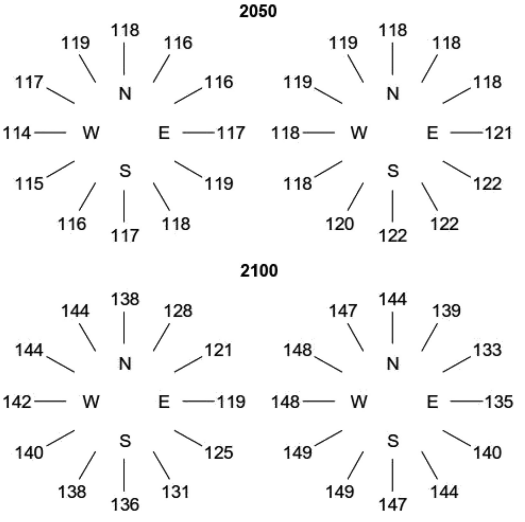


Figure 2. Relative change of the amount of WDR compared to the present climate on coastal area (left) and inland (right).

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Life-cycle modeling of critical slopes in Mexico, including the effect of strong rainfalls

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ABSTRACT

Huge losses, in human lives and property, caused by slopes that fail and are located on populated areas or besides important highways or infrastructure facilities, are producing that a lot of efforts are being conducted to mitigate the risks. A number of attempts to assess the hazard, to build databases and to model the land sliding phenomenon have been undertaken (Glade, 2001; Alcantara-Ayala, 2004; Glade, et al., 2005; Alcantara-Ayala, 2008). Monte Carlo simulation techniques and probability-based approaches have been used to analyze the slope stability and the parameters sensitivity (Wang, et al., 2010; Lari, et al., 2014). In this paper, the expected life-cycle cost is used to assess these risks in order to appraise the economic effectiveness of proposed measures to reduce the impacts of failure consequences. The potential change of slope vulnerability, due to the strong rainfall at the slope region, is considered in terms of the probability that the change on the soil properties trigger the slope instability and subsequent failure (see Fig. 1).

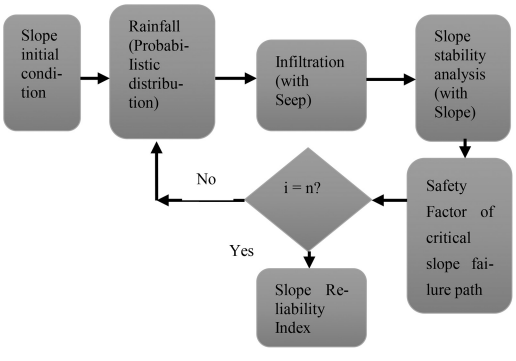


Figure 1. Flowchart with the proposed formulation.

Table 1. Soil properties (initial condition).

Soil	Cohesion	Friction angle (°)	Volumetric weight
Sand	8 kPa	35	18 kN/m^3
Silty Clay	10 kPa	25	19 kN/m^3

The slope initial condition includes the soil properties listed in Table 1.

The slope failure probability is compared to the acceptable value, which is expressed as a function of the level of failure consequences. The expected life-cycle cost of a hypothetical slope is assessed under the scenario of probable rainfalls and the beneficial effect of assumed measures of slope protection, and the cost ratio between investment for safety and the reduction on expected failure consequences are calculated to probe that the benefits offset by far the investments for failure prevention.

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On risk-based design of structures exposed to changing climatic actions

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ABSTRACT

Environmental and climate change is a global issue that will and has already impacted the frequency and intensity of natural hazards in many regions throughout the world. Consequently, climatic actions on structures will be changing and present design practices will need to be adapted to provide for reliable structures with service lifetimes spanning over decades and centuries. This review of present environmental and climate change information is focused on the distinct, but complementary climatic conditions of Central Europe and South Africa.

It is indicated that probabilistic approaches provide efficient tools to analyse the effect of climate change on structures and to support decision making concerning adaptation and mitigation strategies. The reliability analysis of a generic structural member reveals the sensitivity of the reliability index β to changes of the mean μ_Q and of coefficient of variation V_Q of annual maxima of the climatic action (Figure 1). Based on previous studies, the methodology of adjusting design provisions with respect to climate change is proposed.

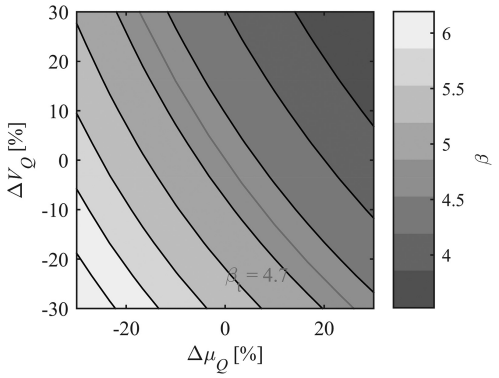


Figure 1. Sensitivity of β to changes of μ_Q and V_Q (annual target reliability index $\beta_t = 4.7$).

The present study suggests that it is more effective to adapt present design strategies for foreseen climate change effects rather than excessively invest into upgrading in future. The following conclusions are drawn:

1. Climate change has an impact on future extreme environmental actions on structures and should be considered; however more data, models and other information are necessary to better extrapolate future predictions of climatic actions.
2. Analysing historical observations, a statistically significant decreasing trend is found in annual maxima of snow loads for numerous locations in Central Europe.
3. Essential contribution of meteorologists and statisticians to civil engineering includes improved projections for trends and extremes in local weather events, and specification of uncertainties in events associated with 500- to 1000-year return period events.
4. Periodic review of statistical data and probability models related to environmental actions is required.
5. Revisions of design standards are recommended to reduce the impacts of climate change on load bearing structures. The scope of such revisions should include limit state failure verifications, global failure aspects and foreseen consequences of extreme events on built infrastructure.
6. Robustness will become more important as structures can be expected in future to be 'overloaded' to some extent due to climate change.
7. Reliability- and risk-based methods are sufficiently flexible to implement additional information related to climate change effects and provide rational background for decision making regarding protective and mitigation measures.
8. For consideration of very extreme events affecting whole regions and communities, resilience-based approaches will be needed.

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Energy balance and global warming potential of soil bioengineering structures

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ABSTRACT

With regard to climate change, energy consumption and consequential Life Cycle Assessment (LCA) is becoming more important. Within the research project 'E-Protect', the implementation of an Environmental LCA model in the field of natural hazards for the Austrian Service for Torrent and Avalanche Control will be realised.

This issue is also becoming relevant for soil bioengineering. It is a technique using plants for civil a hydraulic engineering purposes. It can be applied as standalone solutions or in combination with conventional engineering structures. So far, no LCA models exist for soil bioengineering constructions. Therefore a new systematic scheme with differentiation of the natural hazard processes for bioengineering constructions is developed. The most important output of the scheme is a list of needed materials for each construction type, because this information is necessary as input for LCA studies and working with OpenLCA (software). On the basis of the construction reports (of the WLV) conventional and soil bioengineering constructions are analysed, regarding their construction materials, construction processes and service lifetime. This information is used to expand existing databases (with additional materials and machines), which are used within the software OpenLCA. This is an important step, because the existing assessment schemes are based solely on economic feasibility studies. Furthermore, these innovative Environmental LCA models will provide a higher level of transparency for the responsible planners, by pointing out the effective costs – involving natural resources – of all construction phases and components.

SS4: Long term performance optimization

Organizer: P. Bakker



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Determining a functional responsibility allocation between public and private parties in a long-term maintenance contract for waterworks

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ABSTRACT

A proper allocation of risks and responsibilities is vital for the success of long-term maintenance contracts (Ward, Chapman, & Curtis, 1991). The maintenance phase of DBFM contracts has different characteristics in risk profile compared to the design and build phase. This paper focuses on a method to identify an adequate allocation of responsibilities for the maintenance of waterworks. In the Netherlands, the Dutch agency is responsible for the performance of the waterworks, but recently started to outsource the maintenance of their waterworks in DBFM contracts.

A methodology to verify the performance (regarding the reliability and availability) is available, known as Risk Based Asset Management (RBAM)) (Bogaard & Akkeren, 2011). This probabilistic methodology is contractually required, in order to meet with the Dutch Water Act. However, how to distribute the risks and responsibilities between the public and private parties is an open question.

This paper presents a functional risk allocation method, existing of a risk allocation matrix (see figure 1) and risk allocation conditions.

The risk allocation matrix provides a management structure for long-term contracting based on the degree of two uncertainty variables: frequency of failure and repair time of an element. The risk allocation conditions are imperative to ensure a reasonable and fair allocation. The conditions are related to the assessment and effective management of the responsibilities and risks. Compliance to the nine risk allocation criteria (see table 1) indicates if the risks can be managed effectively.

The method is validated and improved by analysing the application of the risk allocation method of three Dutch waterworks projects. On one hand the functional risk allocation is analysed and on the other hand the organisation regarding the maintenance and operation phase is scrutinised. This method provides a sound basis for the discussion of the degree of outsourcing from a technical point of view, how to maintain control form the client's point of view and how to assure optimal performance versus costs during the life cycle of the asset.

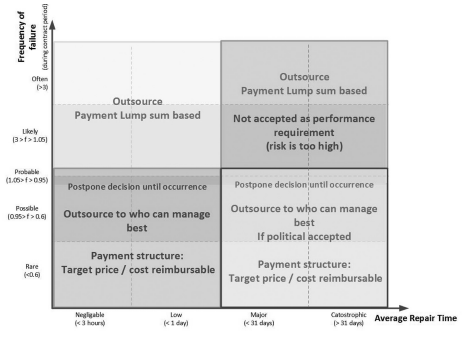


Figure 1. Risk allocation Matrix.

Table 1. Risk allocation criteria.

	Risk allocation criteria
1	Whether the party is able to foresee the risk/Has been made fully aware of the risks they are taking
2	Whether the party is able to assess the possible magnitude of consequences of the risk
3	Whether the party is able to control the risk chance of occurring
4	Whether the party is able to sustain the consequences if the risk occurs
5	Whether the party will benefit from bearing the risk
6	Whether the premium charged by the risk receiving party is considered reasonable and acceptable for the owner
7	The party is able to manage the associated uncertainty, and thereby mitigate risks
8	The party has the necessary risk appetite to want to take the risk
9	Whether the party is able to make use of the prescribed LPAM methodology.

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Interaction of long-term performance objectives and short-term performance requirements; a vision of RWS' asset management approach in 2030

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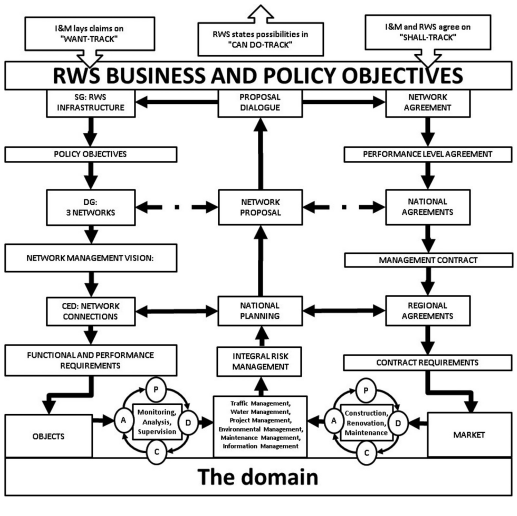
ABSTRACT

This document describes a vision of how for the Dutch main infrastructure the interaction can be managed between strategic performance objectives on policy level for the next 50 years on the one hand, and the functional performance requirements to be handled for the next 5 to 10 years on the other. The following applies here: the strategic performance objectives are determined by the Ministry of Infrastructure and the Environment (I&M), and the functional performance requirements are first applied by Rijkswaterstaat (RWS) to its own infrastructure and subsequently imposed on market parties. Part of this vision is establishing and reinforcing the relation and interaction of performance objectives at network as well as object levels, the so-called performance-driven Asset Management. As a consequence, this document contains a vision of RWS' Asset Management approach in the year 2030.

Three closely intertwined key concepts are used in this vision document:

1. The Performance Management model; this model describes the line of sight from policy goals through networking features to performance, risks and costs on network, network connection and object levels;
2. A cyclical procedure; Performance Management is not a static situation; it is shaped in a dynamic process of consultation between the Asset Owner (I&M), the Asset Manager (RWS) and service providers (market parties) (The three roles recognized as parts of the Asset Management approach);
3. The primary Asset Management process; defined here as the arrangement of essential partial processes (These partial processes are: Traffic Management, Water Management, Project Management, Environment Management, Maintenance Management and Information Management) needed to realize and guarantee the network functionality which the Asset Manager and the Asset Owner agreed on, by contracting service providers.

The main argument of this vision document is that it is possible and desirable for executing agencies with complex tasks, operating in an equally complex and dynamic social environment, to develop and implement a management model with its accompanying toolbox which can well withstand substantial organisational changes. This can be achieved by basing this model on the invariable elements of these organisations' tasks and roles for as much as possible.



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Life-cycle impact assessment of highway pavements for supporting maintenance and rehabilitation decisions

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ABSTRACT

Pavement management systems are widely used and continuously being improved for supporting road pavement maintenance and rehabilitation decisions. The current needs of stakeholders and users are not limited to economic cost savings as a result of road maintenance and rehabilitation but require the consideration of valuable operational characteristics such as safety improvement, travel time and environmental impact reduction. Recent studies pay particular attention to greenhouse gas emissions in sustainable infrastructure management practices (Lidicker et al. 2013, Bryce et al. 2014).

In this work, broad impact analysis and assessment is made with regard to road pavement condition. Further, an optimization model for pavement maintenance and rehabilitation planning and optimal resource allocation during the pavement life-cycle is presented. Several types of impacts are considered including agency cost, user delay, accidents, vehicle operating cost, fuel consumption, emissions and greenhouse gas emissions. Quantification and valuation of these impacts are developed within the decision making process. In addition, pavement performance models are employed to indicate existing and future pavement condition as a function of pavement design and construction quality characteristics, traffic loads, weather and environmental conditions, maintenance history, and pavement age. The optimization goal is the minimization of a generalized cost parameter while preserving the pavement condition at acceptable levels throughout the whole analysis period (Panagopoulou & Chassiakos 2012). Due to the size and complexity of the optimization problem, a genetic algorithm is employed for deriving suitable solutions through the Palisade Evolver software.

The system has been evaluated with several test cases and parameter settings while results have been compared on the basis of the trade-off between agency (maintenance) cost and generalized cost (or average pavement condition) as indicated in Figure 1. Results have been found rational and in good agreement with input data variation. In terms of quantitative results, it appears that the benefit-to-cost ratio of applying maintenance and rehabilitation measures (i.e., the reduction of generalized cost compared to cost of maintenance) is far higher than unity especially in case of low to moderate initial pavement condition. Further results of sensitivity analyses demonstrate the potential of the proposed model to effectively assist stakeholders in making informed and effective maintenance management decisions.

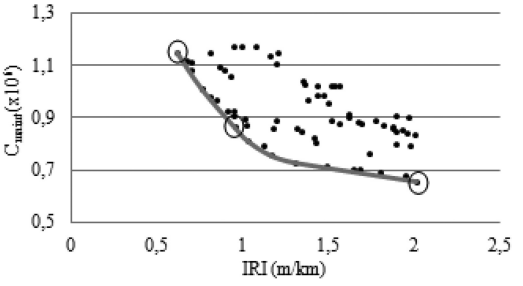


Figure 1. Trade-off between agency cost and pavement condition.

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Objective risk based structural assessment of existing concrete structures

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ABSTRACT: In this paper for concrete bridges various deterioration mechanisms are described. Corrosion of reinforcement due to chlorides seems the main cause of damage. Therefore, the main influence factors for initiation and propagation of corrosion are elaborated, such as cracks. It is concluded that with the existing testing techniques and deterioration models it is not possible to give an accurate prediction of initiation or propagation of corrosion. This is mainly because of the highly (local) variation in concrete and steel-concrete interface. Current inspections and condition assessments mainly focus on the shorter term up to 10 years. But for service contractors in projects where only a few existing structures in the contract have to be maintained for about 30 years, the future maintenance or renovation costs and associated indirect costs for hindrance are needed to minimize the risk of structural failure and optimize the maintenance budget. Therefore improvement of service-life assessment models is needed.

1 INTRODUCTION

Over the last decade, focus within the construction industry shifted from new-build infrastructures to reconstruction, renovation and conservation of existing infrastructures. In example more than 50% of the 2013 investments in the German infrastructure were spent (BMVI, 2015) on the conservation of existing infrastructure. Therefore, the actual service-life-condition of existing structures and the associated maintenance concepts play a dominant role in the overall asset management strategy of infrastructural networks. Large existing structures such as bridges and fly-overs are always important chains in the larger road network. If such a structure is out of service then important connections are unavailable with traffic congestion as a result. Therefore, out of service situations have a substantial economic impact as well as an impact on hindrance (experience). Hence, renovation and maintenance works of existing structures deserves an integrated approach where both the societal and economic effects are being optimized within the technical and safety constraints. All of this starts with a thorough investigation of the actual service-life condition based on different failure mechanism and inspection techniques.

Nowadays maintenance and renovation decisions are mainly made on expert opinion on a more or less reactive manner often based on visual inspections (Haardt, 2009).

A large scatter in the actual condition level of a structure (Moore, Phares, Graybeal, Rolander, & Washer, FHWA-RD-01-020, 2001) or (Kallen & Noortwijk, 2005) is therefore observed. Hence different maintenance and renovation options are advised based on the knowledge of the Advisor. For an Asset Owner and Service provider it is crucial to be in control of maintenance decisions and to have an actual condition assessed as objective as possible.

2 DISCUSSION

From this paper it can be concluded that in the last decade a lot of international research on estimating the condition of reinforced concrete structures and predicting the residual service life and maintenance needs is executed. Due to the variability of concrete and the environment it is still not possible to give accurate results. The variation in influence factors like cover to reinforcement and local chloride concentrations in existing structures are too high to give accurate predictions for local deterioration.

These variations also occur in inspections results between different inspectors. For long term maintenance predictions the current mainly visual inspections aren't accurate enough.

Various non-destructive testing techniques are yet available. But accurate techniques for determining the actual amount of corrosion of reinforcement or (post-tensioned) tendons aren't available.

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Risk-based decision framework for resilient highway bridges

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ABSTRACT

Highway bridges are critical links in the road network and enable personal mobility and transport of people and goods, which are critical to the socio-economic and environmental resilience of communities. The structural systems of highway bridges are subjected to time-varying and uncertain pressures, including aging and deterioration, increased demand, extreme shocks such as earthquake, climate change, or bomb blast, which can lead to the failure of certain systems or components and reduction or disruption in the services they provide. This in turn can have very serious consequences on public safety, security, mobility, environment, and economy as a result of the closure or collapse of a bridge due to aging and/or the effects of natural or man-made hazards.

Considerable and numerous sources of uncertainties are associated with the life cycle performance of bridges, which in turn lead to different risks of failure that must be managed and kept at acceptable levels using difference risk mitigation measures, including the use of more reliable inspection and condition assessment approaches, rehabilitation strategies, reduction in demands/hazards on structures, etc. These lifeline infrastructures should be built or retrofitted to ensure they maintain their structural integrity when subjected to cumulative damage and/or extreme shocks from natural or man-made hazards. This can be achieved by designing resilient structural systems that can withstand these loads with minimal structural damage and rapid recovery of service.

Given the limited available resources and the emerging needs for resilient bridges, a risk-based decision framework is proposed to help decision-makers optimize the design, evaluation and management of highway bridges where all possible hazards can be considered, all possible risk mitigation strategies can be evaluated, and rational criteria are presented to support the selection of the most cost-effective strategies that lead to resilient bridges. The proposed approach is illustrated on an aging highway bridge that is subjected to the effects of corrosion.

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Probabilistic maintenance model for dynamic traffic management systems on highways in The Netherlands

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ABSTRACT

The purpose of this paper is to describe a method for probabilistic life-cycle maintenance modelling for dynamic traffic management systems on highways in The Netherlands. This model can be used for the optimization of maintenance costs, the reliability and the performance of traffic management systems. The performance of a traffic management system is presented as a relation of the traffic flow performance and the traffic safety impacts. These performances and the maintenance costs are expressed in euros.

In this business-case the performance is of one 5 km long representative express lane calculated as a case study with relations between maintenance costs, reliability and performance of dynamic traffic management systems of this express lane.

The purpose of this representative model is to test methods on how maintenance costs, reliability and performance of one representative 5 km long express lane can be modeled using RCMCost application. This representative express lane has 10 portals, 10 detection loops, 10 cameras and 10 rotating panels every 500 m.

Combinations of real and average failure data are used as input data for the RCMCost model. Two different scenarios have been modeled:

– Corrective maintenance scenario;
– Preventive maintenance scenario.

In the corrective scenario the express lane is unavailable for 28 h (0.33%) per year and in the preventive scenario the express lane is unavailable for less than 3 h (0.03%).

The total costs for maintenance are on average 42k€ for the corrective scenario and 63k€ for the preventive scenario.

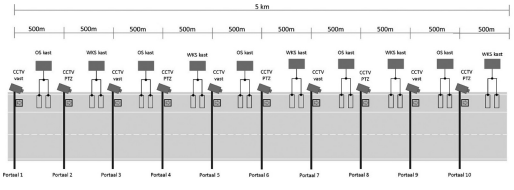


Figure 1. Configuration of representative express lane.

Table 1. Results of RCMCost analyses: availability (average).

Items	Corrective	Preventive (Maintenance)
Unforeseen	0.33%	0.03%
Not available	99.67%	99.97%

Table 2. Results of RCMCost analyses: lifetime costs (25 year).

Items	Corrective (k€)	Preventive (k€)
Corrective Maintenance	647	57
Fixed Maintenance	415	419
Variable Maintenance	–	1,106
Total	1,062	1,581

Table 3. Total maintenance and social costs per year (average).

Items	Corrective	Preventive (k€)
Express lane used	200	200 (days/year)
Cost traffic jam/day	26	26 (k€/day)
Express lane not available	0.66	0.06 (days/year)
Cost traffic jam/year	17.49	1.59 k€
Total social costs	1,079.49	1,583.59 k€

The total costs for maintenance and traffic jams (social costs) are in in the corrective scenario 1079.49 k€ and in preventive scenario 1583.59k€.

This method and model can be used for the modelling of all dynamic traffic management systems on the highways in The Netherlands.

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SS5: Risk based maintenance from life cycle perspective

Organizer: M. Franssen



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CONSISTEND: A model to calculate the influence of the construction process on the life span of asphalt and its implementation in tenders

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ABSTRACT

Quality control during the construction process of asphalt surface courses is, next to road design and material selection, an important factor that determines the life span of surface course. A longer life span has an enormous impact on the carbon footprint of the road.

Contractors and authorities recognize the opportunities of new quality control techniques. It is however not yet possible to objectively weigh the costs of these techniques against the value. In the CEDR project CONSISTEND, a tool is developed to assess the impact of the quality of the construction process on the performance of pavements *and* the implementation in a Most Economic Attractive Tender (MEAT) tender process is elaborated in the project.

The tool is based on a probabilistic model. This probabilistic model to calculate the lifespan of an asphalt road is established on the principles provided by (Hovde et al. 2004) using a linear regression model:

$$L = A_{opt} - \left(\sum_{i=1}^{n} A_i \left(x_i - x_{i,opt} \right) \right)^{1/w} + uS \qquad (1)$$

The characteristics of the probability density distribution defining the project dependent variable x_i are managed differently in the 'during contract phase' and the 'after construction phase'. In the 'during contract phase', the mean value of the probability density distribution is estimated by the user of the tool; in the 'after construction phase', the mean value and standard deviation are defined based on measurement results from the actual construction site.

The tool is tested in projects in Slovenia and United Kingdom. The possibilities of the tool for tendering procedures are theoretically assessed by describing often used tendering processes in some countries and the opportunities of the tool in these processes.

The main results of the tool are as expected: when all project values of the degradation factors (x_i) are appointed to the optimal value, the mean value of the predicted lifespan approximately reaches the maximum lifespan. And when the project values of the degradation factors (x_i) are chosen to be non-optimal or when the standard deviation accompanying the project value of the degradation factors is changed, the predicted lifespan will decrease. However, for this second situation, the calculated change in mean value of the lifespan prediction is relatively small, and smaller than expected.

The model is useable in MEAT tendering processes. In the tendering phase of the project it can be used to objectively calculate the additional value of quality control measures during tendering phase; in the after construction phase of the project the actual obtained value can be checked.

Optimization of the model, regarding the quantity and weight of the project variables is needed. Also further research is needed in order to be able to calibrate the model and quantify the absolute change in service life taking into account countries' specific technological practices, bituminous mixtures types, and climatic conditions.

The CONSISTEND project is part of the CEDR transnational road research program call 2013. The project addressed the topic "Energy efficiency, Materials and Technology".

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Introduction of a semi-probabilistic moisture safety model for tall timber-based building shell – a risk based durability approach

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ABSTRACT

Recently the amount of timber buildings are planned and even built beyond the border of high-rise buildings is growing. The challenge is growing to provide moisture safe conditions for the expected service life of mainly wood-based building envelopes in higher areas with increased exposure. Compared to fire safety and static demands, the risk of moisture damages today is dramatically underestimated in planning, building processes and service life management. The main objective of the research project is to facilitate the confident design of durable and cost-effective component joints for tall timber facades by the blend of best practice with a risk-based concept. Therefore the aim is to develop 'semi-probabilistic safety concepts', similar to those in static calculations, to prevent damage caused by inappropriate reaction of construction to climate exposure. The methodology encompasses a hygro-thermal risk-model representation with vulnerability of timber-based shell and the climate conditions for exposure. Accordingly, the damage mechanisms, which lead to failure and consequences, are identified based on literature review. Moreover, lab tests deliver missing functions of uncertain durability parameters. The uncertainty of human error related to design and construction processes is taken into account on a qualitative basis. To enrich the model it contains the limit state characterizations for mold and other excessive wood moisture content specific failure modes. The construction processes and site conditions have yet to be economic, with the increasing number of facade details per project, and hygrothermal robust to contribute to the success of a project built of wood. These conditions fuse in the development of a moisture-management model for wood-based shells considering specific exposure aspects of wind driven rain, climate change, or interior moisture sources. The development process covers in its core a transient hygrothermal simulation of entire exterior wall cross-sections. Finally, all different risk assessment steps are combined with LCC and LCA methods to a multidisciplinary design optimization setting. For maintenance management and durability, forecasting the accepted level of risk can be chosen due to the prediction of design alternatives and their life cycle costs for wood-based building shells.

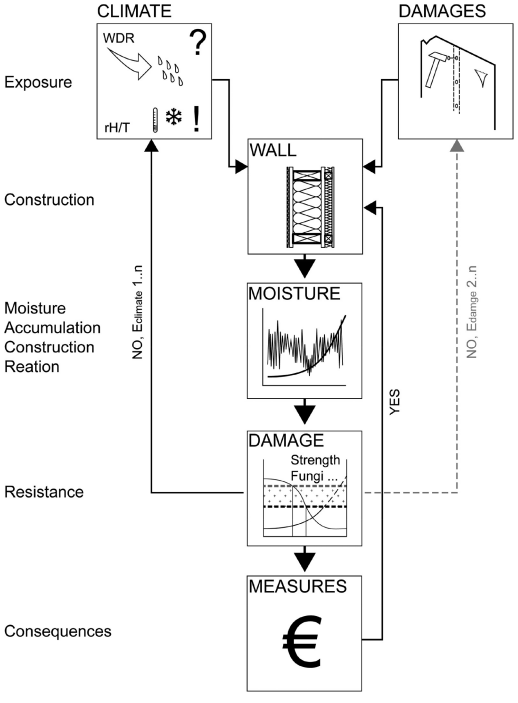


Figure 1. Risk model representation for the moisture management and durability assessment of tall timber facades.

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Risk based asset management of pipeline networks for gas and water

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ABSTRACT

The Dutch soil contains over 1,75 million kilometer of cables and pipes (Taselaar 2009). The Dutch society is strongly dependent on the services provided by these network of cables and pipes transporting gas, water, waste water, sewage, electricity, telecommunication and other services.

Most pipelines are buried, which impedes direct monitoring of the structural reliability of the networks. The deformation of the pipes caused by soil deformation in combination with the network layout may impose hazardous stress in the pipes, threatening the integrity of the network. Considering failure of pipes due to soil deformation, it can be presumed that the more brittle the material of the pipes, the larger the probability of failure due to soil deformation.

For safety and certainty of delivery reasons, the gas and water network operators are planning to reconstruct all brittle pipes. However, as the Dutch water network in total (brittle and non-brittle) contains about 115.00 km of pipes (Taselaar 2009) and the gas network in total contains about 140.000 km of pipes (Taselaar 2009), there is a need to prioritize. In addition, also from a financial perspective it is interesting to be able to estimate the optimal moment for replacement (Courage 2013). Reducing the uncertainty with respect to present and future soil displacements and their effect on the structural response of the pipelines is one of the key instruments for improving condition and risk based asset management strategies.

To be able to make conscious choices and sensible reconstruction planning, the gas and eventually the water network operators joined in a Dutch joint research project together with three research institutes (TNO, Deltares and KIWA-gastec). Aim of this joint research project is to predict failure probability of a pipe at the required moment in time. This is approached through analysis of the stress in the pipe. The magnitude of the soil load on a pipeline is determined by the specific soil-pipe interaction. Due to the soil pipe interaction, induced by either the pipe or the soil, soil deformations and pipe displacement will occur. The deformations lead to increase or decrease of the soil load on the pipe. The pipe stress analysis considers the combination of all loads acting on the pipeline and compares the resulting stresses in the pipeline with the allowable strength of the pipeline.

This paper describes the results from the second phase of the project and the continuing developments in the third phase of the project.

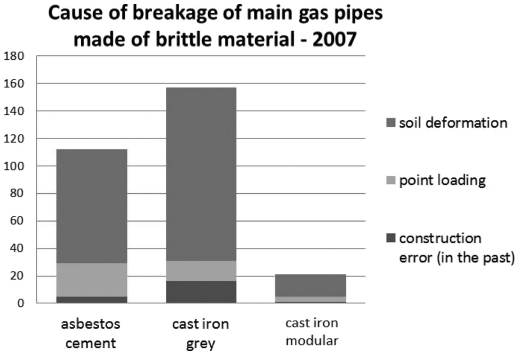


Figure 1. Causes of breakage of main gas pipes made of brittle material in the Netherlands in 2007 (KIWA 2008).

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Risk based asset management aspects in order to cope with successful life-cycle civil engineering

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ABSTRACT

Many asset owners in civil infrastructure struggle how to cope with Life-Cycle Civil Engineering challenges.

Corporate responsibilities forces organisations to give hindsight in the way resources are spent. Thus unacceptable spending of both public and organisational resources is a key element for each stakeholder. In the Netherlands, an asset management method like (semi-) quantitative Risk Based Maintenance (RBM) is specifically used to maintain civil assets during its life-cycle in order to achieve cost effective control over these assets. Whenever the required maintenance then also is outsourced, knowledge about the (semi-) quantitative RBM method, roles and responsibilities of related organisational processes become key elements of successful Risk Based Asset Management.

Any attempt for an organisation to manage an asset requires an asset management system to control the technical system, processes and organisation (Stavenuiter 2003). When the value that needs to be realised from an asset is clear, a thorough chain of control is needed in order to realise this. An asset management system is specifically meant to cope with this.

According to ISO 55000:

> *An asset management system is a set of interrelated or interacting elements of an organisation, that establish asset management policies and objectives, and the processes needed to achieve those objectives.*

The message that rises from former definition emphasizes the ambition and organisational processes will influence the effectiveness of an asset in a considerable way.

In general two asset management systems are commonly used. A Service provider model and an outsourced asset management model (fig.1).

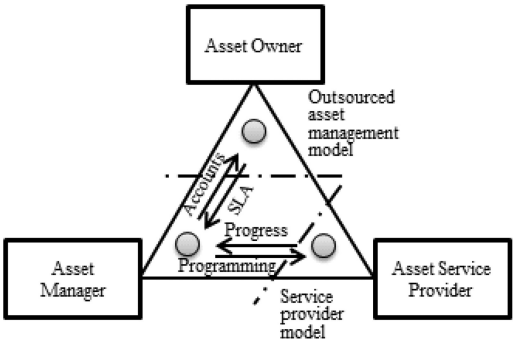


Figure 1. Conceptual design of an asset management model.

In some cases System Oriented Control Management (SOCM) is chosen as a quality control element to create insight in the asset performances. SOCM heavenly relies on a contractor to check its own progress and work, therefore relying on the contractors quality management system and maturity of the business processes. The risk rises that the asset owner is no longer managing the asset on an operational level (De Wulf et al. 2009).

When managing highly-demanded assets, translation of role related tasks should be well considered in order an asset to perform as planned.

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Risk-based ageing management process and technology Simeo™ Ageing dedicated to maintenance optimization of civil work structures

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ABSTRACT

Worldwide, capital intensive infrastructures are built for protecting production units. Therefore, the main goal of such infrastructures is to remain safe and reliable over the years in order to avoid human injuries (which concerns both internal and external sides of the structures), prevent accidents leading to heavy asset and environmental hazards and secure production and asset availability. These objectives require a high level of expertise and know-how in managing the infrastructure life cycle. Oxand has developed and implemented dedicated integrated solution to assist in managing the ageing of civil work structures over operation and extended lifespan. This solution, Simeo™ Ageing, enables to anticipate and optimize the maintenance of the civil work structures thanks to relevant Ageing Management Programs integrating owners' issues such as safety and availability. It consists of a full-web software solution including a tablet application for on-site inspections.

The risk-based asset management process is divided in two main steps: (1) definition of the maintenance framework, (2) deployment of the multiannual maintenance plans.

(1) The article will describe in details how to elaborate a multiannual maintenance covering all failure modes and ageing mechanisms associated with structural components. This methodology, compliant with international standards (NRC, EPRI and IAEA), is based on functional analysis of the assets, then, identification and evaluation of ageing mechanisms. The evaluation method includes estimation of the impact level of each ageing mechanism regarding each function, and evaluation of the uncertainty of this evaluation (lack of data, etc.). Ageing models and acceptance criteria, based on international feedback and Oxand expertise, are implemented in the solution in order to predict and adjust the action plan over time, but also to maintain the right level of maintenance considering current state of structures.
(2) Deployment of maintenance plans includes achievement of maintenance actions, and traceability, exploitation of the actions results that will contribute to update the maintenance plan, optimize the maintenance actions over time and better understand ageing mechanisms (corrosion, erosion, etc.) and their evolution.

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Validating the calculated reliability and availability in Dutch storm surge barriers (and other infrastructural works)

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1 INTRODUCTION

The reliability and availability of the Dutch storm surge barriers are calculated by probabilistic risk assessment and various underlying risk analysis methods. These calculations, however, focus on the numerical probability of the storm surge barrier functioning adequately, and the implementation of the many constraints from the risk analysis is merely an implicit factor. This includes constraints varying between whether the set repair times are feasible and whether the organization is capable of managing the asset adequately. The resulting reliability and availability figures should be validated, verifying the checks and balances on the behavior of the asset manager in terms of the performance of the maintenance and operational processes, but also the quality and knowledgeability of the maintenance and operational teams, among other checkpoints. In other words, the conformability of the organization should be verified during the performance assessment, in order to validate the risk analysis. Within Rijkswaterstaat, and for specific use at the storm surge barriers, a tool has been developed for an internal audit on the resilience of both the organization and the constraints following from the risk analysis – the compass.

For the validation method developed in collaboration between TNO and Rijkswaterstaat the three processes influencing the numerical risk assessment are identified:

1) The maintenance process
2) The operational process
3) The management process

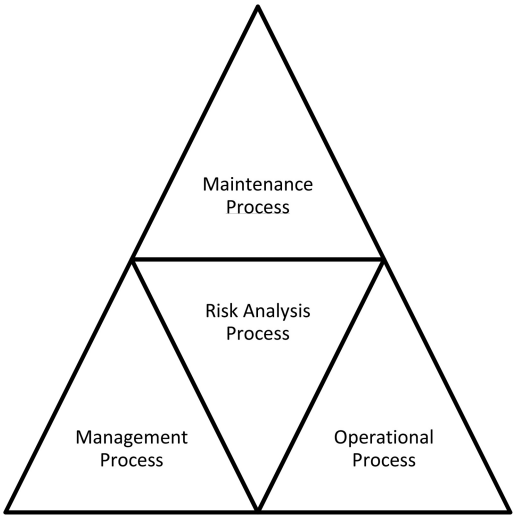


Figure 1. The overall scope of the risk evaluation.

This paper focusses in more detail on the approach Rijkswaterstaat has chosen for the review of the validity of a risk analysis, including the adaptation of ISO and auditing standards, specific check points on risk analysis matters and the self-auditing regime that Rijkswaterstaat proposes for the storm surge barriers and their performance analysis.

Included in the paper are the results from the initial implementation of the validation methods and a critical discussion of the first results, providing focus points for similar implementations in different areas.

SS6: Dynamic contracting: Optimal performance over the life cycle due to better cooperation between contact partners

Organizers: M. Hertogh & W. Leendertse



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Planning and contracting of transport infrastructure in a dynamic environment

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ABSTRACT

The transport infrastructure sector is increasingly confronted with complexity. Infrastructure is aging, which requires planning approaches tailored towards infrastructure renewal instead of infrastructure expansion. Modes of transport have significantly changed thereby challenging the traditional use of the network. Moreover, infrastructure is also increasingly confronted with spatial, societal, economical and natural developments that need to be taken into account in order for the transport infrastructure network to be resilient. This increasing complexity makes the sector less predictable.

Infrastructure planning, however, is traditionally based on predicting and specifying future contingencies for making choices. Based on these choices plans are formulated. To implement these plans governments are cooperating with private parties who carry out construction, maintenance and/or operation. Contracts are used to coordinate this cooperation. Contracts, however, are typically based on the idea that project scopes can be predicted and defined and that risks can be identified and distributed. In practice this creates a mismatch between the expected situation – as defined in the contract – and reality. There is an increasing strand of literature that focuses on dynamic contracting as a way to cope with this mismatch. Dynamic contracts embrace and manage change. However, even in dynamic contracts, the options to adapt to change remain limited.

Therefore, we argue that ways to deal with unpredictability and change do not only have to be incorporated into contracts, but should also be incorporated in planning approaches. This is in line with recent insights in planning literature. Traditional prescriptive infrastructure planning is shifting to more adaptive and interactive planning in order to cope with change and (deep) uncertainty.

The aim of this paper is to explore the relationship between adaptive planning and dynamic contracting and contracts. The paper describes the current development of infrastructure planning and the way it tries to cope with dynamics and complexity.

The paper discusses dynamic contracting in a broader perspective, where contracts are part of a cohesive infrastructure planning approach, which focusses on infrastructure programming and infrastructure 'issue handling' instead of stand-alone projects and contracts.

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In search for contract flexibility in a dynamic environment: A theoretical framework

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ABSTRACT

Construction systems have been subject to significant changes in recent years, resulting from developments in demands, requirements, regulations, financial possibilities, and technological innovations. These changes affect both projects and contracting in the construction sector. Contracts typically suggest a certain level of stability in a construction environment that is actually highly dynamic. Flexibility in construction projects is becoming an increasingly important tool to deal with unpredictable circumstances. The questions arise: how to deal with changing circumstances in this dynamic environment, and how much flexibility is required? Can flexibility in contracts and contracting be achieved? Answering these questions requires rethinking the approach towards long term dynamics in contracting.

This research does not develop a new concept in dynamic contracting, rather it will develop a theoretical framework by merging existing concepts from the dynamic environment, project and contract literature on dealing with changes. First the key concepts will be discussed of construction from previous findings in literature. Key concepts are; dynamic environment, project and contract. Then issues and dealing mechanism will be merged to the key concepts. The theoretical framework aims to provide a lens through which the complexity of construction projects and the numerous factors that affect projects and contracts can be understood from a life cycle perspective. The purpose is to develop a theoretical framework for contract flexibility in a dynamic environment.

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Life-cycle performance as results of basic design considerations

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ABSTRACT

Examples from Life-Cycle and Forensic Engineering show that many problems related to performance of structures, can be avoided if deeper assessments are performed with regards to the conditions during the life-time of a structure. Structural performance depends on more factors than may be apparent in the conceptual phase of a project. Such specific factors should be included in design considerations which are not always well reflected in codes and standards. The paper relates to basic considerations with respect to the general context structures are expected to perform. It reviews different aspects of Life-Cycle performance using examples from the author's experience reflected in the references and others known to the engineering community.



Figure 1. "Weathering" of concrete columns.

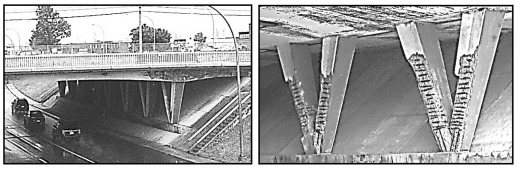


Figure 2. Deterioration due to the salts spread on roads.

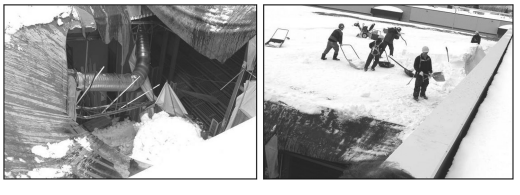


Figure 3. Failure due to snow accumulation.

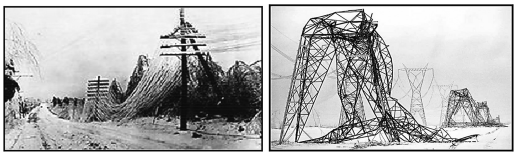


Figure 4. Effects of ice build-up in function of robustness.

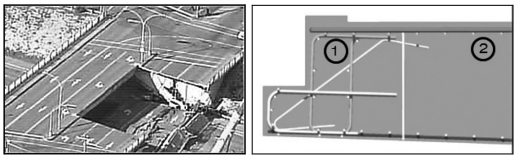


Figure 5. Failure of an overpass in Montreal, critical detail.

The expectation of society to see modern structures perform like ancient structures typically does not correspond to reality. The necessity to invest substantial new money for most structures after years of service is a failure to meet these expectations. Figures 1-5 show some examples of poor performance discussed in the paper.

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Towards the combination of risk analysis, constructability and sustainability for the lifecycle management of construction projects

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ABSTRACT

In this paper, a conceptual basis for the development of a holistic methodology for the lifecycle management of construction projects is presented. Based on literature review, the fundamental principles of constructability, sustainability and risk analysis and management are identified and thoroughly analyzed. Then a methodological approach is proposed for integrating all the aforementioned three fundamental frameworks. This approach comprises the following three stages: a) the delineation and formulation of the integration links and interfaces among the three frameworks (Figure 1), b) the development of a coarse conceptual schema that encompasses the outcome of the first stage along with the key aspects of lifecycle project management (Figure 2), and c) the testing of the applicability of the proposed schema in the case of construction of large bridges.

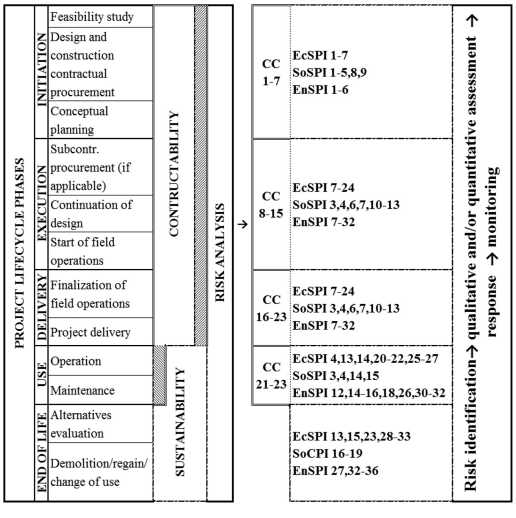


Figure 1. Interconnection links and interfaces between sustainability, constructability and risk analysis.

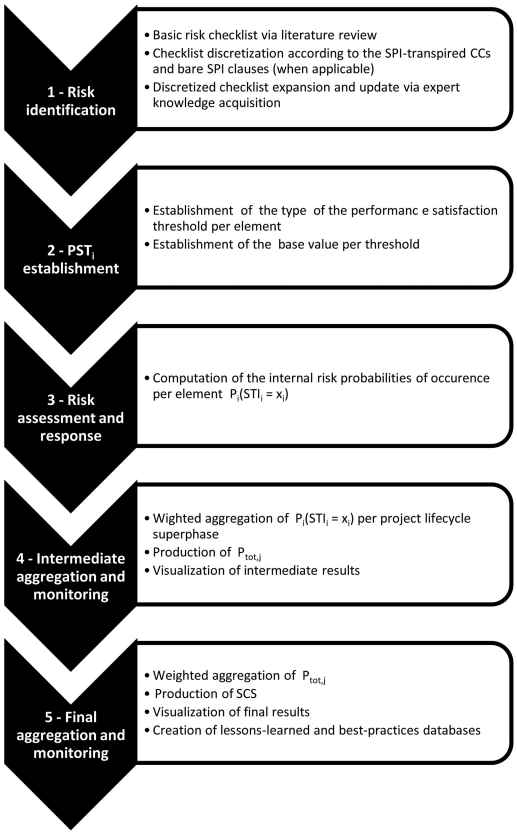


Figure 2. Depiction of the conceptual schema.

The application of the conceptual schema is anticipated to constitute a powerful descriptive and provisional tool at the preliminary (at the initial, long-term project management plan), intermediate (at the management of the processes currently taking place) and final phase of a project's lifecycle (to normalize obtained construction experience and knowledge).

SS7: Standardization of performance indicators and goals for the life-cycle management of highway bridges

Organizers: J. Campos e Matos & J.R. Casas



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Applied and research based performance indicator database for highway bridges across Europe

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1 INTRODUCTION

Deterioration could lead to a decrease of performance to such an extent that a structure could not be able to satisfy the basic serviceability and safety requirements before the design life has expired. In order to prevent the premature failure of a construction, structural codes provide several practical principles and application rules such as the use of protective systems for material exposed in aggressive environment, the construction detailing aimed at avoiding the initiation of degradation, the maintenance actions to be regularly performed, etc. Each construction, during its life cycle, will face with deterioration depending on several factors such as the environmental condition, the natural aging, the quality of the material, the execution of works and the planned maintenance. Therefore, several design procedures based on the prediction of the deterioration that will likely act on the structure will be developed in the framework of the international research. In addition, performance indicators for the present and future structural conditions on deterministic and probabilistic level will be defined and determined. Therefore, it is extremely important to analyse such indicators in terms of used assessment frameworks and in terms of the quantification procedure itself. In particular, the work group 1 of the COST TU 1406 focuses mainly on technical, sustainability indicators and others. The goal in the first step was to explore technical performance indicators of bridge structures, in the course of international research cooperation, which capture the mechanical and technical properties and its degradation behaviour. These properties are already partly covered by norm specifications but not their complex time variable performance. Moreover, environmental condition, natural aging, and the quality of the material regarding to determined indicators have been investigated and evaluated in their meaningfulness. These considerations, however, also include service life design methods, aimed at estimating the period of time during which a structure or any component is able to achieve the performance requirements defined at the design stage with an adequate degree of reliability. On the basis of the quality of input information (mainly concerning with the available degradation models), it is possible to distinguish among deterministic methods, usually based on building science principles, expert judgment and past experience, which provide a simple estimation of the service life, and probabilistic methods. In addition to technical performance indicators, which characterize the ultimate capacity as well as serviceability conditions, sustainability indicators, environmental based, are also part of WG 1. In addition, other sustainable indicators, economic and social based, may be used to evaluate a bridge performance. These indicators capture, based on the technical performance of a structure, additional aspects that may influence the decision process and typically represent the discounted (accumulated) direct or indirect costs associated with construction and maintenance. Summed up over the full life-time, they represent part of or the full life-cycle costs. They can, in the context of multi-objective optimization, be understood as a weighting scheme to arrive to a single objective function that is to be minimized. Finally, the objective of the WG1 is the publication of a report on these performance indicators. Such report will address a general description, how they are assessed with what frequency, what values are generally obtained and, finally, some general recommendations. Moreover, it is a further goal of working group 1 creating a data-base with homogenized performance indicators, performance goals and thresholds to provide the basics for quality specifications for roadway bridges at a European level.

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An overview of COST Action TU1406, quality specifications for roadway bridges (BridgeSpec)

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ABSTRACT

Road asset management is a task of great responsibility, since it involves vital assets to the community. An efficient transportation network is essential for the modern society from the economic, societal and environmental point of view. Today, it is a challenge for operators to manage road infrastructures under their responsibility in an efficient way, meeting the present and future needs of the community they serve.

For this purpose, the authorities need to produce an asset management plan, which should not only define the goals to be achieved by exploiting the roadway bridge network, but that should also identify the investment needs and priorities based on a life cycle cost criteria. In addition, a proper condition assessment of these assets must be conducted to support the decision-making process regarding their preservation.

In Europe, as all over the world, the need to manage roadway bridges in an efficient way led to the development of different management systems. Hence, nowadays, many countries have their own system. Although they present a similar architectural framework, several differences can be appointed, for example, with regard to the condition assessment procedure. These differences constitute a divergent mechanism that may conduct to different decisions on maintenance actions.

Within the roadway bridge management process, the identification of maintenance needs is more effective when developed in a uniform and repeatable manner. This process can be accomplished by the evaluation of performance indicators, improving the planning of maintenance strategies. Therefore, a discussion at a European networking level, seeking to achieve a standardized approach in this subject, will bring significant benefits. Accordingly, a COST Action recently started in Europe with the aim of standardizing the establishment of quality control plans for roadway bridges (European Cooperation in Science and Technology – COST 2014). More information about this Action can be consulted in www.tu1406.eu.

In this context, a first step would be the establishment of specific recommendations for the assessment of roadway bridges, namely, used methods for the quantification of performance indicators. A set of reference time periods for these assessment actions should be also presented. A second step would be the definition of standardized performance goals. Finally, a guideline for the establishment of quality control plans in roadway bridges would be developed. In these plans, it is emphasized the importance of advanced deterioration prediction models. Moreover, the concept of sustainable roadway bridge management, involving the evaluation of environmental, economic and social performance indicators during the whole life cycle, is also highlighted.

By developing new approaches to quantify and assess bridge performance, as well as quality specifications to assure an expected performance level, bridge management strategies will be significantly improved, enhancing asset management of ageing structures in Europe.

ACKNOWLEDGMENTS

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Bridge life-cycle prediction through visual inspection data updating

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ABSTRACT

Bridges and viaducts are commonly recognised as the most strategic elements in infrastructural networks; hence they represent the objective of significant investments, both in economic and technological terms (Pellegrino et al. 2014). Those funding are mainly exploited during bridges' service-life, i.e. the time interval in which a bridge can be considered viable from vehicular traffic, and at the same time, an adequate safety level is ensured. The extension of bridges' service-life is considered fundamental to improve structures' sustainability, and to decrease their economical footprint. Regular maintenance and continuous monitoring of the potential ageing effects are generally accepted as effective in extending bridges remaining service-life.

According to the US Federal Highway Administration (*FWHA*), about a third of the more than 570000 bridges belonging to the American main road network is in a state of severe deterioration, and needs important maintenance or safety measures, to an estimated total amount of 70 billion dollars. During the past decade, the *FHWA* has developed a software called Pontis® (currently used in about 40 States), essentially based on the criterion of minimising bridges' life-cycle costs.

Several Bridge Management Systems (*BMSs)* have raised during the years. However in Italy no national integrated project is currently applied for the management of bridge maintenance interventions, revealing a local backwardness in this field with respect to other European or American countries. Many questions are still left to the discretion of the private companies/ public authorities that, for various reasons, are not always able to ensure the compliance of adequate safety and maintenance standards.

The paper describes an integrated procedure for the evaluation of the life-cycle curve of existing bridges, calibrated with data derived from visual inspections and aimed to assess the deterioration state of their structural/non-structural elements. Visual inspections lead to evaluate a total sufficiency rating (TSR) for the bridges and collect data to be used in the Bayesian updating process of the element deterioration curves. The outcomes have been used with the information provided by the simulation of potential bridge deterioration scenarios with the aim to quantify the mean trend and the related uncertainties of the remaining service-life curve of a bridge structure. The proposed procedure has been applied to two different bridge stocks and results have then been critically discussed. The methodology could allow public authorities/private managing companies to optimize economical resources allocated for the definition of the long/medium term maintenance intervention plans to be performed on the most critical structures.

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Challenges in BMS quality plan development

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ABSTRACT

Quality assurance and control is important in all industrial fields and construction industry is no exception. Bridge management is a part of construction industry activities that ensures that the bridge attains the desired service life and quality level. Important parts of any BMS are quality assurance and control plans that must provide the basis for quality data acquisition and processing.

In order to limit the costs, maximum scope and structure of quality plan procedures must be determined. In general, it consists of three layers of activities in which quality assurance covers the largest part of activities, followed by quality control and the smallest amount of time and costs should be planned for testing (Fig. 1). Quality assurance is a part of inspection processes, data processes and maintenance plans.

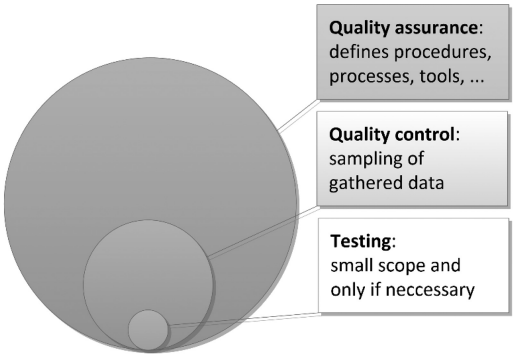


Figure 1. Scope of activities in BMS quality plans.

On the other hand, quality control and testing are exclusively a part of the inspection processes. However, they are interconnected and must be implemented together. There are number of activities to be undertaken, each having its own challenges when the scope and content is being determined.

Reliable input data is essential for all further processes, however ensuring continuously the quality of this data is a demanding task, as the data acquisition is predominantly based on periodic visual inspections. It can only be achieved with a number of quality assurance processes, such as correct use of manuals, regular trainings of assessors, damage assessment unification during coordination meetings etc. Data processing and decision models, on the other hand, are dependent on preselected criteria and decision methods. With the selection of appropriate performance indicators, tools for data analysis and threshold values for triggering maintenance actions, an efficient method for bridge prioritization can be established. The third component of quality assurance and control in bridge management is maintenance planning. During its development, in addition to the decision methods used, the focus must also be placed to finding the right compromise between owner – user and project level – network level optimization, as well as to the time period under consideration, for which the maintenance plans are being prepared. Maintenance planning is the most difficult part of quality plans to address, as different possibilities of objectives are often conflicting. Specialized decision support systems should be developed in order to facilitate the decisions.

The paper describes the components forming a bridge management plan, viable approaches and constraints accompanying their development.

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Quality control plans and performance indicators for highway bridges across Europe

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ABSTRACT

Within the roadway bridge management process, the identification of maintenance needs is more effective when developed in a uniform and repeatable manner. This process can be accomplished by the evaluation of performance indicators, improving the planning of maintenance strategies.

Therefore, a discussion at a European networking level, seeking to achieve a standardized approach in this subject, will bring significant benefits. In this context, a first step would be the establishment of specific recommendations for the assessment of roadway bridges, namely, used methods for the definition and quantification of performance indicators. A second step would be the definition of standardized performance goals. Finally, a guideline for the establishment of Quality Control (QC) plans in roadway bridges would be developed. In these plans, it is emphasized the importance of advanced deterioration prediction models. Moreover, the concept of sustainable roadway bridge management, involving the evaluation of environmental, economic and social performance indicators during the whole life cycle, is also highlighted.

Based on the presented requirements, the objectives of the COST Action TU-1406 were set as:

1. The main objective is to develop, for the first time in Europe, a guideline for the establishment of QC plans in roadway bridges at an European level. The Action aims to achieve the European economic and societal needs by standardizing the condition assessment and maintenance level of roadway bridges.
2. Moreover, it will be also analyzed the possibility of incorporating new indicators related to sustainable performance of roadway bridges. Some of these indicators were evaluated with success within the COST Action C25 (sustainability of constructions: integrated approach to life-time structural engineering). The final purpose is to establish detailed recommendations for assessing them as well as for the definition of specific goals, in a similar way as for the other indicators, and then integrating it in the developed guideline.

The main goal regarding the future implementation in European countries is to develop a performance indicator data base for Europe with flexibility to accommodate countryspecific requirements. To achieve the objectives, it was decided to structure the work in several Working Groups (WG), as presented in Matos et al. 2016 and Casas 2016.

Based on the results of a questionnaire prepared and answered by the different Euroepan countries represented in the Action, it seems that the widely agreed performance goals are the following: any bridge should be safe, functional (serviceable), available (to the user), cheap (looking at the total life-cycle cost) and environmentally friendly. In this sense, some possible performance indicators could be adopted in the following way:

1. Concerning the goal of safety: the load factor, the safety factor, the reliability index to ULS
2. Concerning the goal of serviceability: the condition index, the reliability index to SLS
3. Concerning the goal of availability: robustness (the bridge should be minimally affected by external conditions not specifically foreseen during the design), resilience (the bridge should be quickly recovered from any undesired disruption)
4. Concerning the goal of being cheap: the total life-cycle cost, values related to the durability aspects (a bridge more durable will be a bridge cheaper to maintain). For instance: diffusivity coefficient of chlorides in concrete, permeability of concrete cover
5. Concerning the goal of being environmentally friendly: CO2 foot-print

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Multi-objective bridge performance goals

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ABSTRACT

During the implementation of asset management strategies, maintenance actions are required in order to keep assets at a desired performance level. It is verified that there is a large disparity in Europe regarding the way performance indicators are quantified and how performance goals are specified. Therefore, COST TU 1406 Action aims to bring together both research and practicing community in order to accelerate the establishment of a European guideline in this subject. This paper presents the structure and basic ideas for the development of a guideline document incorporating different aspects of bridge performance goals, which may vary according to technical, environmental, economic and social factors. It discusses the need for agencies to measure bridge performance against objectives on structure and network level.

Bridge management systems are usually not taking into account requirements on the network level and complex organizational and political influences that occur in strategic asset management. Furthermore, these systems typically include single-objective optimization analyses. Since transport infrastructures are deeply embedded in society, they also have to keep up with societal and economic developments and not only with technical requirements. Therefore bridge performance goals should be set as a multi-objective system, taking into account different aspects of bridge and network performance.

Life cycle cost (LCC) analysis and reliability based concepts are well established methodologies for assessing the performance and assisting the optimization process. Reliability, Availability, Maintainability and Safety (RAMS) concept has been relatively recently adopted and applied to road infrastructure. For example Netherlands' Ministry of Infrastructure and the Environment (2012) has developed RAMS SHEEP concept, which additionally to RAMS defines Safety, Health, Environment, Economics and Politics aspects. However, practical indicators for quantification of these aspects within the risk assessment procedure are still lacking.

Multi-criteria decision-making (MCDM) is mostly applicable to provide a systematic approach and to identify and quantify decision-maker and stakeholder considerations about various (mostly) non-monetary factors in order to rank the alternatives.

Alternatively, the multiple performance criteria can be combined into a so-called utility function, in which all the criteria are brought into a single scale.

In order to transform the various out into a single (mostly monetary) scale it is necessary to establish weight factor for the individual types of criteria.

One of the main challenges in future research is how to quantify performance goals other than technical, and how to link strategic level to the performance requirements on the project level. Network or even societal goals tend to be rather broad in their definition. Furthermore, there is often no exclusive relationship between performance indicators set at a lower level and goals at a higher level. An important notion is that in many countries, the main focus of bridge management is still the condition assessment of the particular objects or elements thereof.

In Working Group 2 within COST TU 1406 Action performance goals related to roadway bridges are analysed, based on the international research cooperation and open discussion within the experts' network in this field.

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SS8: Focussing on end-of-lifetime scenarios: Demolition and deconstruction as part of an integrated view on lifetime engineering

Organizer: P. Kamrath



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Focussing on end-of-lifetime scenarios: Demolition and deconstruction as part of an integrated view on lifetime engineering

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ABSTRACT

The total production of construction and demolition waste (C&DW) in the European Union is about 450 million tons per year and represents the most part of waste stream (WMU, 2000).

The lifetime of buildings depends on their flexibility to be reused and, more and more, on economic questions as the annual costs for energy. Beside, most of the towns in dense populated environment do not grow anymore to their outskirts, but are redeveloped on their existing area. Consequently buildings of the last decades are replaced by modern buildings with sustainable and architectural appealing design.

Hereby the deconstruction and the management of construction and demolition waste of the existing buildings is a key issue in the development of sustainable construction. Prevention, re-use and recycling are the basic approaches to waste management.

Recycling is not only a question of the total costs of the deconstruction, but also depends on the fractions of the materials, which do not all permit recycling. Typical buildings at their end-of-lifetime today were not constructed in the past with any thoughts on possibilities of later reuse of materials or structures. But even today, the deconstruction as one possible strategy at the end-of-lifetime is not deeply investigated.

Thus, this paper focuses as well on the question, whether we can reach zero-waste deconstruction techniques in the near future or not. But even if we could, what additional possibilities exist today for concrete-gravel or other recycling products? Especially in high populated areas of Europe the amount of recycled concrete or masonry coming from deconstruction projects is about twice as much as the need for recycled material e.g. as an alternative to natural gravel (Figure 1). While complete reuse of buildings will be even in the next decades a suitable possibility in only a few cases, todays focus lies on pushing recycling rates higher.

Putting the focus on regular housing, today recycling rates of 75% are realistic, if 3rd order recycling is not taken into account (thermal use).

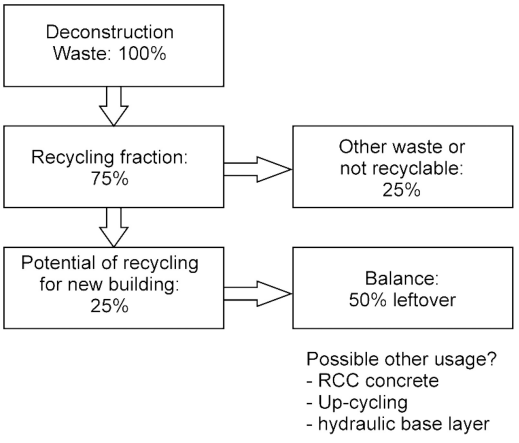


Figure 1. Material stream of deconstruction waste. About 75% of the total waste are recyclable. In the end, about 50% are leftover. The balance could be enhanced with the help of other products which make use of recycled crushed mineral waste.

Because deconstruction today means dealing with contaminations from the past, zero-waste deconstruction is not reachable for the next years (Kamrath & Hechler, 2011).

Technologically all requirements to minimize the impacts due to deconstruction are given: Separation is the key to prepare recycling on the local level.

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Structural damage identification based on non-destructive and destructive investigation of PCT girder removed due to salt damage

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ABSTRACT

Concrete bridges built in the seaside and frozen environment have been damaged due to the salty attacking. In the health monitoring of these concrete bridges, it is important to evaluate the relationship between the structural performance and the state of destructions in order to conduct maintenance works.

In this study, a full scale PCT girder, which was removed at nearly 25-years after construction due to salt damage, have been evaluated to figure out the sensitivity of several damage detection, residual load-bearing capacity and deformations due to destructive test. As a result, even though many damages (see left photo of Figure 1) are observed, the investigated PCT girder performed a sufficient load-bearing capacity. Yielding load is estimated to be about 650 kN, and the PC girder has led to almost the ultimate state at about maximum load 760 kN as shown in Figure 2. This value corresponded to about 1.1 times the calculated value of the ultimate load.

In addition, it is confirmed that the remaining prestress estimation and grout filling estimation (see right photo of Figure 1) play effective role in evaluating the load-bearing capacity of the structure. Furthermore, the non-destructive tests, i.e. using X-rays or impact elastic wave method to check the filling of the grout and so on, have positive effects on the durability of the PC steel material.

Furthermore, a novel damage indicator, called Displacement Assurance Criterion (DAC), based on changes of displacement of each observed points, has been taken into consideration and found as the sensitive damage detection approach as shown in Figure 3.

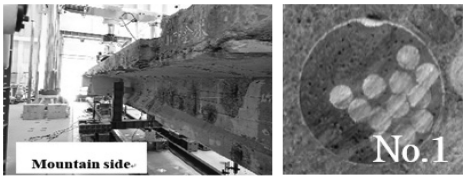


Figure 1. Appearance situation and grout filling situation of the testing specimen.

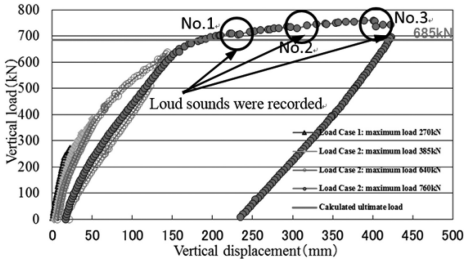


Figure 2. Relationship between the load and displacement at mid-span.

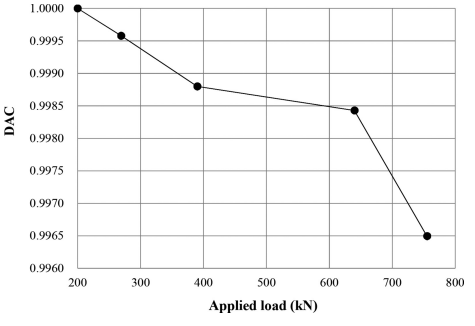


Figure 3. Relationship between applied loads and DAC.

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Study on maintenance management for deteriorated concrete by JSCE-342

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ABSTRACT

The management for reasonable maintenance is important while the performance of the structure is evaluated over time in Japan where the tax revenue decreases and an established structure becomes obsolete. Therefore, the Japan Society of Civil Engineering organized a subcommittee on "priority in maintenance and management of deteriorated concrete structures (JSCE-342)" from May 2010 to December 2015. This paper introduces a part of the final report.

First, examples of the case study promoted under the flow of ideal maintenance are introduced. Table 1 shows the scenario of the maintenance. Also Figure 1 shows results of the structural analysis by using the finite element method. According to this figure, it can be confirmed that the decrease of the load capacity is lesser in the 70th year. Therefore, even when repair is necessary by the grading judgement with the visual observation, the structural performance is same as that of the healthy one. Thus, it can be thought that the timing of repair is delayed. However, it can be confirmed that the load capacity decreases remarkably at the 90th year. Thus, it can be thought that the inspections should be strengthened if the repair was postponed at the 70th year. Herein, the ratio of cost of the numerical analysis among the overall life cycle cost is extremely small. Therefore, it is thought that the numerical analysis is an effective channel because unnecessary repair cost is reduced.

Second, modeling techniques to evaluate the structural performance of the deteriorated member is analyzed while differentiating it from a model used for the design of a healthy member. As a result, it can be confirmed that when the average corrosion weight loss ratio is more than 20%, the destruction mode varies from a bend-tension destruction to a rebar break. Therefore, it can be thought that the coverage of a bending capacity analysis model designed for healthy members is less than 20% of the average corrosion weight loss ratio. Because this assumption applied to the analysis model for a healthy member is not applicable for the deteriorated existing member.

Table 1. Scenario of maintenance

No	Procedure
1	Observation → Detail investigation at 90th year → Numerical analysis → Almost ultimate limit state → Patch repair → Inspection
2	Observation → Detail investigation at 70th year → Numerical analysis → Ultimate limit state in near future → Patch repair → Inspection

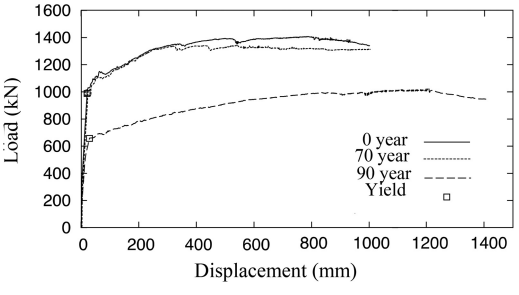


Figure 1. Relationship between load and central displacement.

Third, a method to investigate a substitution value of the performance evaluation model for the deteriorated member on site is analyzed. As a result, it could be verified that the methods for the property value of materials from information obtained by nondestructive test were different between healthy and aged members. Therefore, it is necessary to develop the methods to obtain the property value of the materials in the state in which the structural safety was damaged using the nondestructive test.

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The means of deconstruction engineering

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ABSTRACT

When it comes to the end-of-lifetime, buildings are mostly not interesting anymore for engineers. From the engineering point of view, it may be interesting to analyze, if deconstruction or refurbishment as an alternative could be taken into account. The demolition process itself seems to be relatively easy to handle. In fact, this is wrong. Demolition techniques and the management of construction and demolition waste of buildings are key issues in the development of sustainable construction. Prevention, reuse and recycling are the basic approaches to waste management. Demolition techniques which have hitherto been unsafe, dangerous and uncontrolled are today developing into an engineering discipline. Thus demolition of buildings is now a well-planned part of civil engineering with many aspects to ensure a safe demolition phase. Well engineered projects can influence on costs, on duration and on the impacts of a project.

In some cases, blasting is the best way, to dismantle components or building. Blasting requires special preparatory measures. Firstly, blasting deemed static challenges as quantity, number and location of each explosive charges must be calculated correctly in order to bring the structure as predicted to collapse. Secondly blastings are prepared under the aspect of possible pollutant emissions particularly.

Deconstruction of buildings and other structures are divided into two groups: Buildings with high pollution potential, where the main problem lies in the proper handling of hazardous materials and structures, which require special static conceptions.

Both, particularly contaminated structures and buildings that require special static considerations, require a special degree of planning. The difficulty in dismantling work is always that usually only little documents are available and information either by preliminary investigations or experience must be collected.

Many railway bridges are older date and have already an age of 100 reached. As a result of the aging of such bridges a meaningful rehabilitation can only be reached by way of abandonment and subsequent new building. In the carried out project is a bridge over a railway line.

This paper deals in the 2nd part with the demolition of a railway bridge without influencing the traffic.



Figure 1. Silo after blasting the concrete beams. The silo is mostly not damaged.



Figure 2. Railroad bridge

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The relationship between damages in road pavement and customer feedback

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ABSTRACT

Throughout Japan the road surface condition of expressways is monitored on regular basis. IRI is used as a measure of road roughness and visual inspection by expressway patrol teams is used to check for emergency road damages. Investigation of road surface is carried out every two years. When road damages, such as potholes, are detected by expressway patrol teams, emergency repairs are executed as soon as possible. Deteriorations and damages occur depending on the usage of the road. For this reason, there is a risk that the road will become damaged and not detected between inspection intervals. On the otherhand, some users of expressway lodge complaints when they encounter damage on the road. Such damage included pothole and crack, and other unsafe road surfaces. Since user have this risk, road manager also has some risk on management and operation. Therefor this road has potential risk in terms of structure, manager and road user. In this study, damage probability of road pavement was evaluated using inspection result data between each interchange along an expressway. The relationship between damage probability and customer feedback for trafficability was also considered.

We give three property factors, "consequence of road" "road surface property" "customer's feedback', when we think about the management including customer's complaint (See Fig.1). We conceive consequence of road to be traffic volume. Pavement information we have are based on two records mentioned previously. First record is daily visual inspection to check damages of pavement. Another record is investigation of pavement condition by a road surface condition survey vehicle and evaluated by three measuring items, IRI, which is index of pavement roughness, cracks and rutting. Deterioration and damages of both records have their threshold for repairing or planning to repair. Customer feedback is complaints which only a few user lodge about trafficability of expressway and it is a quite subjective. Therefor its reliability needs to be analyzed. Table 1 shows the index of reliability to evaluate reliability of complaints. And then we try to pick up some credible complaints from data having various characteristic. We consider validity of users' complaint with using these 3 property factors.

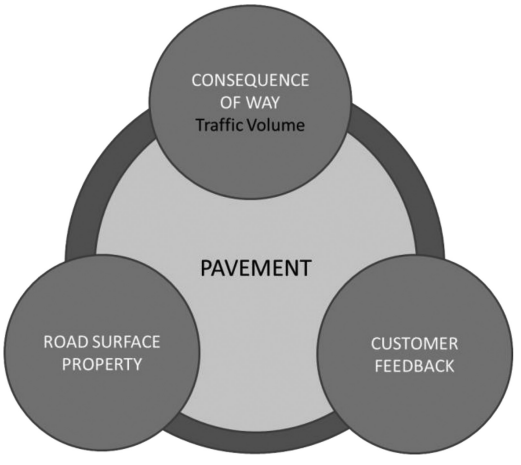


Figure 1. Property Factors of Managing Pavement Including Customer's Complaint.

Table 1. Index of reliability evaluation.

(1) States of Damage
(2) Location of Finding damage
(3) Fact Identified or not by inspection

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SS9: Cost reduction and societal benefits over the life cycle due to monitoring of existing structures and innovative repair techniques

Organizers: J. Kruithof & W. Peelen



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Cost benefit analysis of monitoring modular joints in the Dutch highway network

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ABSTRACT

Maintenance of expansion joints constitute a major part of the life cycle cost of bridges and overpasses, values up to 30% are reported (Klatter 2002, Lima 2009). Also joint maintenance contributes to traffic hindrance. It is expected that using the actual and future technical joint condition in maintenance and replacement decisions could lower these costs. Modern monitoring techniques allow for the real-time assessment of joint conditions (e.g. Chang 200, Guerreiro 2011). Coupled with predictive material models also future condition can be obtained. The technical challenges in developing and operating such systems seem limited (Leendertz 2011, Peelen 2012). The real challenge lies in demonstrating an advantageous cost benefit ratio, making maintenance organization susceptible for these benefits, combining such systems with the maintenance processes already in place and with the way the maintenance organizations organize themselves. In this paper besides the technical feasibility also a positive cost benefit ratio (business case) for predictive monitoring of so called modular lamellae expansion joints is described.

The future costs of joint maintenance are, of course, unsure. This uncertainty is accounted for by taking two extreme scenarios, starting from a "poor joint" and a "sound joint", with high and low costs respectively. The costs for both scenarios can be determined as well as the effect of monitoring on these scenarios.

A cost benefit analyses is reported for monitoring all 166 of such joints installed in 62 bridges in the Dutch highway net. The net present value of the direct savings can amount between 12 and 105 M€ over a time period of 30 years see table 1. The net present value of the direct savings can amount between 87 and 409 M€, see table 1.

The large ranges are due to the uncertainty in the (future) technical condition of these joints. Savings are achieved by reducing and postponing making maintenance made possible by a better insight of the technical condition.

Table 1. Net present benefits (in M€) in case the sound or poor joints would be representative for every of the 62 bridges in the network (Van Meel 2010).

M€	sound joint	poor joint
Direct benefits	12	105
Indirect benefits	87	409
Total Benefit	**99**	**515**
Total / year	**3.3**	**17.2**

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Electro active repair of concrete: Innovation for increased repair durability

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ABSTRACT

Reinforcement corrosion due to chloride causes increasing numbers of concrete structures that need repair. Conventional repair involves removal of chloride contaminated concrete, cleaning of steel and application of new concrete. Conventional repairs have poor durability: 50% of repairs fail within ten years, due to physical and corrosion related factors. They are: insufficient removal of contaminated concrete and steel cleaning and electrochemical effects. The chlorides left behind reactivate the corrosion process, necessitating new repairs.

Electrochemical protection methods are less sensitive for remaining chlorides. In cathodic protection (CP) a small current to the steel suppresses corrosion. CP is applied on a wide scale and can have a long working life. However, the obligation to monitor is difficult for owners. In chloride extraction a high current is passed for several months, removing chloride ions. The long duration is a disadvantage and it is uncertain when the current can be stopped.

The authors propose to improve conventional repair by applying direct current for a short time, which is called Electro Active Repair (EAR). This added step removes chlorides from the steel surface, corrosion products and corrosion pits. The overall process then is as follows. Spalled and chloride contaminated concrete are removed; a temporary material (electrolyte) is placed in the excavation; a temporary anode is installed; a current of about 8 A/m^2 is fed to the steel for about 24 hours; temporary materials are removed; repair materials is placed as usual. The temporary material can be cementitious, a gel, paste or liquid. The current drives chlorides into the electrolyte. Laboratory test have proved the principle and patents have been applied [Polder & Geiker 2015, Geiker & Polder 2016]. This method fits in the conventional repair process and no monitoring is needed. Due to reduced chloride levels at the steel, applying the invention to concrete repairs is expected to increase their life, which consequently reduces the life cycle cost of corrosion affected structures.

Based on two cases, the costs of various repair and protection options were estimated and projected for a life of 25 years. EAR would increase the cost of repair with 50%; CP would increase the initial cost by 50% and 7–15% annually for monitoring. It is assumed that conventional repair will last 10 years and then has to be re-repaired. Repair plus EAR and CP will have working lives of 25 years. For CP, this is according to long-term experience. For repair with EAR, this is an assumption. As can be seen from Figure 1, quite different (relative) cost levels result. The life cycle cost for conventional repair starts low, but increases strongly due to the cost of re-repairs. EAR and CP start at the same level, but due to monitoring cost for CP, the cost at 25 years is about as high as for conventional repair. EAR has the lowest cost over the whole life of 25 years.

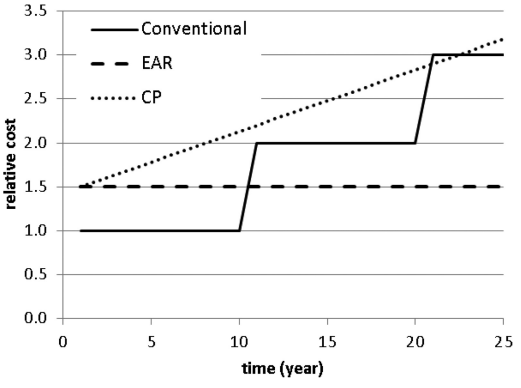


Figure 1. Estimated relative life cycle cost of a case for conventional repair (life 10 years), repair plus EAR (life 25 years) and ICCP (25 years including control).

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Evaluation of thirteen civil infrastructure monitoring pilots in The Netherlands

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ABSTRACT

The number of monitoring pilots in Dutch civil infrastructure with sensing systems is increasing only slowly over the last decade. To identify and help understand barriers for wider implementation of monitoring systems, SBRCURnet-committee 1992 analysed 13 monitoring pilots. The committee consisted of 16 Dutch infrastructure owners, practitioners and researchers. Emphasis was put on matching the needs of infrastructure owners and the technical readiness of monitoring systems for (wide-scale) implementation. To do so, a Monitoring Guidance Tool in the form of a flow chart was used. This paper summarizes the results of the analysis and concludes on the value of the Guidance Tool for stimulating wider implementation of monitoring systems in civil infrastructure.

SBRCURnet commission 1854 developed the first version of a tool to guide practitioners in structuring systems to optimize asset management and maintenance of civil infrastructure artefacts with the help of monitoring techniques. During the analysis of 13 ongoing projects this Guidance Tool has been applied and improved when deemed necessary (SBRCURnet 2015). Figure 1 depicts the resulting Monitoring Guidance Tool in the form of a flow chart.

From the analysis the paper concludes that monitoring technology is available, but stumble upon resistance in practice. The Monitoring Guidance Tool can help to bridge the gap between innovation and practical uptake.

Monitoring systems in civil infrastructure are typically applied in pilot projects and build up custom made from existing off-the-shelf products. A general observation from the 13 pilots is that the more successful pilots have more clear objectives and demand and supply interact sufficiently.

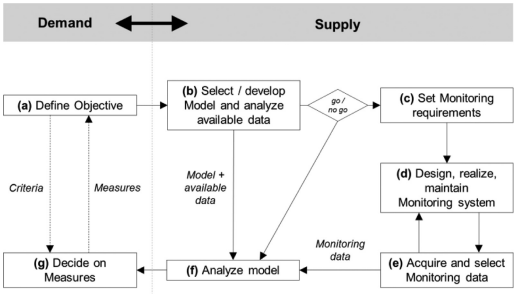


Figure 1. Monitoring Guidance Tool (source: SBRCURnet 2015).

It also turns out that further applications, even after successful pilots can stumble upon resistance from practice. The key to further uptake is a continued interaction between demand and supply, with a clear focus on the business benefits.

Finally, it can be concluded that the Monitoring Guidance Tool proofs to be very useful in assessing monitoring projects.

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Example of a fatigue life evaluation of noise barriers along a high speed railway line

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ABSTRACT

In 2012 a new high speed railway line located in Lower Austria was put into operation by the Austrian Federal Railways. Trains passing with a target speed of up to 230 km/h generate a high aerodynamic impact on noise barriers. Soon damages on the mounting detail of noise barrier posts on bridge sections occured and a first evaluation showed that the original mounting detail of the noise barrier posts was likely to not reach its expected lifetime due to fatigue failure. Therefore new constructions for the posts were developed by local engineers and a test installation with the newly designed posts was realized along the high speed railway line. The presented work shows the results of a detailed fatigue life evaluation for details of this new construction which were assumed to be conservatively designed. Due to the large number of necessary noise barriers along a railway line a more inexpensive design of the noise barrier posts was aspired by the railway operator.

Based on the measured impact from long term monitoring along the track the mean aerodynamic load collective for different types of trains was evaluated and used as input for a numerical finite element analysis. Structural hot-spot stresses of the relevant details were extrapolated from the calculations and used for assessment of the theoretical lifetime of the mounting detail based on the linear damage accumulation law according to Palmgren-Miner.

The assessment incorporated the following steps:

- Derivation of the mean daily train collective for different train types and speed classes from the monitoring data
- Determination of cumulated mean value curves for the aerodynamic impact and the structural response from the monitoring data for different train types and particular speed classes (Fig. 1)
- Regression of the height dependent line loads based on the aerodynamic impact and influence lines
- Static finite element calculations using the derived line loads
- Calculation of the dynamic amplification factor as the ratio of the measured stresses from strain gauges and the static FE calculations
- Calculation of speed dependend Peak-to-Peak stresses for each train type
- Fatigue assessment using the damage accumulation law according to Palmgren-Miner using the impact curves scaled to fit the Peak-to-Peak stresses and with consideration of the dynamic amplification

The results of the assessment showed that the design of the noise barrier posts ist very robust and that new noise barriers can be constructed with a less expensive design which is still robust enough to reach the planned lifetime of the structure. It also shows that a detailed assessment using accurate methods can result in longer expected lifetimes compared to basic methods using conservative estimations as used during design of the noise barriers.

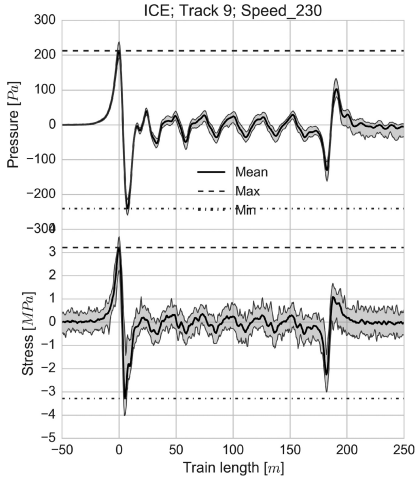


Figure 1. Cumulated curves for the pressure impact (top) and the resulting strain gauge measurement (bottom) for train type ICE at speed $v = 230$ km/h.

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Failure mode evaluation of reinforced concrete bridge columns with isolators subjected to severe ground motions

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ABSTRACT

In the seismic design of infrastructures, it is very important that seismic damage will be induced at a specific member which can be easily repaired in view of time and cost after seismic events. Reinforced concrete bridge columns with isolators subjected to the design ground motion are designed within limited nonlinear response to ensure that seismic energy is mainly dissipated at isolators. Yield strength of the isolator is an important parameter to control the seismic behavior of isolated bridges under the design ground motion. However, lateral force of the isolator can increase due to the post-elastic stiffness under more severe ground motion than the design ground motion as shown in Figure 1. This increase can result in rupture of the isolator or large nonlinear response displacement of the reinforced concrete bridge column.

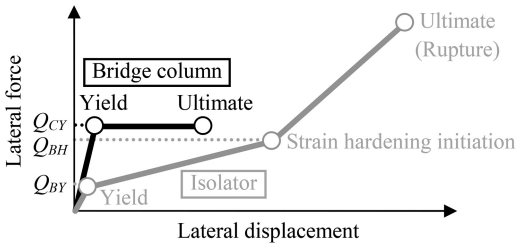


Figure 1. Skeletons of lateral force-lateral displacement relationships of an isolator and a bridge column.

Ultimate failure modes of isolated bridges were investigated based on static and dynamic analysis considering uncertainties in the material and mechanical properties as well as strain hardening of isolators in large shear strain range. After strain hardening of the isolator occurs, the amount of energy dissipation is not sufficient. Thus capacity ratio R_{QH} determined as Equation (1) was used.

$$R_{QH} = Q_{BH} / Q_{CY} \tag{1}$$

where Q_{BH} is the strength at the strain hardening initiation of the isolator and Q_{CY} is the yield strength of the bridge column.

Figure 2 shows fragility curves of the isolated bridges which have different capacity ratios. R_{QH} calculated using the mean values are shown as R^*_{QH}.

It is shown that probabilities of failure at the isolator and the bridge column are almost same and that damage is not induced at a specific member if R^*_{QH} is low. However, seismic damage is mainly induced at the bridge column as R^*_{QH} increases. In particular, it is ensured that seismic damage is induced almost completely at the bridge column on the condition that the strength at the strain hardening initiation of the isolator is larger than the ultimate strength of the bridge column. It is shown that seismic safety and reparability are improved by avoiding the rupture of the isolator which needs a long time to repair.

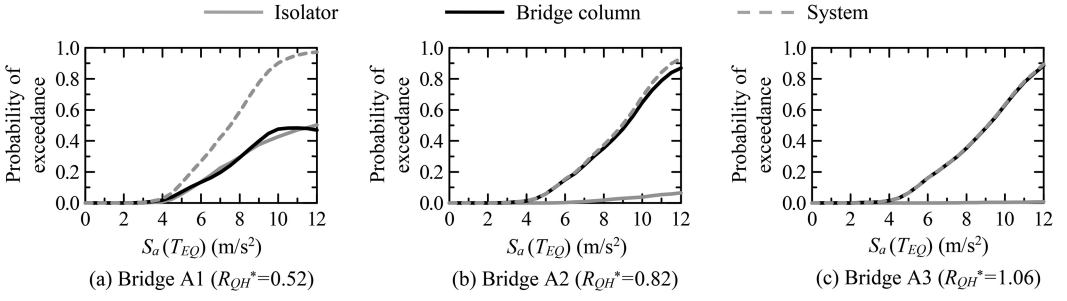


Figure 2. Fragility curves of the target isolated bridges.

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Life expectancy estimation for large pipeline networks based on satellite monitoring

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ABSTRACT

Stedin manages over 23,000 kilometers of gas distribution pipelines and 1.9 million connections into homes in the western part of The Netherlands. Most houses in the Netherlands' soft soil are built on a deep foundation, thereby preventing their subsidence. Gas distribution pipelines on the other hand subside with the soil they are in. This creates a hinge point where the gas pipeline enters the building. These connections are prone to breaking. The severity of ground settlements directly correlates with the damage risks for the gas service lines, as is well confirmed by inspection in the field. In fact, special service line designs are installed on a large scale to counter the effects of ground settlements (Fig. 1). Directly before the hinge point in the façade of a building, an expansion element is included – a curvature in the service line that is able to rotate and stretch for up to 100 cm. Nevertheless, when inspection trenches are dug, it routinely happens that these elements are stretched beyond their design limits.

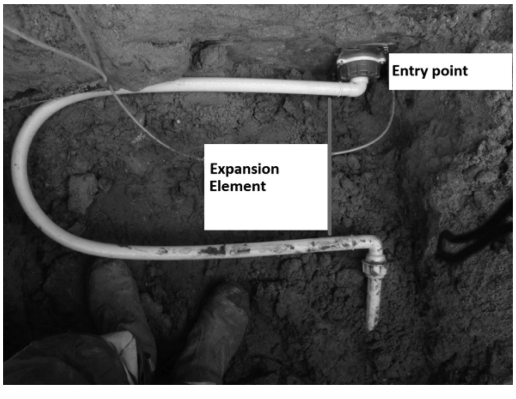


Figure 1. A typical gas service line shows the curved expansion element, allowing for 80 cm of deformation, directly behind the entry point through the foundation beam.

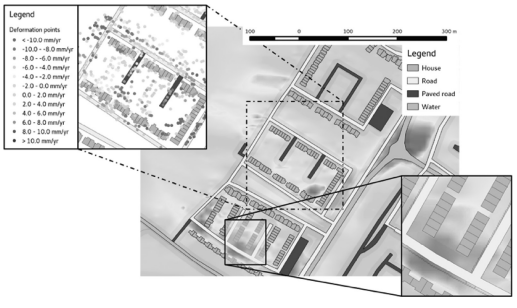


Figure 2. From the original InSAR data (upper left) a IDW-interpolated map is created (center and lower right). This interpolated map is used by field staff on iPads.

So subsidence-related maintenance is integrated in Stedin's long-term planning efforts. In recent years, Stedin has adopted area-wide monitoring of subsidence by radar remote sensing (InSAR) and developed associated life cycle management procedures in order to lengthen the pipelines' life expectancy. In this paper, we will provide an overview of the monitoring technique and its implementation for life cycle optimization of gas pipelines. The benefits, estimated to generate a 15% to 20% increase in effectiveness of the pipeline maintenance budget, are demonstrated at detailed scale in an area near Rotterdam (Fig. 2). Both the monitoring procedure and the adaptations to the organizational maintenance procedures are discussed.

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Motion-blur-compensated structural health monitoring system for tunnels using pre-emphasis technique

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ABSTRACT

The total length of highways in Japan is approximately 8,998 km; 40% of this length, and 21% of tunnels, are more than 30 years old. Hence, efficient and precise monitoring methods utilizing moving vehicles instead of human visual inspection will be essential for a sustainable society. High quality images of tunnel surfaces are necessary for precise visual judgment of abnormalities, to prevent accidents resulting from infrastructure deterioration. However, there is a trade-off between efficiency and precision: as motion blur, caused by high driving speeds, and photo spatial resolution increase, it becomes more difficult to capture sharp images that include detailed textures.

We initially used a motion-blur-compensated monitoring vehicle employing an oscillating galvanometer mirror to offset vehicle speed (Fig. 1). However, owing to the mirror's slow response speed, this system did not correspond with the maximum speed of a standard Japanese highway tunnel: the height is 7 m; the speed limit 100 km/h. Accordingly, in this study, we implement precise path tracking to extend the corresponding frequency spectrum in PID control with pre-emphasis, a technique commonly used in communication engineering. We calculate the pre-emphasis coefficient beforehand to follow a sine wave with zero gain and amplify the input signal. Moreover, we propose a method to combine conventional motion-blur compensation with pre-emphasis and update the system for tunnel health monitoring.

By conducting field experiments in a tunnel, we verified that our system corresponds with the moving speed of 120 km/h determined computationally. As a result, our method captures significantly sharper images, and we were able to confirm that they have detailed texture, distinguishing a 0.2 mm width stripe (See Fig. 2(a)(b)) and a 0.1 mm crack (See Fig. 2(c)(d)), despite 13.9 mm of vehicle motion within the exposure time. Consequently, this result achieved several things: compatibility between high accuracy and high speed; compatibility between the galvanometer mirror size and response speed; two times better performance than previous research; and correspondence with the requirements of Japanese highways. Therefore, in future work, we plan to drive the vehicle on a public highway for tunnel surface health monitoring at a speed of 100 km/h, thus enabling daily inspection without car traffic regulation. Additionally, our system is compatible with other cars, allowing for an increase in structural health monitoring cars, and therefore, more frequent road health monitoring and pre-emptive maintenance. As a result, the life cycle of highways can be prolonged safely and sustainably.

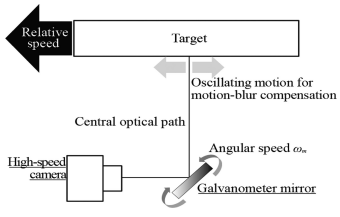


Figure 1. Motion-blur-compensated vehicle diagram.

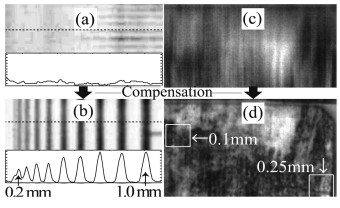


Figure 2. Results of motion-blur compensation with our method. (a) Stripes without compensation. (b) Stripes with compensation. (c) A crack sample without compensation. (d) A crack sample with compensation.

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SS10: Managing infrastructure assets: From performance data to optimal strategies

Organizers: A. Hartmann & B. Adey



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Assessment and decision-making framework for existing concrete structures

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ABSTRACT

Up to now, structural design codes have not systematically adopted life-cycle concepts, as a result of principally providing guidelines for an initial design of new concrete structures. Hence, assessment requirements of the present structural performance, as well as prediction and evaluation of future performance of existing concrete structures are recommended to be examined and included in norms. *fib* Model Code 2010 has for the first time incorporated life-cycle perspective and philosophical concepts such as through-life management into the design of concrete structures. It has promoted a holistic design approach where performance requirements are observed with regard to durability, safety, serviceability and sustainability.

As a part of a research about life-cycle performance of existing concrete structures, the task for authors is to deliver a life cycle tool *LeCIE*. It is based on these recommendations of *fib* Model Code 2010, and is to be used for the assessment, evaluation and decision-making of existing concrete structures. In particular, the developed tool is applicable for reinforced concrete railway bridges. Firstly, the tool applies deterioration models to predefined discretized structural elements. After the determination of the most endangered component and the leading degradation process, considering as well interactions of processes, type and number of interventions are selected, following with the control of other components and their deterioration rates after the repair/protective measure is applied. The life-cycle cost is incorporated in decision about execution time of intervention and the intervention itself. Exact intervention and durability of the same, as well as development od deterioration models through different levels of approximation are examined and developed. Information obtained from inspections and monitoring are updated through inverse and regression analyses, following with a prediction of updated behavior.

The first step in the research had been to develop procedures, main principles, concepts, methods and strategies for a life-cycle probability-based approach, i.e. the framework. Target of this contribution is to give an insight in the proposed framework and explain the philosophy behind an efficient life-cycle assessment procedures for reinforced railway bridges.

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Assessment of need for renewal on a multi-network level

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1 INTRODUCTION

The national networks for transport and water management in the Netherlands developed over the past centuries. Many new structures were built. At present, the second decade of the 21th century the networks have matured and expansion is declining. The assets are ageing and an increasing number objects is expected to reach their end of lifetime the coming decades, while their network functions are still needed. A systematic approach to assess the demand for the renewal need caused by end of service life was developed. This process is integrated in the state budget planning since 2012. The basis is an end of service life prediction for all objects in the networks.

2 PROGNOSIS OF NEED FOR REPLACEMENT AND RENOVATION

A systematic analysis of all assets in the networks is needed. For many of the object classes, renewal is incorporated in the maintenance program. For example, pavement top layers are replaced on a 7 to 20 years interval. This is not the case for larger structures like bridges, tunnels and shipping locks. Their design life is between 50 and 100 years and replacement requires relatively large budgets when compared to maintenance.

We need a reliable prognosis of end of technical service life. The first step is to extrapolate this from inspection results. The experience is this cannot be done accurately more than 10 years ahead. An approach has been developed to add a structure type specific analysis for the intermediate term and the statistical approach for the longer term. These are described in the paper. To complete the picture the program in execution is added, The current prognosis shown in Figure 1.

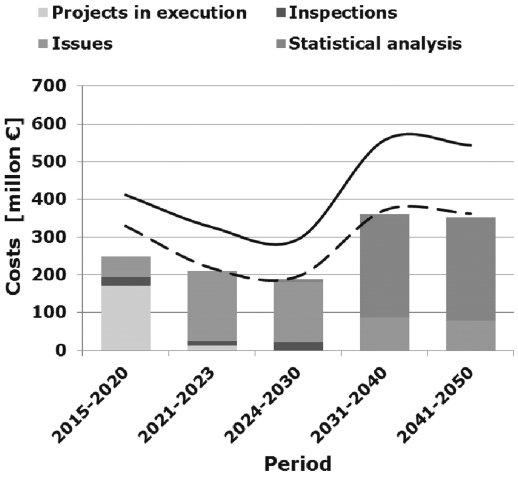


Figure 1. Total budget need renewal.

3 CONCLUSIONS

The renewal challenge offers huge opportunities when we take this at a network level; innovation leads to better performance at lower costs and sustainability will benefit. A reliable longer term prognosis is necessary to prepare for this challenge.

A credible case has to be built to make policy makers willing to allocate sufficient budgets for renewal in time. Procedures are needed to develop solutions to ensure involvement of the stakeholders. Only such a combined effort leads to solid solutions that justify investments that last a structures lifetime of 50 to 100 years. An effective process that can deal with the uncertainties and creates flexibility is needed. The program for replacement and renewal that is under development in the Netherlands shows already many features for such an approach.

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Comparison of pavement condition prediction and life cycle cost models on road section and network level

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ABSTRACT

In every advanced PMS condition prediction and life cycle cost models are utilized allowing a comparison of different maintenance options and an optimization of investment strategies. This paper provides an overview on selected issues in condition survey with the main emphasis on methodical aspects in condition prediction and life cycle costing models. For this purpose, common deterministic prediction models based on shifting or scaling a master functions are compared with the results from simple regression analysis both on section and network level. Calculating transition probabilities for these models in comparison to stochastic discrete approaches clearly shows the limits of homogeneous MARKOV chains. The basic assumptions of constant transition probabilities resulting in a fixed average performance function asymptotically approaching the failure threshold are hardly realistic for most assets. In addition, section specific information on condition development cannot be included limiting specific analysis to the network level. Though Markov chain approaches and life cycle cost models are highly regarded in the literature and have been already implemented in condition prediction for assets with discrete condition assessment they are thus a very limited solution.

With the substantial extension of a presented deterministic life cycle costing approach towards a full stochastic condition prediction and LCC model based on the HOFFMANN – process it is possible to overcome these limitations. This model is entirely stochastic and applies to any ageing and repairable complex system with or without subsystems and elements with correlated or uncorrelated censored or uncensored condition information, if the main model assumptions are largely met. This paper provides a short overview of this process and some of its properties. Furthermore, an example for the application of this approach on section level including a specific reliability and risk assessment is provided. Modeling and optimization of investments for complex assets consisting of several failure types or asset elements with different treatment options are subject of a second paper. In summary, this new approach provides a framework to achieve higher reliability in condition assessment, rating and accuracy of condition prediction leading to lower risks for road users and higher efficiency of invested funds compared to any common approach.

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Holistic asset management and life cycle costs of road tunnels

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ABSTRACT

With the growth of urban regions, high property costs and environmental concerns highway tunnels will gain increasing importance despite their compa-rably high costs. Therefore, the main focus both in literature and practice was on planning and construction of new tunnels or additional tubes with cost – benefit analysis almost entirely neglecting future costs yielding a wide variation between initial esti-mation and actual costs. Furthermore, planning, maintenance and rehabilitation was mainly based on a case by case approach as there has been almost no systematic evidence on actual life cycle costs. The current paper aims to close some of these gaps based on a rigorous analysis of available information on highway tunnels in Austria and the developed standardized life cycle. Clustering the data according to an individual situation and refining this life cycle down to element level based on the developed standardized failure type and measure catalogue may further refine the results for individual cases and may act as a basis for a future tunnel asset manage-ment system in Austria. On network level the pre-sented standardized life cycle is already capable of providing higher accuracy on budgeting needs and asset value as basis for infrastructure charging compared to common approaches for time frames of several decades.

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Implementation of life cycle costing in port infrastructure

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ABSTRACT

Ports are facing to deal both with economical aspects of their investments as well as environmental aspects. The huge investments in port infrastructures like quay walls, jetties, slopes, reclamation all these activities have their impact. For ports it is essential like other business centers that they are or will be sustainable. It is therefore required to adopt a life cycle approach for their investments. This paper discusses the old fashioned method of port investment and proposes and discusses an alternative method to take into account the life cycle aspects such as material costs, construction costs and demolition cost related to the environmental aspects such as transport of material, reuse of material, production of material. Conclusions and recommendations are: i) build a structure based on an standard uniform design and do not let customer needs influence the design, ii) try to predict repair just in time, iii) adjustments to the quay are expensive in the first 20 years, and iv) demolition costs do not influence the business case.

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Lifetime and replacement cost analysis for concrete bridges and overpasses in the Dutch highway network

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INTRODUCTION

Rijkswaterstaat (RWS), the executive agency of the Ministry of Infrastructure and the Environment in the Netherlands, maintains about 4.000 concrete bridges and overpasses in the country's main highway network. Many concrete structures date from the early 1970s. To calculate the life-cycle cost, information on the time and cost of replacement is required. Estimating the remaining lifetime becomes more important as the average age of the structures increases and at the same time the use intensifies. Moreover, in the coming years less structures will be built and the existing structures will be used longer. To get a grip on the (uncertain) lifetime of the concrete structures RWS periodically analyzes their age distribution. Next, RWS is also interested in the future budget requirements for the replacement of the structures.

This paper has two main objectives. The first objective is to estimate the lifetime distribution of concrete bridges and overpasses. To this end the lifetimes of demolished structures and the ages of structures in use are aggregated. A Bayesian analysis is done to estimate the lifetime distribution. The second objective is to estimate the (expected) future cost of replacing the bridges and overpasses. The expected replacement costs are next computed based on the expected lifetime and the lifetime distribution of the structures.

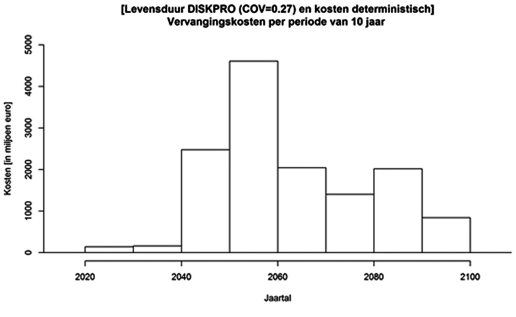


Figure 1. Expected future replacement costs as a function of time based on the expected lifetime (without uncertainty).

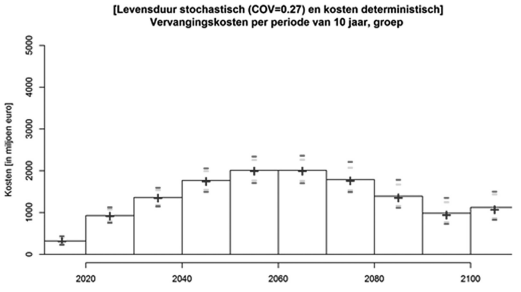


Figure 2. Expected future replacement costs of concrete structures as a function of time based on model 3. The red dashes (–) are 5th and 95th percentiles, the green dashes (–) are 10th and 90th percentiles, and the blue pluses (+) are the 50th percentiles.

The Bayesian analysis of lifetimes of demolished structures and ages of structures in use yields a lifetime distribution for the concrete structures as a group and a lifetime distribution for each individual structure. The generic lifetime estimate for bridges and overpasses is 80 years. This value underestimates the lifetime, since most demolished structures were replaced due to functional reasons. Further analysis should focus on the reason to replace the structure. The uncertainty in the lifetimes is large (coefficient of variation 0.27).

Without taking into account the uncertainty in lifetimes, the expected future costs of replacing the bridges and overpasses show a peak in the period 2040–2060 (see Figure 1). This makes sense, because most structures have been built in the 1970s. The replacement costs level out when considering the lifetime uncertainty (see Figure 2). A significant peak in budget requirements for the 2040–2060 remains and the uncertainty in the replacement costs cannot be neglected.

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Monte Carlo simulation-based life-cycle assessment method for an old roof steel truss

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ABSTRACT

Because the restoration of existing buildings involves different, specific issues, the collaboration of several technical experts is crucial during the whole process from diagnosis to restoration. An accurate material survey, along with structural diagnostics provide a rather detailed damage patterns in structural system, and are essential for successful diagnosis and successive intervention plans. When it comes to evaluate the potential to restore and convert the use of existing buildings, whenever there is evidence of a significant deterioration, it is necessary to focus on estimating the structural residual bearing capacity.

Structural diagnostics provides a comprehensive damage patterns in structural systems, particularly when surveys are detailed and accurate. However diagnostics procedures can be invasive. Most of all they can be applied on a structure locally, rather than to the whole structure. Complex numerical simulations, based on data collected by structural diagnostics, are usually used to study the general structural response of a system. The response obtained from numerical simulations is an approximation of the real structural behaviour. However, whenever the model is adequately calibrated using credible data, the numerical response obtained, though representing only one aspect of the problem, is good enough to support decision-making for strategic interventions. A simulation of the structure life-cycle might optimise the diagnostics process, highlighting the structural vulnerabilities where investigations should be focused on.

Considering the roof steel truss of the old Macello Suini (i.e. slaughterhouse) in Monza, Northern Italy, close to Milan, as case study, this paper investigates the life-cycle of the structure during different stages of the building lifespan along with the damages caused by aging and negligence. The periods analysed are: (a) from construction to disuse (1985), (b) from disuse to today.

The aim of the paper is to identify the main vulnerabilities of the structure, to assess the residual life of the system, to plan possible retrofit strategies for the building conversion. The procedure proposed is based on a Monte Carlo simulation implemented with a material damage law. This integrated method enables to consider different environmental conditions affecting the structure during its life.

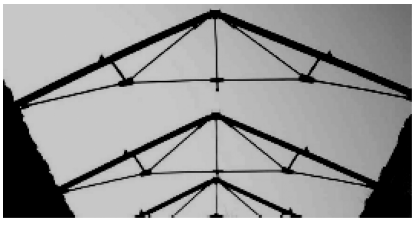


Figure 1. Truss structure of Macello Suini in Monza (Milan, Italy).

The results obtained point out that the disuse has significantly affected the structural conditions leading the risk of collapse to reach a high probability of failure.

Since the case study structure is under the protection of Cultural Heritage Authority, it is important to prove the success of prevention and maintenance strategy simulations in structural reliability and people safety. The procedure here exposed proves to be useful in defining proper intervention strategies. Furthermore authors are now considering the integration of the method with a cost-benefit evaluation for each scenario, and a probabilistic projection of life expectancy for each structural element.

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Optimal maintenance decisions for metro tunnels in soft soil

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ABSTRACT

Tunnels are more prone to deterioration than above-ground structures due to the aggressive environment of water and soil. Observations show that severe structural defects may occur early in their service life, possibly leading to structural failure Thus, preventive maintenance is crucial for avoiding such consequences. The efficiency of maintenance not only depends on inspection and monitoring technologies, but also the optimization of maintenance decisions, which can further reduce maintenance cost. But for metro tunnels, the research on maintenance decisions is limited.

There are several challenges in optimization of maintenance decisions for metro tunnels. First, the degradation modeling of a tunnel is affected by various sources of uncertainties, particularly due to lack of knowledge about the aggressive underground environment. Second, the tunnel cannot be replaced easily. Currently only a limited number of reinforcement techniques are available to repair metro tunnels. The requirements of repairing metro tunnels in urban cities are stringent, such that the ground subsidence and uplift around the tunnel have to be controlled and avoid using excavation method. The third challenge is that it is difficult to simulate and quantify the effects of maintenance measures. Most maintenance measures in metro tunnels are reinforcement techniques, both the degradation speed and degradation level of an existing structure will change after maintenance activities applied, thus they should be treated as imperfect maintenance measures. Also similar maintenance measures applied in different locations may produce different effects.

In this paper, the degradation process of a metro tunnel is simulated by a non-stationary Gamma process. Reinforcement measures commonly used in metro tunnels in soft soil are investigated, and imperfect maintenance is considered in the optimization. Different maintenance decisions to avoid failure and reduce life-cycle maintenance cost of metro tunnels are considered in this paper. Both periodic and aperiodic inspection policies are investigated with control-limit maintenance strategy. Parameters in different maintenance decisions are optimized and compared for the objective of minimizing maintenance cost with sufficient structural safety, as shown in Figure 1.

The results show that by optimizing maintenance decisions the life-cycle maintenance cost of metro tunnels in soft soil can be significantly reduced, and it is more efficient to use a maintenance decision with an aperiodic instead of periodic inspection policy.

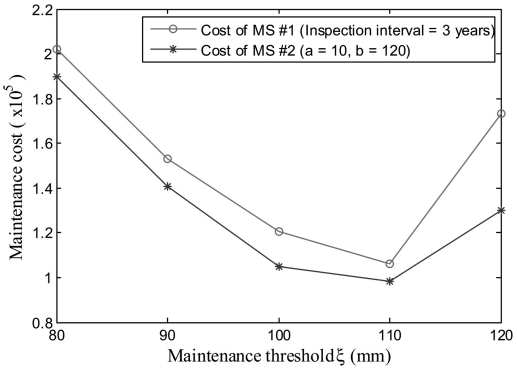


Figure 1. Comparison of different maintenance decisions.

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Optimization of maintenance, rehabilitation and replacement strategies on road pavements

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ABSTRACT

In most advanced asset management (AM) or pavement management system (PMS) condition prediction and LCC-models are utilized allowing a comparison and optimization of treatments and investment strategies. This paper deals with the methodical aspects and their application for the selection and optimization of treatments. Current state-of-art systems try to reduce the complexity of the issues related to the problem by neglecting the interaction between the distresses (elements) and using composite condition indices as a single measure for the optimization with the treatment costs only considered in the budget constraint. Furthermore, the stochastic nature of condition development, treatment impact, costs and service lives is neglected entirely in most PMS and rarely considered to its full extent for other assets. Thus, the aspects of reliability and risk optimization in LCC cannot be addressed in a mathematical sound way.

In this paper we use the initial not aggregated condition data to calibrate the prediction model on each survey section and for each distress type. Each type of distress is addressed with appropriate treatments adding up to associated costs. We determine the optimal type of treatment or combination of treatments, timing for application and length of work zones based on cost-minimization criterion. This model can be extended to a full stochastic approach for any complex system incorporating risks of failure, user costs and external costs. Based on an example of consecutive pavement sections exhibiting multiple distress types the paper shows how this approach may be applied in practice. In addition, common methods are applied as well to this example demonstrating why typical cost-benefit criteria with total condition indices fall short and are leading to arbitrary results compared to our approach regarding life cycle costs. As next step in the future we will provide evidence how a full stochastic model may provide even more insights and better results both in PMS and asset management.

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Practical application of a framework for analyzing replacement strategies for civil structures

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1 INTRODUCTION

A large part of the Netherlands' motorway network was built during the 1960's and 1970's. It is expected a substantial amount of structures will reach the end of their service life in the coming decades.

End of service life may provide an opportunity for a partial redesign of the infrastructural network. Renovation or replacement of structures reaching the end of their service life may have a significant impact on network performance and requires a substantial amount of resources. Added value can potentially be found in coupling infrastructural developments with spatial developments.

A methodology for the long term planning of the replacement and renovation of the major hydraulic structures has been developed within the VONK project (Figure 1). This methodology consists of an integrative framework to provide the necessary information for the decision-making process on the long term replacement and renovation of infrastructure.

This paper explores whether elements from the approach developed for hydraulic structures can be applied to motorway structures. The application focuses on adaptation pathways and is illustrated by the case of the replacement of bridges in the A44 motorway.

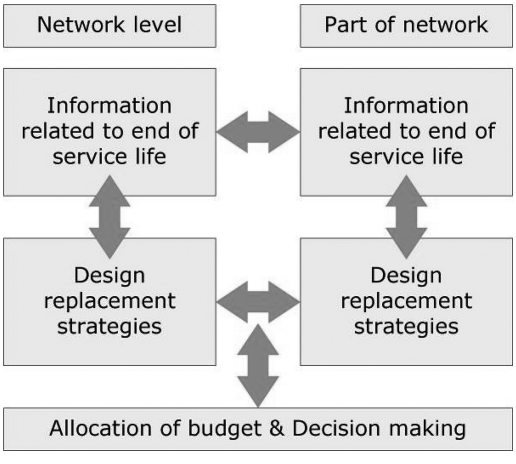


Figure 1. VONK framework.

The results of the analysis were evaluated in both a qualitative and a more quantitative manner. The case study proved the application of the VONK framework for road infrastructure feasible. The analysis provided as a starting point for further, more detailed studies. However, the qualitative evaluation also showed a relative lack of distinction between identified strategies and the study did not yet provided information on the relationship between replacement strategies and long term uncertainties regarding traffic development. A qualitative approach can be useful for a relatively quick first analysis is situations where end of service life is expected and not so much information is yet available. The purpose of such an analysis may be to guide further, more detailed studies.

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Risk based maintenance for civil structures

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ABSTRACT

Civil engineering is, traditionally, focused on construction. Due to the long lifetime of structures and the fact that new construction becomes scarcer, society is challenged to keep the existing infrastructure in good condition and performance. Civil engineers are required to maintain infrastructure in a cost effective and efficient way, whilst ensuring that the asset manager is fully in control. To be in control, knowledge is required on object condition, performance and related risks.

In the paper the authors show that a structured approach is important in risk analysis. This includes the mind-set of the analyst. The analyst has to understand the risks related to a specific object and its function in the network. Risk analysis includes a full evaluation of former and current condition reports and information on the existing structural design (non-damage related object risks). The inherent knowledge of the analyst is needed in the definition of the resulting object maintenance strategy.

To have a full risk based maintenance program several pieces of the puzzle have to be put in place:

- Performance targets have to be set by the as-set owner. These describe what the asset owner deems important.
- It has to be known how the different assets link to these targets.
- In the definition of priorities in programming, the contribution of a structure to its targets has to be evaluated, both for the individual object as well as for the collection of objects on a network link.
- Because mostly quite some time will be spent between inspection/analysis and the execution of works, the result has to be transparent. Transparency ensures that, in the course of time, no knowledge is lost and counterproductive options are selected.

Failure mode analysis is used worldwide, for instance in the oil and gas industry. To determine a chance of failing, a system is decomposed into (often prefabricated, created in high volumes) components of which statistical information is known, like mean time to failure etc. Fixed civil structures, like bridges or viaducts, are mainly unique and built at the site. Therefore, analysis of the structures be-comes more subjective and based on expert judgement. The consequence is that, for an individual risk, one can always argue that a chosen chance or effect category should be higher or lower. Sometimes there is no absolute 'truth'. Therefore, the authors advise to combine competitor's knowledge, at first in separate analysis of the same structures/(sub)systems within clear boundaries and then to evaluate, discuss and learn. Guided by an uninvolved, open-minded steering committee, this can help to create an 'accepted' set of agreements and perhaps assumptions as a foundation for a more standardized way of working.

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The optimal maintenance strategy in BMS considering probability of measuring error

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ABSTRACT

For the bridge maintenance strategy and planning must be required to predict future performance based on the current performance, it is possible more rational decision-making through the higher accuracy of the prediction model. While performing a detailed inspection of the entire bridge can reduce a significant part of the uncertainty, it is impossible to reduce the uncertainty of inspection result and it is always evaluated by probability. In this study, to solve this problem, a Bayesian update method is applied to the optimal maintenance strategy in Bridge Management System (BMS) considering probability of measuring error. Also, examples of application are presented, showing the effects of inspection and updating on the optimization of the bridge maintenance strategies. In this study, application possibility and availability of domestic bridge management system are evaluated by referring to the proposed method in the existing trends.

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Use of a future maintenance demand indicator for network level asset management decision making

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ABSTRACT

Asset management of national road and waterway networks is often performed by executive agencies of governments. The governance structure typically entails an agreement between the owner of the assets (the government) and the asset manager (the agency), called a service level agreement (SLA). In a SLA, the required performance of the network, the risks and the maintenance budget for a certain time period (e.g. several years) are agreed upon. A SLA may also include the performance indicators to be monitored during the SLA period.

The duration of the SLA may be significantly shorter than the typical lifecycle of roads, structures and waterways. This may have undesired consequences in cases where too much attention is paid to the short term performance within the SLA-period. Short-termism may particularly prevail in times of financial scrutiny, forcing governmental bodies to maintain service levels with substantially decreased budgets. To counteract short-term views, more insight in the long-term effects of the SLA is needed. The question, however, is what indicators can be used in to provide indications of the long-term effects of short term (e.g. 3–5 year) agreements.

Previous work (Wessels, Schoenmaker, Van Meerveld, Bakker, & Schavemaker, 2014) was aimed at "developing a clear, proven, consistent and simple indicator, that represents the long term effect of short term decisions". An indicator was developed, which provides the "discounted future maintenance demand" (DFMD) for a time period stretching beyond the initial agreement period. The indicator is expressed in a monetary value. The main assumption here is that the effect of short term decisions are reflected in the future maintenance demand.

The indicator was applied in a case using existing data and information sources. Furthermore, this indicator also provides means for monitoring the development of the future maintenance demand. The application in the case study showed that it is possible to apply the indicators using current existing data and information systems, although several limitations and challenges were encountered.

The work presented in this paper showed the successful further application of the indicator in an simulated environment which is very similar to actual practice. Moreover, the indicator and workshop setting proved a valuable learning ground making use of already existing data. Although there were several limitations encountered, the case organisation considers the approach valuable enough to continue on the path of creating transparency and learning. Through continuous collection of data, analysis (including follow-up investigation), more and more insights are gained in the long term effects of short term decisions.

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Using pavement monitoring data for maintenance budget estimation

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ABSTRACT

For nearly two decades now federal roads in Germany are monitored on a regular basis. Every four years a surface condition recording and assessment regarding evenness, grip and visual detected deteriorations is performed. The collected data of each campaign is stored position related. Overlaying different campaigns the development of pavement condition discloses. Though there are calculation models to predict life time of pavement structures the results comparing calculated and observed time spans are not satisfying.

Investigating different calculation models additional data is needed. An evaluation of data availability on a state road network level shows a very low information density on structural data, which is needed to interpret the condition data at the surface. Besides measures undertaken to increase available information about pavement structures the development of pavement condition seems to be influenced by so many different aspects, that it is a challenge to achieve enough information in sufficient accuracy to perform prediction calculations.

Based on this fact the condition development at all can be stated as stochastically. If so, the performance could be described with probabilistic calculation models. The results will become better the more road sections are evaluated and the more homogenous these road sections are. The uncertainty concerning the life time of a specific road section increases but decreases concerning the overall maintenance budget in a road network. From the perspective of a balance financed road authority responsible for about 7.000 km of roads this is an essential advantage.

Creating a probabilistic model the methodology of assessing existing pavements as well as maintenance measures was improved. The development of the maintenance budget over a time period of ten years was simulated. Using the improved methodology exceptional depreciation influencing the maintenance budget could be reduced by nearly 90% in some years and about 60% in average.

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Common misunderstandings in life cycle costing analyses and how to avoid them

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ABSTRACT

LCC analyses (LCCA) and discounting calculations are applied by public sector organizations in the Netherlands. Still numerous misunderstandings can be recognized. A total of 10 cases was analyzed, representing work of governmental organizations, water boards, water utilities, municipalities and supporting consulting agencies. This leads to an overview of some common misunderstandings in Life Cycle Costing Analyses.

Still a misunderstanding is a failure to recognize the contribution of the time value of money. Some organizations just ignore the time value of money and do not discount the cash flows that occur over time.

Frequently seen is a misunderstanding of the cash flows to be used in (net) present value calculations. Most cases reviewed did not comply with the definition of cash flows to be used in LCC analyses and net present value calculations.

Misinterpretation and unexplained variation of discount rates were seen. In one case the discount rate was interpreted as profit on investment and set to zero. In other cases discount rates used for similar public sector projects showed a variation between 2.5% and 5% and were often not motivated.

Organizations mostly do not know how to deal properly with inflationary effects. Only few of the cases that were investigated handled inflationary effects correctly.

Often seen is the use of an incorrect calculation period. In the economic comparison of public sector assets, life cycles of assets are repeatedly adjusted to analysis periods preferred by governments without a proper truncation of cash flows at the end of this period.

All cases lacked sensitivity and scenario analyses. The future is by definition uncertain. Sensitivity and scenario analyses for capital infrastructure with long service lives and a low discount rates should not be ignored.

Good LCC analyses and present value calculations do matter which will be demonstrated by some practical examples. Six suggestions for better LCC analyses and NPV calculations are given. These include: the definition of cash flow, considerations on (social) discount rates, an explanation of different types of inflationary effects and how deal with these, approaches to deal with the economic comparison between assets or projects with unequal lives and common suggestions to deal with uncertainties.

Concluded is that more awareness on this subject and developing competences, skills and attitude towards LCC analyses and NPV calculations is needed starting with a solid comprehension of accounting and finance, followed by serious study and practice on LCC methodology.

Looking at LCC from a higher perspective, a proper LCC analysis needs: a well defined LCC question, a well defined LCC calculation model appropriate for this question, a good understanding of input parameters and their development in time and a good interpretation of results including a probability analysis.

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The modular knowledge matrix and recommendation for inspection and advice on civil structures

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ABSTRACT

During history the Netherlands has spent a great effort in the realization of crossings for transport in the lowlands with many waterways. For these crossings over the canals and rivers and the protection against high water levels many structures have been built, like bridges, tunnels, sea-walls and locks. These structures were built in several eras, materials and critical functional networks or critical civil structures.

The Dutch national, regional and municipal authorities and the engineering agencies face issues to gain purposeful insight in the structural safe and technical conditions of the existing assets and the way these advisory tasks are being outsourced.

A unique collaboration of the involved parties from both sides supported by SBRCURnet made it possible to agree on the conditions, coherence of the needed tasks and the minimal needed knowledge for filling in the essential insights. These insights are highly needed to manage the assets professionally. The CUR-Recommendation (CUR-Aanbeveling 117 Inspectie en advies kunstwerken) was issued in March 2015. The belonging manuals (CUR handboeken) are in progress and will be issued till 2017.

By connecting the minimal needed knowledge for execution of the inspection and subsequent advisory tasks, a modular setup of tasks with minimal conditions is created. Based on this platform the authorities are able to formulate clear their particular demand to the market. The agencies understand the uniform and modular framework. Exclusions and additions to the CUR-Recommendation are descripted clearly.

The classification of inspection and advisory tasks linked to the knowledge give new opportunities to disclose knowledge by new methods f.i. of web based databases where inspection tooling can refer to. This paper describes the development, experience, and achievements of the CUR-Recommendation for inspection and advice on civil structures.

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SS11: Learning cycles in life-cycle asset management

Organizers: A. Hartmann & I. Stipanovic



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A framework for evaluating the performance of infrastructure assets. Application to the life-cycle of road and railway bridges

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ABSTRACT

Across the world, road and railway administrations face considerable challenges, due to the economic, social and political impact of running their business. These administration bodies are required to cope with a wide range of stakeholders with competing interests and thus, they seek ways of providing reliable, safe and sustainable transportation systems.

These systems rely on infrastructure assets and key engineering components that are expected to perform as required, in order to secure network and route objectives and deliver optimized value.

Bridges and tunnels are a peculiar class of infrastructure assets, due to the extension of their life cycle, which can span for several decades. It is not uncommon for bridges in European railway and road networks to be in service for more than 100 years. Therefore, the performance of these types of assets must be monitored and evaluated, namely in what relates to some degradation mechanisms and other performance parameters that may usually be neglected for shorter life-span assets.

Understanding how performance parameters may be affected, and the forecasting of their behaviour, are key issues for asset management decision-making. These parameters may indeed influence the Life Cycle value and investment decisions for renewing life-expired assets or defining maintenance strategies, amongst others.

Though some of performance parameters are already monitored (e.g. condition rating), there is the need to develop a framework to collect, analyse and evaluate the performance in a systematic way through time. This paper will present a proposal for such framework, giving examples of their applicability in organizations context.

More than considering its current ability to meet the legal requirements (e.g. design loads), the performance of a bridge or bridges portfolios, can be analysed and evaluated considering economical, technical and organizational indicators supporting decision making processes according to the organization's interests.

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A framework for strategic replacement of infrastructure: Dealing with complexity, long term uncertainties and stakeholder involvement

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The Dutch Ministry of Infrastructure and Environment faces a huge challenge. Due to large investments in infrastructure on water management, navigation and flood protection from 1920's to 1960's, the Ministry faces an aging infrastructure for which replacement will likely become a necessity in the coming decades. This operation not only asks for large investments, but has to take network-coherence, long-term uncertainties, unpredictable politicians and stakeholders into account. Without dealing with these challenges the replacement of infrastructure will be not more than a modern upgrade of an existing system, dealing with the demands of a past society, in-stead of an evolving system anticipating on developments and a new future.

This article presents a framework for such a strategic replacement of infrastructure, that enables anticipation on system-coherence, long-term uncertainties and future's stakeholders interests. The framework is based on the following characteristics:

- an interactive set of activities – configured in two levels: network-level and subnetwork-level. Levels and activities interact with each other and give room for decision-makers and stakeholders to play and learn.
- adaptive dealing with uncertainties within these activities by (1) probabilistic assessment of the existing life-span of assets, as well from a technical perspective as from a functional perspective, and (2) use of adaptive paths to develop replacement strategies on a network scale.
- Using a diffuse, interactive way of working, following organisational, technical and political triggers. The framework is not based on a sequential, rational follow-up of activities, but on interactive use of them, following the triggers.
- Using an invitational way of stakeholder-involvement.
- Using a learning way of working within the framework.

The use of the framework will give a better insight into the replacement task and the possible courses of action, exploiting desirable synergies. The framework will facilitate and improve decision making within the asset manager's organization, and between the asset manager and the stakeholders by better structuring of activities and by creating support for decision-making.

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A risk-based model for maintenance decision support of civil structures using RAMS

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ABSTRACT

Nowadays transportation agencies are facing growing challenges such as the gradual ageing of structures, the increasing demands of traffic mobility, the growing pressures of citizens on quality and service and the volatile budgets available for maintenance. To minimise or overcome these challenges, in recent years agencies have been increasing their interest on risk-based asset management methodologies as decision support mechanisms. Nevertheless, agencies still need more structured and consistent risk-based methodologies, especially to guide the selection of maintenance strategies in a risk-oriented manner.

Decision-making in transport asset management requires understanding of risks. Whilst the application of RAMS criteria is consolidated in multiple industries, its adoption within the construction sector is still limited. This paper proposes a systematic risk-based model to support the selection of maintenance actions on civil structures by making use of the RAMS criteria in an integrated and dependent manner. The model aims to support maintenance programmers to select maintenance strategies for individual civil structures. It provides a methodology to assess the risks affecting a structure over a time period, while guiding towards the prioritization and planning of maintenance strategies in a risk-oriented manner.

The model has an open-end nature and supports the understanding of the effects of maintenance through a systematic estimation of the RAMS profiles. This iterative character of the model allows to go backwards on the risk assessment process if the maintenance action does not provide satisfactory levels of functional and structural performance. Since the model includes a maintenance strategy that supports the default option 'do-nothing', the worst case scenario is also considered, which allows for drawing a more complete risk picture. Furthermore, the model supports the translation of inventory and inspection data into a risk-based language, creating a common risk language between practitioners.

To some extent, it can be said that the model provides a platform to re-think risks and is an invaluable basis to understand, communicate and evaluate them within maintenance decision processes. However, the model has limitations that should be addressed in future work. Whilst laying foundations for the use of RAMS in the maintenance of civil structures, the model is still theoretical and lacks object specific requirements. Moreover, the model does not include the translation of inspection results into a condition level and ultimately, the understanding of the impact on an element's function. Therefore, inspectors have difficulties to translate the current condition into specific levels of functional and structural performance. This means that the problem of subjectivity within visual inspections is still unsolved. Being said that, the development of a tool that supports inspectors to translate element condition assessment into functional performance is needed. This can be done, for example through checklists that link each element's condition to a functional level alongside a set of indicators that support the definition of the respective condition. Another aspect for further improvement is the consideration of maintenance costs, the extension of the model to other criteria, such as security, health or politics and ultimately, its extension to other lifecycle phases such as maintenance implementation.

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Life-cycle cost explored by the integrated design and delivery solution framework

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ABSTRACT

Despite a great interest for the use of life-cycle cost (LCC) in order to promote sustainability while choosing the optimal solution, it is hard to observe LCC in practical use in the construction industry. The major objective of this research is to explore the use, or lack of use, of LCC in building projects.

Integrated Design and Delivery Solutions (IDDS, 2013), (see Figure 1) is the theoretical framework chosen to explore the use of LCC (or lack thereof) in the Norwegian building industry. It focuses on the integration of Collaborating People, Integrated Processes and Interoperable Technology.

The three imperatives can be reformulated with a LCC perspective in the following way:

1. Integrated Processes –> use of standards and methods for calculation
2. Collaborating People – multi-disciplinary collaboration that ensure validity of calculations
3. Interoperable Technology –> BIM based software

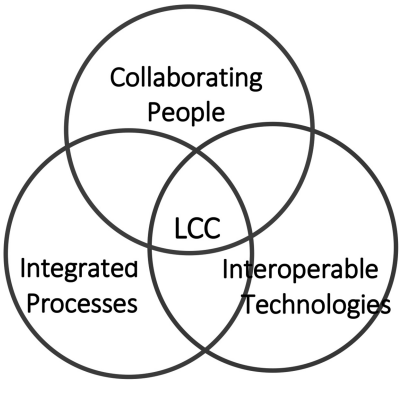


Figure 1. The three aspects of Integrated Design and Delivery Solutions (IDDS, 2013), figure simplified by the authors.

The study start by presenting an overview of how LCC is used in the construction industry. The theoretical framework Integrated Design and Delivery Solutions (IDDS) is then introduced, followed by the methodology chosen to address the research question and the inherent limitations. A survey of a database for tenders and two interviews; one large public builder/facility manager and one private contractor/property developer constitute the starting point of the data analysis. Those three cases are then discussed according to the IDDS framework, providing a better understanding to the appraisal of LCC use in the Norwegian construction industry, and likely other countries.

Our analysis shows that the use of LCC calculations (or lack of thereof) can be related to the level of interaction between the three aspects. There is strong indication that the development of new or revised standards "Integrated Processes" itself will not contribute to increased use. Likewise, there is no evidence that increasing the perspective "Interoperable Technology" or "Collaborating People" alone will contribute to a more widespread use of LCC calculations.

This study indicate that LCC calculation can be increased by focus on the integration between the aspects Integrated Processes, Collaborating People and Interoperable Technology – and not increased development of the separate aspects.

The integrated perspective can contribute to increased use of LCC in the construction industry in a time- and cost effective way.

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Longtime monitoring with smart sensor networks: The case of the Zwartewaterbrug

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ABSTRACT

A pressing need for bridge monitoring concepts and technologies is given by the fact that the majority of bridges in most developed countries were built between 1950 and 1970. These bridges – often key nodes in the transportation networks of the respective countries – not only reach the end of their design life, but were also designed based on assumptions and requirements that no longer reflect current traffic demands.

Despite the progress in monitoring techniques and systems their application has been restricted to single bridges that are rather unique cases due to their criticality or complexity. Monitoring systems have hardly found their way into the asset management practice of road agencies. Their cost-effective exploitation for the large and aging bridge stock in many countries offers the potential for more informed decisions on the life extension of bridges and, thus, for reduced life-cycle costs and enhanced performance.

In this paper experiences with a longtime monitoring system applied to the Zwartewaterbrug in the Netherlands are described. The monitoring system is based on distributed vibration measurements and on the analysis of modal parameters of the bridge. Major benefits of the proposed monitoring system are: it is simple to install, it stays permanently installed and measurements are conducted while traffic runs over the bridge.

The investigated part of the Zwartewaterbrug is a steel tied-arch bridge of 104 meter in length, carrying four lanes. The bridge was built in 1972 and is exemplary for a huge number of aging bridges where the real traffic loads by far surpass the bridge design loads.

The proposed measurement system consists of a data acquisition system and a methodic approach for data analysis. For data acquisition three sensor nodes are distributed over the bridge, each node again is connected to several sensors. The sensor network not only yields benefit in terms of a high flexibility in application but the decentralized data preprocessing on the network nodes also significantly reduces the amount of data to be transferred and stored. The focus of this investigation is to test the functionality of this prototype monitoring system. Special attention is paid to the usability of low cost sensors for long term bridge monitoring

Bridge vibration measurements have been conducted over a period of seven months between October 2014 and June 2015. Results show that a number of mode shapes and modal frequencies can be automatically identified and tracked during the investigation period while the bridge is in full operation.

A set of current bridge vibration data is stored once per hour on a network gateway. A subsequent analysis of the data on a central unit first extracts the modal parameters of each data set and establishes trend charts allowing for a continuous monitoring of the bridge's dynamic behavior.

Bridge vibration has been investigated over a period of seven months. Results show that global vibration parameters can be identified autonomously while the bridge is in full operation.

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Ontology based exchange mechanism for Systems Engineering information

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ABSTRACT

This paper presents a method that enables exchange of Systems Engineering information between involved parties in projects. This method is based on the usage of an ontology, described by a set of information models and a Reference Data Library as defined in ISO 15926 ISO 15962 is a well-known life cycle data integration standard from the process industry. This paper also describes implementation aspects of an ontology, based on RDF (Resource Description Framework) as defined by the World Wide Web Consortium.

The presented method can also applied in combination with e.g. the Dutch CBNL as reference library, the Object Type Library (OTL) and SE-BIM standard as reference model for Systems Engineering.

During the engineering phase of several capital facility projects in the Netherlands, the method has also shown to be helpful in the communication about Systems Engineering between involved parties, improving interoperability. The presented ontology have been validated within real projects respectively based on the software tool Relatics and based on a specific RDF implementation.

Experiences with the described ontology have shown that the topic of ontology is important for Systems Engineering and that there is merit in further examining the suitability of ISO 15288 as an ontological foundation, enabling formalized modeled based Systems Engineering.

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Economic End of Life Indicator (EELI)

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ABSTRACT

Infrastructure ages over the years, both technically and functionally, and at a certain moment structures need to be demolished or replaced, i.e. the "end of life". This concept has many interpretations however. That is because "end of life" is not a scientific concept. Rather, it is a consequence of a human decision, affected by many rational and less rational considerations. This paper describes an "Economic End of Life Indicator" (EELI), an indicator that makes a statement on economic grounds to what extent the maintenance of an aging structure is still financially viable relative to a 1 on 1 replacement.

This indicator was developed by Rijkswaterstaat, (a government agency of the Ministry of Infrastructure and the Environment in the Netherlands) within the "Replacements and Renovations Program". This program aims to quantify the replacement needs for structures in the decades to come. Replacement cost are expected to increase in the coming decades due to functional and technical ageing.

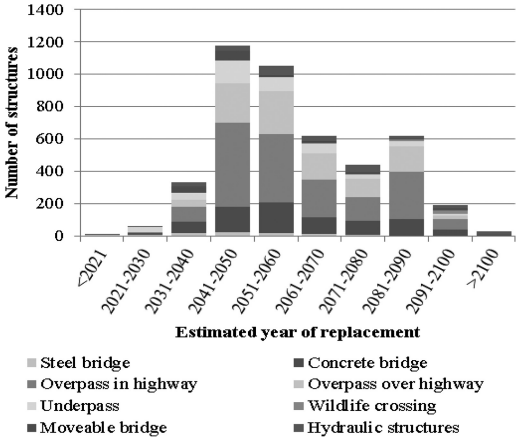


Figure 1. Expectation of bridge replacements for Rijkswaterstaat.

Figure 1 (Klanker et al. 2016) shows the resulting forecast for replacement of bridges.

The costs of such replacements cannot be covered by the regular maintenance budgets. Therefore a program "replacements and renovations" is set up, aiming to assess, quantify and substantiate the replacement needs for the next decades.

For each object with a proper maintenance plan and replacement prognoses it is possible to calculate the present value on the fly. Now suppose that this number is compared with the present value of a whole new identical object. Where the replacement hypothetically starts in the year 0. Then a ratio can be calculated according to equation 1:

$$EELI = \frac{PV_{in} + PV_{best.per} + PV_{RP;t=p}}{PV_{RP;t=0} + PV_{nieuw.per}} \quad (1)$$

In which PV_{in} = present value calculated according to Equation 1 for incidental maintenance activities; $PV_{best.per}$ = present value of the periodic measures for the existing structure (each with an predicted first year of activity t, justified by inspection results), $PV_{RP;t=p}$ = present value of replacement on a planned year t = p, followed by a replacement interval T.

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SS12: Performance of concrete during life-cycle

Organizers: X. Ren, X. Gao & J. Li



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Compressive behavior of concrete under different loading rates: Experimental analysis

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ABSTRACT

The purpose of the experiments presented in this paper is to gain a better understanding of dynamic property of concrete, including randomness, nonlinearity and rate-dependency. 418 prismatic specimens are designed in the same size ($150 \times 150 \times 300$ mm), of which the strength grade ranges from C30 to C60. By using the MTS servo hydraulic testing system, the behavior of concrete at 8 different strain rates from 10^{-5} s^{-1} to 10^{-1} s^{-1} is studied experimentally. The mean value and standard variation of the uniaxial compressive stress-strain curves, as well as the statistical characteristic values of compressive strength and peak strain of concrete with different strength under different strain rate, are obtained through the experiments. Experiment results indicate that the strain rate has a significant influence on the mean value of peak stress while other properties rarely change with strain rate.

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Durability design criteria for concrete structures – An overview of existing codes, guidelines and specifications

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ABSTRACT

Current demands on sustainability of the built environment have posed an increasing emphasis on durability of structures. In this light, the performance of reinforced concrete structures (RC) with respect to durability shall be assessed. Assessment of durability involves the understanding of the mechanisms related to the deterioration process and their modeling, identification of the main variables affecting the problem, and service-life prediction. This is a complex issue that has been addressed in codes, guidelines, and specifications in different formats. Additionally, due to the uncertainties in the variables related to the deterioration process, a probabilistic treatment of these uncertainties must be adopted in the durability assessment and service-life prediction of RC structures.

The work presented herein has been developed on behalf of the Task Group 1 (TG 1): Life-Cycle Performance of Structural Systems under Uncertainty of the Technical Council on Life-Cycle Performance, Safety, Reliability and Risk of Structural Systems, Structural Engineering Institute (SEI) of the American Society of Civil Engineers (ASCE). The purpose of the Task Group 1 is to promote the study, research, and application of scientific principles of safety and reliability in the assessment, prediction, and optimal management of life-cycle performance of structural systems under uncertainty. As such, durability design criteria of RC structures are clearly within the scope of TG 1.

The ongoing activities of SEI/ASCE TC TG1 include a Special Project approved by the SEI Technical Activities Division Executive Committee for the development of a state-of-the-art report outlining the current status and research needs in the fields of life-cycle of civil structure and infrastructure systems. As a first step in contributing to this effort, TG 1 has prepared a report, by identifying some major codes, guidelines, and specifications addressing the subject, and current formats and trends in the treatment of uncertainties in these documents.

A sample of documents related to durability of concrete structures in different regions of the globe (US, Europe, Japan, China, and New Zealand) have been reviewed in this work. While common trends can be observed, it is also clear that different levels of complexity do exist in the treatment of the problem (prescriptive, performance-based, probabilistic, and life-cycle costs).

It shall be emphasized that the list of documents presented herein is not intended to be exhaustive; rather it represents major trends in the treatment of the durability problem of RC structures and the experience of those professionals who have contributed to the development of the TG1 report.

ACKNOWLEDGEMENTS

The authors acknowledge the contributions of TG1 members Hitoshi Furuta (Kansai University, Japan), Xin Ruan (Tongji University, China), and Alessandro Palermo (University of Canterbury, New Zealand) who have helped in the preparation of TG1's report. The first author thanks CNPq ("Conselho Nacional de Desenvolvimento Científico e Tecnológico", Brazil) for the financial support provided through grant 309034/2013-2.

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Performance evaluation of reinforced concrete tunnel suffering chloride attack

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ABSTRACT

Many tunnels experience structural performance degradation due to various deteriorations, and require appropriate performance-based maintenance. This paper presents a procedure (see Fig. 1) to evaluate the structural performance of a deteriorating structure by using a major deterioration analysis method and Markov process-based stochastic method. A fine grid for visual evaluation of the deterioration state was developed along with a solution for the basic transition probability to improve the stochastic method.

The procedure was successfully applied to a 40-year old immersed tunnel which was recently visually inspected for its deterioration condition (See Fig. 2) and measured with respect to its salt propagation. Based on the surveyed data of middle floor slab, the deterioration condition of each slab was evaluated with a fine grid with 5 × 45 grids, and the structural performance was predicted. The results (See Table 1) generally agreed with regard to the structural performance and the initiation time when the four stages of the rebar corrosion were considered to correspond to the four grades of the structural performance. From this study, the following conclusions can be drawn: 1) Evaluating the performance of the most critical component is an effective means to inspecting a large-scale infrastructure system considering a structure usually degrades due to partial and local deterioration; 2) Analysis of the major deterioration (e.g. rebar corrosion) is a viable method for appropriately predicting the structural performance of a new or deteriorating structure by investigating the most critical condition; 3) The Markov chain-based performance evaluation method is useful for directly evaluating the structural performance. The improved stochastic method is recommended for application with the fine grid to precisely define the visual deterioration state and with the basic transition probability matrix to reasonably evaluate the deterioration state. However, many issues affect the structural performance, and their complex effects should be clarified, as well as the analysis approaches should be presented individually.

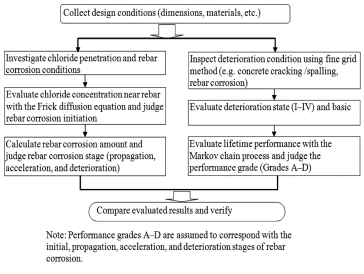


Figure 1. Procedure for performance evaluation.

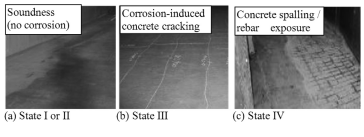


Figure 2. Representative deterioration state of the middle slab.

Table 1. Initiation times of rebar corrosion stage and structural performance grade (year).

	Rebar corrosion/major deterioration				Structural performance			
	Stage 1 (initial)	Stage 2 (propagation)	Stage 3 (acceleration)	Stage 4 (deterioration)	Grade A	Grade B	Grade C	Grade D
Room A	0	8	31	37	0	12	25	37
Room B	0	15	42	50	0	13	68	–
Room C	0	70	83	95	0	68	–	–

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Experimental research on influence of concrete cover on bond behaviors between concrete and corroded bars

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ABSTRACT

In this experiment, Four-groups of specimens were conducted (8 beam specimens in total) to research the bond behaviors including load-slip relationship, failure modes, and bond stress distributions of reinforced concrete in the case of slight corrosion rate, thickness of concrete cover and position of steel bars. Test results indicated that whether the load-slip relationship or failure modes are dependent on the position of bars and corrosion rate. The bonding capacity of bars located at the corner is weaker than that of middle ones and bonding crack of side direction appear early. Compare to the non-corroded beam, the peak load of slight corrosion beam increase about 5%, bond stress near the loaded end is about twice as much but about half of it in the far side. In addition, bond stress distributions in the corner bars and the slight corrosion bars are more uneven than the compared ones. Slight corrosion had no obvious effects on the failure mode of beam specimens, but slight corrosion make the split-position closer to the loading end. Slight corrosion improved the development of the cracks. The location of steel bars had great effect on the distribution of bond stress. In the cover thickness of 50 mm specimen the utilization of anchorage length is higher than that of 30 mm concrete cover, and the ultimate bond strength is higher too.

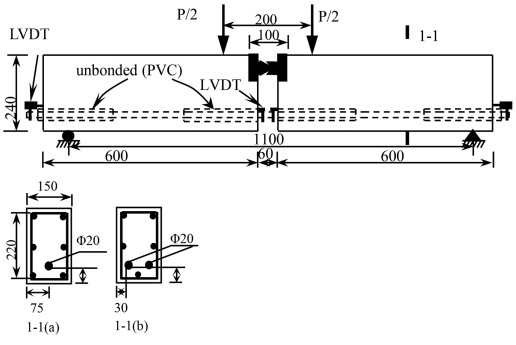


Figure 1. Dimensions of the test beam.

Table 1. Characterization of test specimens.

Specimen	Corrosion	Cover thickness/ mm	Location of bar	Section
M1	NonCorroded	30	Middle	1-1(a)
M2	Non-Corroded	50	Middle	1-1(a)
M3	Slight corroded	30	Middle	1-1(a)
M4	Slight corroded	50	Middle	1-1(a)
S1	Non-Corroded	30	Corner	1-1(b)
S2	Non-Corroded	50	Corner	1-1(b)
S3	Slight corroded	30	Corner	1-1(b)
S4	Slight corroded	50	Corner	1-1(b)

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Study of stirrup corrosion on bond-slip behavior of reinforcing steel in concrete

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ABSTRACT

Stirrups confinement was long recognized to have positive effect on bond strength. However, the effects of stirrup corrosion on bond performance were still lack of studies. This paper investigated the degradation of bond performance between rebar and concrete due to stirrup corrosion. 20 specimens with stirrup corrosion levels targeted from 0 to 20% were designed and manufactured. The specimen was cast as a 200 mm concrete cube, and an 18 mm diameter steel rebar was centrally embedded with two stirrups around the rebar. The 8 mm diameter transverse stirrups were artificially corroded by impressed current techniques to desired level of corrosion with the rebar intact. The effects of stirrup corrosion on crack opening width and length, bond strength and corresponding slip value, energy dissipation and slope of initial bond slip curve, and Residual bond stress were discussed in detail. The mean value and coefficient of variance of these parameters were derived.

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Time-dependent flexural capacity of the reinforced concrete beams

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ABSTRACT

The flexural capacity of reinforced concrete beams will decrease when steel bars rust during their service period due to the cracks and environmental erosion. Beam members are the most typical member in civil engineering. By studying the flexural capacity of corroded reinforced concrete beams, it can acquire the basic theory for the flexural capacity of existing reinforced concrete beams and provide life cycle design of the existing reinforced concrete beams for predicting the residual life of the beams. The effect of the corroded steel bars on the flexural capacity of corroded reinforced concrete beams is mainly reflected in two aspects that is the reduction of the cross-sectional area of the steel bars and the reduction of the bond strength between steel bars and concretes (Azad et al. 2007, Castel 2000, El Maaddawy et al. 2005). At present, the flexural capacity of corroded reinforced concrete beams is determined by the newly built reinforced concrete beam capacity multiplied by a reduction factor, which can indirectly reflect bond performance degradation and the reduction of the cross-sectional area of the steel bars due to corrosion (Tao et al. 1996, Niu & Lu 2002). Although the reduction factor can reflect the deterioration of flexural capacity of reinforced concrete beam, it cannot explain the physical mechanism of the flexural capacity of reinforced concrete beams due to bond performance degradation between steel bars and concrete.

A calculation method of flexural capacity of corroded reinforced concrete beams was presented by comparing the corroded beams with the normal ones. In the calculation method, the reduction of the concrete strength, the steel bar cross-sectional area and the degradation of the bond performance between steel bars and concrete are taken into account. To consider the degradation of the bond performance between steel bars and concrete on the flexural capacity of corroded reinforced concrete beams, the strain hysteresis coefficient m of steel bar proposed by Xu (Xu et al. 2006) is adopted. Because corrosion of the steel bars is the principal cause of the strain hysteresis, 77 test beams about flexural capacity of corroded reinforced concrete beam from five scholars were collected and studied to deduce the relationship between steel bar strain hysteresis coefficient m and steel corrosion rate η. According to the steel bar strain hysteresis coefficient m presented by authors, the calculation expressions of the flexural capacity of corroded reinforced concrete beams have been established by modification of the calculation formulas of the flexural capacity of the normal RC beams. The flexural capacity of corroded beams with corrosion rate η less than 8% can be predicted accurately.

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SS13: System capacity and robustness for new and existing structures

Organizers: A. Strauss, R. Caspeele, J. Campos e Matos & K. Bergmeister



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Development of a methodology for environmental life cycle assessment of alpine protective structures

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ABSTRACT

The existing system of Austria's natural hazard protection has a long tradition. With a comprehensive expert knowledge the Austrian Service for Torrent and Avalanche Control (WLV) builds all alpine protective structures, conventional technical civil engineering structures as well as soil bioengineering interventions. Currently the used assessment methods for protective structures are referencing technically, monetarily and economically. Examples for LCA in civil engineering can be found in road construction projects (Birgisdottir H. et al. 2006). Mroueh U. et al. (2001) has carried out a similar study on life-cycle impacts of road and earth constructions. The benefits and costs are given in the currency unit Euro. In modern protective engineering approaches, additionally to the effective protection of human life and material assets, also socio-economic aspects, environmental impacts and potential added values should be considered.

The research project E-Protect aims at developing Environmental Life Cycle Assessment (LCA) models for this special field of protective constructions (conventional as well as soil bioengineering structures). The project achieves an interdisciplinary and holistic approach by connecting disciplines of structural engineering and soil bioengineering. Both, the Cumulative Energy Demand (CED) and the Global Warming Potential (GWP) are considered in an Environmental LCA. These innovative Environmental LCA models will provide a new transparency for the responsible planners, by pointing out the truth of costs – involving natural resources – of all construction phases and components.

The challenge is to adapt the existing requirements of EN ISO 14040 to the specific field of alpine protective constructions in order to develop a viable method of life cycle assessment. This development offers a comparison of different variants of buildings and is therefore a helpful decision support in early planning stages.

A specific conceptual approach for alpine protective structures will be developed on the basis of existing LCA methodology for buildings (EN 15978, EN 15804). Processes cover all relevant life cycle stages including transports from cradle to grave: production, construction, use and end of life as well as benefits and loads beyond the system boundary. A functional unit based on the benefit of the structures will be defined. The reference service life for the protective construction type (temporal system boundary) will be determined.

The objective is to determine a methodical framework for the database and case studies within four main stages: Goal and Scope definition (G&S), Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), Life Cycle Interpretation (LCIN).

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Lifecycle performances of conventional and soil bioengineering construction materials

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ABSTRACT

Construction materials strongly influence performances of buildings. Not only specific material properties are taken into account when selecting latest constructional standards, but rather all life cycles stages. In the area of water and earthworks in addition to the conventional building materials such as timber, steel and concrete there are also increasingly used soil bioengineering building materials. Soil bioengineering structures use combination of plants with locally available auxiliary materials (wood and stone) as well as plants with classical conventional building materials (Florineth, 2012). Life cycle can be analysed according to the ISO 14040 (ISO, 2006). Both, statistically based degradation processes and forecasting models, as well as monitoring and evaluation methods can be used. This approach causes a high expenditure with the collection of various input variables. The availability of information on natural and classical-conventional building materials determines the reliability of these forecasting models (Strauss and Bergmeister, 2009). The application of LCM methods to soil bioengineering construction materials and structures is complex, because the building changes by the dynamic development of the living material plant. The ELWIRA project focus on the identification of fracture-mechanical parameters for classical concrete types with the aim of establishing a first step towards a database for multiple types of concrete as well as wood and plants as construction materials. The current research was indirectly stimulated by the urgent need for statistical parameters of the fracture-mechanical parameters at different levels of degradation when using software tools for the probabilistic life cycle based assessment of concrete and soil bioengineering structures. For the materials concrete as well as wood material properties were comprehensively described with (a) its variable modulus of elasticity Ec, its tensile strength ft, and its specific fracture energy Gf, and (b) uncertainties in material and geometrical properties caused by aleatoric uncertainties, manufacturing processes and curing. Beyond the determination of the stochastic models of the concrete properties and the validation of testing procedures (e.g. three point bending test results vs. wedge splitting test results), the differences in the scattering behavior of the concrete properties of the different types of concrete turned out to be of high relevance. Similarly compression strength of wood varies depending on storage conditions. Specimens stored exposed to the weathering or as logs showed lower compressions strengths than sheltered ones. All mean values remain below 55 N/mm^2 a mean value for compression strength mentioned in the DIN 68364 (properties of wood species – Density, modules of elasticity and strength). Exposed had means of 39 N/mm^2 and sheltered 45 N/mm^2. ELWIRAs main result of the current research establishes the keystone for a database of statistical parameters and types of probability distribution functions suitable for statistical description of fracture-mechanical parameters. These parameters can be used efficiently for fully probabilistic analyses of concrete and wood structures used in water engineering. The stated distribution types can be seen as prior distributional assumptions and can be updated by additional specimens for generalized validation and in case of specific practical application.

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Robustness of an existing pre-stressed concrete bridge

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ABSTRACT

Robustness has been appointed as a desirable property of systems in order to avoid significant indirect consequences caused by extreme events. In fact, robustness is usually related to global failure or collapse. Nevertheless, its definition is not consensual, having led researchers to propose several quantitative measures. In this work, an intuitive framework for the assessment of robustness as a probabilistic performance indicator of bridges to be applied either to ultimate limit states or service limit state is discussed. Indeed, it aims to achieve a quantitative measure to support road manager's decisions regarding the allocation of resources for investments and maintenance, as well as the mitigation of the consequences. In this sense, a framework based on decision analysis theory and a reliability-based approach are presented.

Our research strategy consists in a review of the state-of-art of robustness of structures, aiming to identify the suitable quantitative procedures to assess system robustness and its contributing attributes. A non-linear finite element model of an existing pre-stressed concrete bridge was used to assess bridge structural performance when it is subjected to several damage scenarios. Herein, reduction of steel cross-section due to corrosion and structural component losses are considered. By means of a probabilistic approach, the load carrying capacity and structural safety are evaluated. To do so, advanced techniques of reliability analysis to efficiently cope with several domains of failure are needed. In this regard, special focus is placed in meta-models, such as response surfaces. Lastly, the main difficulties encountered as well as the limitations of this methodology to compute the reliability at the system level are discussed.

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Safety format requirements for RC columns design based on stochastic simulations

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ABSTRACT

The increasingly complex structural systems and infrastructure requires updated design procedures and frequently utilizes various simulation tools, including nonlinear Finite Element Method. In majority of the current design codes, however, the safety formats are not optimized for probabilistic global nonlinear analysis. The assessment based on numerical simulations and global safety formats, such as introduced in the Model Code 2010, on the other hand, introduces potentially higher model uncertainties and the model validation becomes an important requirement for its application and engineering practice. On the example of reinforced concrete columns the application of design verification by nonlinear stochastic analysis will be shown and the important consequences discussed. Furthermore, respective safety formats and performance indicators will be discussed in a general framework of consistent safety and performance margin.

Safety formats for global nonlinear analysis have been tested in this paper on the stability failure of reinforced concrete columns. Currently the non-linear analysis of concrete structures cannot be considered only as a research tool for improving the understanding of structural behavior, as it is increasingly available for designing complex structures and estimating the actual safety level in existing structures. As a consequence, semi-probabilistic safety formats for the non-linear analysis of RC structures are of great practical interest for structural engineers.

The stochastic simulation results presented here were used to estimate the response characteristics of the investigated reinforced concrete columns by assuming various combinations of concrete class, eccentricity values and correlation structures.

Presented examples concerning the effect of various correlation values for a given couple of concrete parameters assume the typical correlation matrix for the remaining two parameters.

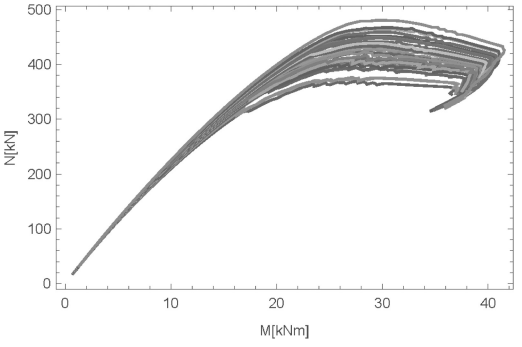


Figure 1. Example of various post-peek courses of the N-M interaction based on the concrete class C45/55, load eccentricity value of 4 cm, 30 LHS samples and correlation between G_f and E_c equals to 0.7.

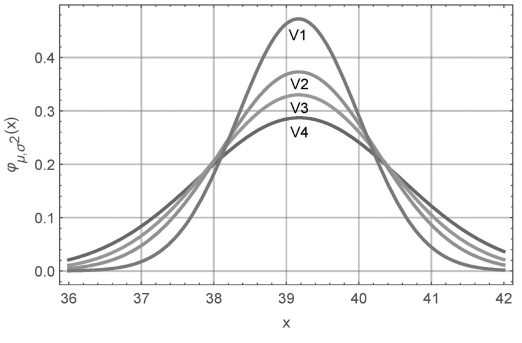


Figure 2. Fitted Normal distribution functions to the maxima of moments for the concrete class C80/95, load eccentricity values of 4 cm and correlation values between G_f and E_c equals to V1 $= -0.7$, V2 $= 0.0$, V3 $= 0.7$, V4 $= 1$.

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Software system to support the planning process of road bridges

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ABSTRACT

With the design proposal, the essential basis for qualitative high-quality bridges is laid, which are safe, fit for purpose and efficient during the manufacturing and usage, as well as being reversible and recyclable. Derived from multiple requirements technical solutions result into far-reaching consequences, which the planning engineer has to consider within a limited time. The presented expert system supports engineers actively during the setup of optimal designs, by giving them advices regarding life-cycle costs, durability and sustainability.

The aim of the planning process is the preparation of a bridge design which meets the highest standards concerning static-constructional, economic and aesthetic requirements. Based on an enormous number of completed bridge construction projects and many construction methods, technology and constructional detail solutions, the state-of-the art and technical expertise in bridge construction has reached a scope with limited access for planners or planning teams in the course of their engineer activity. In addition to the enormous range of technical knowledge and normative regulations, the high time pressure which is often present during structural engineering activity in modern bridge construction restricts the access to already completed and comparable solutions. In many cases the actively used knowledge base is reduced inevitably to a fraction of the theoretically available wealth of experience. It is common practice to refer to internal experience that can be referred to for individual further use.

The creation of optimal construction designs for bridges requires the systematic usage of the accumulated wealth of experience in engineering construction as well as the conceptual approach. The complexity of the task is increased by a variety of hard (technical, technological and economic) and soft influencing variables (e.g. topology, environment, accessibility, aesthetics …), of which the variety of design in most cases leads to unique constructions. The presented software system should in no way replace the creative inventive design activity of the engineer. It creates more decision making tools and recommendations for preferred options.

Currently there is a great demand for such planning tools. This is because the large number of bridge constructions will require significant investment in the future in the area of new construction as well as building preservation due to their age structure and ever increasing wear. This situation will become serious due to the disproportionate growth of heavy traffic. Moreover, the urgently needed economic responsible use of resources leads to a tendency towards lifetime orientation for the design, construction and the operation of buildings which will be supported through the life-cycle-data of existing constructions.

In the 1990's the German Federal Ministry of Transport (BMVI) developed a very well-known software program, called SIB-BW. The focus of this software is on the acquisition of building and damage data, mainly to create status reports of bridge constructions. Although it is in the meantime outdated, it is still very well-known and common in German building authorities. It is not the aim of this research project to be in competition with this software. With this research project it is possible to evaluate data (instead of holding) and to give advice regarding planning and sustainability. This research project also differs to the Bridge Management System (BMS) which is still in development. Its intention is to create strategies for maintaining planning in order to increase its efficiency in terms of maintenance of existing bridges.

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Structural robustness evaluation at selected damage cases of bridges

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ABSTRACT

Every year tens of Polish bridges undergo accidents or sudden environmental influences causing more or less significant defects or failures of their structural elements (see e.g. Fig. 1). In such situations a modification of a damaged bridge structure takes place including changes of its geometry, boundary conditions or even material properties. Detailed analysis of consequences of these modifications for the load carrying capacity is used in evaluation of its structural robustness and should be considered for both the existing damaged structures as well as for designed new ones.

There is a number of approaches to the structural robustness evaluation proposed in literature (see Biondini & Restelli 2008, Cavaco 2013 or Kamiński 2014). The method presented within the paper refers to an energetic approach defined by (Starossek & Haberland 2008) where for simplification of calculations instead of energy the internal forces are used. Precisely, the bending moments and their redistribution due to failure are analysed.

Two approaches to measure the robustness R are applied, differing in relative level of bending resistance, which are defined by a general formula:

$$R = 1 - \max_k \left(\frac{\Delta M_{k,j}}{\Delta M_k^R} \right) \quad (1)$$



Figure 1. Case of a bridge failure: loss of material in PC girder.

where $\Delta M_{k,j}$ = increase of the bending moment in section k after failure (hinge formation) in section j, Nm; ΔM_k^R = bending moment in section k required to reach its ultimate load capacity, Nm.

ΔM_k^R given in denominator of Equation 1 can be taken as the total bending resistance of the section or just as an increase of the bending moment considering its initial level.

Within the study various bridge structures with a hinge formation failure are analysed. For all cases both measures are applied and received results are carefully studied and commented. Final conclusions on effectiveness and usefulness of the measures are formulated.

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The complex approach to optimization of composite bridges

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ABSTRACT

The steel-concrete composite road bridges are one of the often designed bridge solutions for mid-span road bridges not only in the Czech Republic, but also around the world. However, due to the relatively high purchase price of the superstructure it does rarely win the public tenders, where the legislation still chooses the best solution only according to construction cost and ignores all other sustainability markers. Therefore, the need for the optimization of this type of structures arises significantly on the market. For that, the newly developed optimization tool in the MATLAB programming environment can help the designers and project owners to optimize their structures, or verify the existing design. The tool is described in the paper and the verification shown on the planned bridge structure.

Despite the fact, that the primary concept of the bridge is almost the most crucial one and affects the funding of the whole project. There is usually no space and time to do the lengthy optimization process in the early stages of structural design. The main objective is therefore to show the high importance of the sustainable bridge design, which includes all economical and environmental criteria through the whole bridge life cycle. The tool should be helpful to design the optimal structure according to these aspects directly in the planning phase of the bridge without spending much effort.

The Composite Bridges Life Cycle Optimization Tool (CompLOT) was to increase the competitiveness of composite bridges. The tool consists of three main parts, the first part designs the structure on the basis of user-specified input parameters and assesses it according to the valid Eurocodes, the second part assess the sustainability of the whole bridge during its whole lifecycle, normalizes the values of each impact category and weights them into final sustainability performance value and the third and last part optimizes the performance with the use of genetic algorithms.

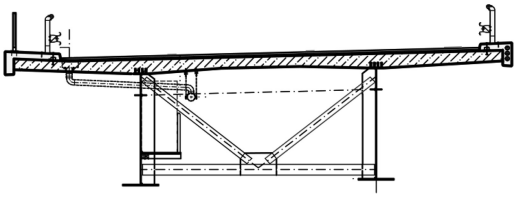


Figure 1. The characteristic cross-section for composite twin-girder bridge on D11 highway.

In order to verify the CompLOT, the input data of real bridge structure were used. The new bridge of length 140 m and carriageway category R25.5/120 on the planned highway D11, connecting Praha – Warszawa. The bridge is straight and the vertical alignment of the carriageway is between 9.39 m and 14.27 m above the ground level.

The attributes of the example bridge model were determined by Sensitivity Analysis and the relations between variables and cost functions are expressed by Spearman's rank correlation coefficient (SRCC). The design space, limited by boundary conditions, was created in the Design of Experiments (DoE) by pseudo-random number generator space filling method. The structure was optimized with the use of single-objective optimization for weighted and normalized values of sustainability performance.

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SS14: Marine structural longevity

Organizers: M. Collette & P. Hess



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An intelligent system for vessels structural reliability evaluation

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ABSTRACT

An intelligent system is proposed within INCASS (Inspection Capabilities for Enhanced Ship Safety) project for evaluating ship structural reliability and assisting in fatigue damage and structure response assessment. As part of the INCASS project several approaches are developed including robotic systems for inspection purposes onboard vessels as well as incorporation of schematics and available historical data. This allows for analysis to take into account the history of a vessel as well as models of the structure that are closer to the physical object. The overall developed INCASS system combines hydrodynamic analysis results, finite element analysis results and structural reliability models in performing a thorough and detailed review of the structure. The hydrodynamic analysis model is not discussed in this paper however is incorporated into the final decision support methodology. The finite element model input is a mesh for the mid-ship part of the vessel as presented in this paper. Finally, the in-house developed structural reliability model uses as input the calculated output of the finite element analysis model as well as models for estimating crack development and propagation, corrosion growth and fatigue loading. The output includes the probability of failure for all the investigated components versus time which can be used to assess safe operation through the developed decision support software. The INCASS project database is a versatile tool with attached interfaces which can receive information from various sources including inspection and robotic systems data. Additionally CAD like representations of the ship can be uploaded and reviewed. Finally the developed decision support software allows the user access to all aspects of the data collected and the ability to review and change the data according to inspection data collected onboard a vessel. For the purposes of this paper a case study of a capsize bulk carrier is demonstrated and the structural evaluation process is discussed. Finally, the calculated data is presented through the decision support software. Concluding, the INCASS approach provides a versatile and easy to use tool that allows for one single point of access to all the data recorded regarding the structure of a vessel of the life of the ship. This approach can be utilized for all vessels and provides predictive maintenance information through the decision support system presented in the Figure 1.

The INCASS project is an FP 7 European funded project which aims to reduce risk onboard a vessel through condition based maintenance decision support while also providing better protection for the environment and human aspect of the modern marine and maritime industry.

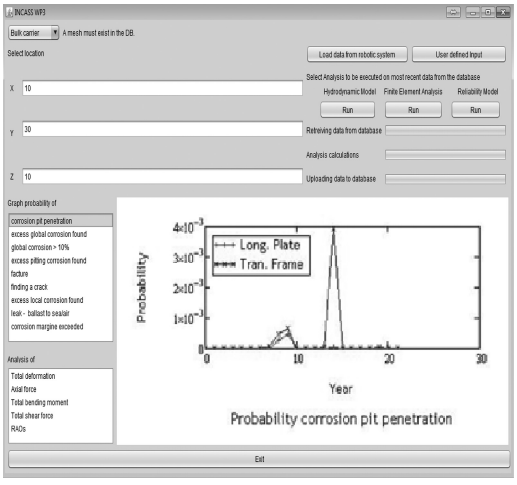


Figure 1. Overview of the decision support software for a case study.

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Evaluation of the effects of design uncertainty on the damage tolerance of composite patches

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ABSTRACT

Composite overlay patches are bonded to damaged or undamaged marine structure as a means to improve or restore damage tolerance and load-carrying capacity (Fig. 1). While this repair and reinforcement method is currently demonstrated on marine structures around the globe, design and analysis methodologies that account for the high variability in design parameters, material properties, and loading conditions are lagging behind its implementation. In order to optimize patch design and to ensure safe performance during the lifecycle of the patch, a comprehensive understanding of the effects of uncertainty on patch performance is essential. This work demonstrates an approach based on sensitivity analysis to quantify the influence of composite overlay design parameters on structural performance.

Because of the detrimental effects of non-visible damage on the patch's lifecycle, low velocity impact loading was chosen as the example problem to demonstrate the sensitivity analysis methodology. While composite patches have proven effective in-service, non-visible damage within the patched structure remains a concern. Patched structure is susceptible to internal damage in the form of fracture, adhesive disbond, delamination within the composite patch, and fiber breaks (none of which may be externally visible). This internal damage can reduce residual strength or propagate to cause patch and consequentially structural failure. Therefore, predicting non-visible damage is imperative to damage tolerant design, installation methods, and determination of inspection type and intervals to ensure structural performance during the entire lifecycle of the patched structure. A typical loading condition experienced by composite overlays that can cause non-visible damage is low velocity impact. Low velocity impact events include conditions such as hail impact, tool drops, and ice removal methods.

To investigate the damage tolerance of patched structure subjected to low-velocity impact loading and to quantify the effects of uncertainty on performance through sensitivity analysis, a 3D high fidelity finite element model of a patched structure was developed and validated. This model of a metal plate with a composite patch that is adhesively bonded captures multiple damage mechanisms including composite damage, delamination between composite layers, adhesive disbond, and plastic deformation of the metal. Computational simulation with this model is performed to study damage tolerance under low-velocity impact with respect to uncertain input parameters. Key components of this study include the demonstration of sensitivity analysis techniques to identify the most influential uncertain input parameters as well as critical combinations of the uncertain parameters that are detrimental to patch performance. The sensitivity analysis methodology also includes the capability to evaluate local regions of sensitivity within a given set of multiple parameters.

The objective of the sensitivity analysis is to quantify the influence of input parameters, both individually and as combinations, in order to identify the parameter sets and their subspace regions that have the greatest influence on the model output. Such knowledge informs design, installation, and maintenance lifecycle decisions as well as identifies which parameters need restricted control on variability and manufacturing tolerances to ensure they are contained in regions of the parameter space that lead to adequate structural performance.

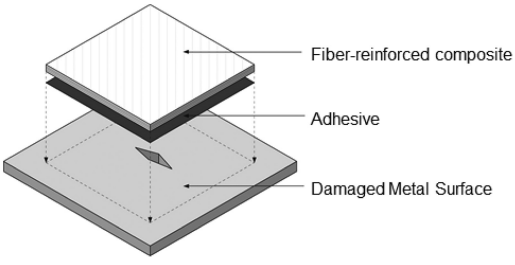


Figure 1. Diagram of a composite overlay repair.

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Fatigue life updating for vessel fleets

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ABSTRACT

Understanding the remaining life, readiness, and future reliability of complex marine structures is one of the central challenges of marine lifecycle structural management. With our enhanced ability to gather structural health data increasing as sensor technologies mature, much effort has been exerted on assessing marine structures using interpretation frameworks (Salvino 2009). A general computational framework was developed by Stull (2011). However, a technique for interpreting raw structural health data to produce meaningful and accurate updated reliability information to decision makers is still lacking.

The authors have previously proposed a parametrically-encoded Bayesian network approach to combine load monitoring, structural deformations and crack inspection results into an updating framework to perform future fatigue life predictions. The framework uses a S-N crack initiation approach, assuming vessels start their service lives with uncertain fatigue strength and load spectral estimates. Additionally, extreme load events are assumed to cause visible deformations of the plating field in the structure. The network updates design-stage estimates of loading and fatigue strength based on in-service measurements. The updated parameters are then used for prognosis of future structural state. In our previous work, a fleet of five vessels, with four inspected and one un-inspected was assumed. In this case, we showed that either positive or negative evidence (e.g. the presence or absence of cracks) was useful to the network for updating. Thus, the value of differing types of evidence was not as critical as may be expected. However, in the previous work the impact of the number of ships inspected was not explored. Here we extend the study to explore how the prognosis capability degrades as fewer and fewer ships are inspected.

In the present work, a common marine probabilistic loading and strength framework is adopted. The magnitudes of independent wave loading cycles are assumed to follow a Weibull distribution. These alternating stresses drive structural fatigue cracking. A Gumbel extreme value distribution is derived from the Weibull distribution to represent the peak loading experienced. This in turn drives the level of permanent deformation observed in the structure. This loading model is combined with a lognormal S-N initiation model for fatigue cracking. Each stochastic variable in this framework is represented by a node in a compact Bayesian network. The network is structured with an un-informative prior distribution of these parameters in the neighborhood of their believed true values. Evidence, in terms of observed fatigue cracks and permanent deformation of the structure, is supplied to the network from an initial inspection. The posterior beliefs in the parameters of this stochastic model are then used to forecast future fatigue cracking.

The updating power of the network was evaluated for one through five ships of evidence assuming both permanent set and fatigue crack initiation were inspected. The network demonstrated its ability to quickly converge on a more accurate prognosis and underlying model without requiring many inspected vessels. Error in standard deviation of the forecast was observed to benefit the most from an increasing number of inspected vessels. Trends in updating power and interactions between inspection types are also discussed.

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Ship structure fatigue and life cycle risk management approaches

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ABSTRACT

Ships must perform their missions with a high degree of reliability to maximize availability through their service life. Current practices by ship structural designers, maintenance planners and operators are based on fixed design parameters and are more reactive than proactive. The long-term hull structure reliability is time dependent with degradation caused by the operational environment and decisions by the operators. While structural reliability approaches have been developed and applied in other industries, the technology transfer has not been fully realized for ship structures. Recent research on ship maintenance strategies includes optimal inspection strategies to detect fatigue cracks and update the structural reliability when the cracks are repaired. This approach relies on repaired failures to determine an updated level of reliability after the repairs are made. This often includes the effects of the repair quality on the reliability updating. However, optimal inspection approaches are not cost effective for complex ship structures in the context of total ownership costs and risk because they are based on finding failed structure. In this paper, risk is defined as the product of the probability of failure and associated consequences. This paper compares the inspection of failure approach to a safe life approach involving inspections with no (or minimal) failures in combination with structural monitoring. The reliability approaches proposed for ship structures have not included an assessment of risk (defined as the product of probability of failure and cost of consequences) or a rational approach for making informed decisions based on quantifiable statistical uncertainties. Furthermore, decisions made in ship structure design, construction, maintenance, and operation have a significant impact on their structural reliability, failure consequences, and lifecycle costs required to minimize Total Ownership Cost (TOC). In this context, structural reliability and related failure consequences define the system risk. Together, the Risk and TOC form a trade space for making cost-effective decisions. This paper presents concepts for assessing ship structural reliability, consequences of failure, lifecycle economics, maintenance approaches and related costs required to minimize TOC at maximum availability and mission effectiveness. Hull Structure Monitoring (HSM) approaches are evaluated for their ability to reduce statistical uncertainties in lifecycle management approaches. The use of hull structure monitoring is evaluated for tracking and forecasting structural maintenance needs within a Risk-TOC approach.

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Structural fatigue life assessment and maintenance needs for a new class of US Coast Guard Cutters

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ABSTRACT

Ship hulls are exposed to millions of stress cycles over their lifetime. These stress cycles may lead to the formation of fatigue cracks. For naval vessels this matter is generally more important because these ships are intended to be operated by the same owner for the duration of their design lifetime, in challenging environmental conditions and preferably with a longer service life. Any necessary ship repairs, both planned and unplanned during that service life can lead to significant costs. Figure 1 shows an illustrative example of total ownership cost considerations related to fatigue design approaches. The figure shows a comparison of time-dependent reliability when considering fatigue in design and the "do nothing approach", as it is known in risk analysis and decision theory. The investment of including fatigue early in design is minimal compared to the risks of the do nothing approach. Because fatigue damage is proportional to the third power of stress range, the benefits of increased fatigue life and cost savings may be realized with small increases in steel weight.

A tool typically used for assessing fatigue during design is spectral fatigue analysis (SFA, Sieve et al. 2000). Uncertainties of the SFA approach are the wave environment, the operational profile, and structural load prediction. One way to mitigate these uncertainties and associated risks is to make measurements as the ship is in service with a hull structure monitoring system (HSM). The first to verify the SFA design approach and the second a longer term monitoring to quantify the lifetime effect of fatigue uncertainties associates with ship operational conditions.

From the first HSM program it was found that the wave environment encountered by USCGC BERTHOLF had lower probabilities of occurrence in significant wave heights greater than 4 m as compared to the wave probabilities used in early fatigue evaluations. Using the Sikora et. al. (1983) and Sieve et. al. (2001) or similar spectral fatigue approach early in the design produces significant returns investment when compared to modifications required late in the design process, unplanned ship repairs and sustainment costs.

Because fatigue damage is proportional to the third power of stress range and influence of the operator in avoiding heavy weather when possible, it is beneficial to monitor the fatigue damage accumulation. Long term monitoring with a simple system provides a cost effective approach for reducing uncertainties and risk in lifecycle and end of service life decisions.

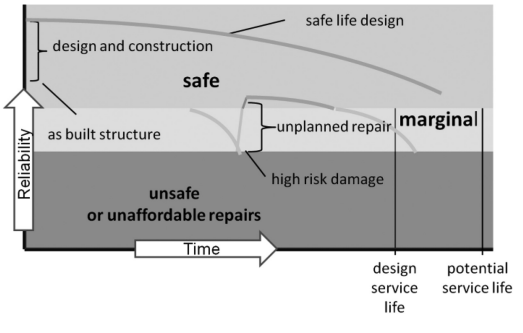


Figure 1. Illustrative example of total ownership cost considerations related to fatigue design approaches. Taken from Stambaugh et al. 2014.

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Structural health monitoring planning of ship structures in a life-cycle perspective

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ABSTRACT

Due to the ever-changing state of an engineering system subjected to deterioration, it is crucial to consider both aleatory and epistemic uncertainties within the structural performance assessment process. Aleatory uncertainties are associated with the randomness of the underlying phenomenon, whereas epistemic uncertainties are associated with models used to predict reality (Ang & Tang 2007). Epistemic uncertainties may be reduced by including information collected from inspections and structural health monitoring (SHM) (Frangopol & Messervey 2007). The overall objectives of SHM include: (a) assessing structural performance, (b) predicting remaining service life, and (c) providing a decision tool for optimum life-cycle management of deteriorating structures (Frangopol 2011).

Ideally, continuous monitoring would be required to accurately assess and predict the performance of deteriorating systems; however, this is neither practical nor financially efficient. Presented herein is a methodology to determine cost-effective SHM plans considering the probability that the performance prediction model based on monitoring data is suitable throughout the life-cycle of a structural system. This probability is used to calculate the expected average availability of monitoring data for prediction during the life-cycle of a system.

Embedded within the presented decision support system for the optimum planning of SHM for ship structures is the performance prediction modeling, which is accomplished using statistics of the extremes and availability theory. Utility theory is used to incorporate the influence of the decision maker's risk attitude on the relative desirability of lifetime SHM plans (Keeney & Raiffa 1993). Various types of utility functions (i.e., exponential, logarithmic, quadratic) are employed to express the relative desirability of lifetime intervention schedules.

Optimization procedures are utilized to simultaneously maximize the utilities associated with monitoring cost and expected average availability in order to determine optimum SHM plans under uncertainty. The outputs of the presented framework are optimum lifetime SHM plans allowing for availability-informed decision making regarding monitoring of ship structures. The effects of the type of utility function and risk attitude of the decision maker on the optimum SHM strategies are investigated. The capabilities of the proposed decision support framework are illustrated on an aluminum wave piercing catamaran.

ACKNOWLEDGEMENTS

The support from the U.S. Office of Naval Research (contracts N00014-08-1-0188, N00014-12-1-0023, and N00014-16-1-2299, Structural Reliability Program, Director Dr. Paul E. Hess III, ONR, Code 331) is gratefully acknowledged. The opinions and conclusions presented in this paper are those of the authors and do not necessarily reflect the views of the sponsoring organization.

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SS15: Optimizing decision making of rail asset management

Organizers: J. Swier, M. van Noort & R. Dollevoet



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Preventive condition-based tamping for railway tracks: A decision support model

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ABSTRACT

The paper will analyze how methods from Operations Research (OR) can support the optimization of maintenance of railway tracks, aimed at minimizing the tamping cost. This paper presents a Mixed Integer Programming (MIP) model which is designed to optimize the predictive railway tamping activities for the planning horizon up to four years. Five technical and economic aspects are taken into account to schedule tamping: (1) track quality (the standard deviation of the longitudinal level) degradation over time; 2) track quality thresholds based on train speed limits; 3) track geometrical alignment; 4) tamping machine operation factors, and finally, 5) the discount rate. The usage of the model is explored in case studies, including a Danish railway track between Odense and Fredericia with 57.2 km of length. The total cost can be reduced with up to 50% using the proposed model, which shows its great potential to support railway tamping planning in practice.

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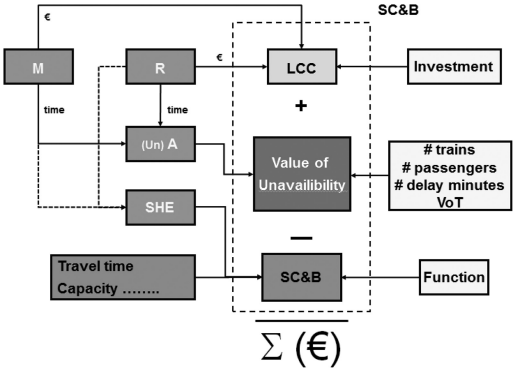
Professional and sustainable decision making with life cycle management

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EXTENDED ABSTRACT: This paper gives you an insight into the method of sustainable decision making. A number of practical examples show how this method is applied within ProRail, the Dutch inframanager. In the end it will be clear why it contributes greatly to the strategic objectives of ProRail to work efficiently and sustainable.

ProRail delivers a product in the interest of society. So it's important that they operate transparently and efficiently and spend public money on matters of social importance. They also have to prove what the costs are to achieve a specific performance level. To achieve that level, it is not sufficient to consider the technical performance only. Economic and social aspects have to be regarded in decision making processes on maintenance, renewal and investments. With ProRail's Life Cycle Management method scenarios can be compared with respect to economic and social aspects. In the past, decisions concerning costs were based on technical arguments and facts.

With the introduction of Life Cycle Management, it became possible to choose the best scenario based on costs and economical aspects during the entire life cycle. To compare scenario's with different functionalities, the social costs and benefits were included. Counting in the benefits of travel time the decision between a normal- or highspeed switch can be made. Currently, the society asks more and more for sustainable decisions. That means that all the costs and benefits must be taken into account. Not only the Reliability Availability Maintainability and if necessary Safety is taken into account, but also the value of Health and Environment.



With LCM, all costs of maintenance, replacements and repair in the current situation or 0-variant are determined. These costs are all lifecycle costs (LCC). Also the social value of planned train free periods and unplanned disruptions are determined. This is called the value of unavailability. The same is done for the other solutions. Usually investments are needed too. These are included in the LCC of this solution. In the end, the sum of the LCC and unavailability cost will be determined for all solutions. The solution with the lowest sum is the preferred solution. When a solution also has social benefits, for example, as a result of better safety, speed increase or capacity, these benefits are deducted from the LCC and unavailability costs. This decision making process can be used in many situations. For example in the case of implementing new systems, new construction projects, maintenance or renewal planning, differentiating between high and low density lines or issues of clustering in time and space. The method is a powerful tool in decision making processes where two or more scenarios have to be compared.

It is important to determine the effects of projects on all relevant environmental qualities. This information can help to determine whether or not a project contributes to sustainability. Sustainability is achieved when investment decisions lead to at least as much wealth and prosperity for our grandchildren as we have now. This means that the ability of our environmental capital stocks (the natural, produced, human and social stocks) to generate wealth and well-being stays at the current level. By comparing the prosperity value of the natural decrease of the stock to the prosperity value of the increase of the produced stock, we can check whether net prosperity rises or falls as a result of the investment.

To embed Life Cycle Management well in an organization a number of conditions must be met to a certain degree. These conditions are leadership, acceptance by employees, knowledge and skills, means and methods, required data, quality system, application area's and transparency. The degree that is achieved by the organization can be determined for all these conditions.

Implementing professional and sustainable decision making with Life Cycle management through the whole organization can reduce cost as well as give a better performance.

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Risk based rail asset management

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ABSTRACT

Rail asset management in the Netherlands has changed significantly in the past twenty year. Trains and Track were separated administrative in 1995 and juridical in 2005, and all executive activities were outsourced after 1998: engineering, maintenance, renewal, material supply, logistics, training, personal safety, etc. What rest was a pure asset manager. The consequences and challenges were huge: (1) rebuild the infra organization from the bottom, (2) outsource maintenance and stay in full control of costs and performance, (3) secure maintenance & renewal knowledge and (4) provide reliable asset information. A conceptual model helped ProRail to keep the right focus on the change of the Maintenance & Renewal (M&R) organization. It describes how costs and performance are managed explicitly and in coherence through risk control with activities within given conditions and circumstances (Figure 1).

Risk management instruments were developed and tested. It became clear that this management technique had a huge potency. Not only to manage asset costs & performance explicitly but also to tender & manage performance contracts, structure the information needs and secure M&R knowledge. ProRail decided in 2010 to develop for all systems – together with the maintenance contractors – detailed M&R-Concepts which consist of performance risk analysis (also known as FMECA[1]) and risk control activities. More than 80% was ready in 2015. Risk management techniques are also used to define "Information Delivery Specifications". They specify how performance should be managed, and structure the specification in the maintenance contract (Figure 2). The specification & Control triangle was developed around 1997 and still proves its value in how to stay in control of performance (risks).

Today performance is specified and managed at two levels: (1) on a re-active top level for Reliability, Availability, Maintainability, Environment and Health, and (2) a pro-active level with technical specifications for Safety and Durability. The contractors prove with condition information that it is safe and his maintenance strategy is life cycle optimal. This separation in type of specs was possible thanks to the M&R-Concepts.

The latest development is the possibility to extract inspection- and maintenance plans from the M&R-Concepts, to calculate the costs of a concept and to model the relation between the performance and activities, the holy grail for an asset manager. All M&R-Concepts will come in one database, accessible for the whole branch. It is up to the contractor to compose the best inspection and maintenance plans to control the performance risks.

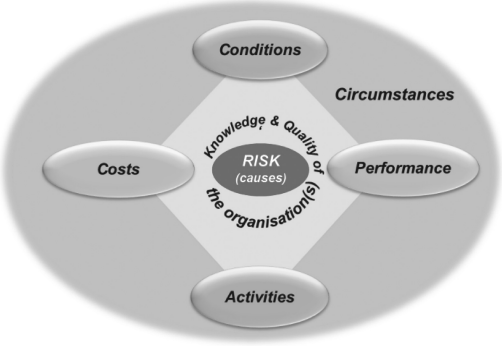


Figure 1. The essence of asset management.

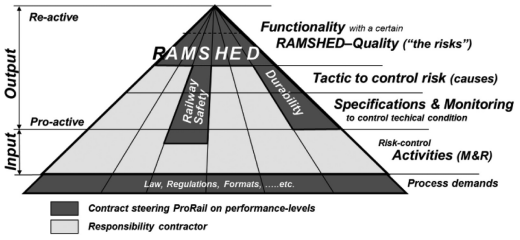


Figure 2. Specification & Control triangle.

[1] FMECA = Failure Mode Effect and Criticality Analysis

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Assessment railway bridges over the river Waal near Zaltbommel

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ABSTRACT

The bridging in the railway line Utrecht – Den Bosch over the river Waal consists of 16 single track bridges with lengths varying between 60 and 180 metres and built between 1932 and 1952.

ProRail (the infrastructure manager of the Dutch railway network) has requested APcon Adviesbureau to determine the remaining, technical, economic and fatigue life of these bridges. APcon was also asked to assess maintenance requirements and the ultimate strategy to keep these bridges in good order. All this on the basis of the ProRail life cycle analysis system.

To supply substantiated answers to these questions the following researches were done:

- Inspection of the complete deck to detect any possible presence of damage caused by fatigue,
- Archive search for any available drawings and calculations and investigation on site,
- Recalculation based on the Dutch codes for assessment of existing structures in case of reconstruction and disapproval (NEN 8700) to determine static strength and maximum loadings allowed,
- Fatigue calculations based on Eurocodes for bridges and a model of the actual railway traffic,
- Verification of fatigue calculations through measuring stresses on details susceptible to fatigue,
- Assessment of the protection system and determination the costs for repair and renewal of the coating,
- Determine the safety requirements to meet the current regulations for personal safety,
- Determine the level of maintenance during the remaining life of the bridges,
- Life cycle analysis to assess the economically most appropriate year for replacement and determine the ensuing maintenance,
- Life cycle analysis of the optimal conservation strategy until the end of the life of the bridges.

This approach has given a good insight into the strength and remaining fatigue life of the bridges; The bridging's economic life could be extended on the basis of a full strengths assessment and life cycle analysis, which results in a considerable saving.

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Railway bridge asset management using a Petri-Net modelling approach

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ABSTRACT

Management of assets can be a challenging undertaking. Along with the multitude of defects that can arise, assets will have had different construction techniques, operational conditions and maintenance actions carried out on them. This can give rise to situations where seemingly every asset is unique which further burdens those who manage a portfolio of assets. Many studies have been undertaken to create a bridge asset management model. The focus of these studies has often been trying to capture the deterioration profile of the bridges. To appreciate the processes and decision making problems that bridge portfolio managers are faced with, a comprehensive model has been developed. This model tries to mimic deterioration, inspection and intervention processes and decisions as closely as possible. Working with industry experts to incorporate features and factors that are neglected in most other models.

The model which has been developed uses a Petri-Net (PN) approach. This is a stochastic model, similar to the popular Markov models that have been used in many bridge asset management models and Bridge Management Systems (BMSs). A bottom-up approach has been employed; therefore rather than modelling at a network level, it is the asset and sub-asset level that is focused upon. The PN model is organised into separate modules. These modules interact to form a robust framework for bridge asset management. The inspection and intervention modules use Network Rail (NR) policies for calibration to make sure that the modules align with industry guidelines.

Capturing the deterioration profile is one of the most important aspects of the model and is used to calibrate the deterioration module. For calibration historical data of 25,949 bridges spanning 16 years of inspections were used. Data analysis was carried out on the inspection records to determine how defects evolved over time. The data was analysed between each of the condition states e.g. an element moving from state "good" to "poor", for instance, and the associated Mean Time to Failure (MTTF) calculated. Failure rates, calculated from the MTTF values were embedded into the transitions of the deterioration module e.g. the transition which connects the places marked "good" and "poor" would be embedded with the failure rate of elements moving from "good" to "poor". When all the transitions in the deterioration module are embedded with their associated failure rate, the deterioration module replicates the deterioration profile found in the historical data.

The model can be simulated to provide outputs for bridge managers. The first is a graph which shows the predicted condition of the element(s) throughout the simulation. The effects of deterioration and intervention create a sawtooth like appearance in the graph. This is useful to see what the effects of the maintenance and inspection strategies are over the lifetime of the element(s); a critical output for bridge portfolio managers. The second output shows what intervention would be necessary if one was required. This also follows a sawtooth pattern as when elements are in good condition only minor intervention would be required. This can be useful for predicting work bank demands. Finally, a nominal and cumulative cost graph is produced. This estimates when and where costs are likely to occur over the lifetime of the elements(s); a critical tool for budget planning.

Overall the model presented tries to capture deterioration, inspection and intervention for a more rounded approach to bridge asset management. A number of unique features are incorporated into the model, including those recommended by industry experts.



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A stochastic model for damage evolution of mode II delamination fatigue of composite wind turbine blades

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ABSTRACT

With the recently increasing attention in renewable and clean energy sources, wind turbines have gained popularity as the main offshore structures for wind energy. Treated as the most critical components in wind turbines, the blades typically are made from fibre reinforced composite materials in order to adapt harsh marine environments. Research showed that the fatigue crack development can be affected by several parameters including mechanical properties of materials and sources of uncertainties such as loads, environments and crack processes (Al-Khudairi et al. 2015). Therefore, the fatigue crack evolution should not be considered as deterministic in realistic practical situations. Therefore, an effective stochastic model for predicting mode II delamination fatigue is needed to evaluate the life time performance of wind turbine blades.

The stochastic model such as gamma process is adopted in this study, which provides a tool for time-dependant reliability analysis for fatigue damage failure of wind turbine blades (Avramidis & L'Ecuyer 2006). On the basis of existing experimental studies (Yun et al. 2015), a Paris Law model is appropriate for simulating the propagation of the fatigue crack growth in this study. By combining the results obtained from Paris model with the stochastic deterioration modelling such as gamma process (Van Noortwijk 2009) for predicting fatigue crack growth, the probability of failure for composite blades under cyclic stress is predicted over the design service life. A numerical example of the fatigue damaged composite wind turbine blade is investigated to evaluate the probability of fatigue failure during the service life. The influence of various factors such as material properties, limited crack length and loading cycles on the probability of failure is also investigated. From the results, the proposed method can provide an effective tool for evaluating the probability of fatigue failure and assessing structural performance of the wind turbine blades under different service life expectations and assessment strategies.

This paper deals a stochastic approach to analyse mode II delamination fatigue for composite blades of wind turbines, simulates fatigue delamination development, and predicts the failure probability of the structures. Based on existing studies, typical Paris law models are used to predict the propagation of the fatigue crack growth for mode II delamination, in order to reproduce the crack length subjected to cyclically repeated loading. From failure probability of the blades, the remaining service time is estimated by stochastic method such as gamma process and the fatigue crack length evolution is predicted. The failure time of wind turbine blades is estimated by the failure crack growth of stochastic process with its pre-determined critical crack width. A numerical example is used to analyse the fatigue damage process for wind turbine composite blades, and the failure probability of blades under different cases is predicted by the stochastic gamma process. The results show that the Paris model with gamma process provides a good prediction on the failure time of the delamination fatigue growth, and this stochastic method for reliability analysis can be used for determining optimum maintenance strategies.

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An experimental study on the influence of initial degree of saturation in mortar on water absorption of mortar with containing chloride ions

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ABSTRACT

It is the object of the present research to use a mortar test piece in which the initial degree of saturation was changed to understand the effect which the initial degree of saturation has on moisture transportation and the permeability of chloride ions.

Figure 1 shows the measurement results and the estimated results of the chloride ion concentration. In the cases when the initial degree of saturation was relatively small, the result that the estimated value becomes larger regardless of the absorption time was obtained. Namely, it is assumed that the transportation of moisture is not only liquid water, but the transportation of water vapor is also included. In the cases when the initial degree of saturation was relatively high, the higher the initial degree of saturation, the more the measurement results of the total chloride ion concentration increased. Further-more, in the case of any of the initial degrees of saturation, the measurement results greatly exceeded the estimated values. It is thought that many of the chloride ions permeate to the mortar surface layer part due to influences such as the diffusion phenomenon and the simulated absorption.

Next, the chloride ion concentration distribution after drying will be used to examine the transportation of chloride ions after dry-wet cycling. Figure 2 shows the estimated value which uses the increase of the degree of saturation from the degree of saturation after drying. With the exception of the vicinity of the water absorbent surface, the estimated value of the chloride ions corresponded with the actual measurement value of the chloride ions, thus, it is verified that the chloride ions permeate in association with the increase of the degree of saturation. It is thought that the permeation of chloride ions associated with the transportation of liquid water (advection) predominates in saline reabsorption after one cycle of dry-wet cycling thereby.

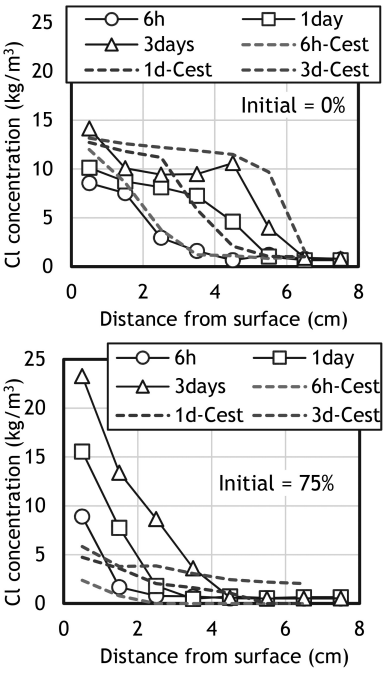


Figure 1. Chloride ion concentration distribution.

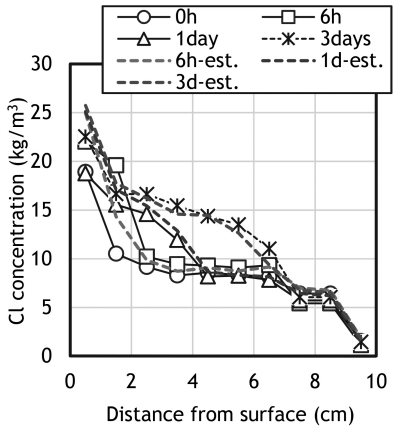


Figure 2. Estimated chloride ion concentration distribution (dry-wet-cycle).

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Corrosion modelling and performance indicators

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ABSTRACT

Concrete durability Codes and Standards in general contain provisions related to: the concrete materials, the limit of dangerous substances, such as chlorides or sulphates, limitations to the crack width transversal to the reinforcement and the recommended cover thicknesses in function of exposure classes. However, there is an increasing demand to incorporate into the current standards more advanced concepts related to concrete durability, due the need to better foresee and prevent distresses, in particular the corrosion of the reinforcement. The consideration of the several approaches to durability design is the basis to propose their classification into categories. In this paper three categories are identified (Andrade et al. 2000) (table 1): I) Deemed to satisfy rules contained in present standards II) Performance Indicators that are concrete properties or performance results and III) the models in which the time is explicit in the formula. In present work, it is analyzed the models used for corrosion initiation prediction and their limitations, as well as the performance indicators that have being proposed to qualify the concrete resistance against the progress of chlorides and carbonation. Among these indicators particular attention is paid to the use of the electrical resistivity to characterize both the initiation and propagation phases of corrosion. Finally is proposed the definition of Performance Indicator to such property which could inform on the degree of damage or anomalous performance and that could be monitored through sensors placed on the structure in order that these measurements could save the need of visual periodic inspections.

The use of resistivity as corrosion Indicator is based in one of the Einstein laws which relate conductivity of electrical charges and Diffusivity (Andrade 1993).

$$D_e = \frac{k_{Cl,CO2}}{\rho_e} = F_{Cl,CO2}\ \sigma \qquad (1)$$

The final expression of the service life model based on resistivity is:

$$t_l = \frac{x^2 \cdot \rho_{ef} \left(\frac{t}{t_0}\right)^q}{F_{Cl,CO_2}} \cdot r_{Cl,CO2} + \frac{P_{corr} \cdot \left(\rho_{ef} \cdot \left(\frac{t}{t_0}\right)^q \cdot W_s\right)}{K_{corr} \cdot 0.00116} \qquad (2)$$

This model has been applied to the concrete works of the new locks of Panama Canal being built by a Consortium named GUPC: Grupo Unidos por el Canal which was recently finalized. In the concrete Technical specification it was prescribed to fulfil 1000 coulombs with no definition of the age and to use a service life model to demonstrate compliance with 100 years of service life. These prescriptions were considered not fulfilled in the initial trials of concrete mixes by the Authority of Panama canal (ACP). The results indicated that the resistivity was equivalent to the rapid Chloride Permeability test which in addition provided the values of the aging factors in a non-destructive manner. It also had a direct relation to the Apparent Diffusion coefficient as indicated by equation 1.

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Damage propagation in corroded reinforcing bars with the effect of inelastic buckling under low-cycle fatigue loading

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ABSTRACT

Corrosion of reinforcing steel is the most significant structural deficiencies in aging bridges located in chloride laden environment. Many of these bridges are also located in regions with high seismic activities. These structures experience dynamic/cyclic loading due to earthquake over their service life. Furthermore, the current design approach allows reinforced concrete (RC) structures dissipate energy during large earthquake events by occurring plastic hinges in beams and columns. The inelastic cyclic deformation in plastic hinge regions during large earthquakes results in a significant tension and compression strain reversals. Among RC components, bridges piers are the most vulnerable components in earthquake due to the simple structural system of bridges. Moreover, there is a large number of existing bridges around the world that were designed prior to the modern seismic design codes and therefore they are not properly detailed for seismic loading. These aging structures are also suffering from long-term material deterioration.

The current performance-based seismic design philosophy of reinforced concrete (RC) structures relies on the proper detailing of plastic hinge regions where most of the inelastic deformations are expected to occur. The inelastic cyclic deformation in plastic hinge regions results in a significant tension and compression strain reversals. Among RC concrete components, RC bridges piers are the most vulnerable components and therefore, they should be able to accommodate a significant inelastic deformation due to earthquake loading.

Meda et al. (2014) have investigated the effect of corrosion on the nonlinear response of RC columns subject to cyclic loading experimentally. The results from these experimental studies show that non-uniform pitting corrosion affects the global response of corroded RC elements subject to cyclic loading. This is mainly due to the influence of corrosion on premature buckling and low-cycle fatigue life of corroded bars.

In this paper, the effect of inelastic buckling on low-cycle high amplitude fatigue life of reinforcing bars is investigated experimentally. The results show that the inelastic buckling is significantly affecting the low-cycle fatigue life of reinforcing bars. Through nonlinear regression analyses of the experimental data a new set of empirical equations for fatigue life prediction of reinforcing bars as a function of the buckling length and yield strength are developed. Finally, these empirical models have been implemented into a new phenomenological hysteretic material model for reinforcing bars.

Furthermore, the combined effect of inelastic buckling and corrosion damage on low-cycle fatigue life of embedded reinforcing bars is investigated experimentally. The low-cycle fatigue tests on corroded reinforcing bars varied in percentage mass loss, strain amplitudes and buckling lengths are conducted. It was found that the fatigue life of corroded reinforcing bars combined with inelastic buckling has a significant path dependency. The results show that in some cases the number of cycles to failure of corroded bars under constant amplitude fatigue test is increased. An example stress-strain response of a corroded and uncorroded bar with $L/D=10$ is show in Figure 1 (L is the buckling length and D is the diameter of uncorroded reinforcement).

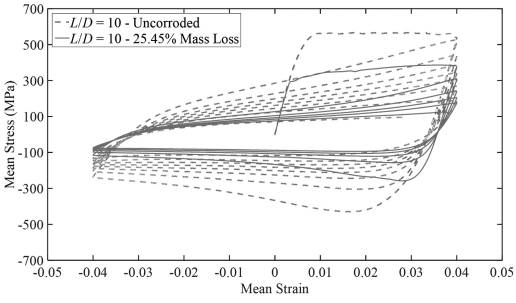


Figure 1. Impact of corrosion on cyclic stress-strain response of reinforcing bars with $L/D=10$.

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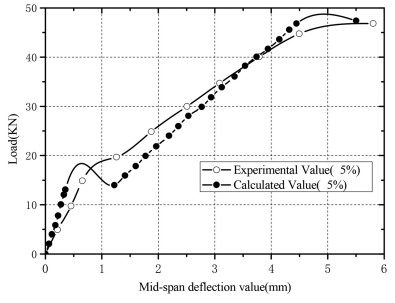
Flexural rigidity of corrosion-affected RC beam in marine environment

Z.H. Lu & X.D. Yang
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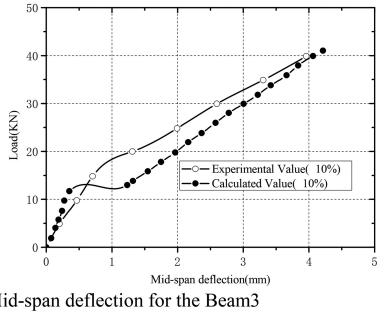
Y.G. Zhao
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ABSTRACT

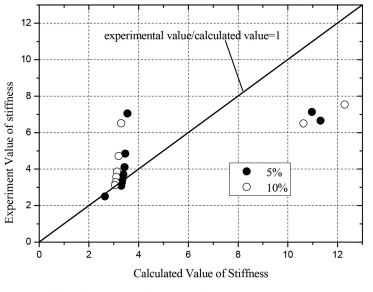
A review of research literatures suggests that the study of mechanical behavior of corrosion-affected reinforced concrete (RC) beams in marine environment is focused more on capacity than on rigidity, although the degradation of the flexural rigidity will result in the loss of serviceability of RC beams. In this paper, the axial force differential equations of corroded reinforcing steel were established, in which the deterioration of the bond-slip relationship between concrete and corroded reinforcing steel was considered. A section coordination coefficient was then suggested for reflecting the effect of the deterioration of the bond-slip relationship on the degradation of flexural rigidity of corrosion-affected RC beam. Based on these investigations, an empirical formula for predicting the flexural rigidity of corrosion-affected RC beam developed from the existing models was proposed. The predictions of the proposed empirical formula for the degradation of flexural rigidity of corrosion-affected RC beams are found to be in close agreement with the experimental results published in the literatures (See Figure 1), which provides useful tools for predicting the flexural rigidity and deflection of corrosion-affected RC beams in marine environment.



(a) Mid-span deflection for the Beam 2



(b) Mid-span deflection for the Beam3



(c) Stiffness of the beams (kN × m)

Figure 1. Comparison of Experimental values and calculated values.

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Model for the long-term corrosion of cast iron pipes buried in soil

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ABSTRACT

The external corrosion of old cast iron water mains is a major concern for water industries in many older cities, including Australia, the UK and the US. To better manage these ageing assets, good quality mathematical models, based on real-world observations, are required for predicting future corrosion. This paper outlines a novel approach adopted by researchers at the University of Newcastle to predict the maximum corrosion penetration on the external surface of a cast iron pipe buried in soil.

The models so far proposed are inadequate as they have been shown to be inconsistent with long-term data and the current understanding of the corrosion processes. To improve on this situation, the long-term behavior of cast irons in soils was reassessed and the general model shown in Figure 1 was proposed for pit depth and corrosion loss. The model is known as the bimodal model, and was originally developed for steels under marine immersion conditions, and was recently shown to be applicable for cast iron corrosion in soil. The long-term corrosion can be approximated with a linear function, which is defined by parameters r_s and c_s.

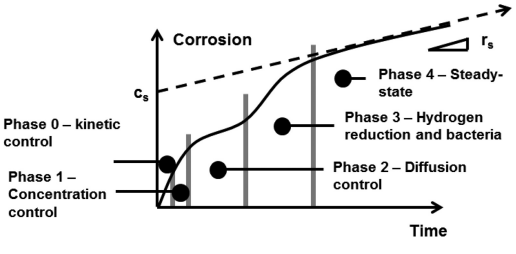


Figure 1. Bi-modal model for corrosion loss as a function of time.

For the models for corrosion to be of any use in actual applications for the estimation of future life, the models must be calibrated to real-world data. New data was sought for calibration of the model and these were collected in a set of novel and comprehensive field data collection studies. This involved sampling soils and pipes from a number of sites used for condition assessment and also from sites where failure had occurred.

The model was calibrated to field data from 37 sites. It was found that the main factors influencing soil corrosion are, in order, time of wetness and inorganic nitrate concentration (for microbiological attack). Time of wetness refers to the length of time that there is a sufficient amount of water in contact with the pipe to allow significant corrosion to occur, and is a function of soil type and climactic conditions. Methods used to quantify this are outlined in the paper. Inorganic nitrates are a limiting nutrient for microbiological attack under wet corrosion conditions, as in the corrosion in a soil. The influence of these variables on external penetration was also quantified in this work. Other parameters including chloride, phosphate and carbonate content were also considered, but were found to be less important. The potential influence of poor quality backfill and physical damage to the pipe on corrosion depth is also discussed.

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Parameter identification of deterioration models by Delphi interview

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ABSTRACT

Many countries have to deal with a worsening condition of infrastructures. The age of the assets, the increasing traffic and the lack of money and staff for repair and renewal actions have often been cited as causes of this state of affairs. To tackle this pressing problem, extensive and prepared data are required not only to ameliorate the results of forecasting analyses, but also to assist decision-makers in taking the right decision at the right moment. The WSV is responsible for a huge number of waterway infrastructures. The construction type is very inhomogeneous and the portfolio consists of 319 locks, 244 weirs (Fig. 1), 420 Culverts, 41 canal bridges, 207 lighthouses and others, which in monetary value is estimated at about 50 billion €.

To support decision-making processes with regard to waterway infrastructure management the federal waterway Engineering and Research Institute (BAW) is developing a maintenance management system.To forecast the condition of the assets for the next 20–30 years different approaches are needed. After analysing the different approaches, two ways were retained for the prediction of deterioration in waterway infrastructure, namely:

- Markov chain to forecast the deterioration of detected damages and
- Survival functions to describe the deterioration of components without damages at the actual time; the actual grade of deterioration will be taken from the age of the component.

To determine the parameters a Delphi-interview was found to be an adequate way. It is a well-known standardised, interactive process to collect expert knowledge or opinion (Häder, 2002). In the described case 28 experts with different focus of expertise were asked. The results of a first questionnaire-cycle were analysed, combined together with another exemplary of the same questionnaire and returned for a second cycle. However, due to the similarity or repeatability of answers the process was not carried further.

By fitting various curves of the deterioration processes (Kleiner, 2001), an average condition grade can be calculated for each deterioration process. Besides, the worst deterioration of the related processes was used as a survival function for a higher level condition grade.

With the developed approaches the deterioration of waterway infrastructure assets was forecasted. Significant effects as the faster deterioration of steel parts compared to concrete parts can also be observed as the short life time of equipment. So the behaviour of different parts of an asset and its influence on the network can be detected and the information can be used to support decision making processes.



Figure 1. Barrage Kachlet at the Danube with weir and lock.

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Study on assessment of chloride ion penetration in concrete subjected to wet-dry cycle

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ABSTRACT

In the wet-dry cyclic environment, it is suggested that chloride ion penetrates not only concentration diffusion but also advection by water movement. In this study, chloride ion penetration test subjected to 3 different dry environments (fig. 1) is carried out to experimentally clarify effect of water movement on chloride ion penetration, and verify chloride ion penetration model considering water movement. From experimental result, it is found that penetration property of chloride ion is extremely different in response to humidity of dry environment (fig. 2). And verification result of chloride ion penetration model considering water movement based on experimental result, although this model has some subjects, it is confirmed that this model could expect penetration property of chloride ion subjected to wet-dry cycle.

Table 1. Mix proportion of mortar.

		Unit Weight (kg/m^3)					
	W/B	*W*	*C*	*BFS*	*F*	*Gyp*	S
OPC	0.5	254	508	–	–	–	1544
BB	0.5	256	256	251	–	5.11	1518
FB	0.5	252	404	–	101	–	1518

*W: Tap water, C: Ordinary Portland cement (3.15 g/cm^3), *BFS*: Blast furnace slag (2.89 g/cm^3), F: Fly ash (2.25 g/cm^3), *Gyp*: Anhydrite (2.96 g/cm^3), S: River sand (2.64 g/cm^3)

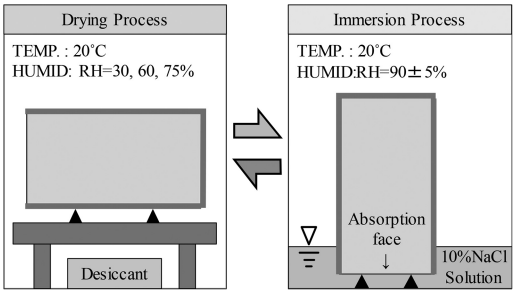


Figure 1. Chloride ion penetration test setup.

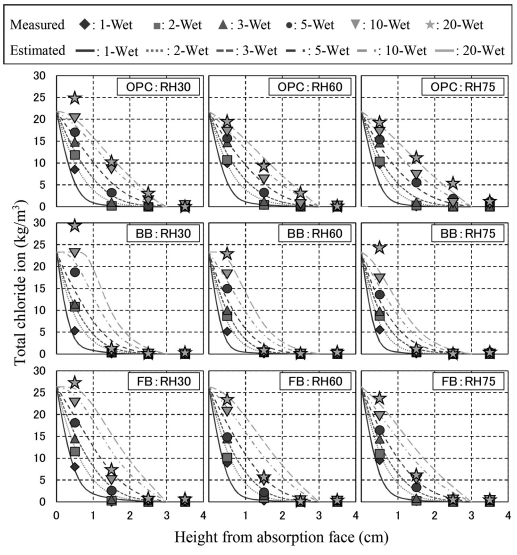


Figure 2. Total chloride profile.

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The bond deterioration of plain round bars subjected to lateral tensile-compressive stresses

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ABSTRACT

Plain round bars have been widely used as reinforcement in historical concrete structures. One important aspect of the assessment of these old buildings is to verify whether the anchorage between concrete and plain round bars is reliable or not. Thus the bond behavior of the plain round bar is widely studied in recent years. Many investigations showed that the lateral stress state of the bar has great influence on its bond behavior. When seismic loads are considered, the steel bars located at corners or beam-slab joints may be simultaneously subjected to tensile and compressive stresses which affect the anchorage between the bars and concrete (Wu et al. 2014). So far, a few studies on the bond behavior of the plain round bar considering the lateral tensile-compressive stresses have been reported, however, the mechanism of bond deterioration has been seldom revealed in theoretical manner.

In this paper, an analytical approach to the bond deterioration of plain round bars under lateral tensile-compressive stresses is presented. As shown in Fig. 1, based on the theory of elasticity, the contact condition of the bar/concrete interface is discussed, and an analytical solution for the ultimate bond strength is further derived when the interface keeps closely contact. A total of 174 pull-out specimens are adopted to verify the analytical solution as shown in Fig. 2. The results show that, with the shrinkage of concrete, the geometric and mechanical parameters of bars and concrete known, it is proper to determine the contact situation of the bar/concrete interface and predict the bond strength of plain round bars under lateral tensile-compressive stresses. However, the damage of concrete due to lateral stresses cannot be accounted for in current model, which should be improved in the further study.

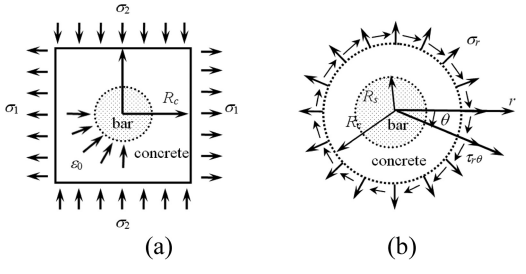


Figure 1. Planar stress state of the plain round bar embedded in concrete subjected to lateral tensile-compressive stresses: (a) under principle stress axes; (b) under polar axes.

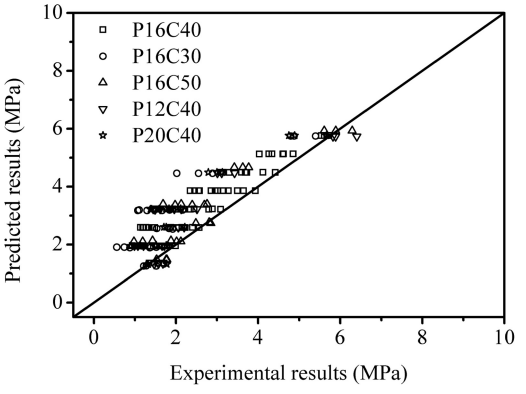


Figure 2. The comparison between predicted and experimental ultimate bond strength.

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Derivation of budget requirements for different levels of fairway quality based on harmonized maintenance strategies for inland waterways

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ABSTRACT

Due to their low energy consumption, low emissions and low external costs compared to other modes of transport, inland waterways are highly regarded in European transport policy. Because of the lack of common definitions of a uniform target infrastructure quality and a decision patchwork of responsible waterway administrations, a case-by-case approach to measure planning, among other aspects, are a limiting factor for efficient maintenance and development of inland waterways.

The developed methodological approach to asset management of inland waterways represents the view of infrastructure operators including costs and impact duration for all relevant measures in terms of infrastructure quality. Moreover, all investments may be optimized from the perspective of a waterway operator, as well as from the operators and users, based on a comprehensive transport cost model that is linked to the availability approach. The developed approach provides evidence that an economically efficient optimization of measures cannot be accomplished on single sections alone. Due to the serial characteristic of waterways, it is instead necessary to aim at uniform and continuous fairway availability on the entire transport route. The described approaches are already implemented in a software tool called WAMS (Waterway Asset Management System). This tool allows for an evaluation of current infrastructure quality, calculation of measures extent for different fairway widths and depths as well as practical planning of dredging measures on waterways.

On the basis of a successful testing phase with data from already conducted riverbed surveys and implemented measures of more than five years the methodical approach has been validated.

The current paper presents an overview of planning of dredging measures for individual shallow sections including calculation of dredging volume, dredging costs and duration of measure implementation for varying levels of fairway width and fairway depth. Consequently, the methodological foundations for the calculation of measure extent and derivation of measures costs are described as well. Recent approaches towards harmonization of measures aiming at a unified fairway depth on entire transport routs are illustrated for the river Danube. The evaluation of measure costs for different target fairway width and depth provides evidence that waterway operators have to carefully consider which fairway width is actually required for current transport volumes and types of vessels.

The paper further offers a practical insight in the derivation of budget requirements for different levels of fairway width and depth based on data of actual riverbed surveys and statistical water levels of the river Danube in Austria. Based on this tool we will provide evidence in this paper how an implementation of different continuous levels of service translates into budgeting needs. Furthermore different optimization options in waterway asset management will be analyzed including optimization for constrained budgets.

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A methodology for the evaluation of performance and damage of RCC dams under dynamic seismic actions

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ABSTRACT

Dams for the hydroelectric power generation are commonly built of earth and rockfill or reinforced concrete. Since the 70's a new technique has been developed to make what it has been called Roller-Compacted Concrete (RCC), which is a special mixture of cement and aggregates with low water content. As RCC dams have many advantages over those constructed with conventional techniques, they have experienced a fast grow in different countries. In Mexico new projects are being developed using RCC dams to increase the proportion of hydroelectric to other types of power generation to achieve the goals related to clean energies.

The aim of this paper is to present a practical methodology for the dynamic seismic analysis of RCC dams and the evaluation of their performance and probable level of damage under any seismic excitation. A case study applying the proposed methodology is presented showing the simplicity and capabilities for practical use.

Only the static and seismic dynamic loads conditions are considered; neither thermal nor construction load conditions are at this time taken into account. To evaluate the seismic response of dams a method based on D'Alembert principle and Duhamel integration or convolution integral is applied.

In regard to the seismic performance and damage criteria recommendations of manuals EM 1110-2-6051, 2003, and EM 1110-2-6053, 2007, may be followed. This assessment is formulated based on magnitudes of demand-capacity ratios, cumulative duration of stress excursions beyond the tensile strength of the concrete, spatial extent of overstressed regions and load combination cases. The acceptable level of damage on the basis of linear-elastic analysis is presented by a performance curve, bounded by a demand-capacity ratio of 2.0 and an inelastic cumulative duration that varies with the type of structure.

Figure 1 show the elaborated finite element model for the case study. Evaluation of the seismic performance and level of damage is shown in Figure 2 only for node "t" which is near the top of the dam.

It can be observed for node "t" that the demand capacity ratio exceeds the value of 2.0. This means that for node "t", it is possible to have some concrete cracking damage.

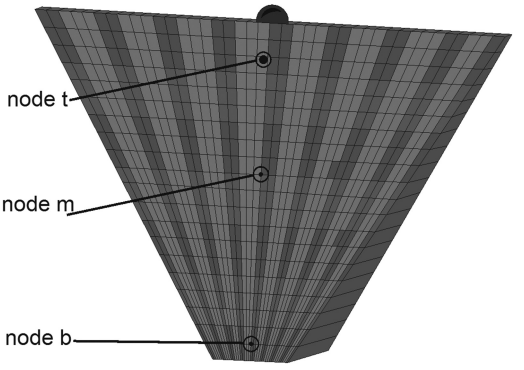


Figure 1. Finite element model and nodes considered for the analysis of seismic performance: Bottom, Middle and Top.

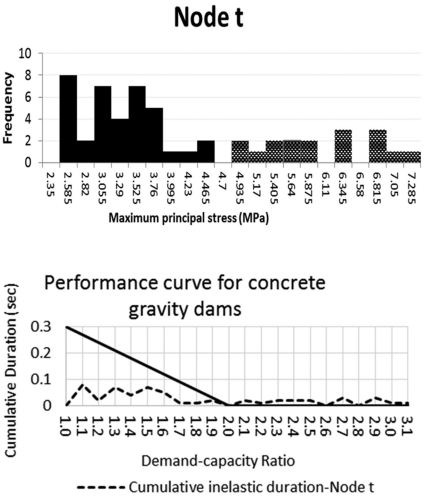


Figure 2. Seismic performance curve for node t.

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The effect of information on the performance of a multiagent system for post-disaster evacuation

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ABSTRACT

The paper presents a new approach of simulating various post-seismic evacuation scenarios for people in Iaşi city, Romania, by using a multiagent system. Within the article, it is analysed the influence that the blocking of an important underpass in Iaşi city, Romania, has upon people's evacuation, in case of a major seismic event. With the aid of the agent-based simulations, several case studies are considered where the state of the underpass and the amount of information agents have about the shelters vary.

The seismic scenarios presented in this paper are simulated using the *REvaSim* software, which was developed within *ROADERS* ERA-NET CONCERT-Japan project, funded under the EU 7th Framework Programme, FP7 (ROADERS 2015).

The case studies analyse the effect of the amount of information on this evacuation performance, quantified as the average or the maximum evacuation time. This problem is actually related to the value of information (Howard 1966), when time itself is considered to have a value. In our case, the amount of information is given by the probability with which the agents can find updated information about the destination shelter when they arrive to a node and thus can choose an alternative if their current goal is no longer viable.

The scenarios consider three operational levels for the road junction affected by a large magnitude earthquake: fully operational, reduced capacity (5% operational) and blocked. The authors consider that 6800 people take part in the evacuation process, distributed in 5 vulnerable areas, from which they have to reach one of the 9 shelters, with a capacity of hosting 6000 people, or 4 hospitals, with a capacity of hosting 800 people (IES Iaşi 2015), depending on their need. In the model, evacuees have two possibilities to reach a certain point: by walking or by car. Moreover, the injured are transported to the hospital by ambulances. The evacuation model was designed to be composed of 4300 people walking, 1900 people using cars and 800 injured, based on the car ownership statistics computed for Iaşi city (IES Iaşi 2015, Olaeru 2012) and the division mentioned above.

In order to study the effect of information about shelter state, five probabilities are considered: 0%, 25%, 50%, 75% and 100%. These are the probabilities of being able to change the current destination when reaching a node.

The authors analysed separately the vehicle and pedestrian evacuation and then presented the results of the general system behaviour. The effect of available information is much more prominent when considering the pedestrian groups. The people using cars and the injured are quickly evacuated and therefore there is in general a high probability that some shelters have already become full.

Although the obtained decrease in evacuation time was somehow predictable, the interesting finding is that the shape of the corresponding functions of evacuation time given the information probability is non-linear, and different network conditions greatly affect their shapes. Some case studies even provided counter-intuitive results, e.g. the actual increase of evacuation time in the presence of serious congestion that is not handled adequately.

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Value of information on the risk/benefit of infrastructure exposed to strong winds in Mexico

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ABSTRACT

Several authors have treated the topic of information value, one of the early works is from the 40's decade (Von Newmann and Morgensten, 1944). Applications range from Computer sciences (Howard, 1966) to the Nuclear industry (Koerner, et al., 1998) including Civil Engineering which has been benefited with many developments that update original information through studies and tests to improve the probabilistic description of parameters used to make engineering decisions.

Valuable infrastructure is frequently damaged by strong hurricanes in Mexico and, as a result, significant losses affect the economy of the country. It is believed that a non large investment to record wind velocities may help to reduce the epistemic uncertainty on the wind hazard model and, as a consequence, the infrastructure failure probability may be reduced to produce better benefits. In this paper, the ratio between these costs and the subsequent expected life-cycle costs is assessed. It is shown that, as the infrastructure importance grows, this ratio strongly reduces, probing that the new information acquired to improve the wind hazard model, is valuable to increase the economic effectiveness of measures taken to protect important infrastructure. The formulation calculates the infrastructure expected life-cycle cost for 2 scenarios: with and without the new information on the maximum wind velocity. The probability distribution of this velocity is updated by fitting a new distribution after adding wind velocities of recent hurricanes and the failure consequences include the service interruption after the damage/failure of the infrastructure. Two examples illustrate the proposed procedure, one is a critical electrical substation (see Fig. 1) and another one a valuable bridge (Fig. 2), and it is shown that the expected life-cycle cost reduction achieved by enhancing the wind hazard model offset, by large, the investment made to record additional data and the cost ratio dramatically increases as the infrastructure failure consequences becomes larger.

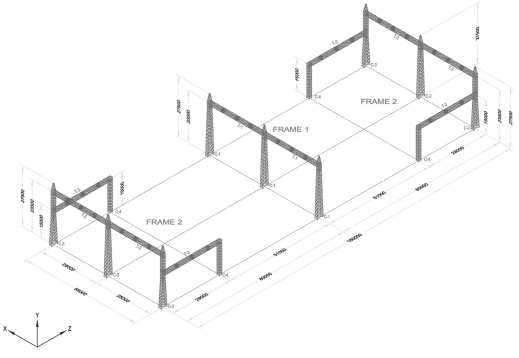


Figure 1. Electrical substation of 400 Kv.



Figure 2. Tampico bridge.

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Rational asphalt technology in function of true life-cycle extension of flexible pavements – how it can be done

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ABSTRACT

State and local budgets are depleted. There is big gap and mistrust between academia and contractors. Practically and officially, there is no sound QC/QA methodology, no valid all-inclusive, universally applicable solutions for composition design of perpetual flexible layers. Consequently, no damage prevention, no life-cycle extension, not even rational troubleshooting.

Why publicly known research failed to deliver anything consistent and reliable? Primarily, because of wrong mental prospective & focus. Recycling of old ideas for new money is useless.

However, High Quality Engineering Solutions Do Exist. They are based on proven Rational Asphalt Technology© and indispensable & ultra-comprehensive Asphalt Optimization Software. Both are ideally suited for this complex job. There is a software 'Step by Step Guidance' covering the following areas: Selection of optimum/compatible input, Optimization of storage & handling, The Intelligent/ Rational Mix Design – outlines critical zones & parameters change, including THE CRUCIAL ONE – Optimization of Concentration of Stone Skeleton (with pores included) within Asphalt System at Denied Compaction

$$y = \frac{100}{1+\left(\frac{a}{b+x}\right)}$$

This last is of the utter importance for most severe & demanding local conditions & projects such as: airports, heavy load & frequency intersections etc. Once the above is defined, the software determines optimum/desired AC content amount making theoretically the asphalt mix FREE from any type of deformation. In order to be practically FREE of deformation Manufacturing Process Must Be Scrutinized and Optimum Compactability & Constructability accomplished by selection of the right parameters in 'Low of Compaction' equation:

$$y = a - be^{-x/c}$$

REMARK: The sense making structural pavement design contributes to general sound solution, BUT ONLY IF ALL ABOVE WAS DONE RIGHT.

This "mental prospective of tomorrow" provides cost efficiency, consistency, and predictability – all missing now. Pavements remain serviceable – almost with no surface or structural damage – for at least 20–25 years, irrespective of geographic location or loads. This approach was successfully pioneered in early eighties … regretfully, NEVER widely recognized & accepted. Now, with AI 'in real time' support this job is much easier to accomplish.

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Effects of corrosion by chloride ion on time-dependent seismic reliability of RC bridges in Persian Gulf zone

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ABSTRACT

Transportation infrastructure in Persian Gulf has a great role in national economy of all the surrounding countries. The environmentally aggressive condition results in rapid degradation of RC structures and ends up to shortening the life cycle of the facility. This can be emphasized when the seismic performance of the structure is of interest in high seismicity of northern coasts. Due to various sources of uncertainties, damages caused by corrosion resulted from the ingress and attacks of chloride ions; necessitate assessment of time-dependent reliability of RC Structures. Chloride-induced corrosion, on the one hand, degrades the mechanical properties of steel, and on the other hand, develops cracking in concrete, decreases bonding strength between rebar and concrete and consequently, reduces the service life of the structure. Considering this issue in regions where the structure is exposed to the chloride ion such as coastal areas or highway bridges subjected to deicing salt with respect to climatic and environmental conditions is of more importance. The main aim of this paper is to investigate the effects of chloride induced corrosion on seismic fragility of a typical RC highway bridge located in Iran as well as assessment of its reliability under environmental conditions complying with the Persian Gulf zone. To this end, corroded members and their nonlinear characteristics was investigated using the existing relations regarding the effect of chloride ingress in RC sections within time in 10-year time intervals for different stages of corrosion (i.e. initiation and propagation) using OPENSEES Software.

In order to estimate the seismic fragility and assess the time-dependent reliability to specify safety index in the typical highway bridge, incremental dynamic analysis has been applied. The time-dependent vulnerability of the structure is investigated through fragility curves for each 10-year interval. The deck spans between the columns include 5 girders with the same length. Total length of the bridge is 47.8 meters with a span width of 11.7 meters.

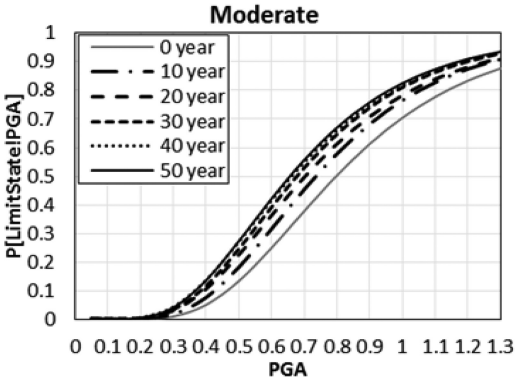


Figure 1. Time dependence of seismic fragility.

For uncorroded materials, a strain of 0.002 for unconfined concrete under the maximum stress and a strain of 0.006 as a yield value are assumed. Confined concrete has a strain of 0.005 at a stress of 26.5 MPa and a strain of 0.05 at a stress of 25 MPa. Seismic fragility and reliability of the modeled structure was evaluated using IDA analysis and probability calculations. Figure 1 demonstrates one of the computed fragility curves during the study; It is shown that corrosion increases the seismic fragility of the structure and decreases the reliability during the time.

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Automated road survey and pavement management on porous asphalt

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ABSTRACT

Accurate and reliable information on road surface condition is essential for effective pavement management. The use of in-traffic measurement systems for this purpose is advancing, but still visual inspection seems to be the predominant inspection method on many roads in Europe. To assess the road surface conditions with minimal impact on road users Rijkswaterstaat (RWS) decided to automate the survey processes of raveling and cracking. Together with the automated survey of skid resistance, rutting and unevenness this delivers the required input for pavement planning on all main roads in the Netherlands.

Since 2007 RWS and TNO are collaborating in several research & development projects to fully automate the survey processes of raveling and cracking and other types of road surface deterioration. In these projects experts of TNO on imaging, big data analysis, and statistical modelling work together with road inspectors and pavement managers of RWS. This has led to a road surface measurement system (Fig. 1) for porous asphalt and algorithms that automatically determines the road surface type, the amount of raveling, the amount of cracking and the estimated remaining service life of each 100 meter road section based on the damage assessment and intervention levels in the Netherlands. Since 2013 all main roads in the Netherlands are measured using the developed system. Every year this means the inspection of 15,000 km road lanes.



Figure 1. RWS road survey vehicle with the developed road surface measurement system for raveling on porous asphalt.

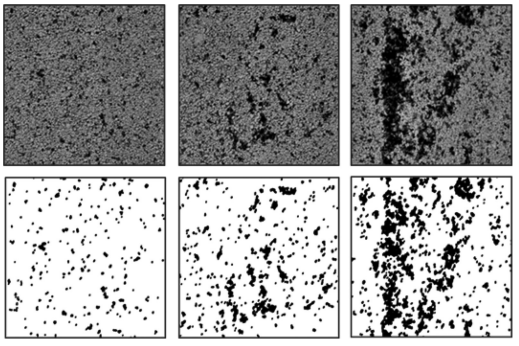


Figure 2. Automatically classified measurement data on porous asphalt, from left to right an examples of low (6% stone loss), moderate (12%) and high (22.5%) severity class.

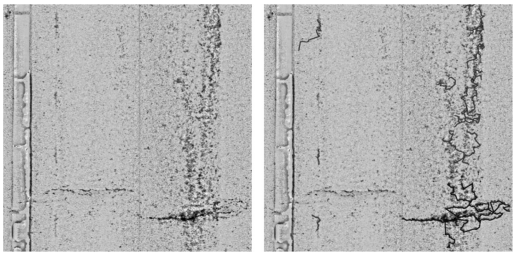


Figure 3. Automatically classified measurement data on porous asphalt, with examples of cracks, raveling, mechanical damage and other damages.

Figure 2 shows three examples of automatically classified raveling damage. The first row shows the generated 3D model of the road. The second row only shows the missing stones (the dark spots in Figure 2) as detected by our algorithm. For detecting road surface cracks we use the software of Pavemetrics. To be able to classify the surface cracks and remove false detections we first cluster and filter the data using a developed algorithm. Figure 3 shows an example of automatically classified road surface cracks in obtained measurement data in the Netherlands.

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Determining the remaining lifespan of concrete structures

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1 INTRODUCTION

Life-cycle civil engineering is becoming more and more important to society and therefore also to the building and construction sector. This importance is not limited to owners of civil structures and buildings, but also to contractors, suppliers, maintenance and repair companies, as well as consulting engineers. DBMO-contracts, which became popular in the Netherlands, stimulated this importance and interest. This since contractors will be responsible for management and maintenance of newly built or renovated civil structures and building over a longer period of time.

Based on the short term goals presented in the preliminary advice, by the end of 2014 a project was started under supervision of SBRCURnet advisory committee 2140. In this committee clients, general contractors, suppliers, consulting engineers and research institutions were represented.

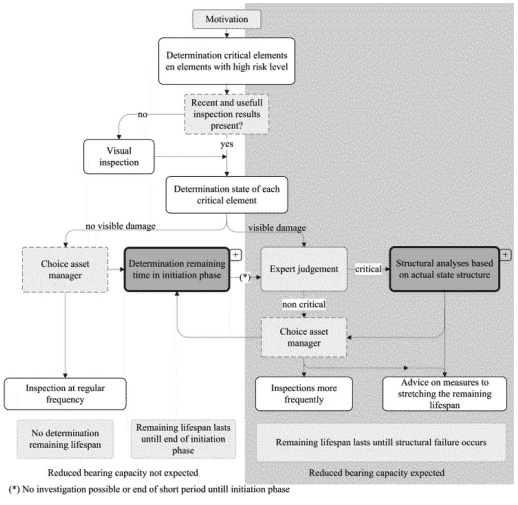


Figure 1. Overview of roadmap in the CUR-Recommendation.

2 RECOMMENDATION AND ROADMAP

The main goal has been to produce a CUR-Recommendation, in the Netherlands considered as a "pre-standard". This Recommendation describes a clear and by all participants accepted roadmap of investigation, as shown in Figure 1. The roadmap includes the use of existing deterioration models, leading to a reliable determination of the remaining life span of the reinforced concrete structure.

As part of the investigation also an inventory of existing (international) simulation models and a global assessment of these models has been executed.

To obtain the necessary information leading to the setting up of this process, interviews were conducted with a total of 14 engineering firms, contractors and clients. They were questioned about their approach, found common damages, used standards and results of their investigation. Also some 40 inspection reports supplied by clients and consulting engineers have been analyzed for this purpose.

Meeting structural safety according to NEN 8700 was and will be the most important starting point. Hence determining critical details or parts of a concrete structure becomes important because of their influence on lifespan and life-prolonging measures required.

The process focuses on practical know how and experience in combination with existing and reliable deterioration models for the initiation phase.

3 CONCLUSIONS

The result of the project is a practical roadmap diagram illustrating an accepted process in order to establish a remaining lifespan of existing reinforced concrete structures

Reporting to the committee have been the engineering firms Movares and Royal HaskoningDHV as well as the firms of SGS Intron and TNO.

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About the economic life prediction for existing RC buildings

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ABSTRACT

In this study some fundamental issues of seismic risk management some are addressed. In particular, the main topic is providing some effective tools to management and mitigate seismic risk.

Based on recent studies, it is evident that two topics play a fundamental role: reduction of seismic vulnerability of existing constructions and limited available resources. For these reasons, alternative and innovative approaches must be adopted in order to define possible intervention prioritization that must be associate with expected performances. Moreover, this approach it is essential to define a time window to reach a accepted low level of risk.

In recent years, many studies have been carried out in order to understanding and investigate the seismic risk. As consequence, it must be highlighted that at present the prediction useful in seismic risk management is actually an hard work. In fact, several methodologies to manage crisis have been developed and applied with goods results in particular on short periods (little days – some months). On the contrary, mitigation and prevention of seismic risk could be more efficient by setting a careful maintenance and retrofitting of the built.

About this important topic, it is the opinion of the authors that quantitative economic model should be defined. This model would be defined considering an economic point of view which involves that the higher level of loss must be adequately captured.

Moreover, in order to define mitigation strategies, the decision to perform a seismic retrofit of existing buildings should be based on rational criteria, which lead into account a number of factors that are able to define the cost-effectiveness of the investment.

In this context, seismic capacities of existing RC buildings have a key role, as shown in recent seismic events. In fact, earthquake losses in terms of economic, social and political activities can be considered generally as a direct consequence of physical damages on the buildings.

On long terms (e.g. after ten or more years), the return to normal conditions (when it happened) is due to considerable economic investments. At this point, a simple consideration must be made. If these resource had been used in peace time for mitigation policies, they would have produced significant economic growth and avoided many casualties.

In the last years, many efforts have been carried out in order to investigate about the seismic risk of building stock. These studies have been made considering only the priority based on the seismic risk of buildings but they may be considered substantially insufficient. In fact, new and correct strategies must consider several important questions as the social and economical convenience related to the seismic retrofit of existing building. The fundamental question is the accurate definition of damage states for each building type and their economic quantification.

In this paper, these different aspects are considered in order to obtain a rational instrument to perform retrofitting investment based on the relationship between cost-effectiveness-suitability.

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Reduced nonlinear finite element models for quick-scan assessment of concrete infrastructure

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ABSTRACT

Assessment of ageing civil infrastructure is a major task in many countries. Nonlinear finite element analysis can determine the 'hidden' capacity of existing concrete structures and possibly extend its life-time without loss of safety. Layered models for beam and shell elements allow for relatively rapid finite element (FE) analysis and can be an alternative to models with volumetric elements for preliminary assessment stages. Standard beam and shell formulations are limited to bending analysis and cannot be used in the assessment of structures with shear problems, as may result in large overestimations of ultimate carrying capacities and ductility.

This paper presents the shear-sensitive reduced FE models (beams and shells) implemented in the software DIANA. The formulations are based on work of Ferreira *et al.* (2014) (Figure 1). These models consider transversal reinforcement, multiaxial strains and stresses in concrete and inclined cracking. Shear failures can be captured by failure of transversal reinforcement and crushing of the diagonal concrete strut.

The models are validated with experimental benchmarks – a RC beam, a PC beam and a RC slab – presenting high influence of shear in the structural response. The reduced models captured relevant effects of shear, such as yielding of stirrups and shear failure, at a low computation cost. The results are also compared with plane stress FE models.

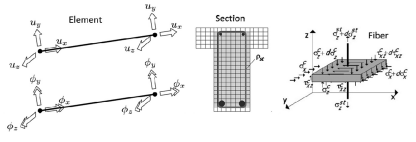


Figure 1. Shear fiber beam model.

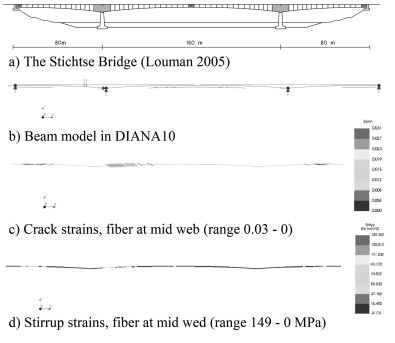


Figure 2. NLFEM of the Stichtse Bridge.

The model was applied to the analysis of *De Tweede Stichtse Brug* in the Netherlands. In addition to the analysis under service load, a nonlinear analysis under increasing two-point loading until failure was performed considering a possible configuration for a proof load test. The bridge presented a flexural response at failure with transversal reinforcement remaining elastic despite of the relevant diagonal cracking (Figure 2). The application of the model to the analysis of a bridge exemplifies how the reduced models can be used in a first stage of the assessment and inspection procedure of existing infrastructure.

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Remaining life prediction of an aged bridge based on carbonation tests for cross-section cutting-off girders

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ABSTRACT

A large number of reinforced concrete (RC) bridges in advanced countries have become aged, requiring increased maintenance and requiring that decisions be made concerning whether to demolish these old bridges. Remaining life prediction is a crucial part of the systematization of bridge maintenance. The service life of a bridge is highly influenced by environmental conditions. Bridges are typically exposed to a range of environmental conditions during their service lives. High levels of carbon dioxide as a result of high traffic volumes contribute to carbonation, which can result in significant deterioration and can have a significant effect on the service life of an RC bridge. Chloride ion attack should be considered as another factor in RC bridge deterioration if the bridge is located near the sea. Both carbonation and chloride ion attack can lead to corrosion of the reinforcing bars. The most serious deterioration mechanisms that occur in RC bridges are associated with corrosion.

Various definitions of service life have been proposed. In this study, the end of the service life was defined as the point at which the total amount of steel corrosion due to carbonation and/or chloride ion attack reached a critical value. The service life was divided into four stages: initiation, propagation, acceleration, and deterioration stages. The initiation stage is identified on the basis of the measured carbonation depth and the thickness of remaining concrete cover. The initiation of corrosion occurs when the thickness of remaining concrete cover falls below 10 mm. The propagation stage can be defined as the stage in which cracking occurs due to corrosion. Cracking will occur if the total amount of steel corrosion is approximately 10 mg/cm^2. The acceleration and the deterioration stages are defined with respect to the critical value of the total amount of steel corrosion, which in this study was taken to be 75 mg/cm^2. Fig. 1 shows a schematic illustration of service life prediction.

Under ordinary circumstances, concrete cores are extracted from some parts of a bridge to evaluate the performance of the concrete. Many studies of carbonation in RC bridges have been conducted. However, this paper describes the first known application of carbonation testing to girder cross sections cut from a bridge. In addition, many studies have proposed methods to predict the service life of RC bridges. However, such methods are typically based on the deterioration due only to carbonation or only to chloride ion attack.

This paper proposes a method to predict the remaining life of an old RC bridge based on the extent of deterioration due to carbonation and chloride ion attack. In addition, a flowchart for this remaining life prediction method is presented. The bridge considered in this study was demolished, and girders were removed from it. Cross sections were cut from these girders, and these cross sections were examined to determine the thickness of the concrete cover and the carbonation depth of the sea sides, bottom sides, and mountain sides of the girders. The remaining life prediction method makes use of the following types of information: (1) the thickness of the concrete cover, (2) the carbonation depth, (3) the carbonation rate, (4) the chloride ion content, (5) the average temperature and (6) the surface moisture content. Information on items (4)–(6) were obtained from tests on concrete cores. The remaining life predicted by the proposed method represents the predicted remaining life for the entire span of the bridge.

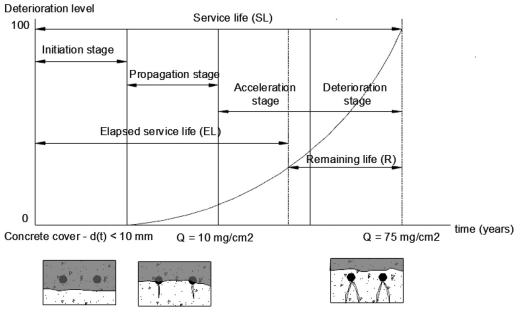


Figure 1. Schematic illustration of service life prediction.

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Pigeon colony algorithm (PCA) and its applications

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ABSTRACT

In conjunction with the rapid development of production, optimization problems have emerged widely in industry, communication, transportation, civil and hydraulic engineering (Li et al. 2012, 2015), and in many other fields. For example, Genetic Algorithms (GAs) have been used in vehicle scheduling (Zuo et al. 2015), and the Monkey Algorithm (MA) has been adopted for sensor placements in a structural health monitoring field (Yi et al. 2012). Traditional optimization algorithms such as Newton's method (Qi and Sun 1993), Simplex algorithm (Spielman and Teng 2004), and the Branch-and-bound method (Zuo et al. 2015) have been used in many fields. However, these approaches demonstrate some limitations in nonlinear, complex situations that have multiple peak functions.

In this paper, a new Pigeon Colony Algorithm (PCA) based on the features of a pigeon colony flying is proposed for solving global numerical optimization problems. The algorithm mainly consists of the take-off process, flying process and homing process, in which the take-off process is employed to homogenize the initial values and look for the direction of the optimal solution; the flying process is designed to search for the local and global optimum and improve the global worst solution; and the homing process aims to avoid having the algorithm fall into a local optimum. The impact of parameters on the PCA solution quality is investigated in detail. There are low-dimensional functions, high-dimensional functions and systems of nonlinear equations that are used to test the global optimization ability of the PCA. Finally, comparative experiments between the PCA, standard genetic algorithm and particle swarm optimization were performed. The results showed that PCA has the best global convergence, smallest cycle indexes, and strongest stability when solving high-dimensional, multi-peak and complicated problems.

The pigeon is a type of common social animal that is characterized by having a strong homing ability, high sensitivity, and good memory, among other traits. This paper refines the characteristics of the pigeon colony and further proposes PCA. PCA includes three processes: take-off, flying and homing. The flowchart of PCA is shown in Figure 1.

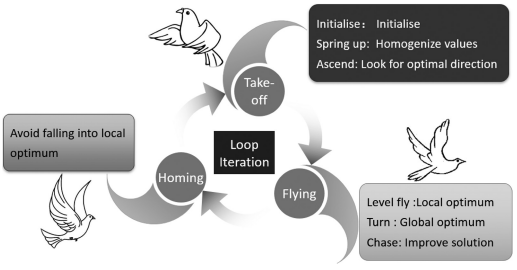


Figure 1. Flowchart of the processes of the PCA.

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A MAP method with nonparametric priors for estimating *P-S-N* curves

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ABSTRACT

In order to minimize the time and the number of specimens required for laboratory testing, a maximum a posterior method has been presented using the Dirichlet process nonparametric prior.

The maximum likelihood method is effective to reduce data dependency. However, it is based on the assumption that the statistical nature of the life data is the same at all applied stress levels of interest. According to our currently known, scatter is very large in fatigue life. scatter is less at high stress amplitudes, and larger at low stress amplitudes. Although the distributions of each stress level cannot be expressed as a single distribution, they are likely to follow some same distributional shape. The parameters θ are uncertain. As a result, we taken the parameters prior information the into consideration, a maximum a posterior method has been presented for estimating P-S-N curves from small size samples.

The most critical and most criticized point of Bayesian analysis deals with the choice of the prior distribution. Once this prior distribution is known, inference can be made in an almost mechanic way by integrating out parameters to find the predictive distributions. Therefore, the prior distribution is the key to the estimation and its determination is the most important step. If we assume that the fatigue life distributions of the same or similar materials is identical, the prior distributions can be constructed by the history test data. Bayesian nonparametric methods can provide full probability models for the data-generating process. Thus they may be used to estimate a predictive distribution for any point outside or inside the sample data, which accounts for uncertainty about distributional shape. In this paper, we model θ using a Dirichlet process prior that is given by:

$$\theta \sim G$$

$$G \sim \mathrm{DP}(\kappa H)$$
$$H \sim \mathrm{N}(\mu_G, \sigma_G^2)$$

The parameters of a Dirichlet process are H and κ, represent the probability measure and scalar respectively. Large values of κ lead G very close to H, the true nonparametric shape of G, while small values of κ put most of its probability mass on a few atoms and allow G to deviate more from H. Because H is a continuous distribution, the Dirichlet process is infinite-dimensional. A draw, G, from a Dirichlet process and can be written in the form

$$G = \sum_{i=1}^{\infty} p_i \delta_{\tau_i}$$

To construct G, we employ the stick-breaking process. The stick-breaking construction represents the distribution as a stick of length 1. Define $p_1 = \gamma_1$, break proportion γ_1 of a stick length 1, else

$$p_i = \gamma_i \prod_{j}^{i-1} 1 - \gamma_{j-1}$$

or written in the recursive form $p_i = (1 - C\gamma_{i-1})\ \gamma_i p_{i-1}/\gamma_{i-1}$. The stick-breaking definition is truncated so that the stick is only broken C times, which assumes that the data can be represented by a maximum of C possible distributions, and $\gamma_i \sim \mathrm{Beta}(1, \kappa)$.

Since the Dirichlet process nonparametric prior distribution of parameters are driven from data, even taking the uncertain of parameters into account, the above assumptions still have not completely solved. The problem will be well resolved if we can find a relationship between the various standard deviations of stress levels, which is exactly what our follow-up study goal.

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Deterioration distributions of tunnel lining in cold region

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ABSTRACT

Infrastructure maintenance is becoming increasingly important in Japan. Especially in Hokkaido, about 40% the conventional construction method road tunnels have been constructed over the past 40–50 years. Therefore, many conventional construction method road tunnels will come to its rehabilitation stage, and almost tunnel linings must be maintenance or repair.

Moreover, Hokkaido is northern part of Japan, which is cold and showy region. The risk of frost damage is high. There have been cases in which the road tunnel lining has deformed as a result of freezing in winter.

A damage distinguishing factor in the winter is a significant impact on the degradation process of the road tunnel lining. So, we focused on the inspection data of road tunnel in Hokkaido.

In this paper consist of three parts:

1) Identification methods based upon actual inspection data in order to carry out strategic maintenance for tunnel structures. The resistance of deteriorating tunnel structures is non-stationary stochastic processes, and reliability problems of such structures are essentially different of time-independent reliability problems (Figure 1).

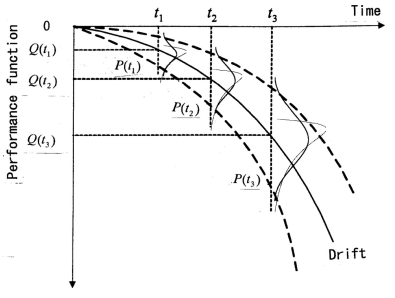


Figure 1. Non-stationary stochastic processes.

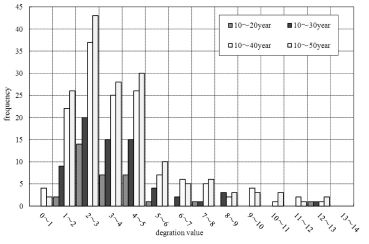


Figure 2. Disability distributions of Tunnel Lining.

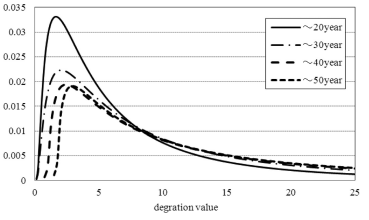


Figure 3. Log–normal distribution (Long tails).

2) The damage distinguishing factor of tunnel linings show log–normal distribution, which excellent fit with various data on the durations of disabilities, irrespective of their severity. Persisting long tails suggest the fractal nature of disability distributions (Figure 2, 3).

And finally, numerical examples are worked out to demonstrate the usefulness of this estimation method for Tunnel Management System. And long tails of the duration distributions for the tunnel linings are analyzed.

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Expert judgment in life-cycle degradation and maintenance modelling for steel bridges

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ABSTRACT

Fatigue mechanism for steel bridge is mainly caused by loading cycles that occur over their lifetime. Fatigue cracks can be multiple and of different degree of severity posing potentially a threat to safety and functionality. Asset managers together with inspectors are thus regularly obliged to inspect and take actions to keep them in a satisfactory safety level to further extend their service lifetime.

The Netherlands counts with more than 300 steel bridges so that assessments of degradation and maintenance forecasts are of primary importance. In order to embed the physical process ruled by fatigue into a probabilistic framework that models those time degradation-maintenance cycles, we propose a combination of Bayesian networks and Markov process-based approach. Accurate and cost-efficient quantification techniques are needed for the input parameters of the model. This paper introduces a structured expert judgment study to obtain those parameters in a compact way.

More precisely, we make use of Cooke's classical method for combined expert opinion (see [1]). The performance of experts as probability assessors is measured by the experts' ability to correctly and precisely provide estimates for a set of seed variables. These variables are from the experts' area of expertise for which the true values are known to the analyst. In our case, those are related to crack development for the Tacitus bridge in the Netherlands for which various techniques of crack measurements were performed between 2006 and 2011. Subsequently different weighting schemes or "decision makers" were applied in order to obtain combined PDFs as a weighted linear combination of the expert's individual PDFs. Bridges deteriorate following a Markov process in combination of a Bayesian network that allows for updating. The Markov process can have various degradation condition each described qualitatively through crack length and number thresholds.

The technique proposed should serve as a generic way to assess continuous quantities of interest, especially in a case of estimating probabilities. In particular, the use of quantities which experts are more familiar with should be emphasized to indirectly quantify the ones of interest. An in-depth identification of such is thus recommended.

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Parameter estimation for ARX models with missing data

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ABSTRACT

Time series output of many processes and systems may be fit with regression models. The parameters of these models may be approximated in several conventional ways in the presence of complete datasets collected from the processes. These parameters may be used to predict future system behavior, or in feature extraction schemes to indicate a change in the system. However, missing observations may arise in datasets, and many conventional parameter estimation tools may produce biased or incorrect estimates in the presence of missing observations.

In this paper, missing data-estimation of parameters of autoregressive-exogenous (ARX) models is considered. The state-space model, Kalman filter, and expectation maximization (EM) algorithm employed determine the maximum likelihood parameter estimates and fill in missing observations. The presented model is similar to that in (Isaksson 1993) in its use of the aforementioned tools, but with modifications to the state space model that allow for adequate calculation of all relevant variance terms.

Structural vibration data collected from a steel frame is used to test the methodology, which was used for complete dataset parameter extraction in (Shahidi, Nigro, Pakzad, & Pan 2015). Here, portions of the data are removed and estimated parameters compared to those from the complete dataset. Primary results of this analysis with changing percentages of randomly missing data are in Figure 1; 1a plots the root mean square normalized error (RMSNE) for parameters, 1b for reconstructed data.

Results indicate that AR parameters are most accurately identified, followed by input AR and X parameters. However, datasets are well approximated regardless of parameter estimates. The explanation for the error in estimated parameters is likely explained by the potential for the EM algorithm to converge to local, rather than global, maxima.

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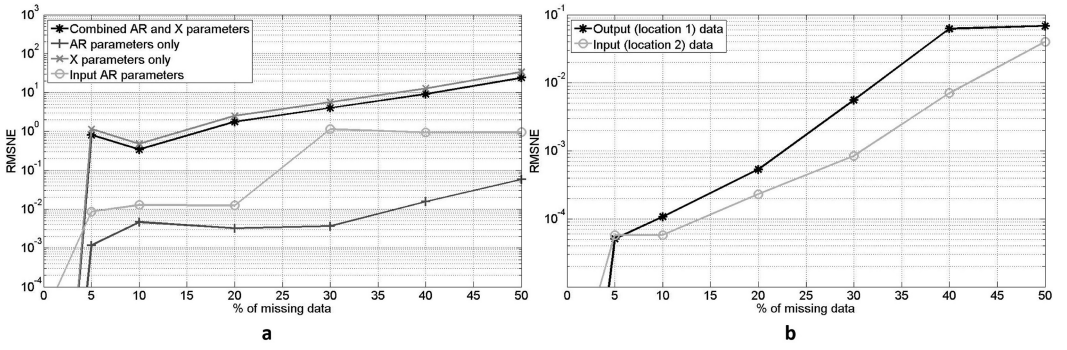


Figure 1. (a) RMSNE means for parameter vectors. (b) RMSNE means for reconstructed data.

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Performance assessment of bridges under multiple hazards

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ABSTRACT

Large parts of the United States are exposed to the natural hazards of geological origin (e.g., earthquakes and tsunamis) or of hydrometeorological origin (e.g., hurricanes and floods). This is in addition to the possibility of occurrence of man-made hazards with intentional sources (e.g., terrorist attacks) or accidental sources (e.g., vehicle and vessel collisions). In recent decades, population growth and economic development in hazard-prone areas have highlighted the need for safe and sustainable civil infrastructure systems that can efficiently serve the community with a variety of transportation, electrical, water, communication, and government services. Existing infrastructure systems typically experience several extreme events and deterioration mechanisms during their service life. As a case in point, the coastal areas of the United States, which possess a high concentration of population (more than 150 million people), have always been a point of concern because of the frequent occurrence of hurricanes, storms, and earthquakes.

Post-disaster investigations of buildings, bridges, and other infrastructure facilities damaged during the most recent natural hazards indicate that the majority of losses have occurred due to more than one extreme event. Significant storm surge following wind effects in Hurricane Katrina (2005) and Hurricane Sandy (2012) or tsunamis effects after seismic excitations in Indian Ocean Earthquake (2004) and Tohoku Earthquake (2011) are examples of correlated extreme events that resulted in enormous human and financial losses. Considering the fact that in many parts of the United States, more than one source of hazard may pose a threat to the built environment, there is an immediate need to fundamentally revisit the design and assessment criteria that have been traditionally developed based on a single-hazard approach.

Multi-hazard reliability analysis deals with the probabilistic performance assessment of structural systems under multiple random loads caused by natural and/or man-made hazards. A multi-hazard approach is necessary to i) assess the lifetime resilience of a system under region-specific hazards and ii) provide appropriate risk mitigation strategies for all the expected hazards, where the strategy implemented to mitigate one hazard will not amplify the vulnerability of the system to another possible hazard.

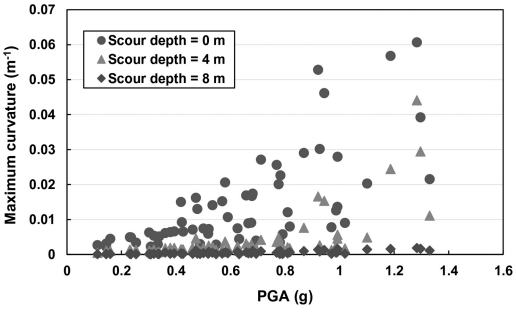


Figure 1. Maximum curvature under ground motions with different PGAs for intact bridges and bridges with 100- and 500-yr flood induced scour.

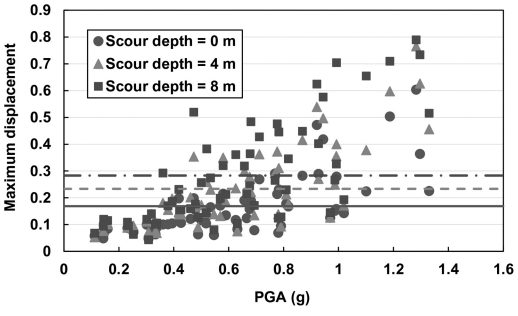


Figure 2. Maximum displacement under ground motions with different PGAs for intact bridges and bridges with 100- and 500-yr flood induced scour.

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Iterative point estimate method for probability moments of function

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ABSTRACT

Point estimate method (PEM) is one of the simplest and most efficient approaches for the analysis of stochastic function or system. The precision of results and the efficiency of implement are two indexes to evaluate the performance of the point estimate algorithm, and the precision is more important. Generally, there are two categories of PEMs. One is using the fixed number of nodes, for example, the PEM proposed by Rosenblueth (Rosenblueth 1975, 1981) needs 2^n nodes for function of n-dimension dependent variables, and Harr's method (Harr 1989) reduced the nodes from 2^n to $2n$; the other is using unfixed number of nodes, for example, Zhao & Ono's method (Zhao & Ono 2000), Li's method (Li 1992), and both methods require $n \times m + 1$ nodes.

Because of the fixed number of nodes, the first category of PEM can only be applied to the system without strong nonlinearity. Theoretically, the second method is more accurate for calculating probability moments by determining m rationally. however, in practice, m is always determined subjectively and empirically which make it difficult to ensure the precision.

In this work, two PEMs have been proposed to ensure the precision of results. One is the direct iterative point estimate method (DIPEM), in which all probability moments from different nodes are compared step by step until the results converge. The other is the adaptive iterative point estimate method (AIPEM), in which the degree of nonlinear for function is deduced via the difference of lower statistical moments from different nodes, then the number of necessary points is determined rationally and the corresponding moments are obtained.

Several numerical cases involving univariate polynomial function, multivariate polynomial function and general polynomial function are investigated to verify the precision and efficiency of proposed DIPEM and AIPEM. Table 1 and table 2 shows the results for the general polynomial function.

According to the analysis results, it can be found that the efficiency of existing PEMs is the best, but the results may be inaccurate, especially for higher statistical moments. The precision of DIPEM and AIPEM are always high enough, and AIPEM is more efficient relatively, naturally more practical. And the same conclusion can be obtained in other cases.

Table 1. The analysis times of general function for different methods.

	X_1	X_2	X_3	X_4	Total times
Zhao & Ono ($m=5$)		5			20
Zhao & Ono ($m=7$)		7			28
DIPEM	57	13	13	13	96
AIPEM	27	7	7	7	48

*X_1, X_2, X_3 and X_4 are the random variables of function.

Table 2. The precision of general function for different methods.

	μ_Y	$M_{Y,2}$	$M_{Y,3}$	$M_{Y,4}$
Zhao &Ono ($m=5$)	1.0000	0.9813	0.7326	0.2820
Zhao & Ono ($m=7$)	1.0000	0.9994	0.9619	0.6993
DIPEM	1.0003	1.0000	1.0000	1.0000
AIPEM	1.0003	1.0000	1.0000	1.0000

*the precision denotes the ratio of numerical values to exact values obtained by symbolic integration, and μ_Y, $M_{Y,2}$, $M_{Y,3}$ and $M_{Y,4}$ are the mean value, variance, third and fourth central moment, respectively.

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A review on the causes and mechanisms of damages of elastomeric bridge bearings

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ABSTRACT

Bridge bearings are key elements located between the superstructure and the substructure to perform three primary functions: (i) to transmit superstructure loads to the substructure, (ii) to permit longitudinal movement of the superstructure-relative to the substructure-due to thermal expansion and contraction (expansion bearings only), and (iii) to allow rotation of the superstructure due to dead and live loads at support positions. Different types of bridge bearings are used on the basis of the type of bridge superstructure support condition. Bearings are hence designed either to prevent relative translational movements (fixed bearings) or to allow such movements (expansion bearings). Among many types of bridge bearings, one may refer to elastomeric bearings, roller bearings, sliding bearings, hinge bearings, rocker bearings, pot bearings, etc. Elastomeric bearings themselves are fabricated in a variety of types and forms to fulfill different tasks. The key role of elastomeric bearings on the health and performance of bridges are undeniable. They act as appropriate and widespread support bearings for bridges superstructures. In some cases, there are many elastomeric bearings in a single bridge and the performance of each of them affects the whole performance of the bridge. This paper presents the results of an inspection campaign with the aim of condition evaluation of more than one thousand of elastomeric bridge bearings under service on Iran's state highway bridges constructed before 1990. It is the first comprehensive survey and filed investigation of this kind. The work was done through visual inspection, analysis of existing bridge maintenance data, condition evaluation and replacement of a significant portion of the inspected bearings. Inspection surveys and analysis of the extracted data identified the problems and the main causes and mechanisms of damages as-well-as the merits and potential improvement of performance of each one of the inspected elastomeric bearings. Replacement of the damaged bearings was performed based on the results of this stage, although has been excluded from this paper.

The discussion which has been presented in the full text of this paper can lead to the following conclusions:

- Elastomeric bearing pads may suffer from various damages. The most important damages are mainly due to improper or poor designs, installation defects, inadequate shear strength of materials, inadequate accuracy of manufacturers in production process and poor maintenance.
- Elastomeric bearing performance can be influenced by the factors such as: structural movement at the bearing region, age, traffic loading, bearing design, material used, production process, condition of substrate, weather and temperature during installation and service, installation method and workmanship during installation, quality of preparation of the top and the bottom surfaces of the bearings, maintenance condition, bridge geometry, number of bearings and bridge structural system.
- Each of these factors could cause inappropriate functioning of the bearings, while they could also influence each other and produce combined effects on the bearing performance.
- A systematic maintenance plan is needed from bridge authorities. It is recommended that all bearing areas should be inspected each year and all the bearings should be inspected one-by-one every 5 years.

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A study on the relationship between pH distribution and degradation depth using the drilled powder

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ABSTRACT

Currently, many of the infrastructures in Japan have passed more than 50 years of service life and decrepit has become a serious problem. However, maintenance of these infrastructures are not said to be feasible considering financial status of the country, hence the realization of effective and efficient maintenance of existing structures is strongly demanded. In most domestic infrastructure, reinforced concrete is used, and if monitoring and measurement of parameters in situ is easy, maintenance of structures becomes easier (MILT, 2012). Representative degradation occurring in concrete structure due to chemical attack by neutralization and sulfate ions lowers the pH value of the internal concrete. Therefore, the state of degradation factors can be more accurately evaluated by measuring the internal pH value. As a method for measuring the pH value of the internal concrete, extraction of pore solution by applying pressure on the concrete has been an effective method (hereinafter referred as "extraction method"). Certain amount of concrete sample are required for the extraction which becomes a time-consuming process, hence, simpler measurement method is desired. Another simplified technique of measuring pH is using concrete fine powder obtained by drilling. The advantages of the drilled method over extraction method is that it is simple and in addition, pH value at arbitrary depth can be measured along with the measurement of chloride ion content in actual structures. However, not many studies have been done on how to elute the alkali ions from the drilled powder. It is necessary to examine the validity and the optimal test conditions.

In this study, with respect to the measurement method of optimal pH, the powder concentration and elution time is determined to check the deterioration depth to compare the estimated value and the actual deterioration depth. In addition, prediction of the rate of deterioration from the distribution of internal pH is also done while considering the degradation estimation accuracy of the method.

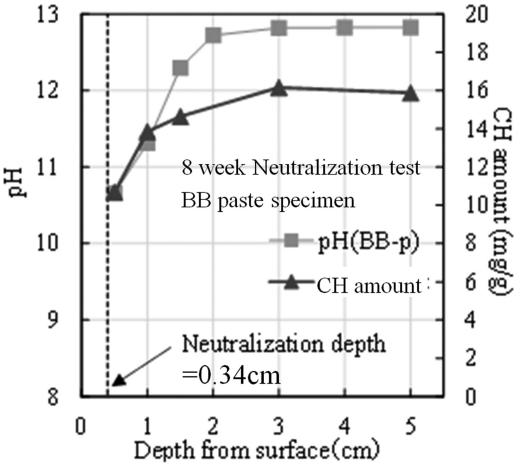


Figure 1. pH and CH amount (BB).

Internal pH distribution of BB pastes specimens after accelerated neutralization test is shown in Figure 1. Neutralization depth up to 8 weeks by the phenolphthalein method confirmed a depth of 0.34 cm in BB specimen. Looking at the pH value distribution, reduction of the pH value from the surface to the position of 2.0 cm is confirmed in the BB specimens. Since the decrease in pH to a position deeper than the ones determined by phenolphthalein was confirmed by drilling method, it is possible to estimate the progression depth of degradation which cannot be confirmed with the help of phenolphthalein method.

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Bridge curvature for detecting bridge damage location

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ABSTRACT

Bridges are a very critical part of a country's infrastructure and many uncertainties surround important factors determining the serviceability and deterioration of bridges. As such, bridges are good candidates for monitoring. Monitoring can extend the service life and avoid or postpone replacement, repair or strengthening work. In recent years, many researchers have shifted to use sensor instrument on the passing vehicle rather than the bridge, called as 'drive-by' bridge inspection. Several damage indicators have been used for detecting the bridge status, such as the change in bridge natural frequency and bridge apparent profile. In this paper the bridge curvature under a passing vehicle is introduced as an alternative bridge damage indicator.

Bridges curvature is the change in slope per unit length of distance along the bridge. The bridge curvature information is updated with time while the vehicle is passing the bridge. It is expected that by using the bridge curvature could increase the sensitivity on locating the damage of the bridge. The detail relation between the moving truck and the curvature will be discussed in the paper. The study uses moving force and moving mass models. The bridge is represented as 1D Euler–Bernoulli beam element. Two bridge properties will be used to represent the damage of the bridge: 1) The loss of bridge stiffness, Sinha (2002), 2) The change in bridge Damping, Curradelli (2008).

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Bridge damage detection using the inverse dynamics optimization algorithm

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ABSTRACT

Bridges represent an important part in transportation network. Many of these bridges have passed their life cycle and still in service. The current methods to identify the bridge damage depend on time consuming visual inspection and/or based on the data collected from a sensor based monitoring making the evaluation process very expensive. In this paper the bridge damage is identified using the data collected from an ordinary strain transducer. In order to demonstrate the method, finite element models using 3-D solid element using LS-Dyna finite element program followed by the Inverse Dynamics Optimization Algorithm analyses are performed. The Inverse Dynamics Optimization algorithm has been first introduced by Law et al (1997) to calculate the passing truck weight using measurement from bridge (Bridge-Weight in Motion). This paper used this algorithm to calculate the force history before and after the damage to the bridge. The damage identification is dependent on the changes in force history resulting from the change in bridge stiffness due to the damage. The proposed process of identifying the bridge damage is divided into two stages: in the first stage, two finite element models are used to simulate the bridge displacement due to quarter car model one representing original bridge before the damage and the other after the damage. In the second stage, inverse dynamics optimization algorithm was used to calculate the damage location.

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Damage identification focused on deterioration degree of bridge members using self-organizing feature map

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ABSTRACT

In Japan, many bridges have passed long time after construction and is progressing aging by corrosion and other factors. In order to maintain the soundness of bridges, efficient and reliable inspection techniques for screening inspection point is required. In this study, we discussed damage identification method focused on deterioration degree of bridge members and position of damaged members by using Self-Organizing feature Map which is a kind of Neural Networks.

We considered damages by changing the thickness of stiffening girder and arch rib as deteriorated member. Position of damaged members are set to each point of the hanging material connecting the stiffening girder and Arch rib, it is selected a total of 10 places the damage location. We were using the Fourier spectrum as a leaning and a recognition data to SOM. In order to calculate the Fourier spectrum, FEM analysis model was created based on the small arch bridge experimental model. The Fourier spectrum by FEM analysis is treated as a leaning data. The Fourier spectrum by small experimental model is treated as a recognition data.

In conclusion, it is found that there is a possibility of performing damage identified by the proposed method.

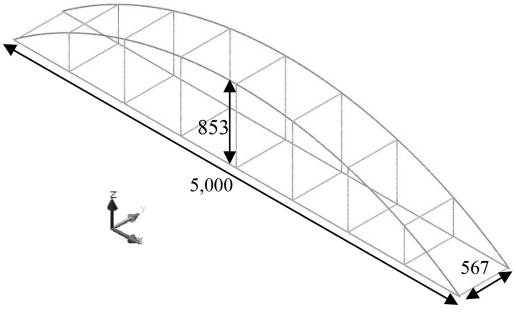


Figure 1. Overview of the analysis model (unit: mm).

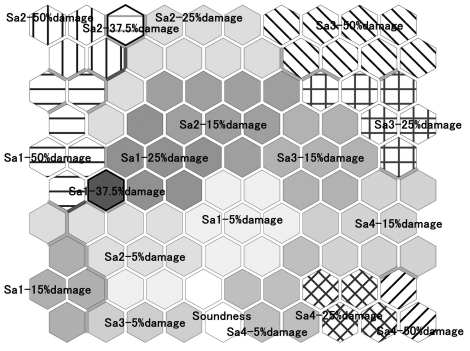


Figure 2. Recognized damage item SOM from 17.1 Hz.

Table 1. The recognized result.

Recognized damage item	Recognition potision	Recognition result
Sa1-10%damage	Sa1-15%damage	○
Sa2-10%damage	Sa2-15%damage	○
Sa3-10%damage	Sa3-5%damage	○
Sa4-10%damage	Sa4-5%damage	○
Sa1-20%damage	Sa1-15%damage	○
Sa2-20%damage	Sa2-25%damage	○
Sa3-20%damage	Sa3-15%damage	○
Sa4-20%damage	Sa4-25%damage	○
Sa1-37.5%damage	Sa1-50%damage	○
Sa2-37.5%damage	Sa2-25%damage	○
Sa3-37.5%damage	Sa3-25%damage	○
Sa4-37.5%damage	Sa4-25%damage	○
Sa1-75%damage	Sa1-50%damage	○
Sa2-75%damage	Sa2-50%damage	○
Sa3-75%damage	Sa3-50%damage	○
Sa4-75%damage	Sa4-50%damage	○

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Damage identification through finite element model updating using wavelet damage function

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ABSTRACT

Finite element model updating (FEMU) is widely used for damage identification in the field of civil engineering. Unfortunately, when the number of unknown variables increases, the difficulty in finding optimum solution surges, which seriously hinders its use in real complicated structures. To solve such problem, Teughels et al. has introduced linear damage functions (LDF) (Teughels et al. 2002). By updating the parameters in damage functions, the number of unknowns could be significantly reduced. Then, Perera & Ruiz successfully used LDF for the damage detection of the I-40 Bridge in combination with multistage procedure and multi-objective evolutionary optimization (Perera & Ruiz 2008).

However, the intrinsic of LDF ensures the smooth distribution of model property in updating results, in other words, LDF is not suitable for precisely detecting and quantifying local damage. Therefore, a new type of damage function named wavelet damage function (WDF) is proposed in this paper, which utilizes the properties of Haar wavelet and wavelet multiresolution analysis (WMRA). Similar to LDF, the unknown number is also remarkably reduced in WDF but it could provide accurate estimation for single or locally distributed damage. In model updating process using WDF, a complicated FE model updating problem with numerous unknowns is divided into several successive steps, where all the former steps only aim to estimate coarse wavelet coefficients while the final step detects the damage location and severity simultaneously. By eliminating small wavelet coefficients, the number of unknowns can be confined within a narrow range in each step, ensuring a stable and precise updating result.

Then the WDF method has been implemented on two numerical studies of a simply supported beam and a continuous girder bridge respectively, followed by a laboratory test to verify its performance in practice. The results indicate this method can estimate the location and severity of damages with good precision, while low computation expense is needed. Since WDF method in these studies only calls for the measurement of low-order modal parameters, it will have high practical significance in real situations.

Future studies may focus on trying other types of wavelet functions in WDF, introducing derivatives of mode shapes in cost functions and implementing multi-objective optimization algorithms, in order to further improve the accuracy and efficiency of this method in large and complicated structures.

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Dynamic identification of a bridge pile modeled in continuous-time domain

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ABSTRACT

Structural Heath Monitoring (SHM) of civil engineering structures using nondestructive test data has become an important field of study for model updating, structural evaluation and damage assessment (Sanayei and Rohela, 2014).

Using dynamic measurement as input data, the presented continuous-time parameter estimation method, could be used to estimate the stiffness and mass parameters of a given model.

SHM based upon some form of bridge response measurements, has the potential to be used alongside traditional methods of visual inspection techniques, and help with de decision making regarding structural management and maintenance. One of the methods used in the global health monitoring is based on vibration data, collected from sensor measurements (Comisu and Boaca, 2010). The vibration measurements can help identify changes in local stiffness, which affect the global dynamic characteristics of the structure. By observing the changes in the stiffness, mass, and damping parameters one can correlate the predicted response with the measured data. Any changes in the structural parameters are associated with structural damage.

The measurement data is used in the process of System-Identification (Sys-Id) to find models that best describe the behavior of the dynamic system (Atanasiu and Horga, 2014).

The dynamical system models can be divided into continuous-time and discrete-time models, based on the processes that characterize these models. The continuous-time models are described as differential equation systems and the discrete-time models are described as difference equation systems. Each model requires its one method of treatment (Atanasiu and Horga, 2014).

A linear time-invariant lumped parameter model can be used to construct a reduced model, that can describe the dynamical behavior of the bridge pile. Such a lumped parameter model subjected to an external loading, can be expressed using the fundamental law motion. Considering continuous-time lumped parametric models the relationships with the physical parameters of the structure are established.

There are two ways of obtaining a continuous-time model. An indirect approach uses the measured data to estimate a discrete-time model, which are later transferred into a continuous-time model. The direct approach is direct identification of a continuous-time model from discrete-time data. For this approach the differential equations used to describe the system are expressed in a linear regression form.

The process of estimating the unknown parameters requires the input data to be pre-filtered by applying Linear Dynamical Operations (LDO), in order to determine the coefficients of the continuous-time lumped parametric model.

The Poisson Moment Functional (PMF) approach can be used as a LDO to solve the derivative terms from the differential equations, as shown by Equation 1:

$$\mathrm{LDO}\{\circ\} = \mathrm{M_k}\{\circ\}\Big|_{t=t_f} \overset{\mathrm{def}}{=} \int_{t_0}^{t_f} h_{k+1}(\lambda, t_f - t)\cdot\circ \mathrm{d}t \qquad (1)$$

where M_k = PMF of k-order; h_{k+1} = gamma kernel of $k+1$ order; λ = real pole value of the PMF; t_f = final time; t = time.

By using PMF the calculus for the continuous-time model is reduced to an algebraic form, used to estimate the unknown parameters.

This paper focuses on the case study for a bridge pile in which the structural parameters are determined using the PMF approach, with the validation of the analytical results by comparing them to the measurement data.

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Investigation of shear fracture mechanism by digital image correlation systems

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The strength of reinforced concrete beams subjected to combined shear and flexure is affected by complex phenomena, such as existing multi-axial states of stresses, the anisotropy induced by the diagonal concrete cracking, the interaction between concrete and reinforcement and the brittleness of the failure mode. Trying to obtain valuable information about the shear transfer mechanisms, a large number of shear tests have been performed during the last 60 years. Currently, both in the US and in Europe the shear design provisions are undergoing a revision. Open questions concern, among others, the existence and magnitude of the size-effect. The influence of reinforcement degree and pre-stress level. Many different model formulations either mostly empirical, based on different physical mechanisms or supported by fracture mechanics have been proposed The major objective of this contribution is a description of an advanced monitoring system for the assessment of shear and flexure performance of pre-stressed reinforced concrete beams.

The assessment has been based on using information from (a) various monitoring systems, (b) experimental component testing, and (c) information from code based destructive test methods on large-scale samples. There is also a keen interest, whether the adjusted non-linear models can capture geometric and material size effects.

Beams were tested under static loading in a three-point bending setup. To simulate shortly the life-cycle, first of all the specimens were subjected to a pre-loading phase consisting of 3 load cycles up to a representative SLS-load level estimated in advance.

The first studies on the digital image correlation systems demonstrate the capability of the method in the recording and interpretation of the crack pattern development in the shear field zone during the loading process up to the shear bearing capacity. The

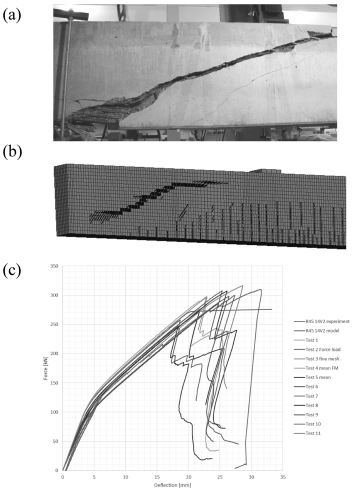


Figure 1. Experimental tested and modelled beams R30 (a) the shear crack pattern at the load capacity, (b) the associated crack pattern of the optimized nonlinear Finite Element model, and (c) the modelled vs experimental tested force-deflection curve. When reaching the upper SLS load level, the crack propagation was recorded by the above mentioned visual inspection. Afterwards the load was increased.

technology also shows a high potential for the understanding and interpretation of complex mechanical processes of the shear behaviour of reinforced concrete. A first comparison of the DIC recorded surface strains with the strains on the embedded reinforcement demonstrate partly a good agreement and hence the possibility to map surface measurements to the reinforcement layers. In addition, it could be shown that the DIC measurements have a high potential for optimizing processes in the arrangement of monitoring systems.

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Non-destructive assessment of concrete defects using the pulse-echo method – laboratory experiences

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ABSTRACT

An effective assessment of the condition of concrete structures requires appropriate non-destructive methods. The ultrasonic pulse velocity technology offers an appropriate non-destructive on-site testing method. The on-site applications of the pulse-echo method and the interpretation of the measured data require essential technical knowledge. Therefore, it is necessary to apply the pulse-echo method under well-defined laboratory conditions in order to verify the complex measurement results.

In the framework of laboratory investigations two special concrete specimens with implemented defects were constructed. For example, inside the specimen P1 there are two different geometries made of Styrofoam: spheres and cubes. One cube is in an origin condition (H1) with an edge length of 10 cm and another one was prepared so that it acts as a honeycombing (H2) with an edge length of about 10 cm. The spheres vary in dimension in a range of 10 cm (H3), 7 cm (H4) and 4 cm (H5), see Figure 1 [Jakob 2015].

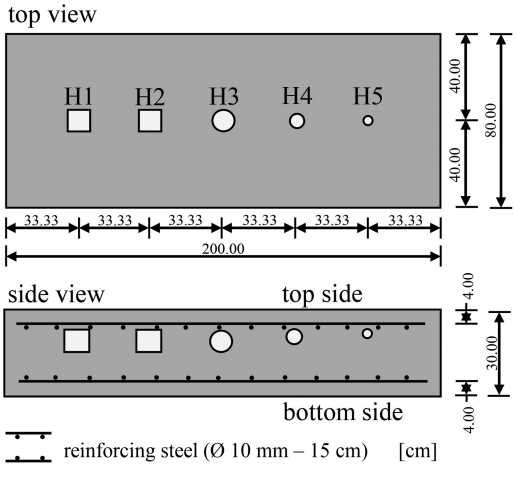


Figure 1. Dimensions and locations of the defects of specimen P1 [Jakob 2015].

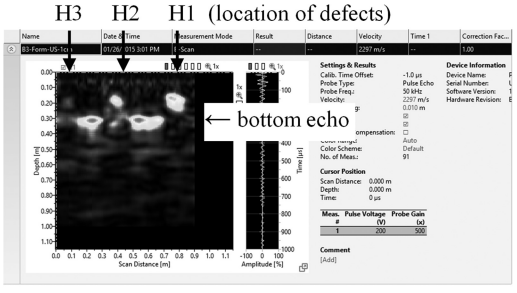


Figure 2. Results of the pulse-echo measurement of specimen P1 (bottom side measurement, see Figure 1) [Jakob 2015].

The laboratory measurement procedure was realized by means of the ultrasonic equipment Pundit [Proceq SA 2015]. For instance, the analysis of the B-Scan measurement procedure of the bottom side of the specimen P1 shows that the sharp-edged cube H1 with the edge length of 10 cm, the cube H2 which acts as a honeycomb and the sphere H3 with a di-ameter of 10 cm could be detected. In the same way the back wall of specimen P1 in the distance of about 30 cm could be well detected.

Finally, concerning the laboratory investigations it has become apparent that the ultrasonic pulse-echo method is generally suitable for the determination of an object thickness and for the detection of defects in objects. However, the application and especially the analysis of ultrasonic pulse-echo measurements require a high expertise and experience of the user.

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Use of automated, imaging methods for the support of structural inspection

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ABSTRACT:

The visual and handnear procedure of structural inspections under DIN 1076 [DIN, 1999][BMVBS, 2013] has proved its reliability in recent decades. This is especially true for inspections carried out on small and medium-sized bridges with easily accessible components which require little or no disruption to traffic flows. Due to their high levels of training and expertise, inspectors are able to react flexibly to the specific factors present at each site.

Nevertheless, as soon as it becomes necessary to inspect larger and/or more inaccessible structures or components, the inspection process suddenly becomes very much more time and cost intensive. At the same time, increasing demands are being placed on high-quality inspections of the state of bridges and other engineering structures on the road network. This is also true for secondary roads. With the latter, it is frequently the case that the inventory documentation belonging to the public authorities is either incomplete or non-existent. By adopting digital image processing technology, it would be considerably easier in cases such as these to document the condition of a bridge or other structure and to display it digitally.

Experience gathered in recent years, together with current research findings and operational results have shown that the targeted use of new access technologies in combination with (partly) automated digital image processing can make a significant contribution to providing high levels of documentation and assessment whilst at the same time working within the personnel and financial parameters available.

By using laser scanners and UAVs, it is possible to take highly detailed digital images of bridges and/or the surface lining of tunnels quickly and conveniently. This also makes it easier to monitor how damaged areas develop over time.

It should, however, be borne in mind that these new technologies are subject to restrictive technical boundary conditions. The use of thermography in a tunnel, for instance, is highly dependent on the local temperature gradient over which the inspectors have no influence. The operational use of drones is (still) seriously constrained by the limited running life of their batteries; thermal effects also determine to a great degree how near to a structure the drone can be flown. Considerable research and development remains to be conducted e.g. in the positioning and stabilizing of airborne systems.

In addition to these technical issues, legal considerations are also becoming increasingly important. As it stands, no standardized regulations exist for permitting and operating flights for commercial purposes. Ever-increasing numbers of inexpensive drones are being operated by private persons and are, in certain cases, causing obstructions or are posing a threat to people's health and safety (see for example the obstruction of the fire service in the USA and interference in the landing approach of aeroplanes). Consequently, experts are discussing and formulating an appropriate body of regulations which would considerably tighten the rules and therefore limit the general use of these systems. In this context, it is to be hoped that the necessary legal regulations and the additional advance outlay they imply will not have an undue financial impact on the operational use of this technology. This is because its technical potential is highly promising [Gößmann, 2016] and the state of the road network (age, condition, type and volume of traffic) is such that it requires the optimal implementation of personnel and finances in order to ensure the reliability of the road traffic system going forwards into the future.

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Reliability-based design method of suppressing chloride ingress for RC buildings located in coastal regions of Taiwan

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ABSTRACT

Many codes or specifications use the compressive strength of concrete as a measure of durability. Although compressive strength may give some indication of potential durability, it is not a valid criterion for several reasons. For instance, the compressive strength of a concrete cube or cylinder constitutes the mean value of a property for the entire cross section of a specimen, whereas concrete durability is governed primarily by concrete-cover properties. Concretes with the same strength grade may have different durability and resistance against chloride ingress, carbonation, and sulphate attack. Concrete durability is largely governed by the resistance of concrete covers to ingress of aggressive media. Therefore, the focus should be on the means of achieving a good-quality concrete cover and determining the needed thickness of concrete covers. This work focuses on how to identify the appropriate thickness of concrete covers to protect against chloride-induced deterioration. Additionally, an estimating procedure is needed, such that building designers can choose an appropriate concrete-cover thickness to meet a specified durability performance.

For an RC structure located within 1.0 km of a coastline in Taiwan, besides of the concrete cover, the concrete water-cement ratio or concrete-surface coating that can function as barriers for chloride ingress can be considered as alternatives to mitigate the chloride-induced corrosion risk. In this work, several methods of suppressing chloride ingress for RC structures are assumed on the basis of practical adaptive design, including the cement mortar, resin, tile and precast cement panel. In addition to the concrete-surface coating, the concrete water-cement ratio is also included in the discussion of suppression of chloride ingress.

This work builds equations for estimating airborne chloride concentrations in coastal regions in Taiwan by regressing measurement data in Section 2. Section 3 mainly incorporates these data into a deterioration model for chloride-induced corrosion and to estimate corrosion of reinforcing steel bars. In addition to RC members without concrete-surface coatings, Section 3 also provides simulation methods of the diffusion of chloride ions in various coating materials. Section 4 presents a novel computational procedure to calculate the risk of corrosion for reinforcing steel bars, while considering uncertainties in environmental conditions, material properties, and model error. Using risk curves of corrosion for reinforcing steel bars, building designers can determine an allowable reliability of durability to determine the minimal required thickness of concrete covers for RC members. Finally, this paper adopts coastal regions in Taiwan as an example to determine the minimum needed thicknesses of concrete covers that can let RC members with a needed durable reliability in Section 4. Furthermore, reliability-based methods of suppressing chloride ingress for RC structures are also suggested for each division zone of Taiwan.

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Monitoring and detection of damage in cement composite under sulphate attack

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ABSTRACT

Deterioration of concrete due to sulphate attack is a major durability problem for structures exposed to sulphate-rich soil and groundwater such as septic tanks, sewage pipes and water treatment plants. Under continuous exposure to a sulphate-rich environment, concrete loses its strength and durability resulting in a reduction of the designed service life.

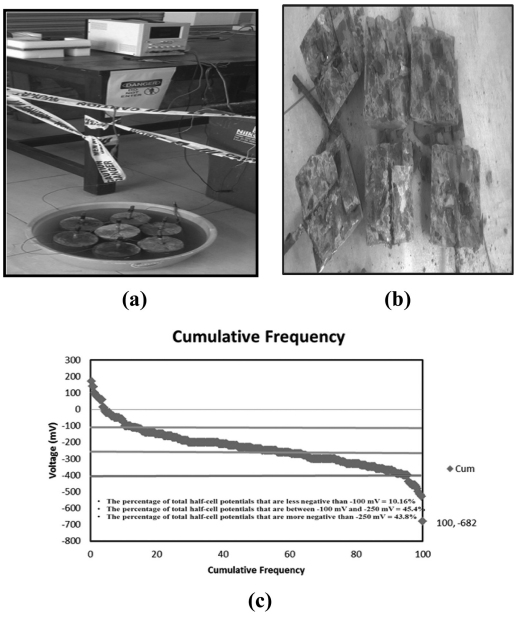


Figure 1. Progressive chloride attack in concrete
(a) Experimental setup for induced sulphate environment for concrete sample
(b) Acid penetration depth test for concrete sample
(c) Cumulative frequency distribution curve for half-cell Potential Values.

The widespread occurrence of sulphate attack and the destruction caused by it have attracted researchers over the years into the study of the deterioration mechanism and methods to combat it. However, different theories about the mechanism still exist and the mechanism is not yet well understood. It is a complex phenomenon where sulphate mainly reacts with the hydration products of cement. The primary products of sulphate attack in concrete are gypsum and ettringite. Decalcification of calcium silicate hydrate (C-S-H) gel and deterioration of the cementitious structure occur at the second stage. "Deterioration of concrete by sulphate attack is found to be irregular in nature and varies with the type of sulphate solution containing different cations" (Hasan, 1963; kalousek et al., 1972, and Santhanam et al., 2001b).

This paper deals with the monitoring of deterioration in concrete for accelerated sulphate environment and detecting damage using half-cell potential method, powder X-Ray diffraction and acid penetration test. The accelerated testing adopted here provides a realistic approach for predicting the deterioration of concrete under Sulphur attack. The paper demonstrates the various stages of changed occurred cement composites during sulphate attach and successfully noted through conventional NDT. The results give in depth understanding microstructural behaviour of concrete elements during chemical attack.

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Corrosion damage research of stayed cable under coupling salt spray environment and loading

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ABSTRACT

A loading device was developed in this paper basing on corrosion experiments of conventional metal and cable through collecting previous research about cable stress corrosion. This newly developed device makes loading possible under low frequency alternating stress and environmental corrosion coupling, and corresponding experiment was also conducted. The co-influence of corrosion and stress to the ductility of strand, the influence of alternating load peak and frequency to corrosion velocity were respectively analyzed. The results suggest that cable corrosion experiment in the case of alternating stress is feasible using the device. The corrosion mechanism of strand cable under low frequency alternating load was explained and concluded on the analysis of experimental data and the other research.

The artificial accelerated corrosion experiments have been carried out for the cable galvanized steel wire of cable-stayed bridge under coupling salt spray environment and loading. The lost weight, tensile strength and other mechanical properties were proposed of the corrosion steel under static tension and alternating stressing. And then it is founded that the extension rate is the most sensitive factor for corrosion fatigue of the galvanized steel wire after interruption. Then stress corrosion and corrosion fatigue mechanism were discussed for the galvanized steel wire. The finite element simulation model was established and the influence of full corrosion and corrosion pit depth was analyzed to equivalent stress distribution in the galvanized steel wire.

(1) Through the different condition for the steel strands corrosion experiments show that the speed of steel strands corrosion in alternating-stress load more faster than non-stress and static-stress in the same conditions. In the corrosion solution with CuCl2, the average corrosion rate of specimens batch under alternating stress is 1.1 times as fast as the average corrosion rate of the static stress of the batch, the stress free batch is 1.34 times; In the corrosion solution without CuCl2, the average corrosion rate of specimens batch alternating stress is 1.26 times as fast as the average corrosion rate of the static stress of the batch, the stress free batch is 1.38 times. And the observation proves that corrosion starts from the pit.
(2) Three groups of verification experiment results show that the plastic deformation effects caused by the tension are much larger than the corrosion. Tensile stress corrosion threshold value 180 kN specimens corrosion speed is 1.47 times that of the other three peak load the specimens. And the ductility is not sensitive to low frequency, the ductility of the specimen is associated with tension and amount of corrosion.

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Deterioration situation of road infrastructure (bridge and tunnel) in cold region

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ABSTRACT

Recently, damages in highly deteriorating road infrastructure in which were bridges and tunnels have become much more serious in Japan.

Especially in Hokkaido, the northeast area in Japan, bridges and tunnels have been seriously damaged owing to quite large quantity of snow and other environmental factors from special cold region. Such serious damages are caused by complex interaction among many factors including salt damages, alkali aggregate reactions, frost damages etc.

And also, Hokkaido is very cold and heavy snowing area. There have been cases in which the road bridges and tunnel linings have deformed as a result of freezing in winter. Moreover, many road bridges and tunnels have been constructed over the past 40∼50 years in Hokkaido.

Therefore, many road bridges and tunnels will come to its rehabilitation stage, and maintenance or repair must be needed for almost bridge deck slabs and tunnel linings. And also, distinguished damage factor in the winter is a significant impact on the degradation process of the road bridge deck slabs and tunnel linings.

So, we focused on the inspection data of bridge deck slab and tunnel in Hokkaido.

In this paper consist of three parts;

1) It is obtained the statistical nature of the deterioration more than the actual inspection data of bridges and tunnels.
2) Log–normal distribution shows excellent fit with various data on the durations of disabilities, irrespective of their severity.

And finally, the deterioration of tunnel concrete linings is mathematically described by a random differential equation driven by compound Poisson process. And also, we are developed a similar stochastic model describing random bridge deck slab degradation, where we try to apply a phenomenological law proposed by Kachanov(1999) in the field of fracture mechanics (Figure 1, 2).

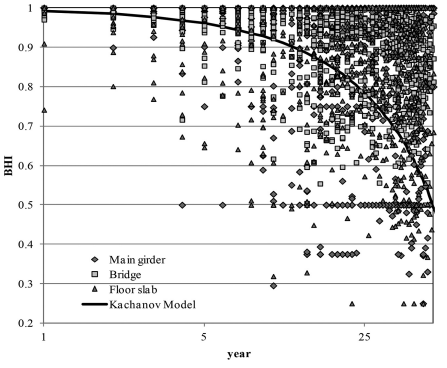


Figure 1. Degrading and average value of bridge.

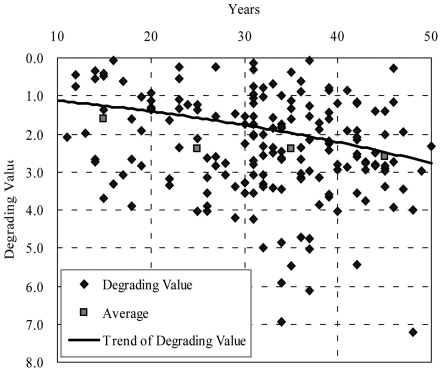


Figure 2. Degrading and average value of tunnel lining.

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Experimental investigation of the lithium transport mechanisms in cementitious materials by NMR

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ABSTRACT

Alkali-silica reaction (ASR) is a chemical reaction between the alkalis and hydroxyl ions in a pore solution and the silica present in aggregates. Hydroxyl ions attack the silicon-oxygen bond of the silica, creating an alkali-silica gel. Next, the gel absorbs water from the cement paste and swells. The expanding gel creates tensile forces causing the concrete to crack. As a result of cracking the permeability of the concrete will increase and external alkalis can penetrate the concrete more easily and hence increase damage due to ASR. Moreover due to cracking, the material will also become more vulnerable to other deterioration mechanisms (reinforcement steel corrosion, external sulphate attack, freeze/thaw action, etc).

It is known that the addition of lithium ions can prevent ASR by forming a non-expansive gel. In new concrete structures the lithium ions can be introduced as admixture to prevent ASR deleterious expansion. In existing structures the lithium ions need to be transported into the cementitious matrix by diffusion or electromigration. The ionic electromigration is probably the most effective mechanism to reach sufficient concentration at larger penetration depth to stop the ASR with in a given time.

Various lithium compounds were investigated over many years to evaluate their effectiveness to reduce the expansion of concrete caused by ASR. The most effective one is *LiOH* that was able to inhibit long-term ASR expansion effectively (Peter & Banahene 1993, Mo, Yu, & Xu 2003, Qi & Wen 2007). Therefore it has been chosen for our study.

The transport of lithium ions into mortar by means of nuclear magnetic resonance (NMR) was studied. Results from this study presents the lithium distribution in sample during diffusion and electromigration experiments. Lithium concentration profiles were measured at different times after treatments. The effective lithium diffusion coefficient was calculated using experimental data. After electromigration the concentration of ions within the specimen were analysed using an ion chromatograph (IC). The results of the present study show that NMR is able to determine the lithium concentration and distribution in the pore solution relatively quickly and non-destructively. This capacity to define the distribution of lithium in the cement or concrete sample is suitable technique for monitoring the movement of ions concentration within sample.

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Investigating building settlements via very high resolution SAR sensors

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ABSTRACT

The ultimate generation of spaceborne synthetic aperture radar (SAR) sensors (i.e. Terra-Sar-X, Cosmo-SkyMed both operating at X-band) currently provides scientists and technicians with very high resolution image datasets that, processed via advanced differential interferometric techniques (InSAR), allow detecting and mapping ground surface displacements as well as monitoring structures/ infrastructures and relative causes of their failures in subsiding urban areas (Cascini et al., 2013, Peduto et al., 2015).

The present paper aims at further investigating and highlighting the contribution that these techniques can provide to the analysis of subsidence-induced building settlements and related damages (Cascini et al., 2007). For this purpose, a densely urbanized neighborhood of Schiedam municipality in The Netherlands, characterized by a subsoil mainly consisting of alternating organic clayey and peat layers, was selected.

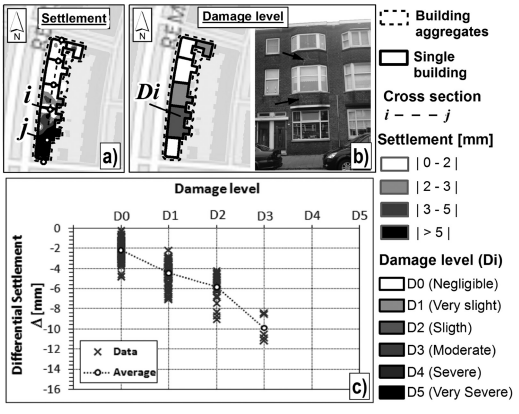


Figure 1. Results of the analysis of TerraSAR-X data and damage surveys: a) cumulative settlements and b) damage severity for a building with piled foundation; c) damage level vs. differential settlements for buildings with piled foundation over the study area.

The first step of the analysis consisted of a comparison of InSAR data on top of the buildings with an available topographic leveling dataset. The results showed a good fitting and thus it confirmed the reliability of these techniques in estimating absolute/differential settlements suffered by buildings, Then, the combination of InSAR data and the results of building damage surveys carried out in the study area allowed investigating the correspondence between cause (differential settlements) and effect (recorded damage) also underlining the specific behavior exhibited by buildings according to their foundation typology. Although in the study area the recorded damage severity did not exceed the moderate class, a general increasing trend of damage severity with the magnitude of InSAR-derived building settlements was shown independently of the foundation typology (Fig.1).

Finally, since the evidence of damage recorded on many surveyed structures highlighted a diffused settlement-induced structural suffering in the area at hand, the proposed analysis could be valuably included in monitoring and control plans as part of integrated management strategies for mitigating subsidence risk.

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Set-up for establishing residual service-life monitoring of bearing capacity and road design of Dutch highways

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ABSTRACT

In order to specify possible weaknesses in the road design in relation to future changes in traffic, transport and climate change, Rijkswaterstaat will conduct a nationwide research of the bearing capacity and pavement design of its highways.

A large fraction of the Dutch highway network was constructed in 1960–1970s. Since then the pavement area increased from 20% to 80% of its current area (approx. 85 km^2). One of the challenges is maintaining the Dutch Primary Road Network in optimal condition to guarantee safe and unhindered passage of traffic and goods. Hence, Rijkswaterstaat started a large research project inventorying the maintenance challenges in the period 2020-2030. This research is a multiannual project. Its goals are establishing the current and futureproof state of the Dutch highways (materials and bearing capacity), anticipating to the effects of climate change and traffic intensities/loads in the coming decade.

Materials & Bearing capacity

One of the research topics is the bearing capacity of the current primary road network. Missing information on the bearing capacity of the pavements should be obtained to make it possible to carry out a risk assessment on the bearing capacity. Hence, the research will combine results from two type of *in-motion* deflectometers, e.g. the Traffic Speed Deflectometer (TSD) and the Curviametre with the current standard and well known stationary Falling Weight Deflector (FWD) measurements used to determine the bearing capacity of the Dutch roads. Dynamic measurements (carried out in traffic) could be very useful to gather information on the bearing capacity in relatively short time, with lower expenses. The current experiences in the Netherlands with these methods are however insufficient and it is still unclear whether the results provide the same level of information needed to determine the bearing capacity compared to the information provided by the standard FWD method. Hence, the potential of the *in-motion* measurement methods is evaluated within the research programme by setting up a pilot using and comparing the different methods in 2016 on the Dutch road network. The first pilots are taking place this summer.

The paper informs you on the background, setup of the research, and our collaboration with international parties and the primary results on tuning the next generation deflectometers on the Dutch situation. Furthermore it presents the research programme and planning in the period 2016–2019.

Future

In 2017 (at BCRRA) we plan to present the first results of the dynamic measurements of the bearing capacity on Dutch Highways and whether they provide additional value for pavement management and maintenance information.

In 2018 we plan to present the collected results on establishing the residual service-life monitoring of bearing capacity and road design of Dutch highways as well as the adaptation strategy for future requirements for the Dutch road network with respect to future growth of traffic loadings and increasing precipitation levels.

In 2019 we combine the collected results on bearing capacity and the pavement/road design climate adaptation of Dutch Highways and present the pavement management and mitigation strategy for a future sustainable road network in the Netherlands.

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Intermit integrated monitoring on long-term performance of an arch bridge

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ABSTRACT

The monitoring and evaluation of bridge long-term performance are essential task for bridge management. Based on the idea of real time monitoring, bridge health monitoring system (bHMS) are firstly applied on bridges with large spans. The cost of large data collection, transmission, store and analysis limit the application of bHMS, especially for middle and small span bridges.

Compared with the traditional monitoring frequency, the changes of bridge performance are relatively slow. Thus, it is of high potential to reduce the monitoring frequency, or monitoring intermittently while keep small amount of data to evaluate the change of bridge performance.

Monitor intermittently the structure performance together with different methods can take advantages of each method. The evaluation result is more reliable and the cost is lower than conventional bHMS. Visual inspection is more direct. The requirement for especial skills or equipment is not high. Load test is more accurate. The noise affect less on the evaluation result. For long-term performance evaluation, the load can be relatively smaller and easier to organize.

In this paper, the monitoring plan and work of a 58m symmetric inclined arch bridge is introduced.



Figure 1. Arch rib monitoring.

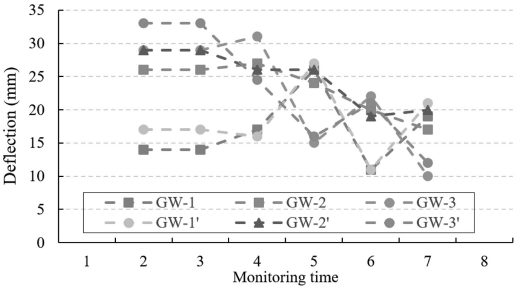


Figure 2. Arch rib deflection under constant load.

Instead of applying bHMS, an intermit monitoring combined with visual inspection and load test are carefully grouped together to assure the safe condition of the bridge. Monitoring data are given as well as some analysis. The results indicate it is a more practical way to monitoring and evaluation the long-term performance of bridges.

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An effective anchorage system for reinforced concrete beams with fiber reinforced polymer composites

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ABSTRACT

The potential of using CFRP sheet anchorage to prevent or delay the detachment of CFRP strips, bonded to the tension side of under reinforced concrete beams, was experimentally evaluated. CFRP strips (50 × 800 mm) were bonded to sixteen beams (100 × 150 × 1400 mm) before fourteen of which were anchored by either segmented or continuous CFRP sheets, attached above and beyond the strips and extend laterally to the beams' soffits for (50–100) mm.

Table 1. Detailing of testing program adopted in the present study.

	Anchorage	Configuration	Description
Designation	Length	hf, mm	S, mm
C	NA		
UA	NA		
A100-S800-DL-E50	100 mm	1st L 25FPB 2nd L 50 FPNB	800
A100-S350-DL-E50	100 mm	1st L 25 mm 2nd L 50 mm	350
A300-S300-DL-E50	300 mm	1st L 25 mm 2nd L 50 mm	300
A300-S300-DL-E100	300 mm	1st L 25 mm 2nd L 100 mm	300
A900-S0-DL-E50	900 mm	1st L 25 mm 2nd L 50 mm	0
A900-S0-SL-E50	900 mm	50 mm	0
A900-S0-SL-E100	900 mm	100 mm	0

NA, not applicable; U, without anchorage; A, Anchorage; E, Soffit Extension; D, Double; S, Single; L, Layer; hf, Lateral extension to soffits; FPB, fiber parallel to specimen axis; FPNP, fiber perpendicular to specimen axis.

Four beams were specified as strengthened without anchorage and control. The mechanical behavior of the beams was evaluated under four-point loading, before the data collected were analyzed for load-deflection, and bond stress versus slippage relationships and their characteristics. Crack formation and failure mode were monitored and characterized, as well. Anchoring CFRP strips at their ends by 300-mm-long CFRP sheet segments, with lateral extension, had improved the structural without degrading the ductility or toughness, hence can be considered as the most efficient and economic anchorage technique. Results of Table 1 provides a summary of the configuration of strengthened and anchored beams. Prior to flexural failure of the strengthened beams, the CFRP composites showed free-end debonding and/or concrete cover rip-off. A finite element model (FEM) was proposed, verified by experimentally obtained data, before used to expand predictions of mechanical behavior and modes of failure to promising anchorage cases that were not studied experimentally. more complicated than previously considered and has important implications for upland water quality.

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Experimental study on cathodic protection effect of galvanic anode system applied to reinforced concrete

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ABSTRACT

The cathodic protection method is an effective countermeasure for enhancing the durability of reinforced concrete structures under a severe corrosion environment. In the case of a galvanic anode system, the cathodic protection effect is influenced by several factors, such as the type of sacrificial anode and the material properties of the cover concrete. However, it is difficult to distinguish how each factor affects the degree of protection.

In this study, the influence of each factor on the cathodic protection effect was examined separately using a simulated reinforced concrete specimen. The target factors were soundness of the steel bar, thickness of the polymer cement mortar (PCM) and degree of saturation of the cover concrete. Table 1 shows the experimental factors.

Figures 1 and 2 show the temporal change in the protection current density and the potential, respectively. In the case of "Sat", a protection current density of 30 mA/m^2 applied for 16 hours induced a steel bar potential shift of 600 mV ($E_{on} - E_{corr}$) so a sufficient cathodic protection effect was achieved for the steel bar in concrete. In the case of "Sat–NaCl", protection current density of 30 mA/m^2 induced a steel bar potential shift of 150 mV ($E_{on} - E_{corr}$) so a sufficient cathodic protection effect was also achieved for the steel bar in concrete.

In the cases of "Dry" and "Dry–NaCl", the potential remained stable for 48 hours so a sufficient cathodic protection effect was not achieved. Both the amount of potential shift and the protection current density in the case of the dry concrete plate were small. This may have been caused by the increase in resistance of the cover concrete (IR drop). Therefore, in the cases of "Dry" and "Dry–NaCl", the potential shift and protection current density become small compared with the cases of saturated cover concrete (Sat and Sat–NaCl).

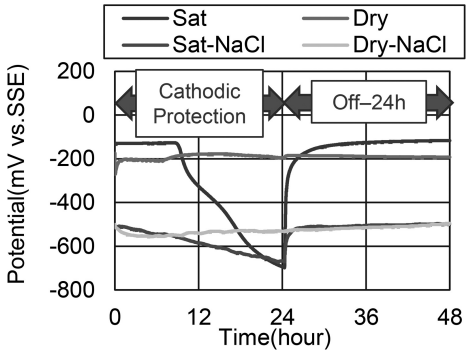


Figure 1. Temporal change of the protection current density.

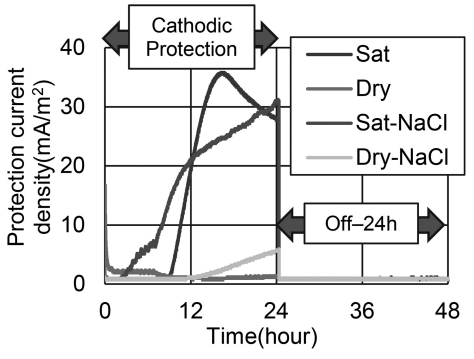


Figure 2. Temporal change of the potential.

Table 1. Experimental factors.

Cover concrete		
Degree of saturation in cover concrete	Chloride ions concentration	Abbreviation
Saturate	Not include chloride ion	Sat
Saturation (80∼90%)		Dry
Saturate	Include chloride ion	Sat–NaCl
Saturation (80∼90%)		Dry–NaCl

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Extending the life of bridges

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ABSTRACT

A summary is presented on the deployment over the past eighteen years of high performance materials in a number of bridges in Kentucky. The field applications range from: (1) a bridge deck in 1997 that is partially reinforced with glass FRP (GFRP) rebars; (2) a spread box prestressed concrete beam bridge constructed in 2001 and having a concrete deck reinforced entirely with 10 mm diameter carbon FRP rebars; (3) a three span prestressed concrete bridge retrofitted for shear using carbon fabric in 2001; (4) a four span reinforced concrete bridge slab on girder retrofitted for flexure using CFRP laminates in 2004 ; (5) repair of reinforced concrete bridge pedestals using carbon fabric in 2006; (6) a retrofit of the ends of prestressed concrete I-beams using carbon fabric; (7) retrofit of two multi-span bridges using high strength steel wire fabric in 2007; (8) retrofit of bridge piers and beams using 3-D carbon fabric since 2010, and (9) retrofit of bridge piers and beams using CFRP Rod Panels (CRPs) since 2011.

The CRPs are produced using CFRP rods mounted on a fiberglass backing with spacing greater than the rod diameter between individual rods. The developed CRPs are typically 1220 mm in length and has a 915 mm fiberglass backing providing 150 mm overlap on either side of the panel for the 'finger joint' between adjacent panels as shown in Figure 1. The 150 mm overlap for the finger joint was conservatively selected observing the results of double lap shear tests. CRPs can be utilized to strengthen and upgrade existing concrete and steel structures. The primary advantage of this new technology lies in its ease and speed of application by a single worker, and its minimal requirement for construction equipment. The CRPs are extremely advantages for repairs and strengthening applications over multilane roadways where the construction can proceed in sections, reducing traffic congestions and detours. They are also cost effective over long spans, especially over waterways, reducing labor and equipment costs considerably when compared to traditional methods.

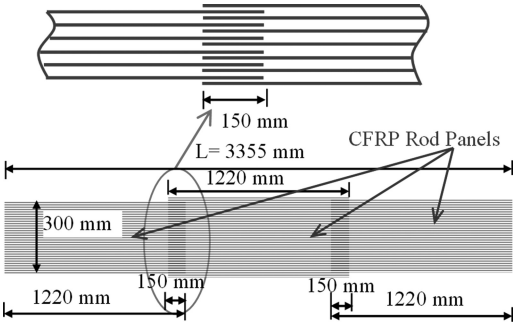


Figure 1. Layout of CRP panels with finger joint connection.

The FRP components used in the new bridges were intended for experimental purpose and material evaluation. The eleven retrofitting projects were chosen because of their economic advantage over other retrofitting alternatives. GFRP and CFRP re-bars were found to be excellent replacements for steel rebars in reinforcing concrete bridge decks. Carbon Fabric wrapping was found to be an effective method for the repair of concrete piers, pier cap pedestals and also deteriorated or damaged precast prestressed and reinforced concrete beams. Steel Wire Fabric was seen to successfully eliminate crack propagation in reinforced concrete beams. FRP laminates proved to be an efficient strengthening technique for reinforced concrete beams. The case studies of the five field applications showed that CRPs were able to effectively retrofit damaged or deteriorated concrete bridges. Further use of FRP material in future bridge construction and retrofit projects are recommended for their application to become more established and for developing design and inspection standards.

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Factors affecting sacrificial anode to protect reinforcing steel corrosion

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ABSTRACT

In order to minimize repairing cost by sacrificial point anode method, maximize distance between anode needs to be considered. This study determined performance of different sacrificial anode materials which are aluminum alloy, zinc alloy and alkaline activated zinc alloy to protect corrosion of reinforcing steel in different concrete mix proportions. Water to binder ratio and fly ash content were varied. Moreover, moisture condition of specimen was varied as wet, wet-dry and dry conditions. Initial chloride was mixed during concrete mixing to initiate corrosion of reinforcing steel. Reinforcing steel was arranged at different distance from sacrificial anode to determine corrosion protected distance.

Half-cell potential of sacrificial anode and reinforcing steel at different distance from sacrificial anode were measure weekly against $Cu^{2+}/CuSO_4$ reference electrode. Corrosion current density between anode and reinforcing steel were also measured weekly by measuring voltage drop across external electrical resistance connected between anode and steel. Concrete electrical resistivity was measured by Wenner's four probe method.

Results showed that aluminum alloy anode had the highest performance of corrosion protection because of its lowest potential and highest current capacity. Activated zinc by high alkaline mortar improved performance of zinc alloy significantly due to dissolving of zinc oxide film. The results showed that fly ash content and moisture condition of specimen significantly affected electrical resistivity of concrete and performance of sacrificial anode. Dry condition and increasing of fly ash content increased electrical resistivity of concrete. Therefore, sacrificial anode performance was reduced. However, specimen with low water to binder ratio had lower electrical resistivity in wet-dry and dry conditions than high water to binder ratio concrete because moisture was more difficult to evaporate during drying. As a result, sacrificial anode perform better in lower water to binder ratio concrete in wet-dry and dry conditions.

In this study, reinforcing steel corrosion protectable distance in wet or damp concrete was found to be as much as 85 cm which is the longest distance from anode tested. This distance is considerably larger than recommendation of interval distance of commercial products. Further studies and analysis will be conducted to ensure the protectable distance from anode and propose practical design methods. As a result, maintenance cost of RC structure can be minimized.

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Fatigue life assessment of orthotropic steel deck with UHPC pavement

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ABSTRACT

In the recent years, a number of large span bridges with orthotropic steel decks were constructed in China. With increasing traffic volumes and higher wheel loads, many fatigue cracks developed at the welds and the edge of cut-out holes. This paper aimed at presenting the numerical analysis on the fatigue performance of the orthotropic steel deck using ultra-high performance concrete (UHPC) overlay as the deck pavement instead of the conventional asphalt concrete pavement. By using Finite Element Method (FEM) model, stress distribution at fatigue sensitive locations under the action of wheel loads was characterized and the obtained stress ranges indicate that the UHPC pavement significantly reduces the magnitude of the stress peak value (as shown in Fig.1 and Fig.2). Comparing with the transverse stress distribution of the deck in the middle span of diaphragms, the stress distribution adjacent to the diaphragm location was much higher.

A suggested truck stream model based on the Weigh in motion (WIM) data of four bridges in China was employed (as shown in Fig.3), to calculate the stress variation at specific fatigue details. Furthermore, the fatigue cumulative damage at fatigue details under the UHPC and conventional asphalt concrete pavement were studied based on the Miner's linear cumulative damage rule and rain flow method. The results indicated that The UHPC+RA05 pavement can improve the fatigue lives of details significantly. Fatigue lives of all the concerned details can exceed over 100 years except the Detail E. However, fatigue lives decreased considerably after the elastic modulus of the UHPC+RA05 pavement reduces to 50% due to the absence of cracks.

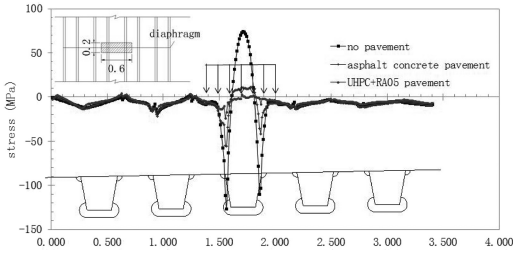


Figure 1. Transverse stress at the bottom of the deck 1cm away from the diaphragm.

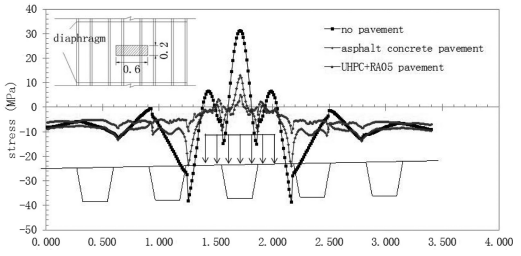


Figure 2. Transverse stress at bottom of the deck in the middle span of diaphragms.

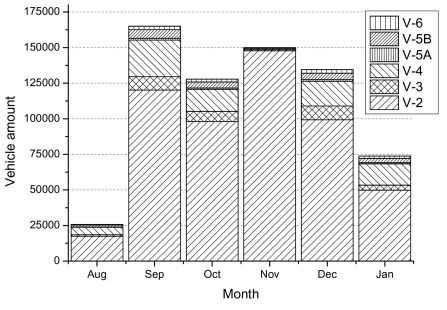


Figure 3. Statistical data of the heavy vehicle lane based on the traffic stream fatigue load.

A parametric study was carried out, regarding to: (1) asphalt concrete pavement thickness, (2) elastic modulus of UHPC, and (3) thickness of steel deck with the UHPC pavement. The results showed that, it was not an effective solution to reduce the stress range of fatigue sensitive details by increasing the thickness of the common asphalt concrete pavement. The fatigue performance of critical areas can be improved considerably by employing the UHPC layer or a relatively thick steel deck.

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Improved asset performance using high strength concrete overlay renovation technique

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ABSTRACT

Within the current bridge stock on the Dutch highway network, there are a number of steel orthotropic deck bridges which are found to be subject to steel fatigue damage. The bridge owner, Rijkswaterstaat (RWS) are addressing this issue using an innovative renovation technique. Fatigue damage typically occurs at locations of stress concentrations such as at welds, attachments and abrupt changes in geometry. The classic fatigue crack location is through the deck plate at intersection of the trough leg and cross-girder, as indicated in Figure 1.

RWS implements a regime of regular inspection and repeated maintenance activities in order to keep the bridges fully operational, with temporary hindrance to road users where repairs are necessary. Repairing the asphalt and the steelwork on a regular basis is not a sustainable maintenance strategy as the frequency and severity of the damage increases with time, and the remediation works become more and more intrusive for both the bridge structure and the road users. Without fundamental rehabilitation, the bridge will reach the end of its useful life earlier than intended.

To address this issue, RWS have developed a solution of applying a concrete overlay to the surface of the steel deck. This repair method is designed to address the fatigue damage that can occur in the deck plate and in the stiffening troughs connected to the deck plate. The overlay prolongs the life of the steel deck and extends the maintenance life of the wearing surface. The solution has been developed since 2000 and has now been applied to a number of large bridges throughout the highway network.

This paper presents the current state of the art with regard to the evolution of the concrete overlay product and recent experiences from the construction works. The information has been developed as part of the RWS Bridge Renovation Programme. As part of this programme of works, the Managing Contractor (Arup, Royal HaskoningDHV and Greisch joint venture) are responsible for the assessment, design, procurement and construction supervision of the works.

More detail with regard to the background of the concrete overlay product and information on these renovation works can be found in various publications (Gration et al 2010, den Blanken et al 2012, Tuinstra 2013, Moore et al 2013).

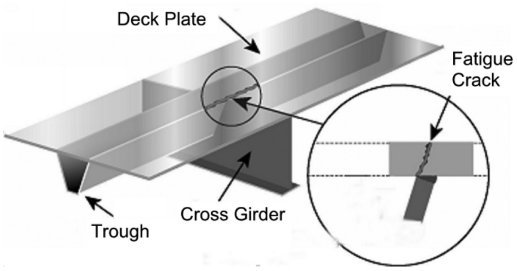


Figure 1. Fatigue crack in orthotropic steel bridge deck.

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Incremental seismic rehabilitation of RC buildings: An application to the school buildings of Basilicata region (Southern Italy)

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ABSTRACT

In countries with mid-high seismic hazard like Italy and having an old public building stock mainly designed without seismic criteria, school buildings can be subjected to high seismic risk, especially thinking to their exposure characterized by the presence of particular users (e.g. children, young students) not always capable of self-protecting themselves during seismic events.

As consequence, during the last decade, comprehensive assessment programs have been carried out in Italy especially on hospitals and schools. Most of these seismic vulnerability assessments for non-seismically designed existing school buildings were carried out in the aftermath of the 2002 Molise earthquake, in compliance with the Ordinances of the Italian Prime Minister (OPCM) 3274/2003 and 3362/2004. The main purpose of these assessments was the construction of priority lists in order to effectively set up strengthening intervention programs. The huge amount of resources needed to retrofit all vulnerable structures requires accurate studies for setting up strategies able to reduce the seismic risk to allowable levels optimizing the use of the available resources.

Under these premises, it appears rather unavoidable to give consideration to the alternative strategy of seismic upgrading, i.e. improving the current seismic resistance without achieving the full retrofit). In other words, policy-makers and public managers should accept the idea of having, even after strengthening interventions, a capacity/demand ratio less than 1.0 (C/D < 1.0). In such a way, seismic risk reduction can be made on a larger number of buildings avoiding heavy interventions for the full retrofit of a few buildings (Frascadore et al., 2015).

Moreover, with specific reference to school buildings, some researchers proposed strengthening techniques able to minimize impact and invasiveness on their functionality. As an example, Chung et al. (2011, 2014), set-up and tested (both in laboratory and in situ on real buildings) a strengthening system for school buildings with partitions made of brick masonry by adding RC frames.

With this aim, the assessment results on a non-seismically designed school building located in Basilicata region (Southern Italy) has been analysed in order to find out whether or not an Incremental Seismic Rehabilitation strategy (FEMA 2003, 2009) could be effectively applicable. An application of the proposed procedure has been made on a case study school building with RC structure designed only to gravity loads. The structure has been firstly evaluated through non-linear static analysis and, based on its performance and, specifically, on the sequence and type of local failures, a design for a staged seismic rehabilitation has been prepared. The design critical choices adopting an incremental seismic rehabilitation, quite different from a single-staged rehabilitation usually adopted by professional engineers, have been identified and discussed.

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Innovative bio-composite systems for re-design of timber structures

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ABSTRACT

In the context of the major concern on environmental impact of built patrimony, the design of structural elements needs to consider their entire life-cycle. Using bio-composite materials in structural applications is a sustainable alternative with positive effects on the environment through the renewable character of natural fibers used as reinforcement at low costs, the reduced energy consumption during their processing, composite production and application, low carbon dioxide emissions and the possibility to reuse/recycle them at the end of their life-cycle.

This paper has the main objective the design of an innovative solution based on bio-composite materials used for timber structures and elements, considering also the compatibility of implied materials. An innovative method to enhance the structural performance of timber frames subjected to both static and dynamic actions is proposed by creating hybrid timber/bio-composite frame joints able to continuously transmit efforts between the structural elements that enter the node. The solution aims to obtain the structural effect of timber frame with rigid nodes.

The advantages of rigidly connected timber frame members toward the traditional joining systems, usually hinged, are the possibility to reduce cross-sections dimensions of the structural timber elements. Also, the possibility to design timber beams with larger spans for the same cross-section as in the traditional case and to configure the structure with a reduced number of bracings and, as a result, with a higher degree of functional flexibility, is of great importance. Another advantage of creating rigid nodes is improving the structural redundancy by introducing a larger number of connections. Achieving the rigid timber frame joints represents both design and technological advances that imply reconsideration of these types of structures, at design level.

The study consisted of finite element numerical simulations, carried out on a reference timber frame node for which all the structural elements that enter the node have the same cross-section dimensions and the same length, resulting in the same rotational stiffness. The innovative joining bio-composite system introduced in the node of the timber frame and its performance are evaluated in order to ensure the rigid node effect, and to enhance its safety, during the structural life cycle. The design of the timber structure, the overlap length, the needed mechanical properties, thickness of the applied composite material and the wood/bio-composite interface properties must be performed in such a way that failure not to occur at the interface. The final results revealed that the proposed bio-composite system is leading to obtain a rigid node, followed by a better behavior of the wooden frame during its life cycle.

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Lifting up a 270 meters length sinking bridge over Guadalquivir river with the technique of Jet-Grouting

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ABSTRACT

The Spanish Administration has carried out between July 1990 and October 1992 the construction of the Road Variant of Alcalá del Rio, which includes a bridge over the Guadalquivir River with nine isostatic spans, whose geometric definition is described later.

The mentioned structure consists of nine spans equal of 30.00 m each one, which sums up a total length of 270.00 m. The deck comprises 10.00 m of pavement plus two sidewalks of 1.00 m, totaling a width of 12.00 m.

The bridge was designed with deep foundation in all its supports, due to the existing soft ground in the zone.

The foundation of the bridge is made by two circular pier-piles of 1.50 m of diameter for any support of the bridge and 25 m of length in the case of piers. In the piers, the piles has 2 m were embedded in gravels and 12 m (8 diameters) in blue marls; the remaining 11 m corresponds to the exempt part of the pier, with the lowest 2 m corresponding to the average water depth of the Guadalquivir River in the above mentioned zone.

In the first week of April of 1993, it was observed a vertical angle in the metal vehicles barriers and in the handrails of the bridge that was indicating the possibility of a descent of the deck, at the level of the piers P-4 and P-5 in the center of the river.

It was decided to verify the level of the mentioned piers by topography, observing average settlements in piers P-4 and P-5 of 13.9 and 5.4 cm respectively. Due to this it was decided to carry out a following-up of the settlements by means of topography fixed bases of leveling on both sides of the bridge.

The following topographic observation showed vertical settlements of 13.9 cm and 5.4 cm in each pier. After a revision of the project, it was concluded that according with the existing geotechnical investigations, the safety coefficient could be enough, but a new Geotechnical Campaign showed a dropping of the compaction of the soil, just in the area of piers P-4 and P-5. Using the new parameters of the soil it was concluded that the safety coefficient was not enough. After studying different solutions, it was concluded that the best technically and economically procedure, was Jet Grouting. With this technique, it was lifted 10.0 cm and 2.5 cm the pillars P-4 and P-5, increasing dramatically at the same time the safety coefficient.



Figure 1. Bridge in phase of construction.



Figure 2. Finished bridge.

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Micropiling two bridges in construction in the Motorway M-410 in Madrid (Spain)

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ABSTRACT

The new highway M-410 in Madrid was constructed in the year 2007. This motorway near to Parla city crosses the road from Madrid to Toledo. To solve this crossing it was needed to constructed three bridges, the central with two spans over the existing motorway and the other two with one span at each side of the previous one. All the bridges where with deep foundations with piles of 1.00 m of diameter separated 1.25 m. In the two lateral bridges, after constructing the piles, it might be removed the earth under the concrete slab to make the two lateral roads.

Just after the construction, it was made sonic transparency essays, which it shows some anomalies in the tip of the piles of the two lateral bridges called PS-18 and PS-19, which implies the necessity of a more deep investigation.

It was decided to make two boreholes one at each bridge in order to obtain samples of the terrain near to the tip of the piles. This investigation shows that the earth at the level of the tip of the piles, was sandy and with a great water flow, so the conclusion was, that it was impossible to retire the earth under the concrete slab on the top, because the piles are not correctly founded.

This paper shows the project and the construction of the solution, consisting of two sheet of micropiles

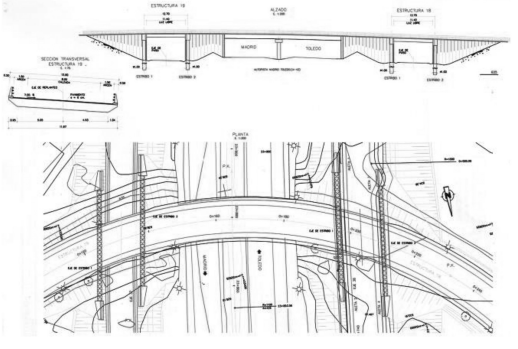


Figure 1. The Bridges in the crossing of M-410 with the motorway Madrid-Toledo.



Figure 2. Central and lateral bridges without removing the earth above last one.

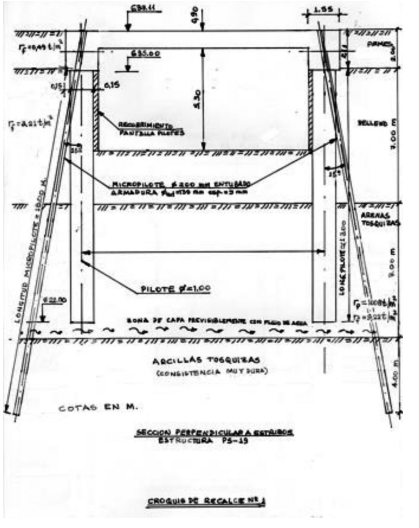


Figure 3. The micropiling bridges PS-18 and PS-19.

deepest at each of the bridges, to resist all the loads and after this, to remove the earth under the concrete slab above (figure 3).

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Parametric study on concrete-filled steel tubular T-joints under axial load

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ABSTRACT

Welded T-joints made of steel circular hollow sections have been widely used in various engineering structures. Recently, filling the chord (the primary member) with concrete has been successfully used to improve the overall performance of the T-joint. The concrete infill improves the stiffness of the tube, absorbs some of the applied energy and hence reduces wall deformations which lead to lower stress concentration.

In the present research, a finite element model has been developed employing ABAQUS software to simulate the performance of chord concrete-filled steel tubular (CFST) T-joints under axial loading on the brace. Exact modelling of the weld according to American Welding Society (AWS, 2010) has been included in the simulation. An 8-node 3D quadratic hexahedral solid element with reduced integration has been used. The concrete filling is assumed to have linear elastic behaviour in the simulation because the non-linear elastic-plastic model for concrete was used, but did not have any effect on the SCFs around the intersection since the applied load was within the elastic range. Stresses over the region recommended by CIDECT (Zhao et al., 2001) have been linearly extrapolated to obtain hot spot stresses in the chord and brace. Forty eight models have been developed to investigate variation of the maximum stress concentration factors (SCFmax), in CFST T-joints under axial loading, with non-dimensional geometric parameters β, τ, γ and α. Graphs showing variation of the maximum SCF, in CFST T-joints, with non-dimensional geometric parameters have been developed and compared with those for non-filled empty T-joints. The outcome of the FEM simulation is verified with existing experimental results obtained Wang et al., (2013).

The graphs developed were used to show variation of the maximum SCF, in CFST T-joints, with non-dimensional geometric parameters β, τ, γ and α. The following observations were made:

- The concrete infill in the chord effectively reduces stress concentration around the chord-brace connection.
- The parameter β, has a significant effect on the maximum SCF in CFST T-joints.
- The trend in variation of the maximum SCF with parameter β in CFST T-joints is different and opposite to that in empty T-joints.
- The trend in variation of the maximum SCF with parameter τ in CFST T-joints is similar to that in empty T-joints yet its effect is less in the CFST T-joints due to existing of the concrete-fill.
- Parameter γ has little or no effect on the maximum SCF in CFST T-joints.
- The trend in variation of the maximum SCF with parameter α in CFST T-joints is different to that in empty T-joints.
- Parameter α has a considerable effect on the maximum SCF in CFST T-joints for values of $\alpha > 12$, $\beta > 0.5$.
- The location of the maximum SCF in CFST T-joints tends to be at the chord saddle when $\beta \leq 0.4$ while it tends to be at the chord crown when $\beta > 0.4$.

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Prolonging the lifetime of steel highway bridges

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ABSTRACT

During the '60's and '70's of the last century the Dutch highway network has been expanded enormously. Both technical and economic developments since that time have led to an increase in traffic load; the number of vehicles has grown tremendously as well as the axis loads. Most existing steel highway bridges are not capable to carry these loads and thereby are reaching the end of their technical lifetime. The Dutch government has decided to renovate some of these bridges instead of building new ones.

A program has been set up by combining the renovation of 14 bridges in order to develop new and innovative renovation techniques and to share knowledge between all parties involved. Continuity in the organisation, knowledge management and risk management have shown to be key aspects of this program in becoming reliable and predictable for both the public decision making and the public.

In 1997 the first signs of fatigue damage showed on the Van Brienenoordbridge at Rotterdam, The Netherlands. Further investigation by the Dutch National Transport Authority, Rijkswaterstaat, showed the so called Orthotropic steel deck structure for bridges is most vulnerable for fatigue cracks. After evaluations of several alternatives, it became clear adding an extra layer of high strength concrete (HSC) on the bridge deck was the most promising solution (Adviesbureau Hageman, 2009).

Rijkswaterstaat initiated tests on several bridges and after improving the application method, HSC has been applied on several bridges successfully, although, the application of HSC as the solution for fatigue problems in steel bridges has been characterized as working on the limits of technical and practical possibilities.

During the above mentioned program the application of HSC has been combined with extensive renovation of most of the fixed bridges within the program. Most important for Rijkswaterstaat was reducing hindrance for traffic on the motorway as well as shipping on the waterways.

The risk profile of a renovation project is higher than a 'green field' project. Extensive project control and risk management have been put in place for the above mentioned program, both on program level as for each bridge project.

As a governmental body, Rijkswaterstaat needs to be reliable and predictable. This is not only important for those who are (political) responsible, but also in the communication with stakeholders and the public. Renovating an existing infrastructure object means 'restyling the shop, while sale continues'. Therefor involving stakeholders in the decision making process and external communication are key success factors. And this goes for all project stages.

In fact it is quite simple: Everyone understands the need to close a bridge for a short period of time as part of an extensive renovation. But nobody wants to change a travel schedule or accept delay if this construction period takes longer then communicated.

The human factor plays an important role in this kind of complex projects. Being open and transparent helps to solve issues. Discussions are to be based on the technical issue and the interests of parties involved. Making this clear (almost) all problems can be solved and the contractual aspects will follow.

Project control and risk management are to support project management. All together it is possible (and great fun!) to carry out complex renovation projects in a predictable and reliable way.

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Ductility enhancement of concrete members under blast load using CFRP external strengthening

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ABSTRACT

Columns are the most critical elements in structural systems. They may fail catastrophically in buildings exposed to bomb blast, which could lead to progressive collapse of the entire structure. Past global blast events have shown that preventing progressive collapse would significantly reduce the number of casualties and minimize structural damage. Hence, columns in existing critical facilities must be upgraded to resist the effects of blast loads in order to minimize the risk of fatalities, injuries, and damage costs. To predict the behaviour of reinforced concrete (RC) structures under blast laod, single-degree-of-freedom (SDOF) dynamic analysis can be used. However, in this analysis the force-displacement relationship (also called resistance function) of the structural member must be identified. An idealized resistance function can be established by simply specifying the moment capacity and the corresponding curvature for the section at different load levels, like yield level (M_y) and ultimate level (M_u) and by knowing the equivalent plastic hinge length (L_p). This length can be predicted using one of the models available in the literature.

In RC columns exposed to catastrophic events (e.g., significant earthquake, significant blast or impact) plastic hinges form at maximum moment regions where the most damage occurs. Plastic hinge length (L_p) can be defined as the virtual length over which the plastic curvature is assumed to be constant. The rotation over a cantilever RC member can be computed by integrating curvatures along the member length if L_p is known, from which the tip displacement can be computed; and vice versa. For this reason it is essential to predict the plastic hinge length with acceptable accuracy since it is a key step in correlating the section-level response to the member level response of a concrete column. Indeed, the plasticity spreads over a larger physical length, referred to as the yield length (L_y). The yield length is the distance between the critical section and the location where the tension steel reaches its yield stress. Hence, the plastic hinge length can be expressed as $L_p = \beta L_y$, where β is a dimensionless reduction factor for the curvature distribution near the support and it is always smaller than 1.0.

While a large number of studies were carried out to estimate the plastic hinge length formed in unretrofitted RC beams and columns subjected to monotonic or cyclic loading, only a very limited studies were conducted to investigate the plastic hinge formation mechanism in FRP-jacketed RC columns. No experimental investigation has been conducted so far to compute the plastic hinge length of RC concrete elements exposed to blast effects despite the importance of this parameter in establishing the resistance function. This function in turn is essential in obtaining the blast response of the member using SDOF model.

The objective of this paper is to present the experimental evidence of the enhancement of the structural performance of RC columns when retrofitted by CFRP laminate. The focus will be on the ductility enhancement by increasing the deformation capacities and plastic hinges length. This paper presents part of the results of a large study to develop high performance protection systems for concrete columns subjected to blast loads. The results show that columns retrofitted with CFRP laminate have higher blast resistance, significantly higher ductility in terms of longer plastic hinge compared to non-retrofitted columns. Columns retrofitted with CFRP laminate containing woven $\pm 45°$ CFRP fabrics developed longer yield lengths than those that had unidirectional fabrics only when subjected to the same blast loads. Hence CFRP strengthening laminate including woven $\pm 45°$ CFRP fabric improved the ductility of the column. It can also be concluded that when the applied lateral load is less than the column lateral capacity, the residual axial load reached 95% of the initial applied axial load and the residual deformation at mid height is very small.

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Sustained load performance of adhesive fastening systems in concrete

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ABSTRACT

In recent years, application of post-installed adhesive anchors has increased since they provide greater flexibility in design of new structural systems as well as for strengthening of existing structures. In general, adhesive products are viscoelastic by nature and have a time-dependent behavior. Therefore, adhesive anchors subjected to sustained loads are prone to creep over their service life which may considerably affect their long-term performance.

Although the short-term performance of adhesive anchors has been extensively studied in the literature (e.g. Elfgren et al. (1987), Cook et al. (1998) and Eligehausen et al. (2006)), their long-term creep behavior under sustained loads is not very well known. To increase the knowledge regarding the sustained loading performance of adhesive anchors, a long-term test program was defined and started in 1984. The main objective of this test program was to study the influence of different sustained loading levels and several in-service conditions on the anchors' long-term performance. Adhesive bonded anchors of size M16 and m20 were subjected to sustained load levels between approximately 23 and 70% of their mean ultimate short-term capacities. Their creep deformations were monitored up to approximately 28.4 years. After sustained loading tests, the remaining anchors that had not failed during the long-term tests were unloaded and monotonically loaded to failure to evaluate their residual bond strengths. The tested in-service conditions were indoor, outdoor, wetness (i.e. water on the surface of concrete) and presence in the concrete of salt additives.

The tested adhesive anchors in the indoor conditions showed relatively small creep during test period and they could carry sustained loads up to 47% of their mean ultimate short-term capacities. However, the adhesive anchors under outdoor environment showed larger creep deformations and failure occurred for sustained loads higher than 23% of the anchors' mean ultimate short-time capacities (see figure 1). Salt additives in concrete and wet conditions showed negligible influence on the long-term performance of adhesive anchors although the wet condition caused corrosion of the steel in the anchors. Figure 2 shows the failure of some of the monotonically loaded anchors to failure.

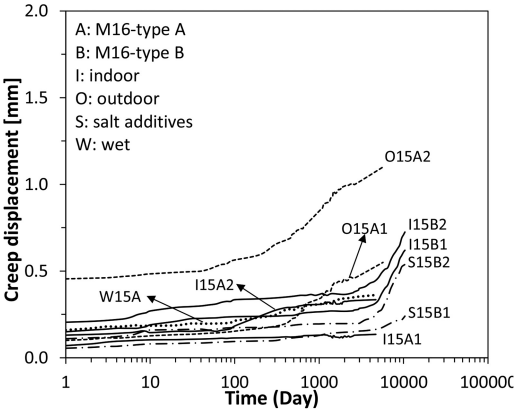


Figure 1. Creep displacement vs. time for M16 anchors under the lowest sustained loads (15 kN).

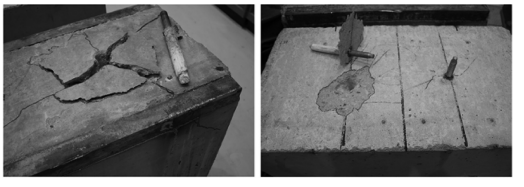


Figure 2. Failure of some of the monotonically loaded anchors to failure after the sustained loading tests.

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The repair method of preventive maintenance for reducing of open-cut communication tunnel life cycle cost

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ABSTRACT

The construction of NTT cable tunnels began in Tokyo in 1928 with open-cut tunnels. Over 60% of the existing tunnels were built at least 30 years ago, and age deterioration of the concrete from which the tunnels were constructed has resulted in cracking and significant degradation from seepage of ground water through the cracks.

Communication tunnels were entered for usual work such as laying cables to support day-to-day safety and sense of security.

The objective of the work reported here is an efficient maintenance and management method that minimizes life-cycle costs. Our approach is to use data from tunnel inspections to predict near future degradation and estimate future costs based on the current situation of progressing degradation in open-cut communication tunnels.

The approach to open-cut communication tunnels repair has been to repair areas where degradation has already occurred and then follow up with maintenance repairs afterwards. However, analysis of inspection data from the database shows that similar degradation has occurred around previous repairs and in places near previous repairs.

As a result, there is a concern that the long-term cost of post-repair maintenance repairs will increase. To avert that problem and reduce long-term repair costs, it was decided to use the results of periodic inspections to predict locations where future repairs will be necessary in open-cut communication tunnels where the progression of degradation is evident, and to perform preventive repairs that include the surrounding area.

We compared the preventive repair approach based on this degradation prediction method (scenario 1) and the conventional partial repair approach in which only the parts where degradation is evident are repaired (scenario 2). We calculated the medium-term to long-term costs to determine whether there is a reduction in the lifecycle cost and to understand the effect of the preventive repair approach.

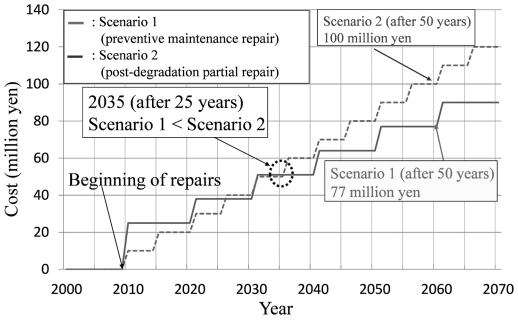


Figure 1. The results of the lifecycle cost analysis.

The work reported here has verified the effectiveness of a preventive maintenance approach to repair of open-cut communication tunnels based on measurement data obtained in periodic visual inspections and detailed inspections.

We conclude that although the current approach to communication tunnel maintenance and management is less expensive in the first few years, a transition to the preventive maintenance approach would be highly economical over the long term.

Performing repair on the basis of predicted degradation will, in the future, clarify the necessity of repairing locations for which immediate repair is not needed. That will enable timely response to progressive degradation, so a long-term preventive effect can be expected and high-quality facility maintenance and management without degradation will be possible.

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Development of risk cost optimized maintenance strategy for infrastructure

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ABSTRACT

Due to its long-term service, coupled with exposure to aggressive environment and increased demands, deterioration of and damage to infrastructure has led to unserviceable or unsafe operation, and in some cases, catastrophic collapses of infrastructure. To ensure the safe and serviceable operation of infrastructure, maintenance is essential. The problem is how to determine when, where and what to maintain at a minimal risk and with effective cost. The intention of this paper is to formulate a framework for developing a risk cost optimized maintenance strategy for infrastructure during its whole service life. A time-dependent reliability method is employed to determine the risk of structural failures. To facilitate practical application of the proposed framework, an algorithm is developed and programmed in a user-friendly manner. An example is provided to illustrate the application of the developed algorithm to RC structures.

The conceptual design of the proposed maintenance strategy is based on the following idea. A structure or component is to be maintained only when it fails but the failure should be predicted with sufficient confidence before it is too late to fix. A structure consists of many components, some of which are redundant. Thus the failure of a structure as a whole i.e. system, should be modeled as a combination of series system for non-redundant components and parallel system for redundant components. Similarly, a component can fail in many modes, some of which reach the ultimate limit state and some reach the serviceability limit state. Thus the failure of the component should also be modeled as a system which is a combination of series system for ultimate failures and parallel system for serviceability failures.

Since failure is not only random but also time-variant, a time-dependent (i.e. when) reliability method should be used to determine the probability of the basic failure, i.e., a component (i.e. where) failure by a mode (i.e. what), resulting in when, where and what maintenance actions are required for the structure. The rationale for a risk cost optimization is that, whilst keeping the probability of ultimate failure under control (to ensure safety), only when the probability of serviceability failure reaches an acceptable limit, the maintenance would be warranted. Mathematically the above idea for risk-cost optimization can be formulated as follows:

$$\begin{aligned} &Minimize: Risk = \sum_{i=1}^{N_n}\sum_{j=1}^{N_c}\sum_{k=1}^{N_m} p_{sys} \times C_{jk} \\ &Subject\ to: \ p_u(t_i) \le p_{u,a}; \\ &\qquad p_s(t_i) \ge p_{s,a}; \\ &\qquad p_{sys}(t_i) \le p_{sys,a}; \\ &\qquad 0 \le t_i \le t_L \end{aligned} \tag{1}$$

The optimization of Equation (1) is very computationally involved and complex. In this paper a numerical algorithm is proposed for the optimization. The outputs of the risk-cost optimization are the maintenance action times (t_i values). Furthermore, at each maintenance action time, the algorithm determines the critical component and failure mode as output. To illustrate the application of the proposed methodology for maintenance strategy and in particular the developed algorithm to practical structures, a reinforced concrete bridge girder with three spans is used as an example. It is found in the paper that an optimum solution exists to the proposed risk cost optimization in developing the maintenance strategy. It is also found that the developed maintenance strategy can predict and then decide when, where and what to maintain for infrastructure to ensure its safe and serviceable operation during its lifespan.

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Life cycle assessment of high rising residential building in Southeast China

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ABSTRACT

Given the nowadays challenge of environmental pollution in China, the importance of environmental impacts for buildings in China cannot be ignored. This study tries to add the knowledge of environment impacts caused by construction and occupied of high rising residential buildings, especially those in southeast China. In order to do so, this study conducts life cycle assessment and considers all the processes in the high rising dwellings' life cycle.

This LCA study follows the ISO 14040/44 methodology (ISO, 2006a, ISO, 2006b). The ReCiPe Midpoint (E) V1.1/World ReCiPe H (Goedkoop et al. 2012) method was used to estimate the environmental impacts. The reference unit in this study is defined as "the construction, occupied and demolition of one m^2 useful space of dwelling over the lifetime of 50 years". "Useful space" here refers to the inside useful area for occupants, excluding the space for structure, stairs, elevators and other technic installation The lifetime of a building is a difficult parameter to standardize since it depends on many factors. This study assume the lifetime as 50 years (Adalberth, 1997, Zabalza Bribián et al., 2009, Cuéllar-Franca and Azapagic, 2012).

Using the data from the high-rising residential building project tenders completed southeast china during 2007–2011, this paper reveals:

1) 1 m^2 useful space of high-rising residential building in southeast China at least emits 5.9 ton over its 50 years life span. The GWP emission mainly stem from the consumption of electricity and nature gas. The use stage, including operation and maintenance, has major responsibility to the environmental impacts.
2) Electricity, nature gas, window, steel, and concrete are the five main contributors for the life cycle GWP emission of high-rising residential building. Therefore, improving the energy efficiency of buildings and appliance, encouraging the use of low-carbon buildings material/component, and optimizing framework design to reduce the amount of such main consumptions would be important.

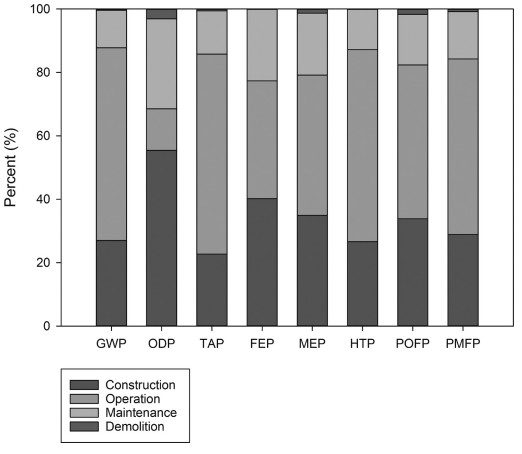


Figure 1. Relative contribution of stages to the life cycle environmental impacts.

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Life-cycle cost analysis of steel bridges under severe chloride exposure: A comparison between conventional and corrosion-resistant steel

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ABSTRACT

Steel bridges are under continuous deterioration due to various environmental and mechanical stressors. This deterioration adversely affects the resistance and reliability of the structure resulting in a corresponding reduction in the safe service life. Among the effects that impact the reliability of aging steel bridges and limit their service life is corrosion. Corrosion affects all steel bridge members and its effects are accelerated in the presence of chloride deposits arising from marine environments or exposure to de-icing salts. Corrosion can lead to a uniform loss in the thickness of affected elements, and in turn, reduce their structural capacity. This may eventually lead to failure in the corroded component when the load effects exceed the diminished capacity of the member.

Different types of steel can be used in steel bridges depending on the desired level of corrosion protection. Carbon steel has long been used in steel bridge industry. This steel depends on layers of coatings to provide the desired corrosion protection. Coatings can also be used to resist abrasion and moisture. However, experience with steel bridge industry shows that bridges constructed from this carbon steel would need regular repainting actions every 20 to 30 years in regular operating environments. Harsh marine environments, mechanical abrasion, or exposure to de-icing salts will significantly reduce the repainting interval.

For better corrosion protection, weathering steels are used in more aggressive environments. Weathering steels rely on the formation of rust patina that is fairly stable and can protect the underlying material from further corrosion. However, in the case of extended time of wetness or with the presence of chloride deposits (due to marine exposure or de-icing salts) the formation of the protecting layer may be inhibited. This can lead to corrosion losses. Accordingly, weathering steel becomes unsatisfactory under the presence of chlorides or long wetness times.

In such situations, stainless steel has been shown to provide corrosion protection that is superior to both conventional carbon steel and weathering steel. Several types of stainless steel exist for steel bridge construction, including duplex stainless steel and the ASTM A1010 steel. These steel types depend on alloying material oxides (e.g. Chromium oxide) to form as a continuous film on the surface to protect underlying material. Although this steel is initially more expensive than carbon steel or weathering steel, the lack of maintenance and the corresponding long service life may deem it a cheaper and more sustainable solution when considering the life-cycle of the structure.

This paper presents the results of an investigation to quantify and compare the life-cycle cost of bridges constructed using carbon steel and ASTM A1010 steel. The life-cycle cost includes the initial construction cost and regular maintenance cost (for carbon steel). Since bridge maintenance is a process that may lead to significant traffic delays, indirect impact on the users of the road network and additional environmental effects should be accounted for when computing the life-cycle cost. These effects are included in this paper in addition to the aforementioned traditional life-cycle cost components.

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Maintenance strategy of highway bridges based on life cycle function

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ABSTRACT

In order to rationally use the maintenance funds in the whole life cycle of highway bridges, the maintenance strategy should be optimized.

The reliability of degradation component for a bridge depends on the type of component, quality of construction, and environmental conditions. Without maintenance, the probability of degradation component decreases with time. The probability function can be approximated by lifetime distribution functions (LDFs) (Leemis 1995). In general, the exponential and Weibull functions are used as LDFs.

The failure of a single component usually does not lead to failure of the whole structure. Most structures are redundant and can resist the load after the failure of one or more of its components. So, structures must be analyzed for different failure modes. The components of a structure are in series and/or parallel connection. For parallel system, the failure of all components leads to failure of the system. For series system, the increase of independent components makes the system safety decrease.

The correlation of components is between zero and one. Then failure probability of system must be between failure probability of independent and fully correlated components. Fully correlated components in parallel lead to high failure probability, while fully correlated subsystem tends to safety for structural system.

The maintenance strategy is proposed by means of life cycle function and structural reliability simulation. The time-dependent failure probability of structural system and the remaining life of the maintenance action for one or multiple components are analyzed. The optimal maintenance strategy can be chosen according to the extended useful life and minimum cumulative maintenance cost by life cycle function.

For deteriorated bridge structure, it is necessary to adopt maintenance measures during the whole life cycle to keep it fit for use. In this paper, the maintenance measures are realized by the replacement of one, several, or all components of a structural system. The replacement of component is essential maintenance and the failure probability returns to its initial value after replacing components. Figure 1 shows the essential maintenance model of system with three-components.

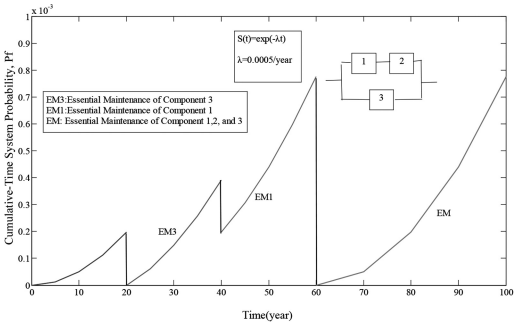


Figure 1. Failure probability of series-parallel system under different essential maintenance actions at different times.

Taking the simple supported reinforced concrete hollow slab bridgeYuanli Bridge as background, the failure probability of the structures were analyzed by considering four failure modes: (i) failure of any beam or deck in structures; (ii) failure of any external beam or any two adjacent internal beams or deck; (iii) failure of any two adjacent beams or deck; and (iv) failure of any three beams or deck and external beam (Estes & Frangopol 1999). The occurrence of the fourth defects in the RC bridge is modeled by Weibull function. In the paper, optimal maintenance strategy is defined by limiting the probability of a defect occurrence to 0.01 during a expected service life. The results show that the optimal costs dependent on the system model.

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Optimizing the procurement under life cycle cost aspects

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The problem in the construction industry is that the construction cost are most time the only decision criteria in the procurement and the potential for the economic optimum over the life time is left behind. The European Union procurement Directive EG 2014/24/EU calls for the integration of life-cycle costs in the contract award process will come into force in 2016. This paper analyzes different heating boilers in case of their efficiency and cost effectiveness. The calculation method is based on the approach of the Directive guideline VDI 4703. The result shows that the efficiency has an impact on the life-cycle cost, especially for cases with a higher energy demand and that the approach supplies a transparent ranking. Furthermore the impact of the different input parameters is investigated by sensitivity analyzes. Therefore typical bandwidths of the parameters were defined and the variances show that the parameters with the highest impact have to be defined from the principal and that the choosing of the parameters should be precisely. The approach allows life-cycle cost procurement. For the practical application in the sense of the definition of product characteristics, there is still a need for further research work, i.e. building up more data sheets which will provide relevant technical systems with tender-related features as standard specifications. This would support and simplify the implementation in the practice. Therefore, it can be concluded that the method is a suitable approach and is in accordance with the future requirements, which is to consider the life-cycle costs in the award thus can be applied in the industry.

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Exploring the important factors for success of private construction projects

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ABSTRACT

21st century private construction projects involve multiple stakeholders, such as designers, contractors, subcontractors, construction managers, and specialists from different sectors. In a great work environment, it is obvious to have clashes in objectives and interests among the different stakeholders. The objective of private project management is to ensure the success of a project which not only involves managing the schedule, cost, and quality, generally called as 'the iron triangle', it satisfying a number of other performance criteria, such as avoiding disputes, and complying with safety features. Identification of the success factors is considered the key to achieving success in the projects. From an extensive literature review, 30 success factors were identified and a questionnaire-based survey was undertaken to typical views of construction professionals on the criticality of these factors for the success of public construction projects. The responses from 35 professionals with an range of 5–15 years of experience in private construction projects in India were collected and analyzed and most important factors for success for various success criteria are presented. The success factors of nature are: owners need thoroughly understood and defined, a high degree of trust shared by project participants members, timely and valuable decision from top management, availability of resources as planned throughout the project, top management support, and regular monitoring and feedback by top management, whereas success factors of specific nature are: by understanding of scope on the part of project manager and contractor, site investigation, regular checking and feedback by owner, no bureaucratic interference, no social and political interference, clearly formed scope of work, quality control and quality assurance activities, and adequate communication from all project participants. The results would be helpful to private construction project professionals in taking proactive measures for successful completion of private projects.

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Behavior of base-isolated liquid storage tanks under synthetic near-fault earthquake pulses

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ABSTRACT

Protection of liquid storage tanks from earthquake hazards is vital as damaging of these structures may result in significant economic losses. Base isolation has emerged as a successful alternative to classical earthquake resistant design of liquid storage tanks. However, near-fault earthquake records may include velocity pulses with long periods and large amplitudes that may cause large seismic responses since the isolation periods of base-isolated liquid storage tanks encompass a similar range with pulse periods of near-fault earthquakes. In order to assess the influence of near-fault earthquakes, here, the behavior of a base-isolated liquid storage tank is evaluated under synthetically generated pulses which represent near-fault earthquakes of different magnitudes recorded at different fault-distances. The methodology presented by Dicleli & Buddaram (2007) is used to generate synthetic near-fault earthquake records of moment magnitudes 6.0 and 6.5 at fault-distances of 5 and 9 km. The benchmark base-isolated liquid storage tank, which was previously used by Alhan & Gazi (2015), is considered this study. It is a radial steel tank equipped with an elastomeric isolation system which provides a rigid-body-mode isolation period of 4.0 s and has a characteristic strength ratio of 10%. It is modeled and analyzed in 3D-BASIS-ME, which is developed by Tsopelas et al. (1994) who demonstrated how the mechanical analog presented by Haroun & Housner (1981) can be employed to model a base-isolated liquid storage tank. The results of the seismic analyses are reported comparatively in terms of time history plots of base displacement, sloshing fluid displacement, isolation system shear, fluid-tank shear force, and fluid shear force along with their peak values. The peak values of the response parameters are listed in Table 1.

Based on the initial results obtained here, it is concluded that all of the investigated seismic response parameters are amplified for larger moment magnitudes and smaller fault-distances with base and sloshing fluid displacements being the most affected ones.

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Table 1. Peak values of the seismic response parameters.

Earthquake		Seismic Response				
Moment magnitude M_w	Fault-distance r (km)	Peak base displacement (cm)	Peak sloshing fluid displacement (cm)	Peak isolation system shear (kN)	Peak fluid-tank shear force (kN)	Peak fluid shear force (kN)
6.5	5.0	18.93	40.74	6912.54	5151.04	1862.47
6.5	9.0	11.86	31.80	6085.17	4519.39	1453.23
6.0	5.0	78.34	15.81	5671.48	4113.72	722.84
6.0	9.0	6.53	12.96	5462.42	3898.87	592.50

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Numerical investigations on circular fiber reinforced elastomeric bearings

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ABSTRACT

Elastomeric bearings has been used widely in the past in bridge engineering with a further use extension in damping of vibrations induced in buildings. This type of bearings consist of reinforcement layers, mainly steel, embedded and vulcanized between rubber layers. Recent experimental and theoretical studies tend to develop and analyze new reinforcement materials as carbon and glass fibers. Fiber reinforced elastomeric bearings are much lighter and easy to produce as conventional steel bearings, as large sheets can be manufactured and then cut to the requested size. This would lead to a cost reduction that would enable the use of seismic isolation systems in currently not cost efficient applications. Also the production of bearings with non standard geometries is facilitated. The elimination of steel reduces also the risk of corrosion and improves the behavior of the bearings in locations with high humidity. Regarding the mechanical behavior, one of the advantages of elastomeric bearings is to sustain very high vertical loads with a simultaneous flexibility in the horizontal direction, which enables the structure to bear large lateral deformations caused by strong ground motions. The possibility of discarding the thick end steel plates used for fixing the elastomeric bearing to the structure has been analyzed in most recent investigations. The resulting elastomeric bearings present an unique behavior called rollover deformations at high horizontal displacements. In a first phase the upper and lower contact layers detach from the supports of the structural system, increasing the lateral flexibility and energy dissipation capacity of the system. If the lateral displacement increases a second phase called stable rollover deformation arises, the lateral faces of the bearings contact with the structural supports, what leads to an overall increase of the system's horizontal stiffness. At that state of lateral displacements, unfixed fiber reinforced elastomeric bearings are expected to perform more efficiently that the fixed version.

The current study aims to extend the result of previous numerical investigations on square fiber reinforced elastomeric bearings, focusing on the accurate definition of the materials that form the analyzed part and transferring the developed numerical model to a new planform geometry.

To capture the nonlinear mechanical behavior of rubber material, an advanced material model accounting for its hyperelastic and viscoelastic properties, as well as damage caused by cyclic loading (Mullins effect) has been calibrated and validated. Furthermore nonlinearities caused by large deflections and contact conditions have been taken into account during the development of the numerical model.

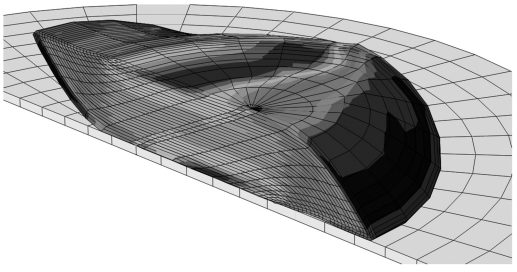


Figure 1. Meshed circular bearing model at 200% t_r horizontal deflection.

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Performance estimation for multi degree of freedom structure with negative stiffness by a bilinear elastic single degree of freedom system

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ABSTRACT

For the earthquake engineering, the most important function of structural stiffness is to resist ambient excitation and prevent structural inter-story deformation, where the inter-story shear force would be increased with the increasing of stiffness (Tsonos, 2014, Kalogeropoulos and Tsonos, 2014). The concept of stiffness weakening was proposed by Reinhorn et al. (2005) and Viti et al. (2006), in which the internal force or acceleration is attenuated by the reducing of structural stiffness. However, if the structure is actually weakened by reducing the strength of beams, it can result in early yielding and permanent deformation, which would be very dangerous for structural safety. Nagarajaiah et al. (2010) proposed the "apparent weakening" that mimics the early "yielding" without inducing the structural inelastic behavior.

In order to make sure the safety of a structure, the structural response should be estimated during structural design. Due to the advantage of NS to reduce the structural internal force, it is necessary to consider the NS property during estimating structural response. Multi degree of freedom (MDOF) structural performance can be estimated by single degree of freedom (SDOF) system according spectrum theory. Additional NS changes the structural property to be bilinear, which complicates the converting process from MDOF to SDOF.

This paper presents a new approximate method to convert the bilinear elastic MDOF to an equivalent SDOF. The MDOF structure with the NS only in the 1st story (MNS1) is considered, which is quite effective in reducing the base shear and displacement. Based on the mode superposition method (Chopra, 2001), the conversion is derived to obtain the approximate SDOF bilinear elastic system (ASBS). An eight-story numerical example is employed to illustrate the accuracy of approximation by the proposed method. The results show that the accuracy of approach is acceptable, and ASBS can estimate the response of the MNS1 as shown in Figure 1.

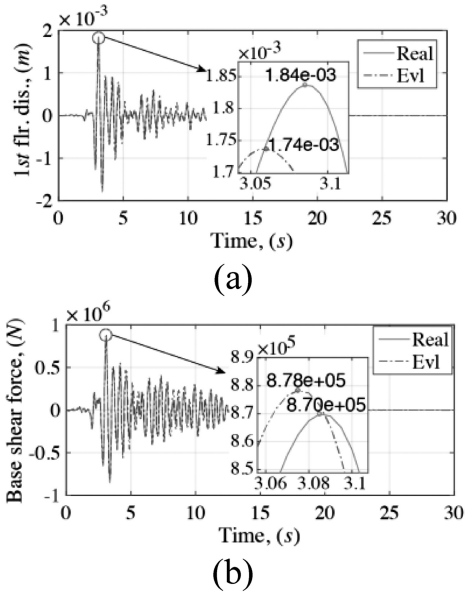


Figure 1. Comparisons of real and estimated displacement on 1st floor and base shear.

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