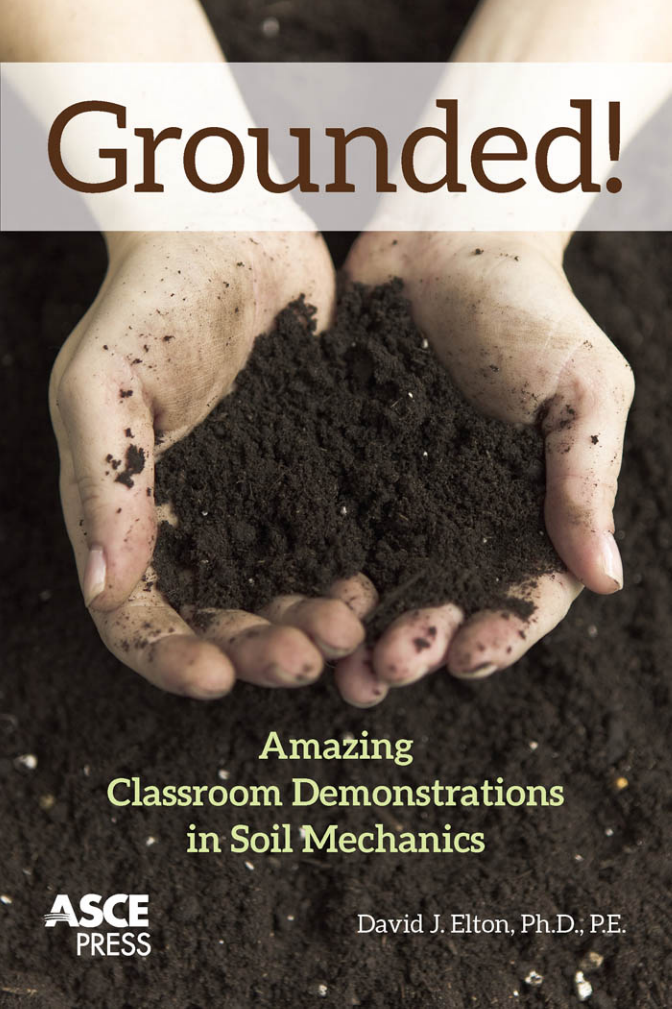

Grounded!

Amazing Classroom Demonstrations in Soil Mechanics

ASCE PRESS

David J. Elton, Ph.D., P.E.

Grounded!

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***Soils Magic*, by David J. Elton, Ph.D., P.E.** (ASCE, 2001). This fascinating collection of simple and inexpensive demonstrations focuses on the principles of soil mechanics for elementary through high school students. (ISBN 978-0-7844-0568-0)

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Grounded!

Amazing Classroom Demonstrations in Soil Mechanics

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ASCE PRESS

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Contents

Preface

Grounded! is a cool collection of engaging science and engineering demonstrations based on the most common of all civil engineering material: soil. Public school and undergraduate students, teachers, and service organizations can do the demonstrations, which illustrate scientific principles. Many have civil engineering applications, the king of all engineering disciplines.

Most demonstrations require only the simplest materials: soil, water, paper, some plastic tubing, and other stuff easily found at hardware stores. The intent is to make the demonstrations accessible to almost everyone.

Layout of the Book

Grounded! consists of two kinds of demonstrations: the fascinating demonstrations with unexpected results and the not-so-fascinating-but-still-instructive demonstrations. These are called Magic Demonstrations and Non-magic Demonstrations in the Table of Contents. The former are for public consumption; the latter are more useful to undergraduate university geotechnical laboratory instructors. The former, which are more fun, produce unexpected magical results. That said, all the demonstrations explain the science and engineering behind them. Many of the demonstrations are followed by engineering applications (e.g., how to build a retaining wall, how to keep a dam from washing away, how to build filters for walls, and how to strengthen soil for building foundations).

This book includes videos! If a picture is worth a kiloword, a video is worth a teraword. The videos help illustrate the assembly and procedure of some of the more complicated demonstrations. The videos are online at http://dx.doi.org/9780784413920.video.

Intended Audience

The demonstrations are suitable for elementary, high school, and undergraduate college students. Most of the demonstrations are captivating. A few are dull (though instructive), but that's life, eh? Overall, they interest people in engineering and science, enticing them to pursue careers in science, technology, engineering, and mathematics.

The book is particularly useful for those tireless souls who conduct university geotechnical teaching laboratories. Many of the principles and applications are part of undergraduate geotechnical engineering classes.

Accessibility

The ability to organize and conduct the demonstrations was a high priority, hence the inexpensive materials for most of them. The more expensive demonstrations require costly Plexiglas® boxes. Demonstrations using X-ray tomography, three-dimensional holographic modeling and printing, hallucinogenic substances, and iPhones were left to future volumes.

An Introduction to Who Are Soil Mechanics and Geotechnical Engineers

Soil mechanics and geotechnical engineers use soils to do something useful, such as build dams, roads, building foundations, embankments, walls, and many other soil structures. Geotechnical engineering is the part of civil engineering that deals with soils—the world's most popular construction material. Soils are used in almost every aspect of the built environment: buildings, walls, slopes, parking lots, subways, zoos, pipelines, landfills, power transmission, transportation, tunnels, power plants, and more. In fact, few civil engineering projects do not involve soils.

Background of the Book

These demonstrations began in the deep recesses of the author's alter ego while he was at The Citadel in Charleston, South Carolina. The evolution from dark, nebulous forms with sinister overtones (such as turning nonperforming undergraduates into frogs) to humorous demonstrations took a while. Some demonstrations in *Grounded!* come from the literature, and others were dreamed up when the author should have been working. The list of demonstrations expanded for more than 30 years, with a little help from the author's friends. If you have more, please send them to him so he can put them in another book and become wealthy. Maybe retire young.

The author, sometimes called the Soils Magician, published another set of cool geotechnical demonstrations, *Soils Magic*, in 2001, from this same publisher. In a sense, *Grounded!* is a companion volume. Buy both. They make great Christmas gifts.

Enjoy!

Dave Elton
Auburn University
Bucknell University
2014

Acknowledgments and Contributors

Thanks especially to Alexandria Crooks and Richard Jannett, who did many of the demonstrations for undergraduate students over the years and are responsible for many of the photos and movies, wherein their hands and arms frequently appear.

My gratitude goes to Bucknell University, which provided a realm of form without desire, opening the illusory nature of perceived reality with sensitivity and intelligence. The climate uncovered the emotional well-springs of the creative process.

Thanks, most sincerely, to Bill Kovacs, who inspires the author to be a better teacher, and to Priscilla Nelson, who started me down the path to becoming the Soils Magician.

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Andrea Welker
Won Wilde Imagination
Albert Yeung
Sam Yuen

Soils Magician Accreditation Procedure

The Elton School for Soils Magicians has established an accreditation board for certifying Soils Magicians.

If you are still certifiably sane after trying each and every demonstration in this book, you are eligible to become a licensed Soils Magician, with all the rights, privileges, and honors pertaining thereto. Whatever that means.

To apply for your license, send a notarized document, attached to a twenty dollar (USD) bill, containing the signatures of at least ten witnesses of your demonstrations to the Soils Magician and await your cool certificate of authentication. Receipt of the certificate allows you to add the letters S.M. (Soils Magician) after your name on all official correspondence. It also certifies that you have entirely too much time on your hands and will likely never advance to the rank of full professor.

Video Demonstrations

Videos of the demonstrations for the following chapters are available at http://dx.doi.org/9780784413920.video.

Chapter 1 Exploding Soils (Extreme Slaking)
Chapter 2 Rice Is Nice (an Exercise in Pile Capacity)
Chapter 4 A Retaining Wall Made of Paper
Chapter 7 Effective Potato Chips
Chapter 8 Foam Balls in a Pipe (Soil Arching)
Chapter 12 Water That Won't Go through a Sieve (and Water That Does)
Chapter 14 Piping Under a Sheetpile Dam
Chapter 16 Liquefaction by Upward Gradient
Chapter 17 Blow It Out (Critical Hydraulic Gradient) and Flowlines
Chapter 20 Sand in a Jar (Strong as You Are)
Chapter 21 Shear and Compression Waves
Chapter 22 Soil Bridge in a Tube
Chapter 23 Capillarity and Cotton Balls (Bonus: Nonwoven Geotextile Strength Demonstration)
Chapter 24 Stick-Slip Behavior
Chapter 32 Settlement Rates of Soils in Jars
Chapter 33 Bearing Capacity (Bigger Is Better)
Chapter 34 Retaining Wall in a Box

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1

Exploding Soils (Extreme Slaking)

Introduction

Some types of shale, a solid rock, break down to mush with single or repeated immersions in water (a process called "slaking"). This is a problem for buildings built on these rocks. Slaking can be demonstrated by immersing hard, dry clay balls in water.

Overview of the Demonstration

A hard, oven-dried kaolinite ball is immersed in a beaker of water (Figure 1-1). After a few seconds, pieces of the ball fracture and spring off the ball and sink (Figure 1-2). The person holding the ball can feel the fractures propagating before the pieces spring off. This is a quick and impressive demonstration.

Equipment

- Powdered kaolinite (from art supply stores),
- Water (from faucet),
- Oven to dry kaolinite balls, and
- Clear beaker large enough to submerge your hand in.

Setup Procedure

1. Add water to the powdered kaolinite until it forms a stiff paste (Figure 1-3). Note: If the kaolinite is fluid, you added too much water.
2. Form the kaolinite into two-inch balls (about the size of a meatball).

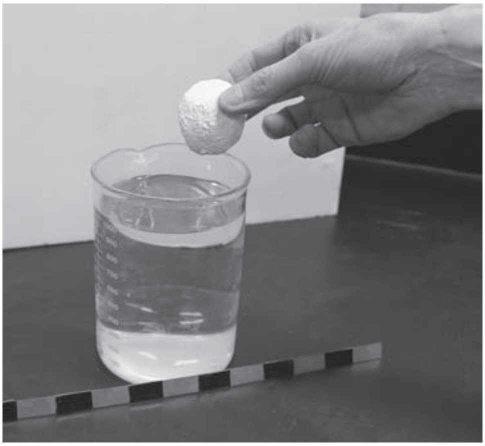


Figure 1-1. Hard clay ball about to slake

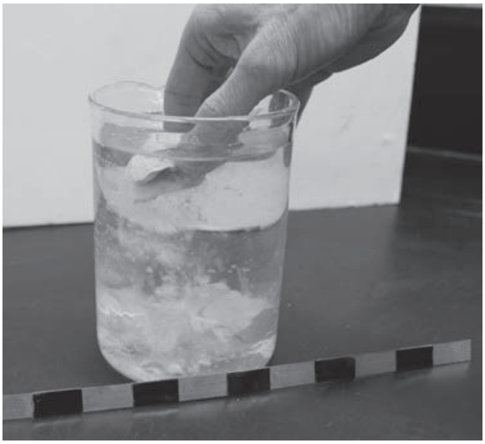


Figure 1-2. Hard clay ball while slaking

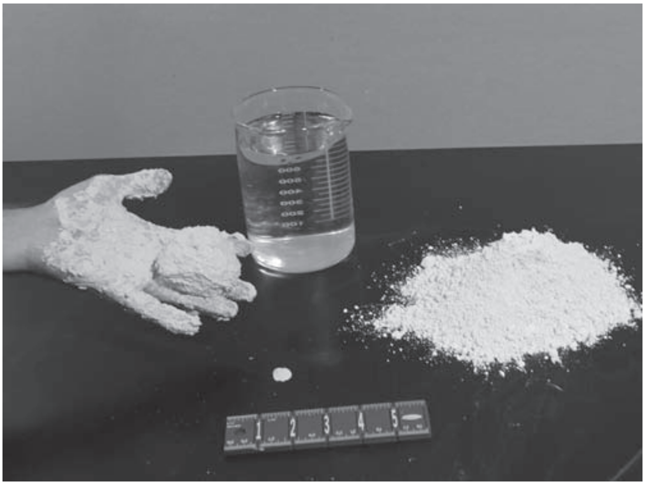


Figure 1-3. (R to L) Dry kaolinite, water, and wet kaolinite ball

Figure 1-4. Wet kaolinite balls prepared for the oven

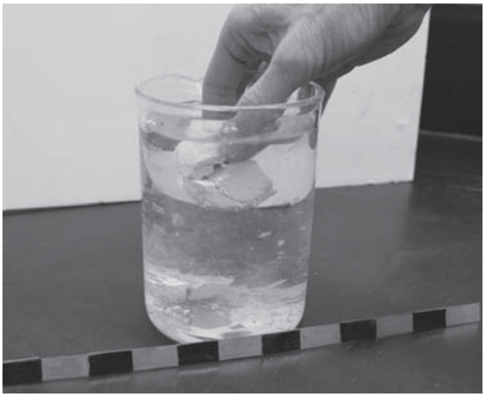


Figure 1-5. Dry ball beginning to slake

3. Make a dozen, because students will want to repeat this.
4. Bake the balls in a pan in a 250°F oven (Figure 1-4) for a few hours until the balls are completely dry.
5. Remove from the oven and let cool.

Operation of the Demonstration

1. Fill a beaker with enough water to submerge your hand.
2. Holding the ball with two fingers, quickly submerge the ball and part of your hand (Figure 1-5).

VIDEO
A video of this demonstration is available at http://dx.doi.org/9780784413920.video.

Expected Result

After a few seconds of submersion, the ball will begin to fracture, and then pieces of kaolinite will spring off into the beaker (Figure 1-6). The user will feel the ball breaking before pieces spring off.

Explanation of the Demonstration

This is why the ball breaks apart violently: Water seeps into the dry clay pores by capillarity. Some of the pores are dead ends; they are not connected to other pores. As the water enters such pores by capillarity, it compresses the air in the pore, increasing pore air pressure. Eventually, the pore air pressure exceeds the strength of the kaolinite. When that happens, the kaolinite fractures, and a piece springs off the ball into the beaker.

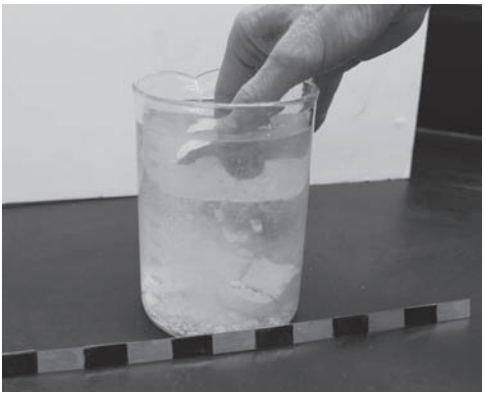


Figure 1-6. Dry ball, advanced slaking

The Magic

The uninitiated will not expect the ball to explode when it is placed in water. At best, they'll expect it to dissolve or turn to mush or, maybe, because it's quite hard, do nothing. The magic consists of the surprise when pieces fly off the ball.

The demonstration may be prefaced by by invoking this magic spell:

These little balls
Are made up of clay.
When placed in the water,
Their parts fly away!

Notes

Most people do not expect the submerged ball to do anything. Those who do expect the ball to slowly dissolve into the water, with clay particles slowly drifting to the bottom. The fracturing, with chunks springing off the ball, is surprising.

This demonstration illustrates slaking, which some shales do, causing building foundation problems. (However, kaolinite specifically doesn't do this in the field.)

The person holding the ball will feel the fractures occurring before the pieces of kaolinite fall to the bottom, enhancing the experience. This is why many students will want to try it. Make lots of balls, so many can do the demonstration.

There are degrees of "slakability"[1]: Some shales take scores of cycles to slake, some only one, and some never slake.

Bentonite, although a clay, does not slake nearly as dramatically as kaolinite, and is a LOT harder to work with, being exceedingly sticky.

Engineering Significance

Only some shales slake. Knowing if the shale being used is slakable before construction starts is important. The test is to run the shale through wet/dry cycles until you're sure it's stable (or unstable). A few hundred cycles may be needed.

[1]The author has always wanted to invent a word, and here it is. He can now die at peace.

Shale is used for fill under buildings and roads to raise the building or road to the required elevation. The wrong shale will slake. Slaking shales fool engineers, because they are very hard, compact well, and have a high compressive strength. However, when subjected to submergence once or repeatedly, they break down into their component particles. When this happens, the fill settles unevenly beneath whatever's on top of the fill. Roads that start out perfectly flat begin to look like roller coasters as the shale decomposes. Considering that half of the exposed rocks on the Earth's surface are shale, this is a common problem.

Supplier of Materials

- Powdered kaolinite

  Starwest Botanicals, Inc.
  161 Main Avenue
  Sacramento, CA 95838
  USA
  http://www.starwest-botanicals.com

Bibliography

Blackwell, P. S. (1992). "Slaking and hardsetting soils: some research and management aspects." *Soil & Tillage Research*, 25(2–3), 111–261.

Federal Highway Administration (FHWA). (1980). "Design and construction of shale embankments—summary." *FHWA TS-80-219*, U.S. Department of Transportation, Washington, DC.

Goodman, R. (1989). *Introduction to rock mechanics*, 2nd ed. Wiley, New York.

2

Rice is Nice (an Exercise in Pile Capacity)

Introduction

Lots of demonstrations show how soil gains strength when it dilates. Here's another one. This one involves food (rice) and a wooden spoon. Here, a spoon, stuck in a tube of rice, can be used to lift the tube off a table (Figure 2-1).

Overview of the Demonstration

A plastic or metal tube is filled with loose, dry rice. When a spoon handle is pushed into the rice, the handle gets stuck, allowing the tube of rice to be lifted by the handle, which doesn't pull out.

Equipment

(See Figure 2-2.)

- Dry, long-grain rice;
- Wooden spoon with rectangular handle;
- Tube (plastic or metal), about three inches in diameter, about eight inches tall;
- Paper towel; and
- Rubber band.

Setup Procedure

1. Wrap a paper towel around the bottom of the tube and secure it with a rubber band (Figure 2-3).
2. Stand the tube, towel down, on the table.
3. Fill the tube with dry rice. Don't vibrate the tube.

Figure 2-1. Tube of dry rice being held up by a spoon stuck in the rice

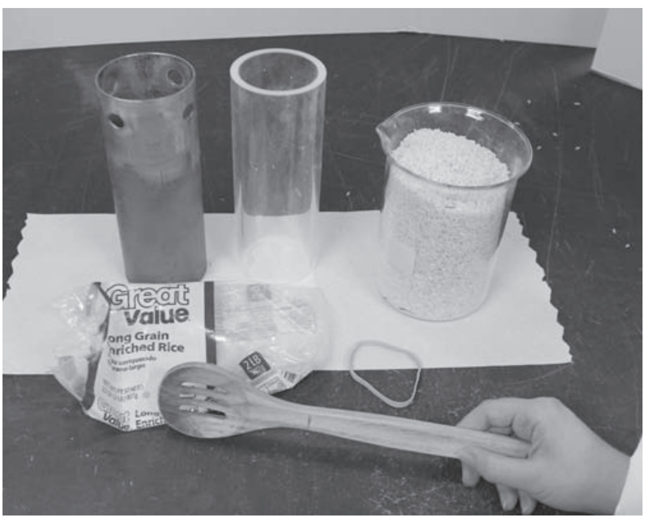


Figure 2-2. Tubes, dry rice, spoon, rubber band, and paper towel

Figure 2-3. Attaching the paper towel to the tube

Figure 2-4. (Left to right) tube full of rice, pushing the spoon into the rice, and lifting the tube by the spoon

Operation of the Demonstration

1. With the tube on the bench, full of rice, quickly press the spoon handle completely into the rice, leaving the spoon bowl exposed.
2. Grasp the spoon bowl and lift the tube off the table (Figure 2-4).

VIDEO
A video of this demonstration is available at http://dx.doi.org/9780784413920.video.

Expected Result

The handle lifts the tube of rice. Accept plaudits.

Explanation of the Demonstration

What's going on? The spoon handle displaces the rice, which dilates in the tube. The dilation causes the rice to press harder against the tube and the spoon handle, increasing the frictional force. The increased force allows one to lift the tube by the spoon bowl.

The Magic

The magic consists of this unexpected result: Who expects you to be able to lift the tube using a wooden spoon? Set up the magic by challenging the audience to lift the full tube of rice with the spoon without spilling a grain of rice. Cast the magic spell below, and plunge the spoon into the rice and lift.

> Lift the rice and the jar,
> With this spoon? Am I able?
> You'll soon see it lifted,
> Right up off the table!

Notes

Vibrating the rice in the tube is counterproductive. Leave it loose. A round spoon handle doesn't always work. Use a square or rectangular one. You can also do the demonstration in a small flower vase or a quart-size canning jar instead of a tube. The demonstration works well with the piece of Shelby tube shown in the background of Figure 2-4. If the tube is too large (heavy) or the spoon handle too small, the experiment won't work. We tried many container and spoon combinations before this worked.

Engineering Significance

Soil (rice) dilatancy increases the hold of soil on pile foundations, which are driven into the ground like the spoon handle was driven into the tube. That is, when you drive in the pile (which is like the spoon handle), some soils dilate, causing increased pile capacity, because the soil is pressed more tightly against the pile. Although this effect is not quantifiable, it gives the pile designer more confidence in the structure, because the pile capacity in a dilatant soil will be higher than shown by conventional calculations.

Supplier of Materials

- Rice

  Kroger Supermarket
  300 North Dean Road
  Auburn, AL 36830
  USA

3

Break that Block (the Power of Bentonite)

Introduction

Bentonite, a clay, swells to a very high pressure when wetted. This demonstration shows how much pressure it has—which is enough to break a concrete block. In the field, swelling clays can move houses, buildings, and walls, upsetting owners the world over.

Overview of the Demonstration

The cavity of a hollow concrete block is filled with bentonite, sealed, and submerged in water. After a long time, the bentonite swells with enough pressure to break the concrete block.

Equipment

(See Figure 3-1.)

- Concrete block;
- Two long bolts, four nuts and washers;
- Two pieces of wood to fit the sides of the concrete block;
- Large pan to accommodate the concrete block;
- Water to fill the pan;
- Soft, fuzzy pipe cleaners;
- Gravel; and
- Bentonite.

Setup Procedure

1. Cut the boards long enough to cover the open sides of the concrete block.

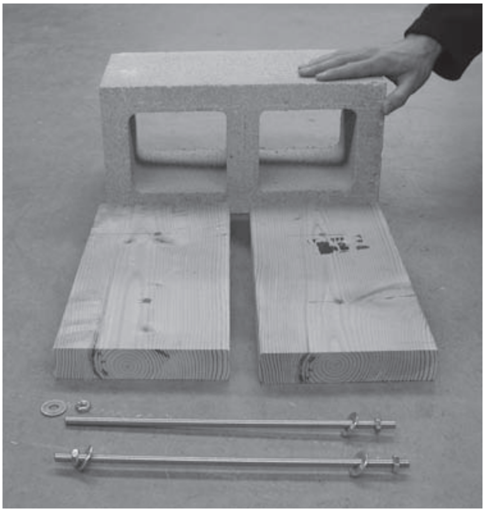


Figure 3-1. Concrete block; two boards, cut to size; bolts; nuts; and washers; not shown: bentonite, gravel, and pan of water

Figure 3-2. Left: assembled block, placement of the gravel layer; right: placement of bentonite over the gravel layer

2. Drill two holes large enough to accommodate the long bolts in both boards; the holes should be centered over the holes in the concrete blocks.
3. Insert the bolts through one of the boards, put one nut and one washer on the end of each bolt, and assemble as shown in Figure 3-2.

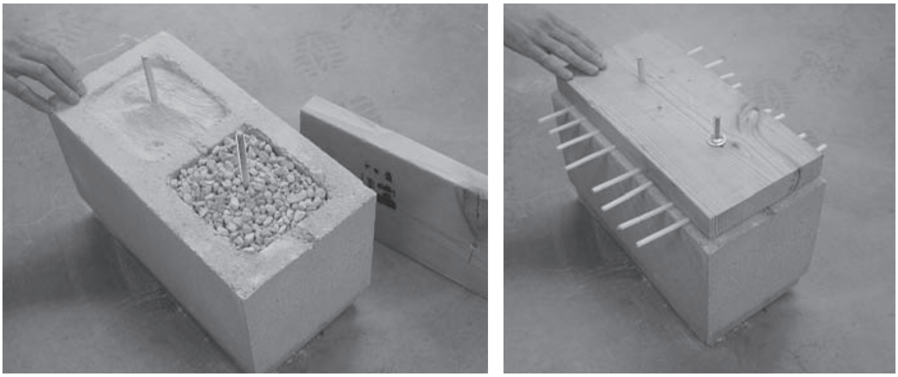


Figure 3-3. Left: block filled with bentonite, one hole covered with gravel, the other pending; right: placement of pipe cleaners, and top board being secured with the nuts and washers

4. Place a thin layer of gravel in each hole to assist with water infiltration.
5. Fill each hole with bentonite.
6. Cover the bentonite in each hole with a thin layer of gravel.
7. Place about ten pipe cleaners across the short direction of the concrete block so that their ends stick out beyond the edge of the block and place and secure the other board over the top of the block with the bolts. The pipe cleaners allow some water to enter the block. Tighten the bolts very securely. See Figure 3-3.

Operation of the Demonstration

1. With the wooden boards tightly bolted to the concrete block, place the assembly in a pan of water deep enough to submerge the block.
2. Wait.

Expected Result

After a while, perhaps a few months, the block will break. See Figure 3-4.

Explanation of the Demonstration

The block breaks because bentonite swells when moistened. Bentonite, like some other clays, attracts a thick layer of water to each clay particle.

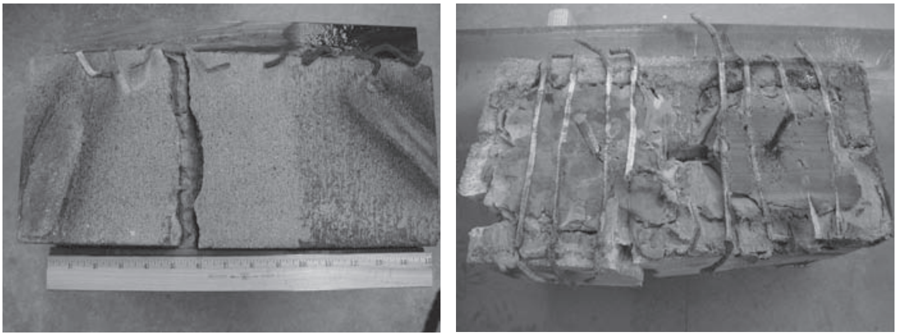


Figure 3-4. Left: broken block, side view; right: broken block, with top piece of wood removed, showing breakage at the end and side of the block

The forces of attraction are so strong that each particle attracts a lot of water. The layer of water that accumulates around the clay particles gets thicker and thicker, pushing the other clay particles away, resulting in swelling of the clay mass.

The Magic

No one expects clay (soil!) to have much strength. This soil has enough strength to break a concrete block. You just have to be patient.

Notes

This demonstration may take more than a month to complete and requires patience. Start it early in the semester, if you're at college. The block will make noise when it breaks, but it's not too scary.

Any form of bentonite will work: powder, chips, or chunks. Chunks may work best, as more water may be able to seep to the middle of the bentonite layer more quickly, speeding the demonstration.

The type of block makes a difference. Use a lighter weight concrete block, as it will break sooner than heavier ones. Larger holes in the block, which accommodate more bentonite, will speed breaking. Do not use a high-density concrete block, because it has a low permeability, so water won't soak into the bentonite very quickly. Low-density block is fairly porous.

Engineering Significance

Swelling clays can move structures such as houses, buildings, bridges, and walls. The pressure that develops is measured in tons/foot^2, which is similar to the range of pressures buildings put on the ground. Some swelling clays exert pressures greater than 10 tons/ft^2. Hence, buildings built on this stuff will move if the clay gets wet. Swelling clays can change the shape of roadways (causing large bumps), crush underground structures, and push over retaining walls.

In case you were wondering, swelling soils cause more dollar damage in the United States yearly than all other natural disasters *combined*. Somehow, it's rarely in the news.

Suppliers of Materials

- Powdered bentonite

  Georgia Underground Superstore
  5158-G Kennedy Road
  Forest Park, GA 30297
  USA
  http://www.georgiaunderground.net

- Concrete block

  Home Depot
  2190 Tiger Town Parkway
  Opelika, AL 36801
  USA

4

A Retaining Wall Made of Paper

Introduction

Many soil retaining walls are made of solid concrete. However, the one in this demonstration is made of sand and copier paper and is very strong (Figure 4-1). How do we do it?

Overview of the Demonstration

A soil retaining wall is built from sand with interbedded layers of copier paper. The paper is not particularly strong, but the resulting composite structure is very strong.

Equipment

(See Figure 4-2.)

- Copier paper, 8.5 inches × 11 inches;
- Custom wooden box with removable front panel (instructions for building the box are in the setup procedure);
- Dry sand;
- Scoop or small bucket; and
- Heavy weight (may use lab instructor).

Setup Procedure

1. Build a plywood box to accommodate the experiment. Use 0.75-inch thick plywood for ease of construction. The *inside* dimensions of the box are 8.5 inches wide, 14 inches long, and 12 inches high to accommodate the paper. The box is open on top and has a front wall panel that slides in and out of grooves cut into the

Figure 4-1. Standing on a wall made of sand and paper without movement

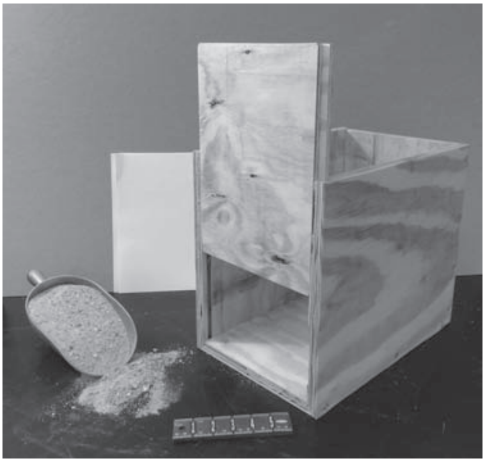


Figure 4-2. Equipment: sand, scoop, paper, custom wooden box

sides of the box (Figure 4-2). The box sides are screwed to the base and each other, except for the sliding front panel.

2. Obtain about 70 pounds of *dry* sand. Coarse sand works better than fine sand.
3. Crease 10 8.5 inch × 11 inch sheets of paper two times each. The creases should be parallel with the short side of the paper and at 1.5 inches and 2.5 inches from one end.

Operation of the Demonstration

1. Slide the face board into place.
2. Place the first sheet of paper so that the second crease is flush with the angle between the bottom and the front of the box (Figure 4-3a). That is, place the 2.5 inches of paper between the second crease and the end of the sheet vertically against the face board.
3. Pour in and level a one-inch layer of sand (lift, in civil engineering parlance; Figure 4-3b).
4. Then fold the reinforcing paper down over the leveled sand (Figure 4-3c).
5. Place the second reinforcing sheet in the same manner as the first, followed by the addition of sand.
6. Continue the process until you have placed about ten lifts. The last flap of paper is tucked down into the top sand lift or covered with a little extra sand to hold it in place.

a b c

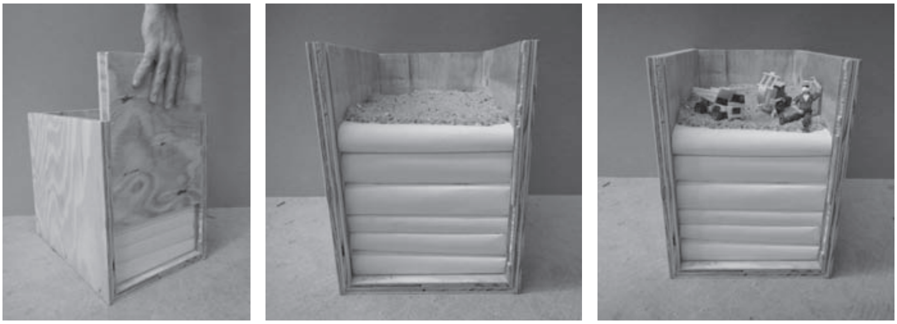
Figure 4-3. Assembling the experiment: a) placing paper (folded against the front wall); b) adding sand; and c) folding paper back in preparation for the next paper layer

7. At this stage, bets can be taken on whether the sand will spill out when the front panel is removed. Do they think that the sand will spill out?
8. Remove the face board. The wall will stand (Figure 4-4).
9. At this stage, bets can be taken on how much weight the paper wall can support (note: at least 200 pounds is possible).
10. Invite someone to stand on the wall.

VIDEO
A video of this demonstration is available at http://dx.doi.org/9780784413920.video.

Expected Result

The wall will support at least 200 pounds without moving (Figure 4-5). Try this on a sand pile without the paper layers; ain't gonna happen. This is pretty amazing, considering paper won't support this load by itself, and neither will the sand.



a b c

Figure 4-4. a) Removing the front plate; b) finished paper wall; and c) finished paper wall with construction worker and equipment

Figure 4-5. Wall holding 200-pound human

Explanation of the Demonstration

Sand may fail either in *shear* or in *compression*. Shear occurs when soil particles slide past one another. This does not take much force. Compression occurs when soil particles push directly against each other. This takes a lot of force. One can easily demonstrate this: sliding one soil particle past another in your hand is very easy (shear). Crushing a soil particle is very difficult (compression). This demonstration shows that sand compressive strength is much higher than sand shear strength.

Normally, soils fail in shear because the shear strength is much lower than the compressive strength. When paper is added to the soil, however, the little soil particles don't slide around (shear), because the paper has friction with the particles, resisting shear. Put another way, the paper *confines* the soil, so it doesn't shear. Instead, the soil carries the load in compression. The compressive strength is exceedingly high, hence its ability to carry the load of a 200-pound human (and likely much more).

The Magic

Few people expect to be able to stand on a pile of sand without the sand moving. But, that's what happens here, and it seems like magic.

You may wish to place a spell on the soil-and-paper-filled box, such as the following, before running the demonstration. Be careful—if mispronounced, an adjacent person may turn into a frog.

> This weak box of paper,
> Layered with the sand,
> Is now like a rock,
> On which you may stand!

Notes

Any sort of paper will do. If you don't tear it during installation, rolled lavatory products will suffice, although you may want to use double-ply for an added factor of safety!

Be sure the sand is at least air dry. Paper is hygroscopic and loses most of its strength when wet. Use *dry* sand.

Engineering Significance

Engineers don't use paper, but add sheets of plastic (geosynthetics) to the soil to make the composite mass stronger than either component. This technique is used to strengthen building walls, embankments, and foundations.

Since discovery of this principle, real retaining walls are built with sheets of plastic—geotextiles or geogrids—or metal strips or mesh. This construction method is fast and inexpensive, making this the wall of choice. Walls may be "wrapped face," like the one in the demonstration, or they may have a covering. Concrete blocks are very popular coverings. The blocks don't hold the soil up, but provide aesthetic appeal and erosion control. Figure 4-6 shows wrapped-face walls built with geotextiles (plastic cloth). Figure 4-7 shows geosynthetic-reinforced soil walls with concrete block facing.

With this technique, soil *slopes* can be built much steeper than before. Although most slopes become unsafe at about 30° from the horizontal, with reinforcement, they are built safely at 60° or more. Bridges, which used to rest on expensive concrete or steel piles, can now rest on soil with

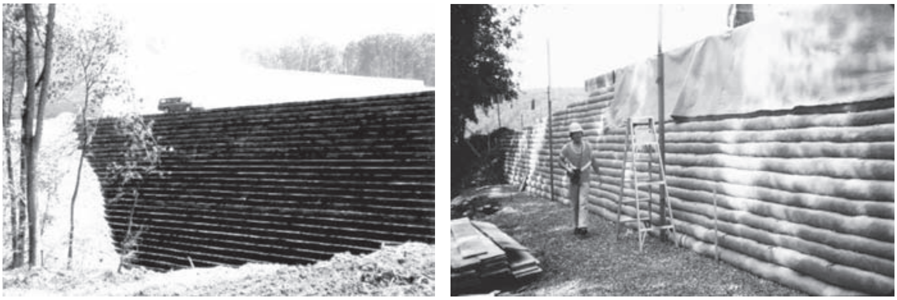


Figure 4-6. Wrapped face walls using geotextiles

Figure 4-7. Walls with concrete block facing (right photo courtesy of R. Barrett)

interbedded layers of reinforcement, with attendant cost savings. In swampy areas, embankments that would have slumped into the very soft soils now stand safely because the soil is much stronger with the addition of geosynthetics.

Supplier of Materials

- Paper for retaining wall

  Office Depot
  2061 Tiger Town Parkway
  Opelika, AL 36801
  USA

Further Reading

Koerner, R. (2005). *Designing with geosynthetics*, 5th edition, Van Nostrand Reinhold, New York.

Murthy, V. N. S. (2005). *Geotechnical engineering*, Marcel Dekker, New York.

U.S. Department of Transportation (USDOT). (2001). "Mechanically stabilized earth walls and reinforced soil slopes design and construction guidelines." *FHWA-NHI-00-043*, National Highway Institute, Federal Highway Administration, U.S. Department of Transportation, Washington, DC.

5

Slip Slidin' away with Effective Stress

Introduction

Water makes a difference in soil strength. The "effective stress" between soil particles governs how much strength the soil has. This demonstration uses paper cups to show how water pressure influences soil strength.

Overview of the Demonstration

Three seemingly identical paper cups are set on a sloping plank. Two of the cups stand still. The third seemingly magically slides down the plank (Figure 5-1).

Equipment

(See Figure 5-2.)

- Six paper cups with a lip on the bottom;
- Water;
- Dried beans;
- Smooth planar plank;
- Cardboard box or other plank support; and
- Workbench that you don't mind getting wet

Setup Procedure

1. Before the audience arrives, puncture five quarter-inch holes in the bottom of a cup with a pencil (Figure 5-3). The holes in the figure were enlarged for visibility. Make yours smaller.
2. When the audience arrives, set the plank on the cardboard box (or other support).

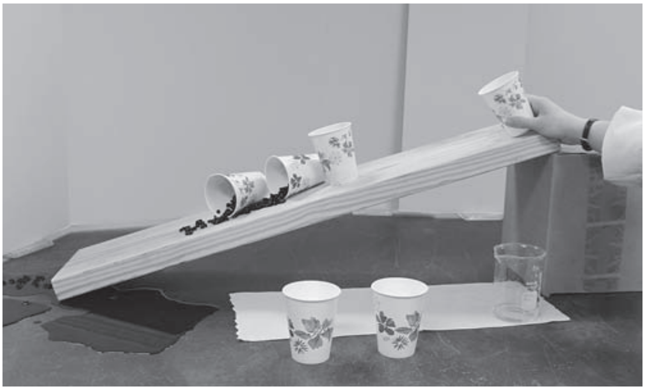


Figure 5-1. Cup 3 appears to magically slide down the plank, upsetting cups 1 and 2; how?

Figure 5-2. Equipment: paper cups, plank, dried beans, water

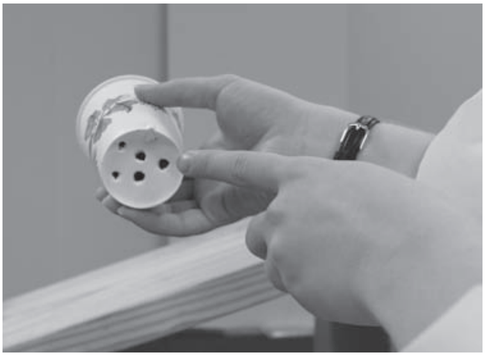


Figure 5-3. The secret to the demonstration: holes in the base of cup 3

3. Set out six cups on the work bench, including the cup with holes. Don't let the audience know there is any difference among the cups.
4. Add about an inch of beans to three cups, including the cup with the holes. Use the same amount of beans in each cup.
5. Add an inch of water to the remaining three cups. Use the same amount in each cup (Figure 5-4). Show the audience that the quantities are equal.

Operation of the Demonstration

1. Set the three beaned cups on the sloping plank (Figure 5-5). Place the cup with the holes above the other two on the plank unbeknownst to the audience. All will be stable on the plank. If they do slide, reduce the angle of the plank. It's best to choose a slope that puts your cups on the verge of sliding.

Figure 5-4. Left to right: adding beans to the cups; adding water to the second set of cups

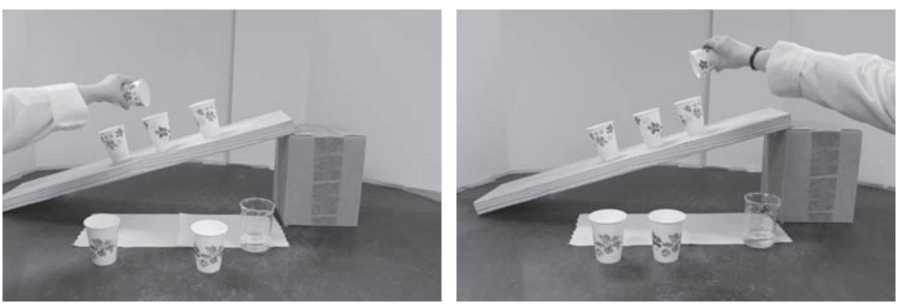


Figure 5-5. Adding water to each cup

2. One at a time, pour water from the water cups into the two lower (non-hole) cups on the plank. Nothing will happen.
3. Now add water to the cup with the holes.

Expected Result

The cup with holes will seemingly magically begin to slide down the plank and bump into the other two cups. If you're lucky, it'll tip the others over (Figure 5-6). How is it that this one slid, and the others didn't? Read on!

Explanation of the Demonstration

The cup with the holes slid down the plank because of pore pressure increase with concomitant decrease in effective stress between the cup and the plank. Water passed through the holes in the base of the cup, built up pressure, and lifted the cup up (somewhat), reducing the normal force between the cup and the plank. With less normal force, there is less frictional force (frictional force = normal force × coefficient of friction), and the cup, on the verge of sliding, begins to slide downhill.

This is similar to a reduction in effective stress in soils. When soils are dry, they are somewhat strong. However, when they are saturated, they lose strength because the soil particles become buoyant, reducing the normal force. That is, the particles weigh less when submerged. The stress the submerged particles pushing on each other (which generates friction, and thus, strength) is called *effective stress*. Read on for an explanation of effective stress.

The effective stress equation is

$$\bar{\sigma} = \sigma - u$$

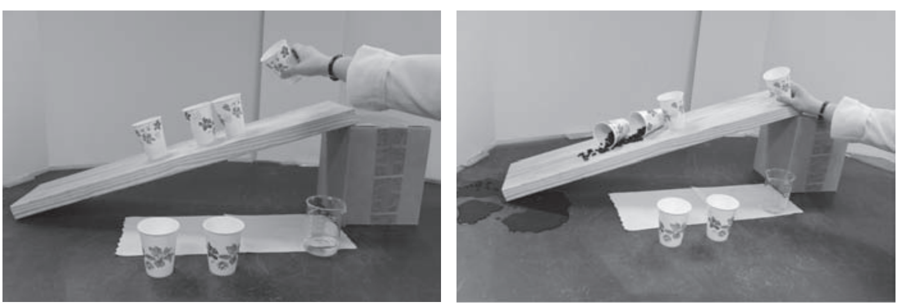


Figure 5-6. Cup 3 moving downhill, spilling the beans

where

$\bar{\sigma}$ = effective stress,

σ = total stress, and

u = pore (water) pressure.

The strength of soils is directly related to the effective stress. High effective stress means high-strength soil, and vice versa.

The Magic

Set up the experiment, carefully leading the audience to know that each cup has the same number of beans in it, and will have the same amount of water added to each. Everything is identical.

The cups are put on the plank. The magician puts his spell on the third cup:

> Here's three cups
> Sitting on the plank.
> Two will stay steady
> And this one will move.
> (The Soils Magician has been experimenting with free verse.)

Then you add the water to the first one—nothing happens. To the second one—nothing happens. To the third one (after waiting a few seconds to heighten suspense), and it slides down the plank.

Notes

Set the plank angle such that the first two cups are on the verge of failure. That way, even a little water will cause the third cup to fail.

Do not use large holes in the base of the third cup because the water will rush out too quickly, and the cup will stop sliding too soon. Use smaller holes, so the water pressure under the cup rises and stays raised long enough for the cup to keep sliding for a while. If the sliding of the cup lasts for too short a time, the effect will be over before the audience notices anything.

Space the cups far enough apart such that the third cup slides for a noticeable amount of time before hitting the second cup. If the third cup is too close to the other cups, the audience may not notice it's moving.

Use a flat plank, so water doesn't escape too readily from under the third cup.

Engineering Significance

"Effective stress governs soil behavior." The cup and the plank represent two soil particles. When the particles are dry, the effective stress is high (low $u \rightarrow$ high effective stress) and hence the particles don't move. But when pore pressure increases in soils, the strength of the soils decreases by as much as 50%. This explains why saturated hillsides (after a long rain) become landslides—the soil has gotten much weaker and cannot support itself on the hillside. It also explains why retaining walls fall over and why some buildings fall over.

6

Magic Beaker (Sand Defies Gravity)

Introduction

When water is added to sandy soil, some of it gets caught in capillary tension, which provides temporary strength.

Overview of the Demonstration

Water is added to sand in a beaker. When the beaker is inverted, the sand doesn't flow out.

Equipment

(See Figure 6-1.)

- Water;
- Two clear 250-ml beakers; and
- Dry, fine sand.

Setup Procedure

Put about 200 ml of dry sand in two 250-ml beakers (Figure 6-2).

Operation of the Demonstration

1. Add enough water to one beaker so that the sand is moist throughout, but is not saturated. No free water should be visible in the beaker bottom.
2. Invert both beakers (Figure 6-3).

Figure 6-1. Water, two 250-ml beakers, and sand

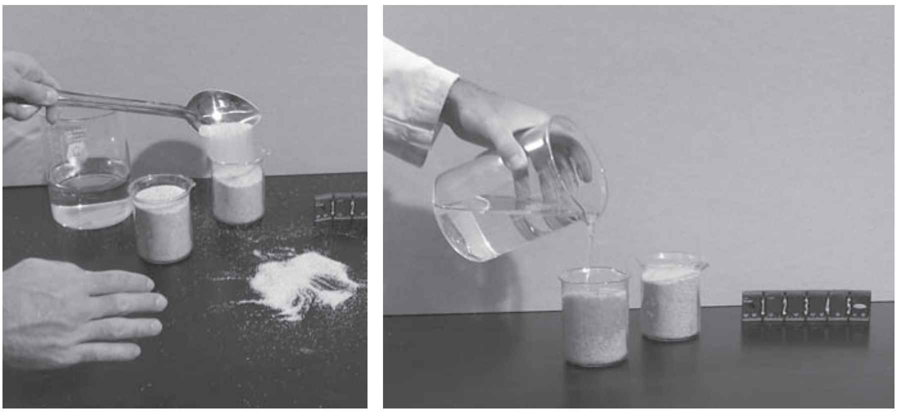


Figure 6-2. Left: adding dry sand to the beakers; right: adding water to one of the beakers

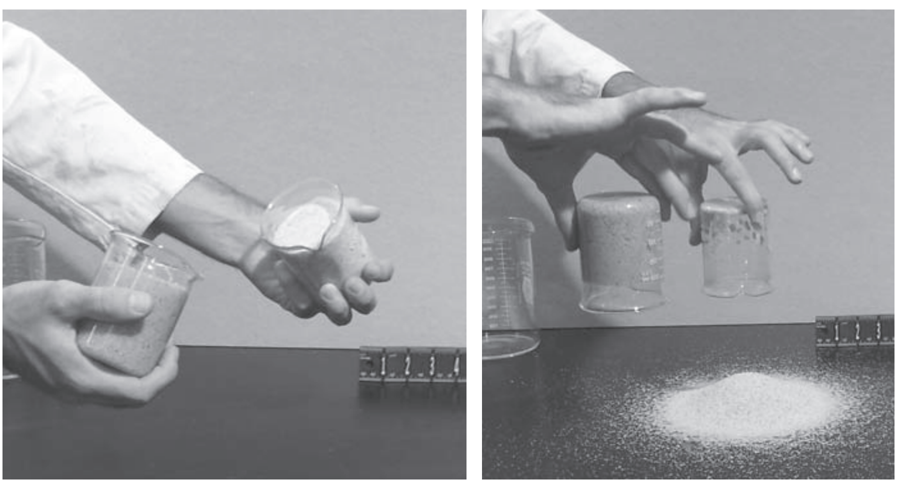


Figure 6-3. Left: beginning to pour the sand out; right: pouring the sand out; only one beaker empties—the dry one

Expected Result

When the beakers are inverted, the dry sand will spill onto the table. However, the moist sand will stay put in the inverted beaker, seemingly defying gravity.

Explanation of the Demonstration

The water is held in the beaker by capillary tension, which holds the soil particles together and keeps the soil in the beaker. The stress holding the soil particles together is calculated with the effective stress equation,

$$\bar{\sigma} = \sigma - u$$

where

$\bar{\sigma}$ = effective stress,

σ = total stress, and

u = pore (water) pressure.

In this experiment, u is negative (water in tension), which makes the effective stress very high, holding the soil mass together.

The Magic

The preparer shows two beakers of dry sand and challenges the audience to turn one of them upside down without spilling one grain of sand. Then after taking bets, the preparer adds water to one beaker, and voilà! the sand stays in the beaker when it's inverted.

Alternatively, the experiment can be completed with alcohol and water. Water is added to one beaker, the same amount of clear alcohol to the other. The preparer casts a spell on both beakers:

Two little beakers,
Moist they are.
This sand here,
Will stay in the jar.

Invert the alcohol/sand beaker, and the sand falls out. Invert the water/sand beaker, and the sand stays in. Since both fluids look the same, it appears to be magic.

Alcohol has a much lower surface tension than water, so it does not generate much capillary force (negative pore pressure) and does not produce much effective stress, allowing the sand to fall out of the beaker.

Notes

If the beaker is too large in diameter, the moist sand will spill out. If the sand is too dry, it will spill out. If the sand is saturated, it will spill out. Add enough water so it's ju-u-u-st right.

Fine sand is best. If your sand is too coarse, the water will not get caught in capillaries and will sink to the bottom of the beaker, ruining the experiment.

Engineering Significance

Capillary attraction holds soil particles together *as long as the soil is not saturated*. Excavated banks of moist soil may stand vertically (!) for a long time, because the capillary force holds the soil particles together with great force. The smaller the soil particles, the greater the force. Hence, gravel (large particles) won't stand vertically, but silt (small particles) will. The geotechnical engineer or contractor can confidently cut a moist silt bank and have it stand for a while.

If the soil dries out (removing the capillary menisci) or saturates in a rainstorm or flood (removing the capillary menisci), the soil loses a lot of strength and collapses.

The lesson here is you can expect moist, fine-grained soils to have some strength, but to lose that strength if they dry out or get saturated.

7

Effective Potato Chips

Introduction

Effective stress governs soil behavior. The higher the effective stress is in a soil, the stronger the soil is. Strong soils are important for many civil engineering designs: building foundations, retaining walls, roads, and hillsides. This demonstration illustrates how effective stress works. Figure 7-1 shows the ultimate result of the demonstration.

Overview of the Demonstration

A bag of potato chips is loaded with weights and then mercilessly stabbed with a knife, releasing excess air pressure.

Equipment

(See Figure 7-2.)

- Potato chips in a small bag, BBQ preferred,
- Weights, and
- Knife.

Hunger is optional.

Setup Procedure

Accumulate the equipment.

Operation of the Demonstration

1. Place the bag of chips on the table.
2. Place a few weights on the bag (Figure 7-3). Pronounce the magic words:

Figure 7-1. Why is this person smiling in the soils lab?

Figure 7-2. Weights, bag of potato chips, and utility knife

Figure 7-3. Placing weights on the bag of potato chips; note that the potato chips are still in the original, uncrushed, low effective stress condition

Such innocent chips,
So fresh and so lush.
We stab with a knife,
And then they get crushed!
(Bwaa-a-ha-ha-ha-ha!!)

3. Puncture the bag with the utility knife (Figure 7-4).

VIDEO
A video of this demonstration is available at http://dx.doi.org/9780784413920.video.

Expected Result

Upon puncturing, the excess air pressure in the bag is released. The bag collapses, increasing the effective stress on the chips beyond their strength, resulting in a bag of crushed potato chips (Figure 7-5).

Explanation of the Demonstration

This is an effective stress experiment. Effective stress involves the air pressure in the bag and total stress on the bag. The effective stress equation is

$$\bar{\sigma} = \sigma - u$$

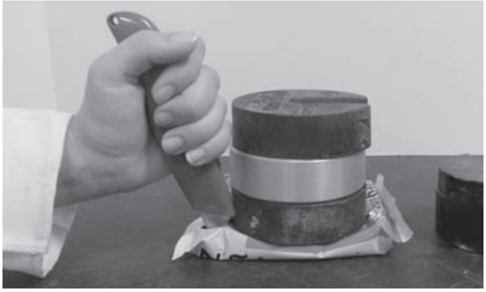


Figure 7-4. The demise of the potato chips; release of pore air pressure increases effective stress beyond the strength of the chips

Figure 7-5. Crushed potato chips, after being subjected to high effective stress

where

$\bar{\sigma}$ = effective stress,

σ = total stress, and

u = pore air (or water) pressure.

When the bag is punctured, the pore air pressure decreases. The effective stress increases (the chips press harder on each other), and the chips are crushed. In soils, the release of air pressure can be likened to a decrease in pore water pressure by, for example, drainage. The result? An increase in effective stress.

When soils are dry, they are relatively strong. The stress the soil particles put on each other (which generates friction and thus strength) is called *effective stress*. When the soil particles are saturated, they lose strength because they become buoyant, reducing the normal force. That is because the particles weigh less when submerged. Moreover, when the water pressure increases, the soil particles are pushed apart, further reducing particle contact pressures.

Now, in the case of the potato chips, the weight increases the air pressure in the bag, resulting in low effective stress. That is, the potato chips don't push on each other with much pressure. When the air pressure is released from the bag (upon puncturing), the effective stress increases, meaning the chips press on each other with greater stress, eventually so great that the strength of the chips is exceeded and they break.

In soil mechanics terms, before puncturing, the air pressure (u) in the weighted bag is high, therefore the effective stress on the chips is low, and the chips survive (see previous equation). This is the “undrained” condition. After the bag is punctured (the “drained” condition), air pressure (u) becomes low, so effective stress becomes high, and the chips crush each other.

The Magic

Not a lot of magic here. Most everyone expects the bag to collapse when punctured.

Notes

This demonstration is notable only in that it’s the only one to produce edible results.

Interesting and Useful Variation

Instead of slashing the potato chip bag, inducing rapid deflation, try the following variation. Get a much larger bag and balance the weights on top of the bag. Then, at the start of the effective stress lecture (or whatever), surreptitiously put a pinhole in the bag. The air will escape very slowly, perhaps taking 20 minutes to deflate. While you’re lecturing, the bag will make the occasional crunching sound as the chips are slowly crushed, distracting the students and emphasizing the effect of change in pore pressure. (Thanks to Roman Hryciw for this variation.)

Engineering Significance

Engineering significance, here, refers to the significance to soil, not potato chips. When effective stress in soils is high, soil particles push on each other with a lot of stress, generating a lot of friction and thus strength. Effective stresses can be increased by lowering the pore water pressure (u) term in the effective stress equation. In geotechnical practice, this means draining the soil so the water pressure falls. The lower the water pressure is, the higher the effective stress is and thus the greater the strength is.

When geotechnical engineers want to stabilize a sliding hillside with a high water table, for example, they insert drains in the slope to reduce the water pressure, which increases effective stress and thus the strength of the soil in the hillside, helping it resist downhill movement. The same principle applies to strengthening soils under buildings and roads and behind retaining walls.

Potato chip manufacturers have known for a long time that chip crushing can be reduced by putting air in the bags. It's doubtful they are former geotechnical engineers who know about effective stress. Until now.

Supplier of Material

- Potato chips

  Winn Dixie Supermarket
  1617 South College Street
  Auburn, AL 36832
  USA

8

Foam Balls in a Pipe (Soil Arching)

Introduction

Soil arching refers to the ability of a hole in cohesionless soils, or loose rocks, to remain open when it should collapse. When civil engineers drive a tunnel, soil (or rock), arching relieves some of the stress caused by the soil (or rock) on the top of the tunnel. Tunnels may be used to carry trains, subways, pipes, or pedestrians.

Soil arching is also present in soil filter formation, the subject of the demonstration in Chapter 19.

Overview of the Demonstration

Foam balls are put in a plastic pipe (Figure 8-1). Although they are smaller than the pipe diameter, they don't fall out.

Equipment

(See Figure 8-2.)

- Plastic pipe, eight inches high, four inches inside diameter;
- Five foam balls, 1.5-inch diameter; and
- Coarse sandpaper.

Setup Procedure

1. Sand the inside of the plastic pipe so it's rough to the touch (Figure 8-3).
2. Place the pipe on end on the table, with the foam balls nearby.

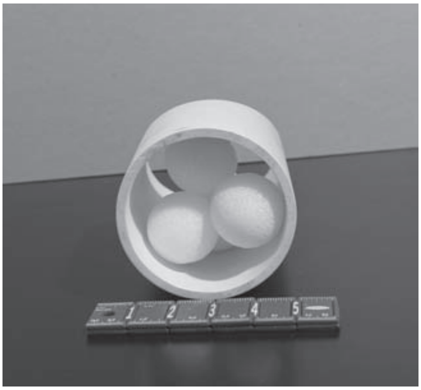


Figure 8-1. Plastic pipe with foam balls (soil particles) arched inside the pipe

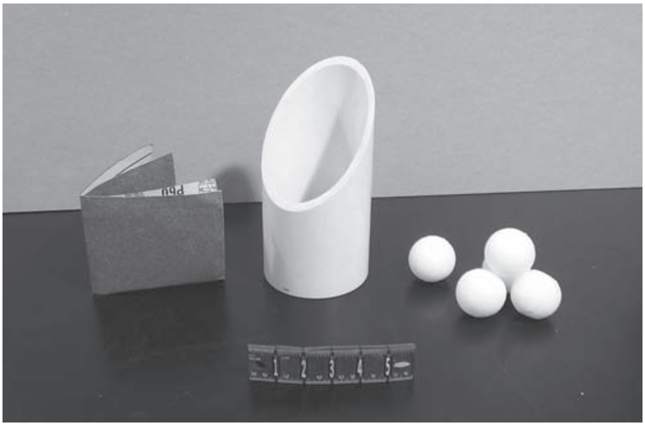


Figure 8-2. Sandpaper, plastic pipe, and foam balls

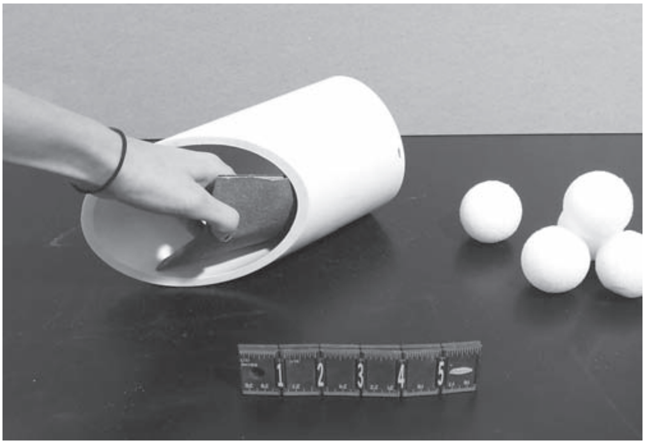


Figure 8-3. Roughening the inside of the plastic pipe with sandpaper

Operation of the Demonstration

1. Drop four foam balls into the pipe (Figure 8-4).
2. Slowly lift the pipe vertically off the table (Figure 8-5 a and b).

VIDEO
A video of this demonstration is available at
http://dx.doi.org/9780784413920.video.

Expected Result

The balls will not fall out of the bottom of the pipe (Figure 8-5 c and d).

Explanation of the Demonstration

The balls push each other and against the sides of the pipe, forming arches. The arch shape transfers the weight of the balls to the side of the pipe, instead of downward, which is why the balls don't fall down—they are held by the friction against the side of the pipe. The effect is shown in Figure 8-6.

Figure 8-4. Balls placed in the pipe

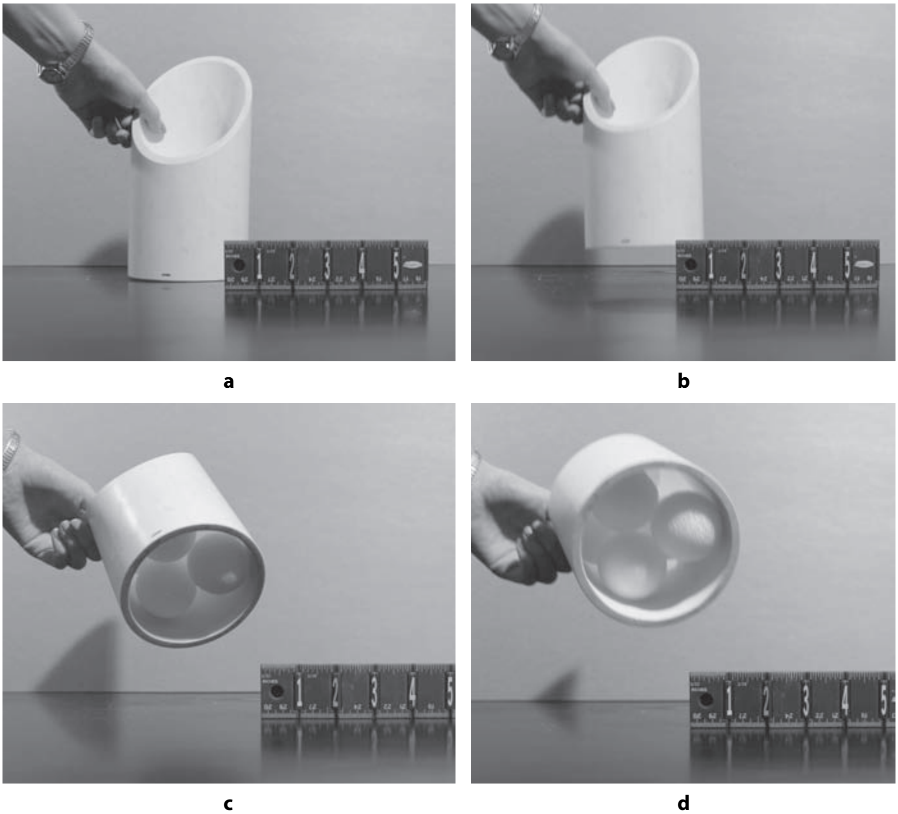


Figure 8-5. The magic! a) balls inside pipe; b) pipe lifted off the bench, and the balls don't fall out!; and c and d) pipe lifted off the bench, turned to reveal the balls in the pipe

Figure 8-6. Two-dimensional arching schematic: the smaller soil particles above the larger ones do not fall down into the larger space between the larger soil particles; arch is shown by dashed line

The Magic

Even though the balls are smaller than the diameter of the pipe, they will not fall out of the pipe, which is not what most people expect.

Notes

Choose the pipe and balls carefully. Use polystyrene foam balls, because they're rough and light and unlikely to fall out of the pipe. We tried all sorts of other balls. Take our word for it—use foam. The pipe must be roughened on the inside.

We cut the plastic pipe on the diagonal to make it look cool.

Engineering Significance

Arching shows up in a few different geotechnical engineering scenarios: soil filters, tunneling, and the arching phenomenon explained in the Soil Filter Demonstration Using Marbles experiment in Chapter 19.

Arching allows you to cut a tunnel in soil without lining the tunnel (although a lining must be added for long-term stability). Arching explains why the soil in front of some tunneling machines stands up, at least for a while, and why tunnel lining doesn't have to hold the full weight of soil or rock above the tunnel.

Roman arches are an example of the arching phenomenon, applied to structural engineering.

Suppliers of Materials

- Foam balls

  Hobby Lobby
  2570 Enterprise Drive
  Opelika, AL 36801
  USA
  http://www.hobbylobby.com

- PVC pipe

  Home Depot
  2190 Tiger Town Parkway
  Opelika, AL 36801
  USA

9

Geotechnical Rorschach Test (Water Flows around a Drain, instead of into the Drain)

Introduction

Draining soil is very important to civil engineers. Drains buried in the ground are supposed to attract groundwater and carry it away in the drain. This demonstration shows that this doesn't happen in unsaturated flow. See Figure 9-1.

Overview of the Demonstration

A gravel drain is constructed in a sandy soil in a clear plastic box. Colored water poured onto the sand seeps downward toward the gravel drain. However, the water flows *around* the gravel drain, instead of *into* the gravel drain.

Equipment

(See Figure 9-2.)

- Clear plastic tank (the one used in the figure is about 15 inches high, about 30 inches wide, and about four inches deep);
- Fine, uniform sand;
- Medium, uniform gravel;
- Water;
- Food coloring; and
- Funnel large enough for the gravel to pass through.

Setup Procedure

(See Figure 9-3.)

1. Put about six inches of sand in the tank, using the funnel. Avoid segregation during placement.

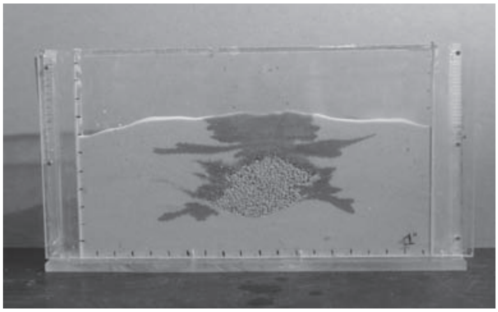


Figure 9-1. Flow going *around* the gravel drain, instead of *into* the drain (no, this is not a Rorschach test)

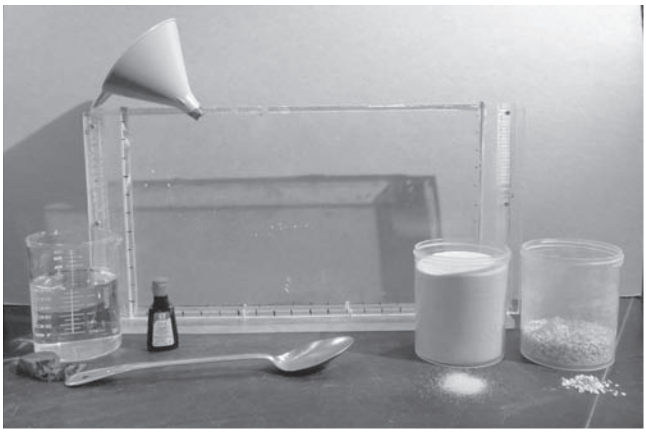


Figure 9-2. Water, food coloring, funnel, plastic tank, fine sand, and fine gravel. Spoon is a rogue in this picture[1]

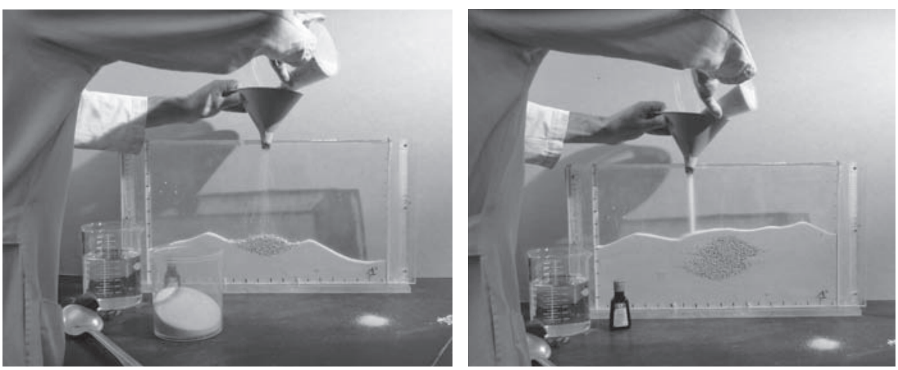


Figure 9-3. Left: adding gravel, using a funnel, to the top of sand, which is also placed with the funnel; right: adding more sand and covering the gravel drain

[1]The spoon has been trying to get into this book for months, and, apparently, has made it past the editors here.

2. Make a depression in the middle of the sand. Using the funnel, place some gravel into the depression, allowing the gravel to mound.
3. With the funnel, cover the gravel with another six inches of sand. Avoid segregation during placement. Ideally, the gravel should form a cylinder, but this is difficult to achieve.
4. Make a one-inch depression in the top of the sand, above the gravel drain.
5. Mix some food coloring and water in a beaker.

Operation of the Demonstration

1. Using the funnel, pour some colored water into the depression above the gravel drain.
2. Let it soak in, by capillarity.
3. Add some more water.
4. Let it soak in.
5. Repeat this process (be patient).

Figure 9-4 shows the operation.

Expected Result

Figure 9-5 shows the expected result: the water flows *around* the gravel drain, not *through* it. When water is introduced at the soil surface, the expectation is that the water will flow to the gravel, which has a lot higher permeability than the sand. The gravel is a low-energy zone, meaning it carries water with a lot lower energy loss than the sand does.

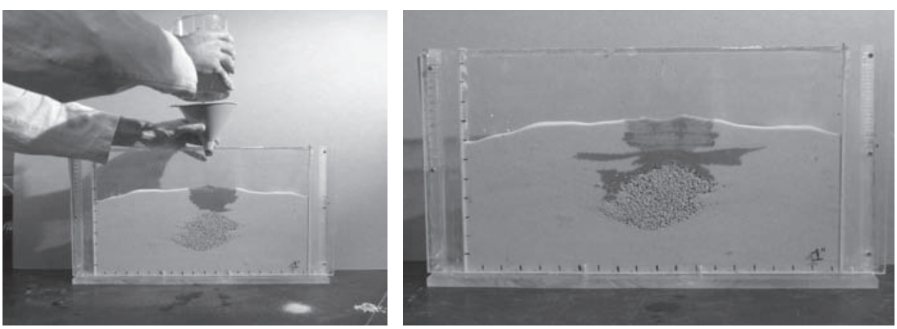


Figure 9-4. Left: adding colored water to the system; right: flow beginning to go around the gravel drain

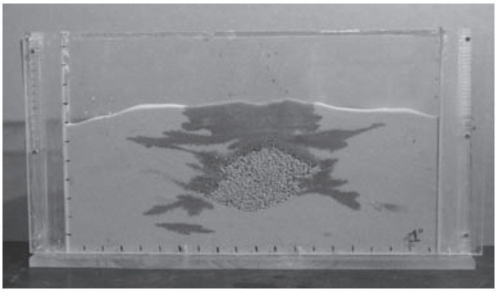


Figure 9-5. Advanced stage of the demonstration, where the water has flowed almost completely around the gravel drain

Explanation of the Demonstration

Normally, in *saturated* soil flow, the water takes the path of least resistance—same as undergraduate engineering students(!). Water flows downhill, by gravity flow, and takes the easiest way to do it. It's easier for water to flow through coarse soil, as opposed to fine-grained soil.

Here, however, the soil is *not* saturated. This is *unsaturated* flow. The water moves from point A to point B by capillarity, not by gravity flow. Capillary flow depends on the formation of capillary menisci among soil particles. The smaller the pore, the larger the capillary force pulling the water through the soil (yes, you read that right, *pulling* the water). Capillary forces do not depend on gravity. This is why the famous Water Flows Uphill experiment works (Elton 2001). If the pores are too large, as in gravel, the capillary forces decrease to about zero. So, the capillary forces in the fine sand are large, pulling the water around the gravel, whereas the capillary forces in the gravel are small and do not pull the water. Cool, eh?

The Magic

The water is expected to flow to the zone of highest permeability, the gravel. Instead, the water *avoids* the high permeability zone and stays in the lower permeability sand. Amazing.

Notes

If the sand is nonuniform and just dropped into the tank, the sand may segregate—that is, larger particles will congregate in one area, and smaller ones in another area. This will lead to the spiky capillary fronts shown in

Figure 9-5. If placed carefully, so it remains uniform, you will achieve a smoother front.

Engineering Significance

Civil engineering soil drains, which are often made of gravel, are supposed to carry groundwater away from the structure of interest, such as retaining walls. Well, as this experiment shows, this works only in saturated flow. With unsaturated flow, the water may flow around the drain and into or against the structure that is supposed to be protected by the drain. The result is moisture problems with the structure, such as formation of mold or mildew, weakening of the soil, and increased unit weight of the soil (leading to more soil pressure on buried structures).

This same principle is used in creating "capillary breaks" in geotechnical structures, such as roads. Here, water rising by capillarity beneath a road encounters a gravel layer and stops rising, because the pore size of the gravel is so large that the capillary forces approach zero. This is used to keep frost heave from occurring, a subject worth reading more about if you're a civil engineer involved in roadbuilding.

When an environmental chemical spill occurs on the ground surface, those who are unfamiliar with this principle will think that the chemical will flow into underground drains (if present), or flow into coarse sand or gravel layers. However, this demonstration shows that this is not so, if the adjacent soil is finer.

References

Elton, D. J. (2001). "Soils magic." *Geotechnical special publication 114*, ASCE, Reston, VA.

10

Hairy Soil

Introduction

Geosynthetics are plastics embedded in soil that enhance some properties of the soil, including strength. This demonstration uses plastic fibers, called Geofibers, to dramatically strengthen cohesionless soil.

Overview of the Demonstration

Geofibers are mixed with moist sand. Soil strength is greatly increased.

Equipment

- Sand,
- Water,
- Three-gallon metal (rigid) bucket,
- Geofibers (Figure 10-1), and
- Fairly heavy human.

Setup Procedure

1. Mix water with sand to a consistency such that it would stand up as if you were going to build a sand castle.
2. Pack the sand into the bucket and invert it on the table, then remove the bucket.
3. Repeat this process, this time mixing in a few handfuls of Geofibers with the moist sand.
4. Invert and remove the bucket as before. You now have two bucket-shaped piles of sand on the table. One is hairier than the other.

Figure 10-1. Geofibers

Operation of the Demonstration

1. Stand on the pile of non-Geofiber sand.
2. Then stand on the pile of Geofiber-enhanced sand.

Expected Result

The pile of non-Geofiber sand will collapse, because it's weak. However, the pile of Geofiber-reinforced sand will hold up the weight of a person (Figure 10-2).

Explanation of the Demonstration

Soils do not have tensile strength, only compressive strength. The Geofibers add tensile strength to the soil, enabling it to support much higher loads, such as the weight of a person. The Geofibers develop their tensile capacity by friction between the soil and the fibers.

The Magic

The magic is impressive. The Geofiber-enhanced sand is not expected to behave much differently than the regular sand. The addition of a handful

Figure 10-2. Left: person standing on Geofiber-reinforced sand (note non-Geofiber sand pile crushed on the right); right: close-up of Geofiber-reinforced sand with foot on it

of plastic shreds does not suggest much change in soil properties. But in fact, relatively speaking, the change is huge. The soil compressive strength can be increased threefold, depending on the soil used and the amount of Geofibers used.

The Magic may be done in this manner:

Here's an experiment,
That always works great!
These little fibers,
Will support my whole weight!

Notes

Choice of materials makes a difference. A well-graded sand works better than a uniform sand. Don't get the soil too wet. Just wet enough that it'll stand by itself. The amount of Geofibers needed in actual construction is much, much less than the amount shown in these figures; 0.5% by weight is typical. Too many Geofibers weaken the soil.

Mixing Geofibers with clayey soils is difficult—both in the laboratory and in the field. Do not use clay for this experiment; it is far too messy, and you run the risk of nonuniform mixing, which will result in failure.

Geofibers have interesting collateral benefits. Use of Geofibers, while increasing strength, also increases permeability and reduces unit weight—three very desirable characteristics. Compaction, by comparison, increases strength but decreases permeability (so the soil doesn't drain as well, tending toward lower effective stresses and lower strength), and increases unit weight, which can increase settlement. One could say Geofibers go three for three!

This experiment, although related to soil strength, is not related to effective stress.

Engineering Significance

There are several ways to strengthen soil so it forms an adequate foundation for a building, or so that it has enough strength to stand as a slope. Compaction is a commonly used method. Geofibers are another method that have the added advantages of increasing permeability and reducing unit weight.

Geofibers are used for building fills, in repairing landslides, and for underfooting reinforcement. Michalowski and Cermak (2003) is a representative reference.

Supplier of Material

- Geofibers

  Fiber Soils
  227 Cornell Avenue
  Baton Rouge, LA 70808
  USA
  http://www.fibersoils.com

Reference

Michalowski, R. L., and Cermak, J. (2003). "Triaxial compression of sand reinforced with fibers." *Journal of Geotechnical and Geoenvironmental Engineering*, 129(2), 125–136.

11

Sand Cylinder Hoisting

Introduction

Dense soils dilate when they are compressed or sheared. If the soil is confined, the dilation causes an increase in strength.

Overview of the Demonstration

Soil is placed in a cylindrical mold and then compressed with a special apparatus that has no mechanical connection to the cylinder. The cylindrical mold can then be lifted off the lab bench (Figure 11-1).

Equipment

(See Figure 11-2.)

- Dry sand;
- Scoop;
- Cylinder, about six inches in diameter and 12 inches high;
- Special compression apparatus (SCA, Figure 11-3), which consists of a threaded rod with a spring and a handle, two 3/8-inch thick plastic disks that are about 90% of the cylinder's diameter, and various nuts and washers (see the setup procedure for an explanation of how these go together); and
- Strong right arm.

Setup Procedure

1. Fill the cylinder about halfway with sand.
2. Assemble the SCA from the handle end in this order (Figure 11-3): nut with handle (black in Figure 11-3), washer, loose pipe, washer, plastic disk, washer, spring, washer, nut, space of about two inches, nut, washer, plastic disk, washer, and nut.

Figure 11-1. Lifting a cylinder of sand without direct connection between the cylinder and the lifting handle

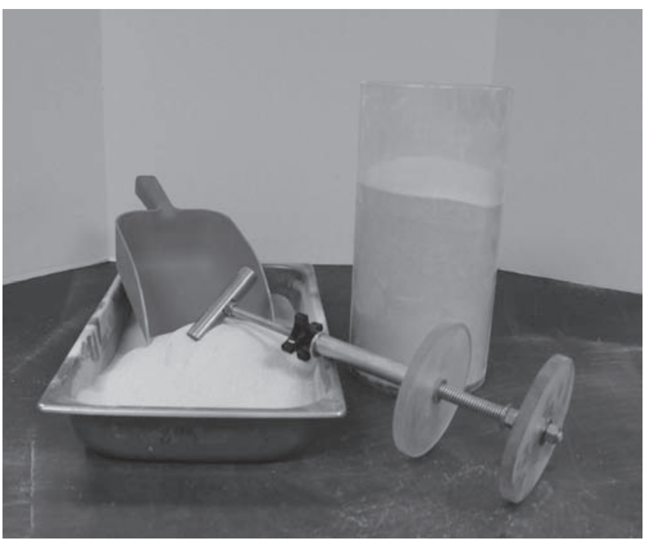


Figure 11-2. Pan with dry sand, scoop, cylinder partially filled with sand, special compression apparatus

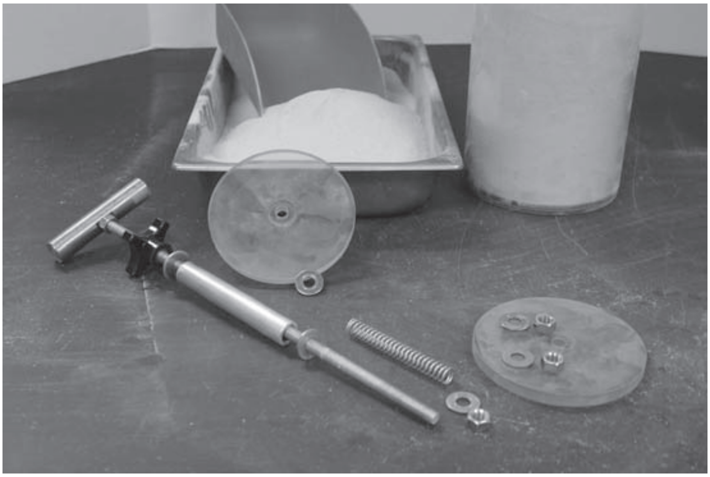


Figure 11-3. View of the special compression apparatus

Operation of the Demonstration

1. Place the SCA into the cylinder, which you have already partly filled with sand.
2. Fill around the SCA with more dry sand, until the SCA is covered (Figure 11-4).
3. Tighten the SCA by holding the handle on top and turning the topmost (handled) nut (Figure 11-5).
4. When the nut is very tight, pull up on the handle on the SCA (Figure 11-5).

Expected Result

When you pull up on the handle on the SCA (Figure 11-5), the entire apparatus will come up off the table.

Explanation of the Demonstration

You are able to lift the cylinder off the table because the sand dilated when you tightened the topmost nut. Squeezing the plastic plates together caused the sand particles to move apart (dilate), increasing the bulk volume of the sand. Because the sand couldn't move up and down, it went

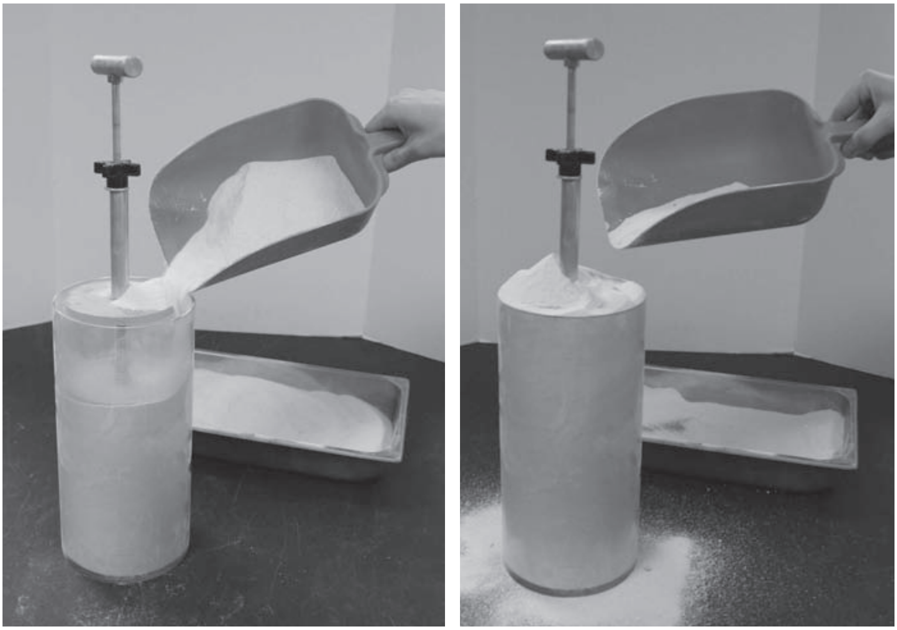


Figure 11-4. Left: filling the cylinder with dry sand; right: cylinder filled with dry sand

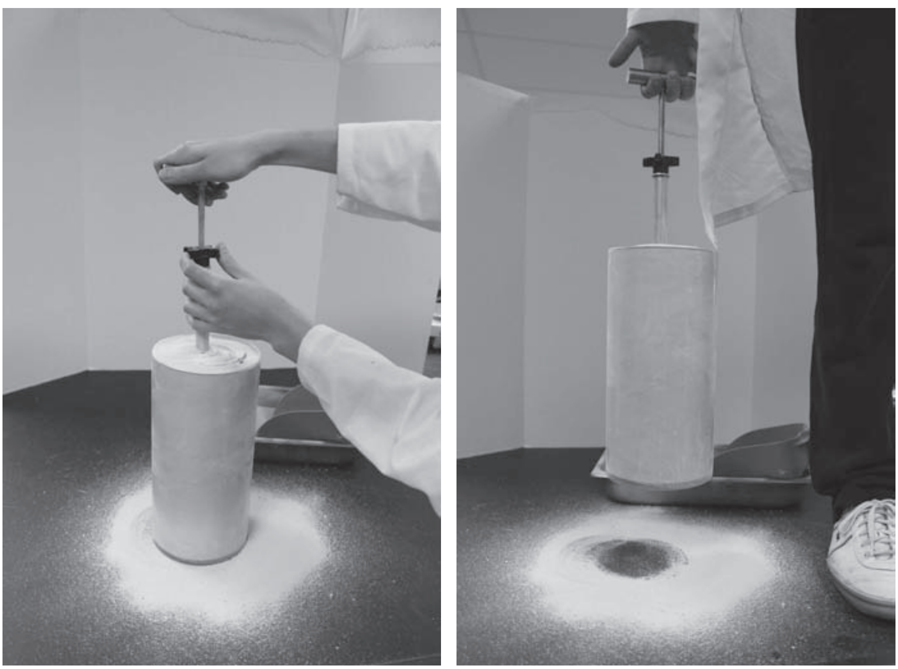


Figure 11-5. Left: tightening the screw; right: lifting the sand cylinder

sideways, squeezing against the sides of the cylinder and generating lots of frictional force; so much frictional force that it's stronger than the weight of the cylinder. This is why you could lift the cylinder without the SCA sliding out. This dilation effect is shown in several other demonstrations in this book. We get a lot of mileage out of this.

If you hadn't tightened the SCA, it would have pulled out readily, spilling a lot of sand on the table.

The Magic

Here's the magic. How can one lift this sand-filled container with this SCA handle *without connecting the SCA handle to the container*? Viewers wonder how it's done. They can understand bolting the rod to the cylinder, but, other than that, how can it be done? After pausing for effect, to let the suspense build, the presenter does the experiment.

Notes

The plastic disks can be made of any stiff material. They need not be plastic. The cylinder can be made of any stiff material. It need not be plastic.

The experiment can be done in two stages, also. In stage 1, pour the sand in around the SCA until it's covered without tightening it. Then gently pull it out. The sand will flow out around the edges of the apparatus as it's pulled out. In stage 2, restart the experiment. Again, pour the sand in around the SCA until it's covered. Then tighten the SCA and lift the cylinder by the handle on the SCA. The comparison between the two stages shows the effect of dilation.

Engineering Significance

The engineering significance of this effect is subtle and not quantified in practice. The geotechnical engineer, given the choice, prefers to keep sand used in foundations confined, so that when it's sheared and dilates, it will generate more friction (strength). Pile capacity, for example, is increased by dilation.

12

Water That Won't Go through a Sieve (and Water That Does)

Introduction

Sieves are meant to let water through but not let particles through. At least some particles. This demonstration has "magic" water that stands on the sieve, while other "water" passes right through (Figure 12-1). Interesting.

Overview of the Demonstration

A no. 200 sieve (0.075-mm openings) is inverted on the lab table. With a straw or an eyedropper, a drop of water is gently placed on the sieve. The drop stands on the sieve and doesn't go through! With another straw, a drop of "water" is placed on the sieve, and it plummets through onto the lab bench. What's happening?

Equipment

(See Figure 12-2.)

- Two small containers;
- Water;
- Clear alcohol;
- No. 200 (0.075 mm) sieve, dry; and
- Drinking straws.

Setup Procedure

1. Put the water in one container.
2. Put the clear alcohol in the other container.

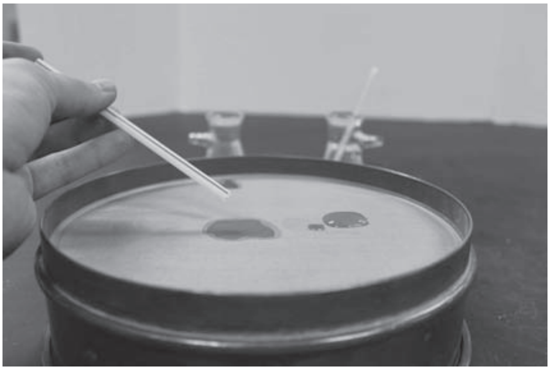


Figure 12-1. Some water passes through the sieve (left), while some does not (right)

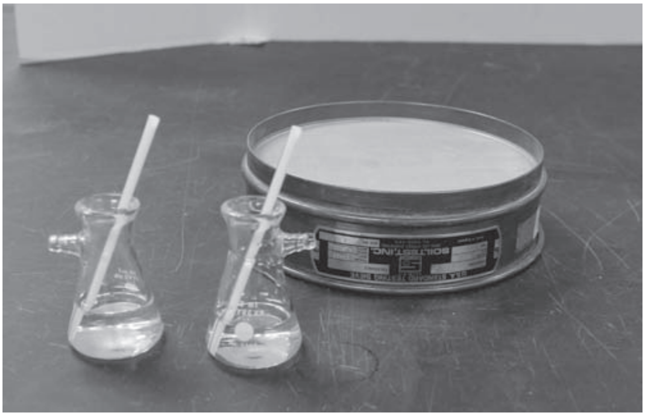


Figure 12-2. Materials for the demonstration: beaker with alcohol and straw, beaker with water and straw, and no. 200 sieve

3. Invert the sieve on the lab bench.
4. Unwrap the straws.

Operation of the Demonstration

1. Dip the straw in the water container and put your finger over the end of the straw, keeping the water in the straw while withdrawing it.
2. With the straw within 0.25 inches from the sieve's surface, remove your finger from the end of the straw, releasing the water onto

the dry sieve. Be careful not to drop the water from too high; the impact will carry the drop through the sieve.

3. Repeat, using alcohol.

VIDEO
A video of this demonstration is available at http://dx.doi.org/9780784413920.video.

Expected Result

The water forms a bead and does not pass through the sieve (Figure 12-3).

The alcohol immediately passes through the sieve (Figure 12-4). Zip!

Explanation of the Demonstration

Here's why water stands on the sieve and alcohol passes through. Every liquid has a property called surface tension. The molecules on the surface of a liquid are arranged differently than those below the surface. The surface molecules form a "skin" having some strength. Water has a much stronger skin than alcohol. The water skin is tough enough to hold the water on the surface of the sieve. The alcohol skin, being much weaker, does not. Hence, the alcohol passes through the sieve while the water does not.

Figure 12-3. Water placed on the sieve forms a bead

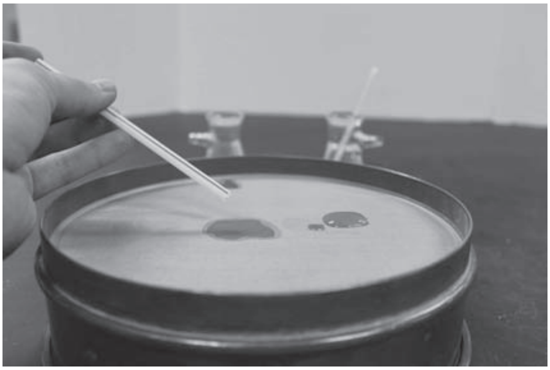


Figure 12-4. Alcohol placed on the sieve passes through immediately

The Magic

The experiment can be set up as magic. Because the liquids are clear, they both appear to be water. The magician casts a spell on one liquid (alcohol) so that it will pass through whereas the other will not (water):

> Here's some water.
> I say to you,
> You're now so special,
> You'll flow right through!

Conversely, one could put the alcohol on the screen first, and then cast a spell on the water:

> Here's some water.
> I make you thick.
> On top of sieve,
> You're sure to stick.

… or some similar lame rhyme.

Notes

Again, be careful not to release the water droplet from much height or the impact may drive the droplet through the sieve. Keep the straws separate: mixing a small amount of residual alcohol with water is sufficient to allow the alcohol-contaminated water to pass through the sieve (alcohol and water are miscible).

The surface tension can be overcome by large amounts of water, the weight of which pushes the water through the sieve. Hence the need in this experiment to keep the drops small.

Students may wish to use other liquids to evaluate their relative surface tensions. Or use other sieves.

This experiment can also be done on a piece of an umbrella or other waterproof, water-resistent fabric. Works great. This principle is what keeps rain from coming through the umbrella and ruining your coiffure.

Engineering Significance

This is the principle that keeps water from going through your umbrella in a storm. It also allows small insects to walk on water. And it's cool.

Geotechnical significance includes the "threshold gradient" principle for geotextile filters. If the geotextile filter has small holes, water will not go through until some minimum (greater than zero) hydraulic gradient is reached. The minimum to get the flow started is greater than that required after flow starts. That is, a larger water pressure is needed to start flow through the geotextile than is needed to maintain existing flow through the geotextile.

Supplier of Materials

- Soil sieve

  Durham Geo Slope Indicator
  2175 West Park Court
  Stone Mountain, GA 30087
  USA
  http://www.durhamgeo.com

13

Dilation in Someone's Hand (Silty Soil Identification)

Introduction

Soil identification is very important to geotechnical engineers, because soil type helps identify soil behavior. Silts and clays behave very differently in civil engineering practice, but are hard to distinguish visually. A very simple manual test to determine if a soil is silt is the dilation test.

Overview of the Demonstration

To distinguish silt from clay, saturate a handful of the suspect soil. After squeezing the soil and releasing it, repeatedly bump the hand. If the soil is silt, it will collapse. If the soil isn't, it will not. The difference is easy to tell visually.

Equipment

(See Figure 13-1.)

- Silt, silica fume, cement, volcanic ash, or rock-crushing fines;
- Water (from faucet); and
- Someone's hand.

Setup Procedure

1. Take the soil in hand.
2. Add water until it's saturated. Not moist, but saturated (Figures 13-2 and 13-3).

Figure 13-1. Water and silt

Figure 13-2. Moist silt

Figure 13-3. Saturating the silt

Operation of the Demonstration

Note: this is best done over a sink or other surface that can get dirty.

1. Squeeze the saturated soil in your hand, removing some of the water. When you open your hand, the soil looks like a hand grenade (Figures 13-4a and 13-4b). Note the surface of the soil is very dull (i.e., in the sense of not shiny, although soils are never that exciting anyway).
2. Vibrate the open, soil-filled hand by bumping it repeatedly on the lab bench or bumping it on the bottom with the other hand.

Expected Result

When the hand is bumped, the soil becomes very shiny, because water doesn't stick to silt particles and will come to the surface (Figure 13-4c). This identifies the soil as silt, not clay. Severe bumping may even cause the soil to liquefy—turn to a fluid—also indicating that the soil is silt, not clay. Clays don't exhibit this behavior, because water sticks to clay particles and can't move readily. Clay will continue to look like a hand grenade, but will not be nearly as much fun.

Explanation of the Demonstration

When the silt was saturated, it collapsed into a dense state. When the silt was squeezed, it increased in volume, or dilated. That is, the void space between the soil particles increased. Although this is counterintuitive, it's

a b c

Figure 13-4. a) squeezing; b) releasing (dull sheen); and c) vibrating silt in the hand (shiny) the truth! Most things decrease in volume when squeezed, but not dense silts. As it dilated, water was sucked into the soil, leaving the surface devoid of water and the color of the silt—not shiny. Think of a squeezed saturated sponge; when it's released, it sucks up water, as did the silt.

Now, when the hand was bumped, the soil collapsed, reducing the void volume and squeezing water out. The water, coming to the surface, produced a shiny appearance. If you have really pure silt, note carefully that the collapsing soil changes shape and begins to flow. This is called liquefaction (quicksand), which happens to saturated silt (and sand) deposits during earthquakes. Interesting.

The Magic

Most people won't expect anything to happen when they bump their hand. The fact that water comes to the surface, making it shiny, gives this experiment an element of magic, because the result was unexpected.

Notes

Silica fume is available commercially. Volcanic ash is available near volcanoes. Silt occurs naturally. Rock-crushing fines are available from quarries that crush rocks. Cement is available everywhere.

However, using cement is not such a good idea. It sticks to your hands and dries them out and doesn't dilate nearly as markedly as the other silts.

Engineering Significance

This simple test distinguishes silts from clays. Both are made of very small particles, making them difficult or impossible to distinguish visually. Although they can be distinguished with expensive analytical equipment, this is much simpler and quicker.

In terms of civil engineering uses, clays behave fundamentally differently than silts do. Clays compress much more slowly (causing long-term distress in buildings), drain much more slowly, are harder to compact, and can be more difficult to excavate.

Supplier of Material

- Silt (use silica fume or powdered cement)

  Advanced Cement Technologies
  435 Martin Street, Suite 2040
  Blaine, WA 98231-4966
  USA
  http://www.metakaolin.com

Further Reading

Dilation

Elton, D. J. (2001). "Soils magic." *Geotechnical special publication 114*, ASCE, Reston, VA, p. 10.

Clay behavior

McCarthy, D. F. (2007). *Essentials of soil mechanics and foundations—basic geotechnics*, 7th ed., Prentice Hall, Upper Saddle River, NJ, Section 2.3.

14

Piping under a Sheetpile Dam

Introduction

Water flows *through* dams. More than 90% of all dams are made of soil (earthen dams). When water flows through too energetically, the soil can wash away. This is called piping, or internal erosion. Piping occurs rapidly, is very hard to stop, and often leads to complete failure.

Overview of the Demonstration

Water is forced, at a high hydraulic gradient, underneath a model sheetpile dam. The soil rapidly pipes to the downstream side of the dam.

Equipment

(See Figure 14-1.)

- Custom sheetpile tank,
- Clean sand, and
- Water.

Setup Procedure

Place sand in the tank. The upstream elevation should be higher than the downstream side, for better effect.

Operation of the Demonstration

Water is added rapidly to the upstream side of the dam.

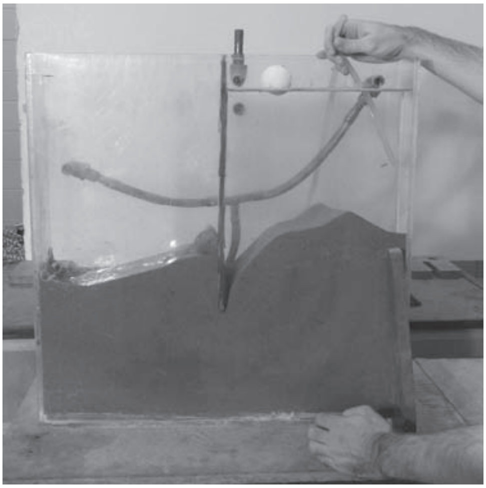


Figure 14-1. Tank with sand and sheetpile dam in center; water is high on the right side, low on the left side

VIDEO
A video of this demonstration is available at http://dx.doi.org/9780784413920.video.

Expected Result

At some point, soil from the upstream side of the dam will flow rapidly under the sheetpile to the downstream side of the dam (Figure 14-2).

Explanation of the Demonstration

When upstream and downstream water elevations are very different, a large energy gradient occurs, giving water flowing through the soil a lot of energy. If the water has sufficient energy, it will move the downstream soil particles away from the dam.

Notes

The apparatus, made of Plexiglas, is rather expensive and difficult to construct because it must be free of leaks, which spoil the effect. The

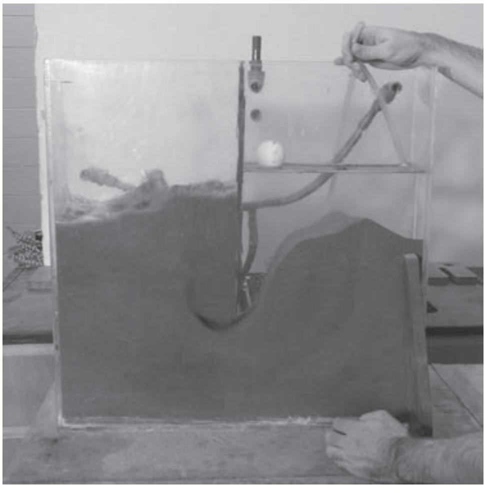


Figure 14-2. Failure occurring as water and sand flow from right to left under the sheetpile dam (action photo)

tank in Figure 14-1 is about 20 inches tall, 24 inches wide, and 4 inches deep. The sheetpile is about 10 inches long. The Plexiglas is 0.375 inches thick and is bonded with acetate. The edges of the Plexiglas must be cut exceedingly straight for the acetate to bond effectively enough to prevent leaks.

The effect is enhanced if the cohesionless soil has no fines.

Engineering Significance

Dams must never experience piping or they will fail. Once piping starts, it progresses at an ever-increasing rate (progressive failure), making it nearly impossible to stop.

Case History

Teton Dam, in Idaho, is one of the most famous piping failures (Chadwick et al. 1976). The dam was built on porous rock abutments that allowed water to seep into the dam with little loss of energy. The high-energy water entering the dam easily caused the silty soil to pipe, leading to complete loss of the dam. Figures 14-3, 14-4, and 14-5 illustrate the process. Figures 14-6 and 14-7 show the aftermath, illustrating the highly fractured rock

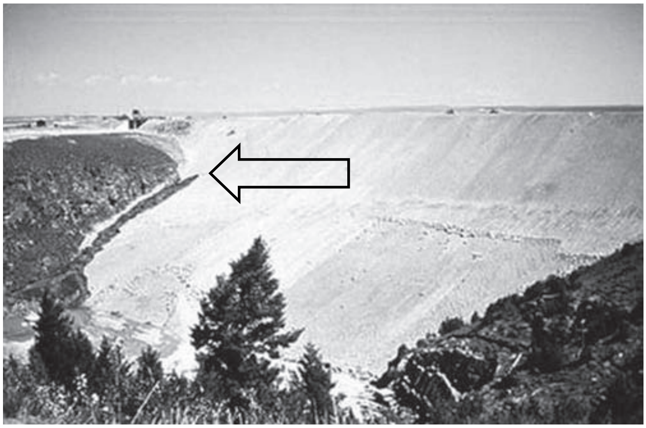


Figure 14-3. Teton Dam showing initiation of seepage near right abutment (Chadwick et al. 1976)

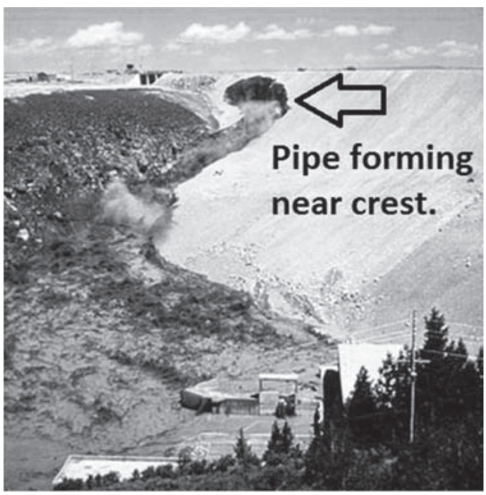


Figure 14-4. Teton Dam showing piping underway near the crest (Chadwick et al. 1976)

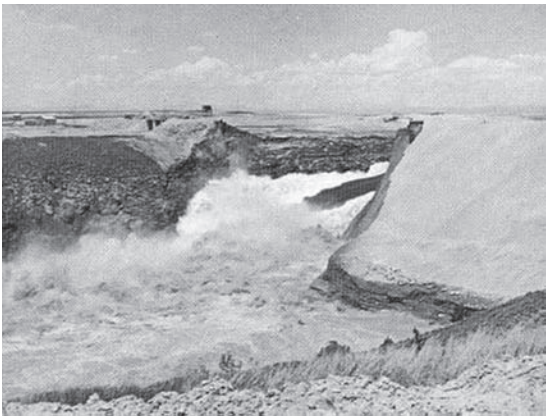


Figure 14-5. Breach of Teton Dam (Chadwick et al. 1976)

Figure 14-6. Breach complete (Chadwick et al. 1976)

Figure 14-7. Teton Dam site showing heavily fractured rock abutment (Chadwick et al. 1976)

abutments through which water could flow, leading to the Teton Dam failure.

References

Chadwick, W. L., et al. (1976). "Report to U.S. Department of the Interior and State of Idaho on failure of Teton Dam by independent panel to review cause of Teton Dam failure." *Superintendent of Documents*, U.S. Government Printing Office, Washington, DC.

15

Jar of Rocks (Soil Void Ratio, Porosity, Unit Weight, and Water Content of Soils)

Introduction

Unit weight, void ratio, and porosity are basic descriptors of soil. These calculated numbers are used in geotechnical engineering to reflect the engineering behavior of soils. This demonstration brings the numbers to life.

Overview of the Demonstration

Use hardware to measure the volume of voids, volume of solids, weight, and total volume to calculate the soil void ratio, porosity, and density.

Equipment

(See Figure 15-1.)

- Balance;
- Two beakers of known volume (one graduated), about one liter each;
- Water;
- Food coloring; and
- Gravel.

Setup Procedure

1. Weigh the empty beaker (without gravel).
2. Fill with gravel and note volume.

Figure 15-1. Balance, beaker of gravel, food coloring, and graduated beaker of water

3. Fill the graduated beaker with water to about the volume of the other beaker.
4. Add food coloring to the water, if desired.
5. Record the volume of water.

Operation of the Demonstration

1. Weigh the beaker full of gravel, and subtract the weight of the beaker to obtain the weight of the gravel. Given the volume of the beaker and the weight of the gravel, divide the two to obtain the dry unit weight, γ_{dry}:

$$\gamma_{dry} = \frac{\text{weight of gravel}}{\text{volume of beaker}}$$

where

$$\gamma_{dry} = \text{dry unit weight of the gravel.}$$

2. Fill the gravel-filled beaker to the top with water, and record the weight of water added. Figure 15-2 shows this. Knowing the volume of the beaker, the weight of the gravel, and the volume of water, calculate the saturated unit weight of the gravel, $\gamma_{saturated}$:

$$\gamma_{saturated} = \frac{\text{weight of gravel} + \text{weight of water}}{\text{volume of beaker}}$$

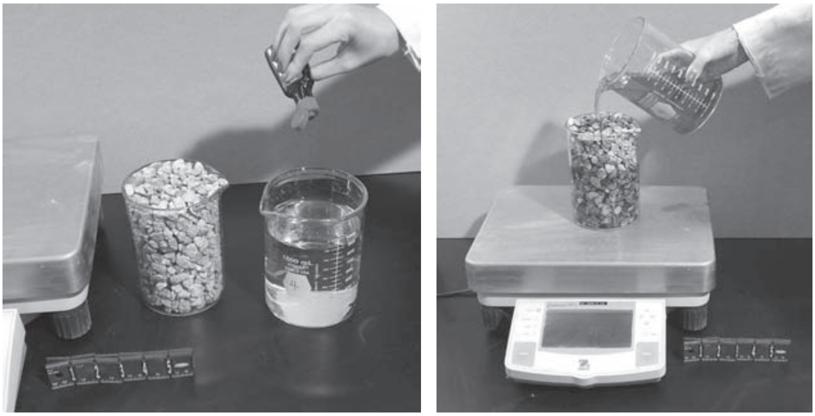


Figure 15-2. Left: adding food coloring to the water; right: adding water to gravel-filled jar, on balance

Figure 15-3. Illustration of saturated unit weight (left) and dry unit weight (right)

where

$$\gamma_{saturated} = \text{saturated unit weight of the gravel.}$$

Figure 15-3 illustrates the difference between saturated and dry unit weight.

3. Knowing the unit weight of water, convert the weight of water added to the beaker to volume of water:

$$\text{volume of water} = \frac{\text{weight of water}}{\text{unit weight of water}}$$

4. Knowing the volume of the beaker and the volume of water added to the gravel-filled beaker, calculate the void ratio, *e*:

$$e = \frac{\text{volume of voids}}{\text{volume of solids}} = \frac{\text{volume of water added}}{\text{total volume} - \text{volume of water added}}$$

5. Next, knowing the volume of the beaker and the volume of water added to the gravel-filled beaker, calculate the porosity, *n*:

$$n = \frac{\text{volume of voids}}{\text{total volume}} = \frac{\text{volume of water added}}{\text{total volume}}$$

6. Finally, knowing the weight of the water and the weight of the gravel, calculate the water content, *w*:

$$w = \frac{\text{weight of water}}{\text{weight of gravel}}$$

Bonus Demonstrations

1. Remove the water from the gravel-filled beaker and gently compact the gravel by rapping (vibrating) the beaker with your knuckles.
2. Refill the beaker with water and recalculate the unit weights, void ratio, and porosity, using the new, lower volume of solids.

The measured porosity, *n*, can be checked with the calculated void ratio using

$$n = \frac{e}{1 + e}$$

When a student is asked to comment on why the numbers are not exactly the same, you can have a discussion of experimental error.

Expected Results

Students will grasp the concepts of unit weight, void ratio, and porosity, which previously were only numbers. Now they're real.

The Magic

There's no magic here, unless you want to bet someone you can calculate the volume of the voids in the gravel in a beaker in less than

15 seconds (don't show the audience the water-filled beaker nearby). People will wonder how you can measure such an odd volume so quickly.

Notes

Colored water makes the presentation more interesting. You could color it in advance and pretend it's cranberry juice or burgundy wine (sip a little).

The first bonus demonstration may not work very well with gravel, which was likely already at maximum density when first placed in the beaker. A well graded sand may work better.

Other ways of estimating the void ratio include tables, based on soil type, penetration resistance, soil classification, or overconsolidation ratio.

You can do the demonstration with marbles, rather than gravel. The students could compare the volume of solids calculated previously with the volume of solids calculated from knowing the number of marbles and the formula for the volume of a sphere.

Engineering Significance

The strength of a soil is related to its unit weight. The higher the unit weight, the greater the strength. Because strength is expensive to measure and unit weight is not, correlations between unit weight and strength are often used to estimate the strength of the soils. In addition, the pressure a soil puts on a foundation wall is related to the soil unit weight. And finally, the amount of settlement a soil fill will cause is also related to its unit weight.

The void ratio (or porosity, which is an indicator of the same thing) is a measure of soil permeability (its ability to allow water to pass through). Soils must be able to drain to maintain their strength. A high permeability means the soil will drain quickly, which is good. When it rains hard on a soil slope that doesn't drain, landslides occur, because the soil weakens and can't hold itself up. Similarly, roads (which are mostly soil) founded on poorly draining soils cannot hold up the loads of passing trucks, leading to pavement failure—rutting, breakup of the asphalt concrete, and potholes.

Void ratio is also a measure of compressibility—how much a soil will compress under a building like the Leaning Tower of Pisa. Permeability and compressibility are related to void ratio.

The strength of a clay soil is related to its water content. Higher water content suggests lower strength. The geotechnical engineer uses the water content to estimate the behavior of a clay.

16

Liquefaction by Upward Gradient

Introduction

Strong soil can turn into a weak liquid, called quicksand, when water flows through it. The phenomenon is called liquefaction. When this happens, large ground displacement and significant damage can occur.

During earthquakes, or significant ground shaking, water may flow through loose, saturated sands and cause liquefaction. Liquefaction can also occur by the upward flow of groundwater, such as that caused by artesian pressure or water flow under a dam. The effect is the same, but not as dramatic, as during an earthquake. This demonstration illustrates the latter: liquefaction by upward flow of water (upward hydraulic gradient). See Figure 16-1.

Overview of the Demonstration

Sand is placed in a container with a hole in the bottom. When water flows upward through the hole, the soil liquefies (turns to quicksand).

Equipment

(See Figure 16-2.)

- Funnel;
- Flexible hose;
- Permeability mold, a standard soils laboratory apparatus (however, any container that allows you to hook up the hose to its bottom will do);
- Steel weight;
- Sand; and
- Water.

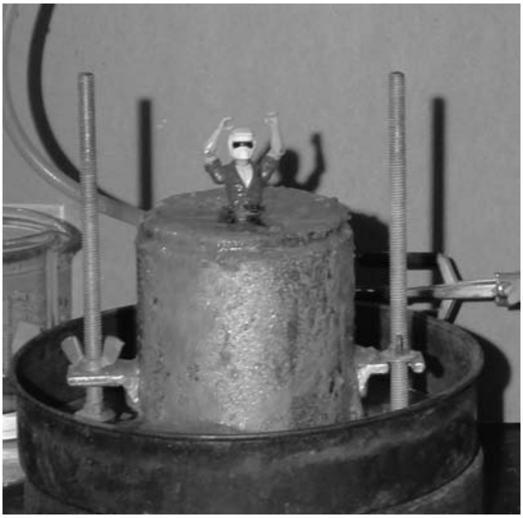


Figure 16-1. Help me, Obi Wan Kenobi! I'm trapped in a liquefaction event!

Figure 16-2. Funnel connected to permeability mold, weight, sand, and water; ring stand not shown; pan optional

Optional:

- Ring stand for the funnel, and
- Pan to catch liquefied soil.

Setup Procedure

1. Set the funnel in the ring stand, with its lip close to the top of the permeability mold.
2. Connect the funnel to the mold with the hose.
3. Open the valve, if you have one (see Figure 16-2 for valve at the base of the mold).
4. Alternate adding water and sand to the mold, in about four cycles, placing the sand *through* the water (Figure 16-3) gently, to keep the sand loose.
5. Slowly fill the funnel with water (Figure 16-4). The elevation *of the water* in the funnel should not go above the top of the mold.
6. Place the steel weight on top of the soil.

Operation of the Demonstration

Raise the funnel quickly. As the funnel rises, water will flow into the bottom of the mold (Figure 16-5).

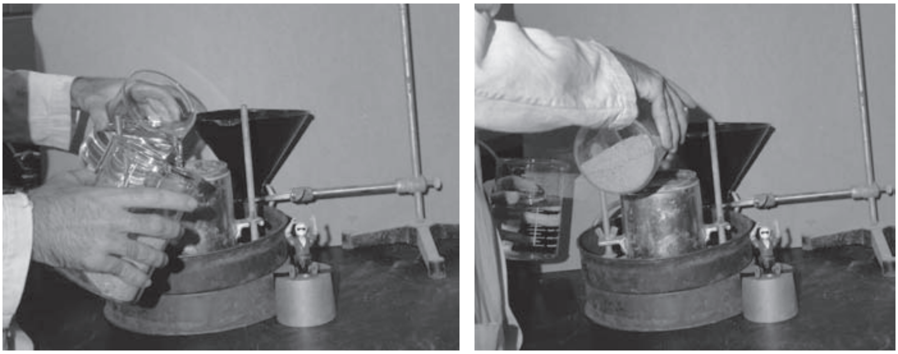


Figure 16-3. Loading the permeability mold, alternating placement of water (left) and sand (right)

Figure 16-4. Filling the funnel with water

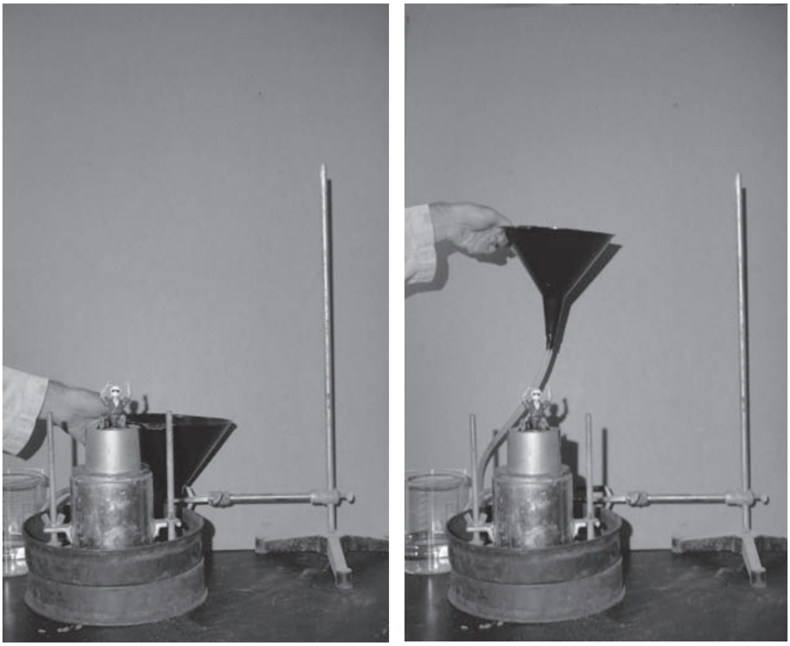


Figure 16-5. Lifting the funnel (left); beginning of liquefaction (right)

VIDEO
A video of this demonstration is available at
http://dx.doi.org/9780784413920.video.

Expected Result

The soil will turn to a fluid (liquefy), and the weight will sink into the mold (Figure 16-6).

Explanation of the Demonstration

The strength of sandy soils is related to how hard the soil particles are pushing against each other. The shear strength of the soils is given by

$$\tau = \bar{\sigma} \tan \bar{\phi}$$

where

τ = the shear strength of the soil,
$\bar{\sigma}$ = effective stress, and
$\bar{\phi}$ = the effective angle of internal friction, a soil property.

The smaller the effective stress (a measure of how hard particles are pushing on each other), the smaller the shear strength of the soil.

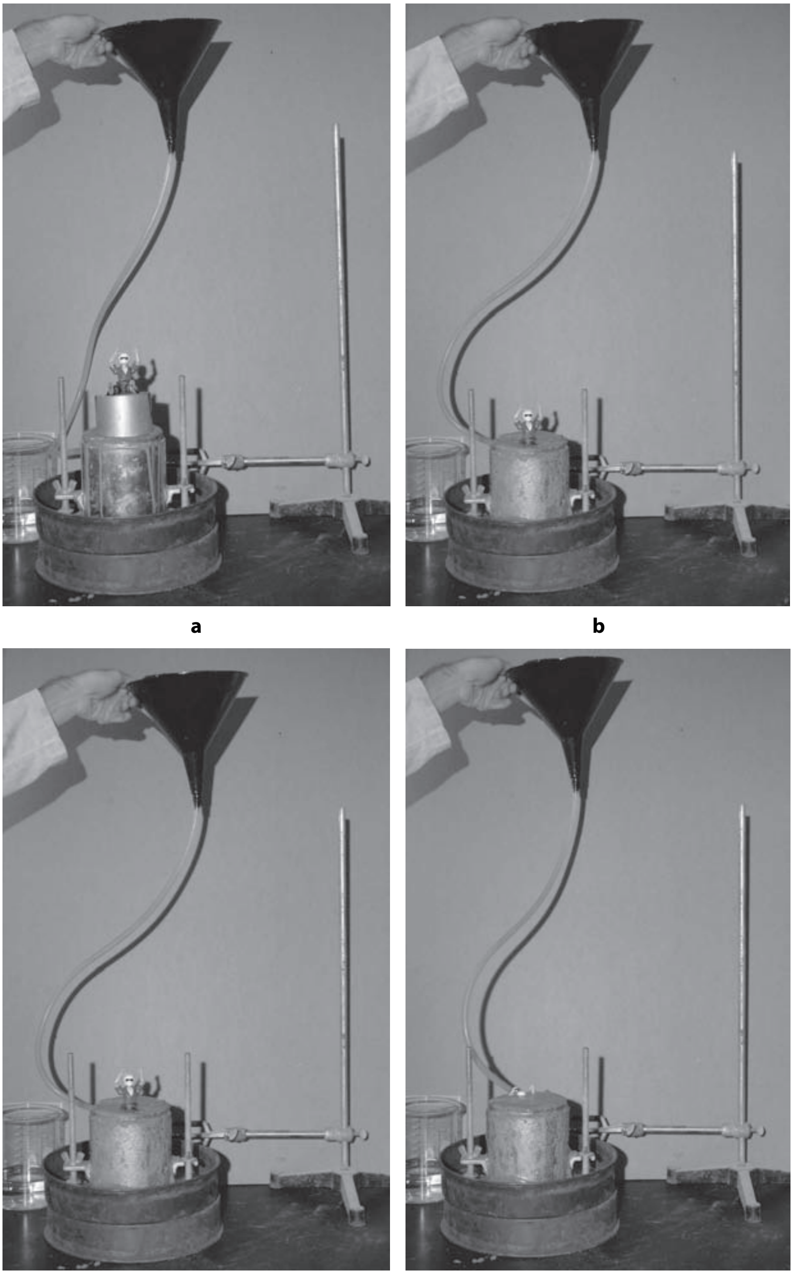
Now, the effective stress equation is

$$\bar{\sigma} = \sigma - u$$

where

$\bar{\sigma}$ = effective stress,
σ = total stress, and
u = pore (water) pressure.

When water flows into the base of the mold, the water pressure (u) increases dramatically. Well, when u goes up, $\bar{\sigma}$ goes down and the shear strength of the soil goes down, meaning that the soil loses strength. If u is large enough, the soil loses all strength. When this occurs, the soil becomes quicksand.



a b c d

Figure 16-6. Liquefaction

The Magic

Most folks won't think the weight will do anything. It's surprising when the weight disappears into the soil.

Perhaps the demonstrator could say

This little guy
Is on solid ground.
When the funnel goes up,
He will go down!

Notes

A stylized weight, perhaps shaped like the house used in Elton (2001), adds drama, as most folks will picture themselves in the house that's disappearing below the ground surface.

Choosing the right sand is important. Any gravel or a very coarse sand, is not likely to liquefy, while an extremely fine sand may heave instead of liquefying. While this, too, is dramatic and unexpected, it's not the intended result in this demonstration.

Despite what you may have seen in the movies, people don't drown in quicksand[1] without significant effort. The density of quicksand is so much higher than that of people, people float effortlessly in quicksand. It's like swimming in the Great Salt Lake, with even greater buoyancy.

Using a taller container makes the effect even more dramatic. More soil will liquefy, and the weight will drop farther into the container. Retrieving the weight, however, becomes more difficult.

Engineering Significance

Upward groundwater flow occurs in nature and can also be induced artificially. Artesian springs are naturally occurring upward flows. They may be seasonal or continuous, depending on the local geology and rainfall. Artificial upward flows can be caused by installing a levee or dam. As water seeps under the dam, it flows upward on the downstream side of the dam, perhaps forming sand "volcanoes." If your structure is

[1]Except in Hollywood.

on one of these, it's in trouble. The best advice is not to build downstream from a dam.

Supplier of Materials

- Soil permeameter with base connection

  Durham Geo Slope Indicator
  2175 West Park Court
  Stone Mountain, GA 30087
  USA
  http://www.durhamgeo.com

References

Elton, D.J. (2001). "Soils magic," *Geotechnical special publication 114*, ASCE, Reston, VA.

17

Blow It Out (Critical Hydraulic Gradient) and Flowlines

Two experiments in one spiffy apparatus

Introduction

Water flows through soils, under dams, and into basements. Civil engineers must predict where the water will flow and how much. Flownets are used to estimate these quantities. This chapter presents two demonstrations.

Overview of the Demonstrations

Water flows through soil in a purpose-built tank. When the water flows too quickly, the soil turns to quicksand and pipes and flows directly through the soil (that's one demonstration). In the second demonstration, the water flowpath can be estimated and the flownet drawn, which allows predictions of the quantity and direction of flow.

Equipment

- Flownet tank with sheetpile dam in the middle (Figure 17-1);
- Sand, uniform size;
- Water supply;
- Lab spoon;
- Potassium permanganate crystals;

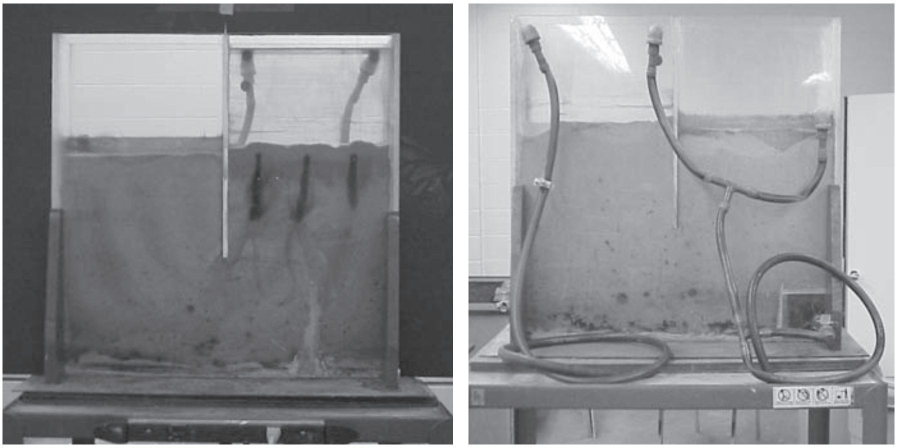


Figure 17-1. Flownet tank with sheetpile dam in center; left: front view with inlet at top right and overflow for upstream inlet at top center; right: rear view with inlet at top left, overflow for upstream inlet at top center, and overflow for downstream outlet at right center (note system drain in lower right corner)

- Tissue paper;
- Stapler;
- Grease pencil;
- Sink, to catch the water; and
- Mop, to clean up water that misses the sink.

Demonstration 1: Critical Hydraulic Gradient

Setup Procedure

1. Partially fill the flownet tank with sand at uneven levels. The sand on the upstream side (where water is added) should be deeper than the soil on the downstream side. Unfortunately, the difference in elevation between the upstream and downstream ground surfaces must be determined by trial and error. The elevation differences are based on the density and permeability of the sand. About an eight-inch difference in elevations is recommended as a starting point.

2. The sand must be uniform (all the same size particles) and placed very carefully to avoid segregation. If the sand segregates (big particles go to one area, smaller ones to another), the flownet will not look right.
3. On the downstream (low) side, add enough water to cover the soil, in an attempt to saturate the soil.

Operation of the Demonstration

1. With the soil in the tank saturated during setup, more water can be added to the system on the upstream (high) side.
2. Add water quickly enough that the upstream and downstream water levels do not match. However, if water is added too quickly, the failure will occur before the audience has a chance to recognize it. The trick is to keep a significant difference in these water elevations. The failure duration is a few seconds.
3. Mark the water levels on the upstream and downstream on the tank with the grease pencil during the entire demonstration.

Figures 17-2 and 17-3 show the setup and operation of the demonstration.

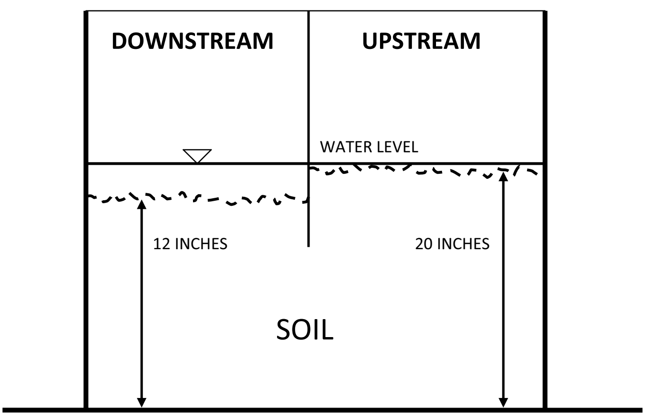


Figure 17-2. Schematic of initial setup for the critical gradient experiment: water levels are the same on each side and close to the ground surface (not to scale)

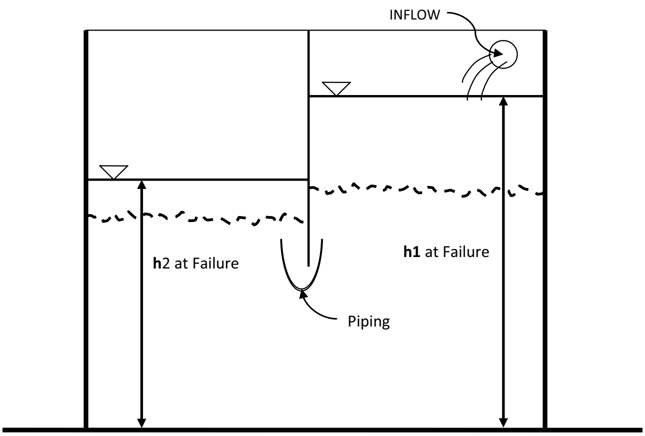


Figure 17-3. Schematic of the critical gradient experiment underway: water is added quickly to the upstream side

VIDEO
A video of this demonstration is available at http://dx.doi.org/9780784413920.video.

Expected Result

As the difference between the upstream and downstream water elevations increases, piping and likely liquefaction (quicksand) will occur in the downstream sand. The demonstration can be dramatic, occurring in seconds and causing significant turbulence. This is best viewed in the accompanying video.

Explanation of the Demonstration

The water flows through the soil because there's an *energy* difference. The high water on the upstream side has more energy than the low water on the downstream side. Like most systems, this one tends toward the lowest energy state and manifests this by water flowing from one side to the other until the upstream and downstream energies are equal (water level is the same on each side). Some of the energy is dissipated by the water rubbing or dragging against the soil particles. If the water does this with enough energy, the soil particles dislodge and move. This is called piping, or internal erosion.

Student Exercise

Based on the water level difference and an estimate of the unit weight of the soil (use 100 pcf), the student can estimate the total stress (σ) and the pore pressure (u) and then calculate the effective stress in the soil at various times prior to failure and at the time of failure.

The effective stress equation is

$$\bar{\sigma} = \sigma - u$$

where

$\bar{\sigma}$ = effective stress,

σ = total stress, and

u = pore (water) pressure.

At the time of failure, the effective stress is very close to zero.

Similarly, students could be asked to estimate the exit gradient at failure. The exit gradient is

$$i = \frac{\Delta h}{\Delta l}$$

where

i = hydraulic gradient,

Δh = change in head (difference in elevation between the upstream and downstream water elevations), and

Δl = average length (distance) a water particle flows from upstream to downstream.

The exit gradient at failure should be about one.

Notes

The water must be added quickly enough to maintain an ever-increasing water table elevation difference between the upstream and downstream sides, but not so fast as to cause instantaneous failure. Finding the right rate of adding water is not difficult, but be sure to do this experiment once before doing it for an audience.

Engineering Significance

Earth dams are made to hold back water. Water flows through earth dams. If the difference between the upstream and downstream water elevations is too large and little or no effective internal seepage control is in place, piping (internal erosion) occurs, the soil washes away, and presto! no dam is left to hold back the water. This is called dam breaching and is considered undesirable in most circumstances. Incidentally, once piping starts, it's virtually impossible to stop, resulting in loss of the entire dam.

The Magic

The magic lies in the manner in which the soil fails: it occurs quickly and large chunks of soil break off, amid lots of churning water. Much different than the peaceful flownet demonstration that follows.

Demonstration 2: Peaceful Flownet

Setup Procedure

1. Set up the flownet tank so that the soil on both the upstream and the downstream side of the sheet pile system is at an elevation of about 10 inches above the table. Saturate the soil before beginning the experiment.
2. Ensure that the sand is uniform (all the same size particles) and place it very carefully to avoid segregation. If the sand segregates (big particles go one area, smaller ones to another), the flownet will not look right.
3. Make three potassium permanganate "tea bags" by wrapping a few potassium permanganate crystals in a piece of tissue paper and stapling the paper shut. The "tea bag" should be about ¼-inch square, about the length of the staple.

Operation of the Demonstration

1. When the soil is saturated, distribute the three potassium permanganate tea bags on the upstream side near the glass surface

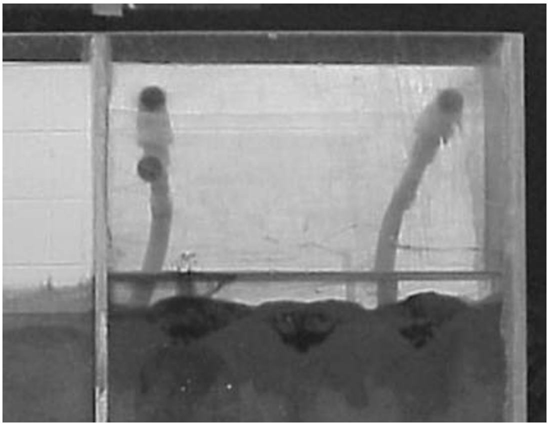


Figure 17-4. Three potassium permanganate tea bags, buried in the upstream side of the tank, beginning to bleed

equidistant from one another, the sheet pile, and the side of the tank.

2. Bury the bags under ½ inch of soil to avoid contaminating the reservoir on the upstream side by diffusion.
3. When the bags are buried, add water to the upstream side until water comes out of the overflow. Add the water slowly, so as not to disturb the bags. The overflow valve will ensure a constant head on the upstream side and an overflow valve on the downstream side will do the same. As the water flows through the system, the potassium permanganate will leave a trace showing the flowlines. Figure 17-4 shows the placement of the potassium permanganate tea bags.

Expected Result

As the water flows from the upstream to the downstream sides of the flownet, it dissolves a little potassium permanganate. This will create a purple tracer (flowline) from upstream to downstream. If the sand is uniform in size and density (and if the tank does not have any leaks) the flowlines will appear as smooth curves. Figure 17-5 shows the formation of the flowlines.

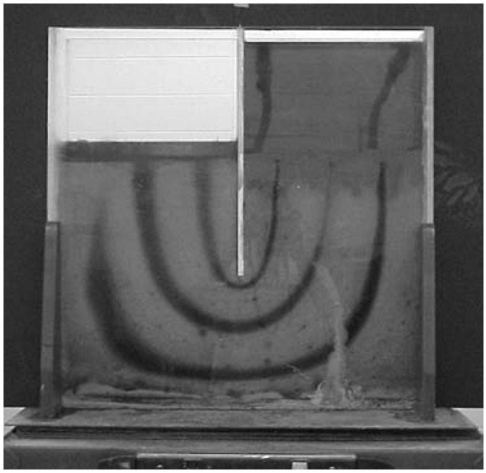


Figure 17-5. Flowlines forming in the tank

Explanation of the Demonstration

Water takes the path of least resistance—the lowest energy path. The flowlines are those paths. They are described by the famous Laplace equation.

The Magic

The uninitiated will think the water travels along the shortest path from upstream to downstream. It doesn't. It takes a curved path, as indicated by the flowlines.

Notes

Be sure the soil is very uniform and placed at a uniform density, or the flowlines will not be smooth curves. Leaks in the tank will cause the flowlines to move to the leak. Placing water in the tank before soil placement may result in greater soil uniformity.

Student Exercise

Once the flowlines run completely from the upstream to the downstream face, use a grease pencil to draw the equipotential lines on the plastic, creating the flownet. The procedure for drawing flowlines (combinations of equipotential and flowlines) to create a flownet is given in Harr (2011) and many undergraduate soils texts, such as McCarthy (2006).

With the flownet drawn, students may calculate the flowrate and compare it with the measured flowrate. They may also calculate the exit hydraulic gradient (to compare with the critical gradient) and calculate the soil permeability. The procedures, again, are given in the noted books.

After estimating the soil saturated unit weight (use 130 pcf), students may determine the effective stress at the upstream soil surface, the base of the sheetpile, and at the downstream soil surface. If the soil is stable, these will all be greater than zero.

Supplier of Materials

- Potassium permanganate crystals

  Fisher Scientific
  300 Industry Drive
  Pittsburgh, PA 15275
  USA
  http://www.fishersci.com

References

Harr, M. E. (2011). *Groundwater and seepage,* Dover Publications, Mineola, NY.

McCarthy, D. F. (2006). *Essentials of soil mechanics and foundations: basic geotechnics*, Prentice Hall, Upper Saddle River, NJ.

18

Relative Density of Soil in a Graduated Cylinder

Introduction

Relative density is a measure of how dense a cohesionless soil is compared with its maximum density. Calculation of relative density requires uncovering the maximum and minimum densities of the soil. While ASTM tests are available for these (ASTM 2006a, b), the following method is often adequate and much quicker and allows for multiple tests in a short time.

Overview of the Demonstration

Loose, dry sand is placed in a graduated cylinder to determine the maximum and minimum dry densities.

Equipment

(See Figure 18-1.)

- Dry sand,
- Graduated cylinder (1 L),
- Water, and
- Balance.

Setup Procedure

1. Weigh the graduated cylinder.
2. Place dry sand in the graduated cylinder and weigh it again.

Operation of the Demonstration

Lowest density. Place one hand over the end of the graduated cylinder and slowly tip the cylinder back and forth, loosening the soil (Figure 18-2).

Figure 18-1. Graduated cylinder with dry sand in it (balance not shown)

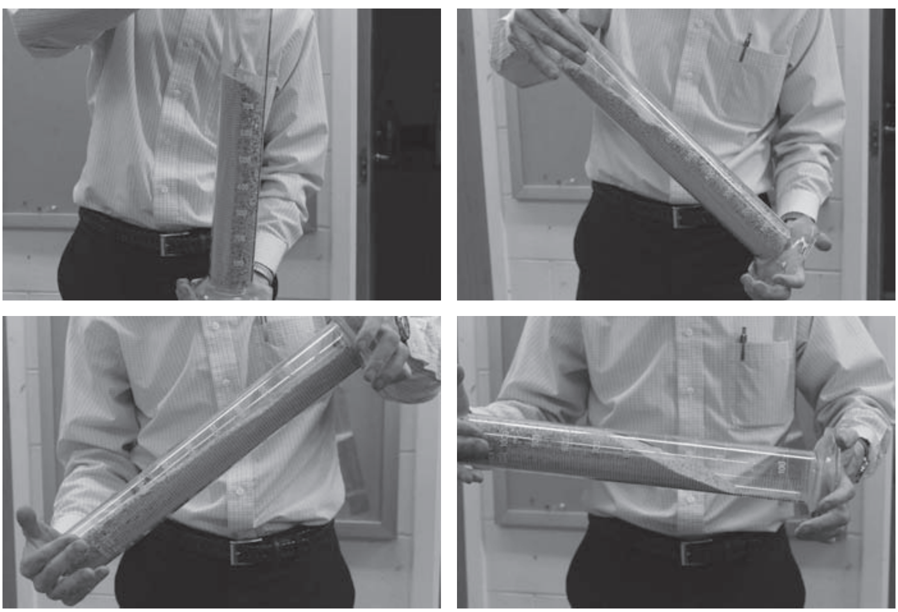


Figure 18-2. Cylinder of soil being gently rocked back and forth

After several slow iterations, carefully place the cylinder on the table and read the volume of soil on the graduated cylinder. Repeat the exercise until satisfied that the lowest density (greatest volume) has been achieved. You can open this up to the audience as a competition.

Highest density. Place the cylinder on the table and bump it repeatedly with your hands, until the volume of soil in the cylinder ceases to decrease. Read the volume of soil on the graduated cylinder. No repetition of the exercise is needed. Just keep banging the cylinder until the volume is minimum.

Expected Result

The sand will have some unit weight (either minimum or maximum) after these demonstrations.

The dry unit weights, in the loosest and densest states, are calculated as follows:

$$\gamma_{\text{dry}} = \frac{\text{weight of sand}}{\text{volume read from graduated cylinder}}$$

where

γ_{dry} = dry unit weight of the soil.

The *relative density*, D_r, of a soil is a measure of how dense a soil is in the field, compared with its maximum and minimum unit weights. With the previously calculated minimum and maximum unit weights and the field unit weight, D_r may be calculated from

$$D_r = \frac{\gamma_{\text{dry max}} - \gamma_{\text{dry field}}}{\gamma_{\text{dry max}} - \gamma_{\text{dry min}}}$$

where $\gamma_{\text{dry max}}$ and $\gamma_{\text{dry min}}$ are determined from the previous exercise and $\gamma_{\text{dry field}}$ is the dry unit weight of the soil in the field. The calculation of D_r requires a value of $\gamma_{\text{dry field}}$. Assume 105 pcf.

Explanation of the Demonstration

The loosest soil is in an arched condition, which is unstable. The soil will stay in this unstable condition until some additional energy is added to the soil, in this case by bumping the cylinder. The soil densifies when the cylinder is struck because the added energy overcomes the static force holding the soil particles in an arched, loose configuration. The soil

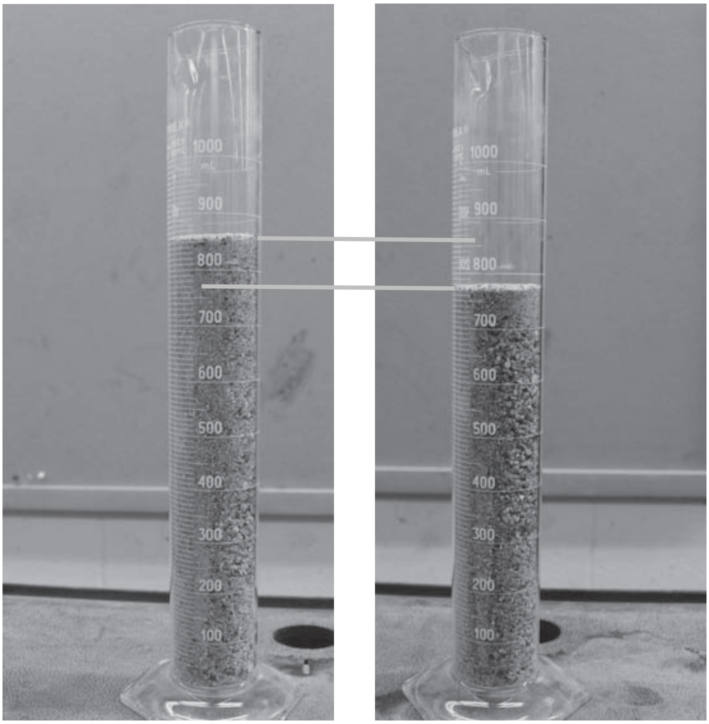


Figure 18-3. Left: before vibration; right: after vibration; lines are added to emphasize the difference in soil heights

particles then collapse under their own weight. Figure 18-3 shows the loosest and densest states.

The Magic

No magic here.

Notes

An even lower unit weight can be obtained by placing soil in a *water-filled* graduated cylinder. Soils placed through water are looser than soils placed through air, because the buoyancy due to water is much greater than that of air. Hence, an enterprising student, seeking the lowest density in a contest, would fill the cylinder with water before carefully placing the soil in it.

This exercise has been done successfully as a competition, with the loosest soil being the winner. The high densities will all be very similar.

Engineering Significance

The unit weight of a soil suggests its strength, compressibility, and permeability. Higher unit weights suggest higher strengths and lower compressibilities and permeabilities. These properties are commonly used in geotechnical engineering design.

However, different soils with the same unit weights will have different strengths, compressibilities, and permeabilities. Hence, the unit weight, while useful and often used to estimate these properties, is not directly transferrable across soil types. To resolve this, the unit weight of a soil compared with its minimum and maximum unit weights (the *relative* density) is transferrable. Soils of the same type, with the same relative densities, are expected to act about the same. So, while the unit weight of a soil is useful for estimating soil properties, the relative density is more useful, though it takes more time and money to determine.

Supplier of Materials

- Graduated cylinder

  Fisher Scientific
  300 Industry Drive
  Pittsburgh, PA 15275
  USA
  http://www.fishersci.com

References

ASTM. (2006a). "Standard test methods for minimum index density and unit weight of soils and calculation of relative density." *D4254*, ASTM, West Conshohocken, PA.

ASTM. (2006b). "Standard test methods for maximum index density and unit weight of soils using a vibratory table." *D4253*, ASTM, West Conshohocken, PA.

19

Soil Filter Demonstration Using Marbles

Introduction

Drains in geotechnical engineering, which are used to remove water, require a filter to prevent soil from entering the drain. The filter may be made of a special soil ("graded granular filter") or a geotextile. This demonstration shows how a graded granular filter works.

Drains and filters are used behind basement walls, retaining walls, in wells, in soil embankments, in landfills, and under roadways. They convey water away from the structure, which has two effects: reducing water pressure on the structure and increasing the strength of the soil. When water is removed from soil, the strength of the soil increases due to an increase in effective stress. Hence, draining soils is very important to civil engineers. Figure 19-1 shows what happens when a wall drain doesn't have a filter: the soil washes into the drain, leaving a hole.

Graded granular filters work because of their structures. They have large particles on bottom, successively grading to smaller particles on the top. Figure 19-2 is a schematic of a graded granular filter for water flowing from top to bottom. The large gravel on the bottom is the drain. The randomly sized particles on top are the soil being drained. The intermediate particles are the graded filter soils. The smaller particles at the top of the filter "arch" or "bridge" over the somewhat larger particles below them. So, even though the spaces among the largest particles on the bottom would allow the smallest particles on the top to pass, those smaller particles do not pass because they are blocked by the layers of intermediate particle sizes.

Overview of the Demonstration

Marbles representing soil particles are placed on a screen representing the drain. Various marble sizes are used. The "graded granular filter" is then

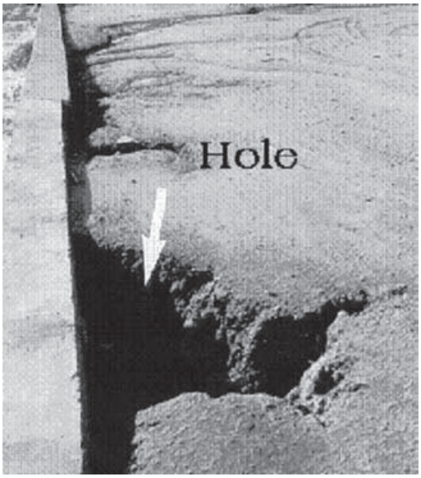


Figure 19-1. Retaining wall with a drain without the filter; soil has washed into the drain, leaving a hole

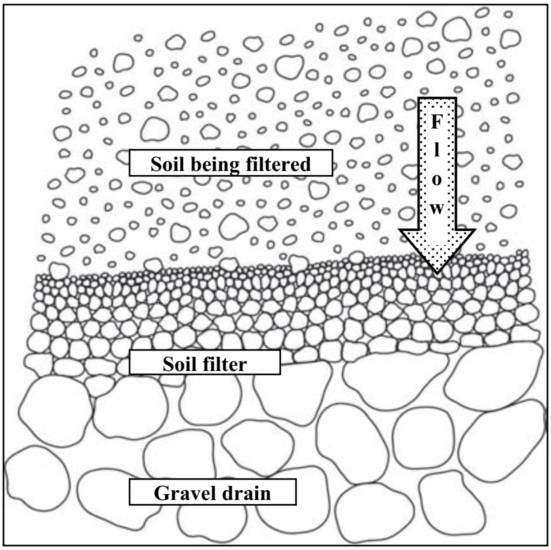


Figure 19-2. Schematic of graded granular filter

constructed by placing marbles of different diameters on the screen to emulate construction of a graded granular filter. When the filter is constructed correctly, fine soil particles (represented by small marbles) do not pass through.

Equipment

(See Figure 19-3.)

- Custom box with screen in base;
- Marbles (spheres) of various sizes; 39, 23, 14, 8, and 3 mm (BBs) diameters are used here; and
- Metal pan.

The custom box with the screen has a critical inside dimension. It must be an even multiple of the diameter of the largest marble, so the marbles arrange themselves as shown in Figure 19-4. Failure to do this may lead to a failed experiment.

Setup Procedure

Put the custom box on top of the metal pan. The metal pan amplifies the noise of the smallest marbles (BBs) passing through the filter.

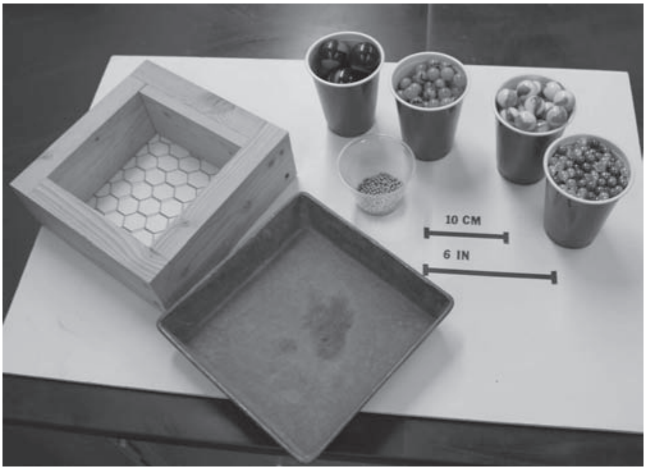


Figure 19-3. Custom box with screen, marbles of various sizes, and metal pan

Figure 19-4. Required arrangement of the first layer of marbles

Operation of the Demonstration

1. Place one layer of the largest marbles in the bottom of the box.
2. Pour the BBs onto these.
3. Place a layer of the second largest marbles on top of the largest marbles in the box.
4. Again, pour the BBs onto this layer.
5. Continue to place layers of successively smaller marbles on the marbles in the box.
6. After placing each layer, pour the BBs on these, and then repeat.

Figure 19-5 shows the process of building the filter.

Expected Result

The first layer of marbles will not retain the smallest marbles. You will see (hear) them pass right through the filter and hit the metal pan. After each successive layer of smaller sized marbles is placed, fewer and fewer BBs pass through the filter. Eventually, none of the BBs will pass through. This demonstrates that a graded soil (marble) filter will keep small particles from washing through the filter into the drain, protecting the soil from washing away and clogging the drain. Figure 19-6 shows the marbles passing through the coarse filter (one layer of marbles) and making a lot of noise as the marbles fall into the metal pan (left); it also shows the smallest marbles held in the completed filter (right).

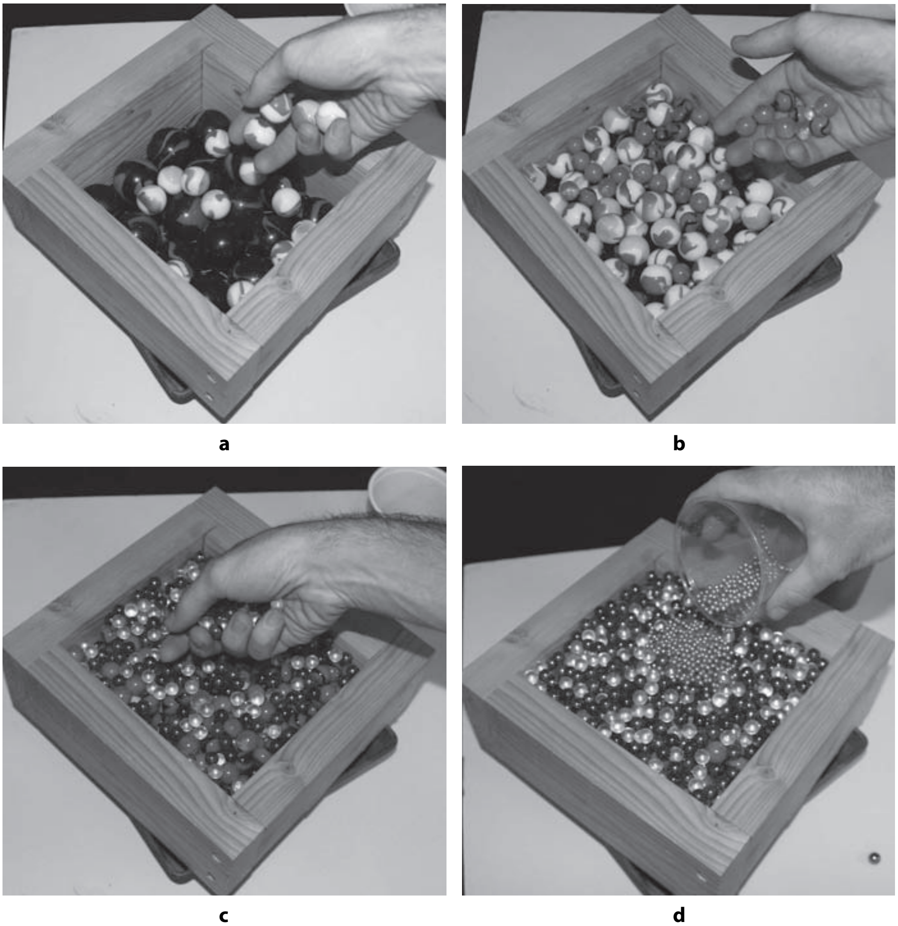


Figure 19-5. Constructing the filter by placing successively smaller marbles on top of each other; note, in d, that the smallest marbles are retained

Explanation of the Demonstration

The reason the smallest particles don't pass through the larger particles below them is because they form arches above the spaces among the larger particles. Even though the spaces are larger than the smaller particles, the particles don't pass through. Figure 19-7 is a schematic of this effect.

The Magic

Ask the audience whether the BBs could be placed in the box without falling out. Then proceed with the demonstration. The audience often is

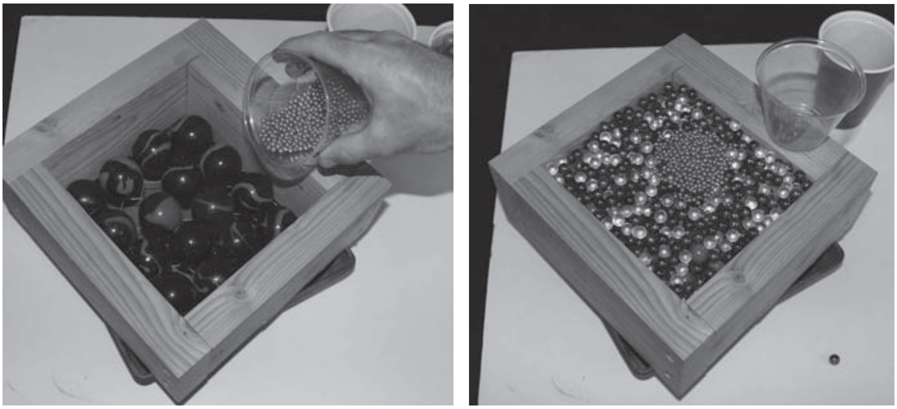


Figure 19-6. Left: BBs pass straight through large marbles and clink into the metal pan below; right: BBs no longer pass through completed filter—no clinking is heard

Figure 19-7. Arching schematic: the smaller soil particles above the larger ones do not fall through the larger space between the larger soil particles

surprised that even though the holes among the marbles are bigger than the particles, the particles don't go through.

Notes

Be sure the first layer of marbles conforms to the criteria in Figure 19-4, or the smallest marbles may leak around the edge of the box.

Brass BBs are used for the smallest marbles. They have a huge coefficient of restitution, as do the marbles. When poured on the marbles, they bounce all over the place. Be careful if these get on the floor because people can slip on them. Plastic BBs may not bounce around as much, but we didn't have the money or patience to try them.

Placing the apparatus on an overhead projector helps illustrate that the paths that particles can pass through close with every layer of marbles. After just a few layers, the light is blocked out.

The experiment may be enhanced by pouring water through the completed setup. If done correctly, water will pass through easily, but will not wash any of the soil particles (marbles) out. This makes more of a mess, but drives home the point that this arrangement allows water to pass easily, but does not allow soil particles to escape—the two criteria for a successful filter.

The experiment can be made more realistic. Real soil filters are not placed in layers of single-sized particles. Rather, the particles are mixed together at placement. As water flows through the filter, some soil particles wash through as the others begin to form soil arches. After a while, the arches form and complete the filter, after which no more soil particles wash through. If you don't mind making a watery mess, place the first layer of soil particles, mix up the other sizes, and then place them. Run water through. Some soil particles will wash out at the start, but after a while, the system forms arches, stopping the further loss of soil. This is more effective if you use rough marbles.

Engineering Significance

Soil filters are used with civil engineering drains to keep the soil being filtered from washing into the drain. If the soil goes into the drain, the drain clogs and the structure may fail. For example, if the soil washes away, roads develop potholes, structures near retaining walls fail, and building foundations move.

Supplier of Materials

- Marbles of different sizes

  Marble King, Inc.
  329 First Avenue
  P.O. Box 195
  Paden City, WV 26159
  USA
  http://www.marbleking.com

20

Sand in a Jar (Strong as You Are)

Introduction

Cohesionless soils (silt, sand, and gravel) develop their strength from friction among the soil particles. This demonstration shows this effect.

Overview of the Demonstration

A sandy soil is tested, qualitatively, for strength in two conditions: confined and unconfined.

Equipment

(See Figure 20-1.)

- One quart jar or other quart container, taller than it is wide;
- Two quarts of dry sand; and
- Weight (alternatively: hammer handle or other rod about one inch diameter).

Setup Procedure

1. Place about a quart of dry sand on the table in a pile.
2. Place the other quart of dry sand in the container.

Operation of the Demonstration

1. Put the weight on the sand pile, and observe the behavior.
2. Put the weight on the sand in the jar, and observe the behavior.

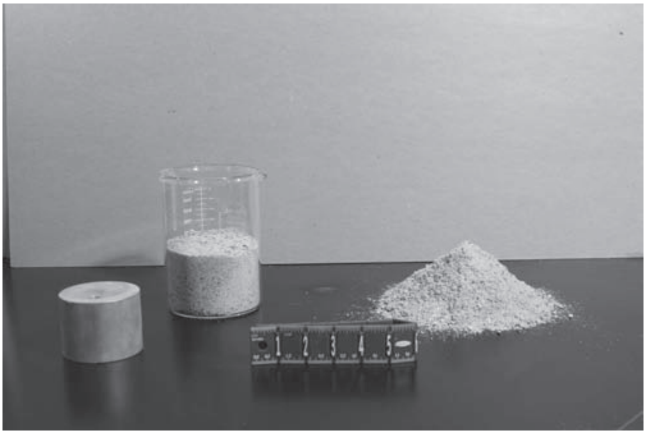


Figure 20-1. Weight, jar of sand, and pile of sand

Alternate

1. Push the rod into the pile of sand on the table.
2. Try to push the rod into the sand in the container.

VIDEO
A video of this demonstration is available at http://dx.doi.org/9780784413920.video.

Expected Result

The weight will displace the sand pile immediately (Figure 20-2, left). The weight will not displace the sand in the jar (Figure 20-2, right).

Alternate

Pushing the rod into the pile of sand on the table is very easy. Pushing the rod into the sand in the container is very difficult. In fact, it likely can't be done.

Figure 20-2. Left: weight crushing loose sand pile; right: weight having no effect on the confined sand in the jar

Explanation of the Demonstration

The strength of sand (and all cohesionless soils) is not a constant. The strength is related to how hard the soil particles are pushing on each other. If they're pushing hard, the soil is strong, and vice versa. Put another way, the soil's strength is related to the stresses on the soil. If the sand is not confined (i.e., soil particles are allowed to move around easily), the interparticle stresses remain small and the strength of the sand is low. This is the case with the sand pile on the table. The stresses are high for a moment, then dissipate as the soil displaces.

When the soil is in the jar, the soil particles can't move much. When the weight is placed on sand, the interparticle stresses increase and stay elevated. These high stresses make the sand strong, so it supports the weight without moving.

This effect is described by the equation for soil shear strength:

$$\tau = \bar{\sigma} \tan \bar{\phi}$$

where

τ = the shear strength of the soil;

$\bar{\sigma}$ = effective stress; and

$\bar{\phi}$ = the effective angle of internal friction, a soil property.

The larger the effective stress (a measure of how hard particles are pushing on each other), the greater the shear strength of the soil.

The Magic

Pushing the same rod into the same soil differs, depending on whether the soil is in a jar or in a pile. Most people would think it'd be the same, regardless, as it is with most materials.

Start with two piles of sand on the table. Dead dry. Claim you can make one pile of sand twice as strong as the other by casting a spell on it. Cast the following spell:

> Here are two piles
> Of wonderful sand.
> I strengthen this one,
> With my magic hand!

Wave hand (or both hands) over pile in mysterious manner. Then pull out the beaker, put the sand in it, and do the experiment.

Notes

The materials used make a little difference. Any jar will do, as long as it's deep enough to show the effect. A pan, being very wide compared with its depth, for instance, won't show this effect. Any cohesionless material will work. Larger materials (frozen oranges) don't show the effect as dramatically as, say, frozen peas. While small candies are likely to be crushed, negating the desired effect, they have other attractions.

The weight is best used for demonstration. The rod is best used when the students do the demonstration. They will feel how very much harder it is to push the rod into the jar of soil compared with the pile of soil.

Engineering Significance

Cohesionless soils' strength may be increased by increasing the confining pressure on the particles. This is useful in shallow foundation design. Here, column footings are placed *below grade* instead of on the ground surface, so the soils under the footing experience greater confinement and hence have greater strength. Not only does this make the building foundation safer, it allows the use of smaller footings, which saves money.

21

Shear and Compression Waves

Introduction

Earthquakes cause the ground to shake. The shaking motion is basically characterized as combinations of waves—primarily shear and compression waves. These waves encounter civil engineering structures (buildings, bridges, tunnels, and canals) and cause damage. Civil engineers need to understand the waves to design to reduce the effect the waves will have on the structures. Then the structures can be designed to reduce damage from earthquakes. This chapter presents two demonstrations.

Overview of the Demonstrations

A soft coil spring is used to model compression and shear waves.

Equipment

(See Figure 21-1).

- A long, soft coil spring with many coils that is commercially available;
- Table; and
- Anchor for one end of the coil spring.

Setup Procedure

Anchor the coil spring to a heavy object on the table (Figure 21-2).

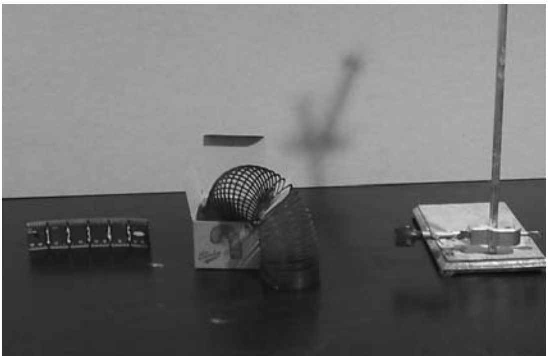


Figure 21-1. Coil spring and an anchor (here, a ring stand and clamp)

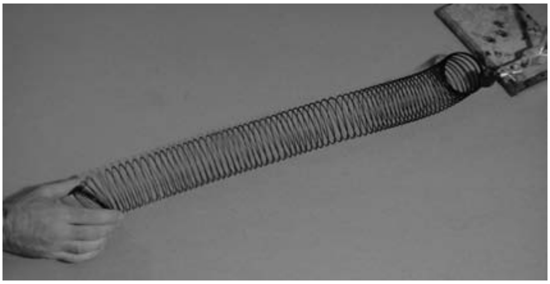


Figure 21-2. Stretching the spring in anticipation of the demonstration

Operation of the Demonstrations

Demonstration 1: Compression Waves

1. Stretch the spring out, away from the anchor (Figure 21-2).
2. Bunch up some of the spring in your hand and release it.
3. Continue to push the spring back and forth, toward the anchor (Figure 21-3).

Demonstration 2: Shear Waves

1. Stretch the spring out, away from the anchor.
2. Slide your hand back and forth, perpendicular to the direction you stretched the spring (Figure 21-4).

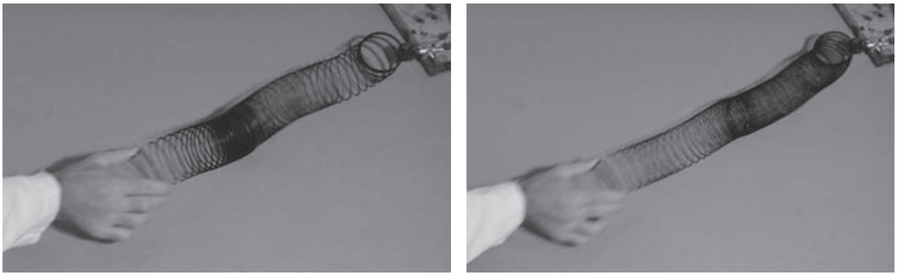


Figure 21-3. Compression wave: left: immediately after release of spring, showing the wave traveling toward the anchor; right: wave returning after bouncing off the anchor

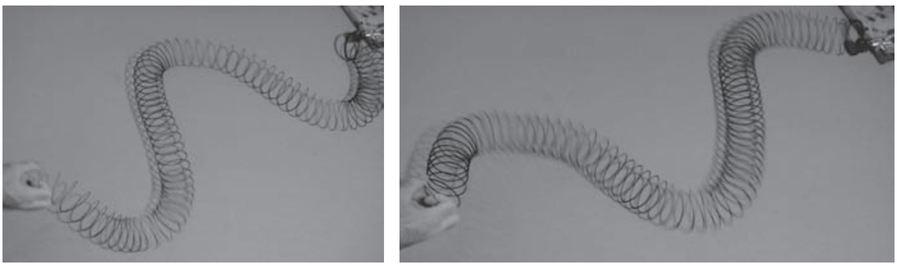


Figure 21-4. Shear wave demonstration; left and right: moving the spring transversely, generating shear waves

VIDEO
A video of this demonstration is available at http://dx.doi.org/9780784413920.video.

Expected Results

Demonstration 1: Compression Waves

The compression wave travels toward the anchor and back a few times, depending on how much you stretched the spring. The compression wave will be visible as a darker area of the spring, traveling. It is darker, because the spring coils are closer together (Figure 21-3).

Demonstration 2: Shear Waves

If you move your hand fast enough, the spring will move back and form S shapes (Figure 21-4). If you move your hand very fast, you can generate a double S.

The results are shown vividly in the video.

Explanation of the Demonstrations

The compression waves are generated by energy imparted in the longitudinal direction. The shear waves are generated by energy imparted in the transverse direction.

The Magic

None available. Suggestions welcomed.

Notes

The compression wave experiment can be done even more effectively by stringing the coil spring over a tight wire strung across the room. The spring is then attached to both walls, and the demonstration is run by compressing part of the spring near a wall and releasing it. This apparatus has much smaller energy losses than the one on the table. The result is that the compression wave will travel back and forth several times without needing to be re-energized. It's also easier for the entire class to see.

Engineering Significance

Earthquake waves shake the ground surface. The type, magnitude, and duration of the waves affect civil engineering structures. In particular, different types of waves affect the structure differently. Typically, shear waves in the plane of the Earth's surface cause more damage than compression waves. Kramer (1995) describes earthquake waves, their effects on civil engineering structures, and geotechnical designs associated with seismic events.

Supplier of Material

- Coil spring (e.g., Slinky)

  Walmart, Inc.
  2900 Pepperell Pkwy
  Opelika, AL 36801
  USA

Reference

Kramer, S. L. (1995). *Geotechnical earthquake engineering*, Prentice Hall, Upper Saddle River, NJ.

22

Soil Bridge in a Tube

Introduction

Cohesionless soils (silts, sands, and gravels) need strength to hold up civil engineering loads, such as bridges, houses, and towers. The strength of the soil is not an inherent property of the soil. The strength depends on the stress that's applied to the soil. This demonstration shows this (Figure 22-1).

Overview of the Demonstration

Cohesionless soil, weak while in a pile on the table, is placed in an inner tube, where it gains strength as if by magic.

Equipment

(See Figure 22-2.)

- Sacrificial bicycle inner tube;
- Scissors;
- Two rubber stoppers, somewhat larger than the inner tube;
- Dry sand; and
- Funnel.

Setup Procedure

Cut a 12-inch piece of inner tube (Figure 22-3).

Operation of the Demonstration

1. Force one of the stoppers into the inner tube. The stopper should be a tight fit. If it isn't, get a bigger stopper.

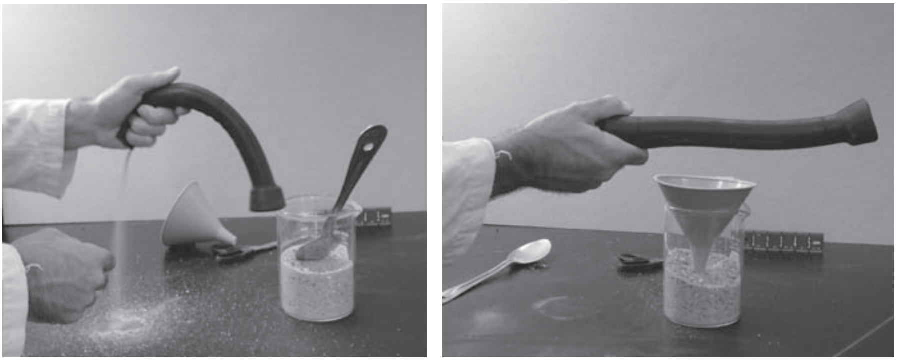


Figure 22-1. Left, before (limp), and right, after (stiff); how does it happen?

Figure 22-2. Spoon, dry sand, funnel, scissors, bicycle inner tube, and stoppers

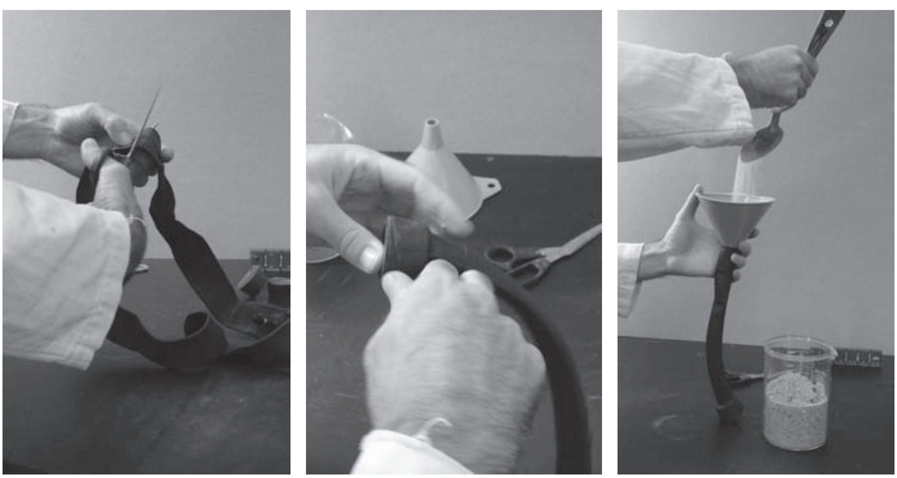


Figure 22-3. Left, cutting the inner tube; center, plugging one end of the inner tube with a stopper; and right, filling the inner tube with dry sand

Figure 22-4. Limp tube with only one rubber stopper in place

2. Using the funnel, pour dry sand into the inner tube, leaving about two inches of air space at the end of the tube (Figure 22-3). Note that this tube, with sand and one stopper, is not very stiff (Figure 22-4).
3. Force the other stopper into the inner tube against the sand. Push hard, so the tube bulges slightly, compressing the sand.

VIDEO
A video of this demonstration is available at http://dx.doi.org/9780784413920.video.

Expected Result

When the second stopper is inserted, the tube, which was formerly flaccid, now is very stiff and can be lifted from one end without bending (Figure 22-5).

Explanation of the Demonstration

With the placement of the soil in a stretched inner tube, the soil has become stronger. This effect is described by the equation for effective stress in combination with the equation for soil shear strength.

Figure 22-5. Tube with stoppers in both ends is now very stiff and strong

Squeezing the sand into the inner tube increases the total stress, σ, on the sand. This results in an increase in effective stress. The effective stress equation is

$$\bar{\sigma} = \sigma - u$$

where

$\bar{\sigma}$ = effective stress;

σ = total stress; and

u = pore (water) pressure (zero, for this experiment, because the sand is dry).

When the effective stress increases, the soil shear strength, τ, increases:

$$\tau = \bar{\sigma} \tan \bar{\phi}$$

where

τ = the shear strength of the soil;

$\bar{\sigma}$ = effective stress; and

$\bar{\phi}$ = the effective angle of internal friction, a soil property.

When the sand is stronger, the formerly flaccid inner tube can no longer bend.

The Magic

The soil, formerly lacking strength as a pile on the table and in the tube before the second stopper is inserted, has become quite strong due to confinement. This is similar to the Iron Glove demonstration (Elton 2001).

Notes

A wider inner tube produces better results than a narrow one. After one demonstration, the inner tube is largely useless to velocipedists.

The stiffened tube may be used as a geotechnical truncheon to keep unruly students in line.

Engineering Significance

Cohesionless soils' strength may be improved by increasing the confining pressure on the soil particles. This is useful in shallow foundation design. Here, column footings are placed *below grade* instead of on the ground surface, so the soils under the footing experience greater confinement and hence greater strength. Not only does this make the building foundation safer, it also allows the use of smaller footings, which saves money.

References

Elton, D. J. (2001). "Soils magic." *Geotechnical special publication 114*, ASCE, Reston, VA.

23

Capillarity and Cotton Balls

(Bonus: Nonwoven Geotextile Strength Demonstration)

Introduction

Capillarity plays a part in soil behavior. The demonstrations in this chapter show the effect of capillarity: it draws things together.

Overview of the Demonstrations

1. A dry cotton ball is observed to be soft and springy. The cotton ball is then wetted, squeezed, and placed in a clear jar of water.
2. An unconfined cotton ball is pulled apart, and a confined cotton ball is pulled apart, sort of.

Equipment

(See Figure 23-1.)

- Cotton ball(s);
- Clear jar of water; and
- Human hand (not shown).

Setup Procedure

Fill a jar with enough water to more than cover a cotton ball.

Demonstration 1: Capillarity

Operation of the Demonstration

Submerge the cotton ball in water. Remove it from the water and squeeze so it's compressed (Figure 23-2). Drop the cotton ball back into the water (Figure 23-3).

Figure 23-1. Fluffy, dry cotton balls and water

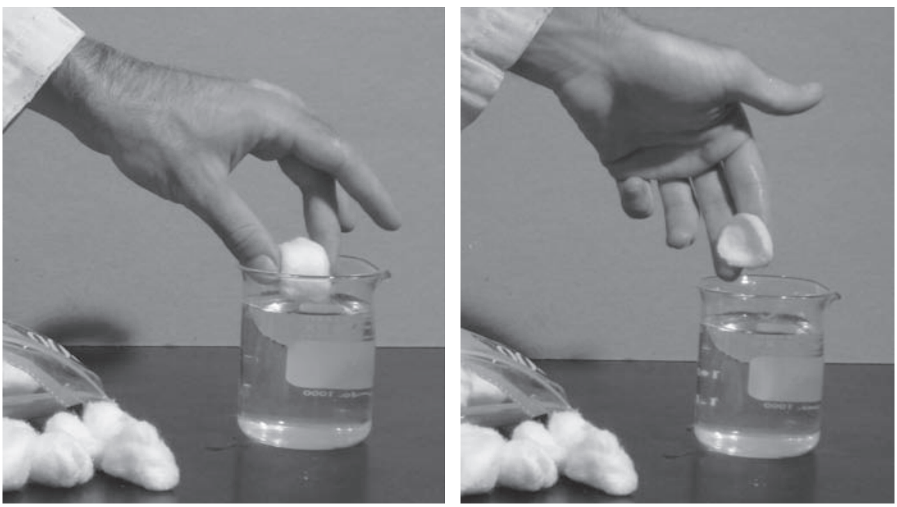


Figure 23-2. Left, placing a large, fluffy, and dry cotton ball in water; right, wet cotton ball that is compressed, small, and flat

VIDEO
A video of this demonstration is available at http://dx.doi.org/9780784413920.video.

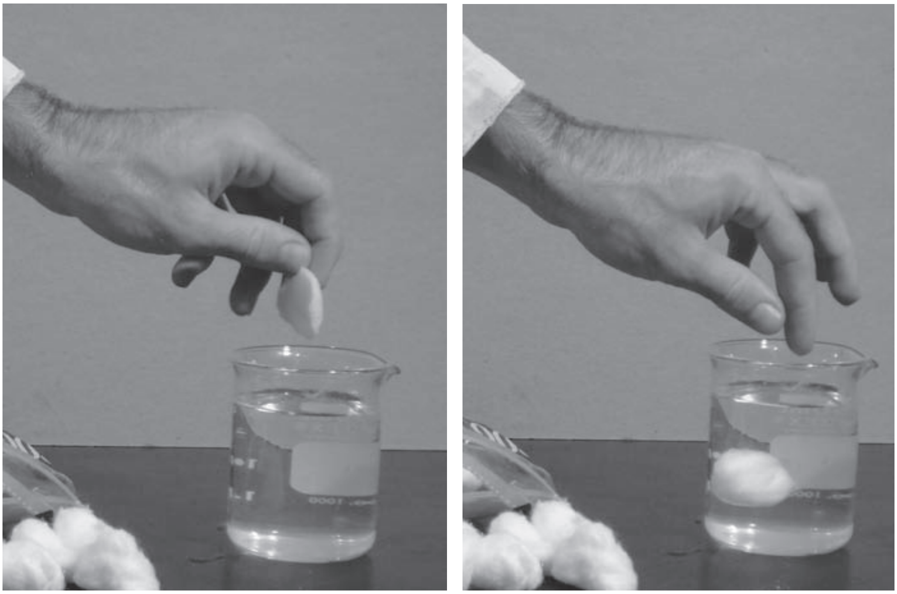


Figure 23-3. Left, replacing the compressed, small, and flat cotton ball in the water; right, *Poof!* cotton ball immediately expands into its large, fluffy condition upon release of capillary tension

Expected Result

When the cotton ball is dropped back into the water, it springs open to the original fluffy shape it had when dry.

Explanation of the Demonstration

In air, the wet, squeezed cotton ball compresses and stays compressed. The reason is that capillary forces from the water pull the cotton fibers together. These forces are caused by the water forming menisci among the fibers. The small fibers have small spaces, causing high capillary forces, holding the fibers together.

When the wet cotton ball is replaced in the water, all the capillary forces immediately release (no menisci occur in a saturated object). This allows the cotton ball to resume its normal, springy shape.

The equation for capillary force is

$$\text{Force} = \frac{2T_s \pi \cos \Theta}{r}$$

where

T_s = surface tension constant for the fluid,
r = radius of the pore opening, and
Θ = contact angle between the fluid and the solid.

The smaller the space among fibers, r, the larger the force holding the fibers together.

The Magic

Most people don't think the squashed cotton ball can become large again while it's still wet. Admire the size and fluffiness of the dry cotton ball. Then add water and compress the ball in front of audience. It becomes a small, wet blob. Challenge the audience to revert the cotton ball back to its original shape *without drying the ball out*. They can't, unless they know to submerge it in water. Put the ball in the water. Once it's below the water surface, voilà! the ball resumes its normal shape. Too cool for words.

Notes

This demonstration never fails. Have a bag of cotton balls handy, so many can try this.

Engineering Significance

Capillary attraction holds soil particles together *as long as the soil is not saturated*. Cut banks of moist soil can stand vertically for a long time because capillary action holds the soil particles together with great force *as long as the soil is not saturated*. The smaller the soil particles, the greater the force. Hence, gravel (large particles) won't stand vertically, but silt (small particles) will. The geotechnical engineer or contractor can confidently cut a moist silt bank and expect it to stand until it dries out or gets saturated. If the soil dries out (removing the capillary menisci) or saturates in a rainstorm or flood (removing the capillary menisci), the soil loses a lot of strength and collapses.

The lesson here is that you can expect moist, fine-grained soils to have some strength, but to lose it if they dry out or get saturated.

Demonstration 2: Nonwoven Geotextile Strength

Setup Procedure

Obtain some cotton balls, the larger the better.

Operation of the Demonstration

This is a two-stage demonstration.

Stage 1: Grasp the cotton ball by the edges and gently pull it apart (Figure 23-4)

Stage 2: Grasp the cotton ball firmly between both index fingers and thumbs, confining the cotton, and attempt to pull the cotton ball apart (Figure 23-5).

Expected Result

Stage 1. The cotton ball pulls apart easily.

Stage 2. While you may tug with great effort, the cotton ball will not pull apart. Seemingly magically, it has gained strength merely be being confined by the fingers and thumbs.

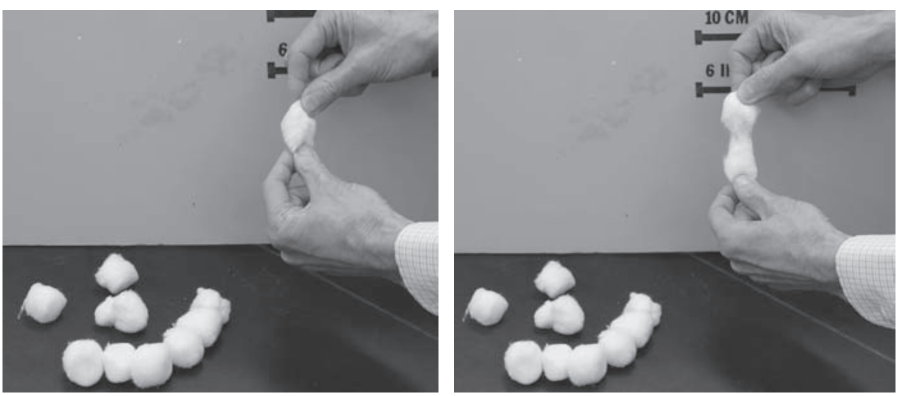


Figure 23-4. Left, grasping the cotton ball by the edges; and right, easily pulling the cotton ball apart

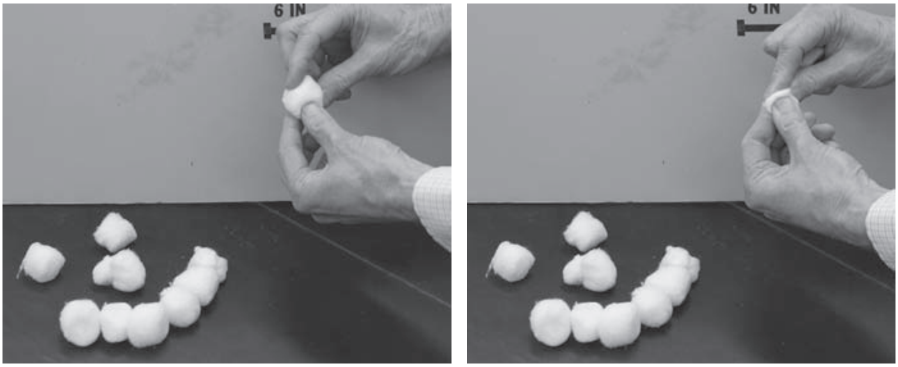


Figure 23-5. Left, confining the cotton ball; and right, having difficulty pulling the cotton ball apart

Explanation of the Demonstration

Stage 1 yields the expected result: cotton balls have little tensile strength when tested in this manner (pulled apart in an unconfined state).

Stage 2, however, yields an unexpected result. The confinement of the cotton ball greatly increases its tensile strength. Here's why. When the cotton ball is squeezed, the fibers are pressed against each other and generate friction, making it hard for the fibers to slide past one another.

The Magic

The cotton ball, unchanged except for confining stresses, has somehow increased in strength. You could use the confined cotton ball to lift heavy objects, while the unconfined ball cannot be used for that purpose. Hook a heavy weight to a wire that hooks to the cotton ball and lift the ball. Without confinement, the ball pulls apart. With confinement, the ball can lift the heavy object.

Notes

Use the largest size cotton ball. Plus sizes preferred.

Engineering Significance

Geotechnical engineers embed nonwoven geotextiles in the ground to strengthen the soil. Nonwoven geotextiles are made of many tiny, tangled fibers, just like the cotton ball. The geotextile adds tensile strength to the soil, which, by itself, doesn't have tensile strength. The geotextile's tensile strength in air (unconfined) may be moderate. However, once the nonwoven geotextile is buried in the ground (confined), the strength increases significantly, just as with the cotton ball. Hence, geotechnical engineers can count on a substantial strength increase once the geotextile is buried.

Interestingly, while the profession can test nonwoven tensile strength *in air* (unconfined), it does not have a test for nonwoven tensile strength *in soil* (confined). Hence, the unconfined (much smaller) strength is used in design.

Supplier of Material

- Cotton balls

  Walmart, Inc.
  2900 Pepperell Parkway
  Opelika, AL 36801
  USA

24

Stick-Slip Behavior

Introduction

Soils subjected to excessive loads from buildings may fail if their strength is exceeded. The strength of soil, however, is not a constant during loading or failure. Failure is initiated after an initial "threshold" strength is exceeded. After that, the force (or stress) needed to keep the soil moving in failure decreases for some soils. This initial, larger force followed by a smaller force is called stick-slip behavior. It is not unique to soils.

Overview of the Demonstration

A block is pulled across a frictional surface with a rubber band by hand.

Equipment

(See Figure 24-1.)

- Rubber band;
- Weight with attachment for a rubber band; and
- Table (carpeting optional, but recommended).

Setup Procedure

Attach the rubber band to the weight.

Operation of the Demonstration

Pull the rubber band, slowly, to get the block moving across the table. Figure 24-2 shows the initial condition. Figure 24-3 shows the weight being pulled across a carpet.

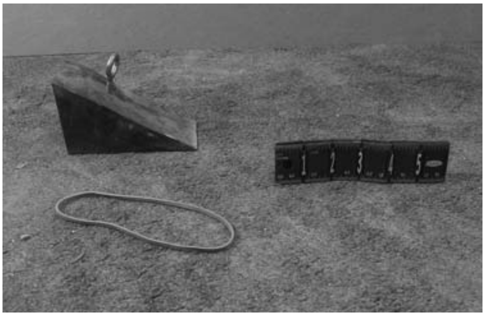


Figure 24-1. Weight, rubber band, and carpeted surface

Figure 24-2. Preparing to pull the weight

VIDEO
A video of this demonstration is available at http://dx.doi.org/9780784413920.video.

Expected Result

As the user pulls the rubber band, the force increases continuously until the weight starts to slide. If the user pulls slowly enough, the user will feel the force decrease slightly as the block starts to slide. The larger force required to initiate movement followed by the smaller force to continue movement is called stick-slip behavior.

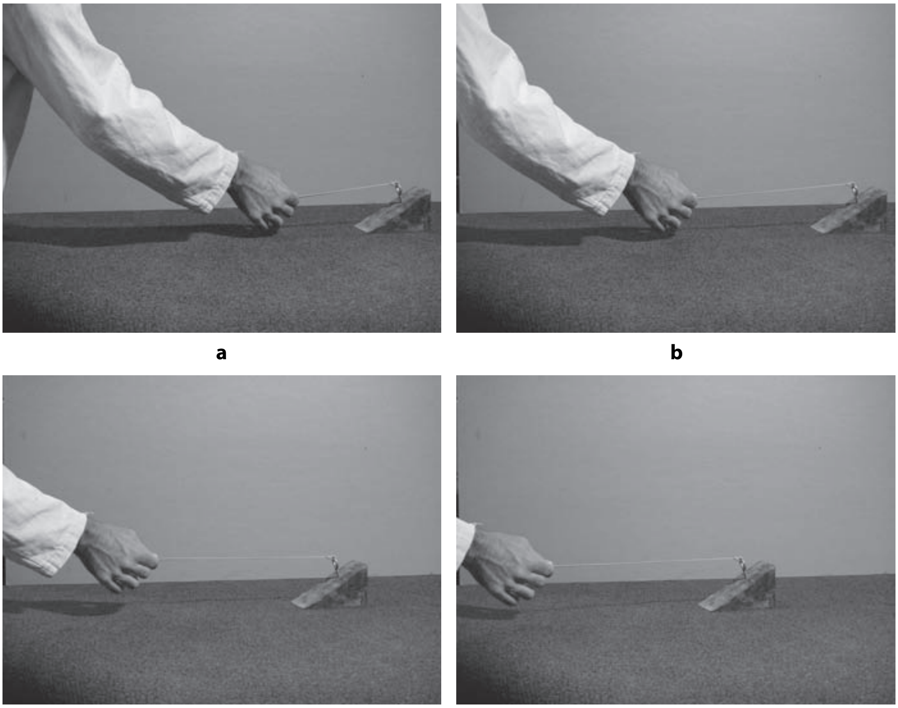


Figure 24-3. a) Initial pulling on the weight; b) more force is applied, but the weight doesn't move; c) static friction is overcome and the weight moves under less force; and d) the weight continues to move with lesser force

Explanation of the Demonstration

Friction comes in three flavors: static, kinetic, and rolling. Stick-slip behavior involves the first two. When the rubber band is pulled, the static friction builds up until failure occurs. Kinetic friction is invoked as the block slides. It may slide so much that the static friction is recovered and the block stops, only to be reactivated by continued pulling of the rubber band.

The Magic

None.

Notes

The figures in this chapter do not illustrate the effect very well. The video is more illustrative. The very best effect is had by doing the experiment.

The experiment simulates two cohesionless soil particles (the weight and the carpet). In geotechnical practice, cohesive soils are more likely to exhibit this stick-slip behavior.

Any size weight will do, in principle, but a larger one (five pounds?) will have a larger difference in forces that is more easily discernible by the user. Here, an iron weight is used. A big box of baking soda or other dense material would also work.

In practice, many materials stick, then slip, then stick again, then slip again, in a pulsing manner. Rocks slipping along faults and causing earthquakes are postulated to move in this manner.

Engineering Significance

Landslides involve soil slipping downhill. The soil may slide, then stick, then slide again. Glaciers, on soil, may slide, then stick, then slide again. Soil particles subject to erosional forces may stick, then slide, then stick again. Perhaps the most researched area in geotechnical engineering concerns rocks slipping along faults, causing earthquakes.

25

Tilt Me up Scotty (Interface Friction)

Introduction

In some civil engineering structures, soils are sometimes placed in contact with non-soils. For example, concrete retaining walls, plastic geomembrane liners, and piles have soil/non-soil interfaces. The designer must know how much friction the soil and the other material can develop to complete the design. This demonstration determines the *interface friction angle*, a measure of this friction.

Overview of the Demonstration

A soil is placed over another material on a table. The table is tilted until the soil slides off. The angle of tilt at the commencement of sliding is measured.

Equipment

(See Figure 25-1.)

- Soil;
- Custom tilt table apparatus (Narejo 2003; Wasti and Ozdüzgün 2001);
- Carpeted plate;
- Woven geotextile plate;
- Nonwoven geotextile plate;
- Geomembrane plate;
- Two test weights, about 3 kg each; and
- Level.

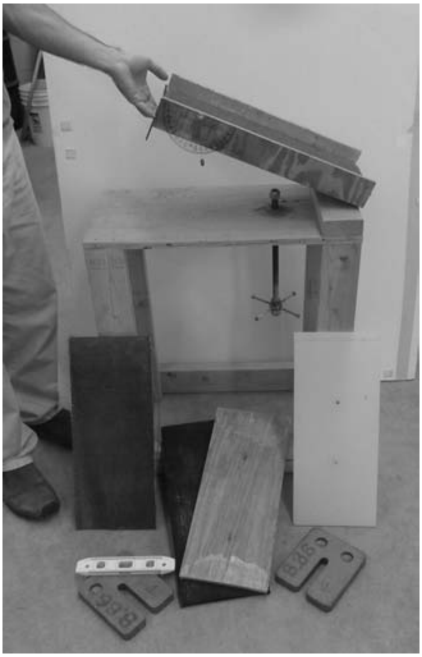


Figure 25-1. Tilt table device: from bottom, weights, level, and boards with varying frictional materials (note the star knob on threaded shaft for raising the table)

Setup Procedure

1. Secure the carpeted plate face up in the bottom of the tilt table.
2. Place the level on the tilt table and adjust the table until it's level (Figure 25-2).
3. Rotate and secure the protractor so the plumb line reads zero or 90 degrees.
4. Place about 0.25 inch of soil on the carpeted plate (Figure 25-3).

Operation of the Demonstration

1. With the apparatus calibrated to zero degrees inclination and the soil in place, set the plate with the material whose interface friction angle is sought face down on the soil, flush with the ends of the table.

Figure 25-2. Leveling the sliding plane prior to operation; use the star wheel to adjust the table

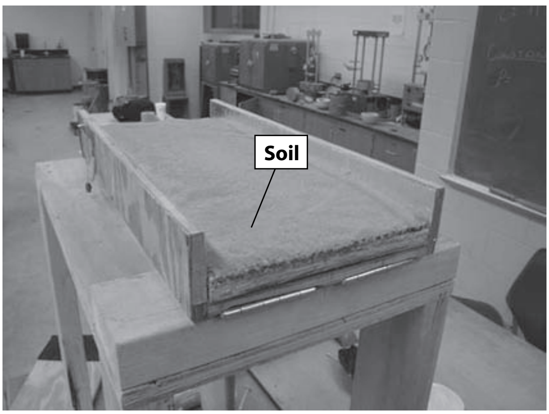


Figure 25-3. Soil placed on carpeted plate

2. Place two weights on top of the face-down plate with the slots in the weights straddling the uphill side of the extruding screw heads (to keep the weights from sliding off the plate onto your toes!). See Figure 25-4.
3. Raise the table by slowly rotating the knob. The interface sliding table surface will begin to tilt. At the critical angle, the top plate with the weights on it will suddenly slide on the surface of the soil. This is the failure point. One-half-inch displacement (or more) is considered failure. Be prepared to catch the plate and the weights, because they slide very quickly off the apparatus and onto your toes.

Figure 25-4. Top plate covering the soil, with weights in place

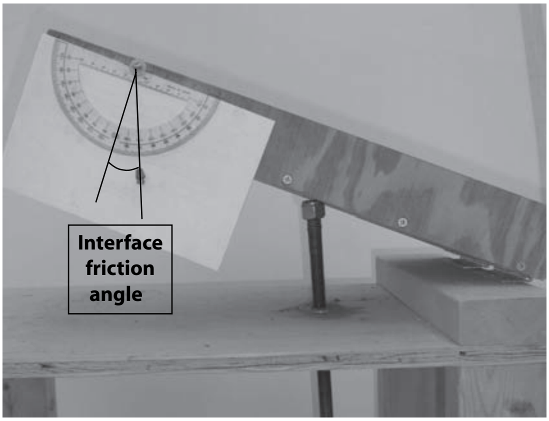


Figure 25-5. Protractor and plumb bob on tilt table, showing interface friction angle

4. At failure, stop rotating the knob and record the angle measured by the protractor and the plumb line (Figure 25-5).
5. Lower the table, recalibrate to zero degrees inclination, and repeat the process with the other plates.

Expected Result

The measured angle is the interface friction angle between the test plate and the particular soil. This number is used in geotechnical designs.

Explanation of the Demonstration

A cohesionless soil fails when the shear stress applied exceeds the soil shear strength. For dry sands, the failure shear strength, τ, is a function of the normal stress, σ, on the soil and the interface friction angle, δ.

$$\tau = \sigma \tan \delta$$

The ratio τ/σ is constant, which is why you can use any set of weights and get the same δ. That is, if you increase the magnitude of the weights (which changes σ), τ increases proportionally, yielding the same value of $\tan \delta$.

The Magic

None. Some experiments are like that.

Notes

You can use any material on the upper plate. Here, geosynthetics were used. A piece of wood or concrete (common civil engineering materials) can also be used. The trick is to use the same material in the test that will be used in the field, because small differences in surface texture yield large differences in δ. However, this is not always easily done.

Engineering Significance

The capacity of a pile, driven in sand, depends on the soil friction developed on the sides of the pile. The pressure a sand puts on a retaining wall depends on the amount of friction at the soil/wall interface. The stability of a slope of municipal solid waste in a landfill depends on the waste/geosynthetic interface friction angle. Each design includes the shear strength at the interface, which can be calculated only if δ is known.

The Tilt Table

The tilt table was built by graduate student Daniel Pitts following the directions given in Narejo (2003). The materials cost less than US$50 (2005). The graduate student labor was, of course, free.

References

Narejo, D. B. (2003). "A simple tilt table device to measure index friction angle of geosynthetics." *Geotextiles and Geomembranes*, 21(1), 49–57.

Wasti, Y., and Ozdüzgün, Z. B. (2001). "Geomembrane-geotextile interface shear properties as determined by inclined board and direct shear box tests." *Geotextiles and Geomembranes*, 19(1), 45–57.

26

Soils Relaxing (the Angle of Repose)

Introduction

Cohesionless soil strength depends on the soil's mineral type, particle size, and particle shape. This demonstration shows the role of particle shape in the soil's strength.

Overview of the Demonstration

Three gravels, with differently shaped particles, are dumped on the table, forming three piles.

Equipment

(See Figure 26-1.)

- Three gravels, with differently shaped particles, about a quart of each;
- Table (carpeted optional, but recommended); and
- Protractor (optional).

Operation of the Demonstration

1. Dump each gravel in a separate pile on the table.
2. If a protractor is handy, measure the angle each gravel pile makes with the table.

Expected Result

Each gravel will form a pile with a certain side slope. All will be different. The gravel with the most rounded particle shape will have a flatter slope,

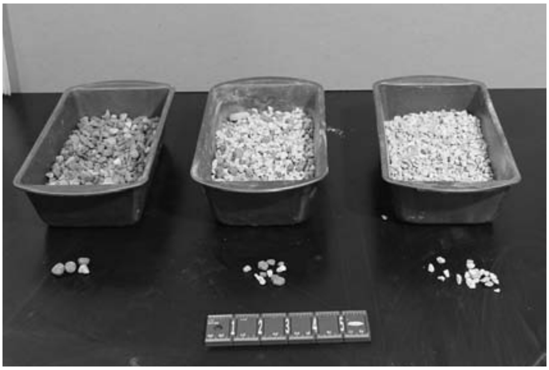


Figure 26-1. Three differently shaped gravels (left to right): rounded, subrounded, and angular

Figure 26-2. Three piles of gravel (left to right): rounded, subrounded, and angular; note the increasing slope angles

while the most angularly shaped gravel will have a steeper slope (Figure 26-2).

Explanation of the Demonstration

Soil strength is related to soil particle shape. More angular soil particles develop higher stresses at the points of contact with each other, generating higher strength. The flat situation produces less stress. The higher-stress situation (angular particles) produces higher strength, which makes it harder for the soil particles to move around (the mass has higher strength) and slide downhill. Hence, the rounded particles slide into a flatter configuration (Figure 26-2, leftmost pile) than the angular particles.

The *angle of internal friction*, ϕ, is the geotechnical engineer's way of describing the strength of dry, cohesionless soils (silts, sands, and gravels). The slope angle of a soil at rest is called the *angle of repose*. For dry cohesionless soils, ϕ is approximately equal to the angle of repose. Hence, this experiment is an inexpensive way to estimate ϕ. Usually, ϕ is determined from an expensive laboratory test, such as the direct shear or triaxial test.

The Magic

None.

Notes

The greater the differences in angularity are, the more pronounced the differences in the angles of the piles. You could use glass marbles or BBs for the rounded "particles" to see the most extreme differences. They won't pile up at all!

Dumping the gravels on a rough surface, rather than on a smooth table, will produce greater differences in the angles of repose. The demonstration in Figure 26-2 used a piece of carpet on the table.

Engineering Significance

The strength of a soil is critical to civil engineering work. Almost all built structures rest on soil foundations, making strong soils as foundations very important. Angular soils provide a much higher strength than rounded soils do. When evaluating a building site for a project, the geotechnical engineer considers the shape of the soil particles.

27

Falling Head over Heels for Permeability (the Permeability of Oobleck)

Introduction

Clay soil permeability is the measure of how easily water flows through soil. Geotechnical engineers measure this in the laboratory using the very slow falling head test. Those teaching undergraduate geotechnical laboratories use this test. However, finding a soil that produces data in this test in a few hours, the usual time for an undergraduate laboratory, is difficult. This chapter explains how to use corn starch to produce a “soil” that gives reasonable falling head permeability data in minutes instead of days. The wet corn starch is pretty gooey stuff (Figure 27-1).

Overview of the Demonstration

Corn starch is mixed with water and placed in a falling head permeability apparatus to simulate testing permeability of a soil.

Equipment

(See Figure 27-2.)

- Falling head permeability testing apparatus,
- Filter paper,
- Water,
- Corn starch, and
- Bowl.

Figure 27-1. Does this gooey stuff have a place in the soil lab?

Figure 27-2. Standard hardware needed for the falling head test, plus corn starch

Setup Procedure

Mix corn starch with water in a bowl until it has the consistency of oobleck. Oobleck is corn starch mixed with enough water so that the mixture slowly drips through your fingers (Figure 27-3).

Operation of the Demonstration

Place the oobleck in the falling head apparatus (Figure 27-4) and assemble the apparatus, then run the falling head test in the normal fashion (e.g., Bowles 1992). Use about 100 cm of head difference.

Figure 27-3. Oobleck at the correct consistency

Figure 27-4. Placing oobleck in the falling head device (left) and assembling the falling head device (right)

Expected Result

For 100 cm head difference, the oobleck will give a permeability of about 10^{-5} cm/sec in about ten minutes, allowing you to run the test several times in a typical laboratory period.

Explanation of the Demonstration

Many undergraduate geotechnical laboratory books, including Bowles (1992) and Liu and Evett (2008), provide an explanation of soil hydraulic conductivity. The essence of the test is that water flows through a soil sample at some measured rate. The coefficient of permeability is calculated from the amount of water that flowed through, the time to do it, and the elevation difference between the higher and lower water surfaces.

The Magic

None. Although playing with oobleck is pretty cool. See Elton (2001).

Engineering Significance

Soil permeability is used in the design of dams, roads, foundations, walls, slopes, ponds, sediment control structures, and landfills. It's important for soils to drain quickly, to maintain their strength. The coefficient of permeability is used to calculate how fast a soil will drain. Conversely, low drainage is needed when the soil is used for, say, a canal lining or a landfill liner, where water retention is desired.

Supplier of Materials

- Soil permeameter

  Durham Geo Slope Indicator
  2175 West Park Court
  Stone Mountain, GA 30087
  USA
  http://www.durhamgeo.com

References

Bowles, J. E. (1992). *Engineering properties of soils and their measurement*, 4th ed., McGraw-Hill, New York.

Elton, D. J. (2001). *Soils Magic, Geotechnical special publication 114*, ASCE, Reston, VA.

Liu, C., and Evett, J. (2008). *Soil properties: testing, measurement, and evaluation*, 6th ed., Prentice Hall, Upper Saddle River, NJ.

28

Bulking of Soils (AKA: Less Soil for Your Money)

Introduction

After soil is purchased, it is excavated, placed in dump trucks, and taken to the site where it'll be used. If you purchase, for example, 20 cubic yards of soil as measured in the ground, you'll need a truck that carries more than 20 cubic yards to carry it away because the soil fluffs up during excavation. This increase in total volume is termed *bulking* and can be demonstrated in a beaker. See Figure 28-1.

Overview of the Demonstration

Dry and moist sand are put in separate beakers. The cylinders are emptied and then refilled. The moist sand exhibits a large increase in volume.

Equipment

(See Figure 28-2.)

- 2 1-L beakers,
- 2 L of dry sand, and
- Water.

Setup Procedure

1. Fill the two beakers with dry sand.
2. Add about 100 ml of water to one beaker and let it soak in. The water must not saturate the sand, only make it moist. There should be enough water so that all the sand is moist. The exact amount will vary depending on the sand. After the water has

Figure 28-1. What's going on here? Swelling soil?

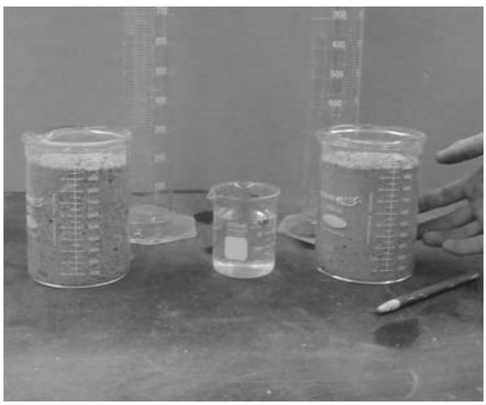


Figure 28-2. Two liters of dry sand, separated by 200 ml of water

soaked in, both beakers will still have the same volume of sand in them (Figure 28-3).

Operation of the Demonstration

1. Tip the dry sand beaker onto the lab desk. This represents "excavation" at the borrow pit (Figure 28-4).
2. Replace the sand in the beaker and note the volume (Figures 28-5 and 28-6).

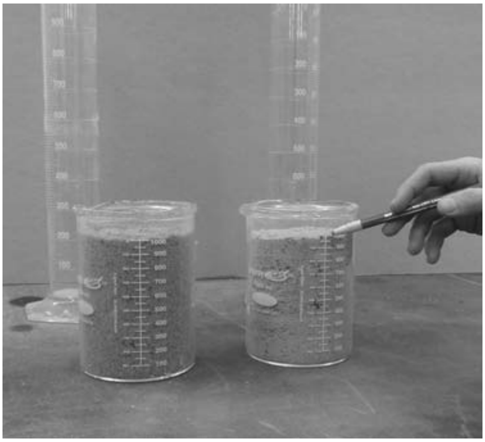


Figure 28-3. Moist sand (left) and dry sand (right)

Figure 28-4. Pouring dry sand out

Figure 28-5. Replacing dry sand in the beaker

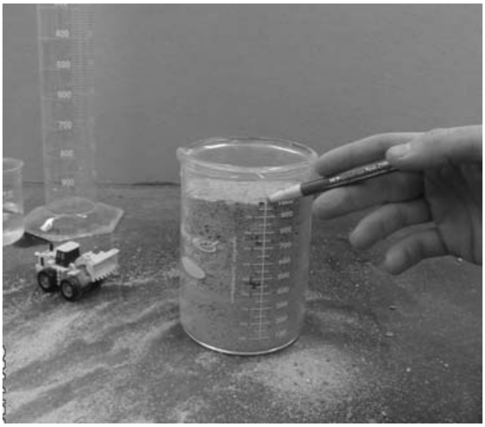


Figure 28-6. Replaced dry sand fills the beaker to the same level

Figure 28-7. Emptying moist sand onto the table

3. Tip the moist sand beaker onto the lab desk. This represents "excavation" at the borrow pit (Figure 28-7).
4. Replace the sand in the beaker and note the volume (Figures 28-8 and 28-9).

Expected Result

The volume of dry sand won't change much, if at all. However, the moist sand volume will increase significantly (Figure 28-9).

Figure 28-8. Replacing the moist sand in the beaker

Figure 28-9. Comparison of replaced moist sand (left) and dry sand (right)

Explanation of the Demonstration

This is an effective stress phenomenon. The effective stress equation is

$$\bar{\sigma} = \sigma - u$$

where

$\bar{\sigma}$ = effective stress,

σ = total stress, and

u is pore (water) pressure.

The strength of the sand is directly related to $\bar{\sigma}$, which is related to the water pressure. The higher the effective stress, the higher the strength is. The water pressure in the dry sand never changes during this experiment, because there's no water. When dry sand is excavated, its effective stress, and hence strength, do not change so it retains its original volume. Or very close to it.

The moist sand, however, has water pressure: negative water pressure. When the moist sand is "excavated" (taken out of the beaker), its effective stress increases because of the *negative* pore water pressure due to capillarity. This increase in effective stress increases the strength. Being stronger, the soil does not collapse back to its original volume, but stands open in a larger volume.

The Magic

The Soils Magician has been unable to dream up a magical exercise to accompany this demonstration. Suggestions welcome.

Notes

Don't put too much or too little water in the beaker. Too much water, and the sand saturates, may fluidize, and may collapse to its original height. Too little water, and the capillarity won't be sufficiently pronounced to increase the sand's strength enough to stand open (bulk) in a larger volume. A fine-grained sand works best. Use clean sand; silt or clay obscures the effect.

Engineering Significance

Contractors purchase soil from vendors by the cubic yard/meter *in place*. The volume paid for is excavated at the borrow pit and hauled away in trucks (or similar). How many trucks making how many trips must be estimated to establish the project budget. The volume of *excavated* soil must be estimated to do this. Having done this experiment, you now understand how the increase in volume arises. However, as a profession, we don't have a good way to quantify it. If you have one, let the author know, and we'll get rich together.

This experiment showed the soil *increasing* in volume when excavated. Dry, extremely loose soils may *decrease* in volume when excavated. That is, the effect may be either positive or negative (you may get more *or* less for your money).

29

Geotextile Puncture Test

Introduction

Geotextiles are plastic cloths used in civil engineering applications such as for strengthening soils and filters for water and soils. Geotextiles are used in retaining walls, embankments, and drains, and for under-footing reinforcement. The geotextile must be strong enough to withstand field installation, where it may be subject to a lot of forces or stresses from construction equipment. Typically, these forces or stresses are unknown to the designer. The geotextile profession has adopted a set of semi-empirical criteria to help evaluate whether the geotextile will withstand certain stresses. One of these is called the California Bearing Ratio (CBR) puncture, which is ASTM specification D5514 (ASTM 2011).

Overview of the Demonstration

A piece of geotextile is cut out, held in a ring, and then punctured with a California Bearing Ratio piston.

Equipment

- Geotextile (use landscaping fabric) sample, about 12 inches square (woven geotextiles produce more dramatic results than nonwoven geotextiles);
- Utility knife;
- CBR mold;
- Custom rings (two);
- Bolts and nuts (four each); and
- CBR piston and test frame.

Figures 29-1 and 29-2 show the equipment. The rings are made from 3/16-inch metal. One of the rings has a recess on it that conforms to the top of the CBR mold. This is not required, but is convenient for centering the ring on the CBR mold. The rings need not be circular, but the large hole must be circular and the same diameter as the CBR mold (six inches). Each ring has four bolt holes (5/16 inch) that are outside the diameter of the CBR mold. Later the bolts will be put through the holes and must not interfere with the edge of the mold. Coarse sandpaper glued to the surface of the rings in contact with the geotextile helps ensure success.

Figure 29-1. Geotextile puncture hardware: clockwise from lower right, two metal rings with holes, bolts, nuts, CBR mold, geotextile with utility knife; not shown: CBR piston and test frame

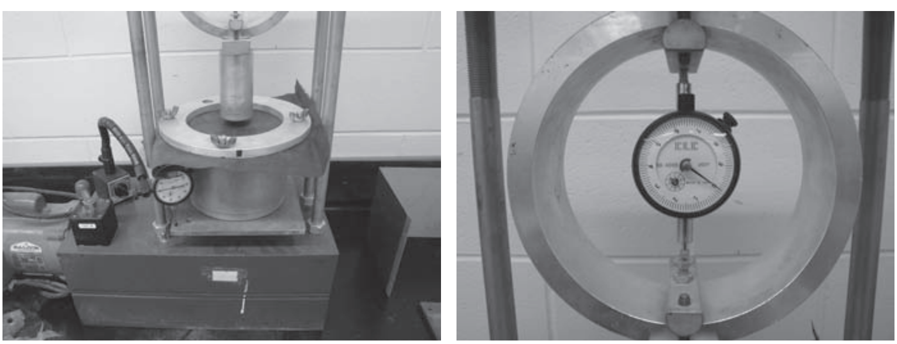


Figure 29-2. Left, sample in CBR apparatus, ready for testing; right, proving ring dial, used to calculate the force

Setup Procedure

1. Cut a 12-inch square of geotextile with the utility knife.
2. Lay one of the rings on the geotextile and mark the holes with a piece of chalk (Figure 29-3).
3. Cut a small X with the knife at each chalk mark (Figure 29-4).
4. Place the bolts pointing up from the bottom of the ring, which has the sandpaper surface facing up.
5. Place the geotextile over the bolts at the X marks.
6. Place the upper ring, sandpaper surface down, over the bolts.
7. Attach the nuts to the bolts and tighten. Wings nuts, finger tight, are adequate (Figure 29-5).
8. With the geotextile clamped between the rings, center the rings on the CBR mold and center the mold in the CBR test frame.

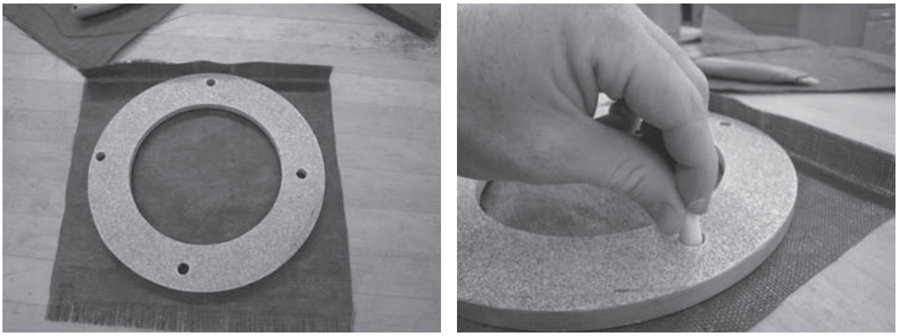


Figure 29-3. Laying out the geotextile and marking the holes with chalk

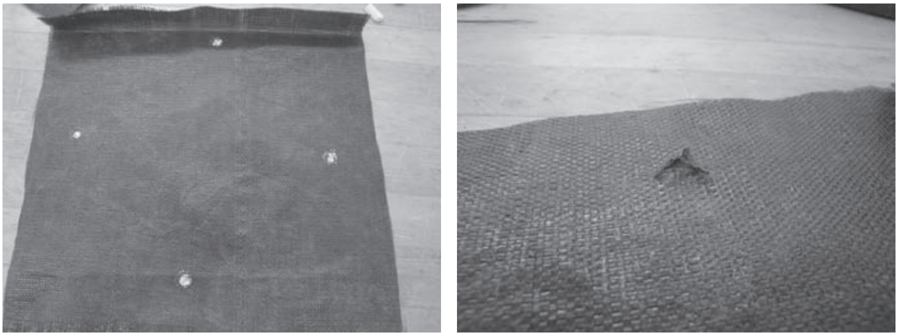


Figure 29-4. Left, marked holes, and right, cut hole

Figure 29-5. Left to right: inserting the bolts, placing the geotextile, and laying the top ring on the geotextile

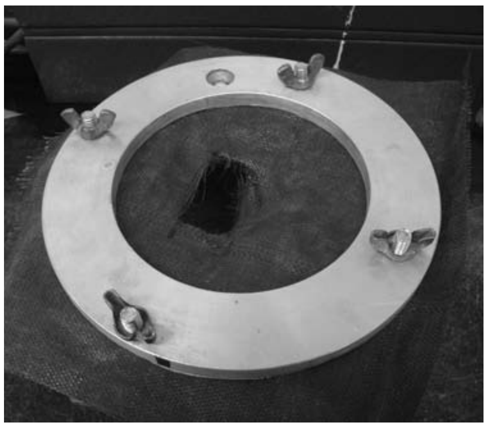


Figure 29-6. Failed geotextile specimen

Operation of the Demonstration

1. Place the assembly of rings, geotextile, and CBR mold in the CBR compression apparatus (Figure 29-2).
2. Push the CBR piston into the geotextile until the geotextile breaks (Figure 29-6). Monitor the dial gauge in the proving ring to record the maximum force—called the CBR puncture force—required to break the geotextile.

Expected Result

The geotextile will deform with increasing load until the geotextile breaks. A loud noise is associated with especially strong woven geotextiles.

Explanation of the Demonstration

The geotextile withstands the force until it breaks. Nothing unusual here.

The Magic

No magic is associated with this experiment. Sorry.

Notes

The stronger the woven geotextile is, the louder the noise when it breaks, which is especially useful in this demonstration. Nonwoven geotextiles, while they have significant CBR puncture forces, do not fail with a loud noise and are not recommended for demonstration purposes.

Engineering Significance

Geotextiles are used in rough field environments. The geotextile must survive installation to perform its function in service. The CBR puncture test is a simple measure of the geotextile's ability to resist installation forces. AASHTO specification M288 (AASHTO 2006) gives this and other geotextile survivability specifications.

Supplier of Materials

- CBR puncture piston and load frame

  Durham Geo Slope Indicator
  2175 West Park Court
  Stone Mountain, GA 30087
  USA
  http://www.durhamgeo.com

References

AASHTO. (2006). "Standard specification for geotextile specification for Highway applications." *M288-06*, Washington, DC.

ASTM. (2011). "Standard test method for large scale hydrostatic puncture testing of geosynthetics." *D5514-06*, West Conshohocken, PA.

30

Soil Dilation and Compaction Using Ping Pong Balls

Introduction

Dense soils dilate when sheared. Loose, cohesionless soils collapse when vibrated. This simple apparatus demonstrates both behaviors.

Overview of the Demonstration

The instructor demonstrates dilation and the effect of vibratory compaction on cohesionless soils.

Equipment

- Custom, clear plastic box, with a slot open halfway up two adjacent sides; and
- 27 ping pong balls, glued together in three nine-ball layers; use 18 yellow balls and nine white ones.

Setup Procedure

Place the layers of balls in the plastic box, with the white balls in the middle layer.

Operation of the Demonstration

1. Show the apparatus to the students, with the balls in the configuration shown in Figure 30-1 (balls in densest state). Explain that the ping pong balls represent soil particles.
2. Push the middle layer into the box.
3. Then, with the balls as shown in Figure 30-2, shake the box gently.

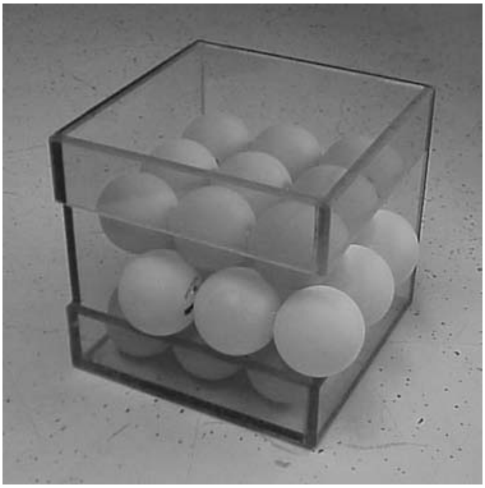


Figure 30-1. Before shearing

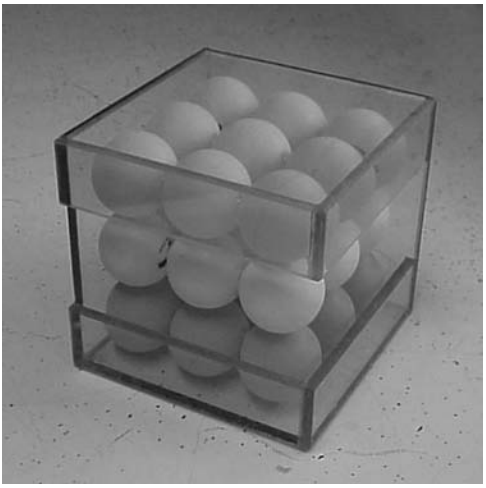


Figure 30-2. After shearing (more volume)

Expected Result

When the middle layer is pushed into the box (soil shearing), the top layer moves up (Figure 30-2). This is soil dilation—the soil mass increases in volume when sheared.

With the balls as shown in Figure 30-2, the box is shaken gently. The ping pong balls then rearrange themselves into the denser, Figure 30-1 configuration. This is the result of vibratory compaction.

Explanation of the Demonstration

The explanation is simply that when tightly packed (dense) soil particles are moved, the soil mass (not the individual particles) increases in volume, creating more void space.

Conversely, when loose cohesionless soils are vibrated, they move together into a denser configuration.

Notes

Use of two colors of ping pong balls makes the demonstration easier to see. The balls are glued together with contact cement, because it remains flexible and is less likely to break compared with brittle glues. It will likely be necessary to repeat the demonstration a few times, because the effect is somewhat subtle.

Engineering Significance

Soil dilation, in saturated soils, causes a negative pore pressure, u. This negative pore pressure increases effective stress. The effective stress equation is

$$\bar{\sigma} = \sigma - u$$

where

$\bar{\sigma}$ = effective stress,

σ = total stress, and

u = pore (water) pressure.

When the effective stress is increased, the strength of the soil increases. So, for example, when a hillside is excavated, a dense soil will dilate a bit. If there's water in the soil, the pore pressure goes negative, and the strength increases. Hence, the ability of some soils to stand vertically if they are in a dilated condition. This is a temporary condition, though. As time passes, other water (rainfall, groundwater, etc.) is sucked into the soil and dissipates the negative pore pressure, weakening the soil (u goes up, strength goes down), leading to a landslide.

31

Campus Geology Tour

Introduction

Geologic materials are used in many civil engineering projects. This exercise helps people recognize this and gain an appreciation for it.

Overview of the Demonstration

Students are sent on a quest to discover geologic materials used in civil engineering. They take pictures and report back.

Equipment

- Camera (a smartphone will do), and
- Good observational skills.

Setup Procedure

Provide some instruction on what type of geotechnical materials are commonly seen in construction. You can offer example applications and use maps with specific areas of investigation, which adds a certain novelty and excitement.

Operation of the Demonstration

Send students, perhaps to given area, to take pictures and/or video record geotechnical materials in use in civil engineering applications. Have the students collect enough information to prepare a presentation on the materials they found, using the pictures garnered from the exercise. They should include use, type, and location. Figure 31-1 shows four different geologic materials.

Figure 31-1. Civil engineering building at Auburn University, showing limestone, brick, concrete, and slate (roof). Also, the birthplace of Soils Magic

Expected Result

Students return with pictures or video of geologic materials used in civil engineering projects, including concrete, limestone, granite, marble, slate, brick, and miscellaneous stone.

Explanation of the Demonstration

Hopefully, no explanation is needed—most people can identify a rock. Students may be asked to prepare a presentation (best) and a report.

Notes

This exercise is best done in conjunction with lectures on geology and a laboratory exercise on rock identification. Different rock classes and types are identified in class and are then found in the field.

Engineering Significance

Geologic materials have long been used to build civil engineering facilities. Their availability, price, and durability are attractive to owners.

32

Settlement Rates of Soils in Jars

Introduction

Soil erodes and finds its way into streams and lakes. If the soil stays in suspension, it causes harm to wildlife. This demonstration shows that soils have different suspension times.

Overview of the Demonstration

Different soils are put in water-filled jars and shaken. The jars are left on a table. The soil settles (comes out of suspension) in the jars.

Equipment

(See Figure 32-1.)

- About 50 g of four different soil types,
- Four clear pint jars with lids, and
- Water.

Setup Procedure

1. Place the four different soils in four different jars.
2. Fill each jar with water and cap and shake the jar (Figure 32-2).

Operation of the Demonstration

Wait.

Figure 32-1. Water, four jars with four soil types (left to right): bentonite, kaolinite, silt, and coarse silty sand

Figure 32-2. Left, adding water to the jars; center, jars awaiting caps; and right, capped jar being shaken

VIDEO
A video of this demonstration is available at http://dx.doi.org/9780784413920.video.

Expected Result

The soils will settle in the water at different rates (Figure 32-3).

Explanation of the Demonstration

How long soil particles stay in suspension in water depends on the particle size. Larger particles settle more quickly than smaller ones. Very fine particles may stay in suspension indefinitely because of Brownian motion—another fascinating topic; see, for example, Holtzclaw et al. (1984).

Figure 32-3. Left, jars immediately after shaking; right, jars two hours later, showing differential settlement

The Magic

None.

Notes

This demonstration used bentonite (a clay), kaolinite (a clay), a local silt, and coarse silty sand.

Don't put too much soil in the jars, or it may take too long to settle.

Challenge students to find their own soils and test settling rates.

Engineering Significance

Silts and sands settle quickly, while clays take more time. Some clays settle more quickly than others. Because finer soils take more time to settle, it's particularly important to keep these from entering creeks and lakes, where they will stay in suspension for a long time, troubling wildlife. This is the reason that silt fences are designed to catch very fine soil particles running off construction sites during rain events, before the soil particles reach a creek or lake.

Supplier of Material

- Canning jars

  Kroger Supermarket
  300 North Dean Road
  Auburn, AL 36830
  USA

References

Holtzclaw, H. F., Robinson, W. R., and Nebergall, W. H. (1984). *College chemistry with qualitative analysis*, D.C. Heath and Co., Lexington, MA.

33

Bearing Capacity (Bigger Is Better)

Introduction

Buildings are often held up by footings underneath the columns. If the soils are too weak or the column load is too big, the footing plunges into the earth in a bearing capacity failure. This exercise demonstrates bearing capacity by identifying the three principal modes of shear failure using various arrangements of piles, foundations, loads, and the factors that contribute to increasing bearing capacity.

Overview of the Demonstrations

A special clear plastic box, filled with short wooden dowels, is subject to model footings, loaded to failure. The movement of the dowels shows the failure planes. These are predicted from bearing capacity theory.

Equipment

(See Figure 33-1.)

1. Custom bearing capacity box, filled with hundreds of 0.25-inch × 3-inch wooden dowels;
2. Board, about 0.5 inches thick, covered with rough sandpaper, slightly narrower than the box;
3. Two iron weights, approximately five and ten pounds, slightly narrower than the box and about three inches wide; and
4. Small board, with twice the footprint of the five-pound weight.

Setup Procedure

Fill the box with the dowels to within an inch or so of the top. This takes some time. You can run three demonstrations with this setup.

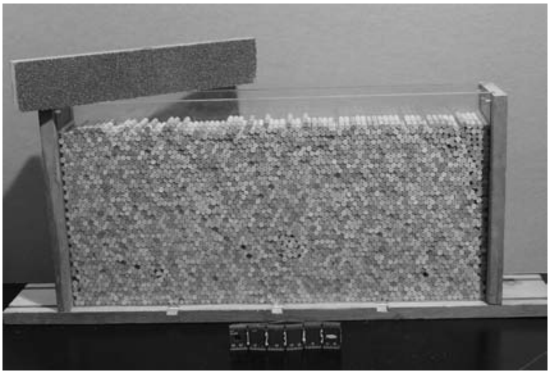


Figure 33-1. Box containing hundreds of three-inch wooden dowels and sandpaper-covered board, above; weights are not shown

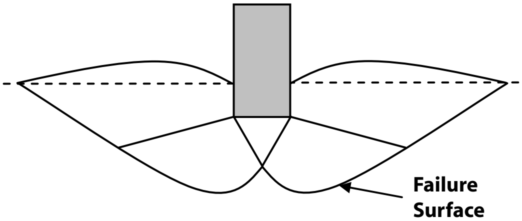


Figure 33-2. General shear failure

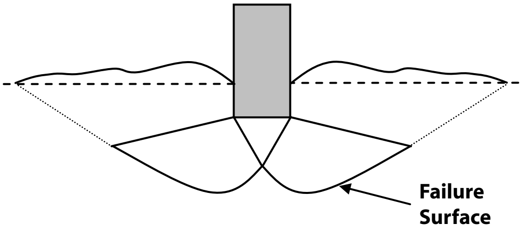


Figure 33-3. Local shear failure

Operation of Demonstration 1

Re-create the three principal modes of bearing capacity failure using a block. Place the block on the surface of the dowels and press down until the dowels move. *While the block is moving*, the general shear failure planes can be seen in the dowels (Figure 33-2). If the dowels are looser, it may be possible to see local shear (Figure 33-3). Even looser, and punching shear may be observed (Figure 33-4).

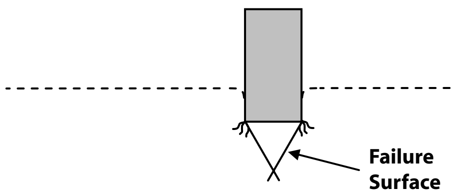


Figure 33-4. Punching shear failure

VIDEO
A video of this demonstration is available at http://dx.doi.org/9780784413920.video.

Expected Result

The failure surfaces should be noticeable while the "footing" is moving. You have to repeat it several times until your eyes acclimate to the movement.

Explanation of the Demonstration

The experiment demonstrates that the soil does not fail randomly and that not all soil particles move when a footing fails in bearing capacity. Instead, the soil fails along distinct failure surfaces, which are modeled by the equations used to predict bearing capacity of footings on soil.

Operation of Demonstration 2

When a load is added near a retaining wall, it causes additional soil pressure that can cause wall failure. Demonstrate this by inserting the board into the box full of dowels and then removing about four inches of dowels from one side of the board. The board simulates a retaining wall. Place a weight on the high side of the wall.

Expected Result

If the weight is heavy enough, the wall moves. If you watch carefully, you'll see the soil moved along a failure plane, demarking a soil failure wedge extending from the base of the wall to the surface of the dowels (Figure 33-5).

Explanation of the Demonstration

Shear strength theory of particulate media predicts that only some of the soil behind the wall is stressed when loads are placed behind the wall. This is shown by the plane where the soil fails, which is the locus of overstressed soil particles.

The theory predicts that the angle of the failure surface will be ($45 + \phi/2$) degrees from the horizontal. Here, ϕ is the angle of internal friction of the soil, a measure of the soil strength.

Operation of Demonstration 3

Demonstrate how the width of a foundation increases the bearing capacity of the soil. Bearing capacity is the *stress* that the soil takes, not the *load*. To carry out the demonstration, put a weight on the dowels that just barely causes the dowels to fail. Repeat the demonstration, but with twice the weight and a small board under the weight that doubles the contact area ("footprint"). See Figure 33-6.

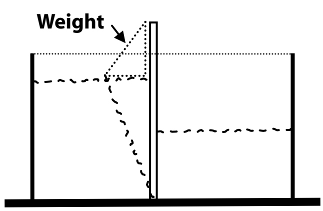


Figure 33-5. Model retaining wall with load behind it

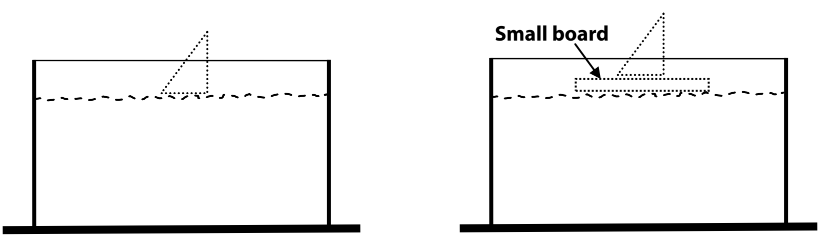


Figure 33-6. Small footing on left and larger footing on right; the triangular object is a steel weight

Expected Result

The first weight plunges into the dowels. The second weight does not.

Because the stresses on the dowels are the same, the uninitiated will expect both weights to cause failure.

Explanation of the Demonstration

Divide the first weight by its footprint to get the stress on the dowels, calculating the stress. This produces the bearing stress that caused the soil to fail.

Divide the second weight by its footprint to get the stress on the dowels. It is the same stress as the first weight's stress. Yet, the soil didn't fail.

Bearing capacity of soil is related to the soil itself *and* to the size of the bearing area. The larger bearing area confines the soil under it, making it stronger (i.e., capable of withstanding more stress). Cohesionless soils, in this case, dowels, gain strength when pressed together under a load, such as a footing. A larger area load presses more soil together, generating higher strength. This is true for all sandy soils, but not necessarily for clays. Another way of saying this is that a given soil's strength is not constant.

The Magic

Use weights that are even multiples of each other in weight and in contact area (e.g., four-pound weigh with eight square inches and an eight-pound weigh with 16 inches^2; one is "twice" the other). The lesser weight should just cause bearing capacity failure. Tell the audience the larger weight is twice the size of the smaller one, so it should cause failure (!!), right? Cast a spell on the larger weight:

> On this weight,
> I cast a spell.
> It will not fail,
> It will do well!

The larger weight will not cause the soil to fail, because the bearing *capacity* (the ability of the soil to resist failure) is larger now.

Notes

Pictures cannot show the formation of the bearing capacity failure surface. The surface is visible only when the dowels are moving, which lasts only a second. Hence, the experiment will have to be repeated a few times until the observer understands what to look for.

If you have more time, do the demonstration in the following manner, which is more impressive: Use a smaller weight, and invite the participants to push down on the weight until it fails. Causing a bearing capacity failure will be much harder when the board is under the weight. Pushing on the weight to failure leaves a much bigger impression of the effect than just setting a weight on the dowels. Seeing the larger weight is not nearly as impressive as being the larger weight.

Originally, the writer used thousands of toothpicks instead of 0.25-inch wooden dowels. A nightmare ensued. The first trial worked just fine. That trial rearranged the toothpicks, which had to be removed and replaced in order. This process takes about two hours and a good measure of patience. Not recommended. Incidentally, contact the author if you need some lightly used toothpicks in large quantities. Discounts available.

The box is custom made from wood and 0.25-inch, clear Plexiglas. It is about 21 inches wide, 18 inches tall and three inches deep. Slots were routed in the wood to accommodate the expensive Plexiglas, which only needs to be on one side for observation. The back of the box can be plywood, which can be used to stabilize the upright parts of the box. We used Plexiglas® on both sides, funded by the sale of used toothpicks. The box used here was also used for the retaining wall demonstrations in Chapter 34.

If you use a large weight with a small footprint, the weight may cause bearing capacity failure and may disappear into the box, requiring you to remove a lot of dowels to retrieve the weight, which is a pain in the neck.

Engineering Significance

This effect is used to size footings under building columns founded on sandy soils. Using a few, large footings with huge loads on them is more efficient than using several small footings with smaller loads on them. “Efficiency” here means less concrete is used for the footing. Figure 33-7 shows a concrete column on a footing.

Figure 33-7. Footing with column above. Exciting, eh?

Supplier of Material

- Wooden dowels

  Home Depot
  2190 Tiger Town Parkway
  Opelika, AL 36801
  USA

34

Retaining Wall in a Box

Introduction

Retaining walls are used to create changes in grade at building sites. They hold soil in a vertical position, creating space in front of the wall that would otherwise be occupied by sloping soil. Walls are used above and below grade. Figure 34-1 shows a wall above grade. Basement walls, for example, are below grade.

Overview of the Demonstration

A model retaining wall is placed in model soil and moved side to side to show the failure surface that forms behind the wall.

Equipment

(See Figure 34-2.)

- Custom bearing capacity box filled with hundreds of 0.25 inch × 3 inch wooden dowels; and
- Board, about 0.5 inches thick, covered with rough sandpaper, slightly narrower than the box.

Setup Procedure

Fill the box with the dowels to within an inch or so of the top. This will take some time.

Operation of the Demonstration

Press the board vertically into the dowels (Figure 34-3) and move the top back and forth. Movement in one direction simulates and exaggerates the movement of a real retaining wall in service.

Figure 34-1. Retaining wall

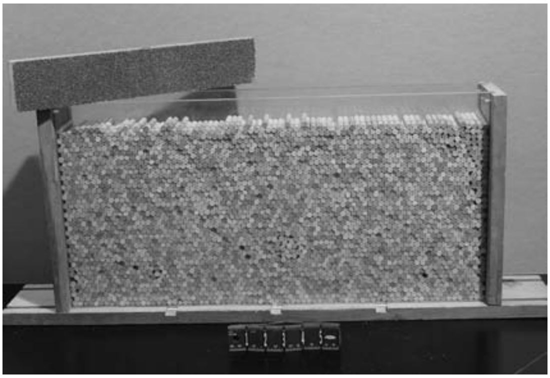


Figure 34-2. A sandpaper-covered board and a box containing hundreds of three-inch wooden dowels

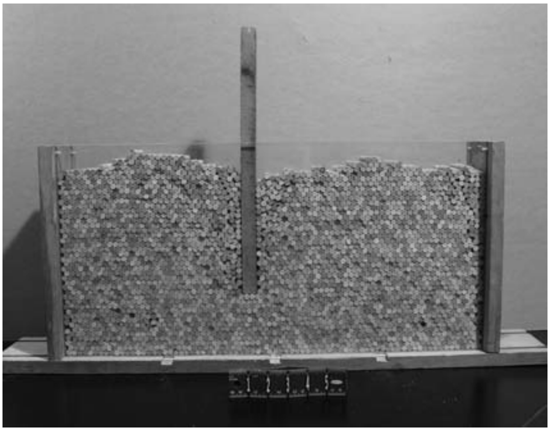


Figure 34-3. Model retaining wall

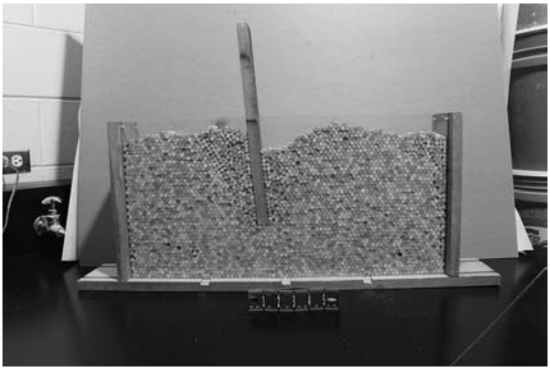


Figure 34-4. Retaining wall after motion. Failure planes subtly visible, left and right of the wall.

VIDEO
A video of this demonstration is available at http://dx.doi.org/9780784413920.video.

Expected Result

The dowels will be pushed back and forth as the board rotates about its lower tip. The dowels will move along a failure surface, highlighted in Figure 34-4.

Explanation of the Demonstration

The angles of the failure surfaces, from the horizontal, correspond to the angles predicted by lateral earth pressure theory. Only some of the dowels between the board and the edge of the box move. Because soil has *internal strength* (the ability to hold itself up), not all the soil moves. Only the soil between the board and the failure surface moves. This is not obvious to the uninitiated, who tend to think that all the soil behind a wall moves. This would be the case only with fluids, which lack internal strength.

The Magic

No magic of note.

Notes

This experiment is not too useful or exciting to the general public. However, it is useful for geotechnical students to show the formation of the failure surface in cohesionless soil, so that that they may better understand the formation of the failure surface and see that retaining wall theory conforms with the demonstration. Particularly valuable for them to see is that the failure surface behind the wall forms at an angle of $(45 + \phi/2)$ degrees above the horizontal for the active case and $(45 - \phi/2)$ degrees above the horizontal for the passive case, in dry soils, where ϕ is the effective angle of internal friction of the dowels (soil). The angle of internal friction is discussed in the angle of repose demonstration in Chapter 26.

Pictures do not show the formation of the bearing capacity failure surface very well. The surface is most visible when the dowels are moving. The experiment will have to be repeated a few times until the observer understands what to look for. The video is more illustrative than pictures.

The box is custom made from wood and 0.25-inch, clear Plexiglas. It is about 21 inches wide, 12 inches tall, and three inches deep. Routed slots in the wood accommodate the expensive Plexiglas, which need only be on one side for observation. The back of the box may be plywood, which can be used to stabilize the upright parts of the box. Here, Plexiglas® was used on both sides, funded by the sale of used toothpicks (see Chapter 33). The box used here is also used for the bearing capacity demonstrations in Chapter 33.

Corollary Demonstration

The sandpaper-covered wooden board may be used to demonstrate pile driving. The board is pushed fairly rapidly into the dowels vertically. The dowels on the sides of the board can be seen to move only for a short distance away from the board, modeling the development of skin friction. The dowels on the end of the board form a bearing capacity wedge/failure surface around the end, modeling the development of a bearing capacity surface on the end of a square-ended pile. As in the retaining wall demonstration, pictures do not adequately show the effect, which is best viewed while the board is moving.

Engineering Significance

Only some of the soil behind the wall moves. If you were to construct something behind the wall, you may wish to construct it farther away from the wall than where the failure surface intersects the ground surface.

In terms of geotechnical theory, this surface is used to help predict the earth pressure on the wall, so it can be built strong enough to withstand that pressure.

Supplier of Materials

- Wooden dowels

  Home Depot
  2190 Tiger Town Parkway
  Opelika, AL 36801
  USA

35

Rockfall Simulator Lab

Introduction

Rockfall (Figure 35-1) refers to rocks falling onto areas that people want to use. Civil engineers analyze rock slopes and cliffs to try to prevent unwanted rockfalls.

Overview of the Demonstration

Various rocks are rolled down particle board or plywood sheets overlying stairs onto various soil types. This exercise gives the student a feel for the rockfall process and for some mitigation measures civil engineers take to keep the rocks from damaging wanted property. The mass and shape of a rock and the material type used in the landing zone are examined to see the effect on the rock's rollout distance during a rockfall.

Equipment

- Two sheets of 4 feet × 8 feet × 5/8 inch particle board or plywood;
- Two large clamps;
- Tarp (greater than 5 feet × 5 feet);
- Ten gallons of sand;
- Rocks of various shapes and mass, most more than five pounds; and
- Stairs, preferably outdoors, with material at the bottom that won't be damaged by rolling rocks.

Setup Procedure

1. Lay a sheet of particle board on the bottom of the stairs to create a ramp.

Figure 35-1. Rockfall (USGS 2013)

Figure 35-2. Left, boards set on stairs; right, detail of clamp holding boards together

2. Place the second sheet of particle board at the top of the first sheet overlapping by 1 foot.
3. Use two clamps at the overlap to hold the boards to each other.

Figure 35-2 shows the setup.

Operation of the Demonstration

Part One

1. Classify the rocks based on the shape and mass of the rock. The shape can be classified using ASTM (2009).

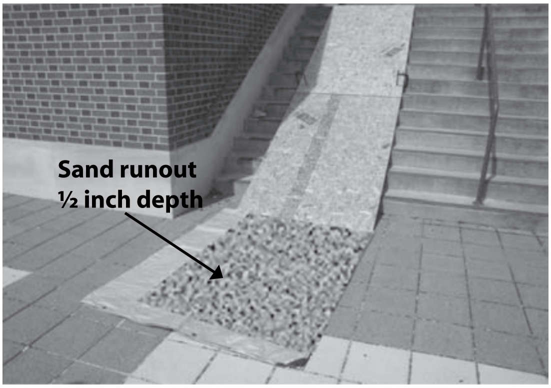


Figure 35-3. Boards set on stairs with sand runout at base

2. With the ramp in place, drop the rocks vertically from about a foot above the top of the ramp and measure each rock's rollout distance from the bottom of the ramp.
3. Do multiple trials for each rock.

Part Two

1. Unfold the tarp at the base of the ramp.
2. Pour the sand evenly onto the tarp approximately ½-inch deep and the width of the ramp (Figure 35-3).
3. Repeat the procedure from part one: drop the rocks and measure the runout distance.

Expected Result

Platy rocks will have a short runout distance. Rounded rocks will have a much longer runout. All rocks will stop dramatically in the sand-covered runout. Figure 35-4 shows a rock with a 4.5-foot runout. Rollout distance of rocks of different mass and similar mass can be plotted. Rollout distance of rocks of similar mass and different shape can be plotted.

Explanation of the Demonstration

This is an energy experiment. A real rock, after detaching from a slope, has some potential energy (energy of position). This quickly becomes kinetic energy. That energy is dissipated by contact with the boards and

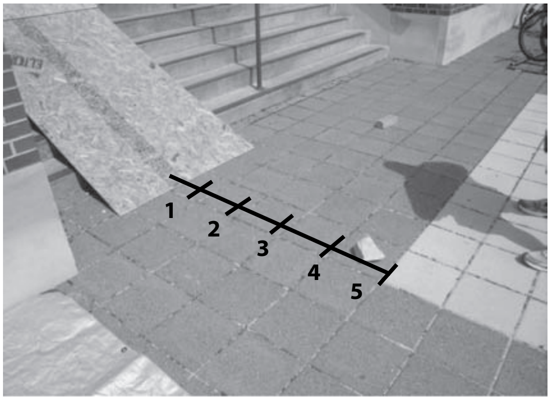


Figure 35-4. Rock with 4.5 foot runout

then with the runout material. A soft runout material (here sand) displaces a lot, thus dissipating a lot of energy and causing the rock to cease movement in a shorter distance.

The Magic

No magic here. Sure is fun, though. Noisy, too.

Notes

The rocks are not likely to roll downhill if they are placed on the boards. Drop the rocks onto the boards from about a foot or so and watch them roll.

This is an outdoor experiment. It's too noisy for indoors and would cause damage to an indoor landing surface. Rocks can be given an additional initial velocity, for fun.

Other arresting materials besides sand may be used, such as gravel, sandbags (geobags), or minifences.

Various shapes of rocks will yield widely differing results. Figure 35-5 shows rock shapes.

Engineering Significance

Rocks that fall toward civil engineering structures must be prevented from damaging those structures. Many methods of arresting rocks exist,

Figure 35-5. Various shapes of rocks used

including rockfall fences, steel cable nets, trenches, solid barriers or walls, and sand pits. The most common of these is the sand-filled trench, which requires the rock to run uphill to get out (which takes energy) and dissipates a lot of energy, as shown in this demonstration.

Supplier of Materials

- Pressboard or plywood sheets, clamps

  Home Depot
  2190 Tiger Town Parkway
  Opelika, AL 36801
  USA

Acknowledgment

Thanks to Jim Hanson for this idea.

References

ASTM. (2009). "Standard practice for description and identification of soils (visual manual procedure)." *D2488*, West Conshohocken, PA.

USGS. (2013). http://geol105naturalhazards.voices.wooster.edu/landslides-durring-a-hurricane/, accessed July 6, 2013.

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Bibliography: Geotechnical Engineering Education

Akili, W. (2007). "Better teaching and learning using case histories in geotechnical engineering." *37th Annual Frontiers in Education Conference—Global Engineering: Knowledge without Borders, Opportunities without Passports*.

Association of Engineering Firms Practicing in the Geosciences (ASFE). (2003). *The real world of engineering—Case histories 1–40*, Silver Spring, MD.

Barber, E. S., and Krizek, R. S. (1967). "Soil mechanics demonstrations." *Third PanAmerican Conference on Soil Mechanics and Foundation Engineering*, 375–389.

Burland, J. B., Manoliu, I., and Radulescu, N. (2008). "Personal reflections on the teaching of soil mechanics." *1st International Conference on Education and Training in Geo-Engineering Science—Soil Mechanics, Geotechnical Engineering, Engineering Geology and Rock Mechanics*, CRC Press and Taylor & Francis Group, London, 35–48.

Dewoolkar, M. D, George, L., Hayden, N. J., and Neumann, M. (2009). "Hands-on undergraduate geotechnical engineering modules in the context of effecting learning pedagogies, ABET outcomes, and our curricular reform." *Journal of Management in Engineering*, 135(4), 161–175.

Herle, J., and Gesellmann, S. (2008). "Demonstration experiments in geotechnical education." *Education and training in the geo-engineering sciences*, I. Manoliu and N. Radulescu, eds., Taylor & Francis, London.

Jestrap, E. M., Charles, T., Jahnren, P. E., and Russell, C. W. (2009). "Integrating industry experts into engineering education: case study." *Journal of Professional Issues in Engineering Education and Practice*, 135(1), 1–57.

Kodicara, J. K. (2000). "The use of simple models for undergraduate teaching of geomechanics." *Geotechnical engineering education and training*, I. Manoliu, I. Antonescu, and N. Radulesci, eds., Balkema, Rotterdam, The Netherlands.

Peck, R. B., and Ireland, H. O. (1974). "Experience in teaching engineering judgment by case histories in foundation engineering." *Proceedings ASCE Conference on Civil Engineering Education*, Ohio State University, 187–192.

Poulos, H. G. (1994). "Patterns and practices in future geotechnical engineering education." *Proceedings 13th International Conferences M&EE*, New Delhi, 245–253.

Poulos, H. G. (1997). "Geotechnical education towards 2000." *Proceedings of the Fourteenth International Conference on Soil Mechanics and Foundation Engineering*, Balkema, Rotterdam, The Netherlands, 2565–2572.

Pyke, R. (2011). "Uses and abuses of analysis in geotechnical engineering." *TAGA Telegraph Avenue Geotechnical Associates*, Lafayette, California.

Sparks, A. D. W. (1997). "Geotechnical education—conceptual and physical models." *Proceedings, International Conference on Soil Mechanics and Foundation Engineering*, 3, 2001–2008.

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About the Author

David J. Elton, Ph.D., P.E., F.ASCE, S.M., has taught civil engineering as a university professor for more than 30 years, specializing in geotechnical engineering. Thousands of students have benefited from his knowledge. Elton is the recipient of teaching and technical awards, including the USUCGER Service Award. He also practices as a professional engineer, is a fellow of the American Society of Civil Engineers, won the TRB Fred Burggraf award, is a member of numerous lettered honor societies, is a past-president of the North American Geosynthetics Society, and is a licensed Soils Magician. This entertaining and useful tome draws on his decades of teaching and laboratory experience.