Fundamentals of Geotechnical Engineering - II

Chapter 5

Soil Compaction

AAiT

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General Outline

- ❖ Introduction
- ❖ Laboratory Compaction
- ❖ Effects of Compaction
- ❖ Field Compaction

1. Introduction

- Definition
- Principles of Compaction
- Effects of Compaction

Introduction

- Soil compaction is perhaps the least expensive method of improving soils. It is a common practice in all types of building systems on and within soils.
- Soil improvement in its broadest sense is the alteration of any property of a soil to improve its engineering performance such as strength, reduced compressibility, reduced permeability, or improved ground water condition.
- This may be either a temporary process to permit the construction of a facility or may be a permanent measure to improve the performance of the completed facility.

Introduction

Let's reexamine the equation for dry unit weight, that is,

$$\gamma_d = \left(\frac{G_s}{1+e}\right)\gamma_w = \frac{\gamma}{1+\omega} = \left(\frac{G_s}{1+\omega G_s/S}\right)\gamma_w$$

How can one increase the dry unit weight?

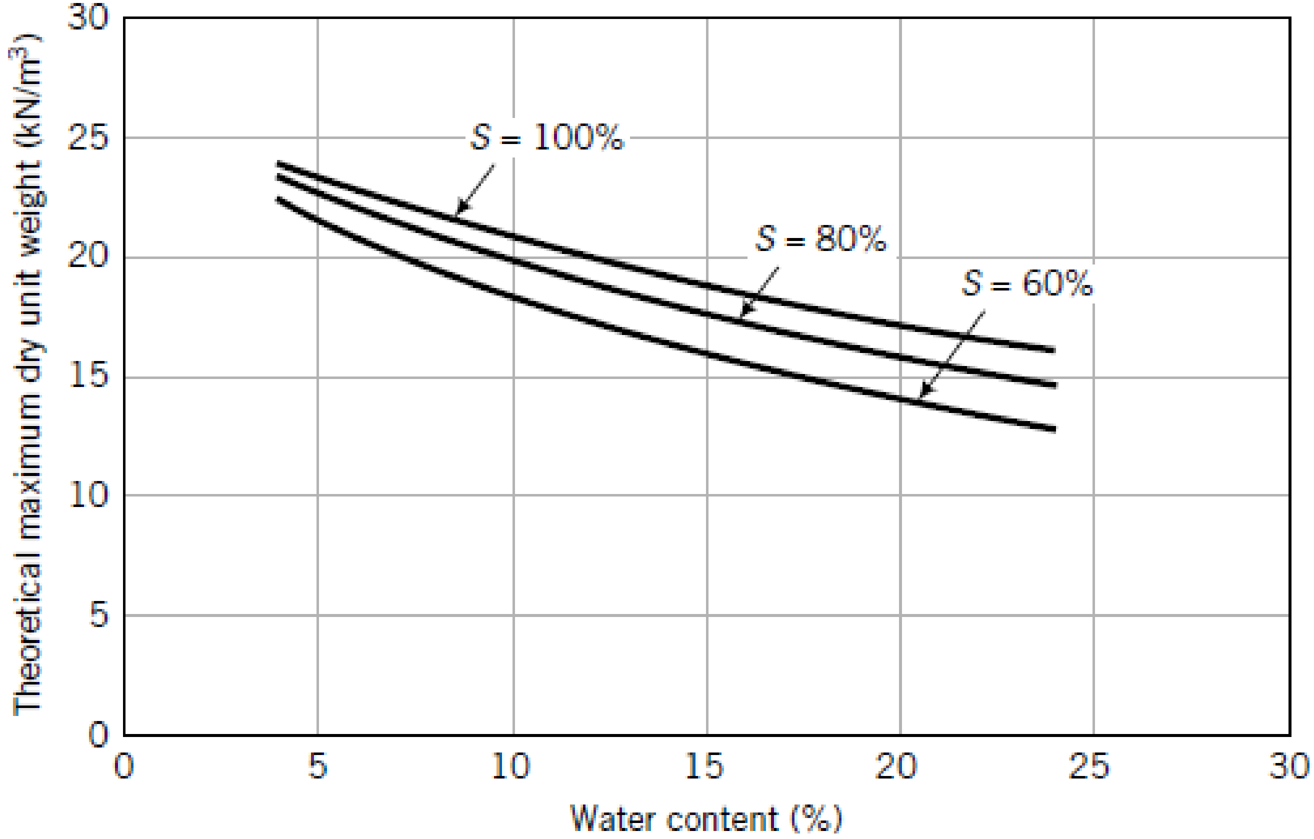
Examination of the equation reveals that we have to reduce the void ratio; that is, ω/S must be reduced since *Gs* is constant.

The theoretical maximum dry unit weight is obtained when $S = 1$ ($S = 100\%$); that is,

$$e_{min} = \omega G_s$$

Introduction

Consider a plot of the theoretical dry unit weight versus water content for different degrees of compaction is shown in figure below.



Introduction

- The theoretical dry unit weight decreases as the water content increases because the soil solids are heavier than water for the same volume occupied.
- The theoretical dry unit weight decreases as the degree of saturation decreases.
- The mass of air is negligible, so as air replaces water in the void space, the volume of soil remains constant but its mass decreases. Thus, the dry unit weight decreases.

The curve corresponding to S=100% is the saturation line, sometimes called the zero air voids curve.

Introduction

Compaction

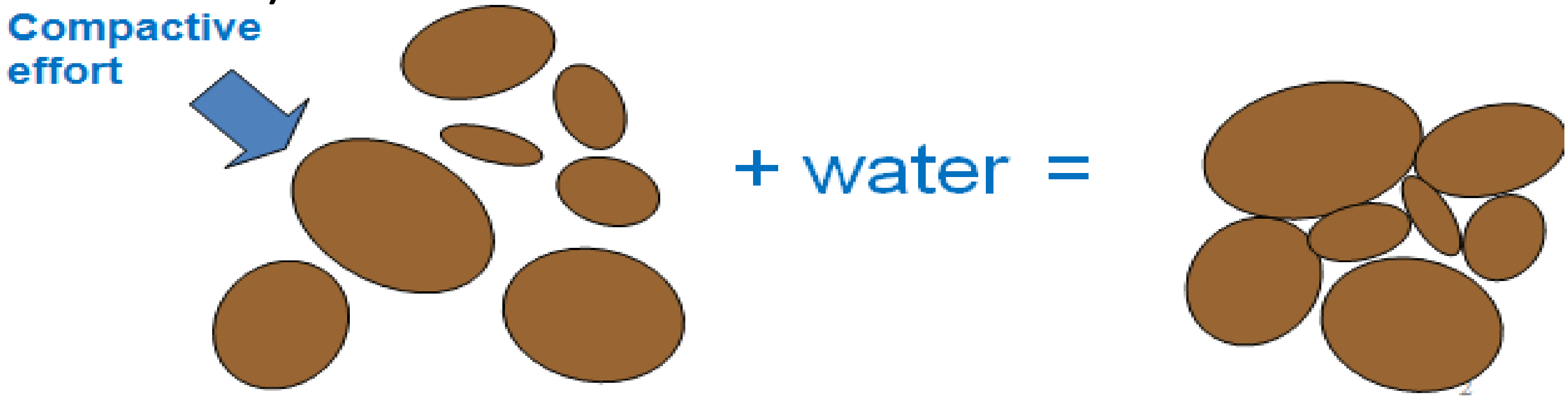
- application of energy to soil to reduce the void ratio.
- densification-reduction in void ratio of a soil through the expulsion of air.
- achieved by the process of increasing the unit weight of soil by forcing the soil solids into dense state and reducing the air void.

- ✓ Its purpose is to produce a soil having physical properties appropriate for a particular project.
- ✓ It's the most popular and least expensive method of improving soils.

Introduction cntd

Many types of earth construction, such as dams, retaining walls, highways, and airport, require man-placed soil, or fill. To compact a soil, that is, to place it in a dense state.

The dense state is achieved through the reduction of the air voids in the soil, with little or no reduction (or increment) in the water content.

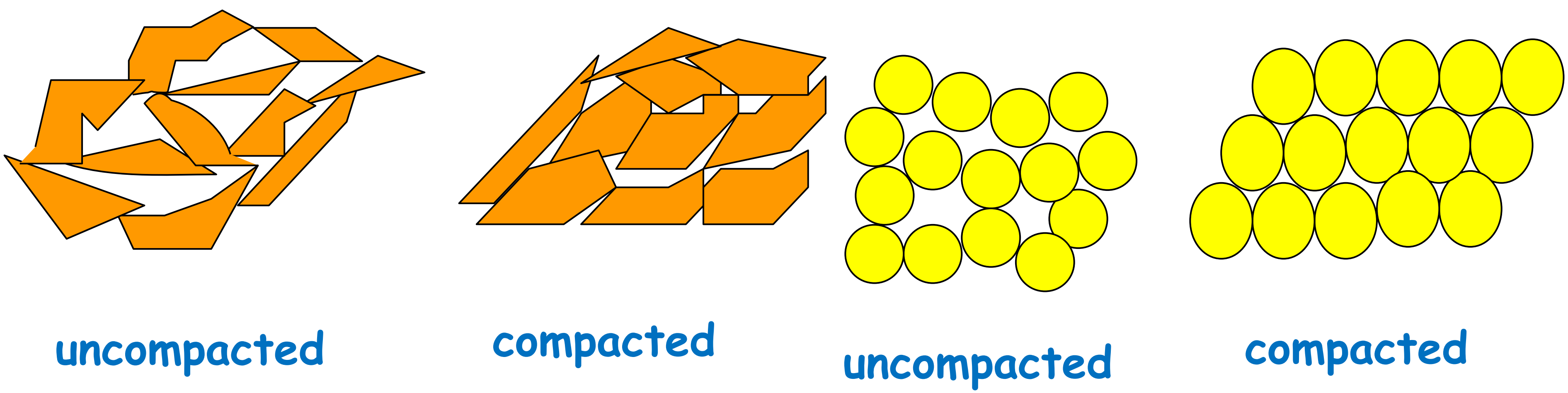


Introduction cntd

Principles of Compaction

-Compaction of soils is achieved by reducing the volume of voids.

-It is assumed that the compaction process does not decrease the volume of the solids or soil grains.



Introduction cntd

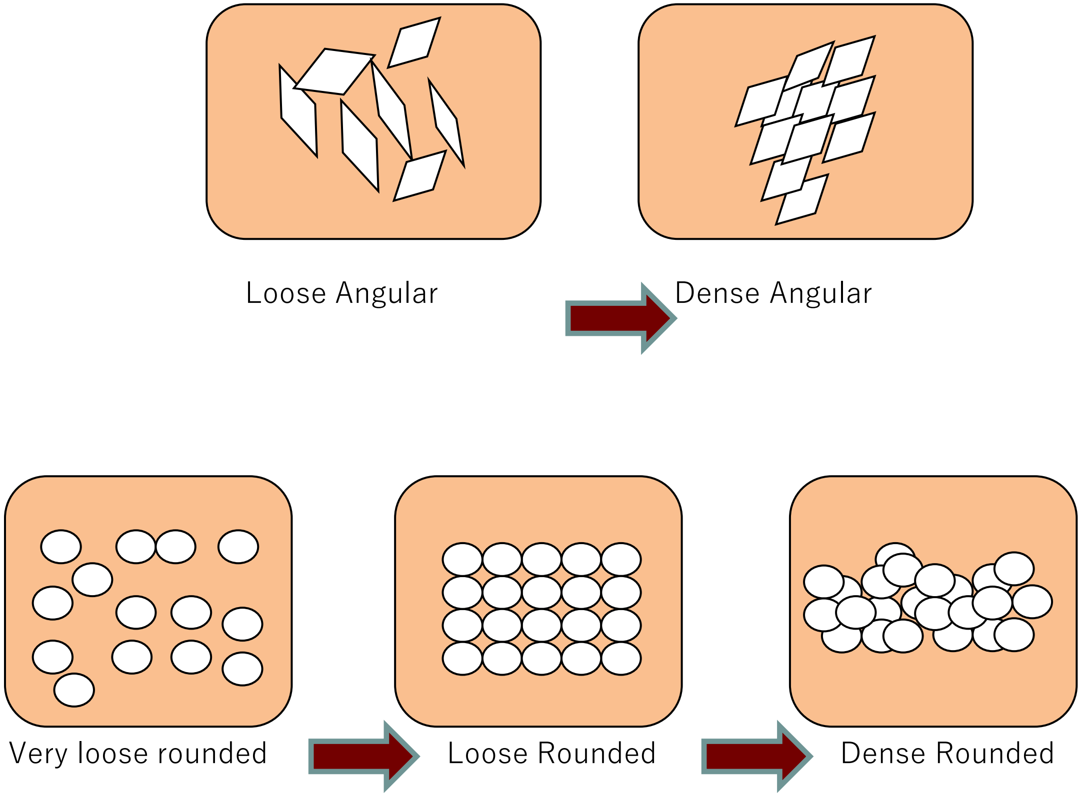
Principles of Compaction cntd

- The degree of compaction of a soil is measured by the dry unit weight of the skeleton.
- The dry unit weight correlates with the degree of packing of the soil grains.

  Recall that $\gamma d = G_s \gamma_w / (1+e)$ ·
- The more compacted a soil is:
  - the smaller its void ratio (e) will be.
  - the higher its dry unit weight (γd) will be.

Introduction cntd

- Due to compaction, loose structure of the soil mass will become denser.



2. Laboratory Compaction

- Introduction
- Variables of Lab. Compaction
- Relevance of Lab. Compaction
- Standard Proctor Test
- Modified Proctor Test

Laboratory Compaction

Origin:

- The fundamentals of compaction of fine-grained soils are relatively new.
- R.R. Proctor in the early 1930's was building dams for the old Bureau of Waterworks and Supply in Los Angeles, and he developed the principles of compaction in a series of articles in Engineering News-Record.
- In his honor, the standard laboratory compaction test which he developed is commonly called the proctor test.

Laboratory Compaction cntd

Proctor Compaction Test: deliver a standard amount of mechanical energy (compactive effort) to determine the maximum dry unit weight of a soil.

Proctor showed that

- ✓ There exists a defined relationship between the **soil moisture content and the degree of dry density** to which a soil may be compacted.
- ✓ That for a specific amount of compactive energy applied on the soil there is one moisture content termed **Optimum Moisture Content (OMC**) at which a particular soil attains **maximum dry density.**

Laboratory Compaction cntd

Purpose:

- The purpose of a laboratory compaction test is to determine the proper amount of mixing water to use when compacting the soil in the field and the resulting degree of denseness which can be expected from compaction at this optimum water

- Proctor proposed tests to determine the relationship between moisture content, dry density or void ratio of a compacted soil in a manner to determine the OMC for the soil.

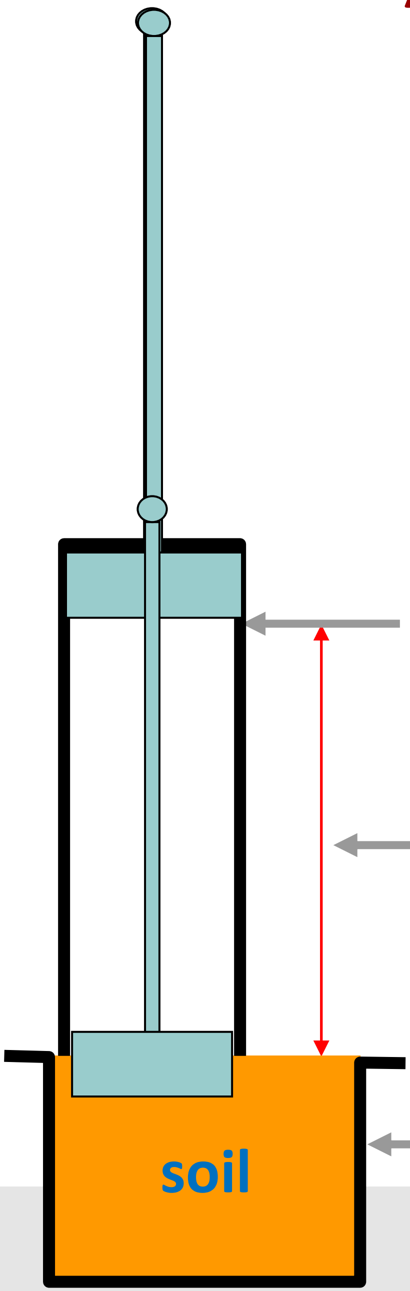
Laboratory Compaction cntd

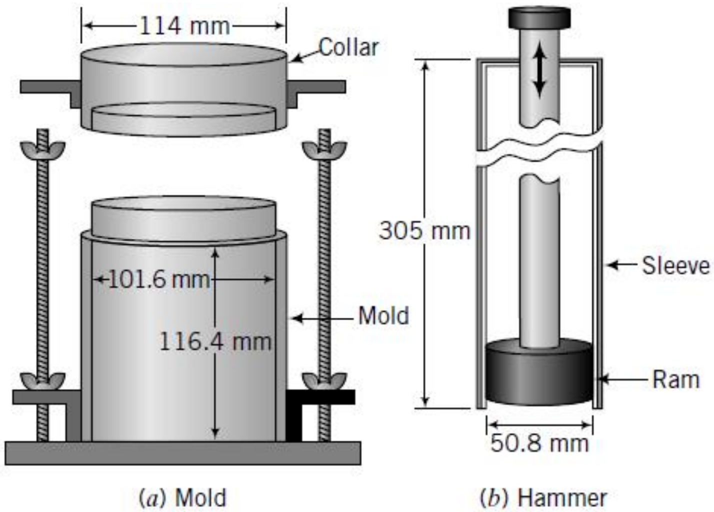
- Compaction = f[dry density, compactive effort and soil type, gradation, presence of clay mineral, etc…]
- Compactive effort is a measure of mechanical energy applied to a soil mass.

Impact compaction:

- The proctor test is an impact compaction.
- A hammer is dropped several times on a soil sample in a mold.
- The mass of the hammer, height of drop, number of drops, number of layers of soil, and the volume of the mold are specified.

Laboratory Compaction cntd





Hammer Weight 24.5 N (5.5 lb)

Drop Height h=305 mm (12”)

Volume 944 cm^3 (1/30 ft^3)
Diameter 10.16 cm (4 in)
Height 11.643 cm (4.584 in)

Laboratory Compaction cntd

Relevance of Lab. Compaction

- Gives the density that must be achieved in the field
- Provides the moisture range that allows for minimum compactive effort to achieve density.
- Provides data on the behavior of the material in relation to various moisture content.

It's not possible to determine whether a density test passes or fails without it.

Laboratory Compaction cntd

Variables of Compaction

Proctor established that compaction is a function of four variables:

(1) Dry density (ρ_d) or dry unit weight (γ_d)

(2) Water content (w)

(3) Compactive effort (energy, E)

(4) Soil type (gradation, presence of clay minerals, etc.)

$$E = \frac{\text{Weight of hammer} \times \text{Height of drop of hammer} \times \text{Number of blows per layer} \times \text{Number of layers}}{\text{Volume of mold}}$$

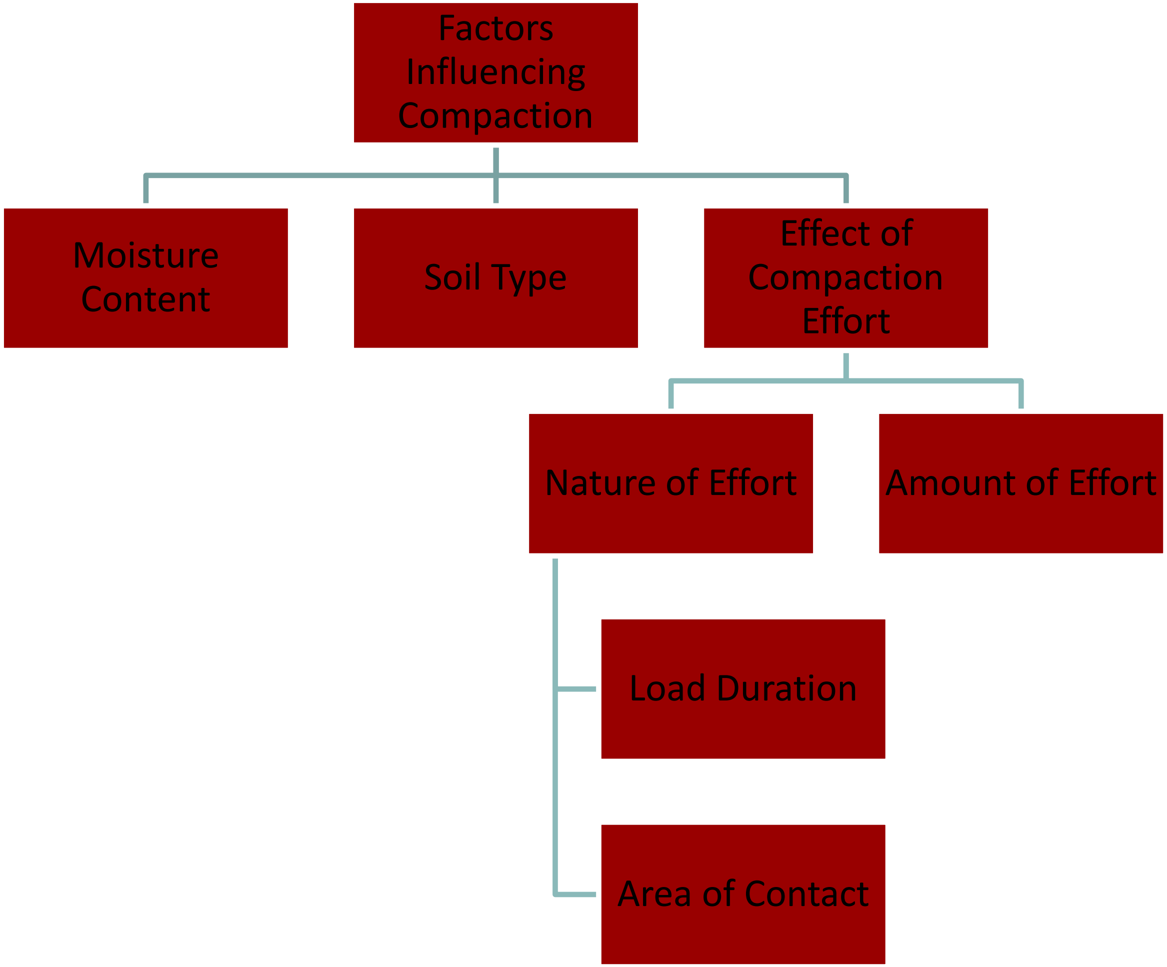
For standard Proctor test,

$$E = \frac{(24.4\,\text{N})(0.305\,\text{m})(3\text{ layers})(25\,\text{blows / layer})}{0.944 \times 10^{-3}\ \text{m}^3}$$

$$= 591.26\ \text{KJ / m}^3$$

Laboratory Compaction cntd

- Factors Influencing Compaction



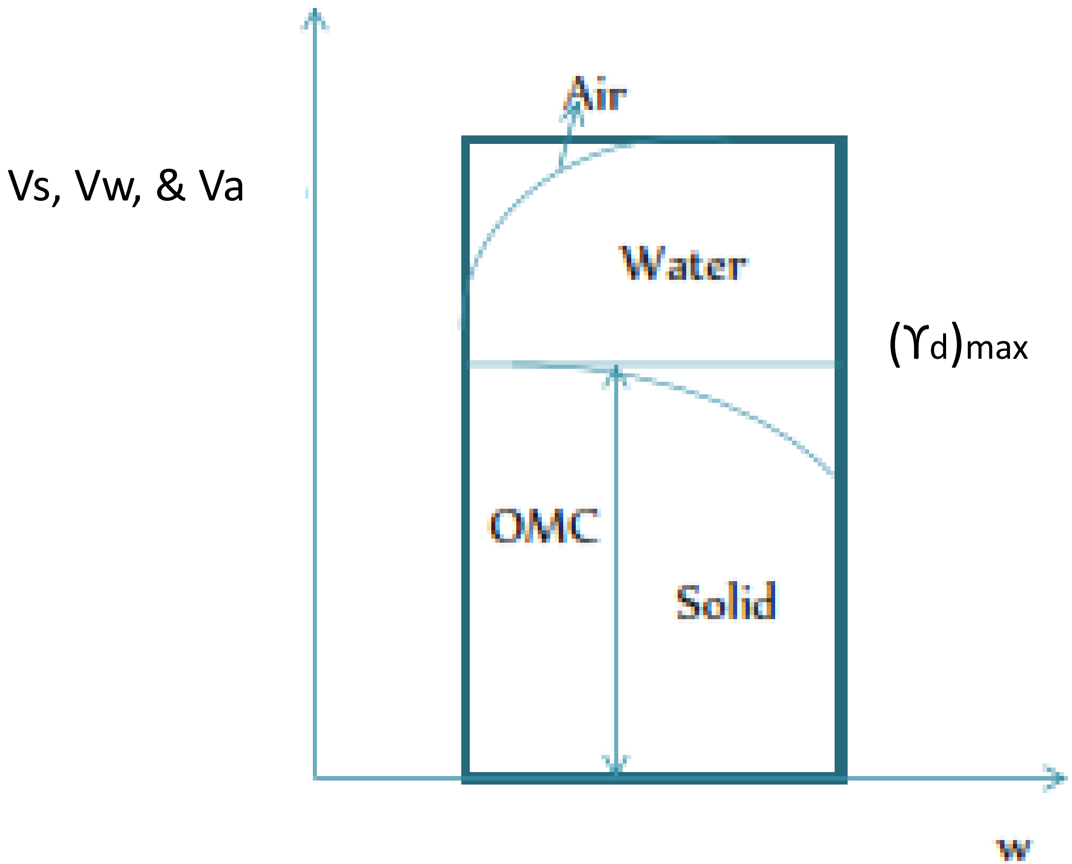
Laboratory Compaction cntd

- Factors Influencing Compaction

1. **Moisture Content**
   - At low moisture contents the strength of clay soils and friction between granular particles is high so a given compactive effort will not be able to remove all air voids leaving the soil in an overall compressible state when it is subjected to stresses from further layers of fill or a structure, and in a potentially collapsible state.
   - At higher moisture content clay soils become weaker and friction between granular particles reduces so the air voids are more easily removed during compaction.
   - At moisture content greater than the OMC the soil particles cannot move any closer together because even though most of the air has been expelled there is more water present in the voids.

Laboratory Compaction cntd

1. **Moisture Content**



Laboratory Compaction cntd

2. Soil Type

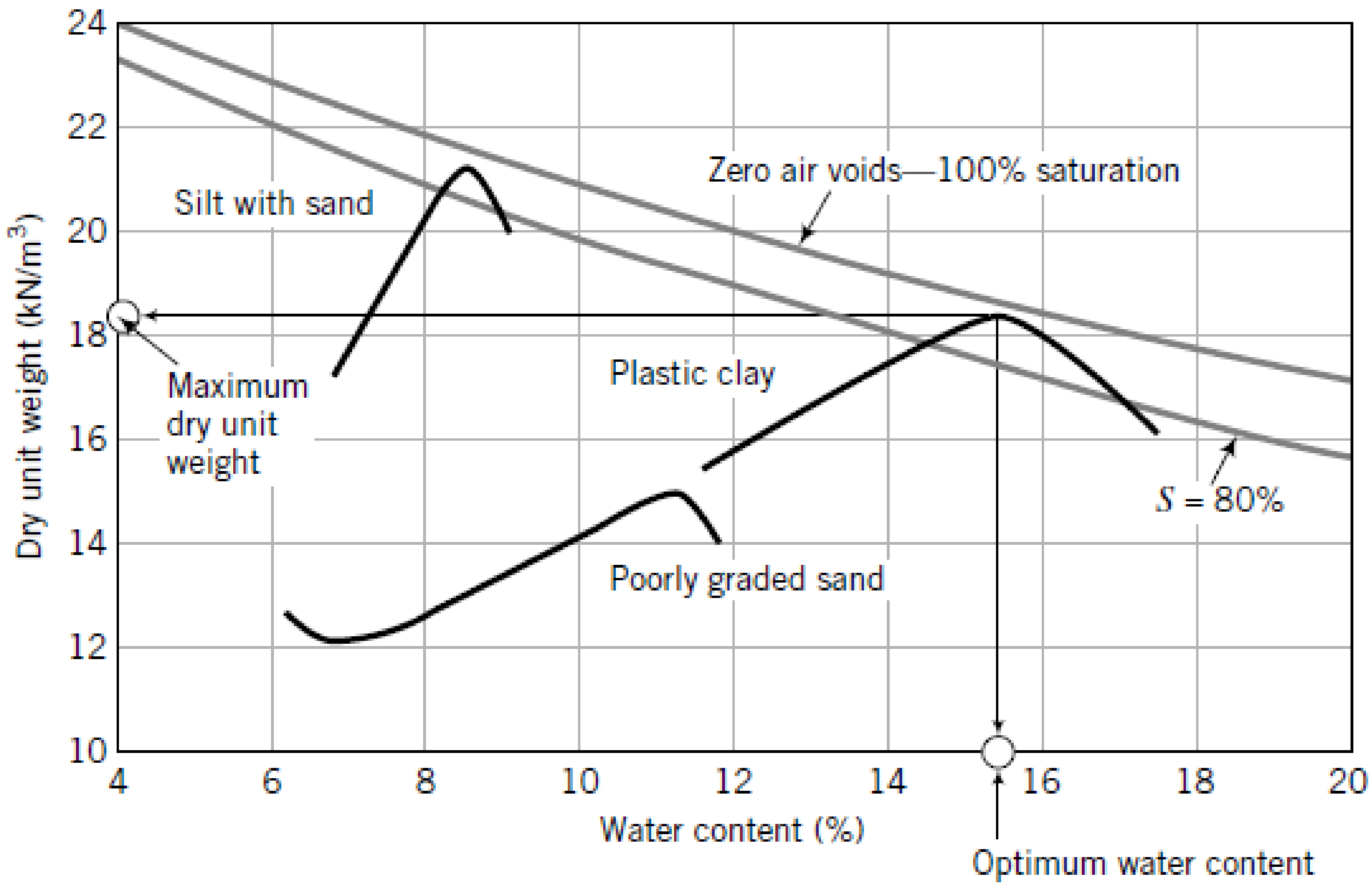
- Soil type, i.e. grain size distribution, shape of soil grains, amount and type of clay minerals present and the specific gravity of soil solids, have a great influence on the dry unit weight and OMC.

- In poorly-graded sand γ_d initially decreases as the moisture content increases, and then increases to a maximum value with further increase in moisture.

- At lower moisture content, the capillary tension in the pore water inhibits the tendency of the soil particles to move around and be compacted.

Laboratory Compaction cntd

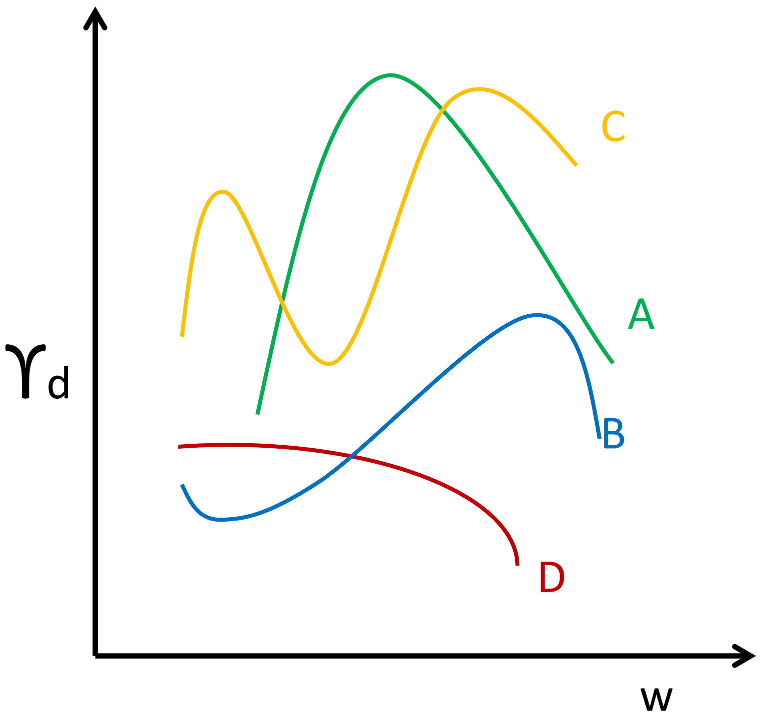
2. **Soil Type**



Laboratory Compaction cntd

2. **Soil Type**

- Lee & Suedkamp (1972) studied compaction curves for 35 soil samples. They observed that 4 types of compaction curves can be found.
  - Type A: single peak. Generally found for soils that have a liquid limit between 30 & 70.
  - Type B: one and one-half peak
  - Type C: double-peak curve
  - Type D: does not have a definite peak, termed odd shaped.
- Type B & C can be found for soil that have a LL < 30.
- Type C & D might be exhibited by soil having LL > 70.

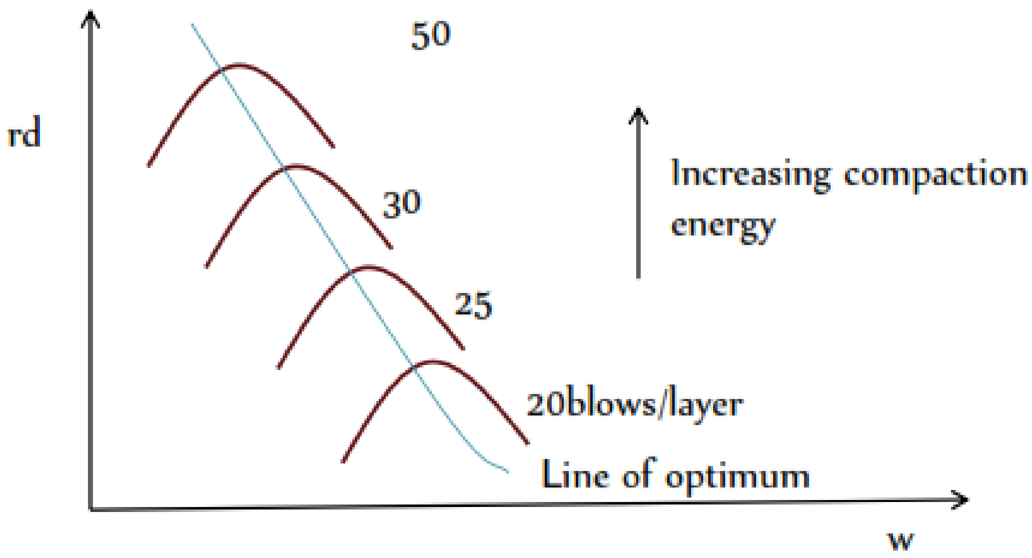


Laboratory Compaction cntd

3. Effect of Compaction Effort

i. Amount of Compactive Effort

- Maximum dry unit weight increases with increasing compactive effort.
- OMC decreases to some extent with increase in compactive effort.

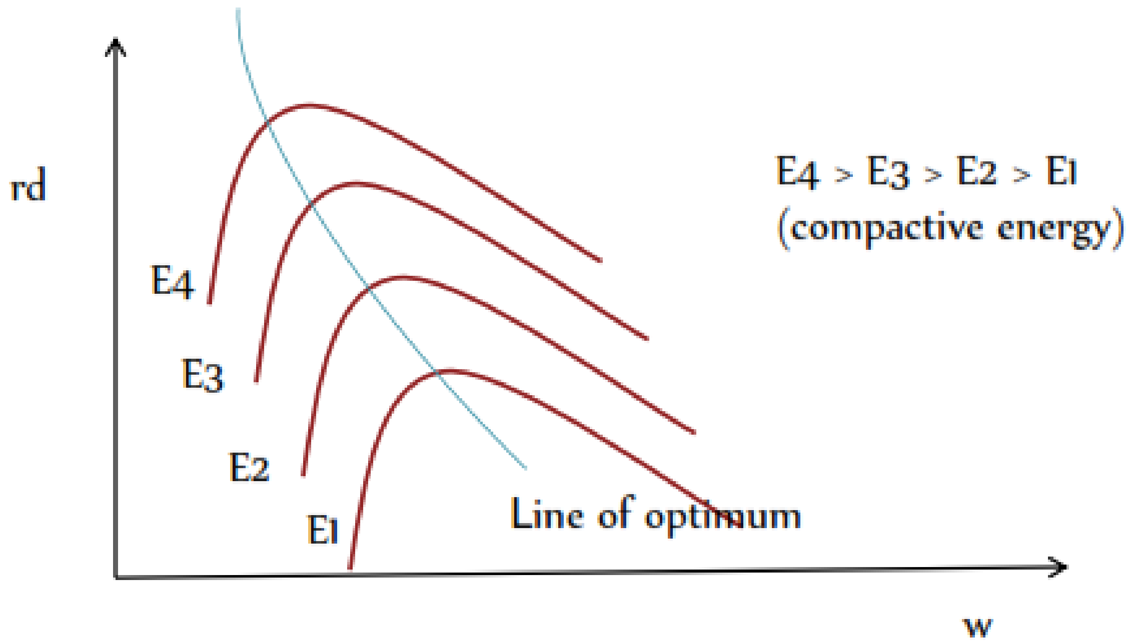


Laboratory Compaction cntd

3. Effect of Compaction Effort

ii. Nature of Effort

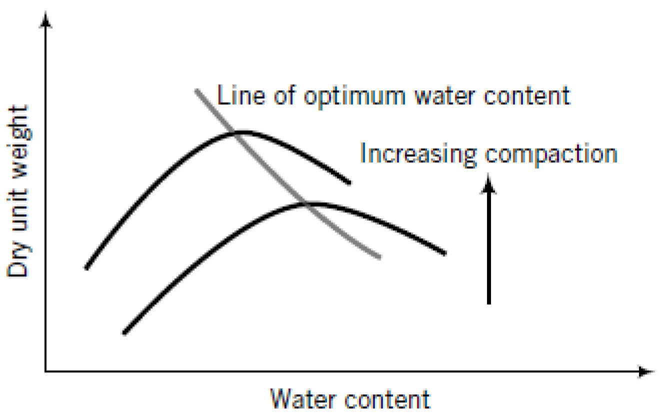
- Longer time duration leads to reduced shear stiffness response and greater compaction.
- Greater contact area leads to greater depth of influence.

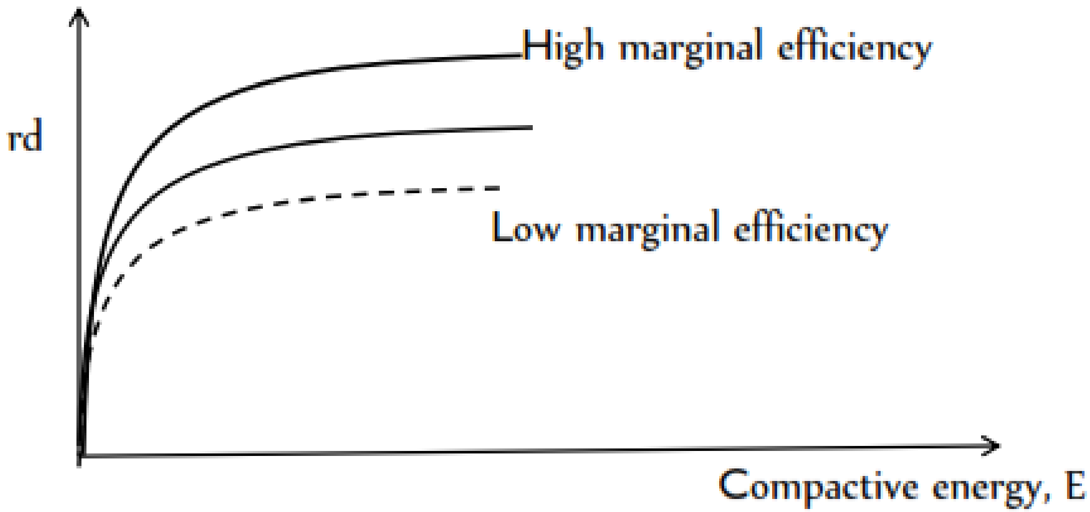


Laboratory Compaction cntd

3. **Effect of Compaction Effort**

- Degree of compaction generally increases with increasing compactive effort.
- However, beyond a certain point, increasing compactive effort produces only very small increase in dry unit weight, i.e. It takes a great deal of additional compactive effort, E, to see significant increase in dry unit weight.





Laboratory Compaction cntd

Standard Proctor Test

- Four or more tests are compacted on the soil using different water contents.
- The last test is identified when additional water causes the bulk unit weight of the soil to decrease.
- The results are plotted as dry unit weight Vs water content.
- At water content below optimum, air is expelled and water facilitates the rearrangement of soil grains into a denser configuration.
- At water content above optimum, the compactive effort cannot expel more air and additional water displaces soil grains.

Laboratory Compaction cntd

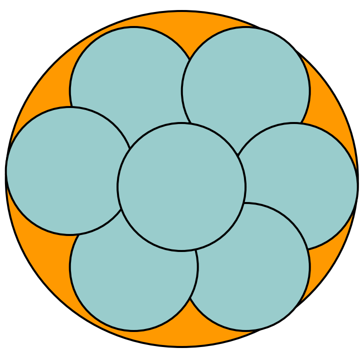
Standard Proctor Test

Laboratory Compaction cntd

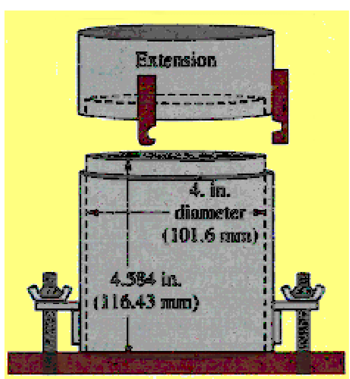
Procedures

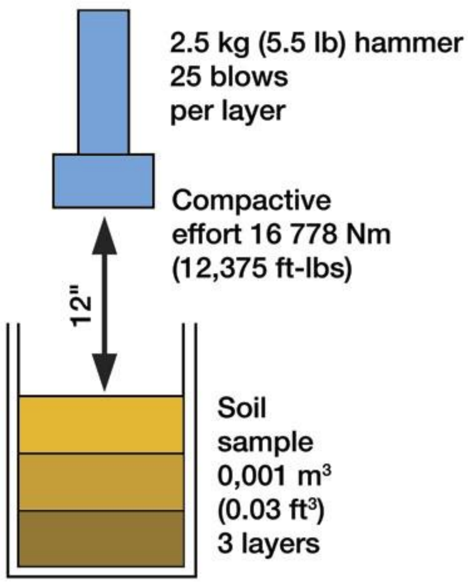
A dry soil specimen is mixed with water and compacted in a cylindrical mold of volume 9.44 x 10^-4 m^3 (standard proctor mold) by repeated blows from a hammer 2.5kg, falling freely from a height of 305mm.

The soil is compacted in 3 layers, each of which is subjected to 25 blows.



25 Blows/Layer



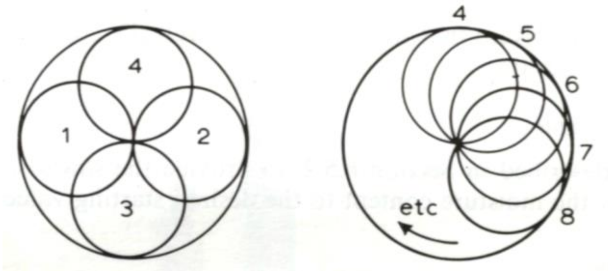


Laboratory Compaction cntd

Procedures cntd

1. Several samples of the same soil, but at different water contents, are compacted according to the compaction test specifications.

The first four blows



The successive blows

2. The total or wet density and the actual water content of each compacted sample are measured.

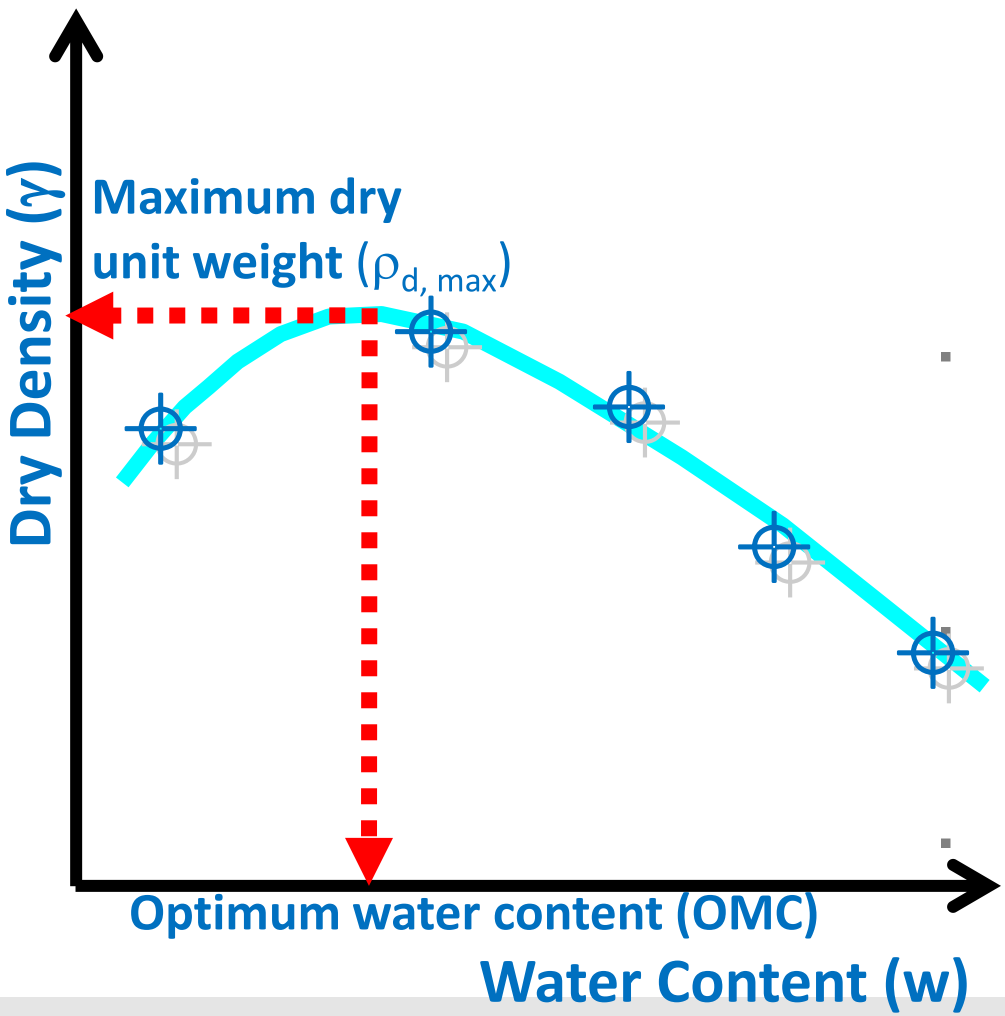
$$\rho = \frac{M_t}{V_t}, \rho_d = \frac{\rho}{1+w}$$

Derive ρ_d from the known ρ and w

3. Plot the dry densities (ρ_d) versus water contents (w) for each compacted sample. The curve is called a *compaction curve*.

Laboratory Compaction cntd

Results Compaction Curve



- Each data point on the curve represents a single compaction test, and usually 4 or 5 individual compaction tests are required to completely determine the compaction curve.
- At least two specimens wet and two specimens dry of optimum, and water contents varying by about 2%.
- Typical values of maximum dry density are around 1.6 to 2.0 Mg/m^3.
- Typical optimum water contents are between 10% and 20%.

Laboratory Compaction cntd

Results

- **The peak point of the compaction curve**:

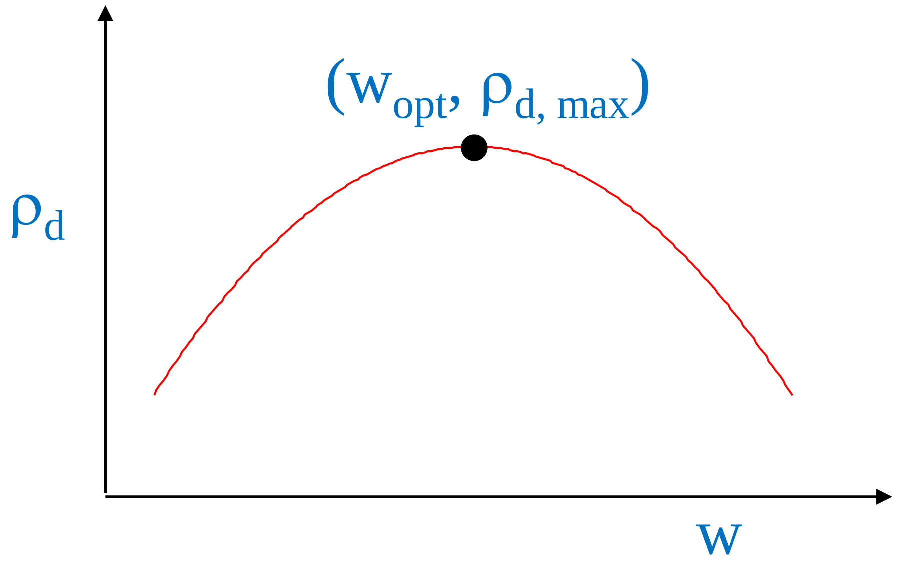
- the point with the maximum dry density $\rho_{d\ max}$.

- Corresponding to the maximum dry density $\rho_{d\ max}$ is a water content known as the optimum water content w_{opt} (also known as the optimum moisture content, OMC).

- Note that the maximum dry density is only a maximum for a specific compactive effort and method of compaction. This does not necessarily reflect the maximum dry density that can be obtained in the field.

Laboratory Compaction cntd

- **Line of optimums**: A line drawn through the peak points of several compaction curves at different compactive efforts for the same soil will be almost parallel to a 100 % S curve, it is called the line of optimums.



Laboratory Compaction cntd

Results

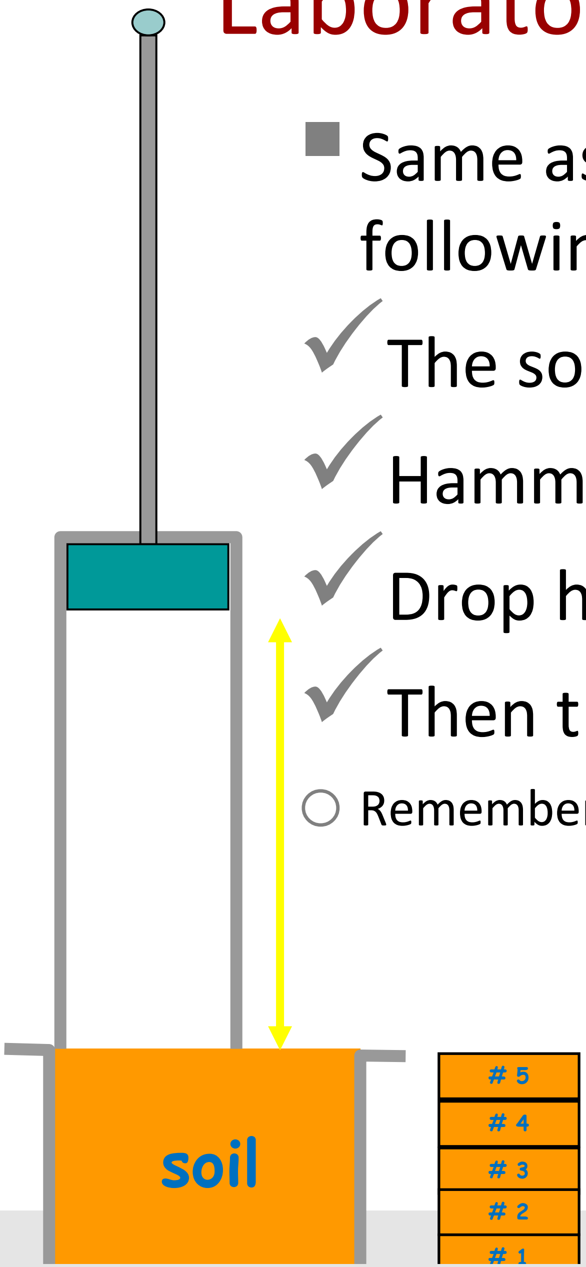
- **Below w_{opt} (dry side of optimum):** as the water content increases, the particles develop larger and larger water films around them, which tend to "lubricate" the particles and make them easier to be moved about and reoriented into a denser configuration.
- **At w_{opt}:** the density is at the maximum, and it does not increase any further.
- **Above w_{opt} (wet side of optimum):** water starts to replace soil particles in the mold, and since $\rho_w << \rho_s$ the dry density starts to decrease.

Laboratory Compaction cntd

Modified Proctor Test

- In the early days of compaction, because construction equipment was small and gave relatively low compaction densities, a laboratory method that used a small amount of compacting energy was required.
- As construction equipment and procedures were developed which gave higher densities, it became necessary to increase the amount of compacting energy in the laboratory test.
- Developed for projects involving heavy loads such as airways and highways
- It uses greater level of compaction and produces higher densities.
- It is adapted by AASHTO and ASTM.

Laboratory Compaction cntd



- Same as the Standard Proctor Test with the following exceptions:
  - ✓ The soil is compacted in 5 layers
  - ✓ Hammer weight is 44.54 N (10 lbs)
  - ✓ Drop height h is 457.2 mm (18 in)
  - ✓ Then the amount of Energy is calculated
- Remember for Standard Proctor, Energy $E = 591.26\ KJ/m^3$

$$E = \frac{(44.54\,N)(0.4572\,m)(5\text{ layers})(25\text{ blows/layer})}{0.944 \times 10^{-3}\,m^3}$$

$$= 2{,}696.46\ KJ/m^3$$

N.B: $\frac{E_{MP}}{E_{SP}} = \frac{2{,}696.46}{591.26} = 4.56$

Laboratory Compaction cntd

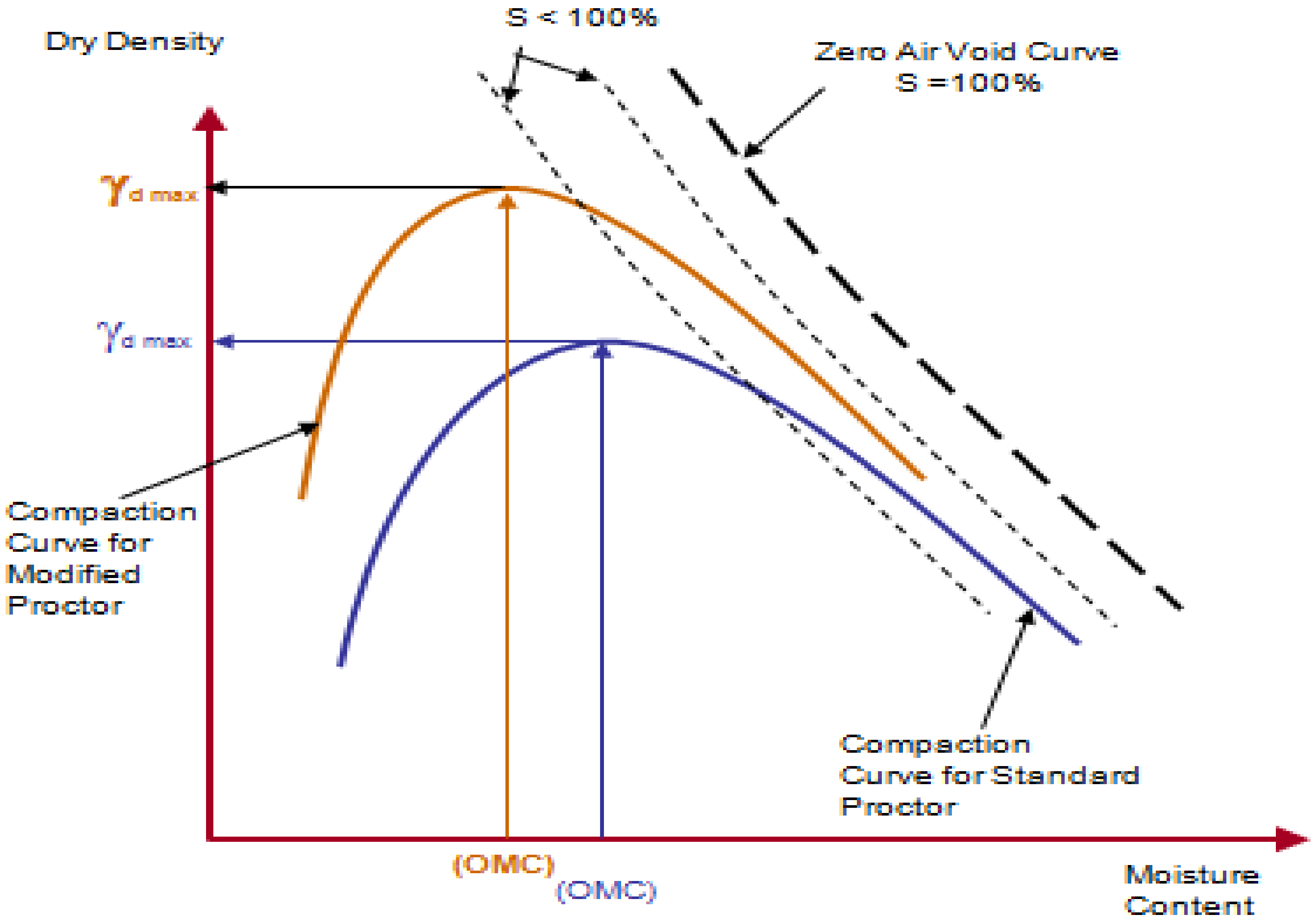
Standard Proctor Test

- Mold size: 944 cm3 (1/30 ft^3)
- 305 mm (12 in) height of drop
- 24.4 N (5.5 lb) hammer
- 3 layers
- 25 blows/layer

Modified Proctor Test

- Mold size: 944 cm^3 (1/30 ft^3)
- 457 mm (18 in) height of drop
- 44.5 N (10 lb) hammer
- 5 layers
- 25 blows/layer

Laboratory Compaction cntd



Laboratory Compaction cntd

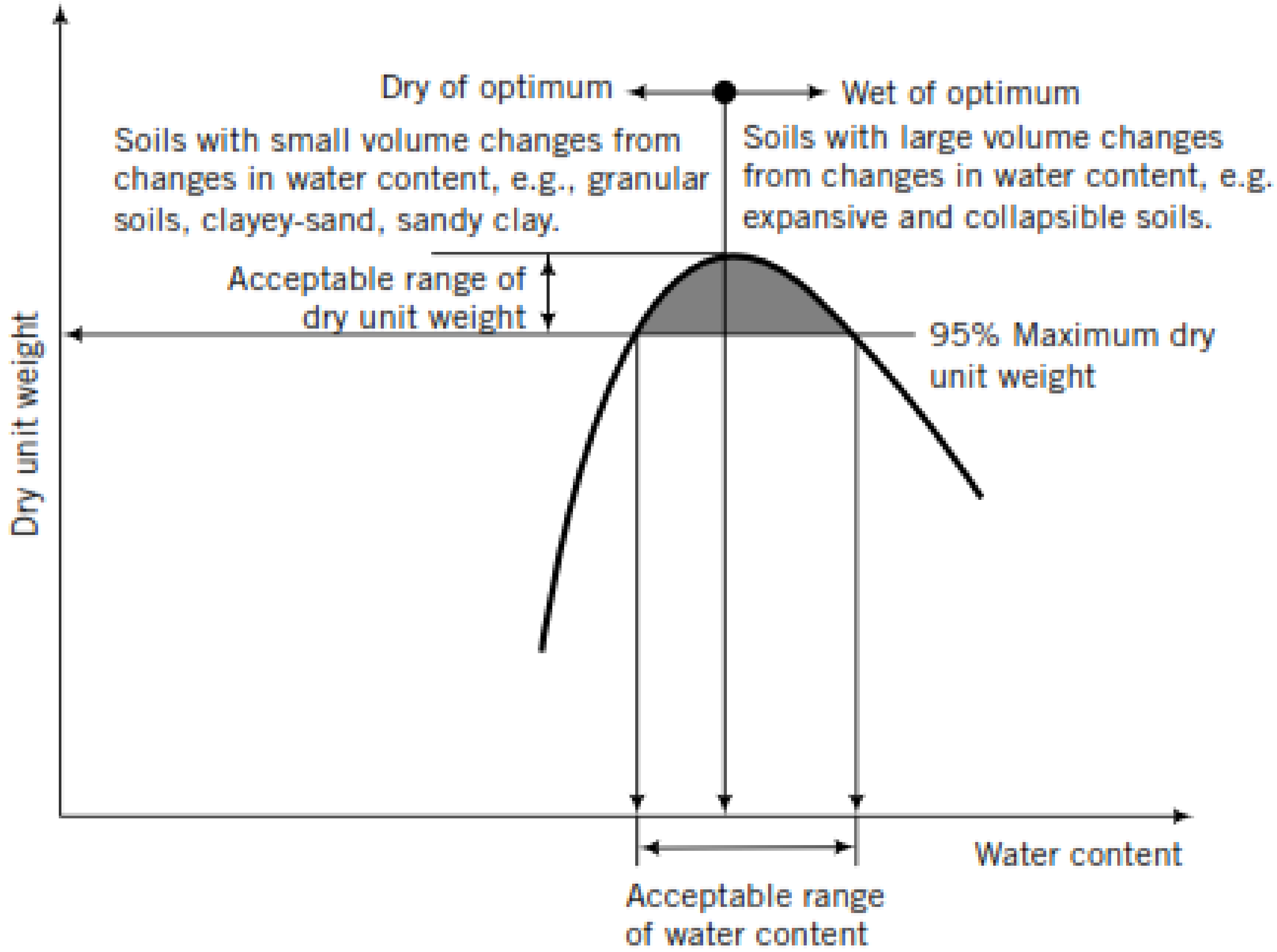
Interpretation of Compaction Test

- For construction specification of soil improvement by compaction usually call for a minimum of 95% Proctor maximum dry unit weight.

$$Relative\ compaction, RC = \frac{\gamma_{d(field)}}{\gamma_{d(max)}}$$

- This level of compaction can be attained at two water contents;
  - Before the attainment of maximum dry unit weight – dry of optimum
  - After the attainment of maximum dry unit weight – wet of optimum
- Normally the former one is used
- The latter one is used for projects where soil volume changes from changes in moisture condition are intolerable.

Laboratory Compaction cntd



Laboratory Compaction cntd

EXCERCISE 5.2.1 – Bulk & Dry Unit Weights

The wet mass of one of the standard Proctor test samples is 1806 grams at a water content of 8%. The volume of the standard Proctor test sample is $9.44X10^{-4}$ m^3.

Determine the bulk and dry unit weights.

Laboratory Compaction cntd

EXCERCISE 5.2.2 – Standard Proctor Test

Below is the results of a standard compaction test.

Water content (%)	6.2	8.1	9.8	11.5	12.3	13.2
Bulk unit weight (kN/m^3)	16.9	18.7	19.5	20.5	20.4	20.1

a) Determine the maximum dry unit weight and optimum water content.

b) What is the dry unit weight and water content at 95% standard compaction, dry of optimum?

c) Determine the degree of saturation at the maximum dry density.

d) Plot the zero air voids line.

3. Effects of Compaction

- On Clay Structure
- On Swelling
- On Soil Permeability
- On Soil Compressibility
- On Soil Strength

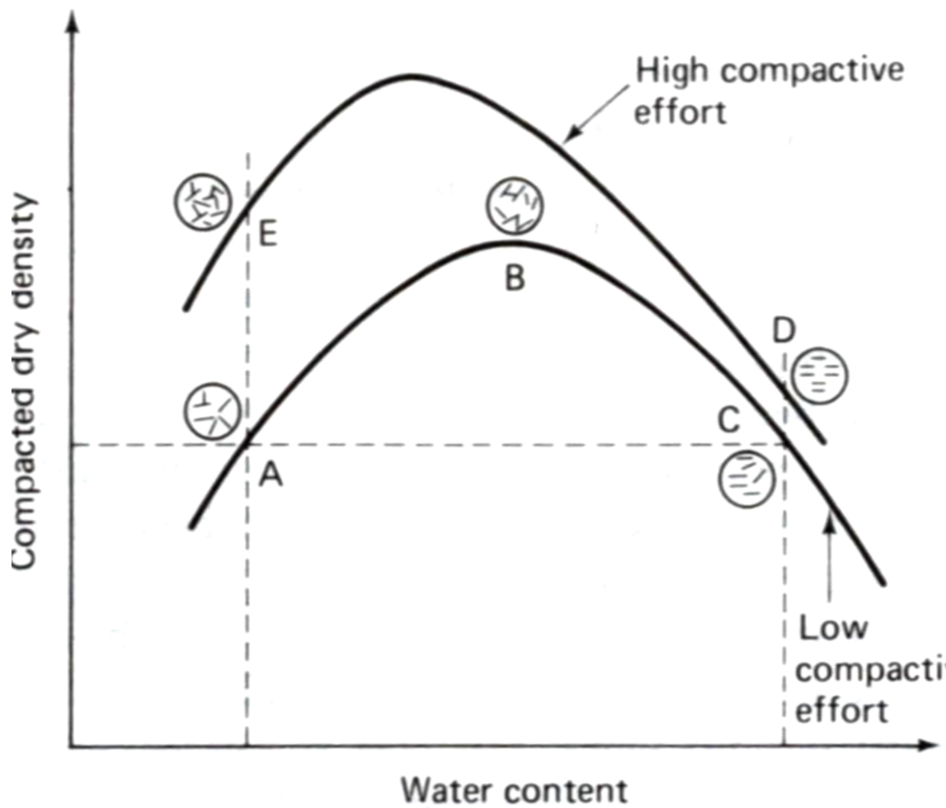
Effects of Compaction

Done Right (Benefits)	Not Done Right (Consequences)
• Increased soil strength • Increased load-bearing capacity • Reduction in settlement (lower compressibility) • Reduction in flow of water (water seepage) • Reduction in soil swelling (expansion) and collapse (soil contraction) • Increased soil stability • Reduction in frost damage	• Structural distress from excessive total and differential settlements • Cracking of pavements, floors and basements • Structural damage to buried structures, water and sewer pipes and utility conduits • Soil erosion

Effects of Compaction: On Structure of Compacted Clays

- For a given compactive effort and dry density, the soil tends to be more flocculated (random) for compaction on the dry side as compared on the wet side.

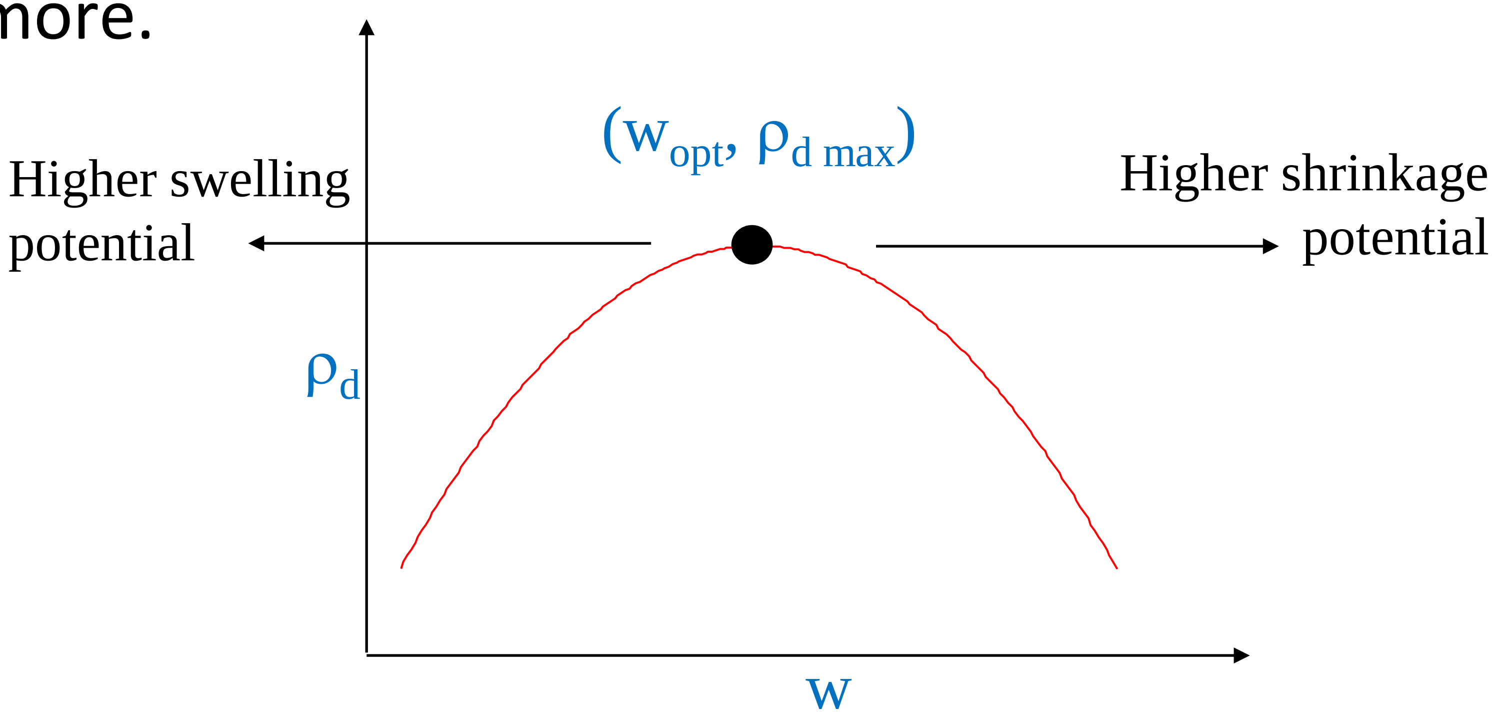
- For a given molding water content, increasing the compactive effort tends to disperse (parallel oriented) the soil, especially on the dry side.



Effect of compaction on soil structure (after Lambe, 1958a).

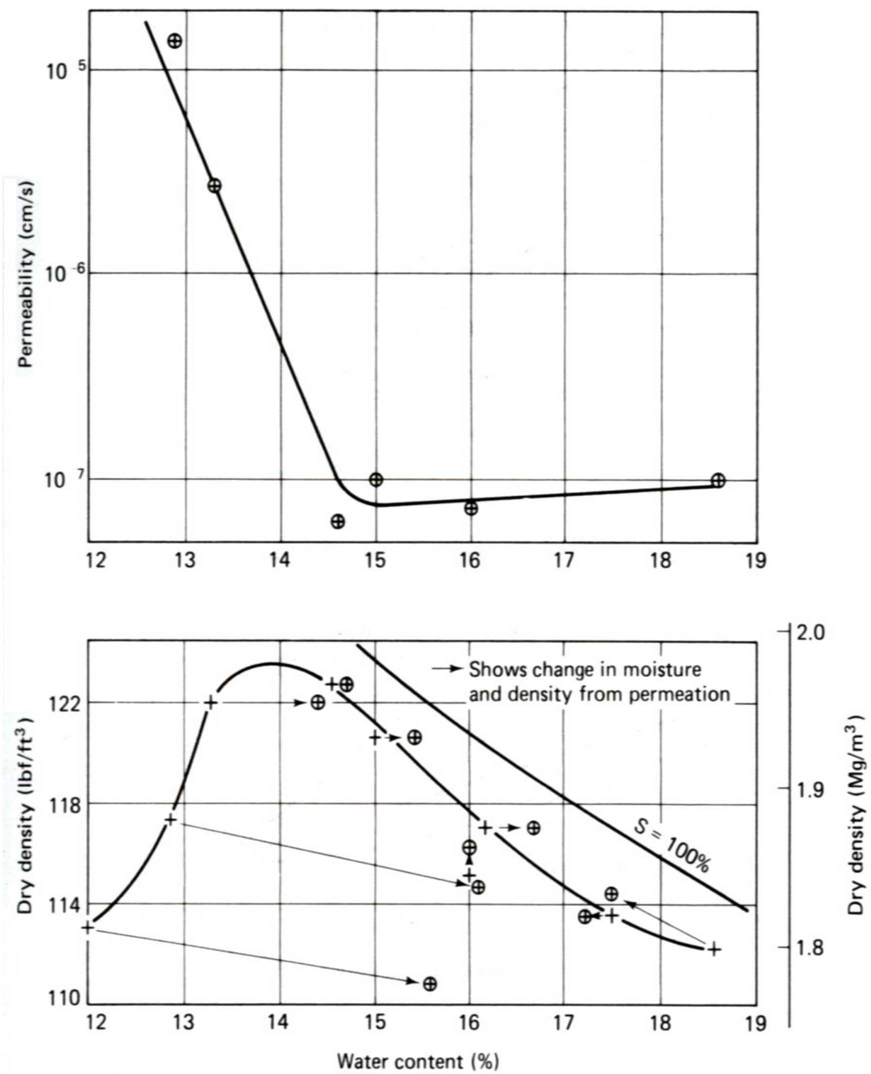
Effects of Compaction : On Swelling

- Swelling of compacted clays is greater for those compacted dry of optimum. They have a relatively greater deficiency of water and therefore have a greater tendency to adsorb water and thus swell more.



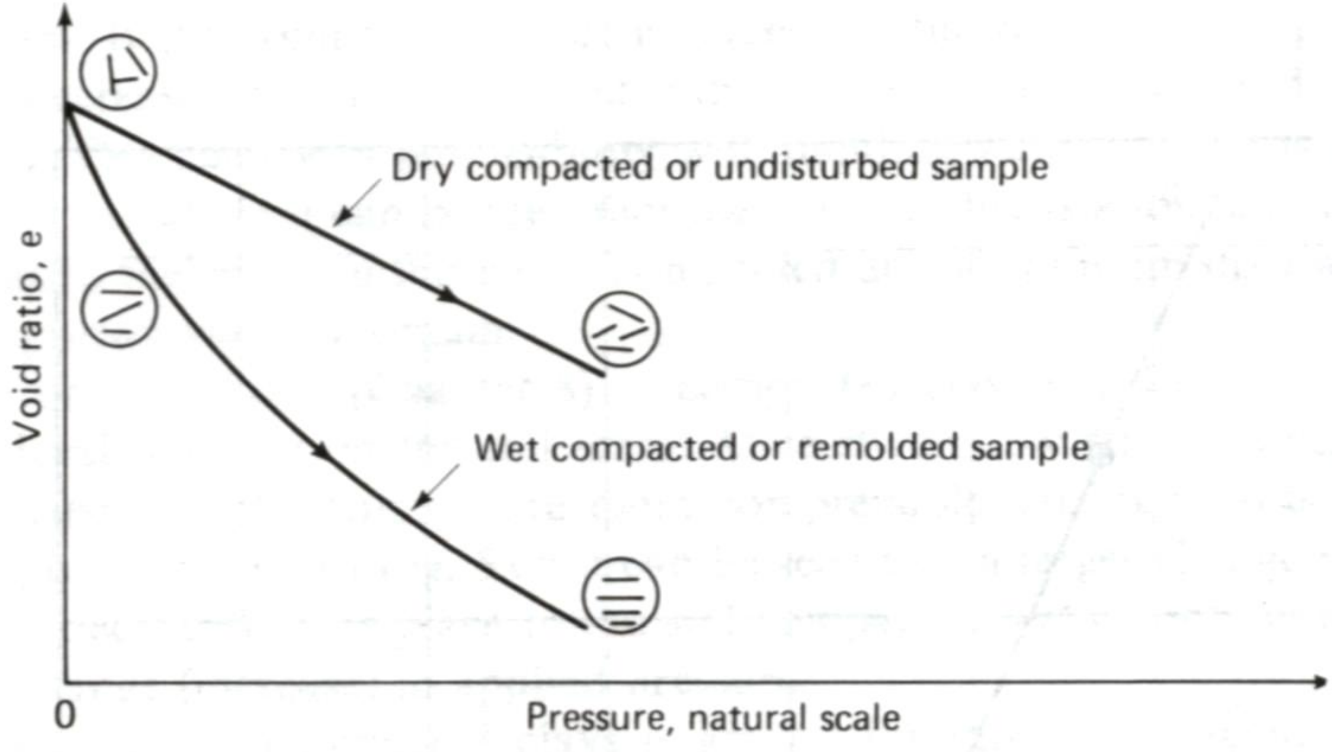
Effects of Compaction : On Permeability

- Increasing the water content results in a decrease in permeability on the dry side of the optimum moisture content and a slight increase in permeability on the wet side of optimum.
- Increasing the compactive effort reduces the permeability since it increases the dry density, thereby reducing the voids available for flow.



Effects of Compaction: On Compressibility

At low stresses the sample compacted on the wet side is more compressible than the one compacted on the dry side.

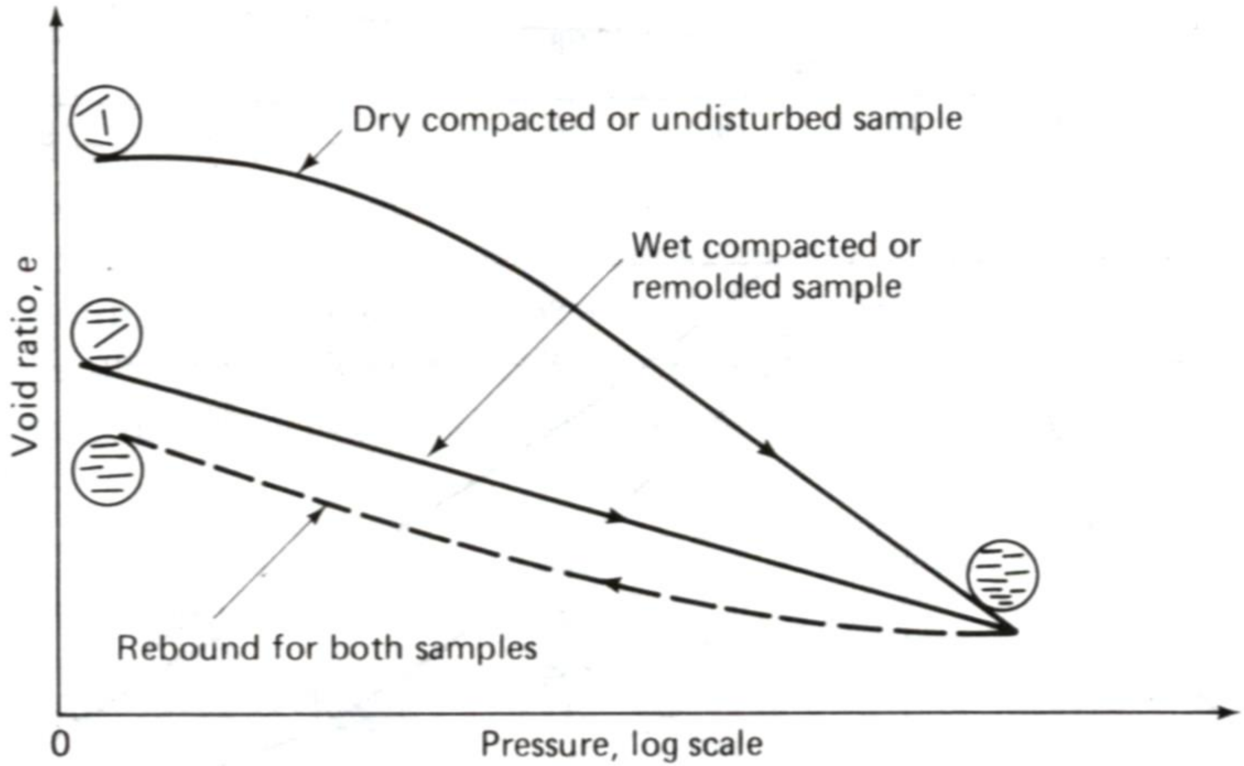


Low pressure consolidation.

51

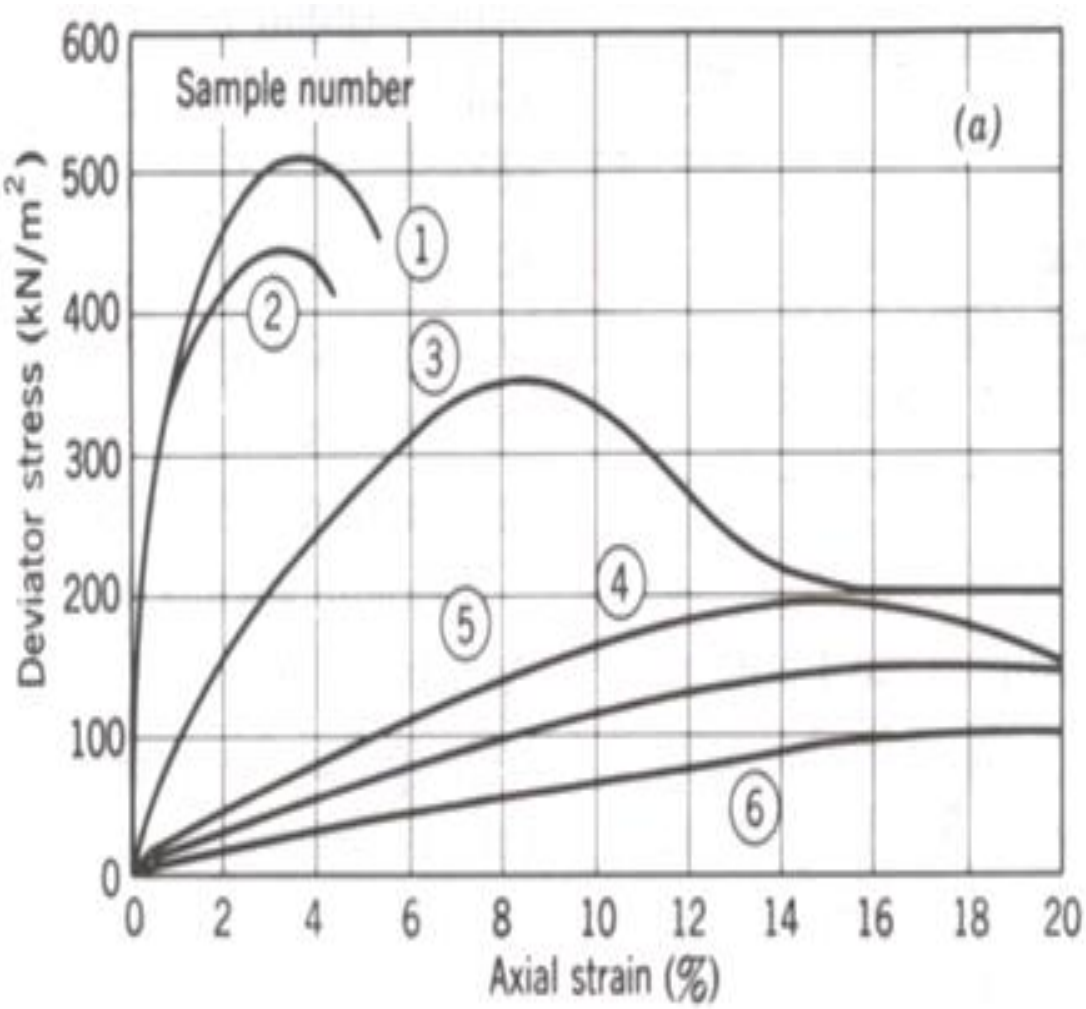
Effects of Compaction : On Compressibility

At the high applied stresses the sample compacted on the dry side is more compressible than the sample compacted on the wet side.

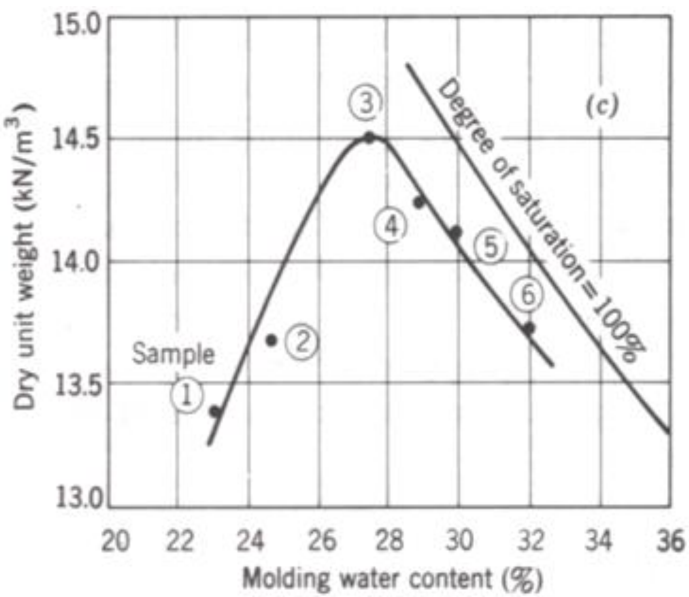


High-pressure consolidation.

Effects of Compaction: On Strength



Samples compacted dry of optimum tend to be more rigid and stronger than samples compacted wet of optimum



3. Field Compaction

- Introduction
- Factors Affecting Field Compaction
- Quality Control

Field Compaction

Introduction

- The soil mass is compacted in layers called **lifts.**
- The stress imparted by compactors, especially static compactors, decreases with lift depth. Consequently, the top part of the lift is subjected to greater stresses than the bottom and attain a higher degree of compaction.
- Lower lift thickness is preferable for uniform compaction.
- Different types of materials will require different lift thickness and a suitable type of field compactors.

Field Compaction

- Compaction is accomplished by

1. Static vertical force

– Applied by a dead weight that imparts pressure and/or kneading action to the soil mass.

– E.g. sheep foot rollers, grid rollers, rubber-tired rollers, drum rollers, loaders and scrapers.

2. Vibratory vertical force

– Applied by engine-driven systems with rotating eccentric weights or spring/piston mechanisms that impart a rapid sequence of blows to the soil surface.

– E.g. vibrating plate compactors, vibrating rollers and vibrating sheepfoot rollers.

Field Compaction

Sheep-foot roller

Drum-roller

Rubber-tired rollers

Vibrating plate compactor

Vibrating roller

Field Compaction

Comparison of field compactors for various soil types

		Compaction type				
		Static		Dynamic		
		Pressure with kneading	Kneading with pressure	Vibration	Impact	
Material	Lift thickness (mm)	Static sheeps-foot grid roller; scraper	Scraper; rubber-tired roller; loader; grid roller	Vibrating plate compactor; vibrating roller; vibrating sheepsfoot roller	Vibrating sheepsfoot rammer	Compactability
Gravel	300+	Not applicable	Very good	Good	Poor	Very easy
Sand	250±	Not applicable	Good	Excellent	Poor	Easy
Silt	150±	Good	Excellent	Poor	Good	Difficult
Clay	150±	Very good	Good	No	Excellent	Very difficult

Field Compaction

- **Factors Affecting Field Compaction**
  - Soil type
  - Moisture content
  - Thickness of lift
  - Intensity of pressure applied by the compacting equipment
  - Area over which the pressure is applied
  - Number of roller passes.

Field Compaction cntd

Control Parameters

- *Dry density* and *water content* correlate well with the engineering properties, and thus they are convenient construction control parameters.
- Since the objective of compaction is to stabilize soils and improve their engineering behavior, it is important to keep in mind the desired engineering properties of the fill, not just its dry density and water content. This point is often lost in the earthwork construction control.

Field Compaction cntd

Control Parameters

- Laboratory tests are conducted on samples of the proposed borrow materials to define the properties required for design.
- After the earth structure is designed, the compaction specifications are written. Field compaction control tests are specified, and the results of these become the standard for controlling the project.

Field Compaction cntd

Relative compaction or percent compaction

$$R.C. = \frac{\rho_{d-field}}{\rho_{max-laboratory}} \times 100\%$$

Correlation between relative compaction $(R.C.)$ and relative density (D_r)

$$R.C. = 80 + 0.2D_r$$

NB.This is a statistical result based on 47 soil samples.

Typically $R.C. = 90\% \sim 95\%$ is required.

Field Compaction cntd

- **Determination of Field Unit Weight of Compaction**
  - We have to know whether the specified unit weight has been achieved while compaction work is in progress in the field.
  - In most specifications for earthwork, the contractor is required to achieve a compacted field dry unit weight (relative compaction) of 90-95% of the maximum dry unit weight determined by the Proctor Test.
  - The standard procedure for determining the field unit weight of compaction include;

$$RC(\%) = \frac{\gamma_{d(field)}}{\gamma_{d(\max,lab}} x100$$

1. Sand cone method

2. Rubber balloon method

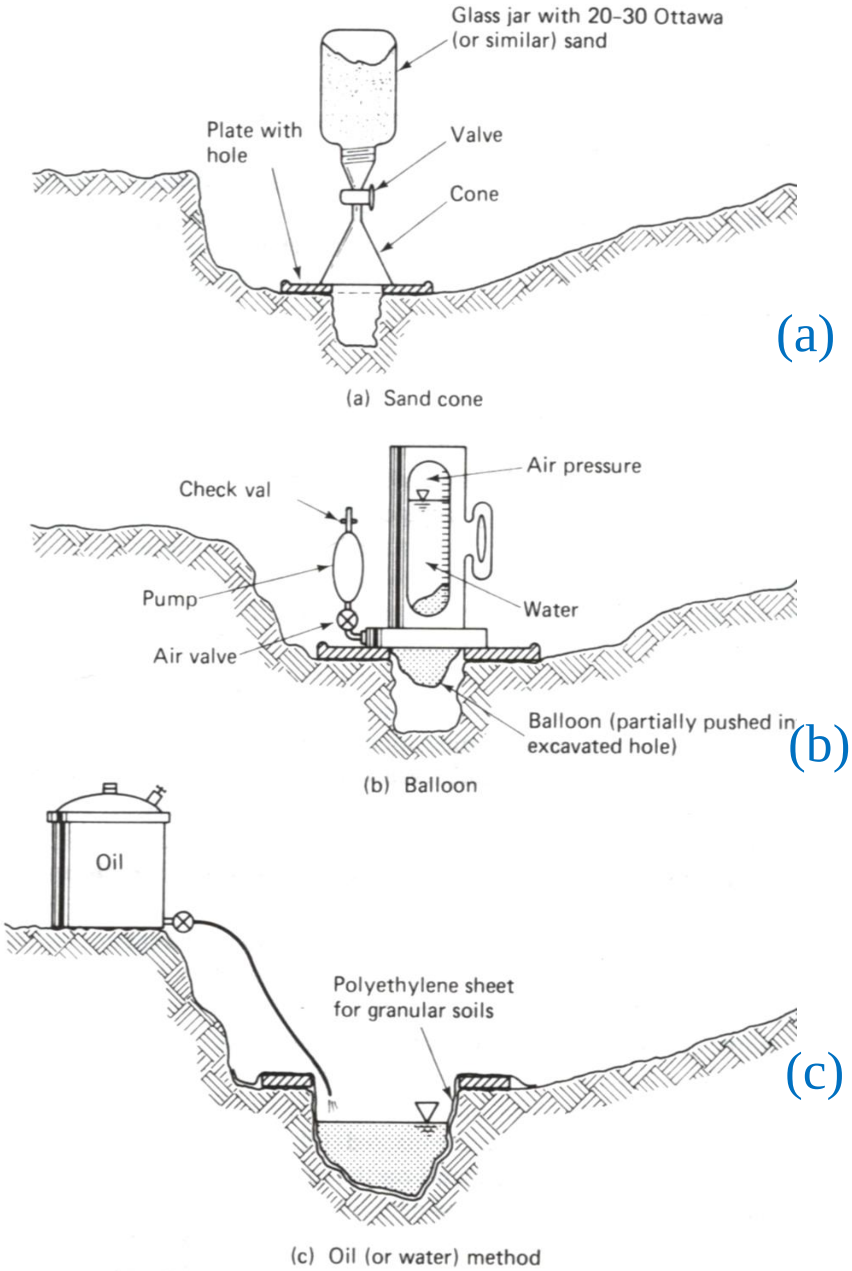
3. Nuclear method

Destructive Methods

(a) Sand cone

(b) Balloon

(c) Oil (or water) method



Calculations

- Know M_s and V_t
- Get $\rho_{d\ field}$ and w (water content)
- Compare $\rho_{d\ field}$ with $\rho_{d\ max\text{-}lab}$ and calculate relative compaction R.C.

Field Compaction cntd

Sand cone method procedures

1. Fill the jar with a standard sand—a sand with known density—determine the weight of the sand cone apparatus with the jar filled with sand (W_1).

2. Determine the weight of sand to fill the cone (W_2).

3. Excavate a small hole in the soil and determine the weight of the excavated soil (W_3).

4. Determine the water content of the excavated soil (w).

5. Fill the hole with the standard sand by inverting the sand cone apparatus over the hole and opening the valve.

6. Determine the weight of the sand cone apparatus with the remaining sand in the jar (W_4).

Sand cone method procedures

7. Calculate the unit weight of the soil as follows:

$$Weight\ of\ sand\ to\ fill\ hole = W_s = W_1 - (W_2 + W_4)$$

$$Volume\ of\ hole = V = \frac{W_s}{(\gamma_d)_{Ottawa\ sand}}$$

$$Weight\ of\ dry\ soil = W_d = \frac{W_3}{1 + \omega}$$

$$Dry\ unit\ weight = \gamma_d = \frac{W_d}{V}$$

Field Compaction cntd

- The measuring error is mainly from the determination of the volume of the excavated material.
- For example, for the sand cone method, the vibration from nearby working equipment will increase the density of the sand in the hole, which gives a larger hole volume and a lower field density.
- If the compacted fill is gravel or contains large gravel particles, any kind of unevenness in the walls of the hole causes a significant error in the balloon method.
- If the soil is coarse sand or gravel, none of the liquid methods works well, unless the hole is very large and a polyethylene sheet is used to contain the water or oil.

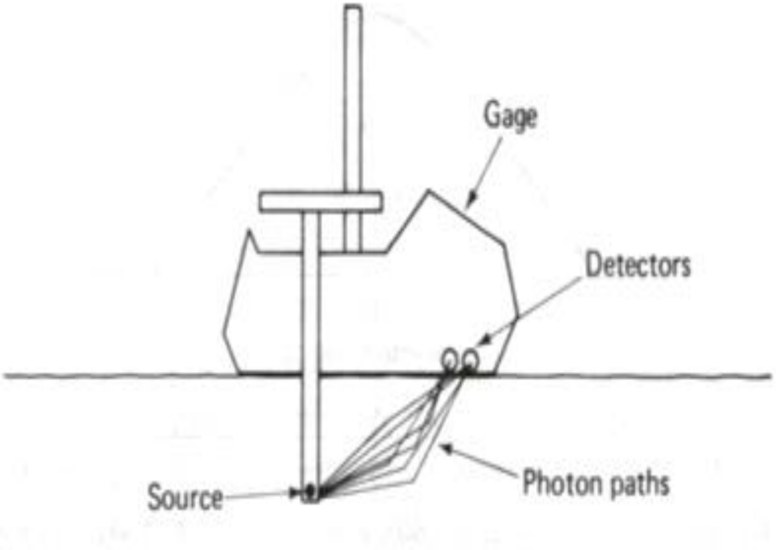
Nondestructive Methods

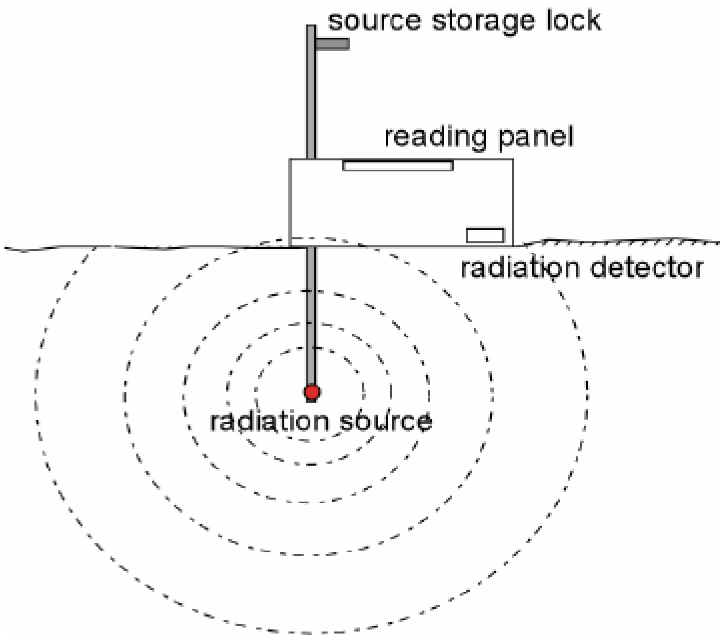
Nuclear density meter

▪**Principles**

✓**Density:** The Gamma radiation is scattered by the soil particles and the amount of scatter is proportional to the total density of the material. The Gamma radiation is typically provided by the radium or a radioactive isotope of cesium.

✓**Water content**: The water content can be determined based on the neutron scatter by hydrogen atoms. Typical neutron sources are americium-beryllium isotopes.





Field Compaction cntd

Advantages and disadvantages of field unit weight measuring methods

Material	Sand cone	Balloon	Nuclear density meter
Advantages	• Low cost • Accurate • Large sample	• Low to moderate cost • Fewer computational steps compared to sand cone • Large sample	• Quick • Direct measurement of unit weight and water content
Disadvantages	• Slow; many steps required • Standard sand in hole has to be retrieved • Unit weight has to be computed • Difficult to control density of sand in hole • Possible void space under plate • Hole can reduce in size through soil movement • Hole can cave in (granular materials)	• Slow • Extra care needed to prevent damage to balloon, especially in gravelly materials • Unit weight has to be computed • Difficult to obtain accurate hole size • Possible void space under plate • Hole can reduce in size through soil movement • Hole can cave in (granular materials)	• High cost • Radiation certification required for operation • Water content error can be significant • Surface preparation needed • Radiation backscatter can be hazardous

EXERCISE 5.3.4 SAND CONE METHOD

A sand cone test conducted during the compaction of a roadway embankment gave the following data.

Calibration to find dry unit weight of the standard sand	
Mass of Proctor mold	4178 grams
Mass of Proctor mold and sand	5609 grams
Volume of mold	0.00095 m^3
Calibration of sand cone	
Mass of sand cone apparatus and jar filled with sand	5466 grams
Mass of sand cone apparatus with remaining sand in jar	3755 grams
Sand cone test results	
Mass of sand cone apparatus and jar filled with sand	7387 grams
Mass of excavated soil	1827 grams
Mass of sand cone apparatus with remaining sand in jar	3919 grams
Water content of excavated soil	4.8%

EXERCISE 5.3.4 SAND CONE METHOD

(a) Determine the dry unit weight.

(b) The standard Proctor maximum dry unit weight of the roadway embankment soil is 16 kN/m3 at an optimum water content of 4.2%, dry of optimum. The specification requires a minimum dry unit weight of 95% of Proctor maximum dry unit weight. Is the specification met? If not, how can it be achieved?

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Galatoma!