Soil Mechanics

Soil compaction

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Course Structure: 2L-0T-2P-0A (8 credits)
Pre-requisites: at least exposure grades in CE 242 and ESO-1 (Mechanics of Solids)

Lectures: WF 15:00-16:00 L16
Laboratory: MTTh 14:00-17:00 GTE Lab
Instructor: Prof. Nihar Ranjan Patra (Office: FB 316, nrpatra@iitk.ac.in, Phone-7623) [Lecture]
Tutor: Swaraj Chowdhury, Ph.D. student [Laboratory, e mail: swaraj@iitk.ac.in]
Course Outline:

- In-situ stresses: Stresses within soil, effective stress principle
- Soil Compaction: Compaction characteristics, water content-dry unit weight relationships, OMC, max. dry density, factors affecting compaction, field compaction, determination of field density
- Permeability: Darcy's law, hydraulic conductivity, lab tests for permeability, in-situ test for permeability, equivalent hydraulic conductivity in stratified soil
- Seepage: Flow nets, capillary rise, piping, quicksand condition, seepage through for geotechnical structures
- Compressibility of Soil: Consolidation characteristics, 1D laboratory consolidation test, consolidation settlement, coefficient of consolidation, time rate of consolidation, consolidation settlement under a foundation
- Shear Strength of Soil: Stresses on soil elements, Mohr's circle, principal stresses, stress path, direct and triaxial shear tests, Mohr-Coulomb strength criterion, drained and undrained tests, strength of loose and dense sand, NC and OC soils, dilation, pore pressures, Skempton's coefficients

Laboratory Session:

- Visual identification of soil
- Standard Proctor compaction test
- Core cutter test
- Sand replacement test
- Constant head permeability test
- Falling head permeability test
- Consolidation test
- Unconfined compression test
- Direct shear test
- Unconsolidation undrained triaxial test

Lecture-wise break-up: (please note that the duration of each lecture is 50 minutes)

Topic	Suggested number of lectures
Stresses within a soil, effective stress principle, stress point and stress path, Soil - water systems- capillarity, flow	4
Darcy’s law, permeability, and tests for its determination, different heads, piping, quicksand condition, seepage, flow nets	6
Compressibility and consolidation characteristics	4
Strength of loose and dense sands, NC and OC soils, dilation, pore pressures, Skempton’s coefficients, etc.	10
Compaction characteristics, water content - dry unit weight relationships, OMC, max. dry unit weight, field compaction control, etc.	2
Total number of lectures	26

Grading Policy:

Attendance : 5%
Quizzes : 10%
Laboratory : 15%
Assignments: 5%
Mid Term Exam : 25%
End semester Exam : 40%

Text Book:

- Principles of Geotechnical Engineering, Braja M. Das, CENGAGE Learning (India Edition).

Reference Books:

- An Introduction to Geotechnical Engineering, Robert D. Holtz and William D. Kovacs, Prentice Hall.
- Basic and Applied Soil Mechanics, Gopal Ranjan and A.S.R. Rao, New Age International Publishers.
- Soil Mechanics, T. William Lambe and Robert V. Whitman, John Wiley & Sons.
- Craig's Soil Mechanics, Craig RF., Taylor and Francis, USA.

Soil Compaction

- In the construction of highway, embankments, earth dams and many other engineering structures, loose soils must be compacted to increase their unit weight

Soil Compaction

General principles

- Compaction, in general, is the densification of soil by removal of air, which requires mechanical energy
- When water is added to the soil during compaction, it acts as a softening agent on the soil particles; the soil particles slip over each other and move into a densely packed position

Soil Compaction

- Beyond a certain moisture content, any increase in the moisture content tends to reduce the dry unit weight; this phenomenon occurs because the water takes up the spaces that would have been occupied by the solid particles
- The water content at which the maximum dry unit weight is attained is generally referred to as "optimum moisture content (OMC)"

Soil Compaction

Standard Proctor Test

- A mold of volume = 944 cm^3,
- diameter = 101.6 mm
- Number of blows = 25
- Number of layers = 3
- Hammer weight = 2.5 kg, height of fall = 30.5 cm

- For each test, the moist unit weight of compaction, γ can be written as

$$\gamma = W/V_{mold}$$

Where, W = weight of soil, V_{mold} = volume of mold

Soil Compaction

Standard Proctor Test

- With the known moisture content, the dry unit weight can be written as

$$\gamma_d = \gamma/(1+w/100)$$

- For a given moisture content, w and degree of saturation S, the dry unit weight of compaction

$$\gamma_d = (G_s*\gamma_w)/(1+e)$$

Again, $Se = G_s w$; therefore $\gamma_d = (G_s*\gamma_w)/(1+G_s w/S)$

Soil Compaction

Standard Proctor Test

- For a given w, the theoretical maximum dry unit weight is obtained when no air is in the void spaces i.e. degree of saturation is 100% (S=1)
- Hence, the maximum dry unit weight at a given w with zero air voids (S=1)

$$\gamma_{zav} = (G_s*\gamma_w)/(1+G_s w) = \gamma_w/(w+1/G_s)$$

Soil Compaction

Standard Proctor Test

- To obtain the variation of γ_{zav}
  - Determine G_s
  - Know γ_w
  - Assume several values of w
  - Use the previous eqn. to calculate γ_{zav} for various values of w

Soil Compaction

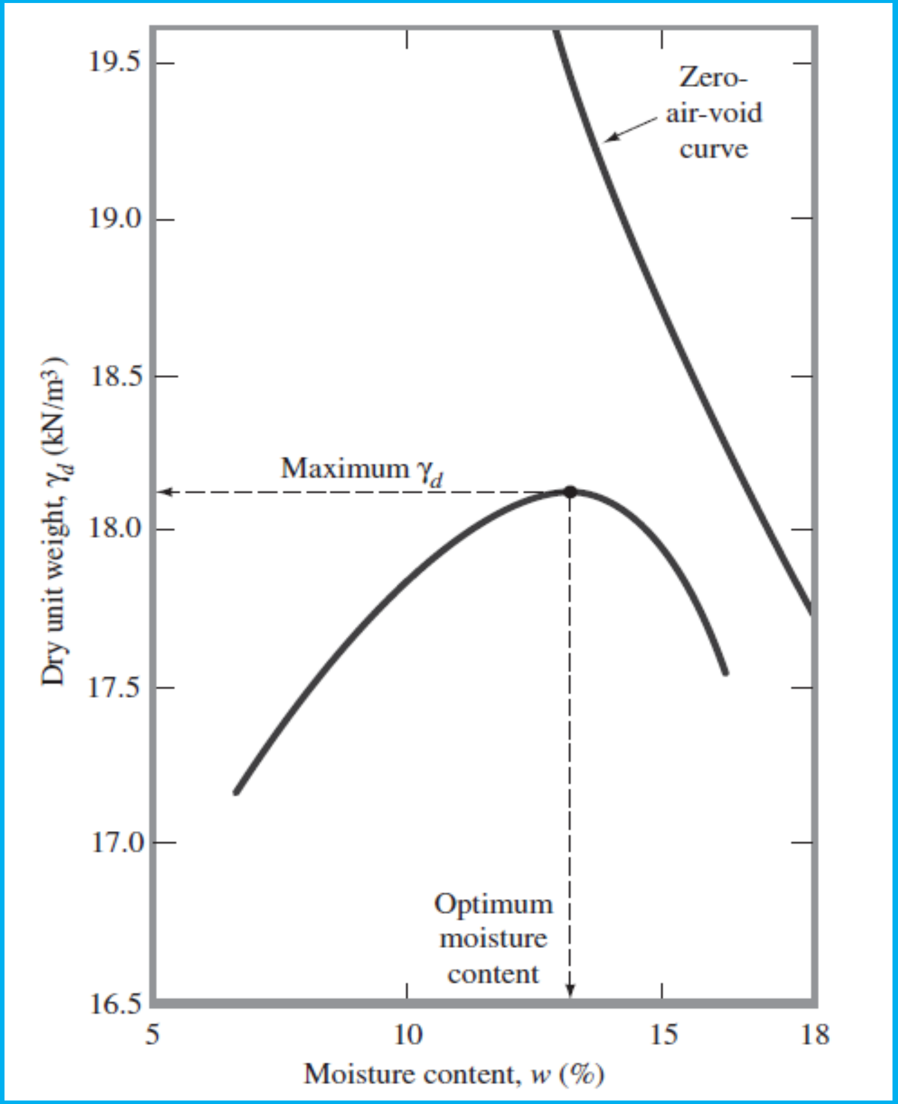

Fig. 1 Typical compaction curve

Soil Compaction

Factors affecting compaction

Effect of soil type

- The soil type i.e. grain size distribution, shape of the soil grains, specific gravity of soil solids, and amount and type of clay mineral present – has a great influence on the $\gamma_{d,max}$ and OMC

Soil Compaction

Factors affecting compaction

Effect of compaction effort

- As the compaction effort is increased, the max γ_d is also increased
- As the compaction effort is increased, the OMC is decreased to some extent

Soil Compaction

Factors affecting compaction

Effect of compaction effort

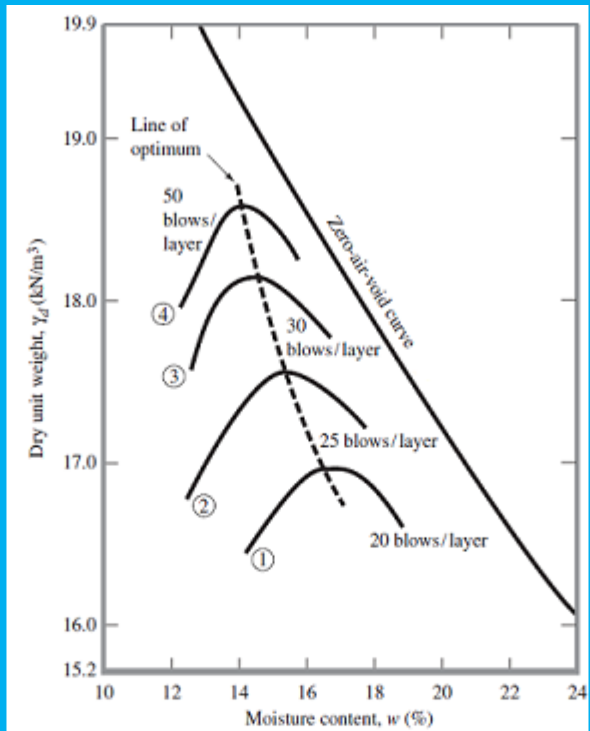

Fig. 2. Compaction curves for different compaction effort

Soil Compaction

Modified Proctor Test

- With the development of heavy rollers and their use in field compaction, the Standard Proctor Test was modified to better represent the field condition
  - A mold of volume = 944 cm^3, diameter = 101.6 mm
  - Number of layers = 5
  - Hammer weight = 4.54 kg, height of fall = 45.7 cm
- Because it increases the compaction effort, the Modified Proctor Test results in an increase in $\gamma_{d,max}$ accompanied by a decrease in OMC

Soil Compaction

Field compaction

Smooth-wheel rollers (smooth drum rollers)

- These are suitable for proof rolling subgrades and for finishing operations of fills with sandy and clayey soils
- Provide 100% coverage under the wheels

Pneumatic rubber-tired rollers

- These are better in many respects than smooth-wheel rollers and can be used for sandy and clayey soil compaction which is achieved by a combination of pressure and kneading action

Soil Compaction

Field compaction

Pneumatic rubber-tired rollers

- They produce 70-80% coverage under the wheels

Sheep-foot rollers

- These are drums with a large number of projections
- These rollers are most effective in compacting clayey soils

Soil Compaction

Field compaction

Vibratory rollers

- These are extremely efficient in compacting granular soils
- Vibrators can be attached to smooth wheel pneumatic rubber tired or sheep-foot rollers to provide vibratory effects to the soil

Soil Compaction

Field compaction

Smooth-wheel rollers

Pneumatic rubber-tired rollers

Soil Compaction

Field compaction

Sheep-foot rollers

Vibratory rollers

Soil Compaction

Specifications for field compaction

- In most specifications for earthwork, it is instructed to achieve a compacted field dry unit weight of 90-95% of $\gamma_{d,max}$ determined in the lab
- The relative compaction can be expressed as,

$$R\,(\%) = [\gamma_{d\,(field)}/\gamma_{d,max(lab)}] \times 100$$

- For the compaction of granular soil, specifications are sometimes written in terms of required relative density (D_r)

Soil Compaction

Determination of field unit weight of compaction

- Procedures for determining the field unit weight
  - Sand cone method
  - Rubber balloon method
  - Nuclear method

Sand cone method (ASTM D-1556)

- Sand cone device consists of a glass or plastic jar with a metal cone attached at its top
- Let, the combined weight of jar+cone+sand = W_1

Soil Compaction

Determination of field unit weight of compaction

Sand cone method (ASTM D-1556)

Fig. 4. Plastic jar and the metal cone

Soil Compaction

Determination of field unit weight of compaction

Sand cone method (ASTM D-1556)

- In the field a small hole is excavated
- Say, the weight of moist soil excavated from hole = W_2
- If the water content of excavated soil is known then the dry weight of soil is

$$W_3 = W_2/[1+w(\%)/100]$$

- After excavation, the cone with the sand filled jar is inverted and placed over the hole; sand is allowed to flow out to fill the hole and the cone

Soil Compaction

Determination of field unit weight of compaction

Sand cone method (ASTM D-1556)

- If the combined weight of jar+cone+remaining sand in the jar = W_4
- The weight of sand to fill the hole and the cone is

$$W_5 = W_1 - W_4$$

- The volume of excavated hole is

$$V = (W_5 - W_c)/\gamma_{d(sand)}$$

Where, W_c = Weight of sand to fill the cone only

$\gamma_{d(sand)}$ = Dry unit weight of sand

Soil Compaction

Determination of field unit weight of compaction

Sand cone method (ASTM D-1556)

- The values of W_c and $\gamma_{d(sand)}$ are determined in the lab
- The dry unit weight of compaction is given by,

$$\gamma_d = W_3/V$$