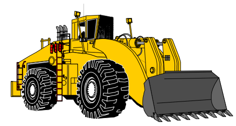
Construction Planning, Equipment, and Methods

Sixth Edition

GEOTECHNICAL MATERIALS, COMPACTION, AND STABILIZATION

A. J. Clark School of Engineering •Department of Civil and Environmental Engineering

4b



By
Dr. Ibrahim Assakkaf
ENCE 420 – Construction Equipment and Methods
Spring 2003
Department of Civil and Environmental Engineering
University of Maryland, College Park

MATERIAL PROPERTIES

Same weight but different volume.

Example 4

The soil borrow material to be used to construct a highway embankment has a mass unit weight 96.0 lb per cu ft (pcf) and water content of 8%, and specific gravity of soil solids is 2.66. The specifications require that the soil be compacted to dry unit weight of 112 pcf and that the water content be held to 13%.

Example 4 (cont'd)

a) How many cubic yards of borrow are required to construct an embankment having a 250,000-cu-yd net section volume?
b) How many gallons of water must be added per cubic yard of borrow material assuming no loss by evaporation and one gallon of water equals 8.34 lb?
c) If the compacted fill becomes saturated at a constant volume, what will be the water content and mass unit weight of the soil?

Example 4 (cont'd)

Borrow:

$$\gamma = 96.0\,\frac{\text{lb}}{\text{ft}^3}, \qquad \omega = 8.0\%, \qquad G_s = 2.66$$

$$\gamma_d = \frac{\gamma}{1+\omega} = \frac{96}{1+0.08} = 88.89\,\frac{\text{lb}}{\text{ft}^3}$$

Embankment:

$$\gamma_d = 112.0\,\frac{\text{lb}}{\text{ft}^3}, \qquad \omega = 13.0\%,$$

$$\gamma = \gamma_d(1+\omega) = 112(1+0.13) = 126.56\,\frac{\text{lb}}{\text{ft}^3}$$

Example 4 (cont'd)

(a):

$$\text{Shrinkage Factor} = \frac{\text{Compacted Dry Unit Weight}}{\text{Bank Dry Unit Weight}} = \frac{112}{88.89} = 1.26$$

$$\text{Volume of Borrow Required} = 1.26(250{,}000\text{ cu yd}) = \underline{315{,}000\text{ cu yd}}$$

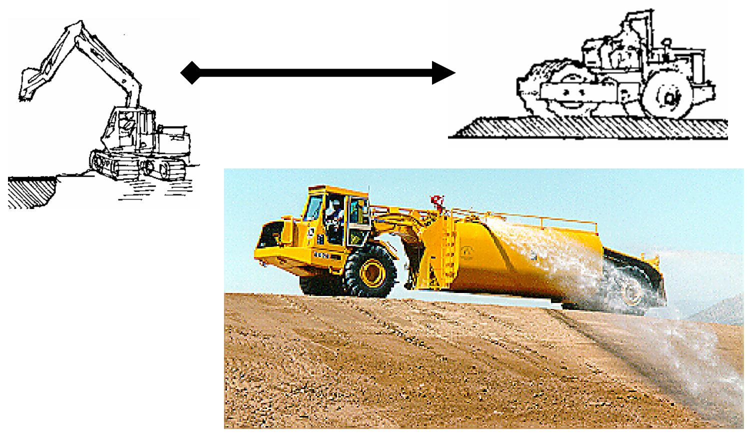
(b):

Water needed in embankment:

$$\gamma - \gamma_d = 126.56 - 112 = 14.56\,\frac{\text{lb}}{\text{ft}^3}$$

$$\text{Weight of Water needed} = \left(14.56\,\frac{\text{lb}}{\text{ft}^3}\right)\left(250{,}000\text{ yard}^3\right)\left(\frac{27\text{ ft}^3}{\text{yard}^3}\right) = 98{,}280{,}000\text{ lb}$$

Example 4 (cont'd)



Example 4 (cont'd)

(b) continued:

Water from borrow :

$$\gamma - \gamma_d = 96 - 88.89 = 7.11 \frac{\text{lb}}{\text{ft}^3}$$

$$\text{Weight of Water from Borrow} = \left(7.11 \frac{\text{lb}}{\text{ft}^3}\right)\left(315{,}000 \text{ yard}^3\right)\left(\frac{27 \text{ ft}^3}{\text{yard}^3}\right) = 60{,}470{,}550 \text{ lb}$$

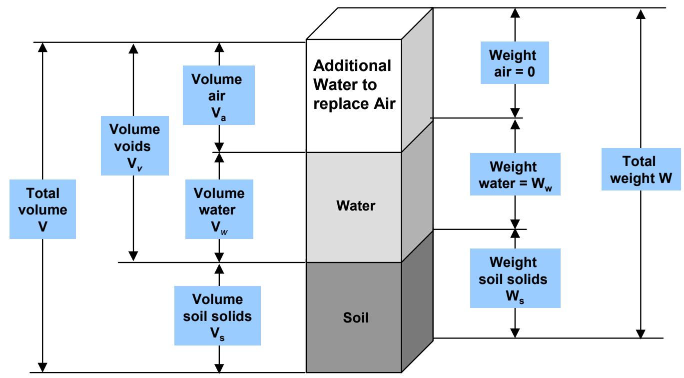
$$\text{Weight of Additional Water Required} = 98{,}280{,}000 - 60{,}470{,}550 = 37{,}809{,}450 \text{ lb}$$

$$\text{Gallons of Req'd Water} = \frac{37{,}809{,}450 \text{ lb}}{315{,}000 \text{ yard}^3} = 120 \frac{\text{lb}}{\text{cu yd}}$$

$$= 120 \frac{\text{lb}}{\text{cu yd}} \frac{1}{8.34 \text{ lb/gal}} = \boxed{14.39 \frac{\text{gal}}{\text{cu yd borrow}}}$$

Example 4 (cont'd)

(c): If the fill becomes saturated all voids between the solid soil particles are filled with water. Therefore, the total weight is increased by the added weight of water:



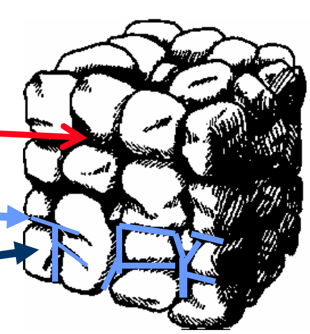
Example 4 (cont'd)

Total volume includes

Air

Water

Solids



Example 4 (cont'd)

(c): continued

$$G_s = \frac{W_s}{V_s \gamma_w} \Rightarrow V_s = \frac{W_s}{G_s \gamma_w} = \frac{112}{2.66(62.4)} = 0.675 \text{ ft}^3$$

$$V_w = \frac{W_w}{\gamma_w} = \frac{14.56}{62.4} = 0.233 \text{ ft}^3$$

$$V_v = 1.000 - 0.675 - 0.233 = 0.092 \text{ ft}^3$$

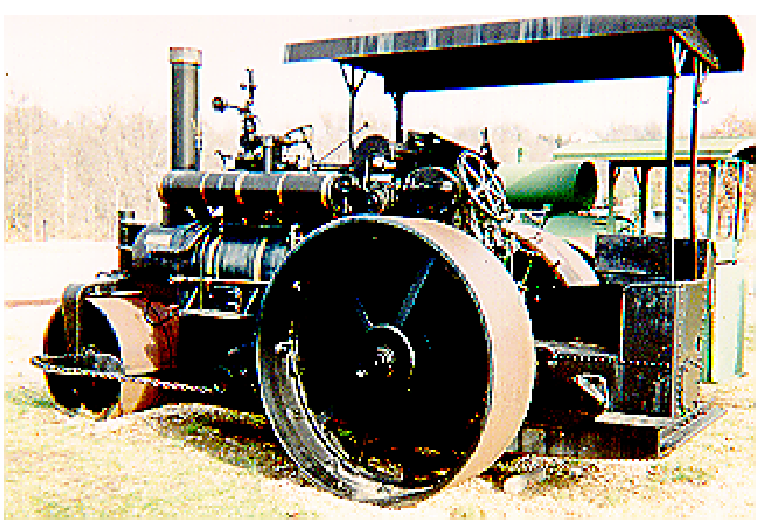
Weight of extra water:

$$W_w = V_w \gamma_w = 0.092(62.4) = 5.74 \text{ lb}$$

$$\omega = \frac{W_w}{W_s} = \frac{(14.56 + 5.74)}{112} = \underline{0.181} = 18.1\%$$

$$\gamma = 14.56 + 5.74 + 112 = \boxed{132.3 \frac{\text{lb}}{\text{ft}^3}}$$

COMPACTION SPECIFICATION AND CONTROL

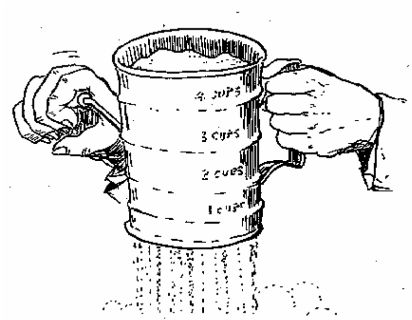


COMPACTION SPECIFICATION AND CONTROL

- The engineering properties of most soils can be improved by compaction.
- Compaction is the art of mechanically densifying materials.

SOIL TYPES

NON-COHESIVE



SMALL GRAINED
< #200 MESH SIEVE
COHESIVE

SOIL TYPES

ORGANIC SOILS

Will usually have to remove before building.

COMPACTION SPECIFICATION AND CONTROL

- Before the specifications for a project are prepared representative soil samples are usually collected and tested in the laboratory to determine material properties.

COMPACTION SPECIFICATION AND CONTROL

- **SOIL CLASSIFICATION (Atterburg Limits)**

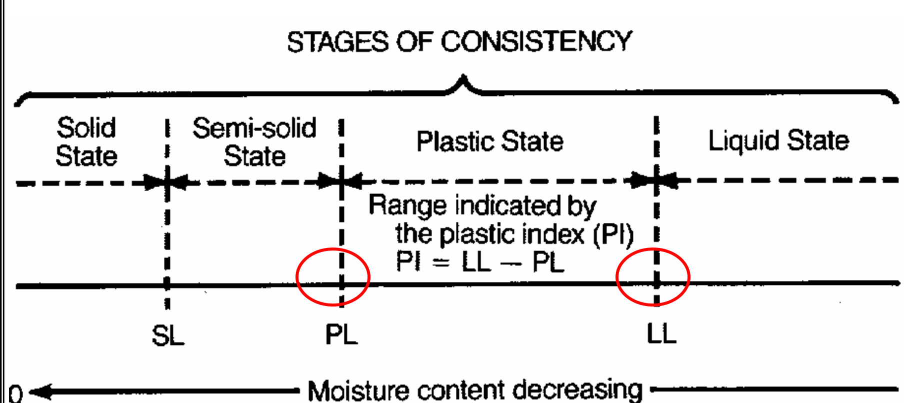
LL - Liquid limit

PL - Plastic limit

PI - Plasticity Index

COMPACTION SPECIFICATION AND CONTROL

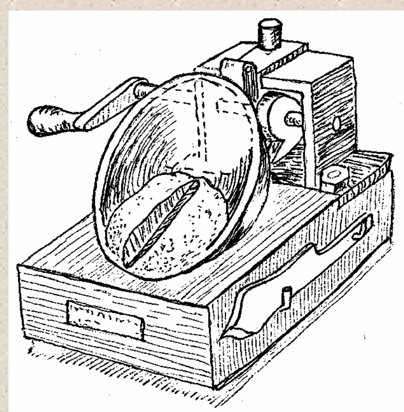
- SOIL LIMITS



SOIL CLASSIFICATION

LL - Liquid limit

is the water content of a soil when it passes from the plastic to liquid state.



SOIL CLASSIFICATION

LL - Liquid limit

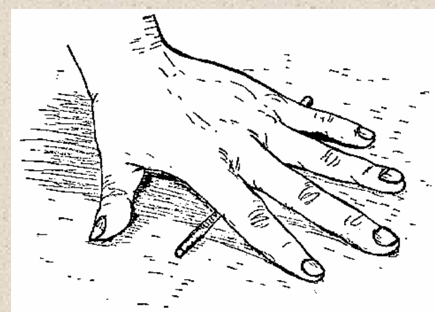
Non-cohesive or sandy soils have low LLs -- less than 20.

Clay soils have LLs ranging from 20 to 100.

SOIL CLASSIFICATION

PL - Liquid limit

is the lowest water content at which a soil remains plastic.



1/8 inch diameter thread

SOIL CLASSIFICATION

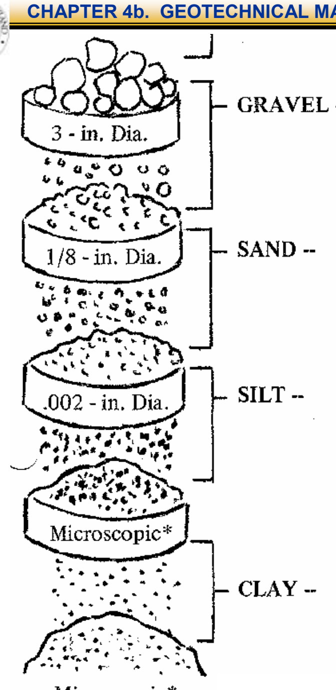
PI - Plastic Index

$$PI = LL - PL$$

The higher the PI the more clay that is present in the soil.

COMPACTION SPECIFICATION AND CONTROL

- **Normal testing would include grain-size analysis because the size of the grains and the distribution of those sizes are important properties, which affect a soil's suitability.**

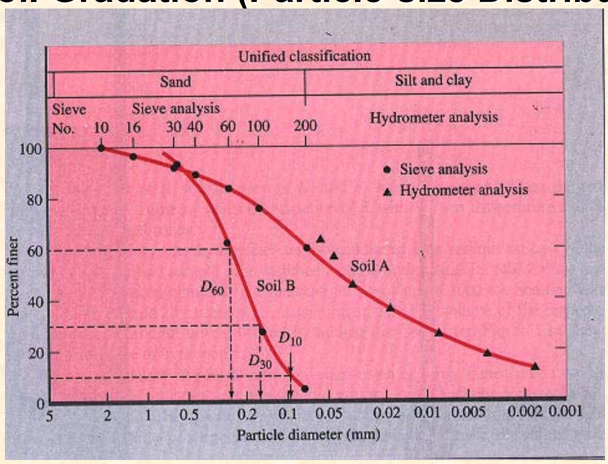


COMPACTION

Soil gradation is the distribution, in percent (%) by weight, of individual particle sizes.

COMPACTION SPECIFICATION AND CONTROL

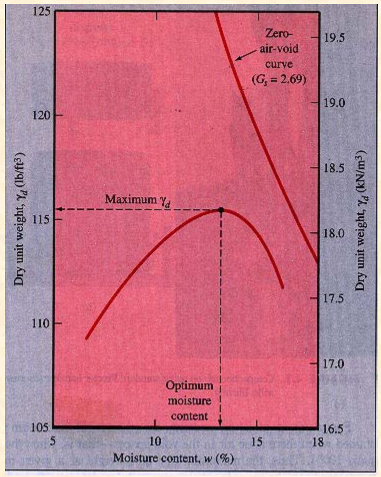
- Soil Gradation (Particle-size Distribution)

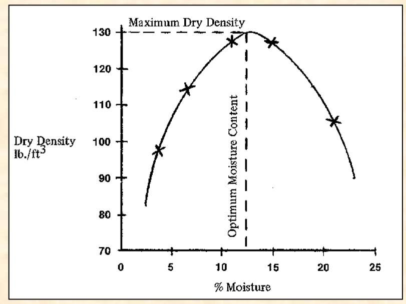


COMPACTION SPECIFICATION AND CONTROL

- Maximum Dry Density/Optimum Moisture
  - ✓Critical test is the construction of a compaction curve.
  - ✓From compaction curves the maximum dry unit weight (density) and the percent water required to achieve maximum density can be determined.

COMPACTION SPECIFICATION AND CONTROL





COMPACTION SPECIFICATION AND CONTROL

- Maximum Dry Density/Optimum Moisture (cont'd)
  - ✓This percent of water, which corresponds to the maximum dry density (for a given compactive effort), is known as the **optimum water content**.

COMPACTION TESTS

- The standard laboratory tests that are used for evaluation of maximum dry unit weights (γ_d's) and optimum moisture contents for various soils are:
  1. The Standard Proctor Test (ASTM D-698 and AASHTO T-99).
  2. The Modified Proctor Test (ASTM, D-1557 and AASHTO T-180)

COMPACTION TESTS

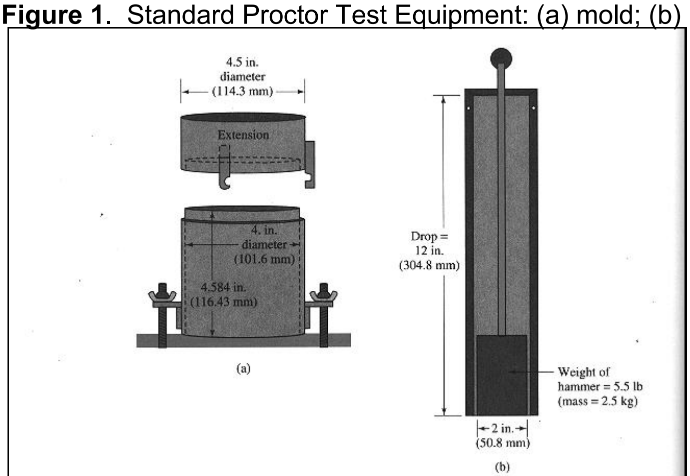
- **Standard Proctor Test**
  - ✓ **The soil is compacted in a mold that has a volume of 1/30 ft^3 (943.3 cm^3).**
  - ✓ **The diameter of the mold is 4 in. (101.6 mm)**
  - ✓ **During the laboratory test, the mold is attached to a base plate at the bottom and to an extension at the top (see Figure 1).**

COMPACTION TESTS

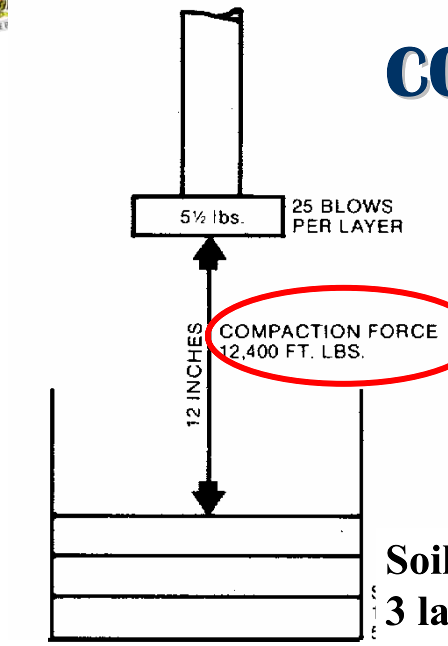
- **Standard Proctor Test**
  - ✓ **The soil is mixed with varying amounts of water and then compacted in three equal layers by a hammer (Figure 2) that deliver 25 blows to each layer.**

COMPACTION TESTS

Figure 1. Standard Proctor Test Equipment: (a) mold; (b) hammer



COMPACTION



PROCTOR TEST

Standard Proctor

or

AASHTO T-99

Soil sample 1/30 cubic foot
3 layers

COMPACTION TESTS

- **Figure 2.** Compaction of Soil using Standard Proctor Hammer

  (courtesy of John Hester, Carterville, IL)

COMPACTION TESTS

- Standard Proctor Test (continued)
  - ✓The hammer weighs 5.5 lb (mass = 2.5 kg) and has a drop of 12 in. (304.8 mm).
  - ✓ For each test, the moist unit weight of compaction γ can be calculated as

$$\gamma = \frac{W}{V_m} \qquad (28)$$

COMPACTION TESTS

- Standard Proctor Test (continued)

  Where

  W = weight of compacted soil in mold

  V_m = volume of mold (1/30 ft^3)

  - ✓For each test, the moisture content w of the compacted soil is determined in the laboratory.
  - ✓With known moisture content, the dry unit weight γ_d can be calculated as

COMPACTION TESTS

- **Standard Proctor Test (continued)**

$$\gamma_d = \frac{\gamma}{1+\omega} \qquad (29)$$

COMPACTION TESTS

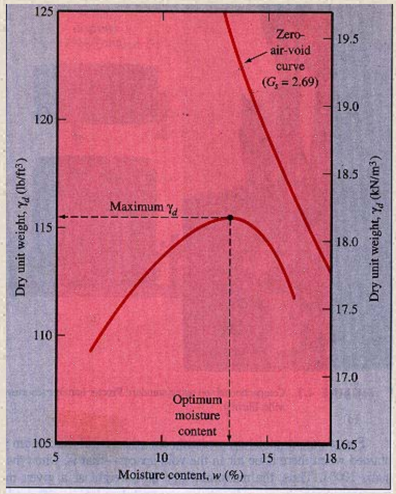
- Standard Proctor Test (continued)

  Where w = moisture content

  ✓The values of γ_d determined from the above equation can be plotted against the corresponding moisture contents for the soil as shown the following figure (Fig. 3), which is a compaction for silty clay.

COMPACTION TESTS

Figure 3. Standard Proctor Compaction Test Results for a Silty Clay



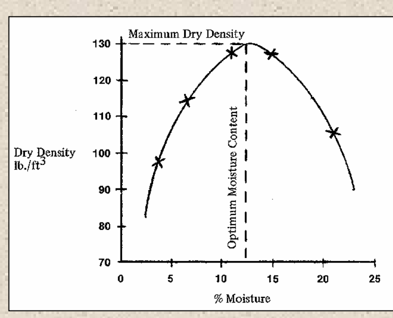


Figure 3

COMPACTION TESTS

- Standard Proctor Test (continued)
  - ✓For a given moisture content ω, the **theoretical** maximum dry unit weight is obtained when there is **no air** in the void spaces, that is, when the degree of saturation S equal 100%. Thus, the maximum dry unit weight at a given moisture content with zero air voids can computed from

COMPACTION TESTS

- Standard Proctor Test (continued)

$$\gamma_{\text{zav}} = \frac{G_s \gamma_w}{1+e} \quad (30)$$

For 100% saturation, $e = \omega G_s$, so

$$\gamma_{\text{zav}} = \frac{G_s \gamma_w}{1+\omega G_s} \quad (31)$$

COMPACTION TESTS

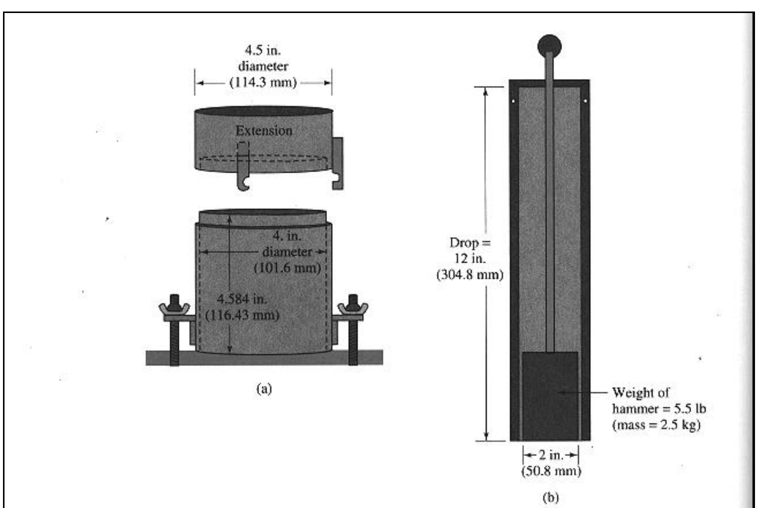
- Modified Proctor Test
  - ✓The soil is compacted in a mold that has a volume of 1/30 ft^3 (943.3 cm^3).
  - ✓The diameter of the mold is 4 in. (101.6 mm)
  - ✓During the laboratory test, the mold is attached to a base plate at the bottom and to an extension at the top (see Figure 4).

COMPACTION TESTS

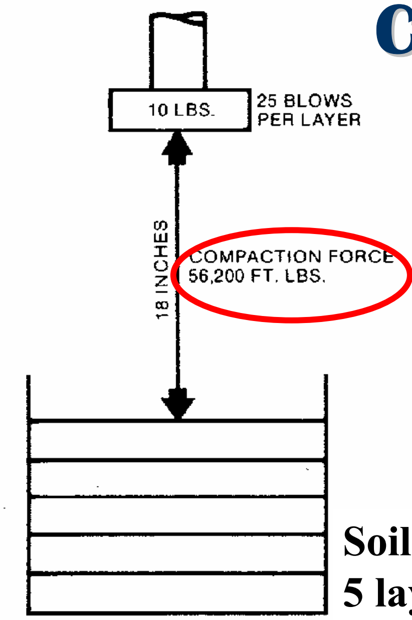
- Modified Proctor Test (cont'd)
  - ✓ The soil is mixed with varying amounts of water and then compacted in five equal layers by a hammer (Figure 2) that deliver **25** blows to each layer.

COMPACTION TESTS

Figure 4. Modified Proctor Test Equipment: (a) mold; (b) hammer



COMPACTION



PROCTOR TEST

Modified Proctor

or

AASHTO T-180

Soil sample 1/30 cubic foot
5 layers

COMPACTION TESTS

- Modified Proctor Test (cont'd)
  - ✓The hammer weighs 10 lb (mass = 4.54 kg) and has a drop of 18 in. (457.2 mm).
  - ✓ For each test, the moist unit weight of compaction g can be calculated as

$$\gamma = \frac{W}{V_m} \qquad (32)$$

COMPACTION TESTS

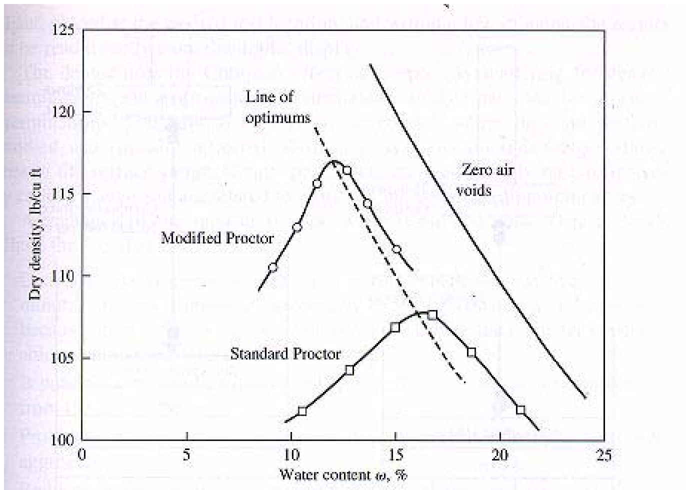
- Modified Proctor Test (cont'd)
  - W = weight of compacted soil in mold
  - V_m = volume of mold (1/30 ft^3)
  - ✓For each test, the moisture content ω of the compacted soil is determined in the laboratory.
  - ✓With known moisture content, the dry unit weight γ_d can be calculated (Eq.29)

COMPACTION TESTS

- Modified Proctor Test (cont'd)
  - ✓The values of γ_d determined from the above equation can be plotted against the corresponding moisture contents for the soil as shown the following figure (Fig. 5).

COMPACTION TESTS

Figure 5. Standard and Modified Compaction Curves



Comparison between Standard & Modified Proctor Tests

- Figure 5 shows compaction curves which illustrate the effect of varying amounts of moisture on the density of a soil subjected to given compactive efforts.
- The two energy levels depicted are known as standard and modified Proctor tests.

Comparison between Standard & Modified Proctor Tests

- It should be noted that the modified Proctor, which is a higher energy level, gives a higher density at a lower moisture content than the standard Proctor, as shown in Figure 5.

Comparison between Standard & Modified Proctor Tests

- In this figure, the optimum moisture for the standard Proctor is 16%, versus 12% for the modified Proctor.

Example 5

- The laboratory test data for a standard Proctor test are given as shown in Table 3. Find the maximum dry unit weight and the optimum moisture content.

Example 5 (cont'd)

Table 3. Test Data for Example 5

Volume of Mold (ft^3)	Weight of Wet Soil in the Mold (lb)	Moisture Content ω (%)
1/30	3.88	12
1/30	4.09	14
1/30	4.23	16
1/30	4.28	18
1/30	4.24	20
1/30	4.19	22

Example 5 (cont'd)

Volume, V (ft^3)	Weight, W (lb)	γ (lb/ft^3)	ω (%)	γ_d (lb/ft^3)
1/30	3.88	116.4	12	103.9
1/30	4.09	122.7	14	107.6
1/30	4.23	126.9	16	109.4
1/30	4.28	128.4	18	108.8
1/30	4.24	127.2	20	106.0
1/30	4.19	125.7	22	103.0

Sample Calculation :

Weight of Wet Soil = 4.09, $\omega = 12\%$, Hence

$$\gamma = \frac{W}{V} = \frac{4.09}{(1/30)} = 122.7\frac{\text{lb}}{\text{ft}^3}, \qquad \gamma_d = \frac{\gamma}{1+\omega} = \frac{122.7}{1+0.14} = 107.6\frac{\text{lb}}{\text{ft}^3}$$

Example 5 (cont'd)

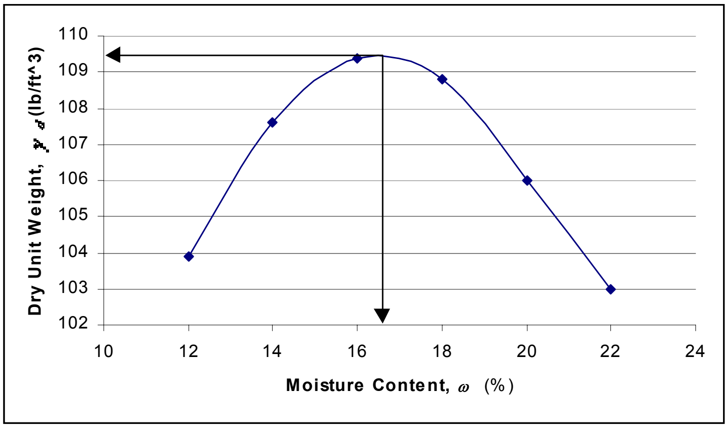
✓Plot the dry unit weight gd against the moisture content w as shown in the following figure(Figure 6). From the figure find the maximum γ_d and optimum ω.

Maximum dry unit weight = 109.5 lb/ft^3

Optimum moisture content = 16.5%

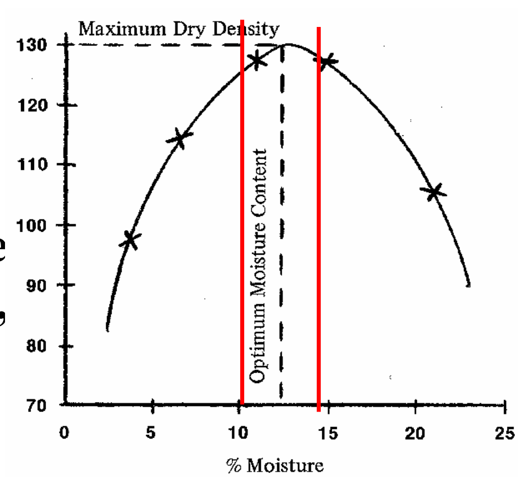
Example 5 (cont'd)

Figure 6. Compaction Curve for the Data of Example 5



COMPACTION SPECIFICATIONS

Typically specifications give an acceptable range of water content, OMC ± 2% for example.

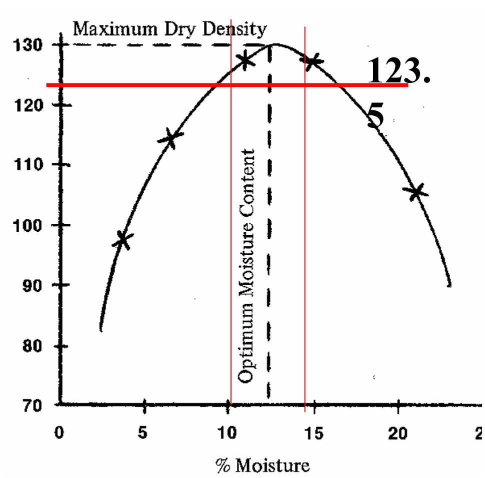


SPECIFICATIONS FOR FIELD COMPACTION

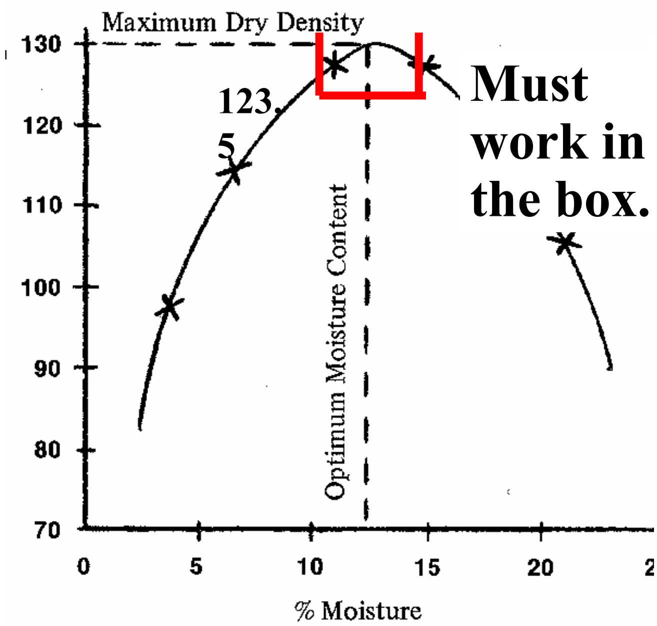
- In most specifications for earth work, the contractor is required to achieve a compacted field dry unit weight of 90% to 95% of the maximum dry unit weight.
- The maximum dry unit weight is the maximum unit weight that is determined by either the ***standard*** or ***modified*** Proctor test.

COMPACTION SPECIFICATIONS

The specification also sets a minimum density, 90% or 95% of max. dry density for a specific test.



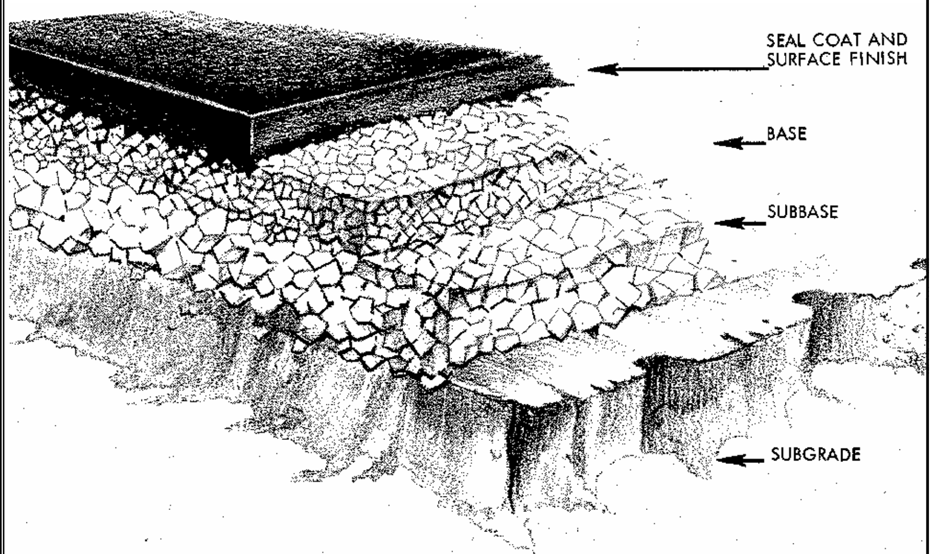
COMPACTION SPECIFICATIONS



COMPACTION SPECIFICATIONS

Lift. A layer of soil placed on top of soil previously placed in an embankment. The term can be used in reference to material as spread or as compacted.

COMPACTION



SPECIFICATIONS FOR FIELD COMPACTION

- The specification for field compaction can be based either on
  - (1) relative compaction *RC* or
  - (2) relative density D_r

SPECIFICATIONS FOR FIELD COMPACTION

- The relative compaction (*RC*), is therefore, defined as the ratio of the dry unit weight of the soil in the field to the maximum dry unit weight of the same soil determined in the laboratory

$$RC\,(\%) = \frac{\gamma_{d\,(\text{field})}}{\gamma_{d\,(\text{max, lab})}} \times 100 \qquad (33)$$

SPECIFICATIONS FOR FIELD COMPACTION

- The relative density D_r is given by

$$D_r = \frac{1}{(1 - R_0)}\left[1 - \frac{R_0}{RC}\right] \qquad (34)$$

$$R_0 = \frac{\gamma_{d\,(\text{min})}}{\gamma_{d\,(\text{max})}}$$

where

$\gamma_{d(\text{min})}$ = dry unit weight in the loosest condition (at a void ratio of e_{max})

$\gamma_{d(\text{max})}$ = dry unit weight in the densest condition (at a void ratio of e_{min})

SPECIFICATIONS FOR FIELD COMPACTION

- ASTM Test Designation D-2049 provides a procedure for the determination of the minimum and maximum dry unit weights of granular soils.
- For sands, this done by using a mold with a volume of 0.1 ft^3 (2830 cm^3).

SPECIFICATIONS FOR FIELD COMPACTION

- For determination of the minimum dry unit weight, sand is loosely poured into the mold from a funnel with a 1/2-in (12.7-mm) diameter spout.
- The average height of the fall of sand into the mold is kept at about 1 in (25.4 mm)

SPECIFICATIONS FOR FIELD COMPACTION

- The value of $\gamma_{d(\min)}$ can then be determined as

$$\gamma_{d(\min)} = \frac{W_s}{V_m} \qquad (35)$$

where

W_s = weight of sand required to fill the mold
V_m = volume of the mold (0.1 ft^3)

SPECIFICATIONS FOR FIELD COMPACTION

- ✓The maximum dry unit weight is determined by vibrating sand in the mold for 8 min.
- ✓A surcharge of 2 lb/in^2 (13.8 kN/m^2) is added to the top of the sand in the mold.
- ✓The mold is placed on a table that vibrates at a frequency of 3600 cycles/min and that has an amplitude of vibration of 0.025 in (0.635 mm).

SPECIFICATIONS FOR FIELD COMPACTION

- The value of $\gamma_{d(\max)}$ can then be determined at the end of the vibrating period with the knowledge of the weight and volume of sand.
- An empirical formula has been developed by Lee and Singh (1971) to give a relationship between *RC* and D_r.

SPECIFICATIONS FOR FIELD COMPACTION

- For granular soils, the relationship is given as

$$RC\ (\%) = 80 + 0.2\ D_r \qquad (36)$$

According to Lee and Singh (1971), the correlation between RC and Dr was based on the observation of 47 soil samples.