CAIRO UNIVERSITY
FACULTY OF ENGINEERING
PUBLIC WORKS DEPARTMENT

Structural Design of Highways
(Part II-A)
Asphalt Pavement Materials

Handout (2) : Soil Compaction

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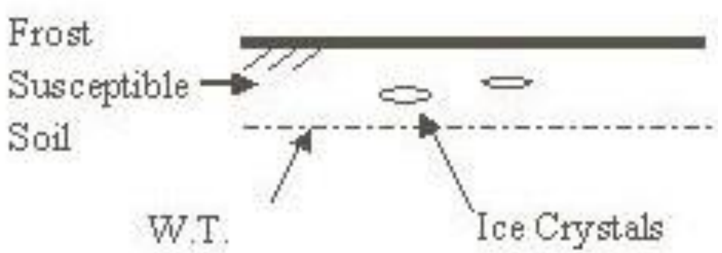
2-2 Soil Compaction

When soil is to be used as embankment or subbase material in highway construction, it is essential that the material be placed in uniform layers and compacted to a high density. Proper compaction of the soil will reduce subsequent settlement and volume change to a minimum, thereby enhancing the strength of the embankment or subbase.

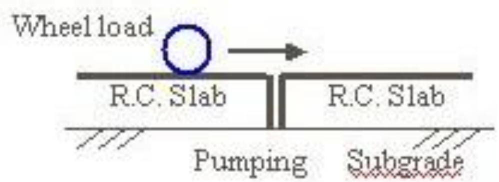
Definition:

Reduction in voids ratio by mechanical means (air is forced out or dissolved in soil water)

Objectives

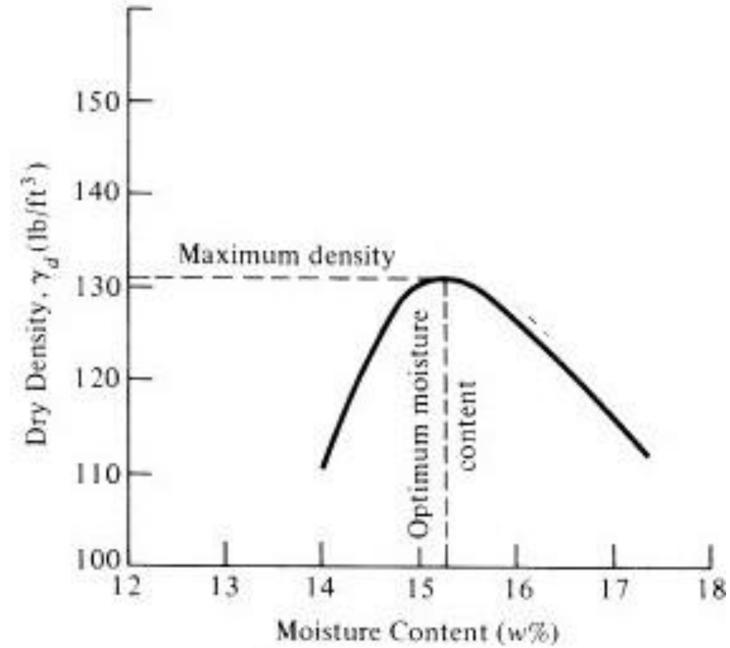


1- **Increase shear strength.**
2- **Reduce permeability.**
3- **Reduce tendency to volume change (shrinkage or swell).**
4- **Reduce tendency to future settlement**
5- **Reduce tendency to frost heave**



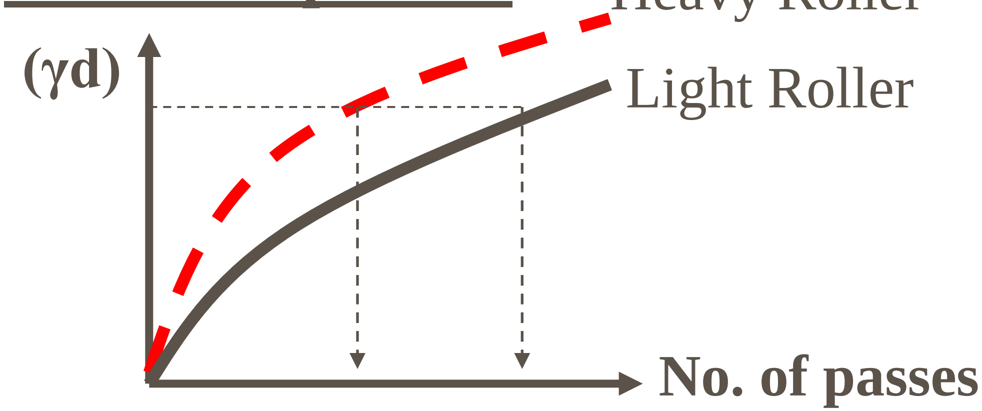
Laboratory Compaction

(Proctor Test)



Typical Moisture-Density Relationship for Soils

Field Compaction



Density Requirements:

$$R.C. = \frac{\gamma_d \text{ field}}{\gamma_d \text{ laboratory}} * 100$$

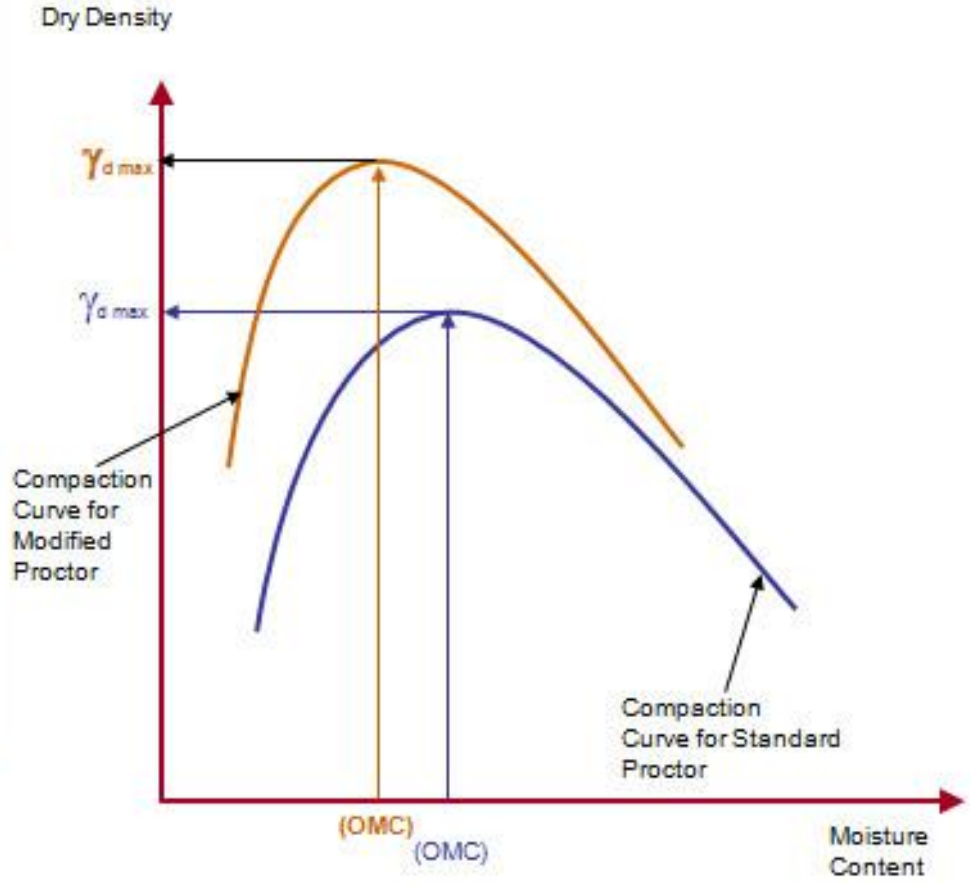
↑ Relative Compaction

≮ 95% or 98% or 100%

Soil Compaction in the Lab:

1- Standard Proctor Test
ASTM D-698 or AASHTO T-99

Energy = 12,375 foot-pounds per cubic foot



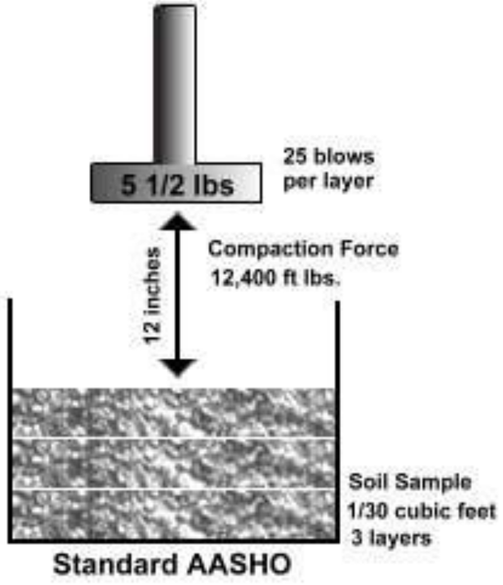
2- Modified Proctor Test
ASTM D-1557 or AASHTO T-180

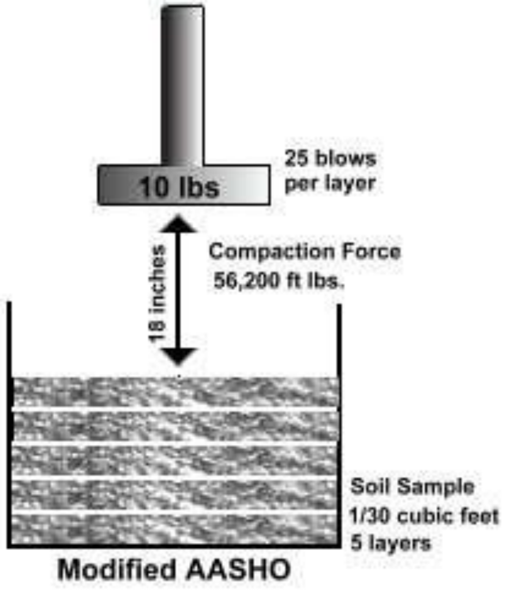
Energy = 56,520 foot-pounds per cubic foot

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

Table 17.6 Details of the Standard AASHTO and Modified AASHTO Tests

Test Details	*Standard AASHTO (T99)*	*Modified AASHTO (T180)*
Diameter of mold (in.)	4 or 6	4 or 6
Height of sample (in.)	5 cut to 4.58	5 cut to 4.58
Number of lifts	3	5
Blows per lift	25 or 56	25 or 56
Weight of hammer (lb)	5.5	10
Diameter of compacting surface (in.)	2	2
Free-fall distance (in.)	12	18
Net volume (ft^3)	1/30 or 1/13.33	1/30 or 1/13.33

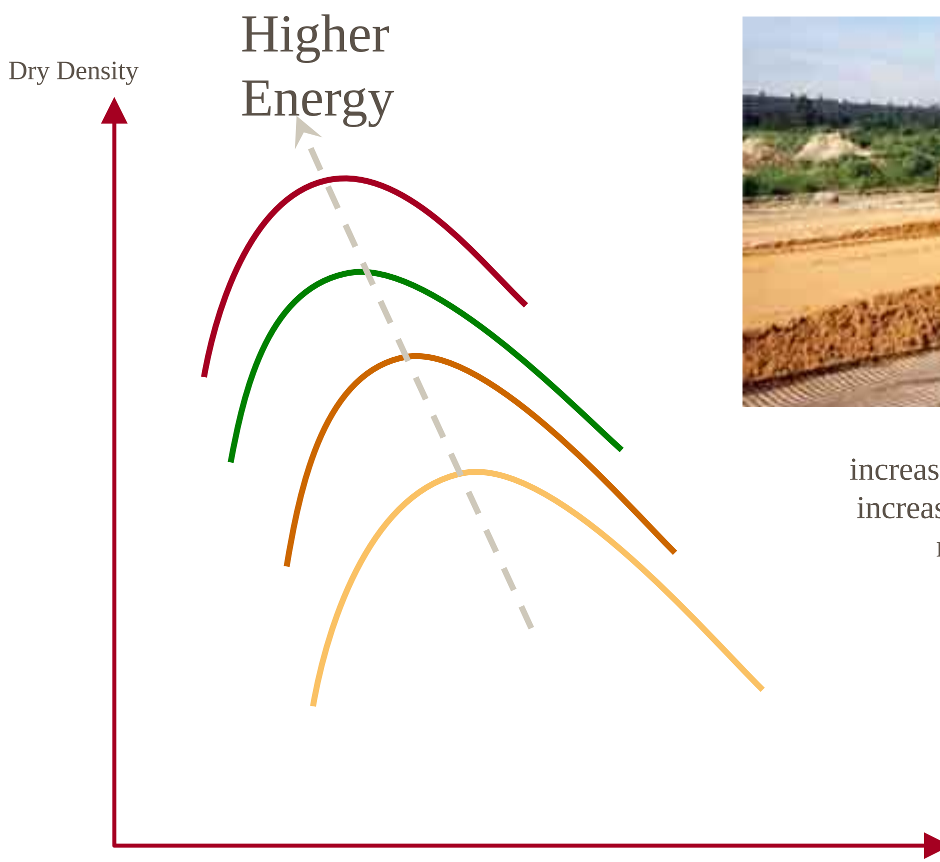




Effect of Energy on Soil Compaction

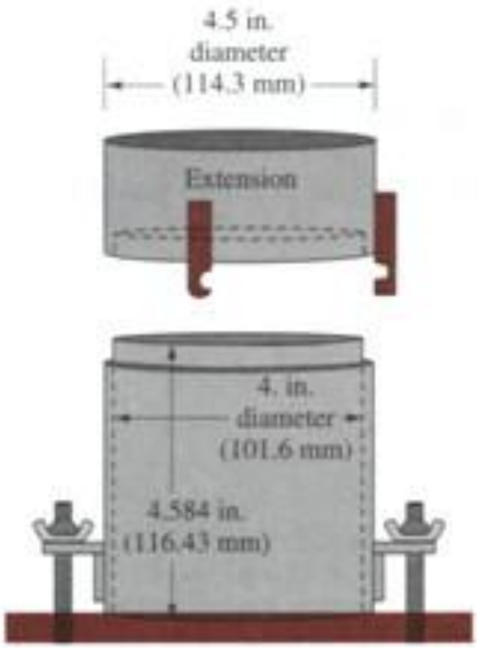
Increasing compaction energy → Lower OWC and higher dry density

In the lab
increasing compaction energy =
increasing number of blows

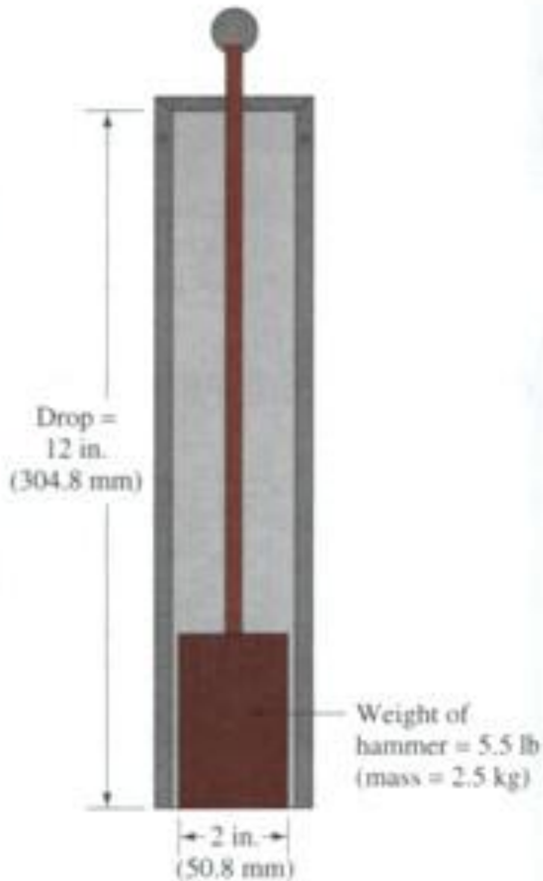


In the field
increasing compaction energy =
increasing number of passes or
reducing lift depth

Standard Proctor test equipment



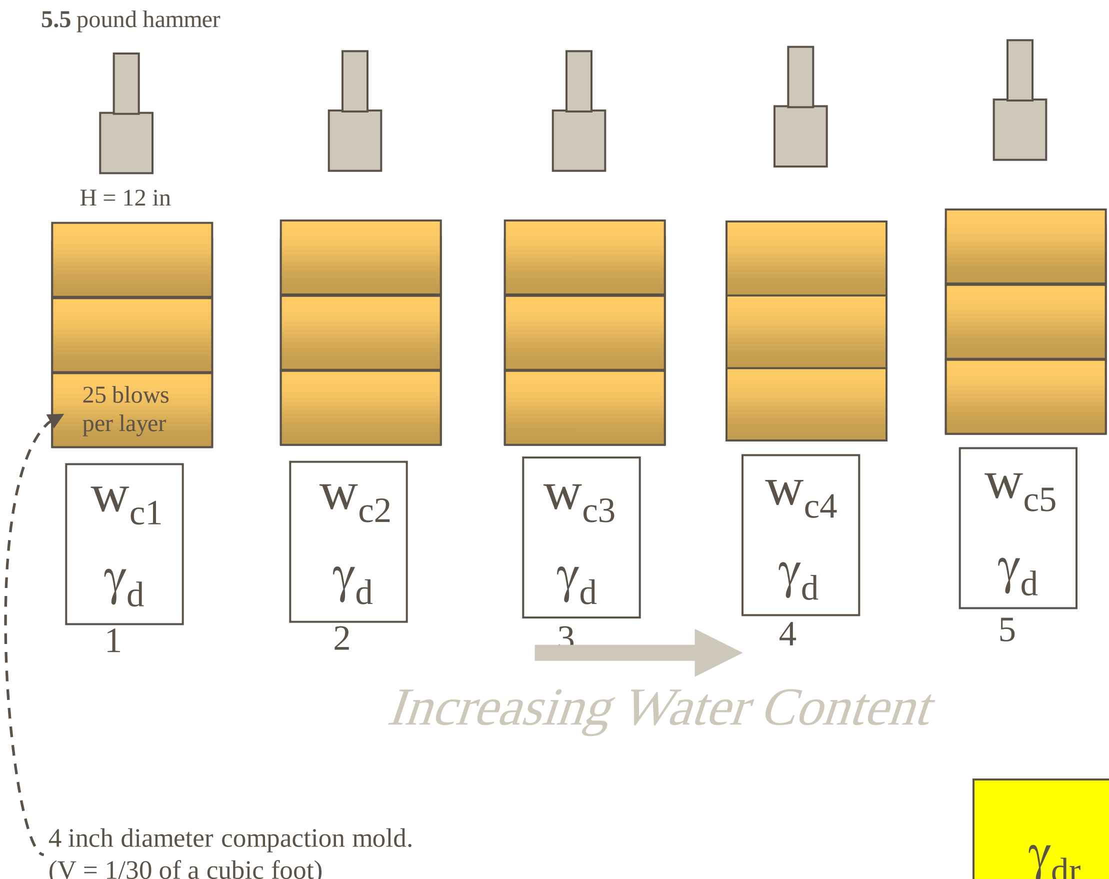
(a)

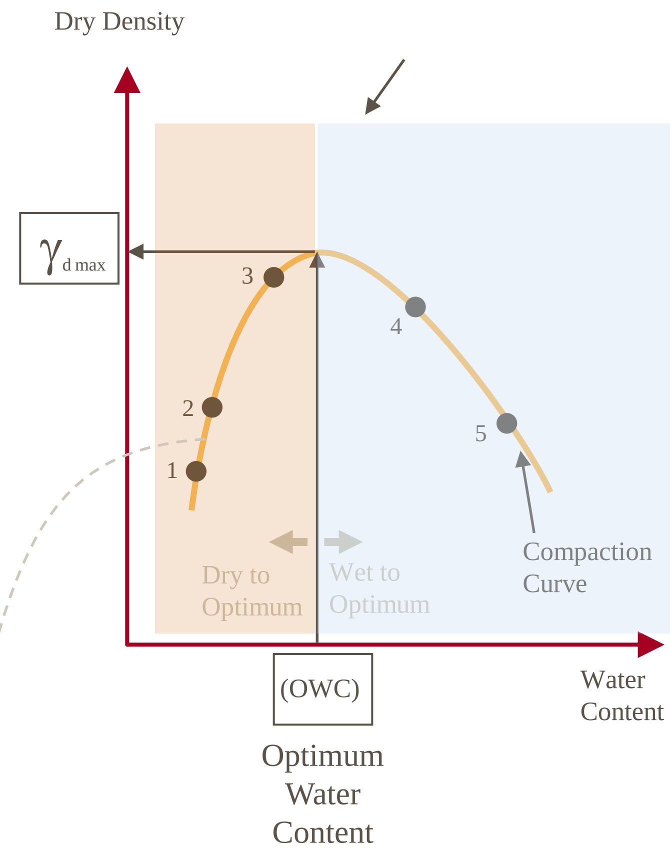


Das, 1998

Soil Compaction in the Lab:

1- Standard Proctor Test

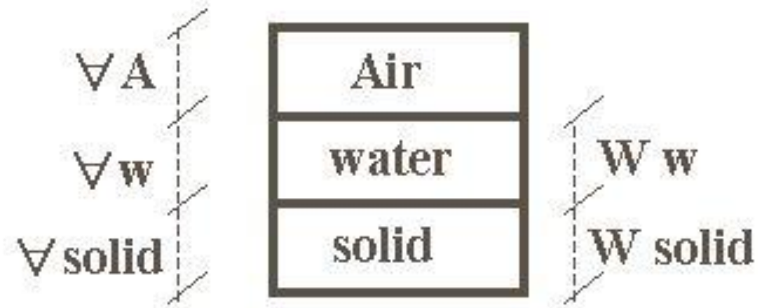




$$\gamma_{dr} = \frac{\gamma_{wet}}{1 + \frac{W_c\%}{100}}$$

Basic Relations

$$W/c = \frac{W\ water}{W\ solid}$$



$$\gamma_d = \frac{W\ solid}{\forall t}$$

$$\gamma_{wet} = \frac{W\ total}{\forall t} = \gamma\ m = \gamma\ bulk$$

$$\gamma_d = \frac{\gamma\ w}{1 + (w/c)} \quad , \quad W\ solid = \frac{W\ total}{1 + (w/c)}$$

Specific Gravity , S

$$S = \frac{\gamma}{\gamma_w} \qquad \text{Or} \qquad \gamma = S \cdot \gamma\ w$$

$\gamma\ w = 1\ gm/cm^3 = 62.4\ ib/ft^3$

Relative Compaction (RC)

Percent Compaction

$$R.C. = \frac{\gamma\ d\ (field)}{\gamma\ d\ (laboratory)} * 100 = \not< 95\%$$

Example 17.7 Determining Maximum Dry Density and Optimum Moisture Content

The table shows results obtained from a standard AASHTO compaction test on six samples, 4 in. diameter, of a soil to be used as fill for a highway. Determine the maximum dry density and the optimum moisture content of the soil.

Sample No.	*Weight Compacted Soil, W (lb)*	*Moisture Content, w (%)*
1	4.16	4.0
2	4.39	6.1
3	4.60	7.8
4	4.68	10.1
5	4.57	12.1
6	4.47	14.0

Solution: Since we are using the standard AASHTO test, 4 in. diameter, the volume of each sample is $1/30$ ft^3. The dry densities are calculated as shown.

Sample No.	Bulk Density, γ (30W (lb/ft^3)	Moisture Content, w (%)	Dry Density, γ_d lb/ft^3 $\left(\frac{\gamma}{1+w}\right)$
1	124.80	4.0	120.0
2	131.70	6.1	124.1
3	138.00	7.8	128.0
4	140.40	10.1	127.5
5	137.10	12.0	122.4
6	134.10	14.0	117.6

Figure 17.13 shows the plot of dry density versus moisture content, from which it is determined that maximum dry density is 129 lb/ft^3 and the optimum moisture content is 9%.

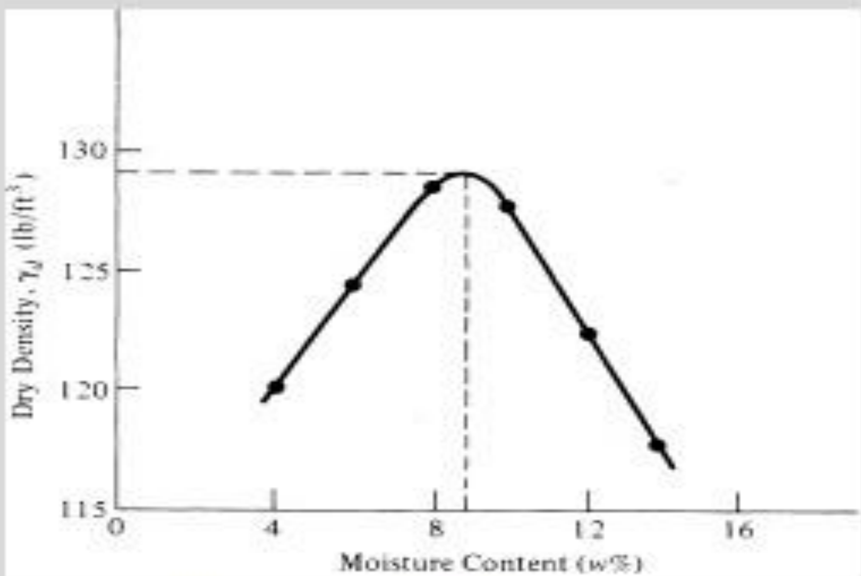
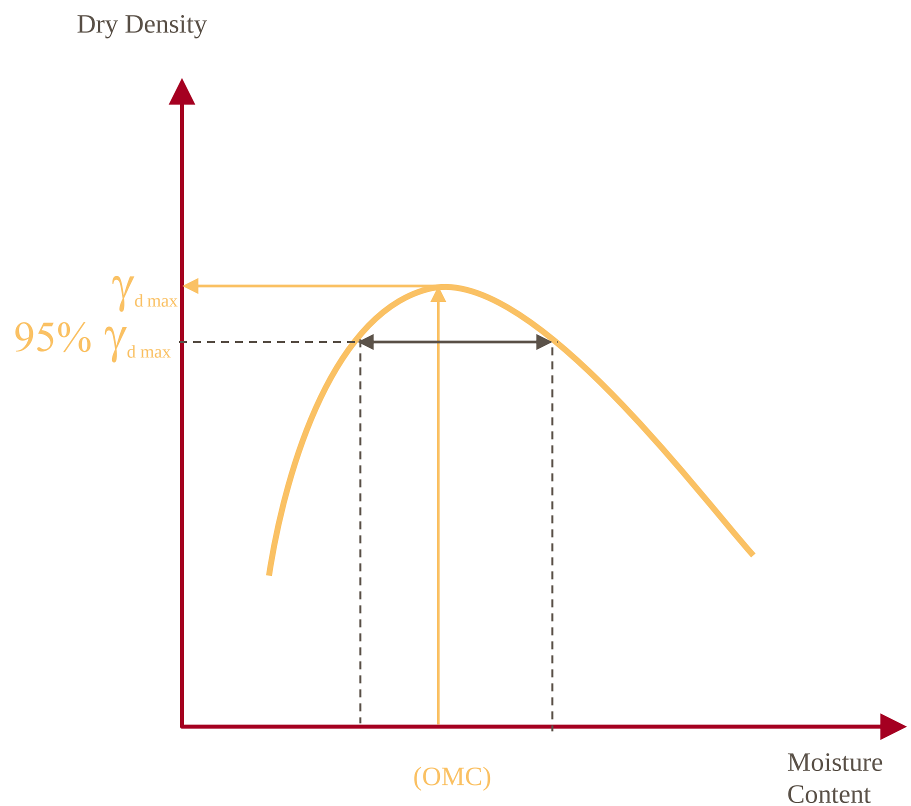


Figure 17.13 Moisture-Density Relationship for Example 17.7

Field Soil Compaction

Because of the differences between lab and field compaction methods, the maximum dry density in the field may reach 90% to 95%.



Compaction Methods and Equipment

(Roller Compaction)

1- Pressure Types →
- **Smooth-Wheeled Rollers**
- **Pneumatic-tired Roller**
- **Sheep's Foot Roller**

(Suitable for cohesive soils)

2- Vibratory Roller Types

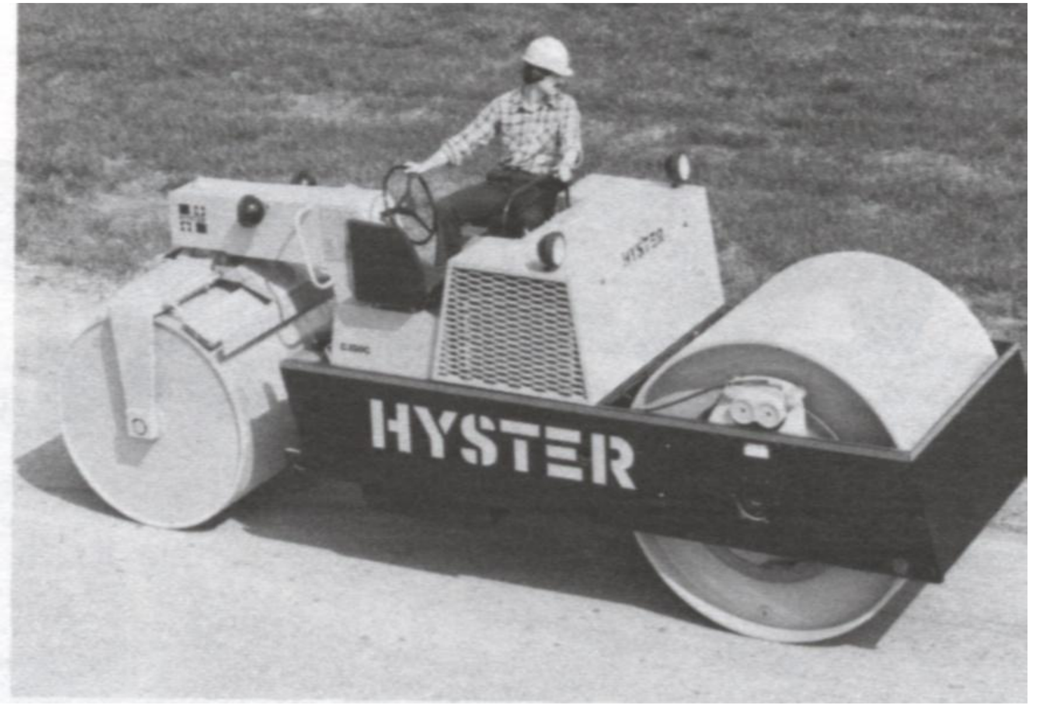
(Suitable for gravel and sand soils)

3- Impact Types

(Plate Compaction)

Field Compaction Equipment

Smooth-wheel roller (drum)

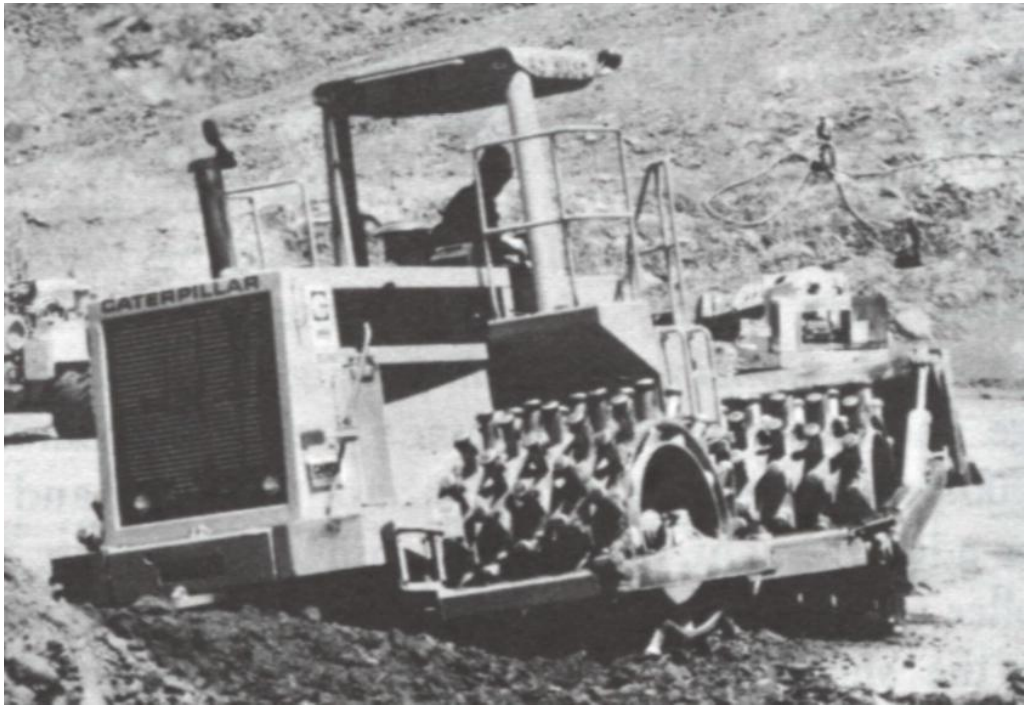


- Can be used on all soil types except for rocky soils.
- Compactive effort: static weight
- The most common use of large smooth wheel rollers is for proof-rolling subgrades and compacting asphalt pavement.

Pneumatic (or rubber-tired) roller

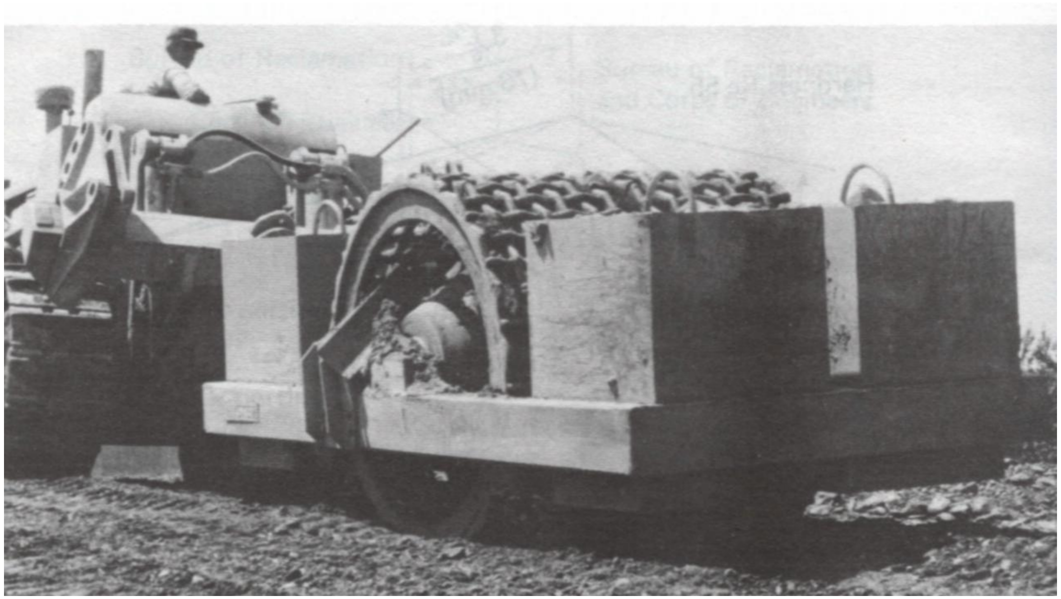
- Can be used for both granular and fine-grained soils.
- Compactive effort: static weight
- Can be used for highway fills or earth dam construction.

Sheepsfoot rollers



- It is best suited for clayed soils.
- Compactive effort: static weight

Mesh (or grid pattern) roller



- It is ideally suited for compacting rocky soils, gravels, and sands. With high towing speed, the material is vibrated, crushed, and impacted.
- Compactive effort: static weight and vibration.

Quality control tests

To determine γ_d of a soil (subgrade, base or subbase) in the site

1- Sand Cone Test

a) Relatively Slow

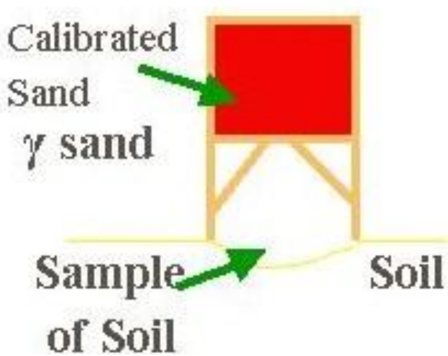
b) For any type of soil.

W1 = weight of cone before filling

W2 = weight of cone after filling

W sand = W1 – W2

$$\forall \text{sample} = \frac{W \text{ sand}}{\gamma \text{ sand}}$$

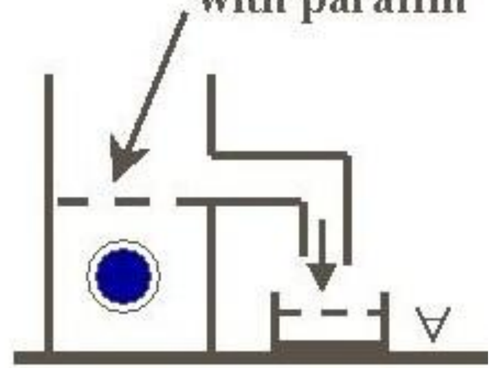


2- Volumenometer Method

$$\gamma_d = \frac{W \text{ solid}}{\forall t}$$

a) Slow

b) For Cohesive soil only.



$\forall = \forall \text{sample} + \forall \text{paraffin}$

$\forall$paraffin =

(1)Determine W sample (before coating)

(2) Determine W sample + W paraffin (after coating)

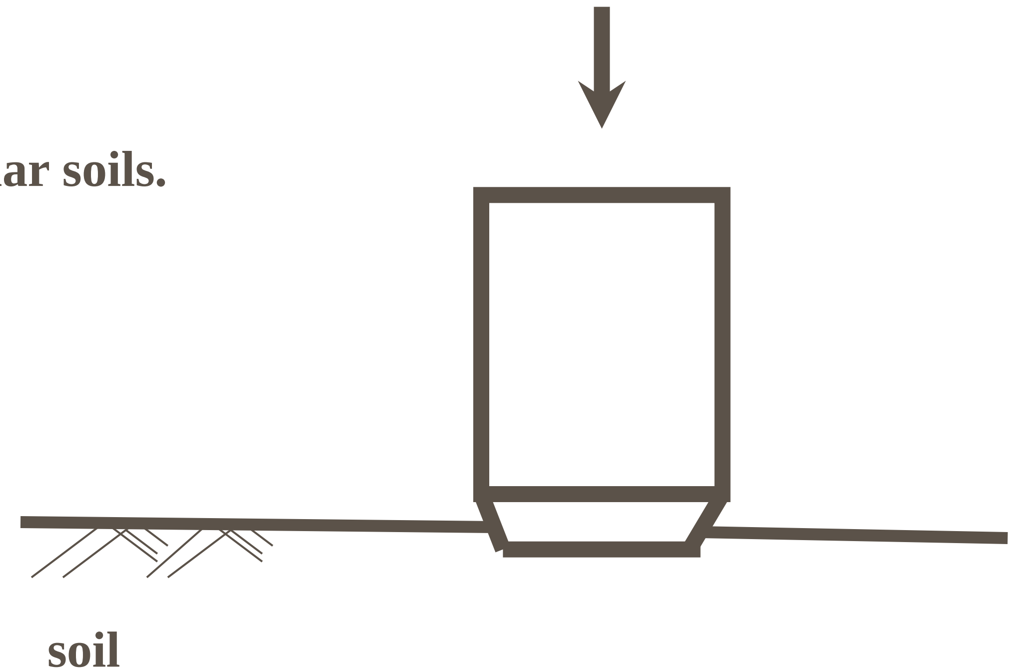
W paraffin = (2) – (1)

$$\forall \text{paraffin} = \frac{W \text{ paraffin}}{\gamma \text{ paraffin}}$$

Quality control tests (cont.)

3- Core-Cutter Test

a) Quick.
b) Not suitable for granular soils.



$\forall$sample = 0.036 ft^3

To increase the max. dry density

1- Increase the No. of passes of roller.

2- Increase the weight of roller.

3- Modify water content (probably increase the (w/c)).

4- Decrease the thickness of layers (increase no. of layers).

5- Change the roller type.