SOIL COMPACTION

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- Compaction, in general, is the densification of soil by removal of air, which requires mechanical energy.

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

- The degree of compaction of a soil is measured in terms of its dry unit weight.

- Compaction on site usually conducts by mechanical means such as rolling, ramming or vibrating.

Purposes of Compaction

- Compaction is the application of energy to soil to reduce the void ratio
- Compaction also decreases the amount of undesirable settlement of structures
- Increases the stability of slopes embankments.
- Compaction increases the soil strength
- Compaction makes water flow through soil more difficult, decrease permeability value.
- Compaction can prevent liquefaction during earthquakes

Compaction tests provide the following basic data for soils:

1) The relationships between dry density and moisture content for given degree of compaction effort.

2) The moisture content for the most efficient compaction (OMC) that is, at which the maximum dry density is achieved under that compactive effort.

3) The value of the maximum dry density so achieved.

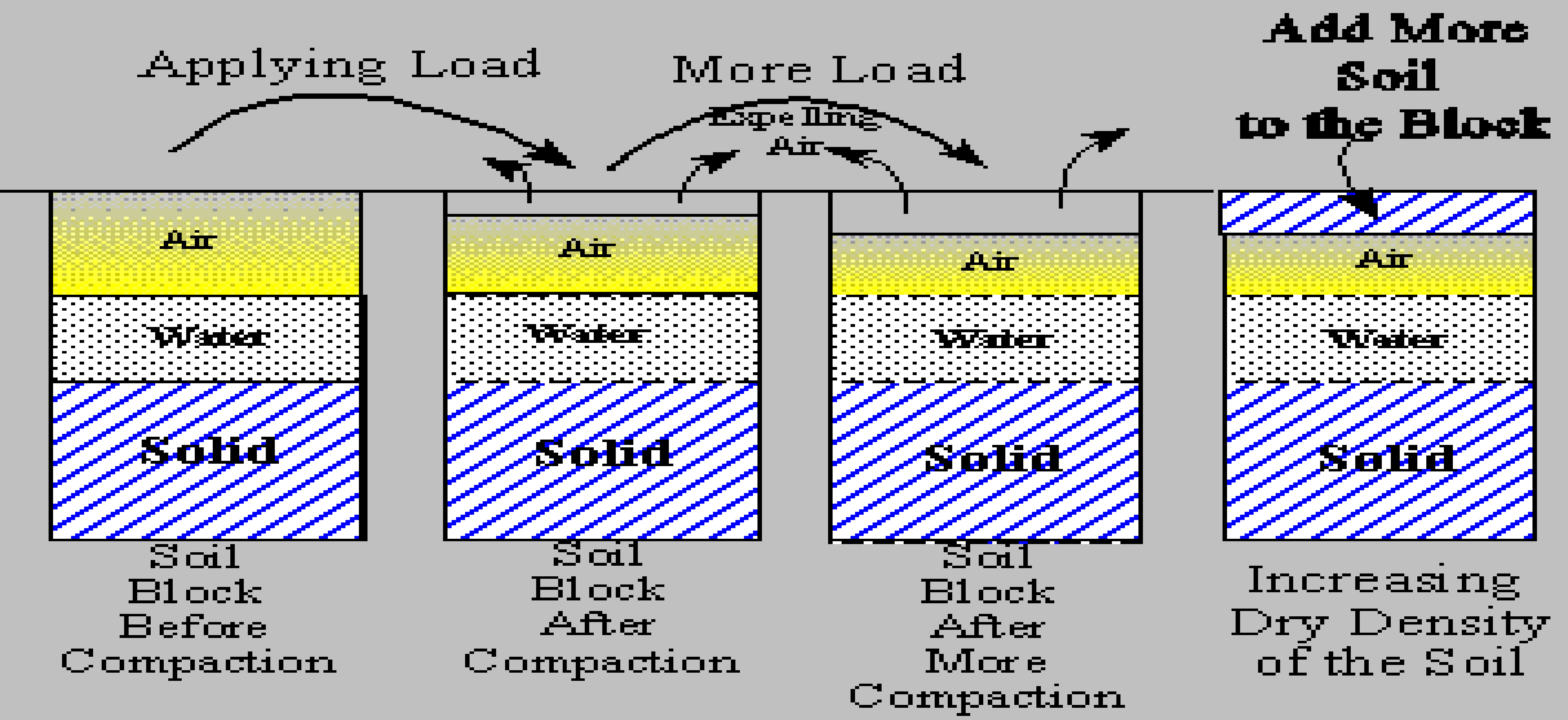
Compaction Process

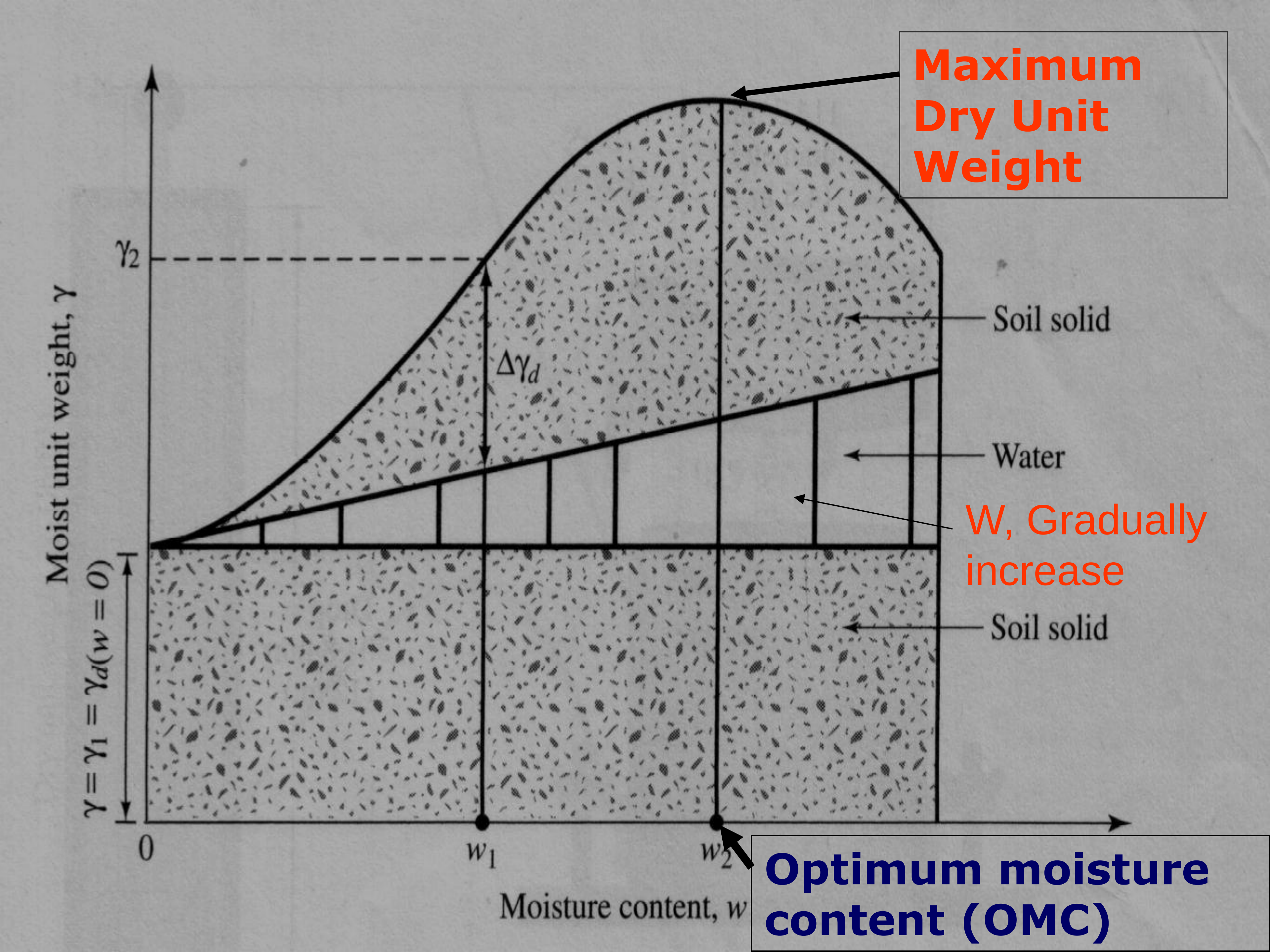
- When water is added to the soil during compaction, it acts as a softening agent in the soil particles.
- The soil particles slip over each other and move into a densely packed position.
- The dry unit weight after compaction first increases as the moisture content increases.
- When the moisture content is gradually increased and the same compaction effort, the weight of the soil solids in a unit volume gradually increases.

Compaction Process

- 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 solid particles.
- The moisture content at which the maximum dry density (MDD) is attained is generally referred to as the optimum moisture content (OMC).

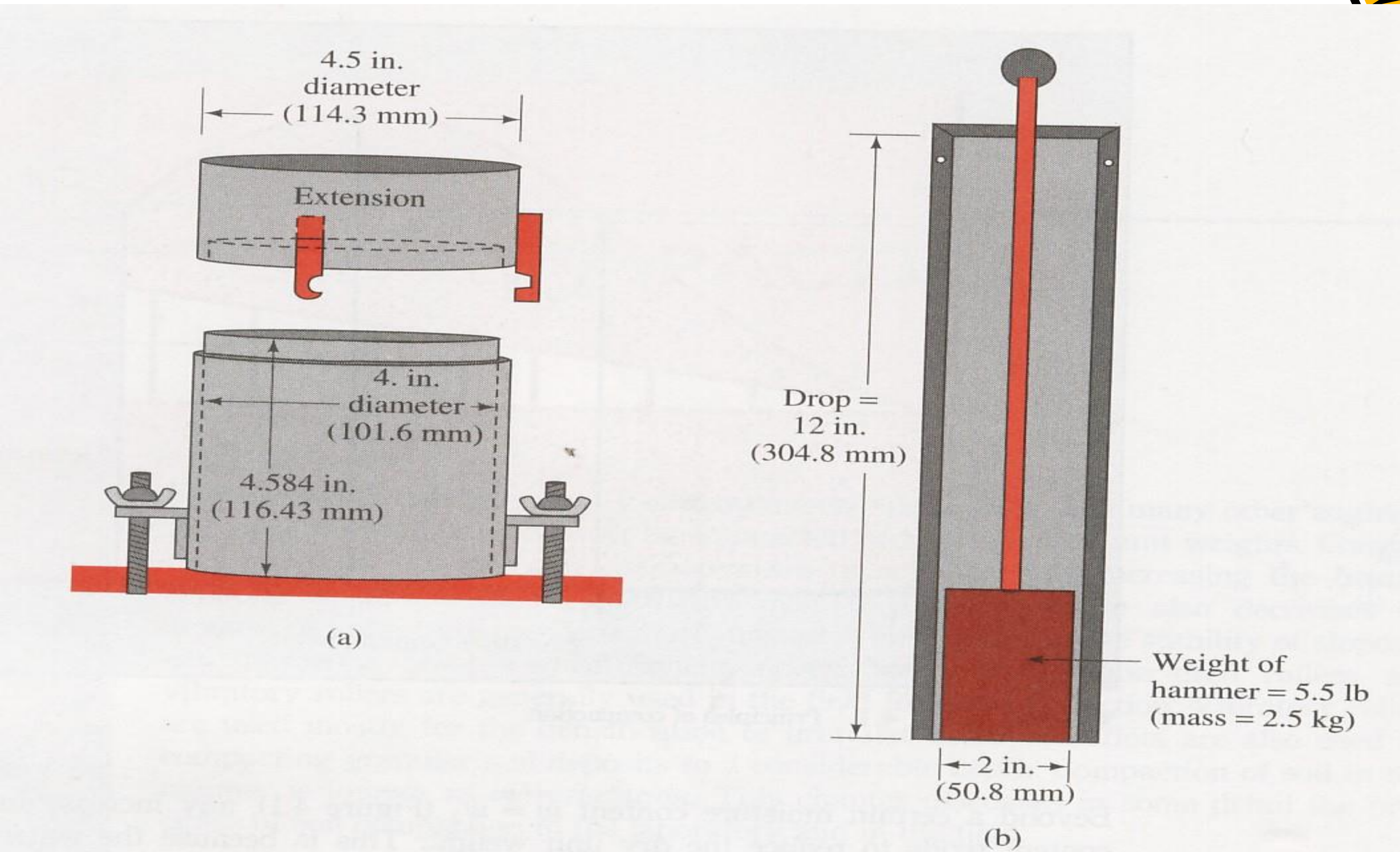
Compaction process





Maximum Dry Unit Weight
γ_2
$\Delta\gamma_d$
Soil solid
Water
W, Gradually increase
Soil solid
Moist unit weight, γ
$\gamma = \gamma_1 = \gamma_{d(w=0)}$
0
w_1
w_2
Moisture content, w
Optimum moisture content (OMC)

Proctor Test Apparatus



Specification between Standard and Modified Proctor Test

Specification/Test	Standard	Modified
Mould volume	$1000cm^3$ / $1x10^{-3}m^3$ / $^1/_{30}ft^3$	$1000cm^3$ / $1x10^{-3}m^3$ / $^1/_{30}ft^3$
Hammer: Mass Fall Distance	 2.5kg 300mm	 4.5kg 450mm
No. blows/ layer	25	25
No. Layer	3	5
Soil sample: Pass Sieve no. 4		

Presentation of results

1)Bulk density
2)moisture content
3)Dry density

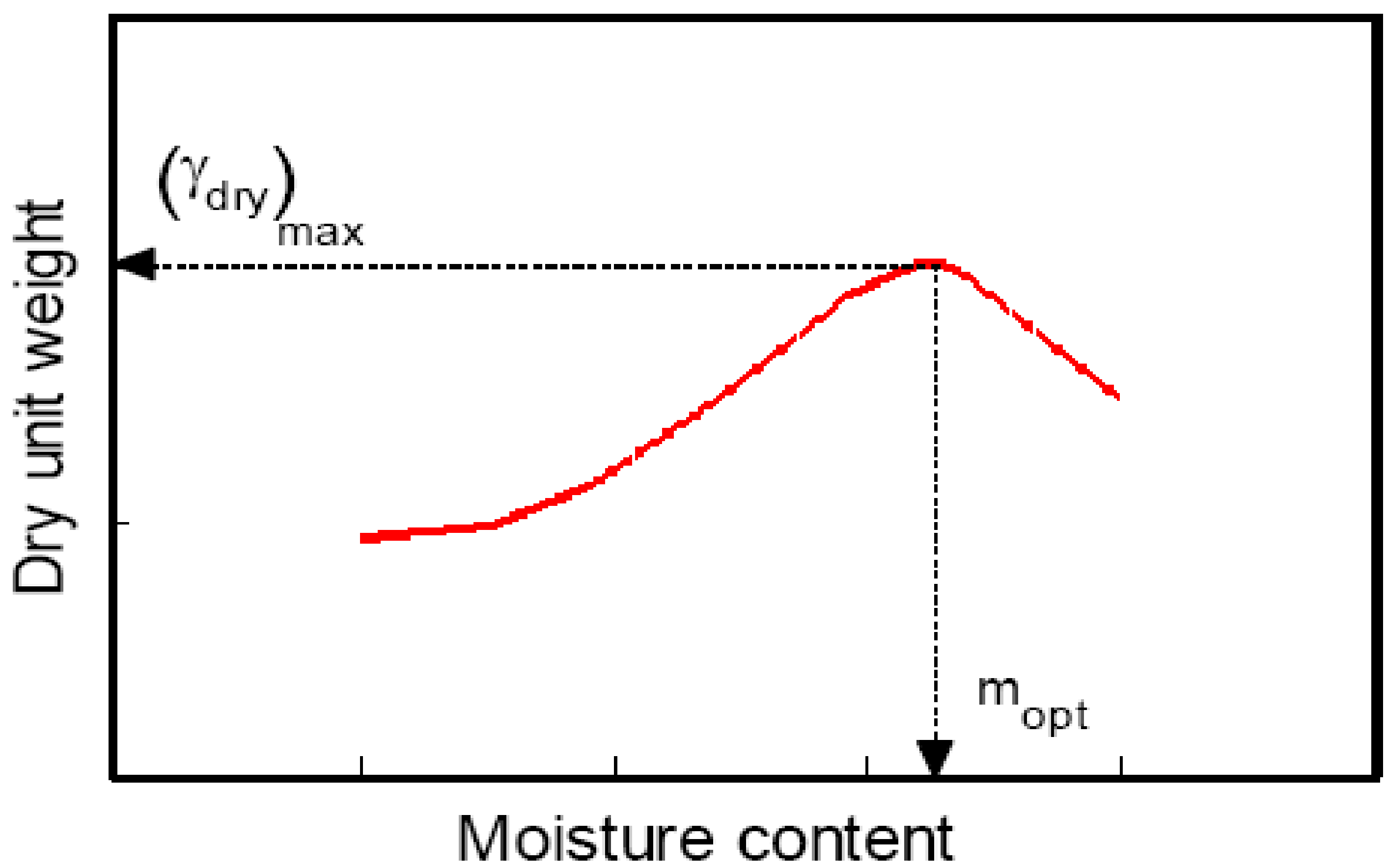
$$w = \frac{\text{Wt of Water}}{\text{Wt of Solids}} = \frac{W_w}{W_s}$$

$$\gamma = \frac{W}{V} = \frac{\text{Wt of Solids} + \text{Wt of Water}}{\text{Total Volume}} = \frac{W_s + W_w}{V}$$

$$= \frac{(1+w)W_s}{V}$$

$$= (1 + w)\,\gamma_d$$

$$\gamma_d = \frac{\gamma}{1 + \frac{w(\%)}{100}}$$



A typical compaction test result

For given moisture content, the theoretical maximum dry unit weight is obtained when there is no air in the void spaces-that is, when the degree of saturation equals 100%. Thus, the maximum dry unit weight at given moisture content with zero air voids can be given by

$$\gamma_{zav} = \frac{G_s \gamma_w}{1+e}$$

where γ_{zav} = zero-air-void unit weight

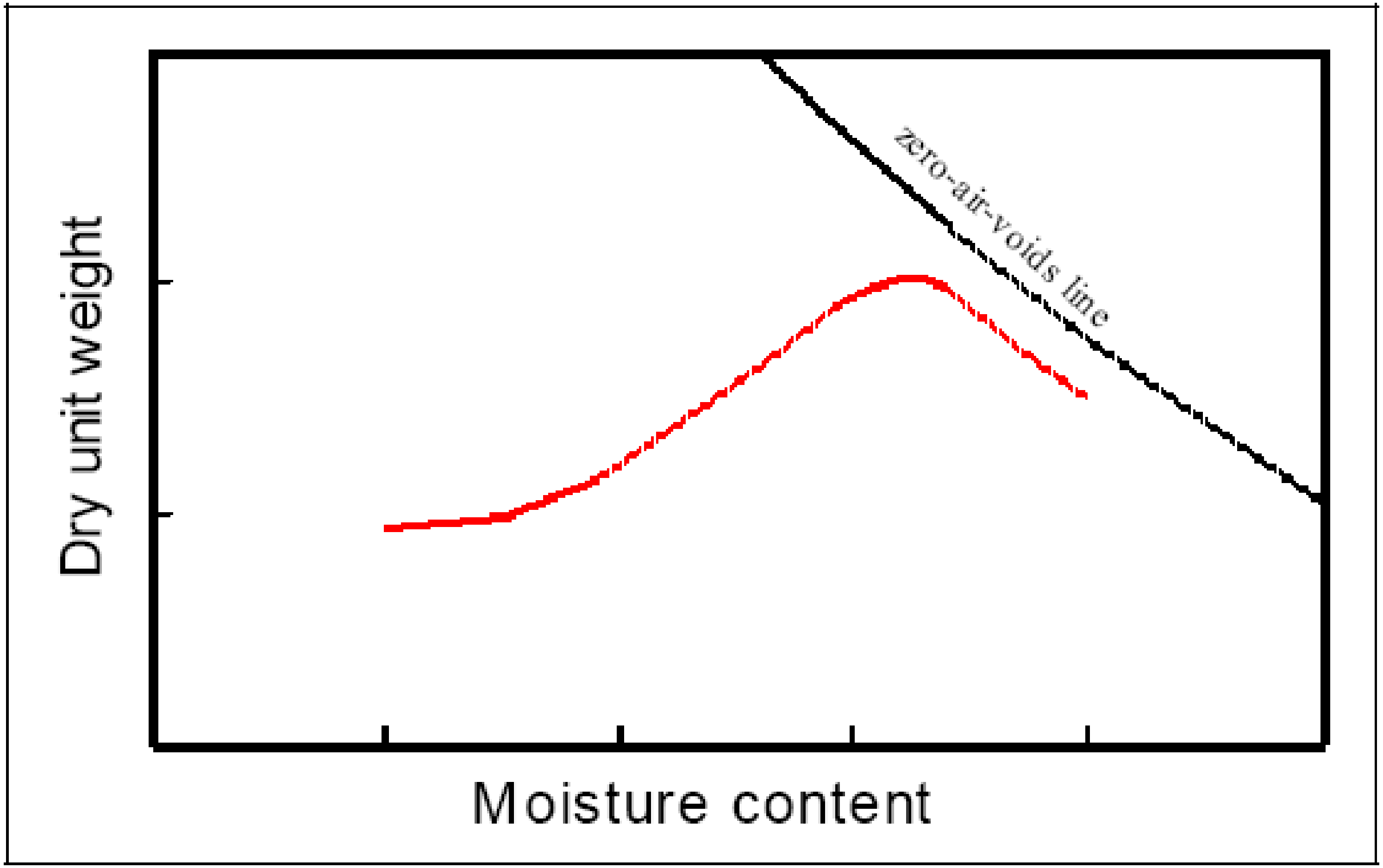
γ_w = unit weight of water

e = void ratio

G_s = specific gravity of soil solids

For 100% saturation, $e = wG_s$, so

$$\gamma_{zav} = \frac{G_s \gamma_w}{1+wG_s} = \frac{\gamma_w}{w + \frac{1}{G_s}}$$



Typical compaction curve showing no-air-voids curve (line)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Example

- Standars proctor compaction results for a given soil are as follows:

Jism tanah basah dalam acuan (kg)	1.791	1.937	2.038	2.050	2.022	1.985
Kandungan lembapan, w (%)	8.4	10.6	12.9	14.4	16.6	18.6

- Volume of mould is $0.945 \times 10^{-3} m^3$, G_s = 2.70 dan ρ_w= 1000kg/m^3

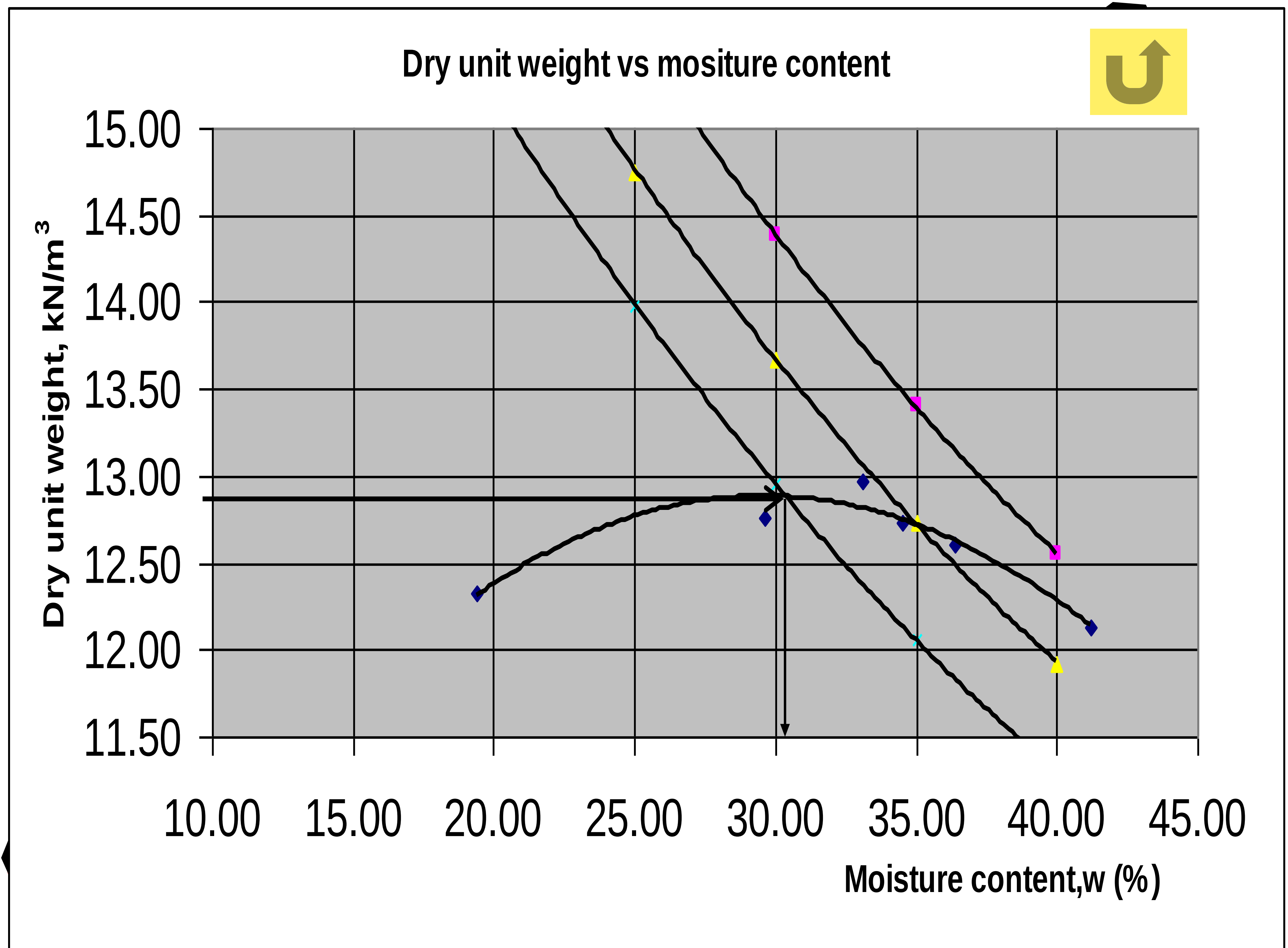
Question (Example)

a) Plot the typical compaction curve and determine the MDD and OMC

Solution (Example)

a) $\rho = M / V$

$\rho_d = \rho / (1 + (w/100)) =$ Answer



Dry unit weight vs mositure content
15.00
14.50
14.00
13.50
13.00
12.50
12.00
11.50
Dry unit weight, kN/m3
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
Moisture content,w (%)

Air Void Curve

- To understand the shape of the curve it is helpful to develop relations between γ_{dry} and the percentage of air voids, *A*.

- The curve is a zero air void line represent the dry density when saturation. The line represent, in theory, the upper limit on density at any moisture content (roughly parallel).

Air Void Curve

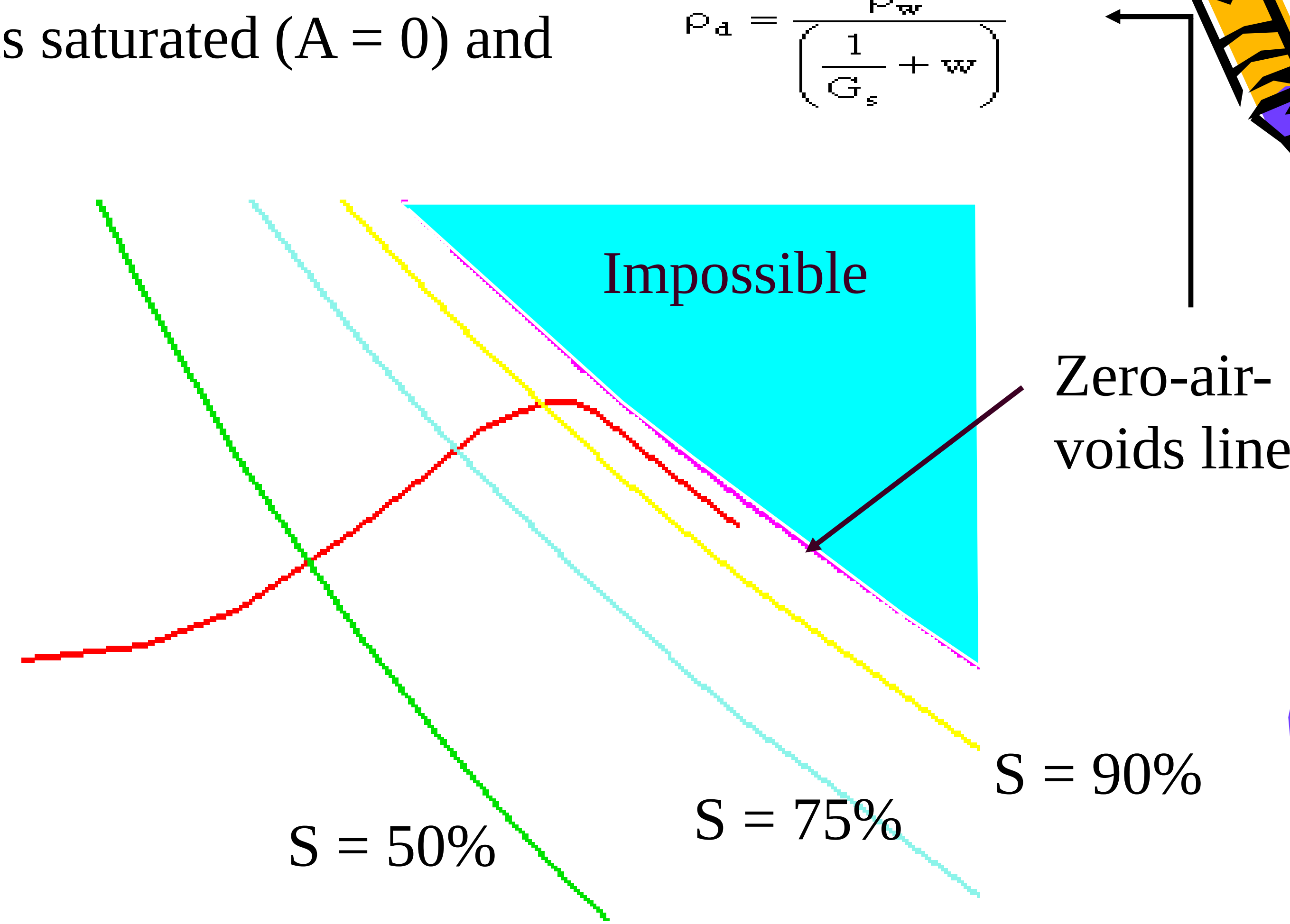
- Assume you given a value of specific gravity for soil, G_s and choose any value of moisture content around optimum moisture content and use equation below for the value of dry density.

$$\rho_d = \rho_w \frac{(1 - V_a)}{\left(\frac{1}{G_s} + w\right)}$$

V_a = percentage of air void content.

Air Void Curve

If the soil is saturated (A = 0) and $\rho_d = \dfrac{\rho_w}{\left(\dfrac{1}{G_s} + w\right)}$



Question (Example)

b) Plotkan garisan kandungan udara sifar A = 0% dan A = 5%

Solution (Example)

b) $\rho_d = \rho_w \, ((1-V_a)/((1/G_s)+w))$ = Answer

Factor Affecting Compaction

- Effect of Moisture Content
- Effect of Soil Type
- Effect of Compaction Effort

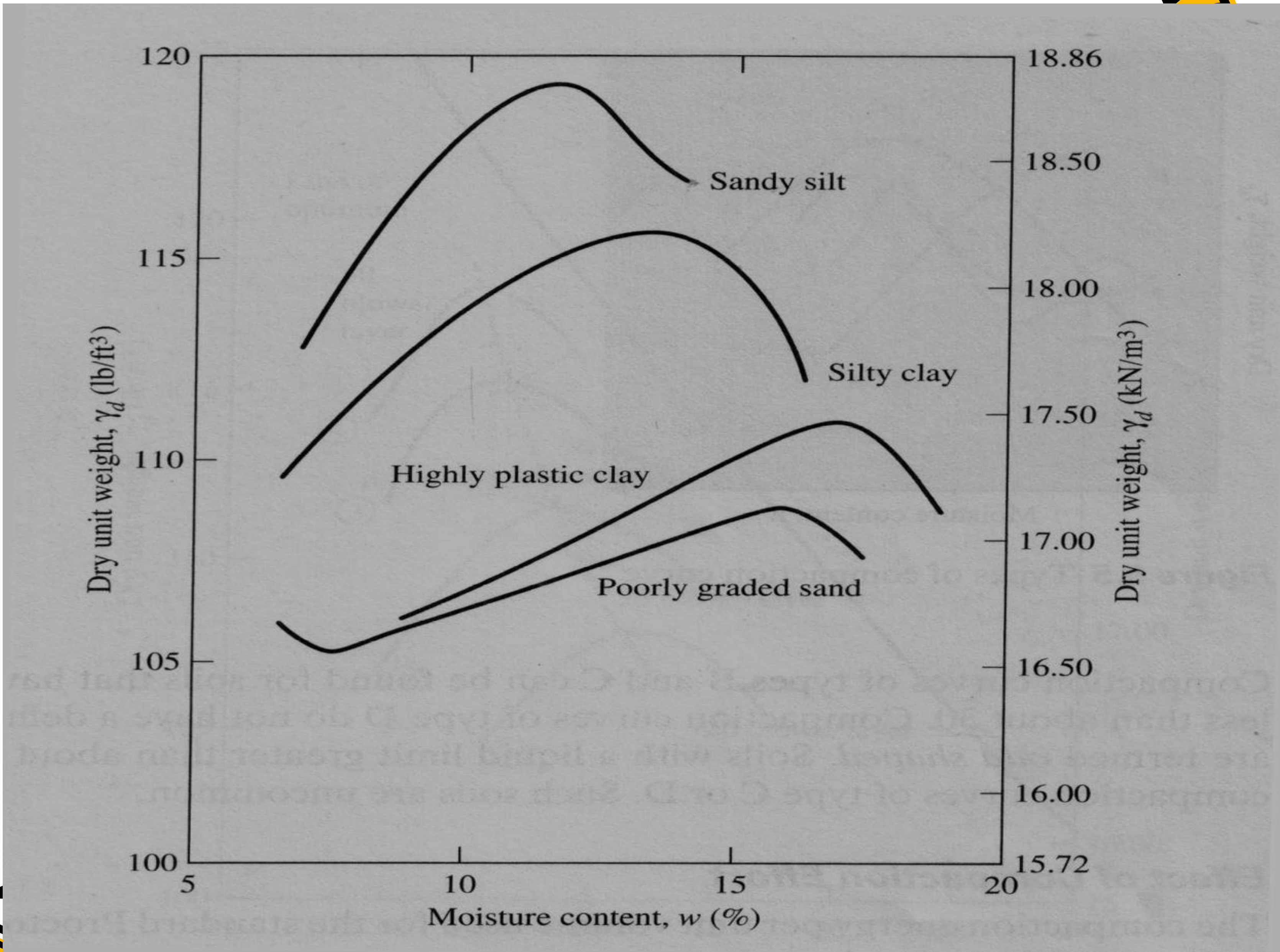
Effect Of Compaction On Soil Type

- The soil type-that is, grain size distribution, shape of the soils grains, specific gravity of soil solids, and amount and type of clay minerals present-has a great influence on the maximum dry density and optimum moisture.

- For sands, the dry density has a general tendency first to decrease as moisture content increases, and then to increase to a maximum value with further increase of moisture.

Effect Of Compaction On Soil Type

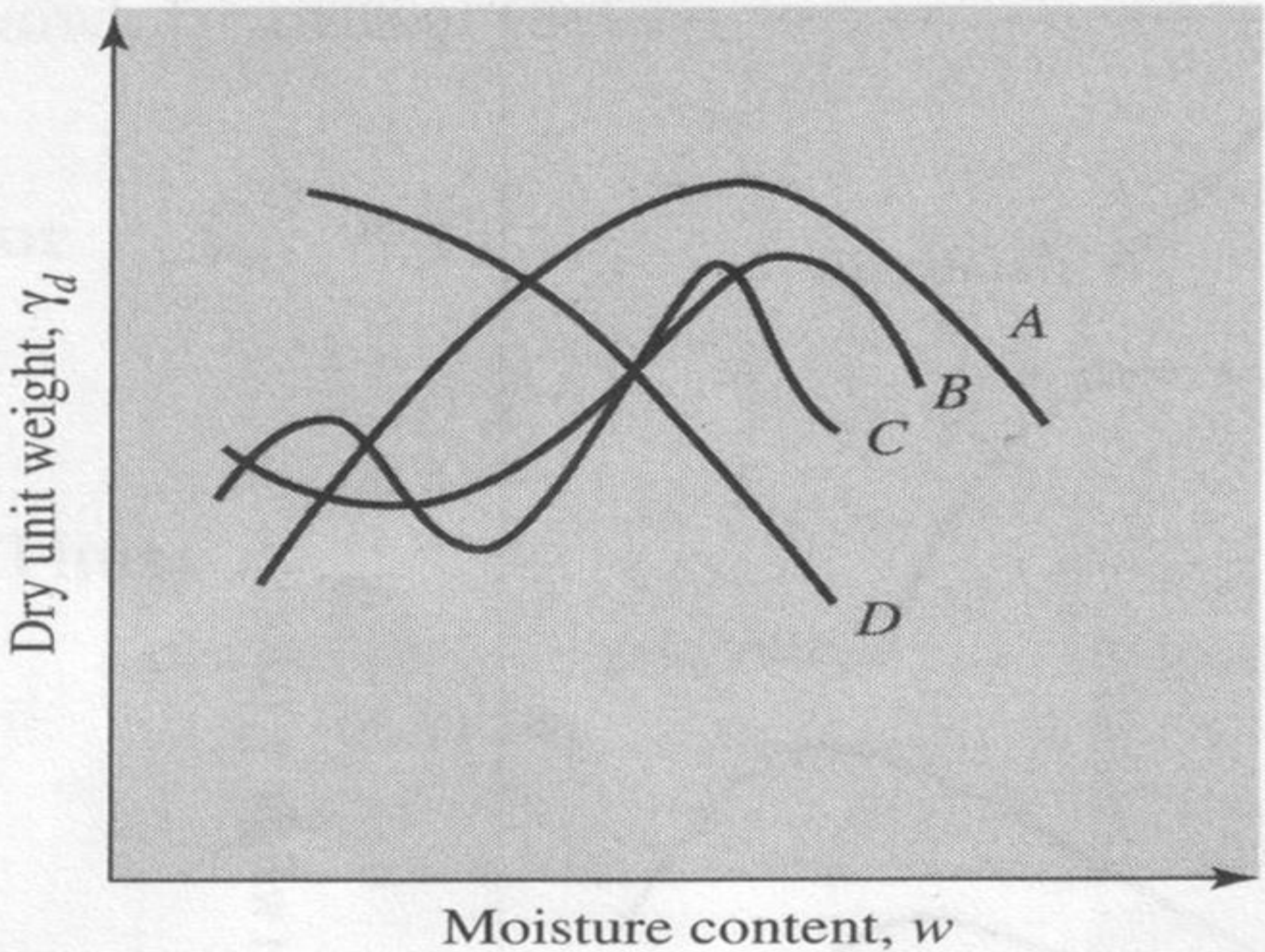
- For most clayey soil, note that the bell-shaped compaction curve is typically.



Sandy silt
Silty clay
Highly plastic clay
Poorly graded sand
120
115
110
105
100
18.86
18.50
18.00
17.50
17.00
16.50
16.00
15.72
5
10
15
20
Dry unit weight, γ_d (lb/ft³)
Dry unit weight, γ_d (kN/m³)
Moisture content, w (%)

Effect Of Soil Type (Cont.)

- Type A compaction curves are those that have a single peak. This type of curve is generally found for soils that have a liquid limit between 30 and 70.
- Curve type B is a one-and-one half peak curve, and curve C is a double-peak curve. Compaction curves of types B and C can be found for soils that have a liquid limit less than about 30.
- Compaction curves of type D do not have a definite peak. They are termed odd shaped.
- Soils with a liquid greater than about 70 may exhibit compaction curves of type of C or D. Such soils are not very common.



Dry unit weight, γ_d
A
B
C
D
Moisture content, w

Compaction Effort

- Compaction effort is an energy use on mass of compacted soil for each volume. The unit for CE is kJ/m^3.

- The basic equation is:-

E = {No. of blows /layer}x{No. of layer}x{Weight of hammer}x{Drop height of Hammer}/Volume of mold

- **Standard**

$$CE = \frac{25 \text{ blows/layer} \times 3 \text{ layer} \times 24.5 \text{ N} \times 0.300 \text{ m}}{0.000944 \text{ m}^3 \times 1000}$$

$$= 584 \text{ kJ/m}^3$$

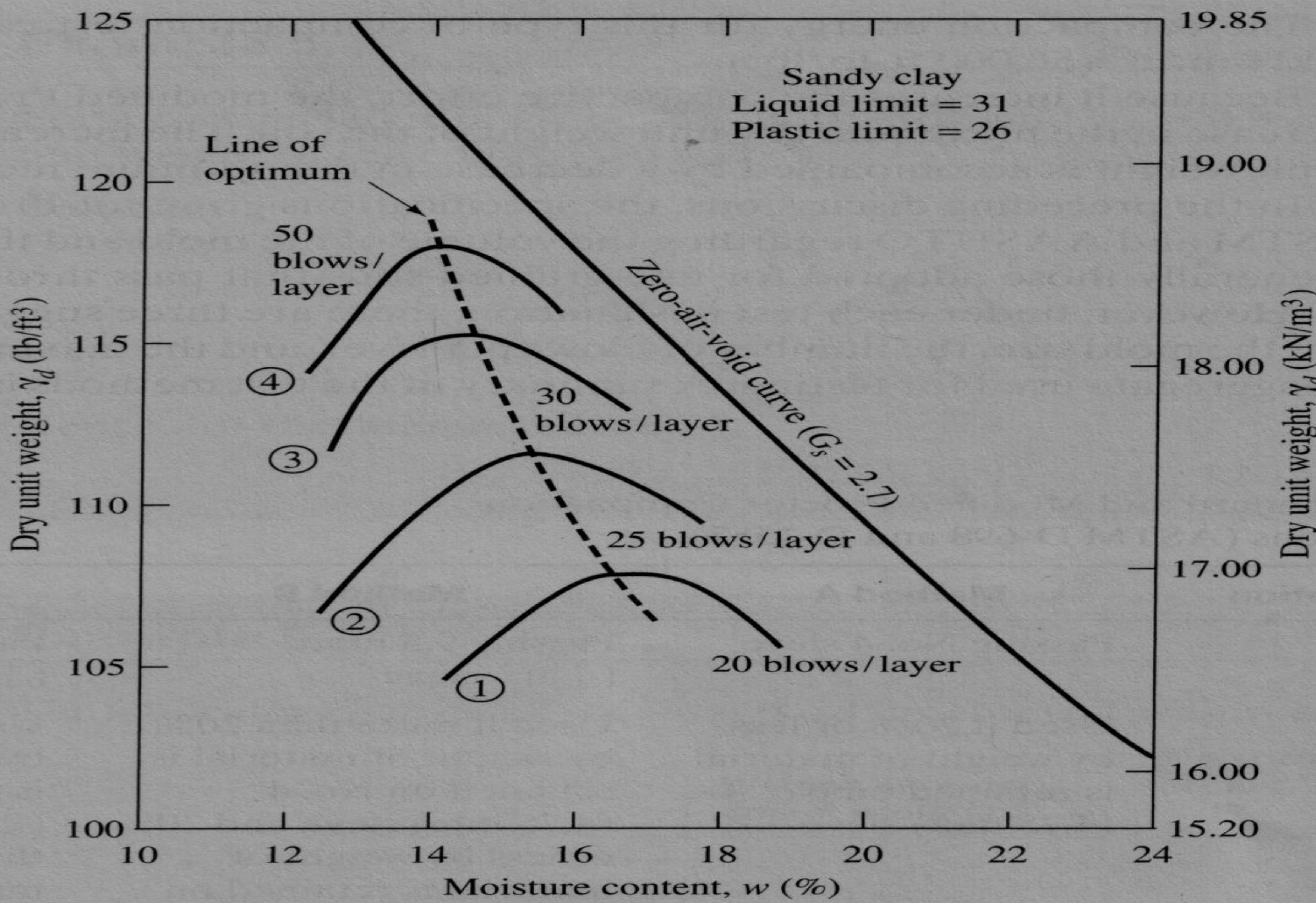
Compaction Effort (Cont.)

- **Modified**

$$CE = \frac{25 \text{ blows/layer} \times 44.5 \text{ N} \times 5 \text{ layer} \times 0.450\text{m}}{0.000944 \text{ m}^3 \times 1000}$$

$$= 2653 \text{ kJ/m}^3$$

Effect of CE on the compaction of sandy clay



Compaction Effort (Cont.)

- ***From pervious figure, it can be seen that:***

a) As the compaction effort is increased, the maximum dry unit weight of compaction is also increased.

b) As the compaction effort is increased, the optimum moisture content is decreased to some extent.