COMPACTION

9.0 ILLUSTRATIVE EXAMPLES

Example 9.1: An earth embankment is compacted at a water content of 18% to a bulk density of 19.2 kN/m^3. If the specific gravity of the sand is 2.7, find the void ratio and the degree of saturation of the compacted embankment.

Solution:

Water content, $w = 18\%$

Bulk density, $\gamma = 19.2$ kN/m^3

Specific gravity, $G = 2.7$

Dry density, $\gamma_d = \frac{\gamma}{(1+w)} = \frac{19.2}{(1+0.18)} = 16.27$ kN/m^3

But $\gamma_d = \frac{G.\gamma_w}{(1+e)}$, where γ_w 9.81 kN/m^3

$\therefore \quad (1+e) = \frac{2.7 \times 9.81}{16.27} = 1.63$

Void ratio, $e = 0.63$

Also, $wG = S.e$

$\therefore$ The degree of saturation, $S = \frac{wG}{e} = \frac{0.18 \times 2.7}{0.63}$

$= 0.7714$

$\therefore$ The degree of saturation = **77.14%**

Example 9.2: A moist soil sample compacted into a mould of 1000 cm^3 capacity and weight 35 N, weighs 53.5 N with the mould. A representative sample of soil taken from it has an initial weight of 0.187 N and even dry weight of 0.1691 N. Determine (a) water content, (b) wet density, (c) dry density, (d) void ratio and (e) degree of saturation of sample.

If the soil sample is so compressed as to have all air expelled, what will be the new volume and new dry density?

Solution:

(*a*) Water content, $w = \frac{(0.1870 - 0.1691)}{0.1691} \times 100 = $ **10.58%**

Wet wt. of soil in the mould = (53.50 – 35.00) = 18.50 N

Volume of mould = 1000 cm^3

(*b*) Bulk density, $\gamma = \frac{18.5 \times (100)^3}{1000 \times 1000}$ = **18.5 kN/m³**

(*c*) Dry density, $\gamma_d = \frac{\gamma}{(1+w)} = \frac{1850}{(1+0.1058)}$ = **16.73 kN/m³**

$$\gamma_d = \frac{G\gamma_w}{(1+e)}$$

Assuming a value of 2.65 for grain specific gravity,

$$16.73 = \frac{2.65 \times 10}{(1+e)}, \text{since } \gamma_w = 10 \text{ kN/m}^3$$

$$(1+e) = \frac{2.65 \times 10}{16.73} = 1.584$$

(*d*) Void ratio, $e = \mathbf{0.584}$

Also, $wG = S.e$

$$S = \frac{wG}{e} = \frac{0.1058 \times 2.65}{0.584} = 0.48$$

(*e*) Degree of saturation, S = **48%**

If air is fully expelled, the solid is fully saturated at that water content.

∴ $wG = e = 2.65 \times 0.1058 = 0.28$

New dry density = $\frac{2.65 \times 10}{(1+0.28)}$ = **20.7 kN/m³**

New volume = $\frac{(1+0.28)}{(1+0.584)} \times 1000$ = **808 cm³**

Example 9.3: The soil in a borrow pit has a void ratio of 0.90. A fill-in-place volume of 20,000 m³ is to be constructed with an in-place dry density of 18.84 kN/m³. If the owner of borrow area is to be compensated at Rs. 1.50 per cubic metre of excavation, determine the cost of compensation.

Solution:

In-place dry density = 18.84 kN/m³

Assuming grain specific gravity as 2.70 and taking γ_w as 9.81 kN/m³,

$$18.84 = \frac{2.70 \times 9.81}{(1+e_i)}$$

$$(1+e_i) = \frac{2.70 \times 9.81}{18.84} = 1.406$$

e_i = 0.406 (in-plane Void ratio)

Void-ratio of the soil in the borrow-pit,

e_b = 0.90

In-place volume of the fill, V_i = 20,000 m³

If the volume of the soil to be excavated from the borrow pit is V_b, then:

$$\frac{V_b}{V_i} = \frac{1+e_b}{1+e_i} = \frac{(1+0.90)}{(1+0.406)}$$

∴ $V_b = \frac{1.90}{1.406} \times 20{,}000 \text{ m}^3 = \mathbf{27.027} \text{ m}^3$

The cost of compensation to be paid to the owner of the borrow area = Rs. (1.50 × 27,027)
= Rs. **40,540.**

Example 9.4: A soil in the borrow pit is at a dry density of 17 kN/m³ with a moisture content of 10%. The soil is excavated from this pit and compacted in a embankment to a dry density of 18 kN/m³ with a moisture content of 15%. Compute the quantity of soil to be excavated from the borrow pit and the amount of water to be added for 100 m3 of compacted soil in the embankment.

Solution:

Volume of compacted soil = 100 m^3
Dry density of compacted soil = 18 kN/m^3
Weight of compacted dry soil = 100 × 18 = 1800 kN
This is the weight of dry soil to be excavated from the borrow pit.
Weight of wet soil to be excavated = 1800 (1 + w) = 1800 (1 + 0.10) = 1980 kN.
Wet density of soil in the borrow pit = 17 (1 + 0.10) = 18.7 kN/m^3

Volume of wet soil to be excavated = $\frac{1980}{18.7}$ = **105.9** m^3

Moisture present in the wet soil, in the borrow pit for every 100 m^3 of compacted soil = 1800 × 0.10 = 180 kN

Moisture present in the compacted soil of 100 m^3
= 1800 × 0.15 = 270 kN
Weight of water to be added for 100 m^3 of compacted soil
= (270 – 180) kN = 90 kN

= $\frac{90}{9.81}$ m^3 = **9.18 kl**

Example 9.5: The following data have been obtained in a standard laboratory Proctor compaction test on glacial till:

Water content %	5.02	8.81	11.25	13.05	14.40	19.25
Weight of container and compacted soil (N)	35.80	37.30	39.32	40.00	40.07	39.07

The specific gravity of the soil particles is 2.77. The container is 9.44 cm^3 in volume and its weight is 19.78 N. Plot the compaction curve and determine the optimum moisture content. Also compute the void ratio and degree of saturation at optimum condition.

Solution: The dry density values are computed and shown in Table

Water content %	5.02	8.81	11.25	13.05	14.40	19.25
Weight of container and compacted soil (N)	35.80	37.30	39.32	40.00	40.07	39.07
Weight of container (N)	19.78	19.78	19.78	19.78	19.78	19.78
Weight of compacted soil (N)	16.02	17.52	19.54	20.22	20.29	19.29
Volume of container (cm^3)	944	944	944	944	944	944
Bulk density of compacted soil (kN/m^3)	16.97	18.56	20.70	21.42	21.49	20.43
Dry density of compacted soil (kN/m^3)	16.16	17.06	18.61	18.95	18.78	17.13

The compaction curve is shown in Fig.

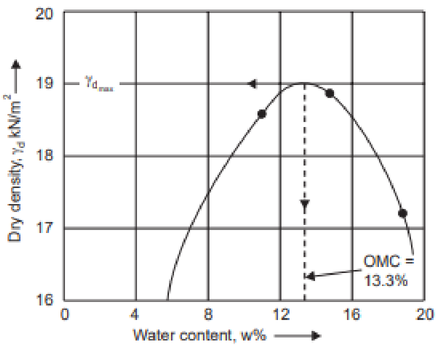

Fig. Compaction curve

From the curve,
Optimum moisture content = 13.3%
Maximum dry density = 19 kN/m^3
At the optimum condition, if the void ratio is e_0.

$$\gamma_{d_{max}} = \frac{G.\gamma_w}{(1+e_0)}$$

$$\therefore \quad 19 = \frac{2.77 \times 10}{(1+e_0)}$$

$$(1 + e_0) = \frac{2.77}{1.90} = 1.46 \text{ (approx)}$$

$\therefore$ Void ratio = **0.46**

Since $S.\,e = w.\,G$,

Degree of saturation, $S = \frac{w.G}{e}$

$$= \frac{13.3 \times 2.77}{0.46}\% = \mathbf{80.1\%}$$

Example 9.6: Given standard soil compaction test results as follows:

Trial No.	*Moisture content % by dry weight*	*Wet unit weight of compacted soil (kN/m^3)*
1	8.30	19.8
2	10.50	21.3
3	11.30	21.6
4	13.40	21.2
5	13.80	20.8

The specific gravity of the soil particles is 2.65. Plot the following: (a) Moisture-dry density curve, (b) Zero air voids curve, and (c) Ten per cent air content curve. (90% Saturation curve) Determine the optimum moisture content and the corresponding maximum dry density of the soil.

Solution:

Also determine the correct values of the maximum dry density and optimum moisture content if in the above test, the material retained on 20 mm Sieve, which was 9%, was eliminated. The specific gravity of these oversize particles was 2.79. The dry density values

Table Dry density values

Trial No.	*Moisture content, w%*	*Wet unit weight (kN/m^3)*	*Dry unit weight (kN/m^3)*
1	8.30	19.8	18.28
2	10.50	21.3	19.28
3	11.30	21.6	19.41
4	13.40	21.2	18.70
5	13.80	20.8	18.28

Since $\gamma_d = \frac{G.\gamma_w}{(1+e)} = \frac{G.\gamma_w}{\left(1+\frac{wG}{s}\right)} = \frac{2.65 \times 9.81}{\left(1+\frac{w \times 2.65}{s}\right)}$,

for Zero air-voids condition, $\gamma_d = \frac{2.65 \times 9.81}{\left(1+\frac{2.65 \times w}{100}\right)}$, w being in %,

and for Ten per cent air-voids condition, $\gamma_d = \frac{2.65 \times 9.81}{\left(1+\frac{2.65 \times w}{90}\right)}$, w being in %.

From these equations, the following values are computed:

Water content (% w)	Dry density γ_d (kN/m^3)	
	Zero air-voids condition	Ten per cen air content condition (90% saturation)
8	21.45	21.04
10	20.55	20.10
12	19.73	19.20
13	19.34	18.80
14	18.96	18.40
16	18.26	17.66

The moisture-dry density curve and the zero air-voids and ten per cent air-voids lines are shown in Fig.

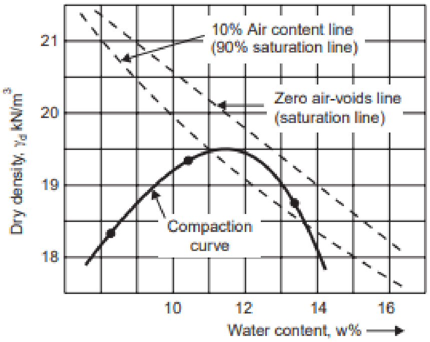

Fig. Compaction curve and saturation lines

From the figure,

Optimum moisture content = **12%**

Maximum dry density = **19.5 kN/m³**

Correction for oversize fraction:

$$G = 2.79 \text{ for gravel } n_1 = 0.09 \; n_2 = 0.91$$

$$\text{Corrected maximum dry density} = \frac{G.\gamma_w \gamma_{d_{max}}}{n_1 \gamma_{d_{max}} + n_2 G \gamma_w}$$

$$= \frac{2.79 \times 9.81 \times 19.5}{(0.09 \times 19.5 + 0.91 \times 2.79 \times 9.8)} = \mathbf{20\ kN/m^3}$$

Corrected optimum moisture content

$= n_1 A_0 + n_2 w_0 = 0.91 \times 12\%$ (taking A_0 as zero)

= **10.9%**