GATE – CIVIL ENGINEERING

GEOTECHNICAL ENGINEERING

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8.9 Compaction

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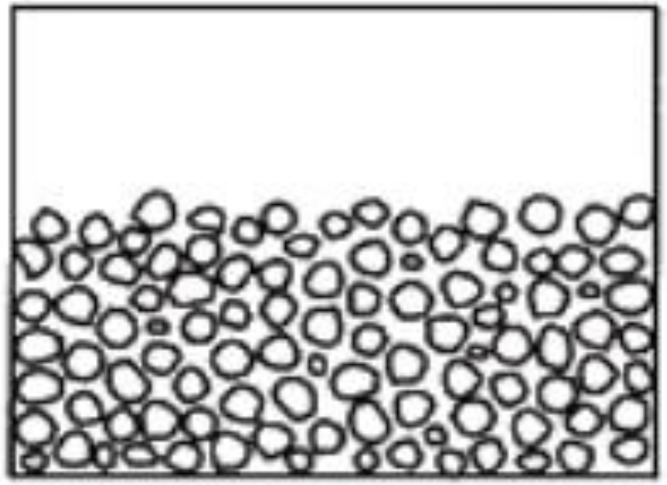
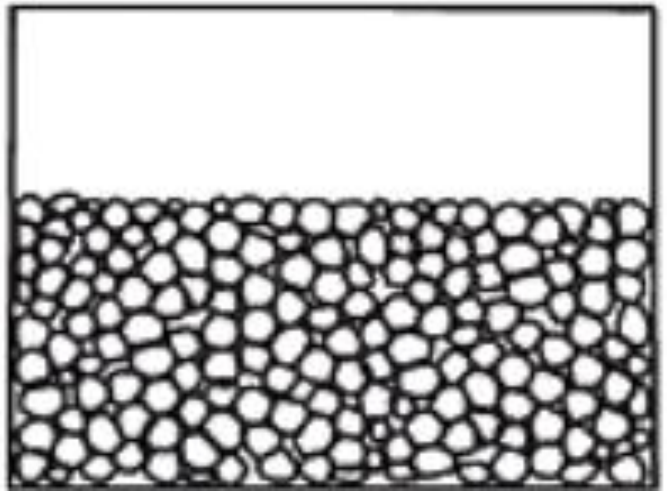
8.9 Compaction

Compaction of Soil:

- Compaction is pressing the soil particles close to each other by mechanical methods.
- Air is expelled from the void space in the soil mass and hence the mass density is increased.
- Compaction is done to increase engineering properties of soil.
- Medium cohesion soils are compacted by means of rolling.



Loose Soil



Compacted soil

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- Cohesionless soils are most effectively compacted by vibration.
- The degree of compaction of a soil characterized by its dry density
- The degree of compaction depends on
  - i. moisture content
  - ii. the amount of compactive effort or energy expended
  - iii. nature of the soil
- Compaction increases density, shear strength, bearing capacity and stability of slopes
- Compaction decreases settlement, permeability, void ratio and compressibility of soil

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S.No	Compaction	Consolidation
1.	Expulsion of pore air	Expulsion of pore water
2.	Soil involved is partially saturated	Fully saturated soil
3.	Applies to cohesive as well as cohesionless	Applies to cohesive soils only
4.	Brought about by artificial or human agency	Brought about by application of load or by natural agencies
5.	Dynamic loading is commonly applied	Static loading is commonly applied
6.	Improves bearing capacity and settlement characteristics	Improves bearing capacity and settlement characteristics
7.	Relatively quick process	Relatively slow process
8.	Relatively complex phenomenon involving expulsion, compression, and dissolution of air	Relatively simple phenomenon
9.	Useful primarily in embankments and earth dams	Useful as a means of improving the properties of foundation soil

- Both the process causes reduction in volume.
- Permeability, void ratio, compressibility decreases.
- Shear strength and density increases.

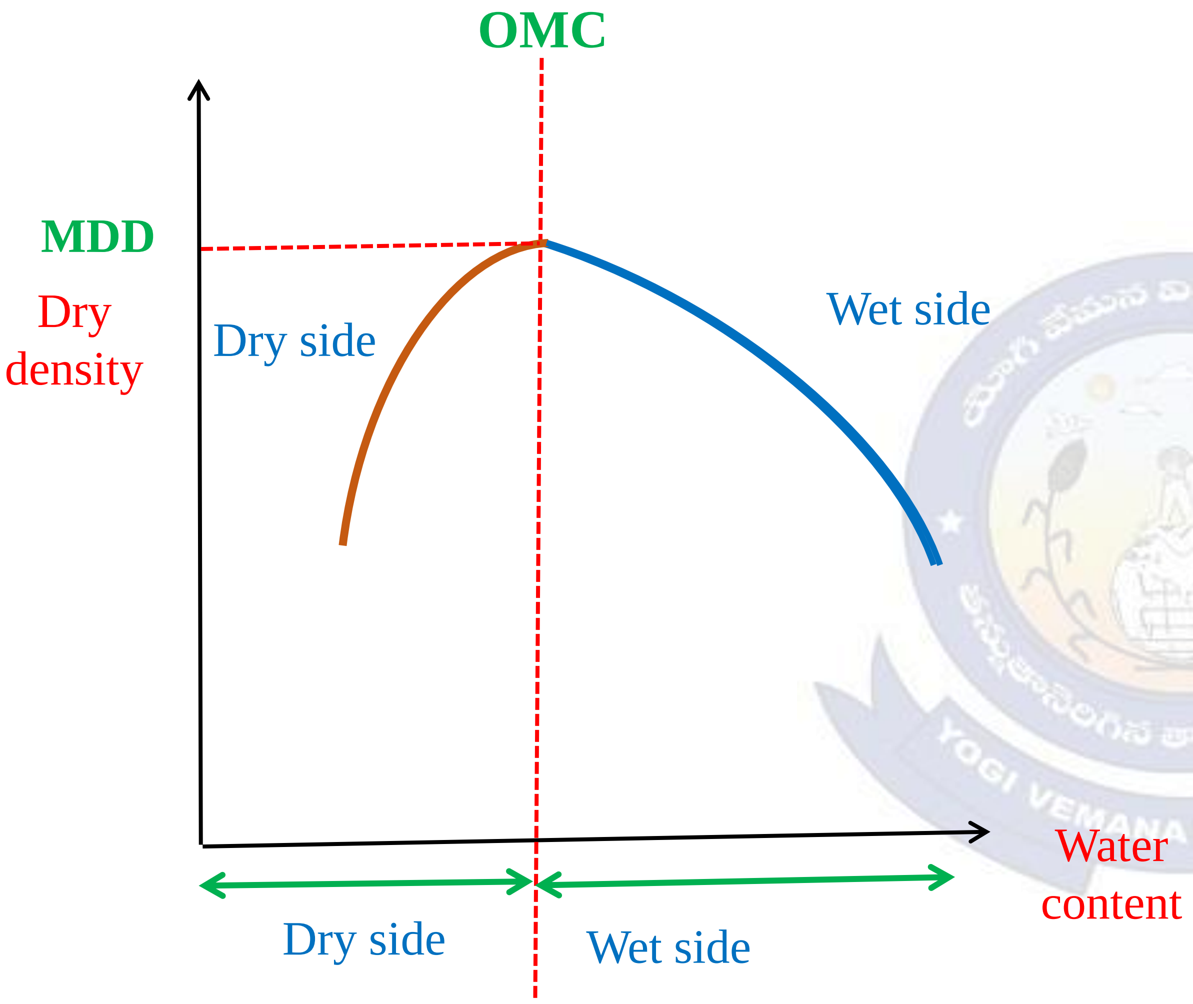
Compaction Theory : $\gamma = \gamma_d (1 + w)$

γ_d = Dry density of soil

γ = Bulk density of soil

w = Water content

- Initial stage: When water content is very small, the soil is in stiff condition having more voids and less density.
- Addition of water to initial dry soil: Water acts as a lubricant by the formation of thin film around soil grains and thereby attractive forces increases (Wanderwall forces). The dry density increases as the water content increases up to certain stage.
- Peak: At certain stage of water content, the lubrication effect is maximum causing the force of attraction between the milecules is maximum and hence maximum density occurs.
- Optimum Moisture Content is the water content at which the soil attains maximum dry



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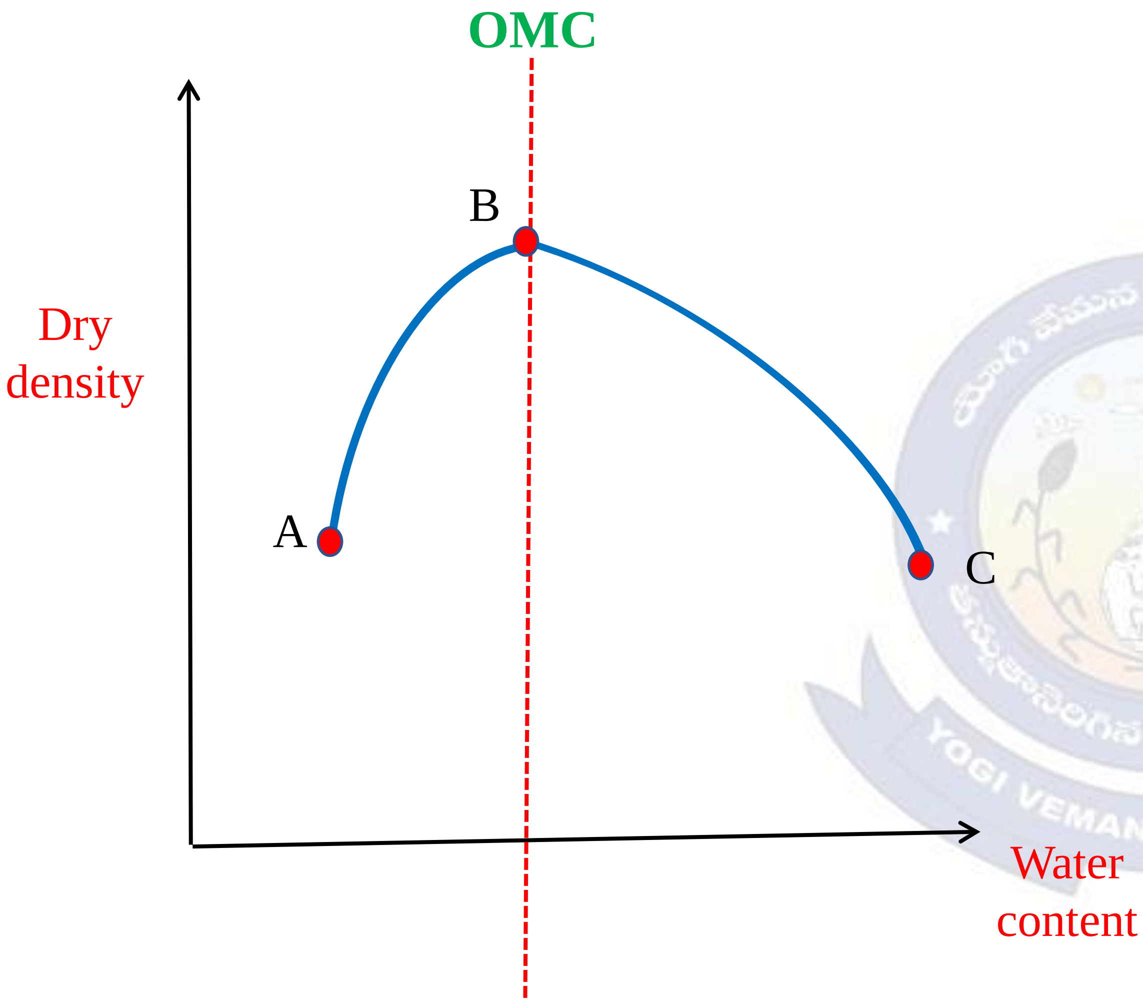

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- Beyond peak: The water content beyond certain stage, water does not act as a lubricant, it occupies the void spaces between solid grains and hence as the water content increases dry density of soil decreases.
- Optimum Moisture Content (OMC) is the water content at which the soil attains maximum dry density.
- Maximum Dry Density (MDD) is the dry density of soil corresponding to Optimum Moisture Content.

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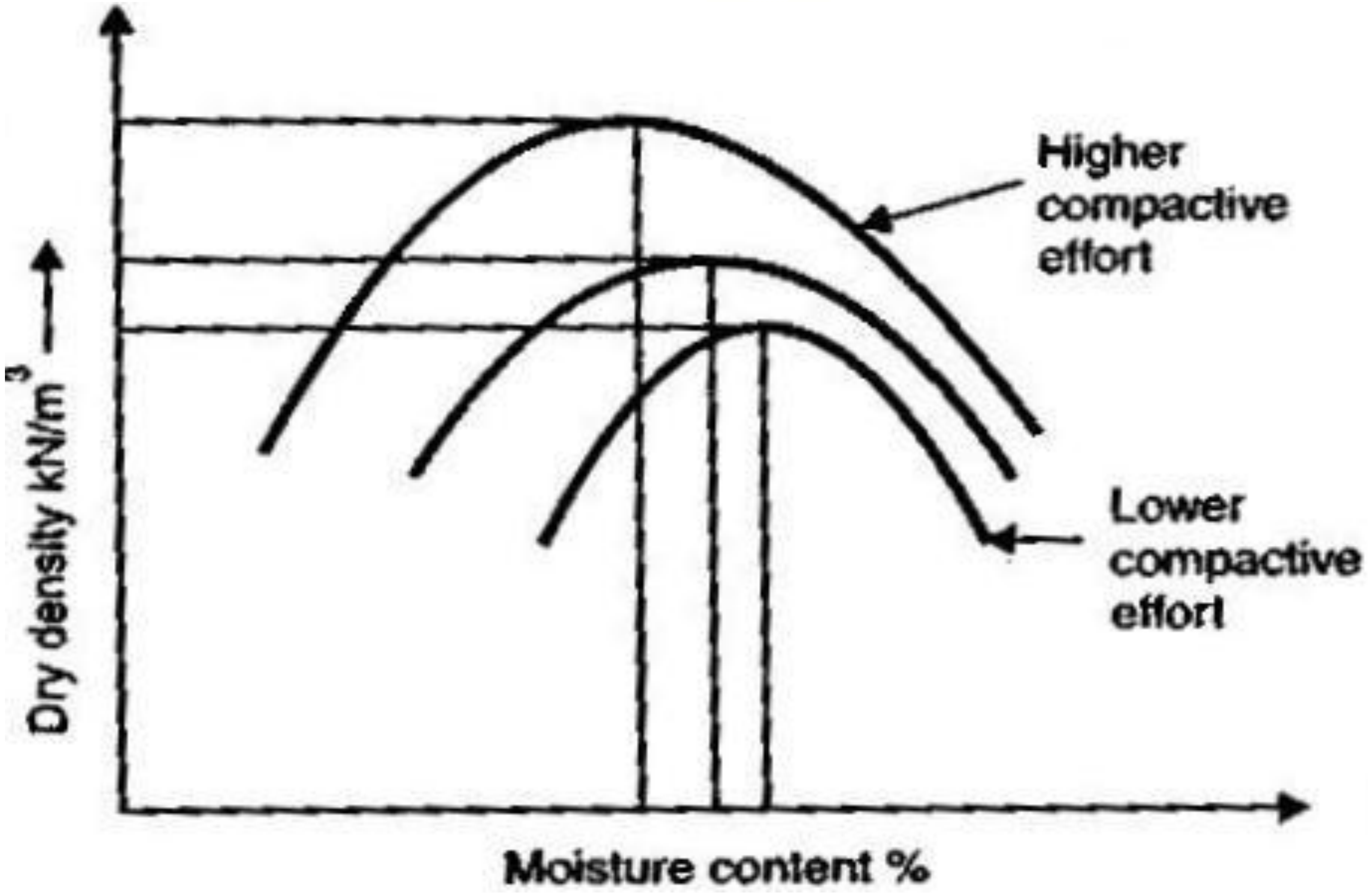
Effect of compactive effort:

Increase in compactive effort or the energy expended will result in an increase in the maximum dry density and a corresponding decrease in the optimum moisture content.



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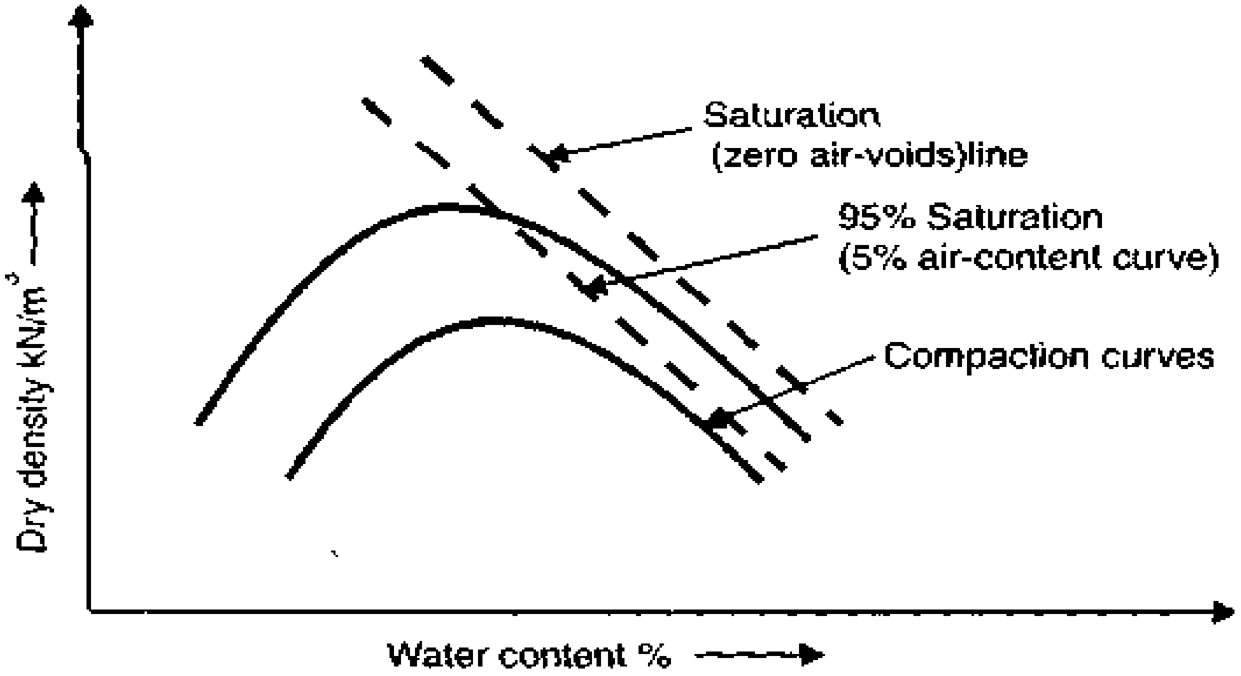
Zero Air Void Line (or) 100% Saturation line (or) Theoretical Maximum Density line: It is a plot between dry unit weight and water content corresponding to degree of saturation of 100% or Zero Air voids. This is plotted along with compaction curve.

$$\gamma_d = \frac{G\gamma_w}{1+e} = \frac{G\gamma_w}{1+\dfrac{wG}{S}}$$

$$\gamma_d = \frac{(1-n_a)G\gamma_w}{1+wG}$$



Saturation lines superimposed on compaction curves

- Zero air void line is used to compare and understands the level of compaction

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For S=100% $\gamma_d = \dfrac{G\gamma_w}{1+wG}$

For $n_a = 0\%$ $\gamma_d = \dfrac{G\gamma_w}{1+wG}$

For S=90% $\gamma_d = \dfrac{G\gamma_w}{1+1.11wG}$

For $n_a = 10\%$ $\gamma_d = \dfrac{0.9G\gamma_w}{1+wG}$

n_a : Percentage of air voids

- 100% saturation line and zero air void line are identical
- 10% air void line and 90% saturation line are not identical
- 10% air content line and 90% saturation line are identical.

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Indian standard compaction test :

Standard proctor test or light compaction	Indian standard Heavy compaction
Conducted for highways, embankments and canal banks Rammer weight : 26 N Falling height : 310 mm No. of blows : 25 Mould capacity : 1 litre (1000 cm^3) No. of layers : 3 Diameter of mould : 100 mm	Conducted for modern express highways, runways Rammer weight : 49 N Falling height : 450 mm No. of blows : 25 Mould capacity : 1.0 litre (1000cm^3) No. of layers : 5 Diameter of mould : 100 mm

- If 150 mm diameter mould (capacity : 2.25 litres) is used, the number of blows in each layer is 56 for SPT and MPT.

- The Compactive effort in the modified Proctor test is about 4.55 times than that in the standard Proctor test

$$\frac{49\times450\times5\times25}{26\times310\times3\times25}=4.55$$

- If Percentage soil retained on 4.75 mm I.S sieve is >20%, mould capacity 2.25 litres is recommended. In such a case, number of blows per each layer shall be 56 for both SPT, MPT.
- The amount of energy used per 1000 cm^3 of soil in a standard proctor test:

For SPT, Energy $= \frac{26\times0.31\times3\times25}{1000} = 605\,\text{Nm per}\,1000\,\text{cm}^3$

For MPT, Energy $= \frac{49\times0.45\times5\times25}{1000} = 2756\,\text{Nm per}\,1000\text{cm}^3$

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Factors Affecting Compaction:

a. Water content: As water content increases, compaction increases, reaches to maximum value and then decreases.

b. Amount of Compaction:

As Compactive effort increases, the compaction increases and OMC decreases.

c. Type of Soil:

- The coarse grained soil attains a higher density and lower OMC.
- Fine grained soils will have more OMC compared to coarse grained soils.
- The specific surface area of fine grained soils is very large and have more affinity towards water because of particles having negative charge.
- Clay possessing high plasticity has low MDD and more OMC.
- Coarse material has high MDD and low OMC.
- Increase of organic content in clay soil increases OMC and decreases MDD.

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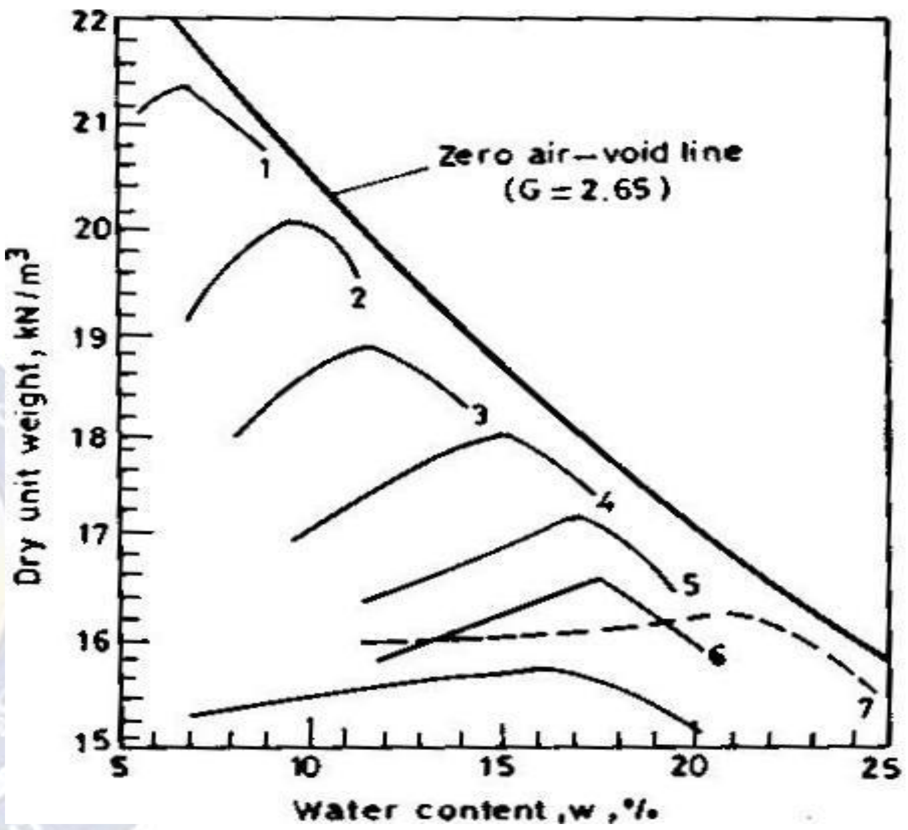
Type of soil:

1. Well- graded to loamy sand (SW-SM)
2. Well-graded sandy loam (SM)
3. Medium-graded sandy loam (SM)
4. Lean sandy silty clay (CL)
5. Lean silty clay (CI)
6. Loessial silt (ML)
7. Heavy clay (CH)
8. Poorly graded sand (SP)



d. Method of Compaction:

For the same amount of Compaction effort, the dry density will depend upon the method of Compaction utilizes kneading action, dynamic action or static action.

$$(\gamma_d)_{static} < (\gamma_d)_{SPT} < (\gamma_d)_{MPT}$$

$$(OMC)_{static} > (OMC)_{SPT} > (OMC)_{MPT}$$

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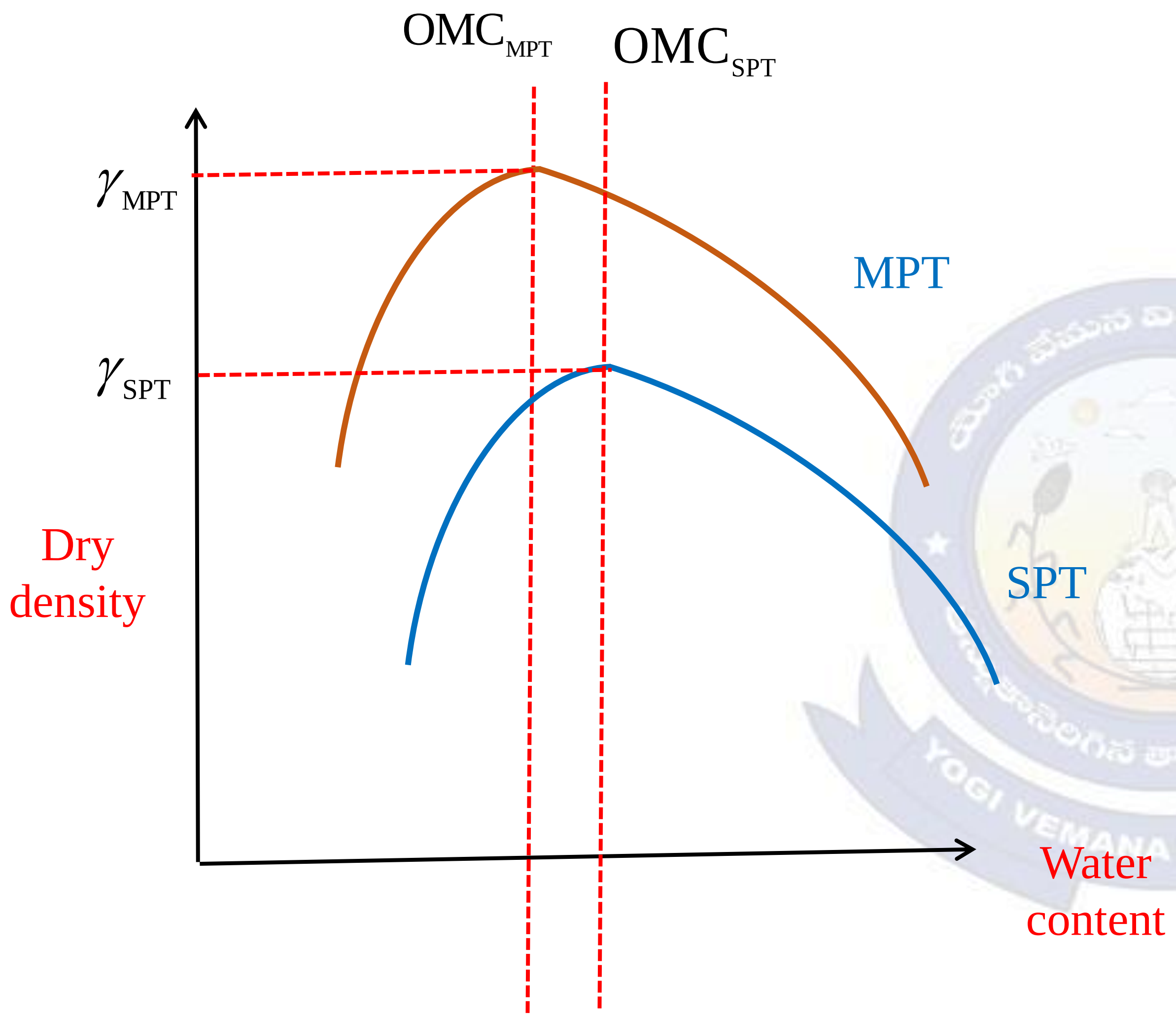

$\gamma_{MPT} > \gamma_{SPT}$

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e. Admixture:

The Compaction properties of soil can be explored by the use of admixtures. eg: lime and cement.

- If flyash is added to the clay, MDD increases and OMC decreases

f. Placement water content:

- The soil compacted on wet side of OMC to avoid large expansion and swelling pressures. eg. Core of earth dams, Under Pavements, Under floors
  - Core of earth dam: Low permeability, Low swelling
- The soil compacted on dry side of OMC to have high shear strength and low compressibility. eg. Outer shells of earthen dam, Highway embankment
  - Outer shells of earthen dam: High strength, Low pore water pressure, High permeability
  - Highway embankment: High strength, Low compression

Effect of Compaction:

S.No	Property	Dry side of OMC	Wet side of OMC
1	Structure	Flocculated	Dispersed
2	Water deficiency	High	Low
3	Permeability	High	Low
4	Compressibility At low stress At high stress	 Low High	 High Low
5	Swelling	High	Low
6	Shrinkage	Low	High
7	Pore water pressure	Low	High
8	Undrained strength	High	Low
9	Stress behaviour	Brittle	Ductile

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Proctor Needle (Plasticity Needle): Used to find in-situ water content and dry density

- It is punched by 7.50 cm into the soil to know the penetration resistance, thereby the placement water content and dry density are obtained from the calibration curve.

Relative Compaction:

$$\text{Relative compaction} = \frac{\text{Dry density in field}}{\text{Maximum dry density}} \times 100$$

- Usually 90 to 100% relative compaction can be obtained.

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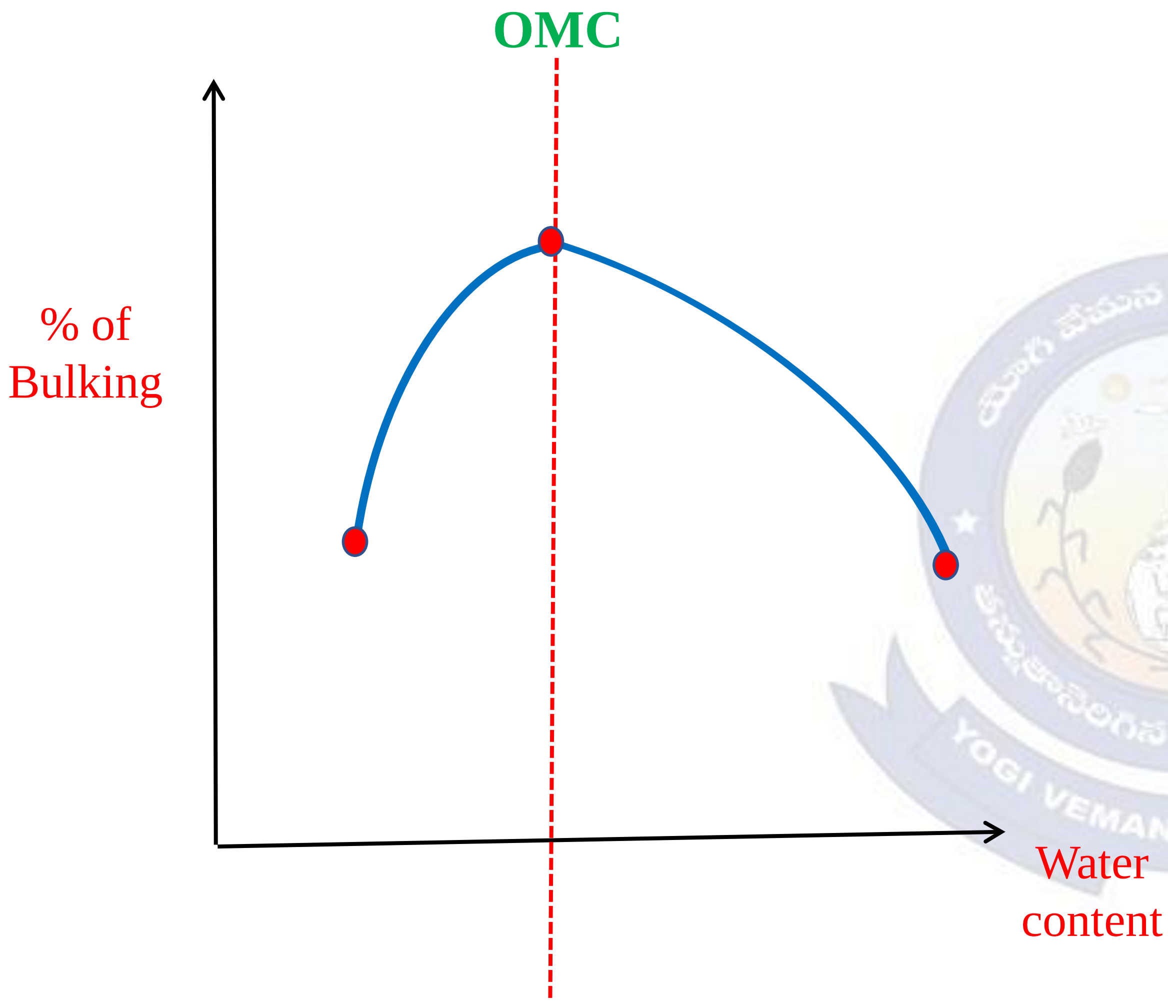

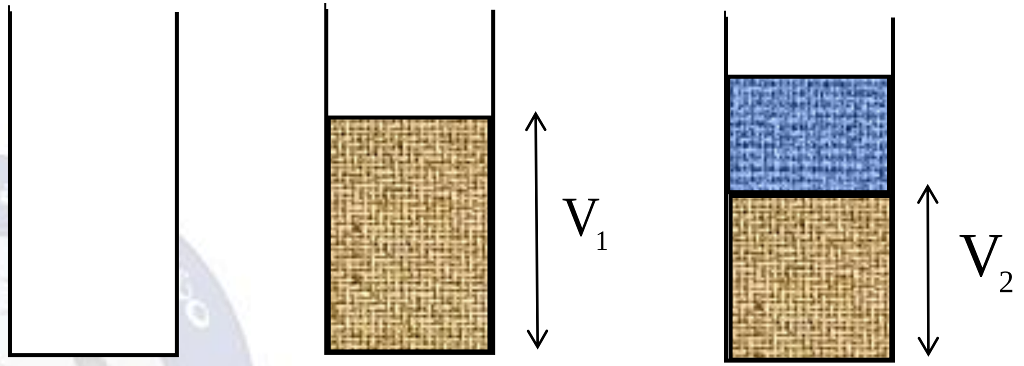

$$\% \text{ of Bulking} = \frac{V_1 - V_2}{V_2} \times 100$$

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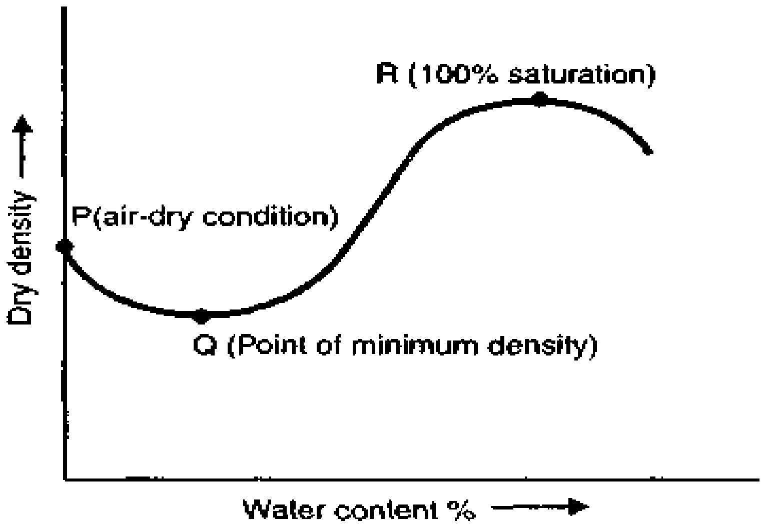
Compaction of Sands:



Typical moisture-density relationship for sand

- Sands do not have well defined OMC.
- The capillary tension resists the tendency of soil particles to take a dense state and volume increases.
- Bulking of sand is the phenomenon of increase in volume due to capillarity tension between the water molecules around the soil particles.
- For sands, compaction curve is of little practical importance.
- For sandy soils, the relative density is used as a criterion for the level of compaction achieved.

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In-situ for field compaction:

- Granular soils can be adequately compacted in thick layers than fine grained soils and clays.
- For a given soil type, heavy compaction equipment is capable of compacting thick layers than light compaction equipment.
- Cohesive soils: Tamping, kneading and Impact principle are effective
- Cohesionless soils: Tamping, kneading and vibratory principle are effective
- Primary types of compaction equipment

  1. Rollers 2. Rammers and 3. Vibrators

1. Rollers:

a. smooth wheeled rollers :

- Used for compacting Gravel in WBM road
- Imparts static compaction to the soil
- Compaction pressure is low because of large contact area
- Suitable for compacting granular base courses and paving mixtures for highway.
- 8 passes are required to achieve the equivalent standard proctor compaction.
- To provide smooth surface at the end of days work and to quickly drain off rain water.

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b. Pneumatic tyred rollers :

- Used for compacting casing of earth dam.
- Compaction by kneading action
- Wobble wheel – exerts steady pressure on uneven ground
- Suitable for all types of soil (cohesive and non-cohesive)
- Most suitable for wet cohesive soil

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c. Sheep foot rollers :

- Used for compacting core of earth dam.
- Compaction is achieved by a combination of tamping and kneading
- Suitable for cohesive soils (clays) only
- It is unsuitable for granular soils as the sand tend to loosen these continuously.

d. Grid rollers:

- Suitable for all types of soils including wet clays and silts

Sheep footed roller

Grid roller

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Rammers:

a. Dropping type b. pneumatic type and c. Internal commission type

- Used for cohesionless soils
- Used in confined areas eg. Beds of drainage trenches, backfills of bridge Abutments.

Dropping type rammer

Pneumatic type rammer

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f. Tampers: Manual compaction using tampers

Used for soils of inaccessible areas, trenches, behind retaining walls

g. Vibrators :

Used for compacting sandy soils.

a. Vibrating drum:

Smooth drums, sheeps foot drums may be used

Layers of soil of the order 1m could be compacted.

b. Vibratory pneumatic type :

300 mm thick granular soil will be compacted satisfactorily.

c. Vibrating plate :

Compacting granular base courses

d. Vibrofloat :

Vibroflotation: A method suited for compacting thick deposits of loose sandy soil.

Vibroflotation method first compacts deep zone in the soil and then works it away towards the surface.

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8.9 Compaction

Numerical Questions

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1. An embankment is to be constructed by compacting the layers of 300 mm thick. The rammer used for compaction has the foot area 0.04 m^2. The energy induced per drop of hammer 500N-mm. Assuming 50% more energy in each pass over compacted area due to overlap. The number of passes required to develop compactive energy as per IS light compaction is …………

Ans:

Energy imparted as per IS light compaction = 26×0.31×3×25 = 604.5Nm/m^3

Energy imparted on soil layers $= \frac{500\times10^{-3}}{0.04\times0.3}$ Nm/m^3 $= 41.67$ Nm/m^3

In each pass over length, energy supplied is 50% more than the energy due to rammer on account of layers.

$$1.5\times41.67\times n = 604.5$$

$$n = 9.6 \cong 10 \text{ passes}$$

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2. Void ratio of granular soil deposit is 0.6. The maximum and minimum void ratio of the soil were found to be 0.8 and 0.4 respectively. The relative density and relative compaction respectively are ……….

Ans. $e = 0.6 \quad e_{max} = 0.8 \quad e_{min} = 0.4$

$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}} = \frac{0.8 - 0.6}{0.7 - 0.4} = 0.5 = 50\%$$

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

$$\gamma_d \alpha \frac{1}{1+e}$$

$$R_c = \frac{\gamma_{d\,field}}{\gamma_{d_{max}}} = \frac{1+0.4}{1+0.6} \times 100 = \frac{1.4}{1.6} \times 100 = 86\%$$

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3. An embankment is to be constructed from the borrow pit with properties $e = 0.8$ $w = 15\%$ and $G = 2.66$ The compacted volume of the embankment is 1000 m^3 and its unit weight is 20 kN/m^3 at in-situ water content of 20%.

a. The truck of 10 m^3 is used to transport the soil from borrow pit during excavation and dumping of soil in truck, the soil increases in volume by 10%. The number of trucks required for transporting the soil are ………..

b. The quantity of water to be applied for the embankment to achieve desired water content is ………..

Ans. $V = 1000 m^3$ $\gamma = 20 kN/m^3$ $w = 20\%$ $G = 2.66$

Embankment:

Volume of the soil, V=1000m^3

Weight of the soil, W=1000×20=20,000 kN

$$w = \frac{W_w}{W_s}$$

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Weight of solids, $W_s = \frac{W}{1+w} = \frac{20000}{1+0.2} = 16666.7\text{kN}$

Weight of water, $W_W = W - W_s = 20000 - 16666.7 = 3333.3\text{kN}$

Volume of solids, $V_S = \frac{W_s}{G\gamma_w} = \frac{16666.7}{2.66 \times 10} = 626.6\text{m}^3$

For borrow pit:

$$\frac{V_S}{1} = \frac{V}{1+e} \qquad V = V_S(1+e)$$

Volume of soil transfer from pit $V = 626.6(1+0.8)$ $V = 1127.9\text{m}^3$

Allowing 10% allowance in transportation = 1.1×1127.9 = 1240.67 m^3

No. of trucks required $=\dfrac{1240.6}{10}=124.1\simeq125$ tucks

Weight of water in soil from borrow pit, $W_W = w.W_S \quad = 0.15\times16666.7 = 2500\text{kN}$

Additional water required, $W_W = 3333.3 - 2500 \qquad W_W = 833\text{kN}$

$$V_W = \frac{833.3}{10} = 83.33\text{m}^3$$

For Embankment:

$$\gamma_d = \frac{\gamma}{1+w} = \frac{20}{1+0.2} = 16.67\text{kN/m}^3$$

$$\gamma_d = \frac{G\gamma_w}{1+e} \Rightarrow 16.67 = \frac{2.66\times10}{1+e} \Rightarrow e = 0.596$$

$V_1 = 1000\,\text{m}^3 \qquad e_1 = 0.596 \qquad \dfrac{V_2}{V_1} = \dfrac{1+e_1}{1+e_2}$

$V_2 = ? \qquad e_2 = 0.8 \qquad V_2 = \dfrac{1+0.8}{1+0.596}\times1000 = 1127.8\text{m}^3$

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Allowance of 10% during transportation, $V = 1.1 \times 1127.8 = 1240.6\text{m}^3$

Number of trucks required $n = \dfrac{V}{\text{Volume of truck}} = \dfrac{1240.6}{10} = 124.1 \simeq 125$

$$W_S = \frac{W}{1+w}$$

$$W_W = w.W_S = w.\frac{W}{1+w} = 0.05 \times \frac{20000}{1+0.2} = 833.33\text{m}^3$$

4. The in-situ moisture content of the soil is 10% and its unit weight is 18 kN/m^3. The specific gravity of soil solids is 2.7. Soil is to be excavated and transported to a construction site and then compacted to a dry unit weight of 18 kN/m^3 at a moisture content of 20%.

a. the volume of excavated soil needed to produce 1000 m^3 of compacted fill is……..

Ans. $(W_S)_{Borrowpit} = (W_S)_{embankment}$

$$\gamma_{db} = \frac{\gamma}{1+w} = \frac{18}{1+0.1} = 16.36\text{kN/m}^3$$

$$(V.\gamma_d)_{borrowpit} = (V.\gamma_d)_{embankment}$$

$$\gamma_{dE} = \frac{\gamma}{1+w} = \frac{18}{1+0.2} = 15\text{kN/m}^3$$

$$V_B \times 16.36 = 1000 \times 15 = 1090.7\text{m}^3$$

b. If the truck carries 20 tonnes, the number of trucks needed to transport the excavated soil is ……..

Capacity of each truck = 20 t = 200kN

Weigh of soil from borrow pit, $W = V.\gamma = 1090.7 \times 18 = 19632.6\text{kN}$

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No of trucks required $= \frac{19632}{200} = 98.16 \simeq 99$ trucks

c. Quantity of water required to be added at the construction site is ……….

Additional water required at construction site

$$= (w_2 - w_1) W_S = (20 - 10) 18 \times 1000 = 18000 \text{kN}$$

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5. A standard proctor compaction test was performed on a clayey soil. The test results are as shown in table below

$w\%$	2	4	6	8	10	12	14	16
$\gamma_{d1} kN/m^3$	17	18.1	18.4	19.0	18.6	18.2	17.9	16.8

Specific gravity of soil solids is 2.70. Assuming the variation between the points in graphs is linear.

a. Degree of saturation at the optimum moisture content is ……..

Ans. OMC = 8%

$$\gamma_{d,\max} = 19.0 kN/m^3 \Rightarrow e \Rightarrow \gamma_d = \frac{G\gamma_w}{1+e} \Rightarrow 1.9 = \frac{2.7\times 10}{1+e} \Rightarrow e = 0.421$$

$$S = \frac{w.G}{e} = \frac{0.08\times 2.70}{e} = \frac{0.08\times 2.70}{0.421} = 0.513 \Rightarrow S = 51.3\%$$

b. If the relative compaction of the soil is to be achieved at 90% in the field then the dry unit weight of the soil in the field is ……..

$$\text{Relative compaction} = \frac{\gamma_{d,\,field}}{\gamma_{d,\max}}$$

$$\gamma_{d,\,field} = 0.9 \times 19 = 17.1\text{kN/m}^3$$

c. If the moisture content is raised to 15% in the field, the unit weight of soil is ………..

$$\gamma = \gamma_d\left(1+w\right) = 17.1\left(1+0.15\right) \Rightarrow \gamma = 19.66\text{kN/m}^3$$

6. An embankment for a highway of 24 m wide 1 m thick is to be constructed from a sandy soil trucked from a borrow pit. The water content and void ratio of borrow pit are 12% and 0.7 respectively. Length of road is 1 km. G of soil = 2.7

(i) The dry unit wt of sandy soil from borrow pit is …….

(ii)The number of $10 m^3$ truck loads of sandy soil required to construct embankments are…

(iii) Weight of water transport per truck load of soil is …………..

Ans. $$\gamma_d = \frac{G\gamma_w}{1+e} = \frac{2.7\times 10}{1+0.70} = 15.88 kN/m^3$$

Volume of construction = 24×1×1000

=24000 m^3

No of trucks required $= \frac{24000}{10} = 2400$ trucks

Truck load = $10m^3$

$$\gamma_d = \frac{W_S}{V} \qquad W_d = 15.88\times 10 = 158.8 kN$$

$$W_W = 0.12\times 158.8 = 19.5 kN$$

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Previous GATE Questions

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01. Let G be the specific gravity of soil solids, w the water content in the soil sample, the unit weight of water, and the dry unit weight of the soil. The equation of the zero voids line in a compaction test plot is CE2 2017

a. $\gamma_d = \frac{G\gamma_w}{1+Gw}$ b. $\gamma_d = \frac{G\gamma_w}{Gw}$ c. $\gamma_d = \frac{G_w}{1+\gamma_w}$ d. $\gamma_d = \frac{G_w}{1-\gamma_w}$

Ans. a

Air voids line is a line which shows the water content, dry density relation for the compacted soil containing a constant percentage of air voids.

$$\gamma_d = \frac{(1-n_a)G\gamma_w}{1+e} = \frac{(1-n_a)G.\gamma_w}{1+\frac{wG}{S}}$$

Zero air voids line or the saturation line is a line which shows the water content, dry density relation of the theoretical maximum compaction of soil containing no air voids ($n_a = 0$ and $s = 1$)

$$\gamma_d = \frac{G\gamma_w}{1+wG}$$

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02. OMC-SP and MDD-SP denote the optimum moisture content and maximum dry density obtained from standard Proctor compaction test, respectively. OMC-MP and MDD-MP denote the optimum moisture content and maximum dry density obtained from the modified Proctor compaction test, respectively. Which one of the following is correct? CE2 2016

a. OMC - SP < OMC - MP and MDD - SP < MDD - MP

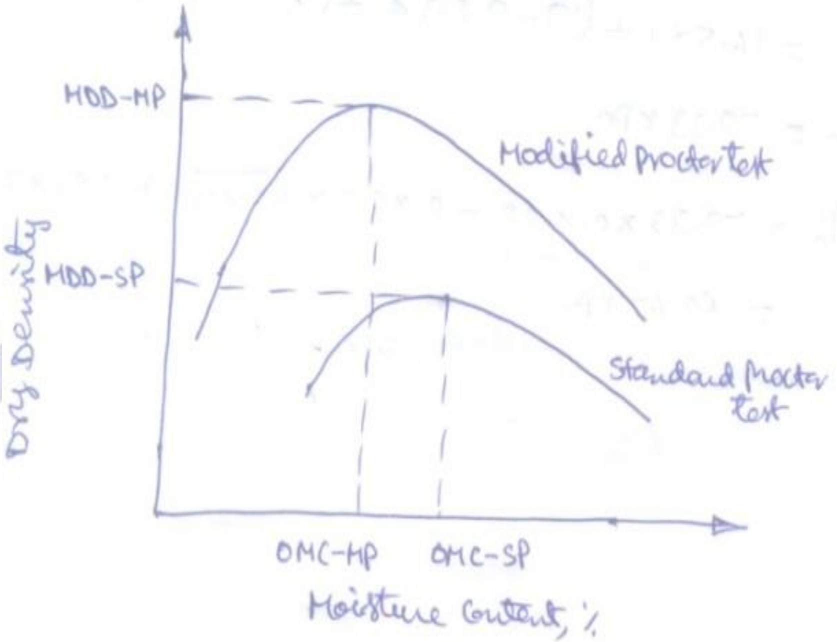
b. OMC - SP > OMC - MP and MDD - SP < MDD - MP

c. OMC - SP < OMC - MP and MDD - SP > MDD – MP

d. OMC - SP > OMC - MP and MDD - SP > MDD – MP

Ans. b

For the same soil, the effect of heavier compaction increases the maximum dry density and decreases the optimum moisture content.



OMC-SP>OMC-MP MDD-SP<MDD-MP

03. An earth embankment is to be constructed with compacted cohesion less soil. The volume of the embankment is 5000 m^3 and the target dry unit weight is 16.2 kN/m^3. Three nearby sites (see figure below) have been identified from where the required soil can be transported to the construction site. The void ratios ( ) of different sites are shown in the figure. Assume the specific gravity of soil to be 2.7 for all three sites. If the cost of transportation per km is twice the cost of excavation per m^3 of borrow pits, which site would you choose as the most economic solution? (Use unit weight of water=10 kN/m^3). CE1 2015

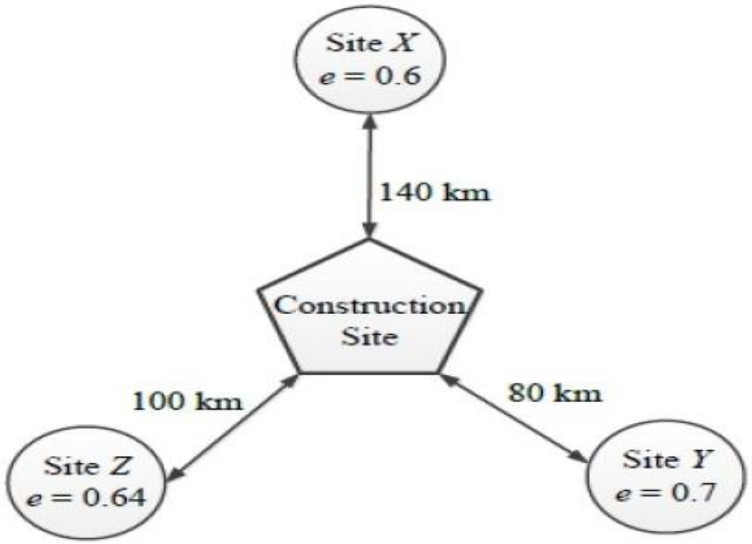
a. Site X

b. Site Y

c. Site Z

d. Any of the sites

Ans. a



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03 Ans. a

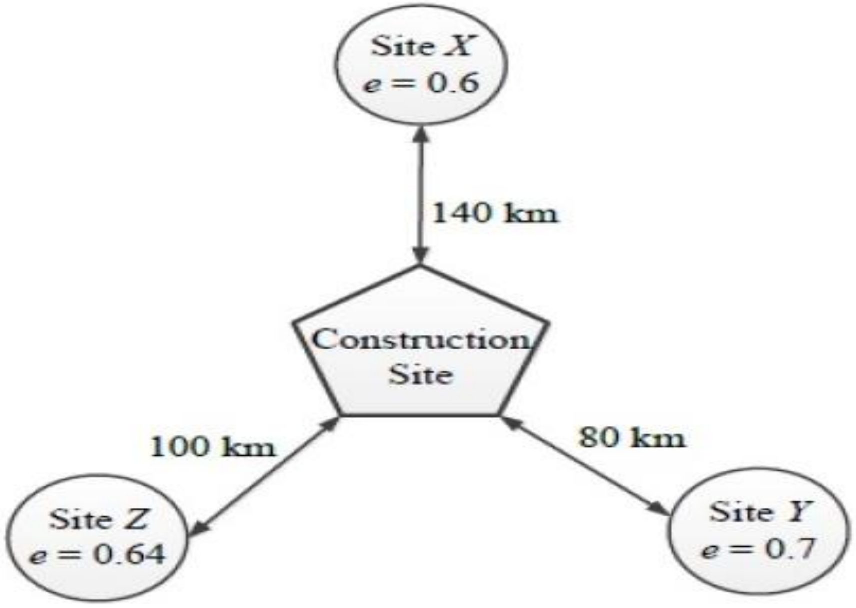
Volume of embankment, V = 5000 m^3

Target dry unit weight, $\gamma_d = 16.2\,kN/m^3$

$$\frac{V}{1+e} = \frac{V_x}{1+e_x} = \frac{V_y}{1+e_y} = \frac{V_z}{1+e_z}$$

$$\gamma_d = \frac{G\gamma_w}{1+e} \Rightarrow 16.2 = \frac{2.67\times 10}{1+e} \Rightarrow e = 0.648$$

V_x = 4854.4 m^3 V_y = 4975.7 m^3 V_z = 5157.8 m^3



Let cost of excavation of 1 m^3 of borrow point is C

Cost of transportation of 1m^3 per km = 2C

Total cost from site X, $C_x = C\times 4854.4 + 2C\times 140 = 5134.4C$

Total cost from site Y, $C_y = C\times 4975.7 + 2C\times 80 = 5135.7C$

Total cost from site Z, $C_z = C\times 5089.8 + 2C\times 100 = 5289.8C$

Choosing site X is more economical.

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04. Following statements are made on compacted soils, where in DS stands for the soils compacted on dry side of optimum moisture content and WS stands for the soils compacted on wet side of optimum moisture content. Identify the incorrect statement.

a. soil structure is flocculated on DS and dispersed on WS

b. Construction pore water pressure is low on DS and high on WS.

c. On drying, shrinkage is high on DS and low on WS

d. on access to water, swelling is high on DS and low on WS 2013

Ans. c

DS: Soils compacted on dry side of optimum moisture content.

WS: Soils compacted on wet side of optimum moisture content.

4 Ans.

On Dry side

i. soil structure is flocculated

ii. pore water pressure is low

iii. on access to water, swelling is high

iv. on drying, shrinkage is low.

On wet side,

i. soil structure is dispersed

ii. pore water pressure is high

iii. on access to water, swelling is low

iv. on drying, shrinkage is high.

05. Two series of compaction tests were performed in the laboratory on an inorganic clayey soil employing two different levels of compaction energy per unit volume of soil. With regard to the above tests, the following two statements are made.

I. The optimum moisture content is expected to be more for the tests with higher energy.

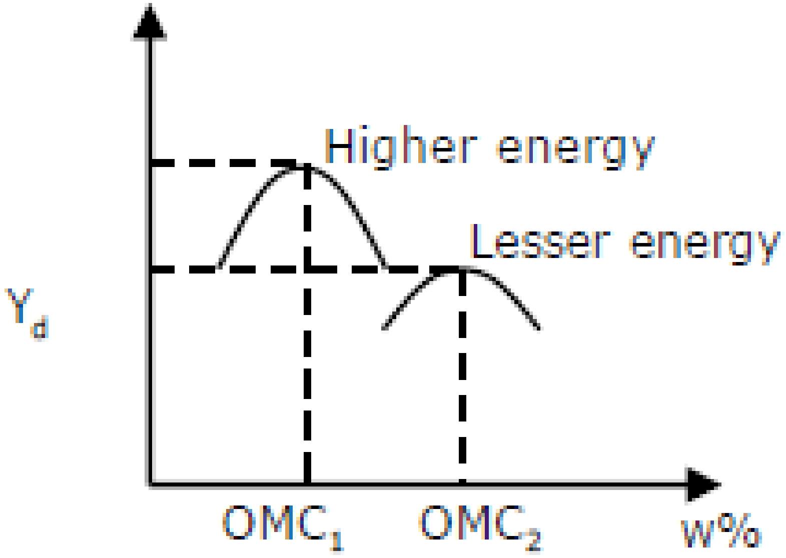
II. The maximum dry density is expected to be more for the tests with higher energy.

The CORRECT option evaluating the above statements is 2012

a. only I is TRUE **b.** only II is TRUE

c. both I and II are TRUE d. neither I nor II is TRUE

Ans. b



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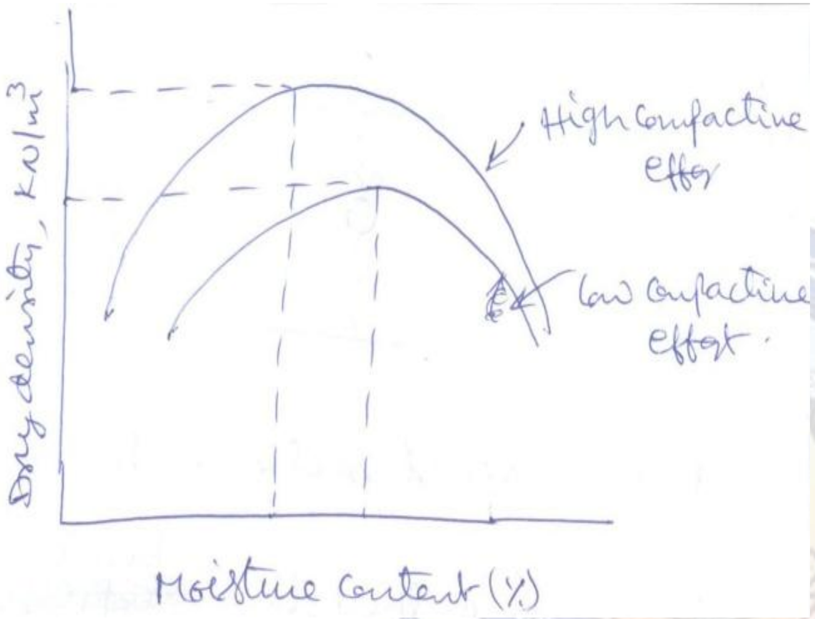
05 Ans. b



Increase in compactive effort will result in an increase in the maximum dry density and a corresponding decrease in the optimum moisture content.

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06. In a compaction test, , , and represent the specific gravity, water content, degree of saturation and void ratio of the soil sample, respectively. If represents the unit weight of water and represents the dry unit weight of the soil, the equation for zero air voids line is 2010

a. $\gamma_d = \dfrac{G\gamma_w}{1+Se}$ **b.** $\gamma_d = \dfrac{G\gamma_w}{1+Gw}$ c. $\gamma_d = \dfrac{G\gamma_w}{e+\gamma_w S}$ d. $\gamma_d = \dfrac{Gw}{1+Se}$

Ans. b

G : Specific gravity

e : Void ratio

γ_w : Unit weight of water

S : Degree of saturation

w : Water content

γ_d : Dry content weight of soil

γ : Bulk density of $= \gamma_d (1+w) = \dfrac{G\gamma_w}{1+e}(1+w) = \dfrac{(G+S.e)\gamma_w}{1+e}$

$S = \dfrac{w.G}{e}$

For dry unit weight, $S = 0$

$\gamma_d = \dfrac{G\gamma_w}{1+e} = \dfrac{G\gamma_w}{1+\dfrac{wG}{S}}$

For zero voids, $S = 100\% \Rightarrow \gamma_d = \dfrac{G\gamma_w}{1+Gw}$

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07. Compaction by vibratory roller is the best method of compaction in case of

a. moist silty sand **b.** well graded dry sand

c. clay of medium compressibility d. silt of high compressibility 2008

Ans. b

Soil type	Method of compaction
Moist silty sand	Smooth wheeled rollers
Well graded dry sand	Vibratory Roller
Clay of medium compressibility	Pneumatic tyred rollers
Silt of high compressibility	Sheep foot rollers

08. In a standard proctor test, 1.8 kg of moist soil was filling the mould (volume = 944 cc) after compaction. A soil sample weighing 23 g was taken from the mould and oven dried for 24 hours at a temperature of 110^0C. Weight of the dry sample was found to be 20 g. Specific gravity of soil solids is G = 2.7. The theoretical maximum value of the dry unit weight of the soil at that water content is equal to

a. 4.67 kN/m^3 b. 11.5 kN/m^3 c. 16.26 kN/m^3 **d.** 18.85 kN/m^3 2006

Ans. d

Volume of the mould, V = 944 cc

Weight of moist soil, W = 1.8 kg

Weight of moist soil sample, w_1 = 23 g

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Weight of oven dried soil sample, w_2 = 20 g

Specific gravity of soil solids, w_2 = 2.7

Theoretical maximum dry density of soil, $\gamma_{d_{\max}} = \dfrac{G\gamma_w}{1+e}$

Bulk density of soil, $\gamma = \dfrac{1.8 \times 1000}{944} = 1.907 \text{ g/cm}^3$

Water content, $w = \dfrac{23-20}{20} \times 100 = 15\%$

For theoretical maximum dry unit weight, degree of saturation should be 100%.

$$S = \frac{w.G}{e} \qquad e = \frac{0.15 \times 2.7}{1} = 0.405$$

$$\gamma_{d_{\max}} = \frac{G\gamma_w}{1+e} = \frac{2.7 \times 9.81}{1+0.405} = 18.85 \text{ kN/m}^3$$

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09. A clayey soil has a maximum dry density of 16 kN/m^3 and optimum moisture content of 12%. A contractor during the construction of core of an earth dam obtained the dry density 15.2 kN/m^3 and water content 11%. This construction is acceptable because 2005

a. the density is less than the maximum dry density and water content is on dry side of optimum.

b. the compaction density is very low and water content is less than 12%.

c. the compaction is done on the dry side of the optimum.

d. both the dry density and water content of the compacted soil are within the desirable limits

Ans. d

9 Ans. d

Maximum dry density, $\gamma_{d,\max} = 16\,\text{kN/m}^3$

Optimum moisture content = 12%

Dry density during construction, $\gamma_d = 15.2\ \text{kN/m}^3$

Water content = 11%

Relative compaction= $\dfrac{\gamma_d}{\gamma_{d\max}} \times 100 = \dfrac{15.2}{16} \times 100$= 95%

Relative compaction of the order 90 to 100% is acceptable.

10. Compaction of an embankment is carried out in 500 mm thick layers. The rammer used for compaction has a foot area of 0.05 sq.m and the energy imparted in every drop of rammer is 400 Nm. Assuming 50% more energy in each pass over the compacted area due to overlap, the number of passes required to develop compactive energy equivalent to Indian Standard light compaction for each layer would be 2003

a. 10 b. 16 c. 20 **d.** 26

Ans. d

As per Indian standard light compaction test, a hammer of 2.6 kg is allowed to fall from a height of 310 mm and 3 layers are tamped 25 times in a mould of volume 1000cc.

10 Ans. d

Compactive energy $= \dfrac{2.6\times 0.31\times 3\times 25}{10^3\times 10^{-6}} = 60450\,\text{kg-m/m}^3 = 604.5\times 10^3\,\text{Nm/m}^3$

Compactive energy per drop provided by the hammer per cu.m of soil

$$= \frac{400}{0.05\times 0.5} = 16000\,\text{N-m/m}^3$$

- However, in each pass over a layer, the energy supplied will be 1.5 times this value on account of overlap of hammer foot points.
- If is the number of passes required to develop compactive energy equivalent to Indian Standard light compaction,

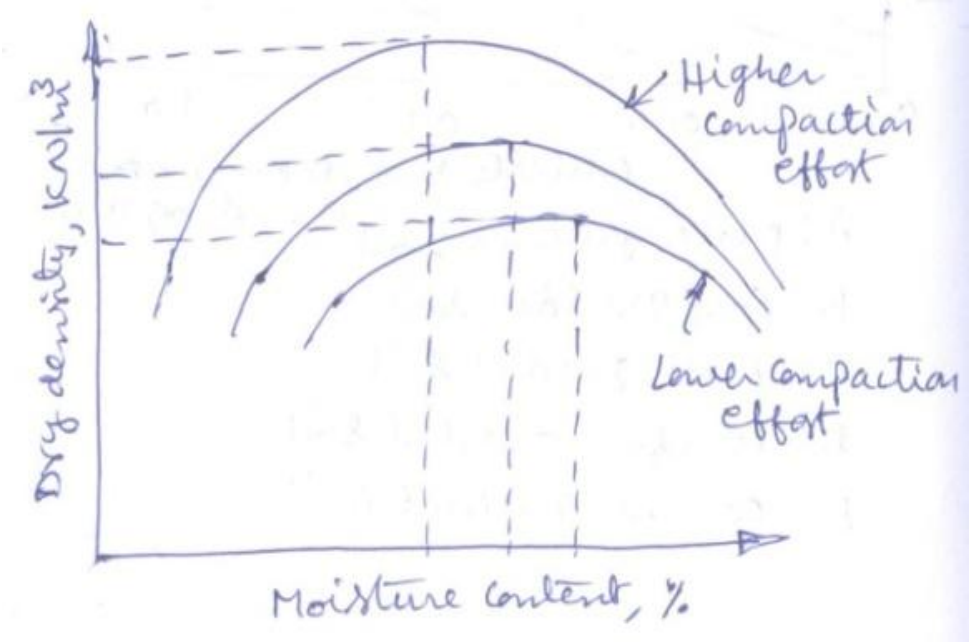
$$n\times 1.5\times 16000 = 604.5\times 10^3 \Rightarrow n = 25.18 \approx 26$$

11. In a compaction test, as the compaction effort is increased, the optimum moisture content 1997

a. decreases b. remains same c. increase d. increases first there after decreases

Ans. a

Increase in compactive effort or the energy expended will result in an increase in the maximum dry density and a corresponding decrease in the optimum moisture content.



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12. The measure of soil compaction is its wet density. True / False 1995

Ans. False

The measure of soil compaction is its dry density.

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13. The unit weight of a soil at zero air voids depends on 1995

a. specific gravity b. water content c. unit weight of water **d.** All of the above

Ans. d

Dry density of soil, $\gamma_d = \dfrac{(1-n_a)G\gamma_w}{1+e}$

Unit weight of soil, $\gamma = r_d(1+w) = \dfrac{(1-n_a)G\gamma_w(1+w)}{1+e}$

For zero air voids in a soil mass, $n_a = 0$

$$\gamma = \frac{G\gamma_w(1+w)}{1+e} = \frac{G\gamma_w(1+w)}{1+wG}$$

Unit weight of soil depends on specific gravity, unit weight of water, water content.

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14. The zero-air voids curve is non-linear owing to 1992

a. the standard proctor test data of dry density and corresponding water content plotting as a non-linear curve

b. the dry density at 100% saturation being a non-linear function of the void-ratio

c. the water content altering during compaction

d. the soil being compacted with an odd number of blows

Ans. b

Dry density of soil, $\gamma_d = \dfrac{(1-n_a)G\gamma_w}{1+e}$

The zero air void curve is non linear between the dry density at 100% saturation and void ratio.