<u>MODULE- 2</u>

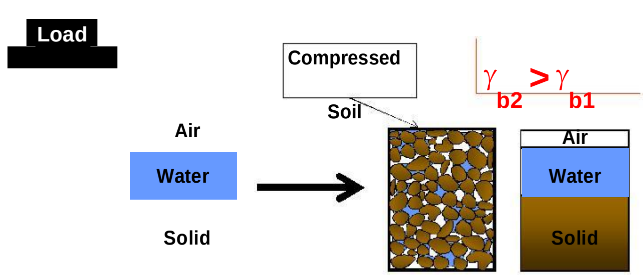
Soil Structure and Clay Mineralogy Single grained, honey combed, flocculent and dispersedstructures,Valence bonds, Soil-Water system, Electrical diffuse double layer, adsorbed water,base-exchange capacity, Isomorphous substitution. Common clay minerals in soil and theirstructures- Kaolinite, Illite and Montmorillonite and their application in Engineering.Compaction of Soils: Definition, Principle of compaction, Standard and Modified proctor'scompaction tests, factors affecting compaction, effect of compaction on soil properties, Fieldcompaction control- compactive effort & method of compaction, lift thickness and number ofpasses, Proctor's needle, Compacting equipments and their suitability.

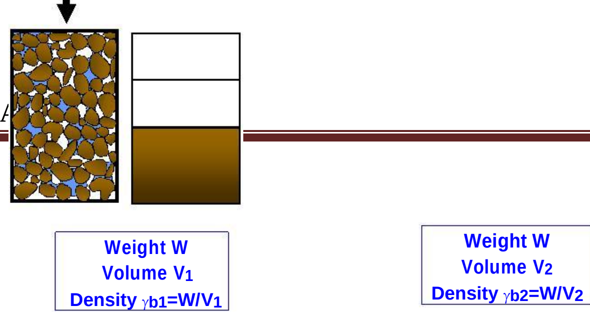
Definition of Compaction

Compaction is the process of increasing the Bulk Density of a soil or aggregate by driving out air. For any soil, at a given compactive effort, the density obtained depends on the moisture content. An "Optimum Moisture Content" exists at which it will achieve a maximum density. Compaction is the method of mechanically increasing the density of soil. The densification of soil is achieved by reducing air void space. During compaction, air content reduces, but not water content It is not possible to compact saturated soil. It should be noted that higher the density of soil mass, stronger, stiffer, more durable will be the soil mass.

Hence, Compaction

1) Increases density
2) Increases strength characteristics
3) Increases load-bearing capacity
4) Decreases undesirable settlement
5) Increases stability of slopes and embankments
6) Decreases permeability
7) Reduces water seepage
8) Reduces Swelling & Shrinkage
9) Reduces frost damage
10) Reduces erosion damage
11) Develops high negative pore pressures (suctions) increasing effective stress

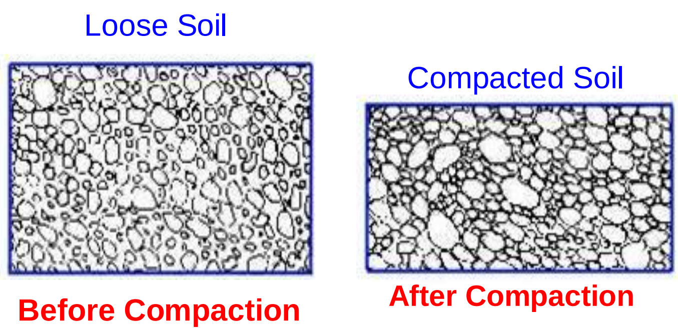




Applications of Compaction

The following are the situations in which compaction will improve the existing field condition.

1. Compaction of foundation soil for house construction.
2. Compaction of soil/gravel/crushed rock/asphalt in road & pavement construction.
3. Compaction of soil in earth embankments.
4. Compaction of soil behind retaining walls.
5. Compaction of soil backfill in trenches.
6. Dam construction
7. Construction of clay liners for waste storage areas
8. Ground improvement



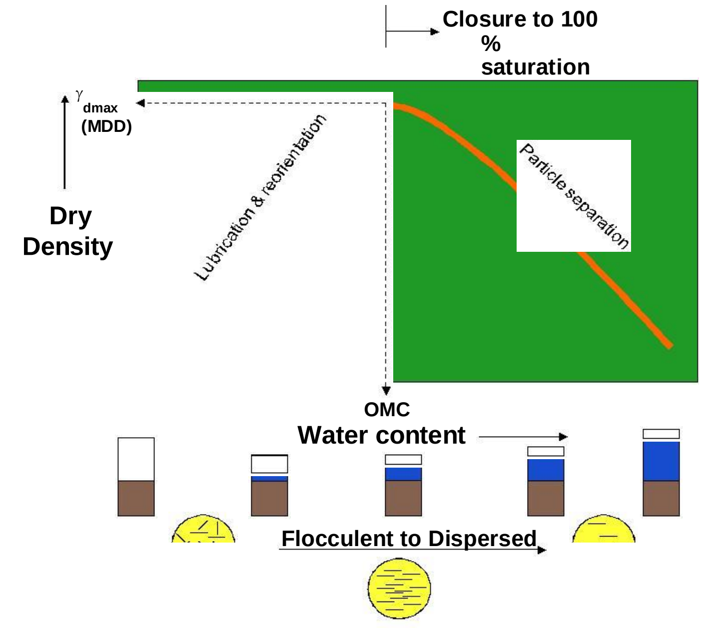
Distinction between Compaction & Consolidation

The following are the important distinctions between compaction and consolidation.

COMPACTION	CONSOLIDATION
Man made	Natural
Expulsion of air	Expulsion of pore water
Fast process	Gradual process
Possible in dry or partially saturated soil	Possible in saturated soil

Results in increased density	Results in dense packing

5.0 Mechanism of Compaction



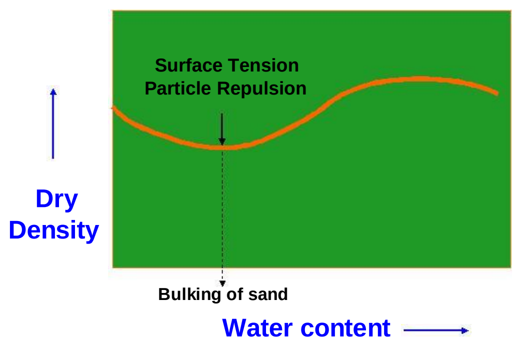
Optimum Moisture Content (OMC) is the moisture content at which the maximum possible dry density is achieved for a particular compaction energy or compaction method. The corresponding dry density is called Maximum Dry Density (MDD). Water is added to lubricate the contact surfaces of soil particles and improve the compressibility of the soil matrix. It should be noted that increase in water content increases the dry density in most soils up to one stage (Dry side). Water acts as lubrication. Beyond this level, any further increase in water (Wet side)will only add more void space, there by reducing the dry density. Hence OMC indicates the boundary between the dry side and wet side. Hence the compaction curve as shown in figure indicates the initial upward trend up to OMC and the down ward trend.

Reasons for the shape of curve

1. On dry side of OMC, clayey soil shows high suction, lumps are difficult to break or compact.
2. Increasing the water content reduces suction, softens lumps, lubricates the grains for easy compaction.
3. As water content increases, lubrication improves compaction resulting in higher dry density.
4. Now nearly impossible to drive out the last of the air – further

increase in water content results in reduced dry density (curve follows down parallel to the maximum possible density curve – the Zero Air Voids curve)

5. MDD and OMC depend on the compaction energy and are not unique soil properties
6. For sand, suction at low water contents also prevents compaction (but not if completely dry)
7. In cohesionless soils, MDD is achieved either when completely dry, or when completely saturated
8. At low water content, grains are held together by suction (water at grain contacts only)
9. This prevents compaction
10. Laboratory test for MDD on sand requires fully saturated sample, and involves vibration



Problem 1

A laboratory compaction test on soil having specific gravity of 2.7 gave a maximum dry density of 18 kN/m^3 and a water content of 15 %. Determine the degree of saturation, air content and percentage air void at the maximum dry density. What would be the theoretical maximum dry density corresponding to zero air voids at the optimum water content?

Data

G = 2.7

γ_d = 18 kN/m^3 ω = 15 %

Step 1 : Determination of Void Ratio

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

$$\therefore e = 0.47$$

Step 2 : Determination of Degree of saturation

$\omega G = Se$ $\therefore S = 86.2\ \%$

Step 3 : Determination of Air Content

$A_C = 1 - S$ $\therefore A_C = 13.8\ \%$

Step 4 : Determination of Percent Air Voids

$\gamma_d - \frac{(1-n_a)G\gamma_w}{1+\omega G}$ $\therefore n_a = 4.42\ \%$

Problem 2

A cohesive soil yields a MDD of 18 kN/m^3 at an OMC of 16 % during standard Proctor's Test. If G = 2.65, what is the degree of saturation? What is the MDD it can further be compacted to?

Data

MDD = 18 kN/m^3
OMC = 16 %
G = 2.65

Step 1 : Determination of Void Ratio

$$\gamma_d = \frac{G\gamma_w}{1+e} \qquad \therefore e = 0.442$$

Step 2 : Determination of Degree of saturation

$$\omega G = Se \qquad \therefore S = 95.9\ \%$$

Step 3 : Determination of Theoretical MDD corresponding to Zero Air Void

$$\gamma_{dZAV} = \frac{G\gamma_w}{1+\omega G} \qquad \gamma_d = 18.24\ kN/m^3$$

6.0 Laboratory Test on Compaction

1. Standard Proctor's Test
2. Modified Proctor's Test

6.1 Objectives of Laboratory Compaction Tests

1. To simulate field condition
2. To provide data for placement conditions in field
3. To determine proper amount of mixing water
4. To determine the density in field

The fundamentals of compaction of fine-grained soils are relatively new. R.R. Proctor in the early 1930's was building dams for the old Bureau of Waterworks and Supply in Los Angeles, and he developed the principles of compaction in a series of articles in Engineering News-Record. In his honor, the standard laboratory compaction test which he developed is commonly called the *Standard Proctor Test*.

6.2 STANDARD PROCTOR'S COMPACTION TEST

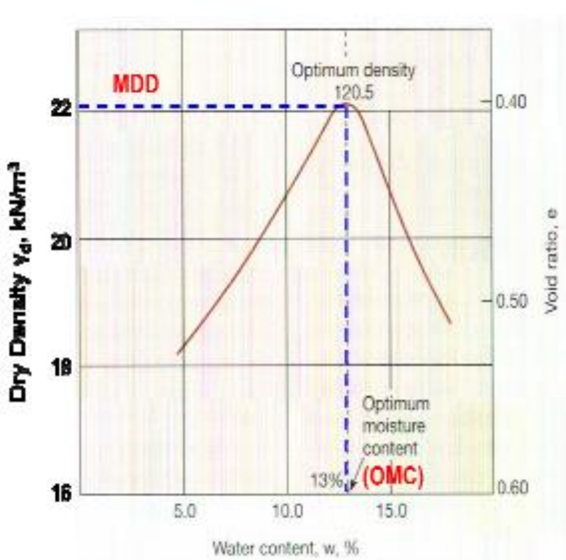
Refer IS 2720 – Part VII – 1987

Apparatus

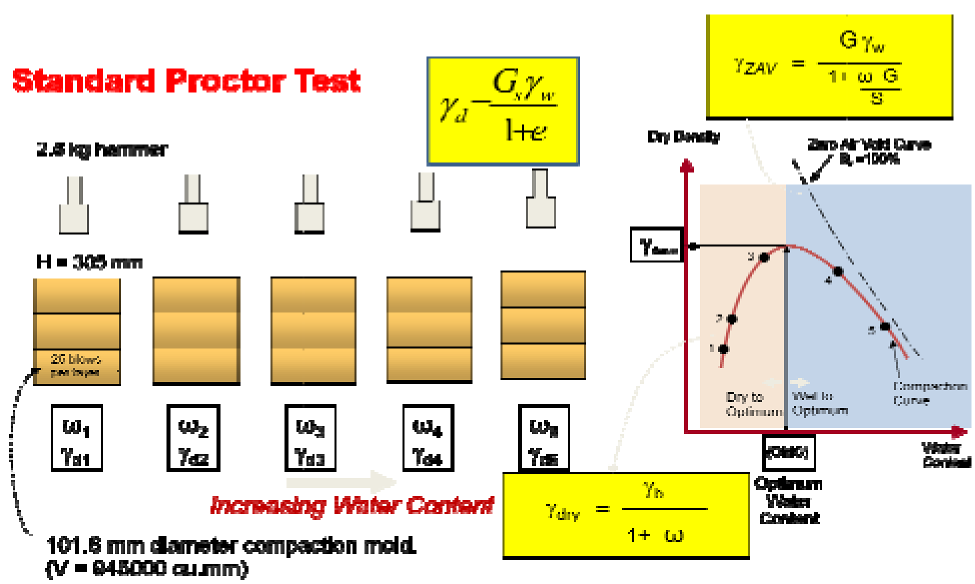
1. Cylindrical metal mould with detachable base plate (having internal diameter 101.6 mm, internal height 116.8 mm and internal volume 945000 mm^3)
2. Collar of 50 mm effective height
3. Rammer of weight 2.5 kgf (25 N) with a height of fall of 304.8 mm

Procedure

1. About 3 kg of dry soil, with all lumps pulverized and passi ng through 4.75 mm sieve is taken.
2. The quantity of w ater to be added in the first trial is decide d. (Less for Corse grained soil and more for Fine grained soil).
3. Mould without ba se plate & collar is weighed (W_1).
4. The inner surfaces of mould, base plate and collar are greas ed.
5. Water and soil are thoroughly mixed.
6. Soil is placed in m ould and compacted in three uniform layers, with 25 blows in each layer. Blows are maintained uniform and vertical and height of drop is controlled.
7. After each layer, t op surface is scratched to maintain integrity between layers.
8. The height of top l ayer is so controlled that after compactio n, soil slightly protrudes in to collar.
9. Excess soil is scra pped.
10. Mould and soil are weighed (W_2).
11. A representative s ample from the middle is kept for the determination of water content.
12. The procedure is repeated with increasing water content.
13. The number of tria ls shall be at least 6 with a few after the decreasing trend of bulk density.



Trial Number	1	2	3	4	5	6
Volume of mould						
Weight of mould (W_1) Weight of mould + soil (W_2)						
Weight of wet soil Bulk density of soil						
Weight of cup Weight of cup + wet soil Weight of cup + dry soil						
Water Content						
Dry density of soil Dry density corresponding to ZAV						



6.3 Modified Compacti on Test

In early days, compaction achieved in field was relatively less. With improvement in knowledge and technology, higher compactio became a necessity in field. Hence Modified Compaction Test became relevant. It was developed during World War II by the U.S. Army Corps of Eng ineering to better represent the comppaction required for airfield to support heavy aircraft.

6.4 Distinction between Standard & Modified Comp action

Standard Proctor T est	Modified Proctor Test
305 mm height of drop	450 mm height of drop
25 N hammer	45 N hammer
25 blows/layer	25 blows/layer
3 layers	5 layers
Mould size: 945 ml	Mould size: 945 ml
Energy 605160 N-mm per m^3	Energy 2726000 N-mm per m^3

Compactive energy

$$\frac{\text{No. of blows per layer} \times \text{Number of layers} \times \text{Weight of hammer} \times \text{Height of drop of hammer}}{\text{Volume of mould}}$$

6.5 Compactive Energy in Standard Proctor's Test

6.5

Comp active Energy in Standard Proctor's Test

Number of layers = 3
Height of drop = 0.305
Weight of hammer = 25 N
Number of blows = 25
Volume of mould = $945 \text{ X } 10^{-6}\ m^3$

Energy = 605160 N-m m per 1000 ml (m^3)

6.6 Compact ive Energy in Modified Proctor's Test

Number of layers = 5
Height of drop = 0.450
Weight of hammer = 45 N
Number of blows = 25
Volume of mould = 945 X 10^{-6} m^3
Energy = 2726000 N-m m per 1000 ml (m^3)

Compactive energy in Modified Proctor's Test is 4.5 times bigger than in Standard Proctor's Test

Problem 3

The following are the res ults of compaction test.

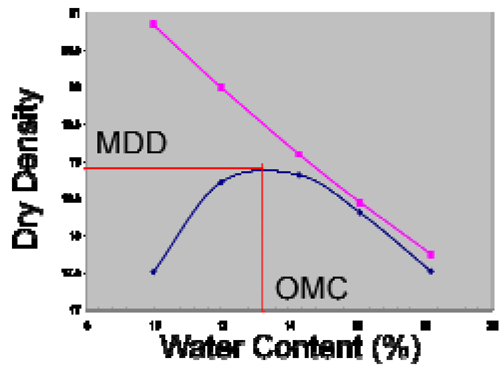
Weight of mould + wet soil (N)	29.25	30.95	31.50	31.25	31.70
Water content (%)	10.0	12.0	14.3	16.1	18.2

Volume of mould =$1X10^6$ mm^3, Weight of mould = 10 N, Spec ific gravity of soil solids = 2.7. Fin d the OMC and MDD. Plot zero air voi d line. Find the degree of saturation a t MDD.

Relationship betwee n dry density, percent air void and water content

$$\gamma_d = \frac{(1-n_a)G\gamma_\omega}{1+\omega G} \qquad \therefore \gamma_{dZAV} = \frac{G\gamma_\omega}{1+\omega G}$$

Weight of mould + wet soil (N)	29.25	30.95	31.50	31.2 5	30.70
Weight of wet soil (N)	19.25	20.95	21.50	21.2 5	20.70
Bulk Unit Weight (kN/m^3)	19.25	20.95	21.50	21.2 5	20.70
Water content (%)	10.0	12.0	14.3	16.1	18.2
Dry Unit weight (kN/m^3)	17.50	18.71	18.81	18.3 0	17.51
γ_{dZAV}	20.83	19.98	19.09	18.4 4	17.74



$$\gamma_d = \frac{G\gamma_\omega}{1+e}$$

$$\omega G = Se$$

MDD = 18.85 kN/m^3 OMC = 13.5 %

e = 0.43 **ω = 14.3 %**

Compaction Behavior o f soil is a function of

1. granular soil type
2. moisture content
3. lift thickness of c ompacted layer
4. number of roller passes
5. weight of compact ors

<u>7.0 Factors affecting C ompaction</u>

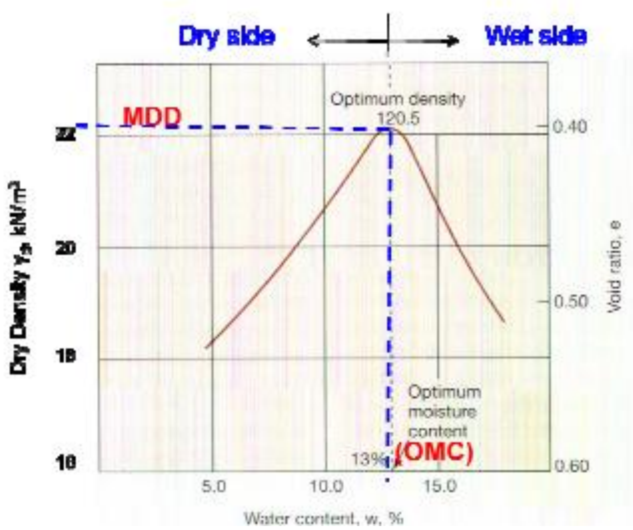
1. Water Content
2. Amount of Compa ction
3. Method of Compaction
4. Type of Soil
5. Addition of Admi xtures

7.1 Effect of Water Con tent

1. With increase in w ater content, compacted density increases up to a stage, beyond whi ch compacted density decreases.
2. The maximum den sity achieved is called MDD and the corresponding water content is ca lled OMC.
3. At lower water co ntents than OMC, soil particles are held b y electrical forces that prevent s the development of diffused double layer leading to low inter-partic le repulsion.

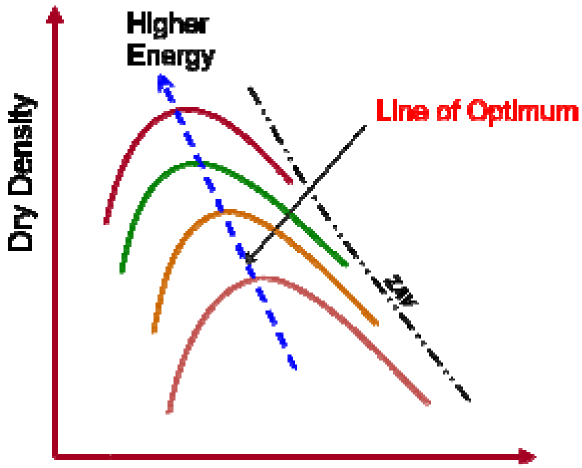
Compaction of Soils

4. Increase in water r esults in expansion of double layer and reduction in net attractive force between particles. Water replaces air in void space.
5. Particles slide over each other easily increasing lubrication, helping in dense packing.
6. After OMC is reac hed, air voids remain constant. Further i ncrease in water, increases th e void space, thereby decreasing dry density.



7.2 Effect of Amount of Compaction

1. As discussed earli er, effect of increasing compactive effort is to increase MDD And reduce OMC (Evident from Standard & Modified Proctor’s Tests).
2. However, there is no linear relationship between compactiv e effort and MDD


Higher
Energy
Line of Optimum
Dry Density
ZAV

7.3 Effect of Method of Compaction

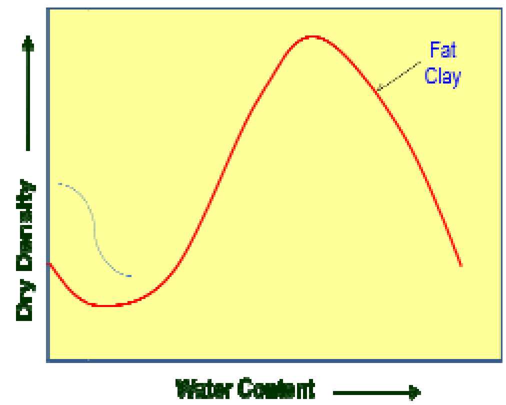
The dry density achieved by the soil depends on the following ch aracteristics of compacting method.

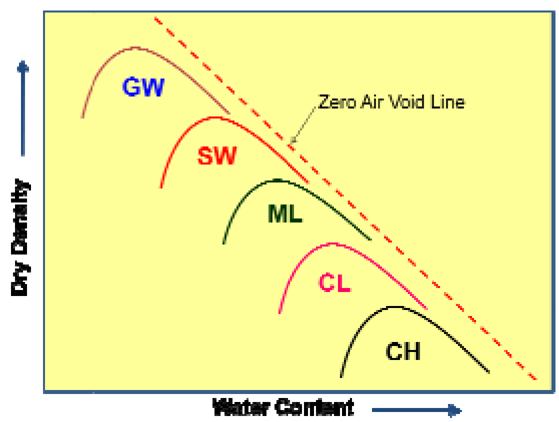
1. Weight of compacting equipment
2. Type of compactio n - Impact, Kneading, Rolling, Static Pr essure
3. Area of contact of compacting equipment with soil
4. Time of exposure
5. Each of these a pproaches will yield different compactive effort. Further, suitability of a particular method depends on type of soil.

7.4 Effect of Type of Soil

1. Maximum density achieved depends on type of soil.
2. Coarse grained soi l achieves higher density at lower water content and fine grained soil a chieves lesser density, but at higher wate r content.

Typical Compaction Curve for Fat Clay





7.5 Effect of Addition of Admixtures

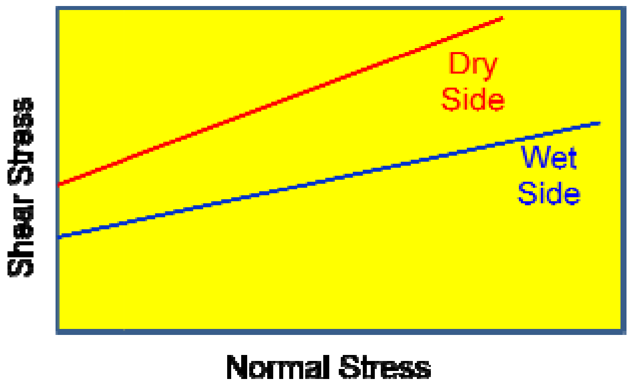
1. Stabilizing agents are the admixtures added to soil.
2. The effect of addi ng these admixtures is to stabilize the soi l.
3. In many cases the y accelerate the process of densification.

8.0 Influence of compac tion on soil properties

1. Density
2. Shear strength
3. Permeability
4. Bearing Capacity
5. Settlement
6. Soil Structure
7. Pore Pressure
8. Stress Strain chara cteristics
9. Swelling & Shrink age

8.1 Influence on Density: Effect of compaction is to reduce t he voids by expelling out air. This results in increasing the dry density of soil mass.

8.2 Influence on Shea r strength: In general, effect of comp action is to increase the number of contacts resulting in increased she ar strength, especially in granular soils. In clays, shear strength depends on dry density, moulding water content, soil structure, method of compaction, strain level, drainage condition etc. Shear strength of cohesive soils compacted dry of optimum (flocculated str ucture) will be higher than those compacted wet of optimum (dispersed stru cture).


Dry
Side
Wet
Side
Shear Stress
Normal Stress

8.3 Effect of compaction on permeability

1. Increased dry density, reduces the void space, thereby reducing permeability.
2. At same density, soil compacted dry of optimum is more permeable.
3. At same void ratio , soil with bigger particle size is more permeable.
4. Increased compacttive effort reduces permeability.

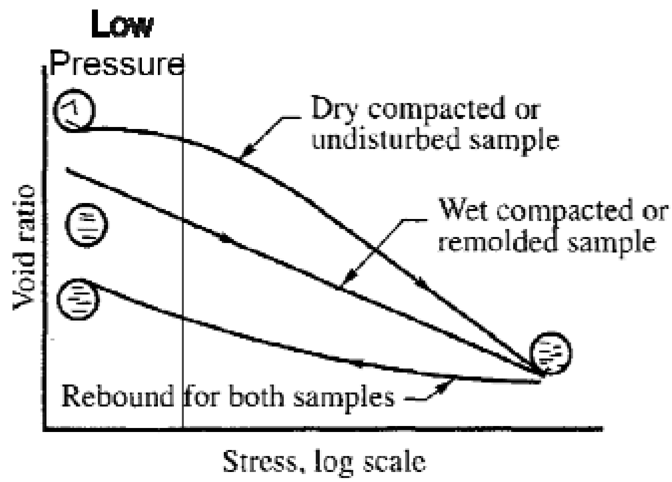
8.4 Influence on Bearing Capacity

1. Increase in compaction increases the density and number of contacts between soil particcles.
2. This results in increased .
3. Hence bearing capacity increases which is a function of density and .

8.5 Influence on Settlement

1. Compaction increases density and decreases void ratio.
2. This results in reduced settlement.
3. Both elastic settlement and consolidation settlement are reduced.
4. Soil compacted dry of optimum experiences greater compression than that compacted wet of optimum.

8.6 Influence on Compressibility: At low pressure, soil compacted wet of optimum shows more compressibility than that on dry side. But at higher pressure, behaviour is similar.

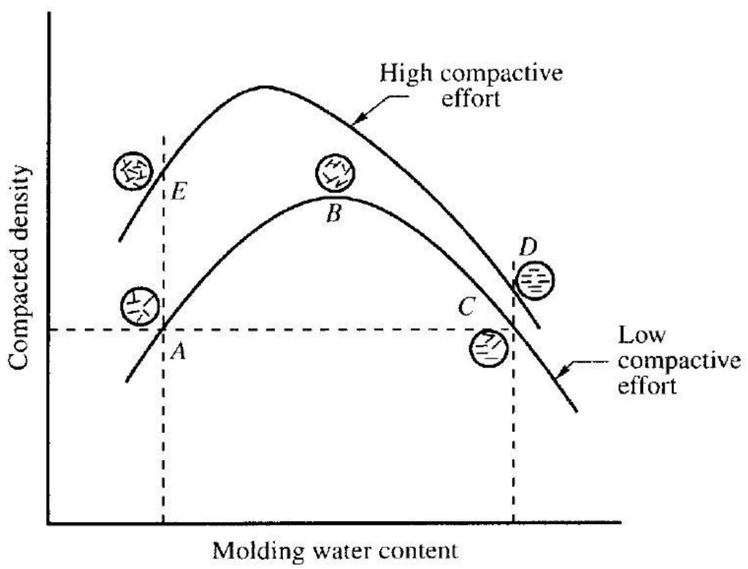

Low
Pressure
Dry compacted or
undisturbed sample
Wet compacted or
remolded sample
Void ratio
Rebound for both samples
Stress, log scale

8.7 Influence on Soil Structure

In fine grained soil

1. On dry side of optimum, the structure is flocculated. The particles repel and density is less.
2. Addition of water increases lubrication and transforms the structure in to dispersed structure

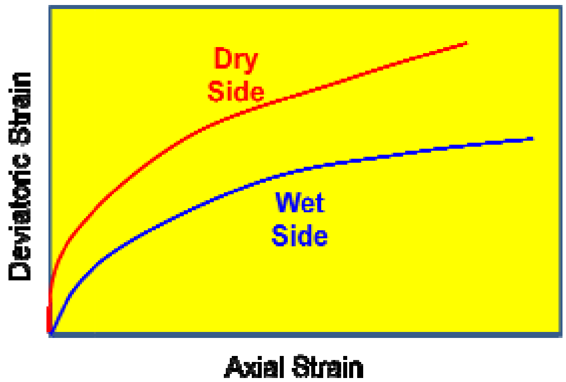
In coarse grained soil, single grained structure is maintained In composite soil, behaviour depends on composition.



8.8 Influence on Pore Pressure

1. Clayey soil compacted dry of optimum develops less pore water pressure than that compacted wet of optimum at the same density at low strains.
2. However, at higher strains the effect is the same in both the cases.

8.9 Influence on Stress Strain Characteristics: The strength and modulus of elasticity of soil on the dry side of optimum will always be better than on the wet side for the same density. Soil compacted dry of optimum shows brittle failure and that compacted on wet side experiences increased strain.

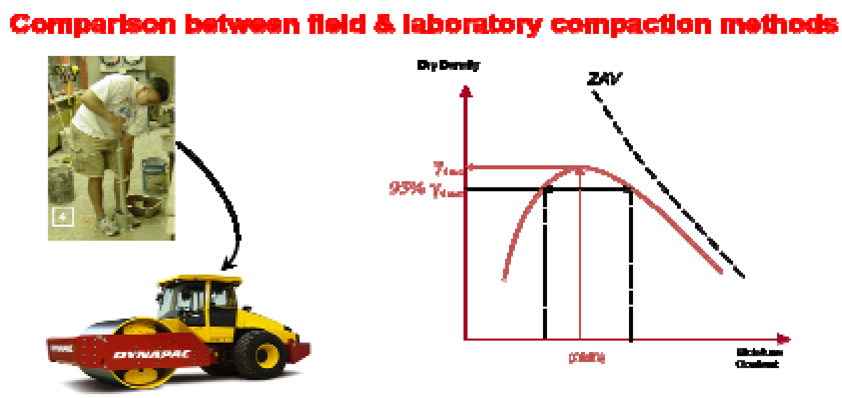


8.10 Influence on Swell Shrink aspect: The effect of comp action is to reduce the void space. Hence the swelling and shrinkage are enormously reduced. Further, soil compacted dry of optimum exhibits greate r swell and swell pressure than th at compacted on wet side because of random orientation and deficiency in water.

Engin eering Properties-Summary		
	Dry side	**Wet side**
Structure	More random	More oriented (parallel)
Permeability	More permeable	Less permeable
Compressibility	More compressible in *high* pressure range	More compressibl e in *low* pressure range
Swelling	Swell more, higher wat er deficiency	Shrink more
Strength	Hig her	Lesser

9.0 Field Compaction C ontrol

It is extremely important to understand the factors affecting co mpaction in the field and to estimate the correlation between laboratory and field compaction. Field compaction control depends on (i) Place ment water content, (ii) Type of eq uipment for compaction and (iii) Lift thickness and (iv) Number of passes ba sed on soil type & degree of compaction desired

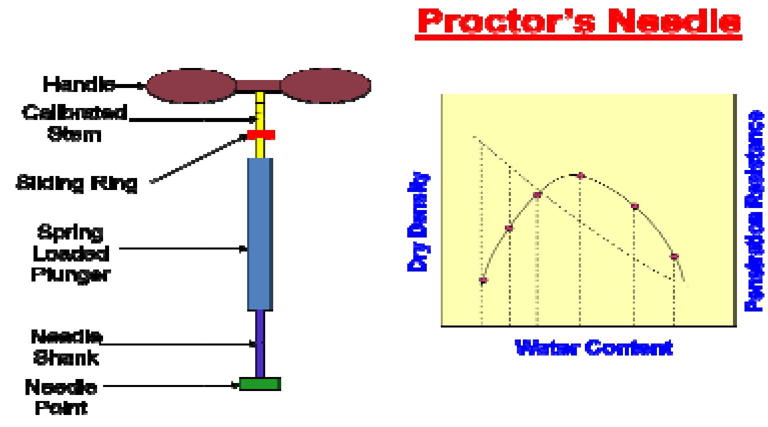


10.0

Placement water conte nt is the water content at which the ground is compacted in the field. It is desirable to compact at or close t o optimum moisture content achiev ed in laboratory so as to increase the e fficiency of compaction. However, i n certain jobs the compaction is done at lower than or higher than OMC (by about 1 – 2 %) depending on the desired function as detailed in the table.

Dry side	Wet side
Highway embankment c ompacted dry of optimum to achieve high strength, low volume compressibility and good resistance to deformation	Cohesive subgrades u nder pavements compacted wet optimu m to eliminate swelling and swelling pressure upon submergence
High earth dams compacted at 1 to 2.5 % less than OMC to reduce pore pressure development	Impervious core of earth dam is compacted on wet side to achieve low permeability, greater safety against cracking due to differential settlement

Proctor's Needle



1. Used for rapid determ ination of water content of soil in field.
2. Rapid moisture meter is used as an alternative.
3. Proctor's needle consists of a point, attached to graduated needle shank and spring loaded plunger.
4. Varying cross sections of needle points are available.
5. The penetration force is read on stem at top.
6. To use the needle in field, Calibration in done on the specific s oil in lab and calibration curve is prepared and the curve is used in the f ield to determine placement water content.

11.0 Compaction contr ol in field

There are many varia bles which control the vibratory compaction or densification of soils.

Characteristics of th e compactor:

(1) Mass, size
(2) Operating frequen cy and frequency range

Characteristics of th e soil:

(1) Initial density
(2) Grain size and sha pe
(3) Water content

Construction proced ures:

(1) Number of passes of the roller
(2) Lift thickness
(3) Frequency of oper ation vibrator
(4) Towing speed

Degree of Compaction

Relative compaction or degree of compaction

$$R.C. = \frac{\gamma_{d-field}}{\gamma_{d\max-laboratory}} \cdot 100\%$$

Correlation between relative compaction & relative density $R.C. = 80 + 0.2D_r$

It is a statistical result based on 47 soil samples.

Typical required R.C. >= 95%

12. 0 Types of field Compaction Equipment

1. Smooth Wheeled Steel Drum Rollers
2. Pneumatic Tyred Rollers
3. Sheepsfoot Rollers
4. Impact Rollers
5. Vibrating Rollers
6. Hand Operated Vibrating plate & rammer compactors

12.1 Smooth wheeled steel drum rollers

1. Capacity 20 kN to 200 kN
2. Self propelled or towed
3. Suitable for well graded sand, gravel, silt of low plasticity
4. Unsuitable for uniform sand, silty sand and soft clay

12.2 Pneumatic Tyred Rollers

1. Usually two axles carrying rubber tyred wheels for full width of track.
2. Dead load (water) is added to give a weight of 100 to 400 kN.
3. Suitable for most coarse & fine soils
4. Unsuitable for very soft clay and highly variable soil.

12.3 Sheepsfoot Roller

1. Self propelled or towed
2. Drum fitted with projecting club shaped feet to provide kneading action.
3. Weight of 50 to 80 kN
4. Suitable for fine grained soil, sand & gravel with considerable fines.

12.4 Impact Roller

1. Compaction by static pressure combined with impact of pentagonal roller.
2. Higher impact energy breaks soil lump and provides kneading action

12.5 Vibrating Drum

1. Roller drum fitted with vibratory motion.
2. Levels and smoothens ruts

12.6 Plate & Rammer Compactor: It is used for backfilling trenches, smaller constructions and less accessible locations

Equipment Applications				
	Granular Soils	**Sand and Clay**	**Cohesive Clay**	**Asphalt**
Rammers	Not Recommended	Testing Recommended	Best Application	Not Recommended
Vibratory Plates	Best Application	Testing Recommended	Not Recommended	Best Application
Reversible Plates	Testing Recommended	Best Application	Best Application	Not Recommended
Vibratory Rollers	Not Recommended	Best Application	Testing Recommended	Best Application
Rammax Rollers	Testing Recommended	Best Application	Best Application	Not Recommended

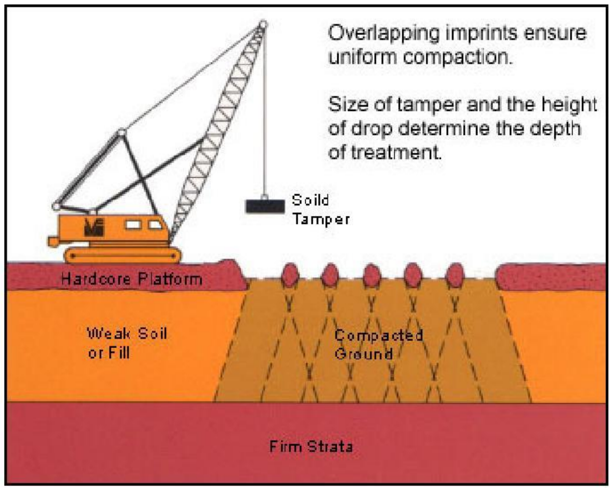
How Does a Contractor Modify Compaction in the field?

1. Adjust Water Content
2. More Passes
3. Thinner Lifts
4. Bigger Rollers
5. Right Compactor for the Soil Type

13.0 Dynamic Compaction

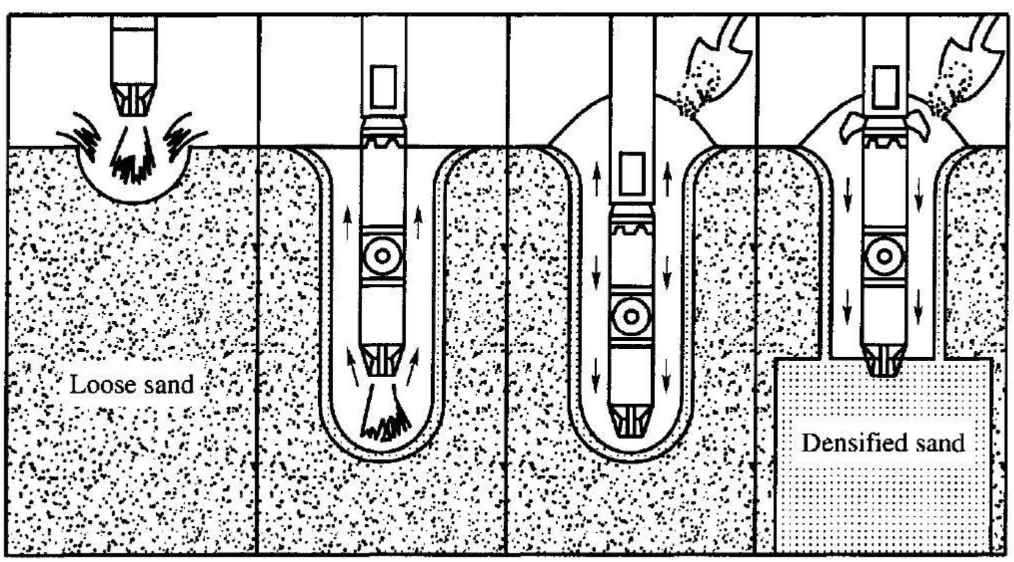
1. Used to compact both cohesive and cohesionless soils.
2. A crane is used to lift a concrete or steel block weighing up to 500 kN up to a height of 40 to 50 m.
3. From this height, weight is allowed to freely fall on the ground surface.
4. The process is repeated over the area.
5. Soil at surface is disturbed. It is then refilled and levelled.
6. Depth of compaction is up to 12 m.

7. The method is quick and produces uniform settlement.



14.0 Vibrofloatation

1. Used for compacting granular soil in the field.
2. Consists of cylindrical tube, eccentric weight and water jet.
3. Vibrofloat is sunk in to the ground and vibratory motion develops an enlarged hole.
4. Hole is backfilled with suitable granular material.
5. Applicable up to about 30 m.
6. Spacing of vibrofloatation depends on initial density and desired density. Usually 2m spacing can enhance relative density up to 70 %.



Typical examination Questions

1. Distinguish b/w Standard & Modified Proctor's Tests
2. Distinguish b/w Compaction & Consolidation
3. Factors influencing compaction
4. Effect of compaction on Engineering properties of soil
5. Problem on Lab compaction
6. Problem on quantity of soil required from borrow pit to fill in compacted ground
7. Field compaction methods
8. Placement water content
9. Dynamic compaction
10. Vibrofloatation

Questions from past examinations

1. Sketch a typical compaction curve for a cohesionless soil and explain the characteristic features of it. In what way this is different from that of a cohesive soil? (8 Marks- Feb 2002)
2. What are the different compacting equipments used for compacting the soil in the field? Explain briefly. (6 Marks - Jan 2005)
3. Discuss the effect of compaction on soil properties. (6 Marks - Jan 2005)
4. Differentiate between compaction and consolidation. (6 Marks Jan 2005 Old)
5. Calculate the compactive energies applied in modified proctor test and standard proctor test. (6 Marks Jan 2005 Old)
6. Distinguish between standard and modified proctor tests. (3 Marks Jan 2006)
7. Briefly explain the use of proctor needle in field compaction control. (5 Marks Jan 2006)
8. List the differences between standard proctor compaction test and modified proctor compaction test. (06 Marks - Jan 2007)
9. List the factors affecting the degree of compaction. How does compaction differ from consolidation? (06 Marks - Jan 2007)
10. List the differences between standard proctor compaction test and modified proctor compaction test. (4 Marks - July 2002)

11. List the factors affecting the degree of compaction. How does compaction differ from consolidation? (6Marks - July 2002)

12. Calculate the compaction energy corresponding to standard proctor and modified proctor compaction.(6 Marks - July 2004)
13. With a neat sketch, define the term "line of optimums". (03 Marks - July 2007)
14. Obtain the value of compactive energy imparted to the soil during modified proctor compaction test. (04 Marks - July 2007)
15. Discuss the effect of compaction on soil properties. (08 Marks - June 2009)
16. Explain Vibro-floatation technique for in-situ densification of soils.(06 Marks - June 2009)
17. Calculate compaction energy used in Standard Proctor test and modified Proctor test. (06 Marks - June 2009)
18. Explain the use of Proctor needle in the field compaction control. (5 marks - March 2001)

Solution to numerical problems from examination

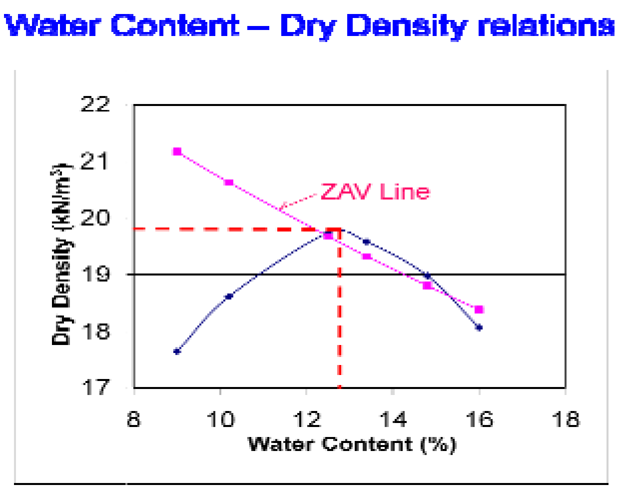
Problem 4

The results of a compaction test on a soil are set out below.

Moisture Content (%)	9.0	10.2	12.5	13.4	14.8	16.0
Bulk unit weight (kN/m^3)	19.23	20.51	22.20	22.20	21.79	20.96

Plot the dry unit weight - moisture content curve and determine the maximum dry unit weight and corresponding optimum moisture content. If the particle specific gravity is 2.68, determine the air void percentage at maximum dry unit weight. (10 marks - Jan2003)

Water Content (%)	Bulk Density (kN/m^3)	Dry Density (kN/m^3)	Dry Density Zero Air Void (kN/m^3)
9.00	19.23	17.64	21.16
10.20	20.51	18.61	20.63
12.50	22.20	19.73	19.67
13.40	22.20	19.58	19.32
14.80	21.79	18.98	18.81
16.00	20.96	18.07	18.38



OMC = 12.6 %
MDD = 19.7 kN/m^3
G = 2.68
γ_ω = 9.8 kN/m^3

$$\gamma_d = \frac{(1-n_a)G\gamma_\omega}{1+\omega G}$$

n_a = - 0.336 %

Problem 5

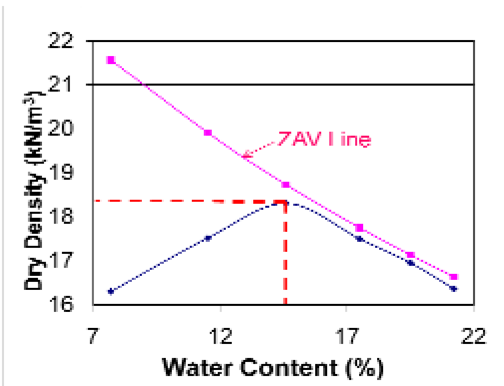
The following are the observations of a compaction test.

Water content, ω (%)	7.7	11.5	14.6	17.5	19.5	21.2
Weight of wet soil W (N)	16.67	18.54	19.92	19.52	19.23	18.83

If the volume of compac tion mould is 950 C.C, assuming G=2.65, Draw compaction curve. Repo rt maximum dry unit weight and optimum moisture content (OMC). Draw 10 0% saturation line (zero air voids line). What is the degree of saturation at OMC?
(12 Marks - Jan 2006)

Water Content (%)	Weight of wet soil (N)	Bulk Density (kN/m^3)	Dry Density (kN/m^3)	Dry Density Zero Air Void (kN/m^3)
7.7	16.67	17.55	16.29	21.57
11.5	18.54	19.52	17.50	19.90
14.6	19.92	20.97	18.30	18.73
17.5	19.52	20.55	17.49	17.74
19.5	19.23	20.24	16.94	17.12
21.2	18.83	19.82	16.35	16.63

Water Content – Dry Density relations



OMC = 14.7 %

MDD = 18.3 kN/m^3

G = 2.65

γ_ω = 9.8 kN/m^3

$$\gamma_d = \frac{G\gamma_\omega}{1+e}$$

e = 0.42

$$\omega G = Se$$

S = 92.75 %

Problem 6

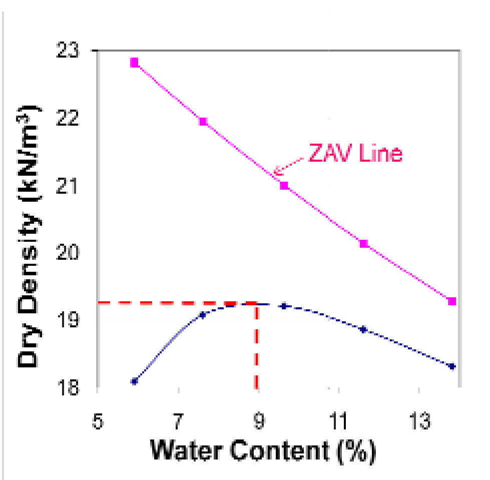
The following data was obtained from proctor compaction test:

Water content %	5.90	7.60	9.61	11.61	13.81
Weight of wet Sample (N)	18.20	19.50	20.00	20.00	19.80

Specific gravity of soil = 2.70, Volume of the mould = 9.5×10^{-4} m^3. Plot the moisture content-dry density curve and zero air void line. Determine OMC and maximum dry density of the sample. (10 Marks - July 2002)

Water Content (%)	Weight of wet soil (N)	Bulk Density (kN/m^3)	Dry Density (kN/m^3)	Dry Density Zero Air Void (kN/m^3)
5.90	18.2	19.16	18.09	22.82
7.60	19.5	20.53	19.08	21.95
9.61	20.0	21.05	19.21	21.01
11.61	20.0	21.05	18.86	20.15
13.81	19.8	20.84	18.31	19.27

Water Content – Dry Density relations



OMC = 9.0 %
MDD = 19.3 kN/m^3
G = 2.70
γ_ω = 9.8 kN/m^3

Problem 7

A standard proctor compaction test was conducted on a soil with G = 2.85 and following results were obtained:

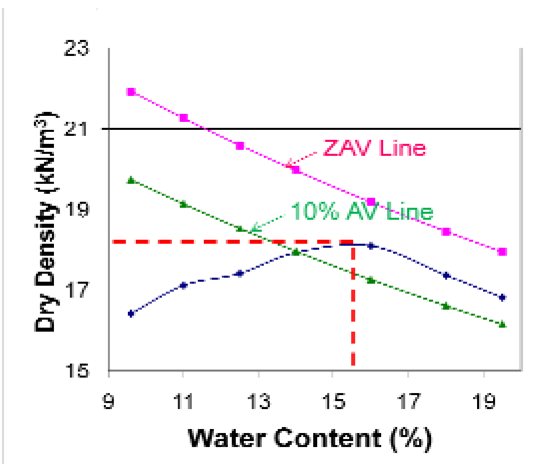
Find OMC. Draw the zero air voids line. Draw 10% air voids line. Show specimen calculations for these.

(12 Marks - July 2007)

Bulk unit weight, kN/m^3	18.00	19.00	19.60	20.45	21.00	20.50	20.10
Water content, %	9.60	11.00	12.50	14.00	16.00	18.00	19.50

Water Content (%)	Bulk Density (kN/m^3)	Dry Density (kN/m^3)	Dry Density Zero Air Void (kN/m^3)	10% Air Void Density (kN/m^3)
9.60	18.00	16.42	21.93	19.74
11.00	19.00	17.12	21.26	19.14
12.50	19.60	17.42	20.59	18.53
14.00	20.45	17.94	19.96	17.97
16.00	21.00	18.10	19.18	17.26
18.00	20.50	17.37	18.46	16.61
19.50	20.10	16.82	17.95	16.16

Water Content – Dry Density relations



OMC = 15.6 %

MDD = 18.3 kN/m^3

G = 2.85

$\gamma_\omega = 9.8$ kN/m^3

Problem 8

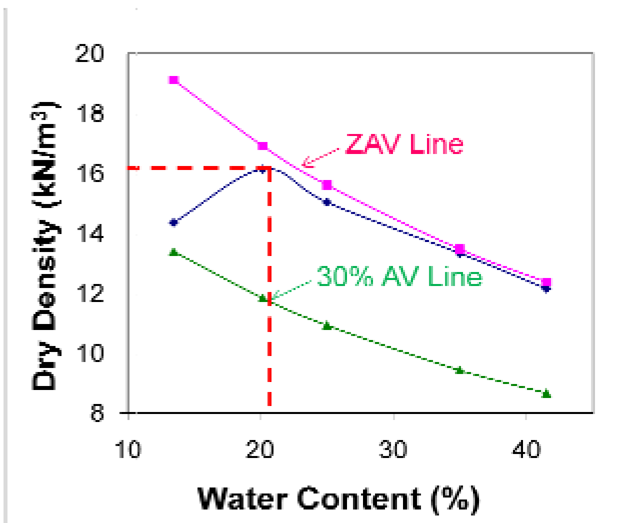
The following are the results of standard compaction test on a soil.

Water content, %	13.5	20.2	25.0	35.0	41.5
Bulk unit weight, kN/m^3	16.3	19.4	18.8	18.0	17.2

Plot the dry unit weight vs. water content relationship and get the maximum dry unit weight and optimum water content. Show 70 % and 100 % saturation lines on the plot. Take G = 2.65. (10 marks - March 2001)

Water Content (%)	Bulk Density (kN/m^3)	Dry Density (kN/m^3)	Dry Density Zero Air Void (kN/m^3)	30% Air Void Density (kN/m^3)
13.50	16.30	14.36	19.13	13.39
20.20	19.40	16.14	16.92	11.84
25.00	18.80	15.04	15.62	10.93
35.00	18.00	13.33	13.47	9.43
41.50	17.20	12.16	12.37	8.66

Water Content – Dry Density relations



OMC = 21 %

MDD = 16.2 kN/m^3

G = 2.65

γ_ω = 9.8 kN/m^3

Problem 9

During a compaction test, a soil attains a maximum dry density of 18kN/m^3 at water content of 12%. The specific gravity of soil is 2.67. Determine the degree of saturation, percentage air voids at maximum dry density. Also find the theoretical maximum dry density corresponding to zero air void at the optimum moisture content. (8Marks Jan 2005).

Data

MDD = 18 kN/m^3

OMC = 12 %

G = 2.67

$$\gamma_d = \frac{G\gamma_\omega}{1+e} \qquad \omega G = Se \qquad \gamma_d = \frac{(1-n_a)G\gamma_\omega}{1+\omega G}$$

e = 0.454

S = 70.6 %

γ_{dZAV} = 19.82 kN/m^3

Problem 10

The wet weight of a sample is missing in a proctor compaction test. The oven dry weight of this sample is 18.5N. The volume of the mould is 1000000 mm^3. If the degree of saturation of this sample is 90%, determine its water content and bulk density. Take G = 2.7. (8 Marks Jan 2005 Old)

S = 90 %

G = 2.7

γ_ω = 9.8 kN/m^3

γ_d =18.5 kN/m^3

$$\gamma_d = \frac{G\gamma_\omega}{1+e}$$

$$\omega G = Se$$

e = 0.43

ω = 14.3 %

Problem 11

A laboratory compaction test on a soil having G = 2.68 gave a maximum dry density of 17.85 kN/m^3 and the moisture content 17%. Find the degree of saturation, air content and percentage of air voids at the maximum dry density. Also find the theoretical maximum dry density with respect to zero-air voids at OMC. (08 Marks - Jan 2007)

G = 2.68
MDD = 17.85 kN/m^3
OMC = 17 %
γ_ω = 9.8 kN/m^3

$$\gamma_d = \frac{G\gamma_\omega}{1+e}$$

$$\omega G = Se$$

$$\gamma_d = \frac{(1-n_a)G\gamma_\omega}{1+\omega G}$$

e =0.471
S = 96.73 %
A_c = 1 – S = 3.27 %
n_a = 1.07 %
When n_a = 0, γ_{dZAV} = 18.04 kN/m^3

Problem 12

The soil from a borrow area having an average in-situ unit weight of 15.5 kN/m^3 and water content of 10% was used for the construction of an embankment (total finished volume is 6000 cubic metres). In half of the embankment, due to improper control during rolling, the dry unit weight achieved was slightly lower. If the dry unit weight in the two parts are 16.5 and 16 kN/m^3, find the volume of borrow area soil used in each part and the amount of soil used. (8Marks - July 2004)

Borrow Area	Fill 1	Fill 2
γ_b = 15.5 kN/m^3 ω = 10 % γ_d = 14.09 kN/m^3 e = 0.88 V_v = 0.88 V_s	V_1 = 3000 m^3 γ_{d1}= 16.5 kN/m^3 e_1 = 0.604 V_{v1} = 0.604 V_{s1} $V_1 = V_{v1} + V_{s1}$ = 1.604V_{s1} = 3000 m^3 V_{s1} = 1870 m^3	V_2 = 3000 m^3 γ_{d2}= 16 kN/m^3 e_2 = 0.654 V_{v2} = 0.654 V_{s2} $V_2 = V_{v2} + V_{s2}$ = 1.654V_{s2} = 3000 m^3 V_{s2} = 1814 m^3

$G = 2.7$

$\gamma_\omega = 9.8\ kN/m^3$

$$\gamma_d = \frac{G\gamma_\omega}{1+e}$$

$V_s = V_{s1} + V_{s2} = 3684\ m^3$

$V_v = 0.88V_s = 3242\ m^3$

$V_{borrow} = V_s + V_v = 6926\ m^3$