Rajiv Gandhi University of Knowledge Technology-Nuzvid

DEPARTMENT OF CIVIL ENGINEERING

SOIL MECHANICS

BY

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COMPACTION

UNIT- IV (Compaction)

Syllabus of Compaction

- Significance
- Factors affecting compaction
- Effect of compaction on mechanical properties of soil
- Mechanism of compaction
- Compaction control

INTRODUCTION

- ‘Compaction’ of soil may be defined as the process by which the soil particles are artificially rearranged and packed together into a state of closer contact by mechanical means in order to decrease its porosity and thereby increase its dry density.
- This is usually achieved by dynamic means such as tamping, rolling, or vibration. The process of compaction involves the expulsion of air only.
- In the natural location and condition, soil provides the foundation support for many structures.
- Besides this, soil is also extensively used as a basic material of construction for earth structures such as dams and embankments for highways and airfields.
- The general availability and the relatively low cost are the chief causes for using soil as construction material.

- Properly placed and compacted, the resulting soil mass has better strength than many natural soil formations. Such soil is referred to as a ‘compacted earth fill’ or a ‘structural earth fill’.
- For the purpose of supporting highways or buildings or for retaining water as in earth dams, the soil material must possess **certain properties** while in-place.
- These desirable features can be achieved by proper placement of an appropriate soil material. Most of these desirable qualities are associated with **high unit weight** (or dry density), which may be achieved by compaction.
- Virtually any soil can be used for structural fill, provided it does not contain organic matter.
- Granular soils are capable of achieving high strength with relatively low volume changes.
- Properly compacted clay soils will develop relatively **high strengths** and **low permeabilities** which may be desirable features as for earth dams

COMPACTION VERSUS CONSOLIDATION

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 soils	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 power and settlement characteristics	Improves bearing power and settlement characteristics
7.	Relatively quick process	Relatively slow process
8.	Relatively complex phenomenon involving expulsion, compression, and dissolution of pore air-in water	Relatively simple phenomenon
9.	Useful primarily in embankments and earth dams	Useful as a means of improving the properties of foundation soil

Purpose of Compaction

- Maximum shear strength occurs approximately at minimum void ratio.
- Large air voids may lead to compaction under working loads, causing settlement of the structure during service.
- Larger voids if left may get filled with water which reduces the shear strength.
- Increase in water content is also accompanied by swelling and loss of shear strength in some clays.

Objectives of compaction

The objectives of compaction are:

- To increase soil shear strength and therefore its bearing capacity.
- To reduce subsequent settlement under working loads.
- To improve Load carrying capacity of pavement sub-grades.
- To reduce soil permeability making it more difficult for water to flow through.
- To control undesirable volume changes (by frost action, swelling, shrinkage).

COMPACTION PHENOMENON

- Compaction, in general, is the densification of soil by removal of air, which requires mechanical energy.
- The degree of compaction of a soil is measured in terms of its dry unit weight.
- The addition of water to a dry soil helps in bringing the solid particles together by coating them with thin films of water. At low water content, the soil is stiff and it is difficult to pack it together.
- As the water content is increased, water starts acting as a lubricant, the particles start coming closer due to increased workability and under a given amount of compactive effort, the soil-water-air mixture starts occupying less volume, thus effecting gradual increase in dry density.

- As more and more water is added, a stage is reached when the air content of the soil attains a minimum volume, thus making the dry density a maximum.
- The water content corresponding to this maximum dry density is called the 'optimum moisture content'.
- Addition of water beyond the optimum reduces the dry density because the extra water starts occupying the space which the soil could have occupied.
- The curve with the peak is known as the 'moisture-content dry density curve' or the 'compaction curve'.

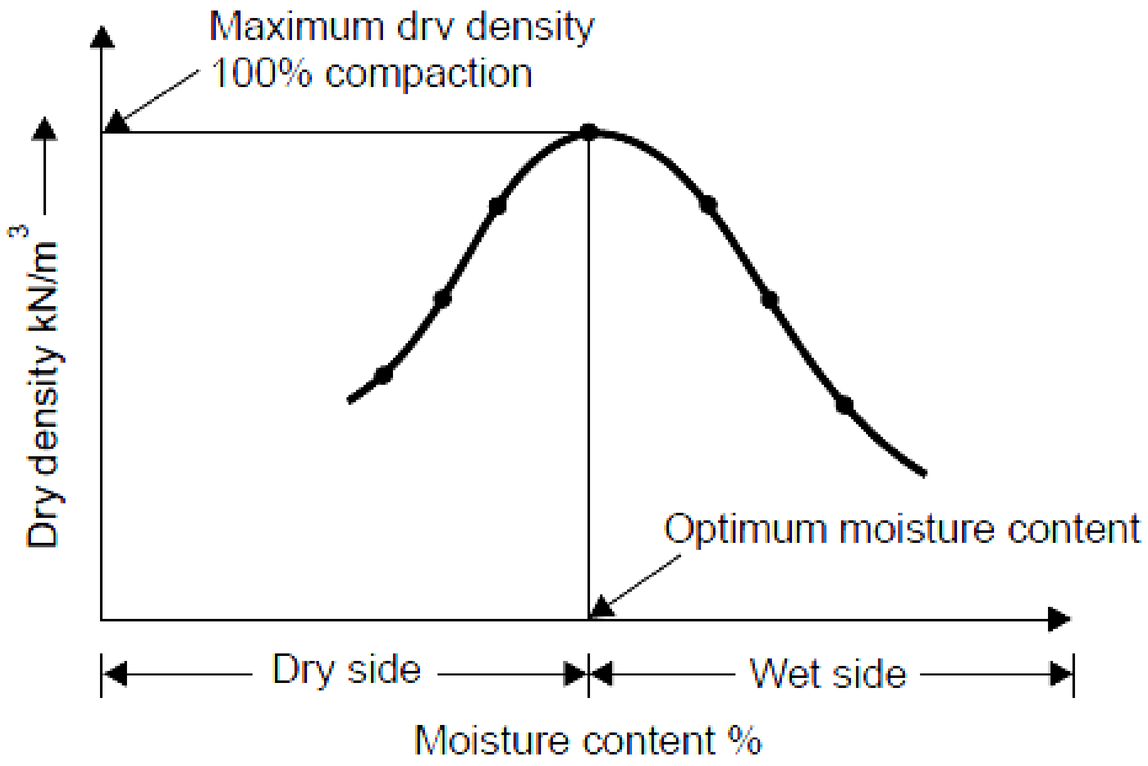


Fig: Moisture content versus dry density at a particular compactive effort

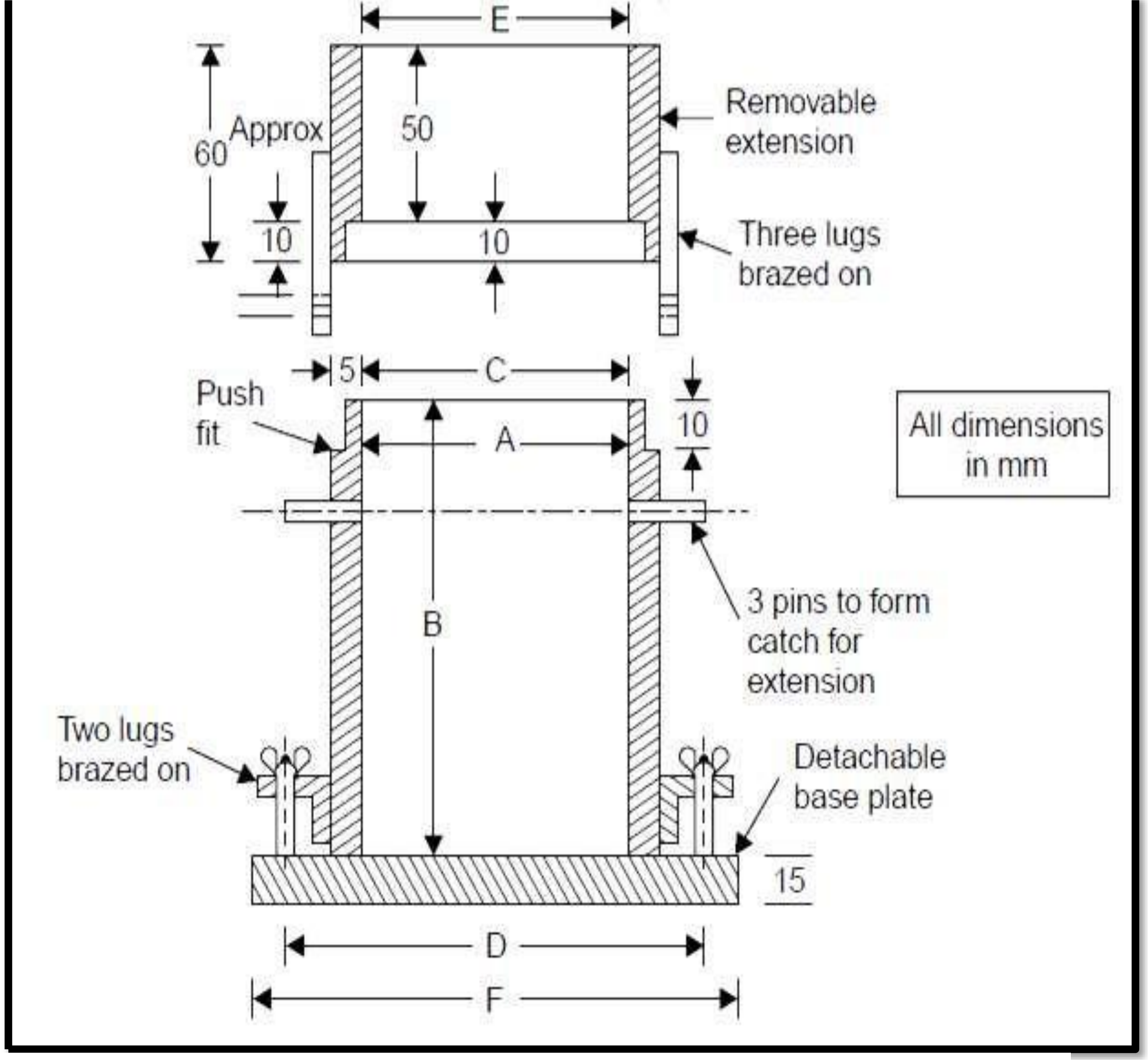
- The state at the peak is said to be that of 100% compaction at the particular compactive effort; the curve is usually of a hyperbolic form, when the points obtained from tests are smoothly joined.

LABORATORY COMPACTION TESTS

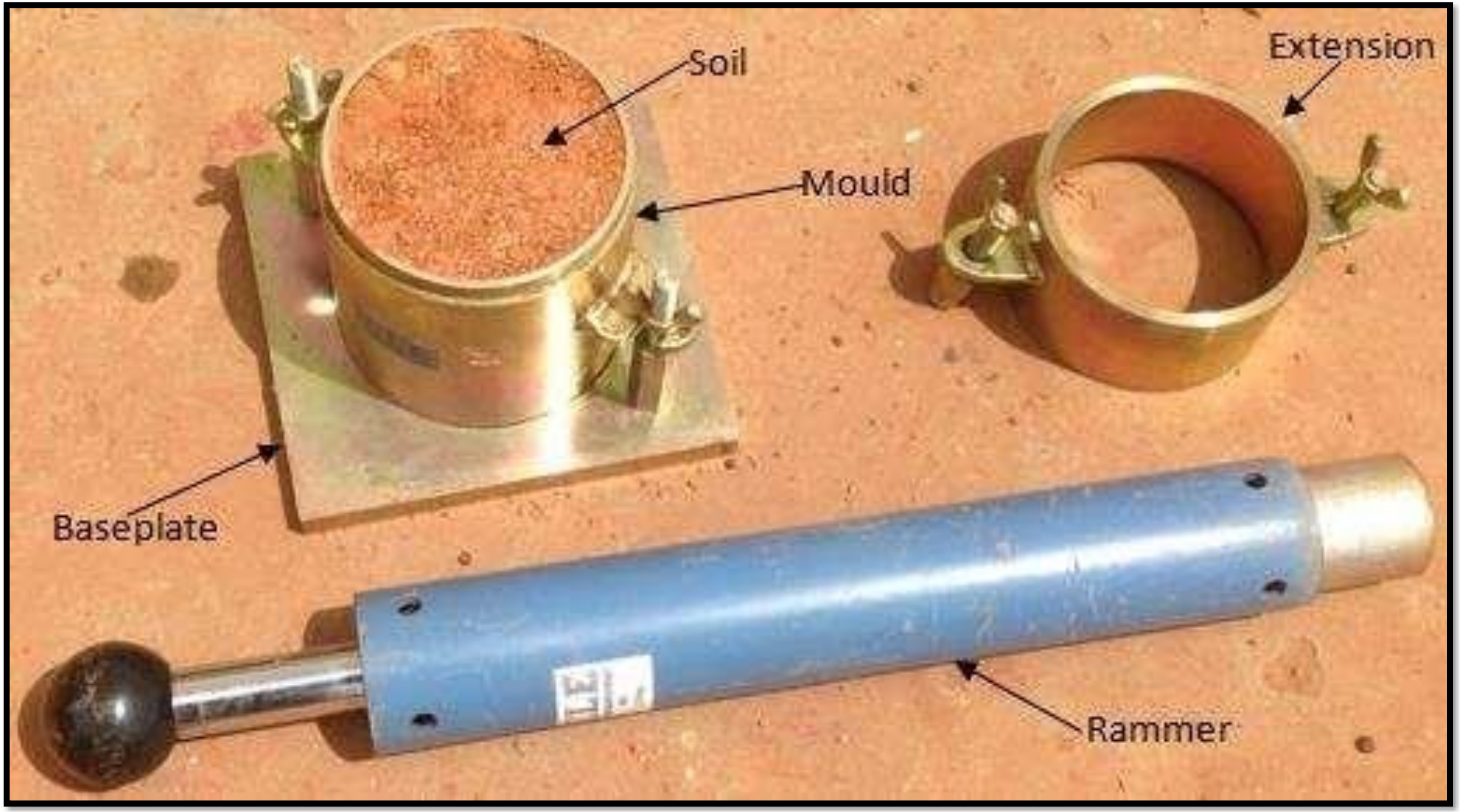
- The compaction characteristics, viz., maximum dry density and the optimum moisture content, are first determined in the laboratory.
- It is then specified that the unit weight achieved through compaction in the field should be a certain high percentage of the laboratory value, for quality control of the construction.
- The various procedures used in the laboratory compaction tests involve application of impact loads, kneading, static loads, or vibration.
- Some of the more important procedures covered are:
- Standard Proctor (AASHO) Test,
- Modified Proctor (Modified AASHO) Test,
- I.S. Compaction Test,
- Harvard Miniature Compaction Test,
- Dietert Test, Abbot's Compaction Test and
- Jodhpur Minicompacter Test.

Indian Standard Compaction Tests

- Indian Standards specify, among the methods of test for soils, procedures for compaction tests using light compaction [IS: 2720 (Part VII)—1983] and using heavy compaction [IS:2720 (Part VIII)—1983].
- For light compaction, a 26 N rammer falling through a height of 310 mm is used, while, for heavy compaction, 48.9 N. rammer falling through a height of 450 mm is used.
- Figure shows the details of typical mould for compaction for light compaction and for heavy compaction respectively.



Volume cm^3	*A dia.*	*B*	*C dia.*	*D*	*E dia*	*F*
1000	100	127.3	110	150	120	180ϕ or 150 sq.
2250	150	127.3	160	200	170	230ϕ or 200 sq.


Soil
Extension
Mould
Baseplate
Rammer

The Test Procedure Consists of the Following Steps:

- A representative sample weighting about 200N is taken.
- Enough water should be added to the specimen to bring its moisture content to about 7% (sandy soils) and 10% (clayey soils) less than the estimated optimum moisture content.
- The processed soils should be kept in an airtight tin for about 18 to 20 h to ensure thorough mixing of the water with the soil.
- The wet soil shall be compacted into the mould in three equal layers (five equal layers for heavy compaction), each layer being given 25 blows if the 100 mm diameter mould is used (or 56 blows if the 150-mm diameter mould is used) from the rammer weighing 26 N dropping from a height of 310 mm (from the rammer weighting 48.9 N dropping from a height of 450 mm, for heavy compaction).
- The rammer is pulled in the sleeve to the maximum height and then allowing it to fall freely. The position of the rammer is changed each time to distribute the compactive energy evenly to the soil. Each layer is raked with a spatula before placing fresh soil to provide proper bond.
- The collar is removed and the extra soil trimmed off to the top of the mould and the weight of the mould obtained. The wet weight (*W) of the soil is got by subtracting* the weight of the empty mould.

- The bulk unit weight (γ) of the soil is obtained by dividing the wet weight of soil by the volume of the soil (V) which is the same as that of the soil.
- $\gamma = W/V$
- A representative sample of the wet soil is taken and the moisture content (w%) determined in the standard manner through oven-drying.
- The dry unit weight (γ_d) is obtained as:

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

- The soil is broken with hand an remixed with increased water so that the moisture content increases by 2 to 4% nearly.
- The test is repeated with a least six different water contents. The wet weight of the soil itself gives an indication whether the number of readings is adequate or not, because it first increases with an increase in water content, up to a certain value, and thereafter decreases. The test must be done such that this peak is established.
- The moisture content-dry density curve, called the 'compaction curve' is drawn.
- The optimum moisture content and the corresponding maximum dry unit weight are read off from the graph.

SATURATION (ZERO-AIR-VOIDS) LINE

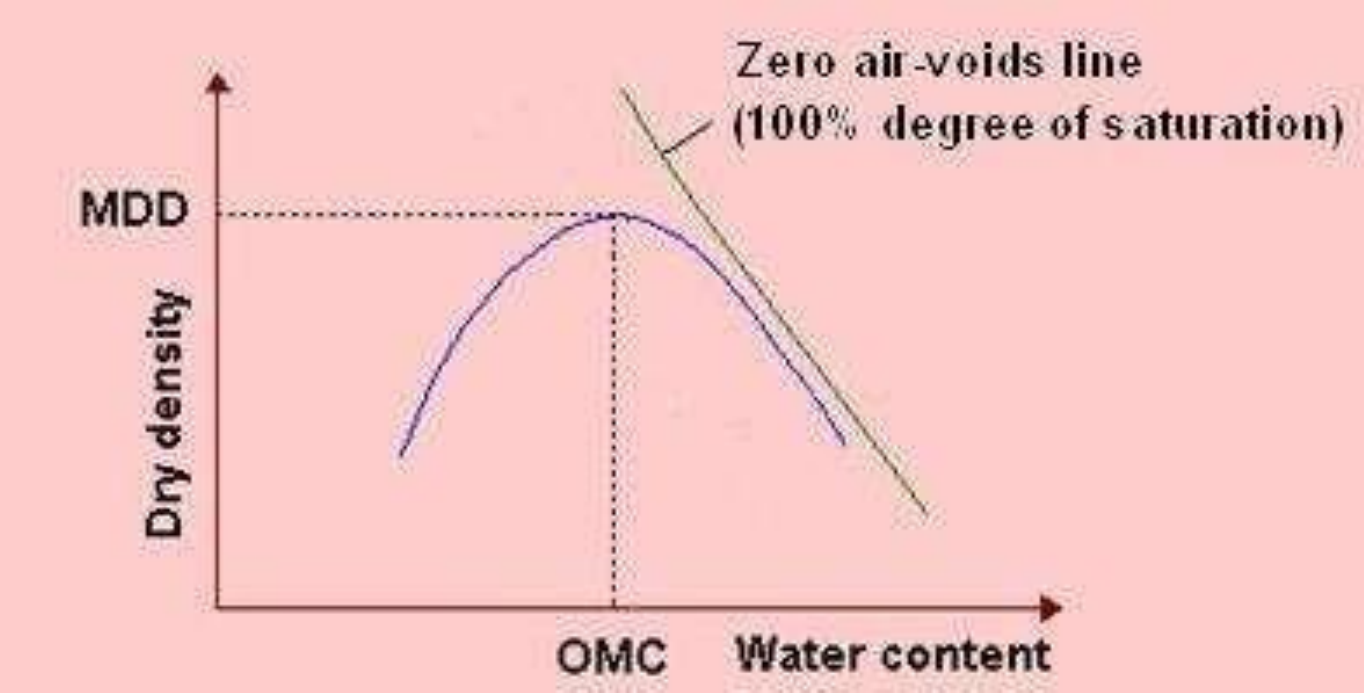
- A line showing the relation between water content and dry density at a constant degree of saturation S may be established from the equation:

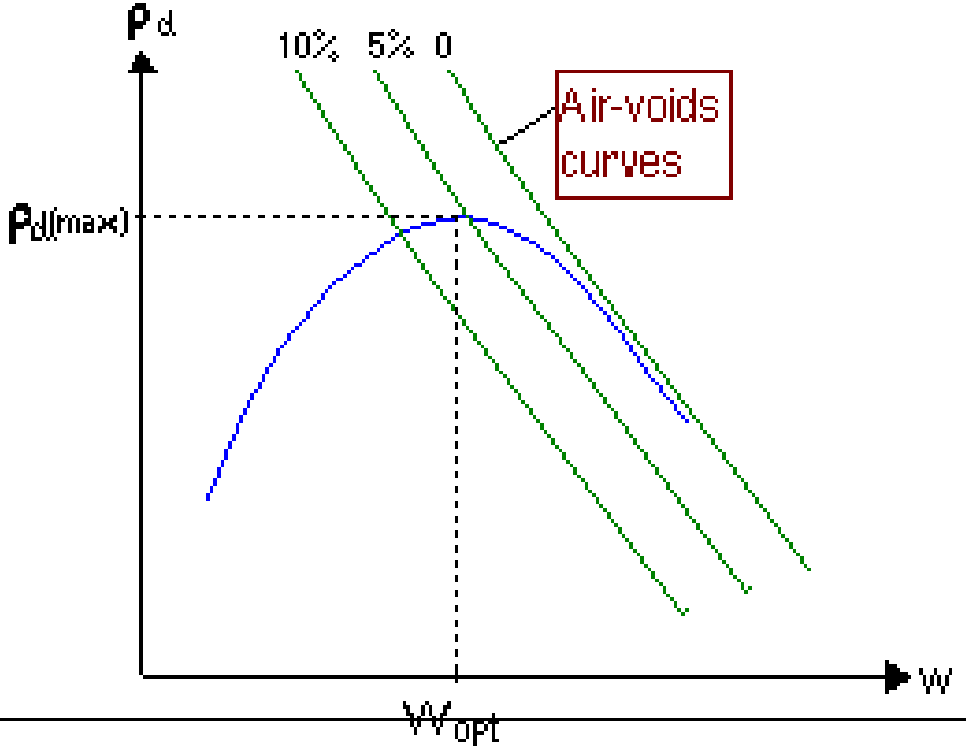
$$\gamma_d = \frac{G\gamma_w}{\left(1+\dfrac{wG}{S}\right)}$$

- Substituting S = 95%, 90%, and so on, one can arrive at γ_d-values for different values of water content in %. The lines thus obtained on a plot of γ_d versus w are called 95% saturation line, 90% saturation line and so on.
- If one substitutes S = 100% and plots the corresponding line, one obtains the theoretical saturation line, relating dry density with water content for a soil containing no air voids.
- It is said to be 'theoretical' because it can never be reached in practice as it is impossible to expel the pore air completely by compaction.

- We then use $\gamma_d = \dfrac{G\gamma_w}{\left(1+\dfrac{wG}{100}\right)}$ for this situation.

- or $\gamma_d = \dfrac{(1-n_a)G_s \cdot \gamma_w}{1+wG_s}$





Compactive Energy E applied to soil per unit volume

$$E = \frac{NnWh}{V}$$

- Compaction effort for light compaction

  = (25*3*26*0.31)/(1000) = 605 kJ/m^3
- Compaction effort for heavy compaction

  = (25*5*48.9*0.45)/(1000) = 2750 kJ/m^3

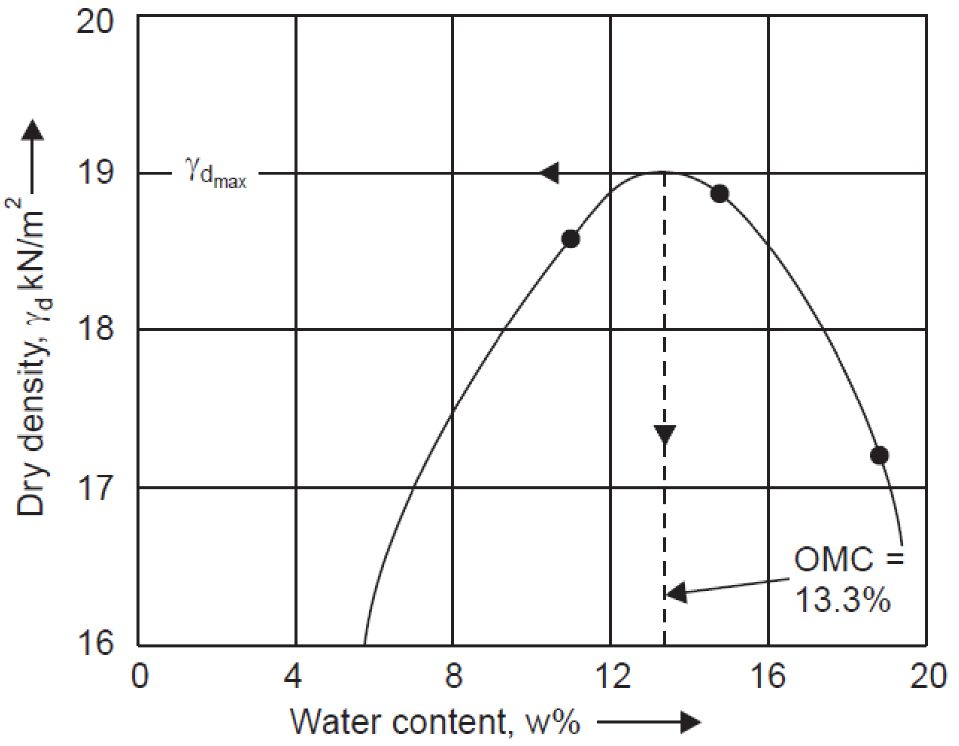
- N= No. of blows per layer
- n= No. of layers
- W= Hammer weight
- h= Height of drop
- V= Volume of mould

Example 1: 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 944 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.

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



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.

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

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

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

$$\therefore \qquad \text{Void ratio} = \mathbf{0.46}$$

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 2: 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.

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

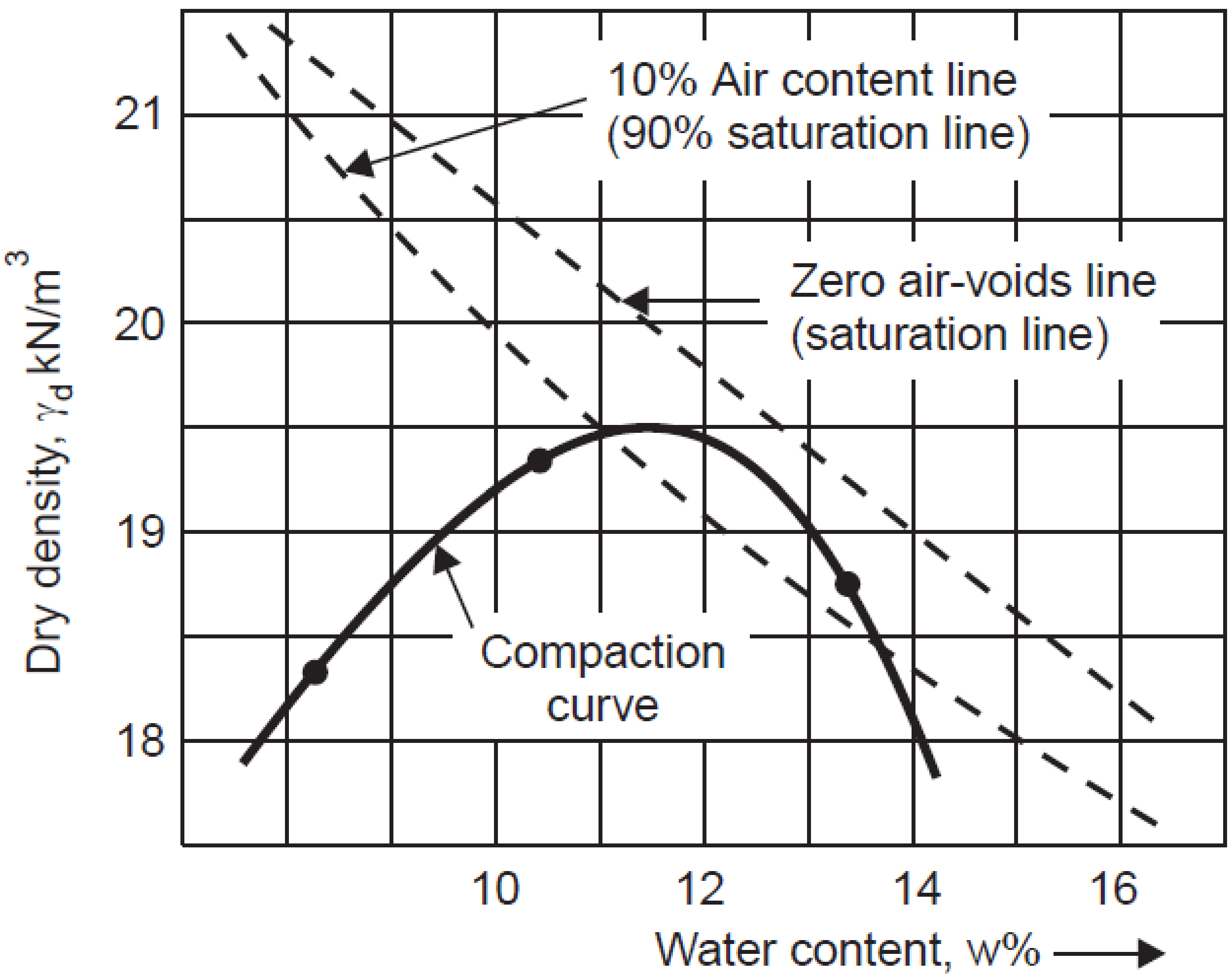
Since $\gamma_d = \dfrac{G.\gamma_w}{(1+e)} = \dfrac{G.\gamma_w}{\left(1+\dfrac{wG}{s}\right)} = \dfrac{2.65 \times 9.81}{\left(1+\dfrac{w \times 2.65}{s}\right)}$,

for Zero air-voids condition, $\gamma_d = \dfrac{2.65 \times 9.81}{\left(1+\dfrac{2.65 \times w}{100}\right)}$, w being in %, and for Ten per cent air-voids condition, $\gamma_d = \dfrac{2.65 \times 9.81}{\left(1 + \dfrac{2.65 \times w}{90}\right)}$, w being in %.

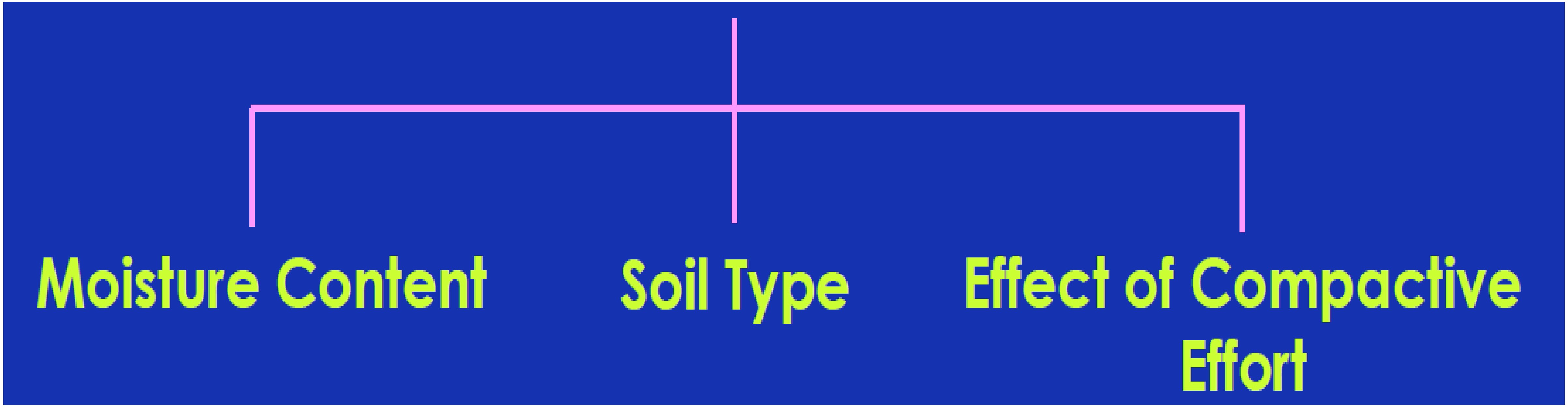
From these equations, the following values are computed:

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

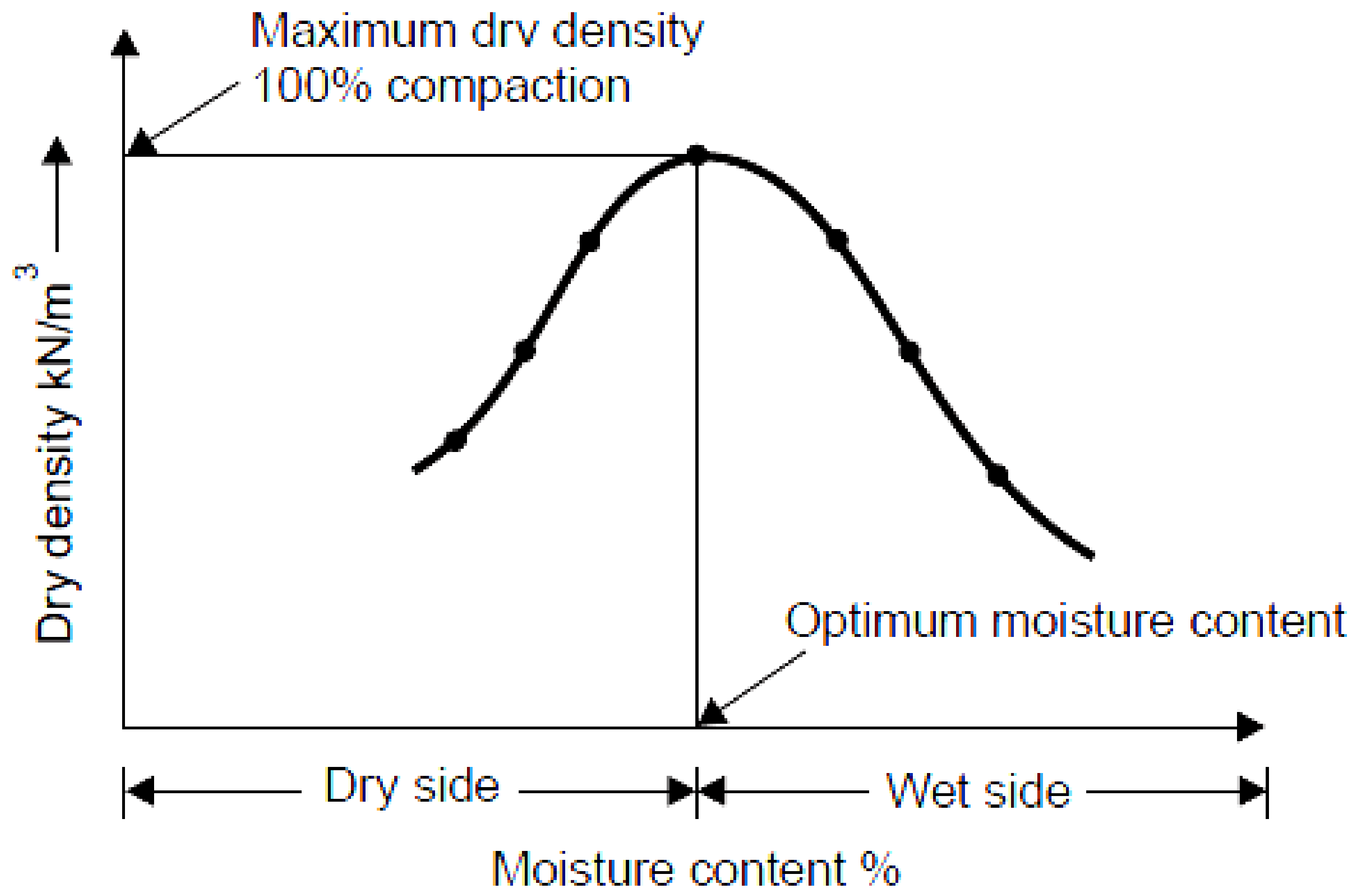


Factors affecting Compaction



Moisture Content

- Water content has significant effect on compaction characteristics of soil.
- At low water content, soil is stiff and soil grains offer more resistance to compaction. As the water content increases, water films are formed around the soil grains and water around the soil grains act as lubricant. Due to this, soil grains come close to each other and make a dense configuration. At optimum moisture content, soil reaches the maximum unit weight as lubrication effect is the maximum at this stage.
- Further addition of more water replaces the soil grains. Thus, addition of more water after optimum moisture content reduces the unit weight as unit weight of water is less than the unit weight of soil grains. Because of the addition of water dry unit weight of soil increases upto a certain water content value (OMC) and beyond that addition of more water decreases the dry unit weight of soil.
- This can be also explained by concept of soil structure and electrical double layer theory.


Maximum drv density
100% compaction
Dry density kN/m^3
Optimum moisture content
Dry side
Wet side
Moisture content %

At lower water content

- Vander Waal forces between two clay particles exist
- Adsorbed water layer around the clay particles is not fully developed
- Net force between the particles is attraction so flocculated structure would form, so more voids so mess density

At higher water content

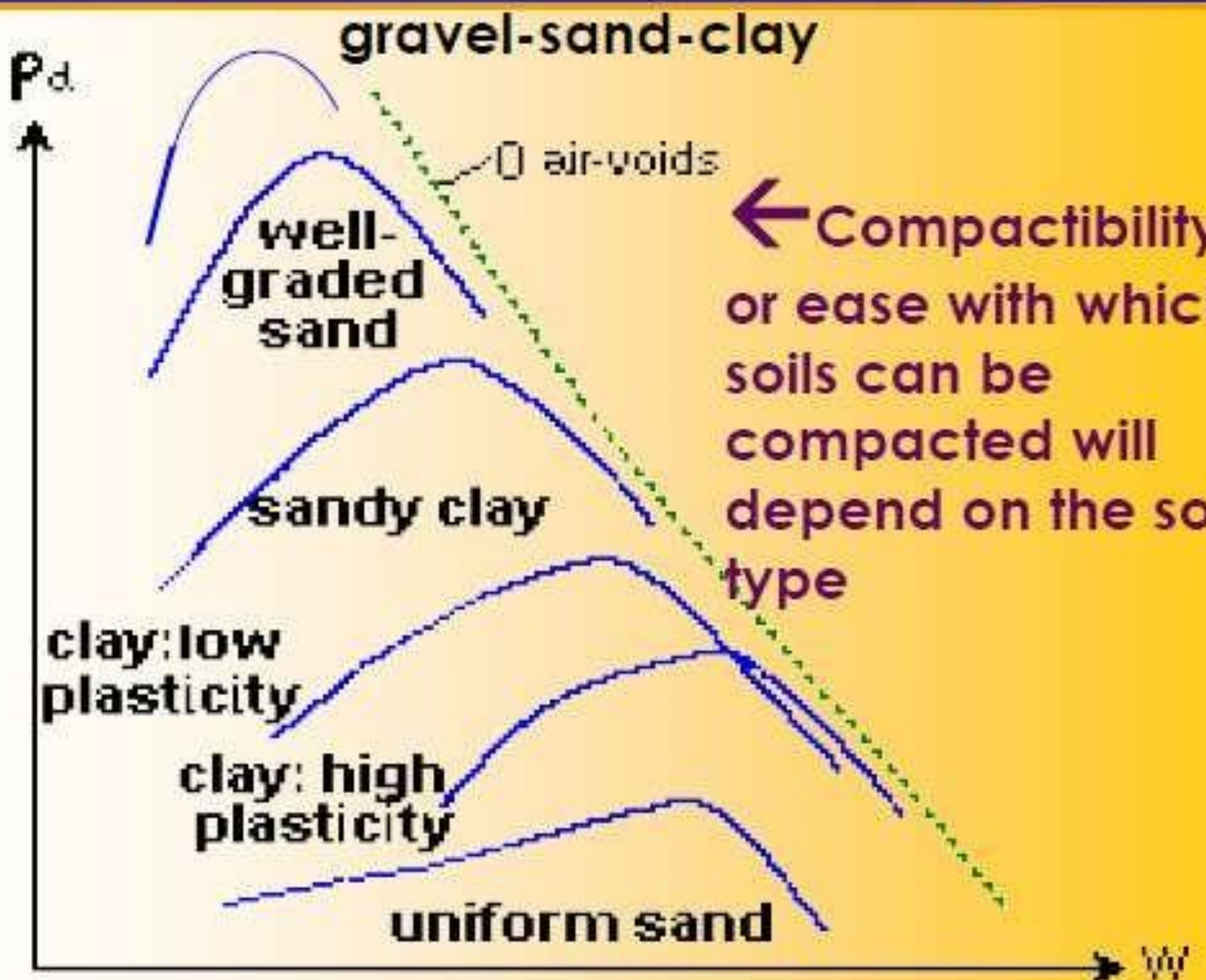
- Net force between the particles become repulsive
- Dispersive structure would form
- Void ratio decreases as the particles arranged in a particular manner

If we further increase the water content the place occupied by the soil particles will be replaced by water. Unit weight of water is less than the unit weight of solids, hence dry unit weight keeps decreasing.

Soil Type

- The soil type—that is, grain-size distribution, shape of the soil grains, specific gravity of soil solids, and amount and type of clay minerals present—has a great influence on the maximum dry unit weight and optimum moisture content. Figure shows typical compaction curves obtained from four soils.
- Note also that the bell-shaped compaction curve shown in Figure is typical of most clayey soils.
- For sands, the dry unit weight has a general tendency first to decrease as moisture content increases and then to increase to a maximum value with further increase of moisture.
- The initial decrease of dry unit weight with increase of moisture content can be attributed to the capillary tension effect. At lower moisture contents, the capillary tension in the pore water inhibits the tendency of the soil particles to move around and be compacted densely.
- At a given moisture content a clay with low plasticity will be stronger than a heavy or high plastic clay, as it will be easier to compact.

Compaction curve – effect of soil type

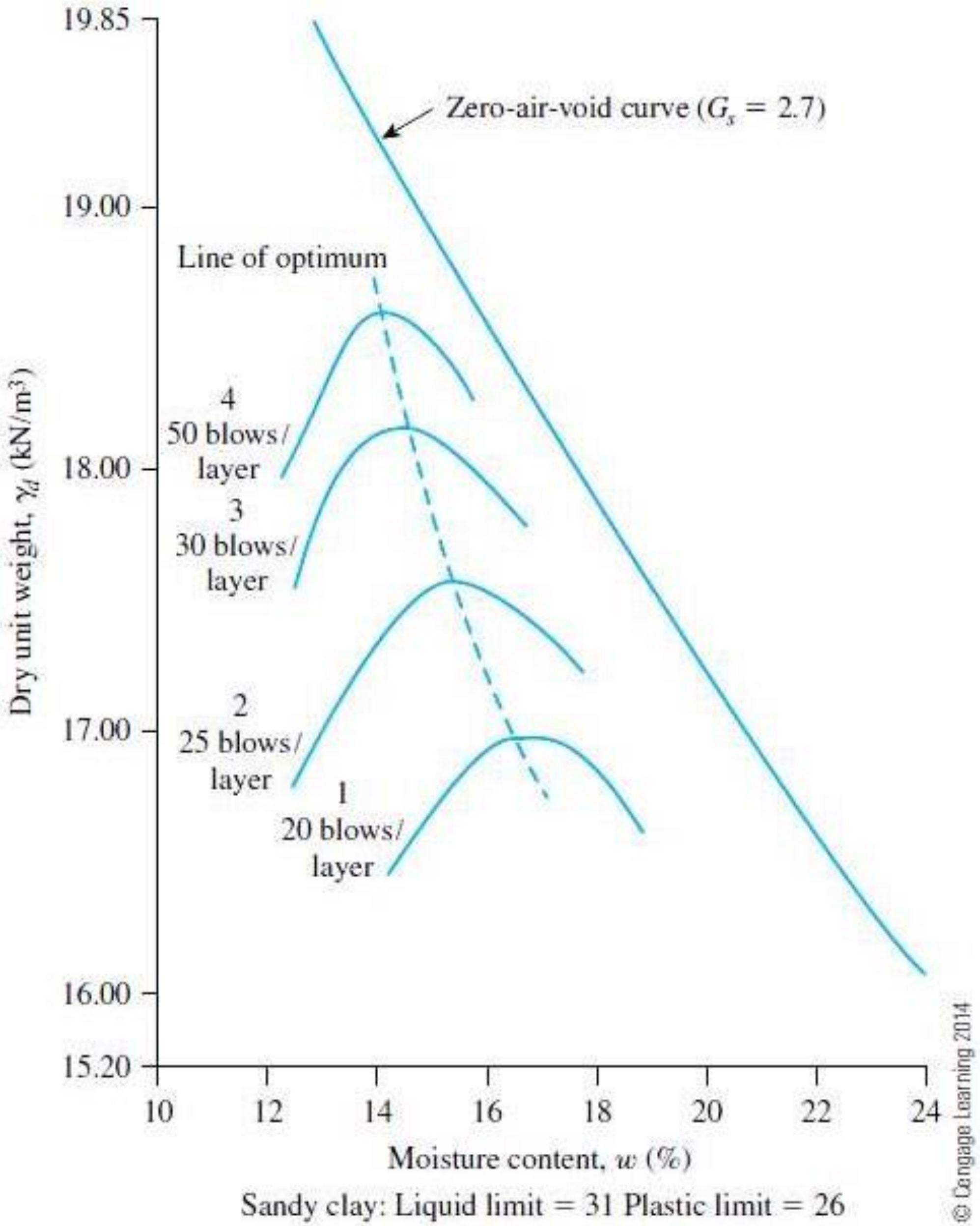


← Compactibility or ease with which soils can be compacted will depend on the soil type

Effect of Compactive Effort

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

- Maximum dry unit weight increases with increase in compactive effort.
- Increase in compactive effort decreases optimum moisture content to some extent.
- If the compaction effort per unit volume of soil is changed, the moisture–unit weight curve also changes.



Effect of Compactive Effort

- If a soil is already moist, weaker and above OMC then applying more energy is wasteful since air can quickly be removed. Applying large amounts of energy to a very moist soil may be damaging since no more air can be expelled but high pore water pressures can build up which could cause:
  - Slope Instability during construction
  - Consolidation settlements as they dissipate after construction.

IN-SITU OR FIELD COMPACTION

- In any type of construction job which requires soil to be used as a foundation material or as a construction material, compaction in-situ or in the field is necessary.
- The construction of a structural fill usually consists of two distinct operations—placing and spreading in layers and then compaction.
- The first part assumes greater significance in major jobs such as embankments and earth dams where the soil to be used as a construction material has to be excavated from a suitable borrow area and transported to the work site.
- In this phase large earth moving equipment such as self-propelled scrapers, bulldozers, graders and trucks are widely employed.

- The phase of compaction may be properly accomplished by the use of appropriate equipment for compaction.
- The thickness of layers that can be properly compacted is known to be related to the type of soil and method or equipment of compaction.
- Generally speaking, granular soils can be adequately compacted in thicker layers than fine-grained soils and clays; also, for a given soil type, heavy compaction equipment is capable of compacting thicker layers than light equipment.
- Although the principle of compaction in the field is relatively simple, it may turn out to be a complex process if the soil in the borrow area is not at the desired optimum moisture content for compaction.
- The existing moisture content is to be determined and water added, if necessary.
- Addition of water to the soil is normally done either during excavation or transport and rarely on the construction spot; however, water must be added before excavation in the case of clayey soils.
- In case the soil has more moisture content than is required for proper compaction, it has to be air-dried after excavation and compacted as soon as the desired moisture content is attained.

- Soil compaction or densification can be achieved by different means such as tamping action, kneading action, vibration, and impact.
- Compactors operating on the tamping, kneading and impact principle are effective in the case of cohesive soils, while those operating on the kneading, tamping and vibratory principle are effective in the case of cohesionless soils.
- The primary types of compaction equipment are: (*i) rollers, (ii) rammers and (iii) vibrators.* Of these, by far the most common are rollers.
- Rollers are further classified as follows:
- (*a) Smooth-wheeled rollers,*
- (*b) Pneumatic-tyred rollers,*
- (*c) Sheepsfoot rollers, and*
- (*d) Grid rollers.*
- Vibrators are classified as:
- (*a) Vibrating drum,*
- *(b) Vibrating pneumatic tyre*
- *(c) Vibrating* plate, and (*d) vibroflot.*

Rammers are classified as:

- *Dropping weight (including piling equipment)*
- *Internal combustion type*
- *Pneumatic type*

Equipment	Most suitable soils	Least suitable soils
Smooth steel drum rollers (static or vibratory)	Well-graded sand-gravel, crushed rock, asphalt	Uniform sands, silty sands, soft clays
Pneumatic tyred rollers	Most coarse and fine soils	Very soft clays
Sheepsfoot rollers	Fine grained soils, sands and gravels with > 20% fines	Uniform gravels, very coarse soils
Grid rollers	Weathered rock, well-graded coarse soils	Uniform materials, silty clays, clays
Vibrating plates	Coarse soils with 4 to 8% fines	
Tampers and rammers	All soil types	

a) Smooth-wheeled rollers:

- This type imparts static compression to the soil. There may be two or three large drums; if three drums are used, two large ones in the rear and one in the front is the common pattern.
- The compaction pressure are relatively low because of a large contact area. This type appears to be more suitable for compacting granular base courses and paving mixtures for highway and airfield work rather than for compacting earth fill. The relatively smooth surface obtained acts as a sort of a ‘seal’ at the end of a day’s work and drains off rain water very well.
- These rollers provide 100% coverage under the wheels, with ground contact pressures as high as 310 to 380 kN/m^2.
- They are not suitable for producing high unit weights of compaction when used on thicker layers. Suitable for gravels, sands, hardcore, crushed rock and any material where crushing action is needed.
- The number of passes varies with the desired compaction; usually eight passes may be adequate to achieve the equivalent of standard Proctor compaction.

(b) *Pneumatic-tyred rollers:*

- This type compacts primarily by kneading action. The usual form is a box or container—mounted on two axles to which pneumatic-tyred wheels are fitted; the front axle will have one wheel less than the rear and the wheels are mounted in a staggered fashion so that the entire width between the extreme wheels is covered.
- These are better in many respects than the smooth-wheel rollers. The former are heavily loaded with several rows of tires. These tires are closely spaced—four to six in a row. The contact pressure under the tires can range from 600 to 700 kN/m2, and they produce about 70 to 80% coverage.
- Pneumatic rollers can be used for sandy and clayey soil compaction. Compaction is achieved by a combination of pressure and kneading action.

- The number of passes required is similar to that with smooth wheeled-rollers.
- This type is suitable for compacting most types of soil and has particular advantages with wet cohesive materials.

(c) Sheeps foot rollers

- This type of roller consists of a hollow steel drum provided with projecting studs or feet; the compaction is achieved by a combination of tamping and kneading.
- The drum can be filled with water or sand to provide and control the dead weight. As rolling is done, most of the roller weight is imposed through the projecting feet.
- The area of each projection may range from 25 to 85 cm2. These rollers are most effective in compacting clayey soils. The contact pressure under the projections can range from 1400 to 7000 kN/m2.
- During compaction in the field, the initial passes compact the lower portion of a lift. Compaction at the top and middle of a lift is done at a later stage.
- This type of roller is found suitable for cohesive soils. It is unsuitable for granular soils as the studs tend to loosen these continuously. The tendency of void formation is more in soils compacted with sheepsfoot rollers.


HAMM


BOMAG


CAT CS-563

(d) Grid rollers:

- This type consists of rolls made from 38 mm steel bars at 130 mm centres, with spaces of 90 mm square.
- The weight of the roller ranges from 55 kN (5.5 t) to 110 kN (11 t).
- This is usually a towed unit which is suitable for many types of soil including wet clays and silts.

Vibrators

- These are vibrating units of the out-of-balance weight type or the pulsating hydraulic type. Such a type is highly effective for cohesionless soils. Behind retaining walls where the soil is confined, the backfill, much deeper in thickness, may be effectively compacted by vibration type of compactors.
- A few of this type are dealt with below:
- (a) Vibrating drum: A separate motor drives an arrangement of eccentric weights so as to cause a high-frequency, low-amplitude, vertical oscillation to the drum. Smooth drums as well as sheepsfoot type of drums may be used. Layers of the order of 1 metre deep could be compacted to high densities.
- (b) Vibrating pneumatic tyre: A separate vibrating unit is attached to the wheel axle. The ballast box is suspended separately from the axle so that it does not vibrate. A 300 mm thick layer of granular soil will be satisfactorily compacted after a few passes.

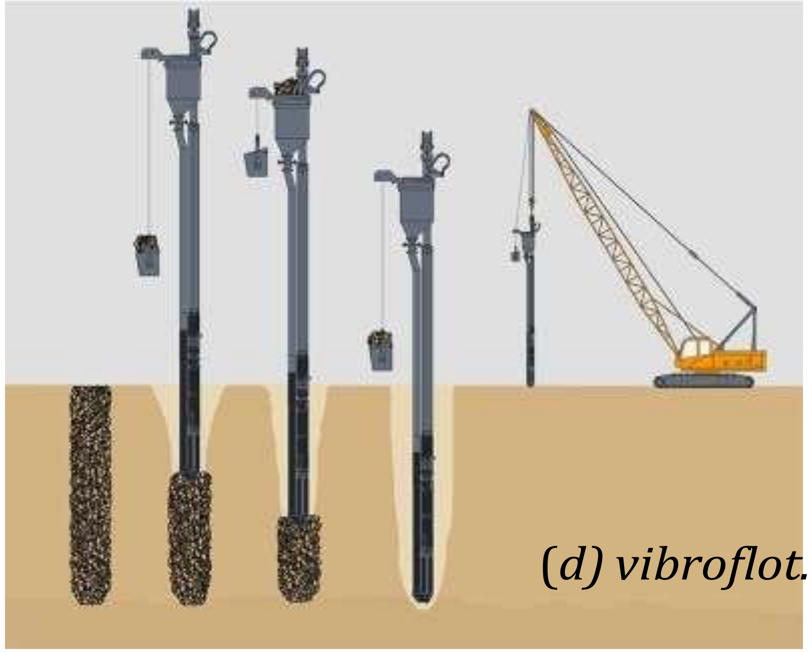
- (c) Vibrating plate: This typically consists of a number of small plates, each of which is operated by a separate vibrating unit. These have a limited depth of effectiveness and hence are used in compacting granular base courses for highway and airfield pavements.
- (d) Vibroflot: A method suited for compacting thick deposits of loose sandy soil is called the 'vibroflotation' process. The improvement of density is restricted to the surface zone in the case of conventional compaction equipment. The vibroflotation method first compacts deep zone in the soil and then works its way towards the surface. A cylindrical vibrator weighing about 20 kN (2 t) and approximately 400 mm in diameter and 2 m long, called the 'Vibroflot', is suspended from a crane and is jetted to the depth where compaction is to start.

Vibrators are classified as:
(a) Vibrating drum,
(b) Vibrating pneumatic tyre
(c) *Vibrating* plate, and
(d) vibroflot.

(a) Vibrating drum,

(c) *Vibrating* plate

(b) Vibrating pneumatic tyre



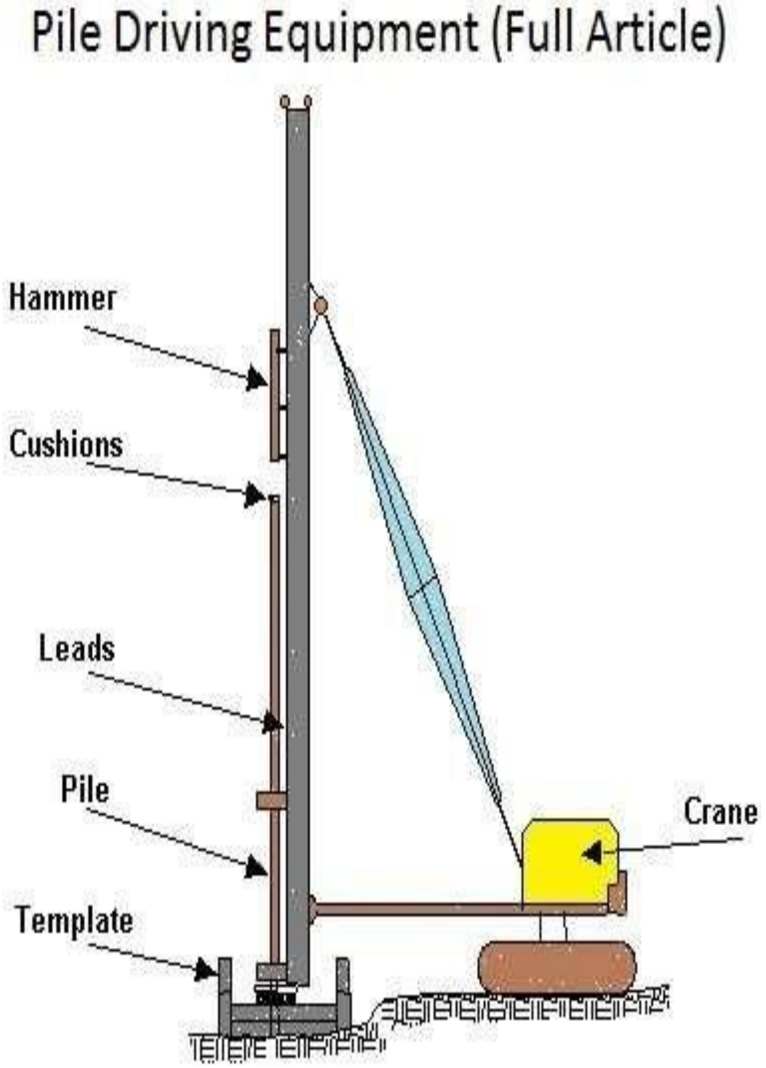
(d) vibroflot.

Rammer is light weight compaction equipment used for compacting small areas by providing impact load to the soil. This compaction equipment is light and can be hand operated or machine operated. Rammers are most suitable for cohesive and semi-cohesive soils. Due to light weight, it is used for interior floor compaction. It is also used for repair of road, shoulders, pavements, highways and streets.

Rammers are classified as:

- *Dropping weight (including piling equipment)*
- *Internal combustion type*
- *Pneumatic type*

•Rammer is small size and light weight equipment. Its base dimensions all 15 cm x 15 cm or 20 cm x 20 cm or more.
•In the case of machine operated rammers, the weights of the rammers vary from 30 kg to 1 tonnes.
•Rammers delivers a high impact force on the soils. Frequency range is 500 to 750 blows per minute.
•Rammers gets compaction force from a small gasoline or diesel engine powering a large piston set with two sets of springs. Rammer compacts the surface through impact and vibration.
•Internal combustion type has frog hammer weighing up to 1 tonne. A frog hammer compacts relatively thick layer of non-cohesive soils. The thickness of layer compacted depends on the size of the base dimension of the rammer. Rammers are generally used in that place where rollers or other heavy compaction equipment are not able to operate, places like trenches and behind the bridge abutment.


Pile Driving Equipment (Full Article)
Hammer
Cushions
Leads
Pile
Template
Crane

1

2

3

EFFECT OF COMPACTION ON PROPERTIES OF SOIL

1. PERMEABILITY

- The effect of compaction is to decrease the permeability. In the case of fine grained soils it has been found that for the same dry density soil compacted wet of optimum will be less permeable than that of compacted dry of optimum.

2. COMPRESSIBILITY

- In case of soil samples initially saturated and having same void ratio, it has been found that in low pressure range a wet side compacted soil is more compressible than a dry side compacted soil, and vice versa in high pressure range.

3. PORE PRESSURE

- In undrained shear test conducted on saturated samples of clay it has been found that lower pore pressures develop at low strains when the sample is compacted dry of optimum, compared to the case when the sample is compacted wet of optimum. But at high strains in both types of samples the development of pore pressure is same for same density and water content.

EFFECT OF COMPACTION ON PROPERTIES OF SOIL

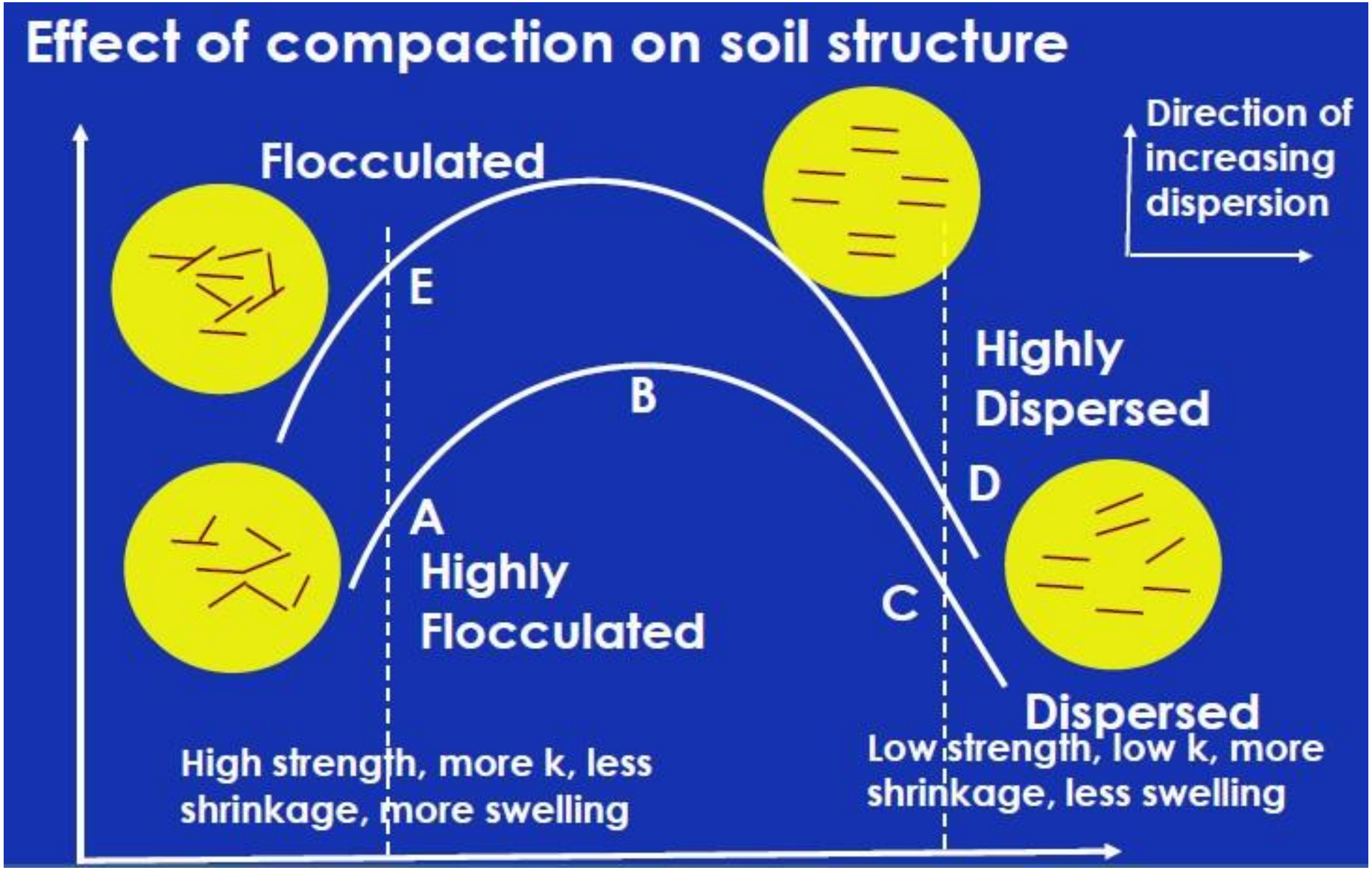
4. STRESS-STRAIN RELATION

- Samples compacted dry of optimum produce much steeper stress-strain curves with peaks at low strains, whereas samples compacted wet of optimum, having the same density, produce much flatter stress-strain curves with increase in stress even at high strains.

5. SHRINKAGE AND SWELLING

- At same density a soil compacted dry of optimum shrinks appreciably less than that of compacted wet of optimum. Also the soil compacted dry of optimum exhibits greater swelling characteristics than samples of the same density compacted wet of optimum.

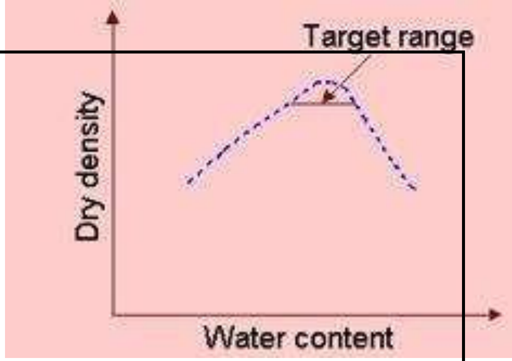
6. Effect of Soil Structure:



Effect of compaction on soil structure

1. At low water contents, attractive forces between clay particles predominate, creating a more or less random orientation of plate like particles. (results in low density)
2. The addition of water increases repulsion between particles leading them to assume more parallel orientation near OMC.
3. If compacted wet of optimum parallel orientation is further increased leading to what is described as dispersed structure.

Field compaction and specifications



- To control soil properties in the field during earthwork construction, it is usual to specify the **degree of compaction** (also known as the **relative compaction**).
- This specification is usually that a certain percentage of the maximum dry density, as found from a laboratory test (Light or Heavy Compaction), must be achieved.
- For example, it could be specified that field dry densities must be greater than 95% of the maximum dry density (MDD) as determined from a laboratory test.
- Target values for the range of water content near the optimum moisture content (OMC) to be adopted at the site can then be decided, as shown in the figure.
- For this reason, it is important to have a good control over moisture content during compaction of soil layers in the field.
- It is then up to the field contractor to select the thickness of each soil lift (layer of soil added) and the type of field equipment in order to achieve the specified amount of compaction.
- The standard of field compaction is usually controlled through either end-product specifications or method specifications.

End-Product Specifications

$$\text{Relative compaction} = \frac{\text{Achieved field dry density}}{\text{Laboratory maximum dry density}}$$

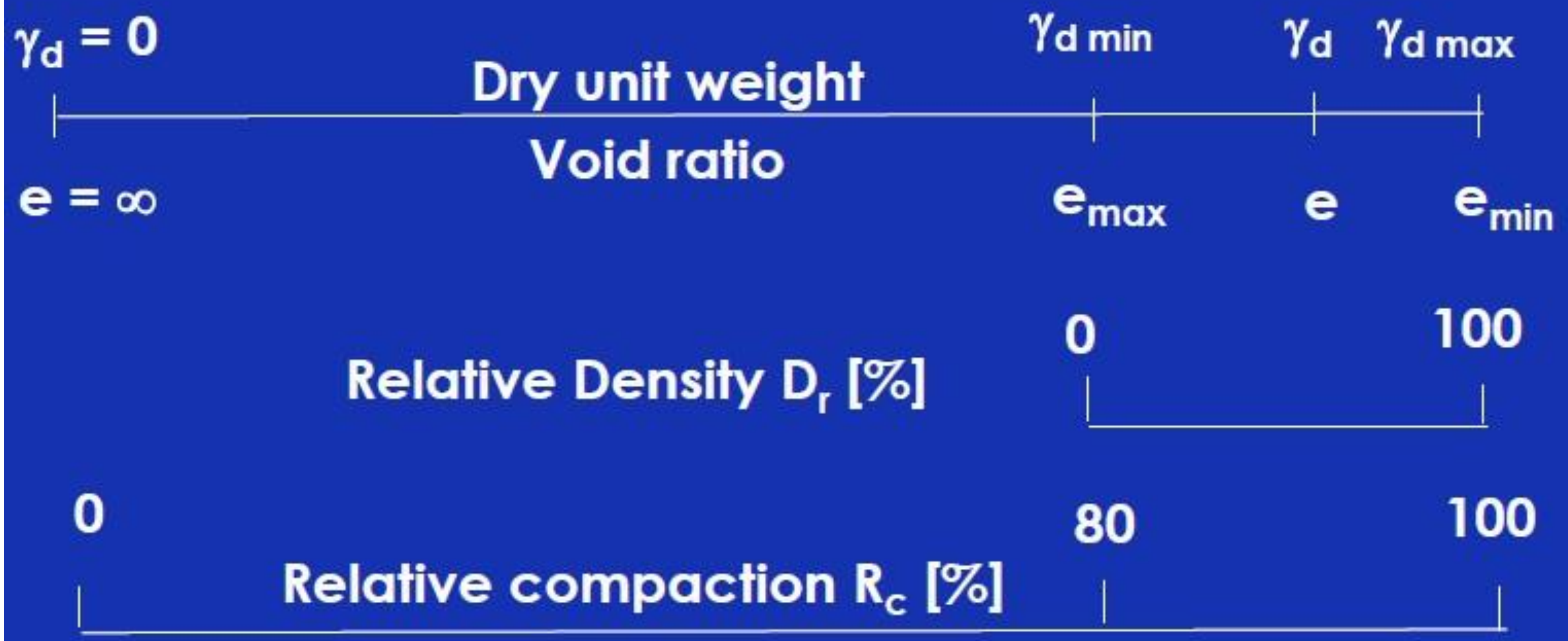
- In end-product specifications, the required field dry density is specified as a percentage of the laboratory maximum dry density, usually 90% to 95%. The target parameters are specified based on laboratory test results.
- Relative compaction is defined as the ratio of field dry unit weight $(\gamma_d)_f$ to the laboratory maximum dry unit weight $(\gamma_d)_{max}$, according to some specified standard test.
- The field water content working range is usually within ± 2% of the laboratory optimum moisture content.

  It is necessary to control the moisture content so that it is near the chosen value. From the borrow pit, if the soil is dry, water is sprinkled and mixed thoroughly before compacting. If the soil is too wet, it is excavated in advance and dried.
- In the field, compaction is done in successive horizontal layers. After each layer has been compacted, the water content and the in-situ density are determined at several random locations. These are then compared with the laboratory OMC and MDD using either of these two methods: the sand replacement method, or the core cutter method.

Method Specifications

- A procedure for the site is specified giving:
- Type and weight of compaction equipment
- Maximum soil layer thickness
- Number of passes for each layer
- They are useful for large projects. This requires a prior knowledge of working with the borrow soils to be used.

Field compaction and specifications



A relationship between RD and RC…

Relative Compaction

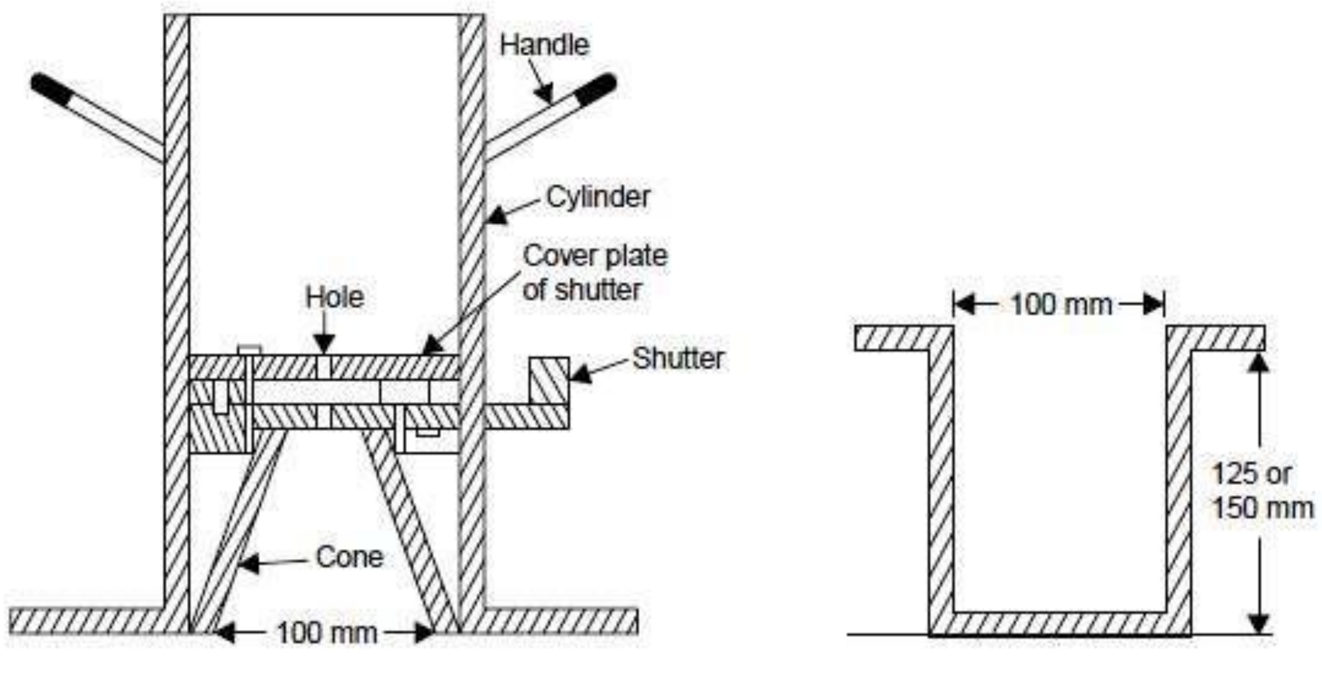
Type of project	Required R_C ,%
Fills to support buildings or roadways	90
Top 150 mm of subgrade below roadways	95
Aggregate base material below roadways	95
Earth dams	100

Determination of Field Unit Weight of Compaction

- When the compaction work is progressing in the field, knowing whether the specified unit weight has been achieved is useful. The standard procedures for determining the field unit weight of compaction include
- 1. Sand cone method/ Sand Replacement method/ Core cutter method
- 2. Rubber balloon method
- 3. Nuclear method (Non- destructive)
- 4. Proctor needle method

Sand Replacement method IS–2720 (Part XXVIII)

- The principle of the sand replacement method consists in obtaining the volume of the soil excavated by filling in the hole in-situ from which it is excavated, with sand, previously calibrated for its unit weight, and thereafter determining the weight of the sand required to fill the hole.
- The apparatus consists of the sand pouring cylinder, tray with a central circular hole, container for calibration, balance, scoop, etc.



(a) Sand-pouring cylinder

(b) Calibrating container

- The procedure consists of calibration of the cylinder and later, the measurement of the unit weight of the soil.
- (a) **Calibration of the Cylinder and Sand:** This consists in obtaining the weight of sand required to fill the pouring cone of the cylinder and the bulk unit weight of the sand. Uniformly graded, dry, clean sand is used. The cylinder is filled with sand almost to be top and the weight of the cylinder with the sand is taken (W_1).
- The sand is run out of the cylinder into the conical portion by pulling out the shutter. When no further sand runs out, the shutter is closed. The weight of the cylinder with the remaining sand is found (W_2). The weight of the sand collected in the conical portion may also be found separately for a check (W_c), which should be equal to ($W_1 - W_2$).
- The cylinder is placed centrally above the calibrating container such that the bottom of the conical portion coincides with the top of the container. There sand is allowed to run into the container as well as the conical portion until both are filled, as indicated by the fact that no further sand runs out; then the shutter is closed. The weight of the cylinder with the remaining sand is found (W_3).

•The weight of the sand filling the calibrating container (W_{cc}) may be found by deducting the weight of sand filling the conical portion (W_c) from the weight of sand filling this and the container ($W_2 – W_3$). Since the volume of the cylindrical calibrating container (V_{cc}) is known precisely from its dimensions, the unit weight of the sand may be obtained by dividing the weight W_{cc}, by the volume V_{cc}.

•The observations and calculations relating to this calibration part of the work will be as follows:

•Initial weight of cylinder + sand = W_1

•Weight of cylinder + said, after running sand into the conical portion = W_2

•∴ Weight of sand occupying conical portion, $W_c = (W_1 – W_2)$

•Weight of cylinder + sand, after running sand into the conical portion and calibrating container = W_3

•∴ Weight of sand occupying conical portion and calibrating container = $(W_2 – W_3)$

•∴ Weight of sand filling the calibrating container,

•$W_{cc} = (W_2 - W_3) - W_c = (W_2 - W_3) - (W_1 - W_2) = (2W_2 - W_1 - W_3)$

•Volume of the calibrating container = V_{cc}

•∴ Unit weight of the sand:

$$\gamma_s = \frac{W_{cc}}{V_{cc}}$$

- (b) Measurement of Unit Weight of the Soil: The site at which the in-situ unit weight is to be determined is cleaned and levelled. A test hole, about 10 cm diameter and for about the depth of the calibrating container (15 cm), is made at the site, the excavated soil is collected and its weight is found (W).
- The sand pouring cylinder is filled with sand to about 3/4 capacity and is placed over the hole, after having determined its initial weight with sand (W_4), and the sand is allowed to run into it. The shutter is closed when not further movement of sand takes place. The weight of the cylinder and remaining sand is found (W_5). The weight of the sand occupying the test hole and the conical portion will be equal to ($W_4 - W_5$).
- The weight of the sand occupying the test hole, Ws, will be obtained by deducting the weight of the sand occupying the conical portion, W_c, from this value. The volume of the test hole, V, is then got by dividing the weight, W_s, by the unit weight of the sand.
- The in-situ unit weight of the soil, γ, is then obtained by dividing the weight of the soil, W, by its volume, V. If the moisture content, w, is also determined, the dry unit weight of the soil, γ_d, is obtained as

- Thus, the observations and calculations for this part may be set out as follows:

Initial weight of cylinder + sand $= W_4$

Weight of cylinder + sand, after running sand into the test hole and the conical portioin $= W_5$

$\therefore$ Weight sand occupying the test hole and the conical portion $= (W_4 - W_5)$

$\therefore$ Weight of sand occupying the test hole, $W_s = (W_4 - W_5) - W_c$

$$= (W_4 - W_5) - (W_1 - W_2)$$

Volume of test hole, $$V = \frac{W_s}{\gamma_s}$$

In-situ unit weight of the soil, $= W/V$

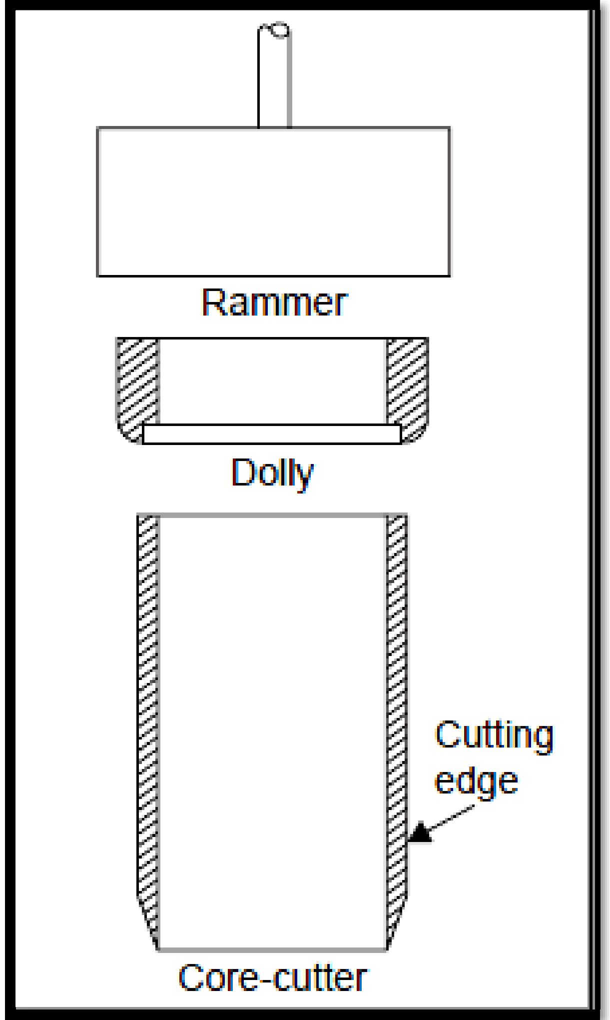
Dry unit weight, $\gamma_d = \gamma/(1 + w)$,

where, w = water content (fraction).

Rubber Balloon Method: In an alternative approach, the volume of the test hole may be determined more directly by inflating a rubber balloon into the hole, making it fit the hole snugly, and reading off the fall in water level in a graduated Lucite cylinder which is properly connected to the balloon.

Core-cutter Method IS: 2720 (Part XXIX)

- The apparatus consists of a mild steel-cutting ring with a dolly to fit its top and a metal rammer
- The core-cutter is 10 cm in diameter and 12.5 cm in length. The dolly is 2.5 cm long.
- The bottom 1 cm of the ring is sharpened into a cutting edge.
- The empty weight (W_1) of the corecutter is found.
- The core-cutter with the dolly is rammed into the soil with the aid of a 14-cm diameter metal rammer.
- The ramming is stopped when the top of the dolly reaches almost the surface of the soil.



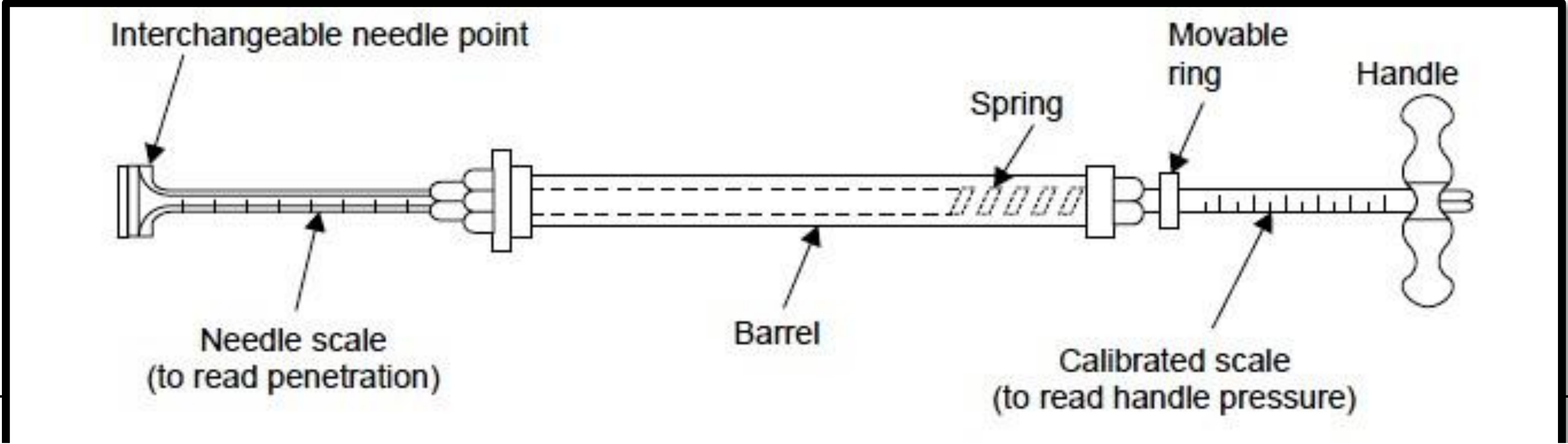
- The soil around the cutter is excavated to remove the cutter and dolly full of soil, from the ground.
- The dolly is also removed later, and the soil is carefully trimmed level with the top and bottom of the core-cutter.
- The weight of the core-cutter and the soil is found (W_2). The weight of the soil in the core-cutter, W, is then got as (W_2 – W_1). The volume of this soil is the same as that of the internal volume of the cutter, V, which is known.
- The in-situ unit weight of the soil, γ, is given by W/V. If the moisture content, w, is also found, the dry-unit weight, γ_d, may be found as

$$\gamma_d = \gamma/(1 + w).$$

- This method is suitable for soft cohesive soils. It cannot be used for stiff clays, sandy soils and soils containing gravel particles, which could damage the cutting edge.

Proctor Needle method

- The Proctor needle approach is an efficient and fast one for the simultaneous determination of in-situ unit weight and in-situ moisture content, it is also called 'penetration needle'.
- The apparatus basically consists of a needle attached to a spring-loaded plunger through a shank. An array of interchangeable needle tips is available, ranging from 6.45 to 645 mm^2, to facilitate the measurement of a wide range of penetration resistance values.
- A calibration of penetration against dry unit weight and water content is obtained by pushing the needle into specially prepared samples for which these values are known and noting the penetration.



- The penetration of the needle and the penetration resistance (load applied) may be shown on a graduated scale on the shank and the stem of handle respectively.
- The procedure for the use of the Proctor ‘plasticity’ needle, as it is called, is obvious.
- The spring-loaded plunger is pressed into the compacted layer in the field with an appropriate plasticity needle.
- The penetration resistance is recorded for a standard depth of penetration at a standard time-rate of penetration.
- Against this penetration resistance, the corresponding values of water content and dry unit weight are obtained from the calibration curve.
- The size of the needle to be chosen depends upon the type of soil such that the resistance to be read is neither too large nor too small.