SOIL COMPACTION

Introduction

- The soil is used as a fill material for many civil engineering projects
- When ever soil is placed as a fill, it is in loose form.
- So it has to be compacted to a dense state to obtain the required engineering properties.
- Compaction in field is usually is obtained by mechanical means, such as roller ramming or by vibration.
- **Compaction**
- It may be defined as the process of bringing soil particles closer to a dense state by mechanical means.
- The voids are reduced due to expulsion of air, the particles are packed close to each other. Thus unit weight is increased.
- During compaction there is no significant change in the volume of water
- Higher the degree of compaction higher will be the shear strength and hence greater will be the stability and bearing capacity.
- Compaction is also done to reduce the compressibility, shrinkage, frost susceptibility and permeability of soil
- For the compaction of deep soil layers to decrease settlement **"Vibrofloat"** and dynamic compaction methods is used

Introduction

- For indoor and small compaction areas rammers or tempers vibrating plates are commonly employed.
- Roller is used when large areas are involved
- Cohesive soil is compacted with the help of roller, while non cohesive soil with the help of vibrators

Use of Soil as a Fill

- The soil is used as a fill material for following purpose
- To back fill an excavation, e.g. for foundation
- To develop a mad up ground to support structure.
- As a sub-grade, sub-base for roads, railways and airfield
- As an earth Dam
- To raise the floor level.
- Back fill behind retaining wall

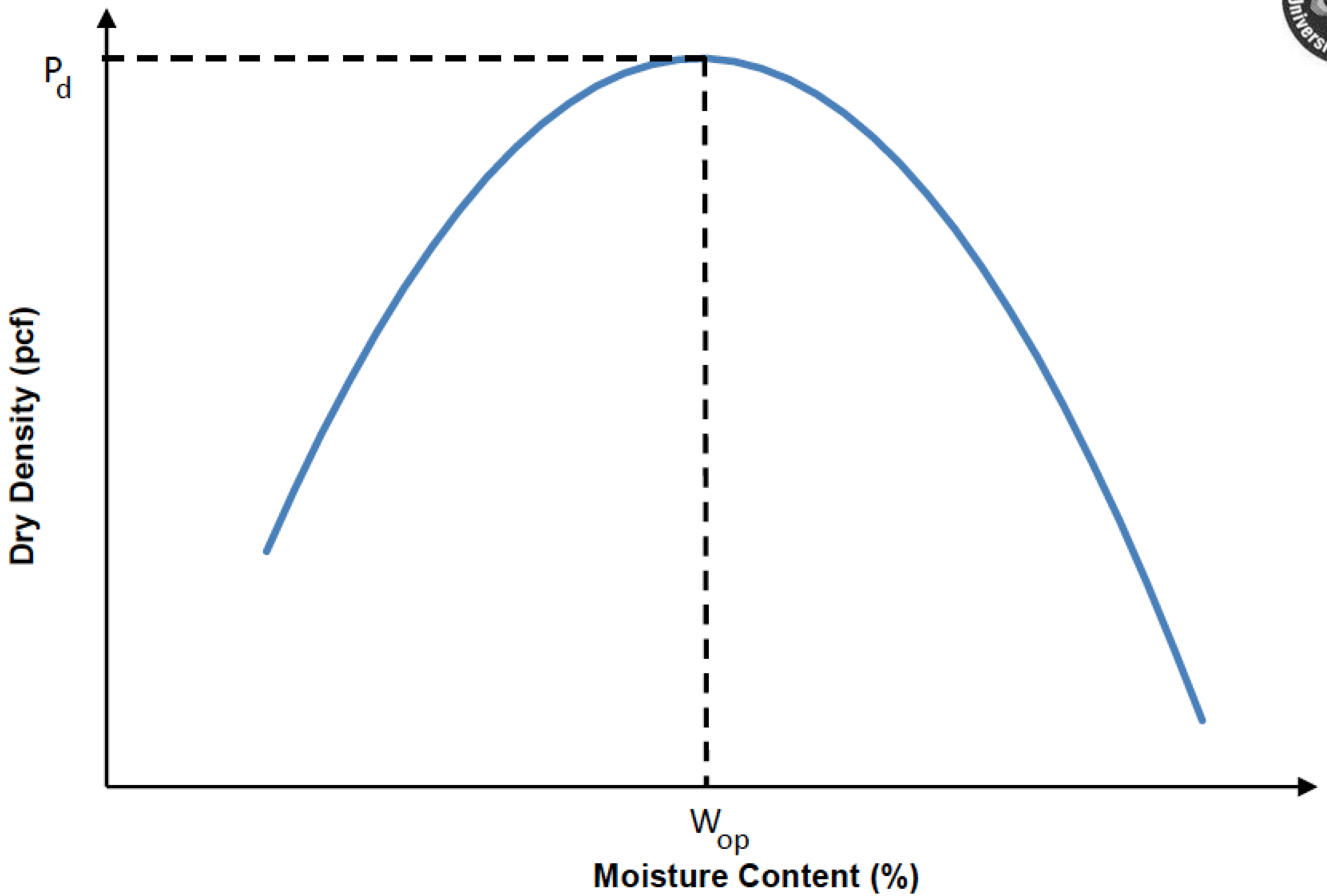
Objective if Compaction

- To increase the shear strength
- It provides higher bearing capacity for foundation support
- To lower the compressibility and hence small the settlement
- To lower the permeability
- To reduce the frost susceptibility
- To reduce the degree of shrinkage

Factors Affecting Compaction of Soil

1. Moisture Content
2. Compaction Effort
3. Soil Type
4. Method of Compaction
5. Admixture

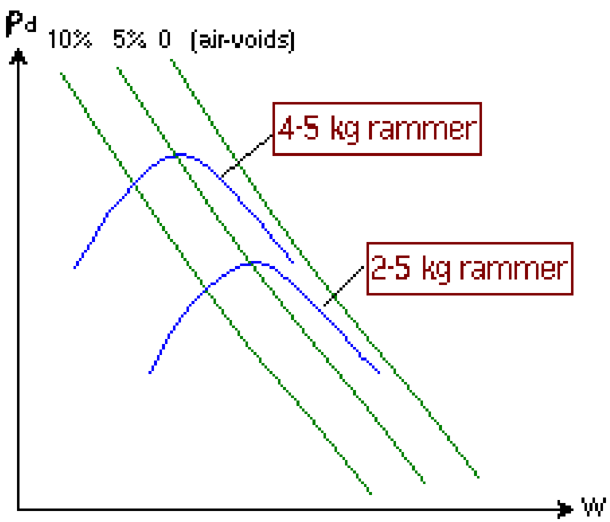
- **Moisture Content**
- Moisture content is the most important factor, which greatly influence the compaction of soil.
- For given amount of compaction, there exist for each soil a moisture content, known as Optimum Moisture Content (OMC), at which the dry density of soil is maximum
- At low moisture content soil is stiff and difficult to compact, thus low density high air content is obtained by compaction.
- When water is added to the soil, it acts as a lubricant causing the soil to soften and become more workable.
- Due to film of water around the soil particles the slide one an other more easily and packed in to more densely position. This result in high density and low moisture content



Pd
Dry Density (pcf)
Wop
Moisture Content (%)

Factors Affecting Compaction of Soil

- For the same compaction energy, dry density increases with increase in moisture content.
- This occur up to the optimum moisture content (OMC).
- Beyond the (OMC) the film of moisture around the soil particle increases which tend to keep particles apart and causes the dry density to fall
- **Compaction Effort/Energy**
- Compaction effort means the mechanical energy applied to the soil mass for densification.
- Irrespective of soil type and method of compaction, an increase in the amount of compaction result in increase in the maximum dry density and decrease in (OMC) as shown in Fig



Factors Affecting Compaction of Soil

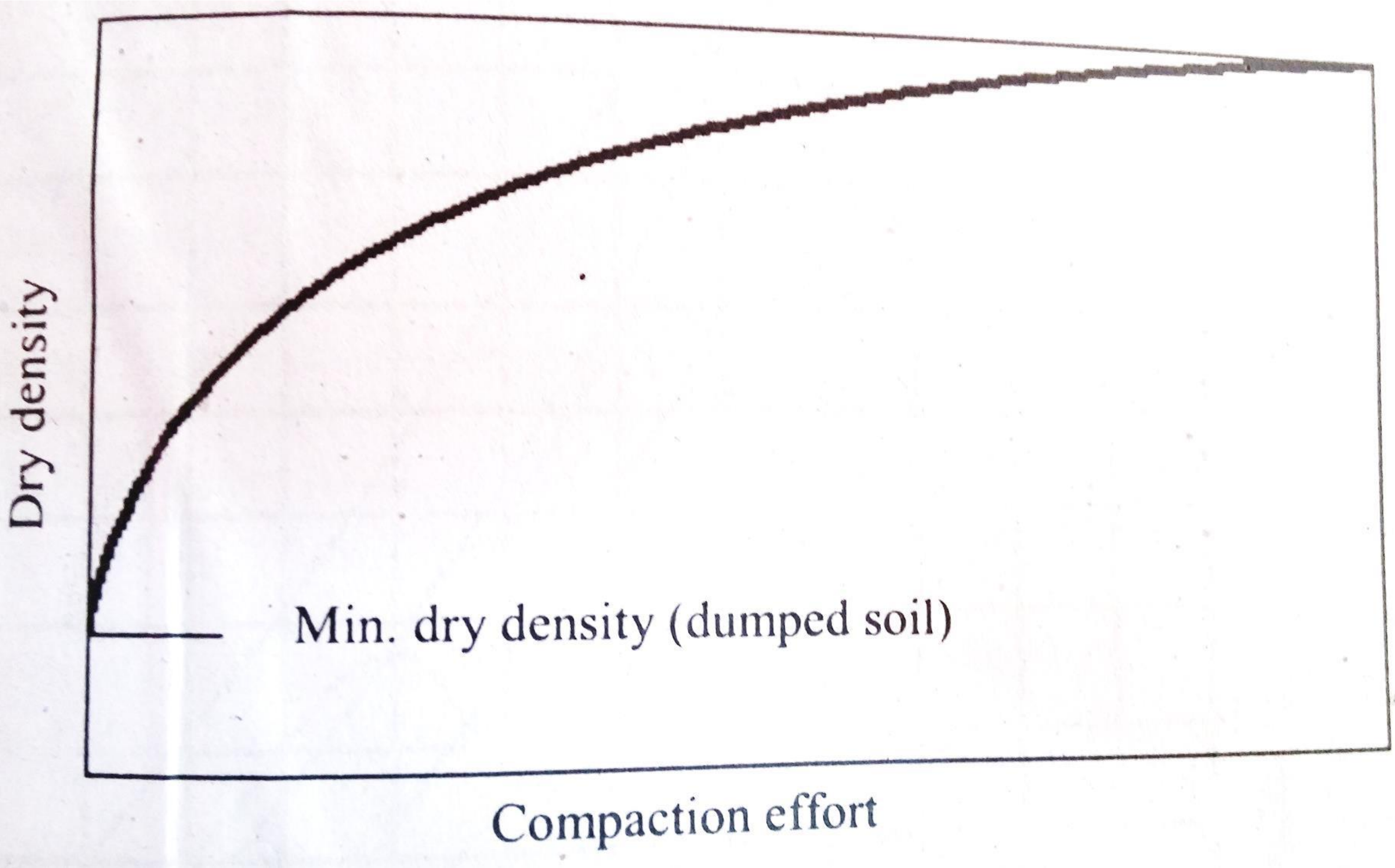
- The compaction energy per unit volume "CE" applied in a laboratory compaction test is calculated by the following equation.

$$CE = \frac{(Number\ of\ Blows\ Per\ Layers)\,X\,(Number\ of\ Layers)\,X\,(Weight\ of\ Hammer)\,X\,(Height\ of\ Drop\ of\ Hammer)}{(Volume\ of\ Mold)}$$

- For standard AASHTO test the "CE" is

$$CE = \frac{(25)\,X\,(3)\,X\,(5.5)\,X\,(1)}{(1/30)} = 12375\,ft - lb/\,ft^3\,(593 kJ/m^3)$$

- It should be noted that degree of compaction is not directly proportional to the compaction effort.
- In other words the maximum dry density does not go on increasing indefinitely with increase in compaction effort. As shown in Next figure



Dry density
Min. dry density (dumped soil)
Compaction effort

Factors Affecting Compaction of Soil

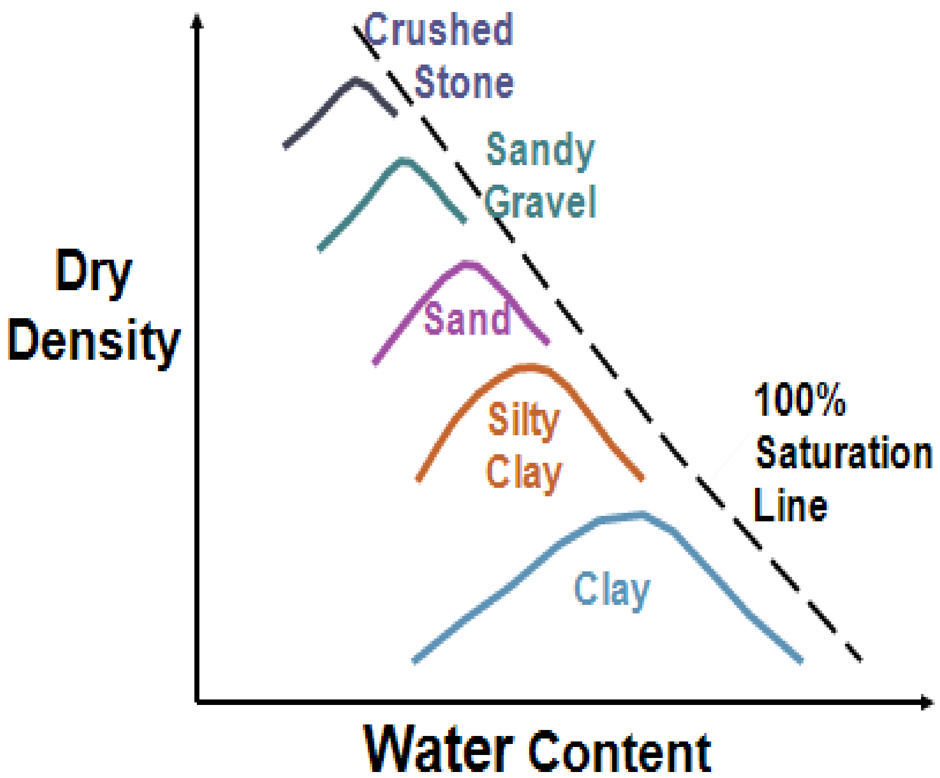
- **Soil Type**
- The soil type, based on particle size distribution, shape of the particles, specific gravity of soil solids and amount and type of clay minerals present in the soil has a great influence in the soil has a great influence on the maximum dry density and (OMC).
- Following figure shows a typical comparison.
- It should be noted that both

The shape and the position of the

Curve changes as the texture of

The soils varies from coarse

To fine



- Maximum dry density may

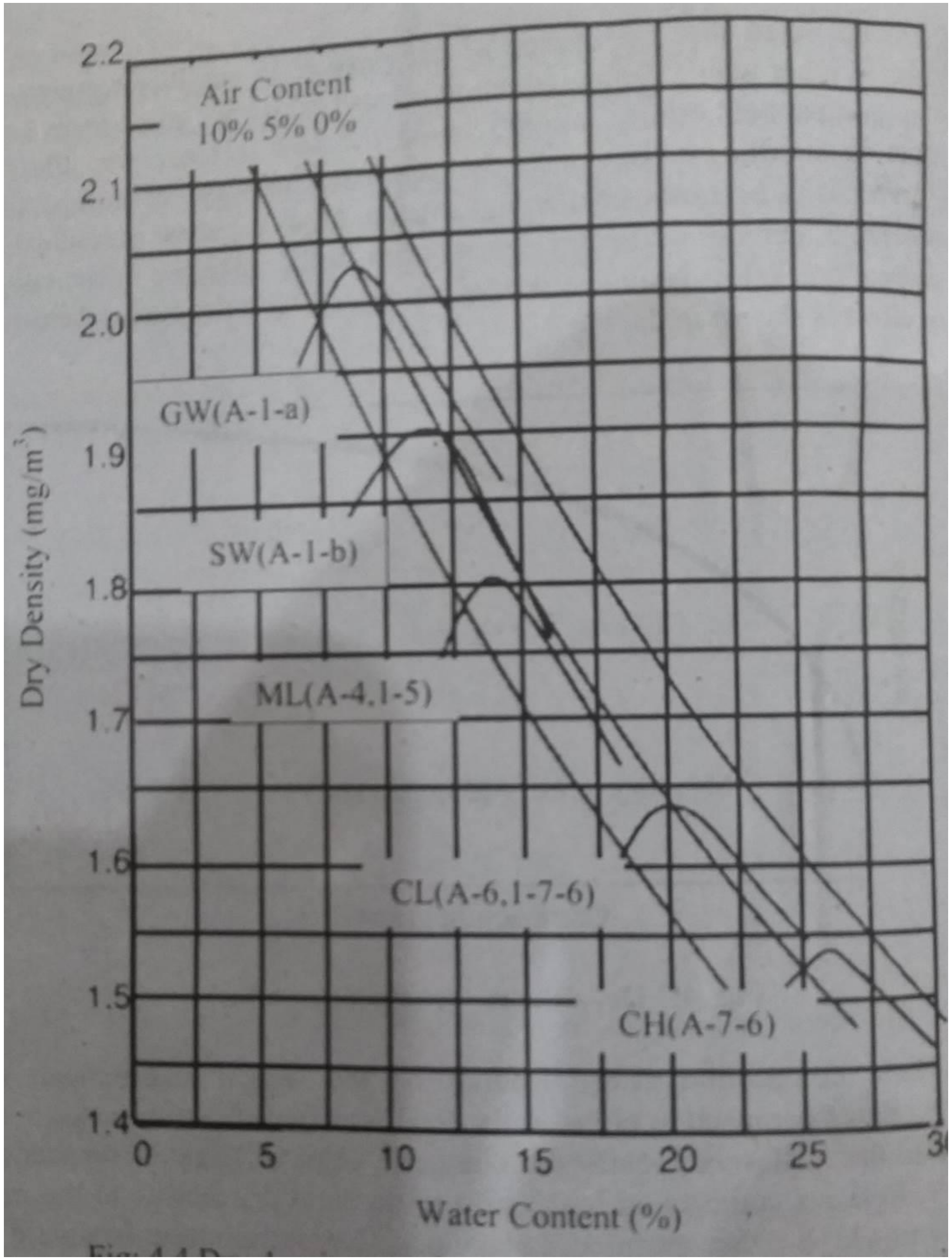
Range from about 60 lb/ft^3

For organic soil to 145 lb/ft^3

- For well graded granular material

OMC may rang from 5% for granular

Material to 35% for plastic silt and clay



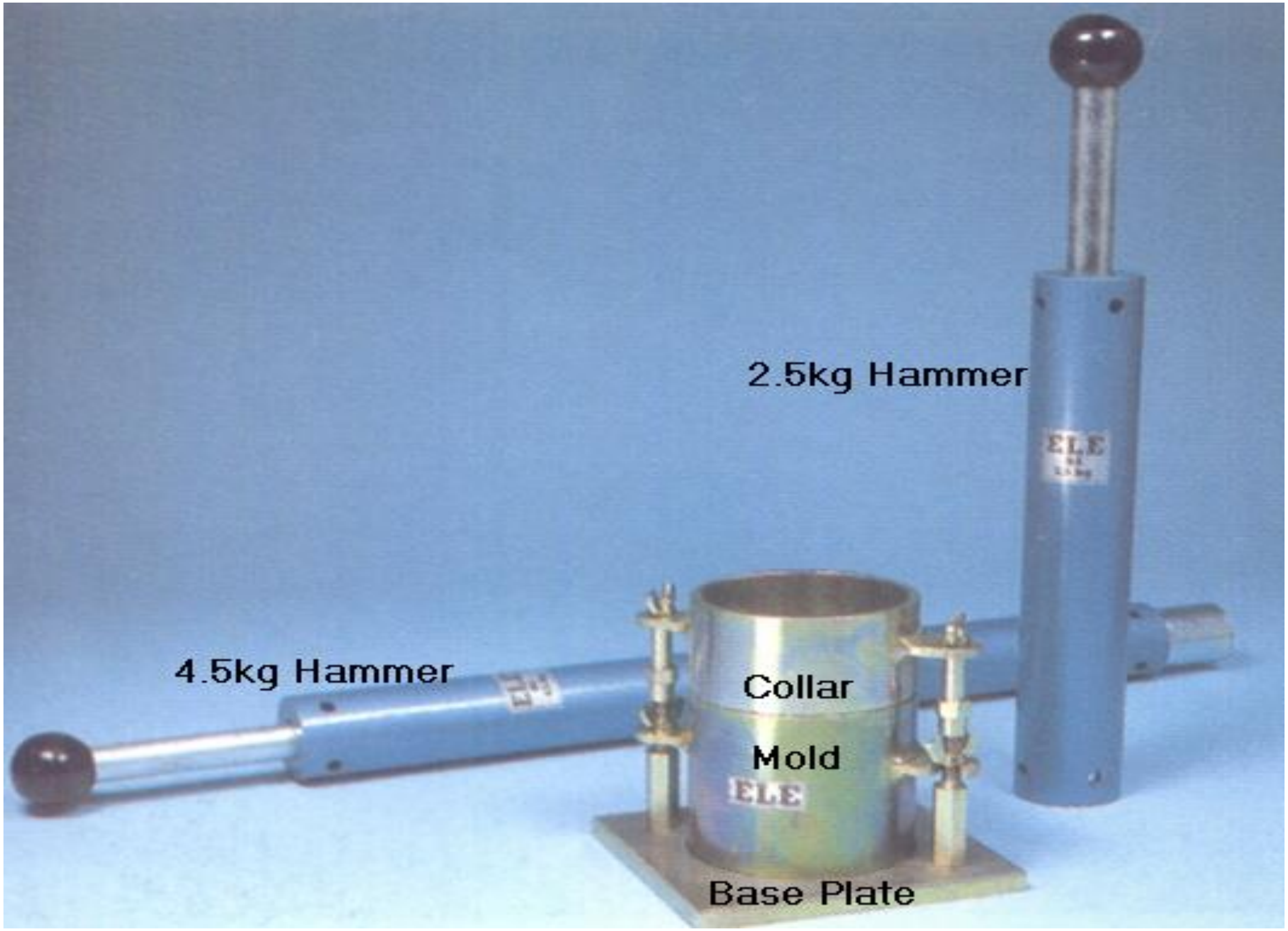
Air Content
10% 5% 0%
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
Dry Density (mg/m³)
GW(A-1-a)
SW(A-1-b)
ML(A-4,1-5)
CL(A-6,1-7-6)
CH(A-7-6)
0
5
10
15
20
25
Water Content (%)

Factors Affecting Compaction of Soil

- **Method od Compaction**
- The dry density obtained by compaction depends to some extent on the method of compaction.
- For same amount of the compaction energy, the dry density will depend upon whether the compaction is applied by kneading, dynamic or the static action..
- Different methods of give different shape of compaction curves, so line of OMC is different
- **Admixture**
- The properties of soil are improved by adding other material, known as admixture.
- The most commonly used admixtures are lime, cement and bitumen.

Compaction Test

- **Standard AASHTO Compaction Test**
- **Apparatus**
- The apparatus required for the test is
- Standard Mold (4 inch inner Diameter, 4.584 inch Height)
- Hammer (5.5 lb, 2.5 Kg)
- Collar
- Base plate
- Weighing Balance
- Drying oven .
- Straightedge for trimming the soil
- Sieve No. 4 (4.75-mm.)
- Containers for moisture content determination


2.5kg Hammer
4.5kg Hammer
Collar
Mold
ELE
Base Plate

Compaction Test

- **Procedure**
- Take 3-kg. soil passing 4.75-mm. (No.4) sieve .
- The mold is attached to the base plate at the bottom and the collar at the top.
- The soil is mix with varying amount of moisture
- Then compaction effort is applied in three layers by applying 25 blows per layer.
- The hammer weight is 2.5 kg, dropped from the height of 12 inch
- At least five sample at different moisture content is tested.
- For each sample Bulk density is determined after Compaction

$$\gamma_b = \frac{w}{v_m}$$

- Where
- W= Weight of compacted sample
- V= Volume of the mold (1/30 ft^3)
- For each sample moisture content is determined and then dry density

$$\gamma_d = \frac{\gamma_b}{1+m}$$

Compaction Test

- Add water to increase the moisture content of the soil by one to t[wo] percent and repeat the above procedure for each increment of water added
- Continue this series of determinations until there is either a decrease or no change in the wet density of compacted soil .
- **Theoretical Maximum Dry Density**
- For a given moisture content, the theoretical maximum dry density is obtained when there is no air in the soil, when the degree of saturation is 100%
- Where

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

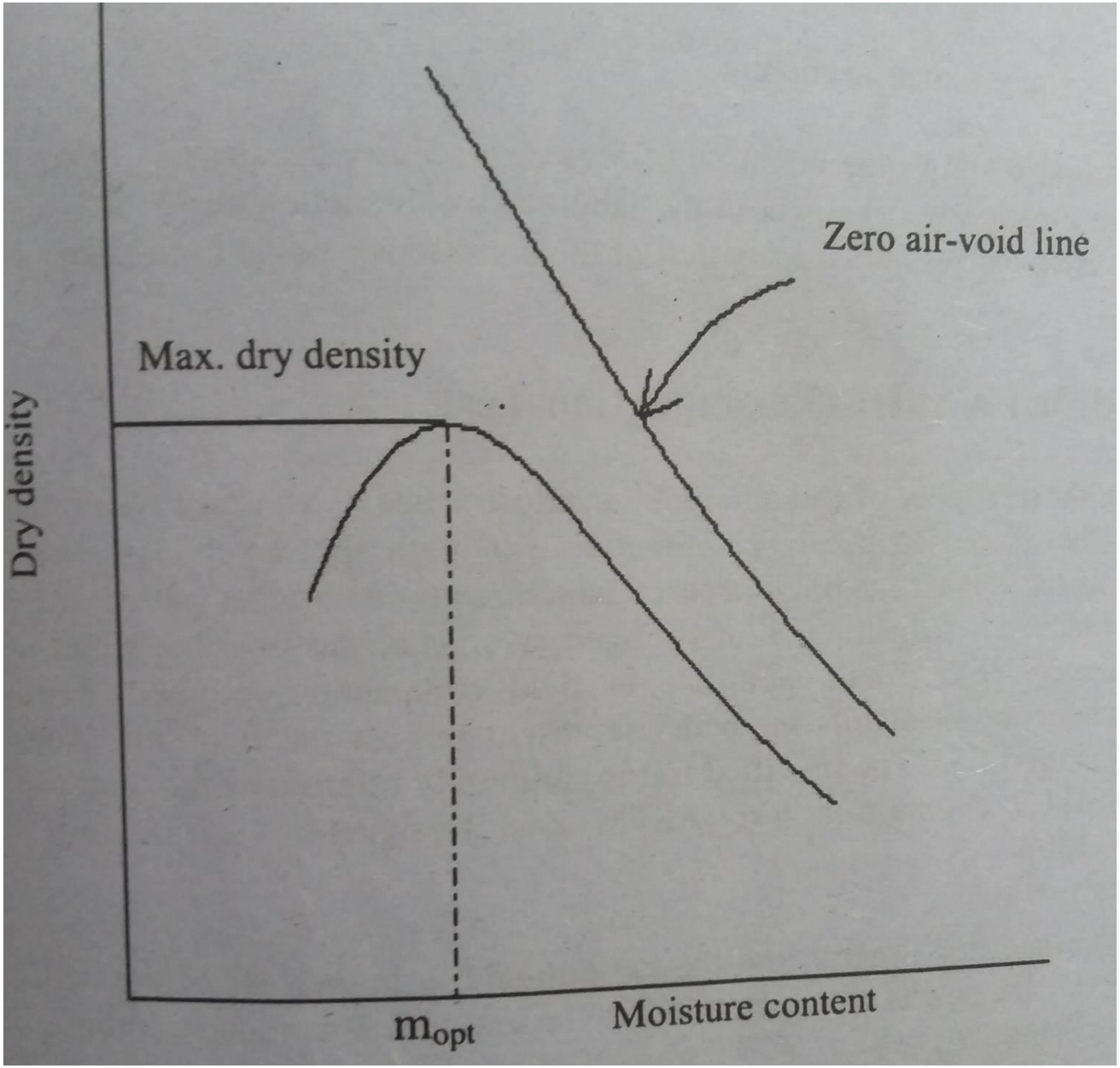
- γ_{zav} = Zero air void density

$e = m.G_s/S$

- G_s= Specific gravity of soil
- γ_w = Density of water
- For 100% saturation $e = m. G_s$
- So,

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

- For any soil it is impossible for compaction cure to exist at right side of zero air void line

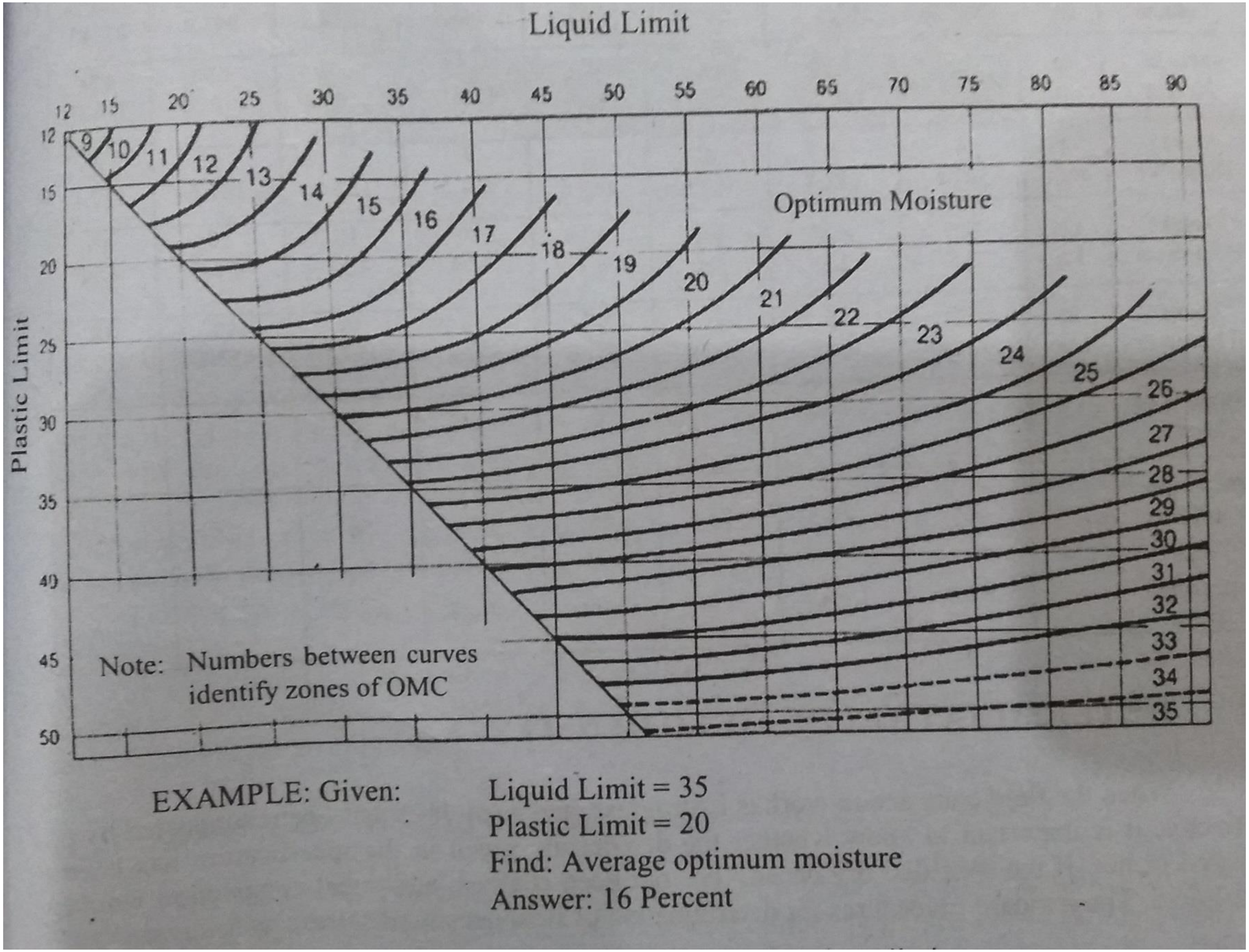

Zero air-void line
Max. dry density
Dry density
m_{opt}
Moisture content

Compaction Test

- **Comparison**

No	Item	Standard AASHTO	Modified AASHTO
1	Volume of mold	1/30 ft^3	1/30 ft^3
2	Mass of Hammer	2.495 kg (5.5 lb)	4.536 kg (10 lb)
3	Height of Drop	12 inch	18 inch
4	No of blows per layer	25	25
5	No of layers	3	5
6	Compaction Energy	593 kJ/m^3	2698 kJ/m^3
7	Curve Detail	The compaction curve is below and the right of Modified AASHTO curve	The compaction curve is Above and the left of Standard AASHTO curve
8	Dry density	Maximum dry density is 1.1 to 1.25 times less than that of Modified AASHTO	Maximum dry density is 1.1 to 1.25 times more than that of Standard AASHTO
9	CE	Compaction Energy is 4.545 times less than	Compaction Energy is 4.545 times more than

Relationship Between OMC and Atterberg Limit



Determination of Field Density

- When the field compaction work is in progress and the soil layers has bee compacted by a contractor, it is important to know whether the dry density given in the specification has been achieved or not.
- If it is not achieved then further compaction is dine.
- Following are the method to find field density of soil

1. Drive cylinder Method
2. Sand replacement method
3. Rubber balloon method
4. Nuclear density method

- **Drive cylinder Method (ASTM D 2937, AASHTO T-204)**
- **Apparatus**
- Steel drive cylinder (85.7 mm) inside diameter and 108 mm height with cutting edge at bottom.
- The volume of the cylinder is 620 cc.
- **Procedure**
- The soil surface at the surface is clear from all loose particles
- The drive cylinder is placed on the surface

Determination of Field Density

- Drive head is seated on the drive cylinder.
- Driving of cylinder is achieved by applying blows on it.
- Penetration in continue un till top of the cylinder is approximately 12 mm below the surface
- Drive head is removed with all soil in it.
- Then it is weighted
- Which gives Bulk density.
- After determination of moisture content, Dry density is found.
- **Rubber Balloon Method (ASTM D-2167, AASHTO T-205)**
- The procedure of rubber balloon method is similar to the sand replacement test
- In this test soil is excavated from the site, and moisture content is determined.
- Volume of hole is determined by placing the rubber balloon filled with water from a calibrated cylinder, from which the volume is directly read.
- Then dry density is calculated by dividing the weight of soil excavated by volume of hole

Merits and Demerit of Field Density Method

- The drive cylinder method is easy and quick.
- The cutting edge is easily damaged and required re sharpening
- The sand cone method is relatively slow, but it can be used for any type of soil
- The rubber balloon method is easy and quick, but the result are not very reproducible owing to the difficulty of controlling the air pressure and ensuring that the balloon confirm to the shape of hole.
- The method is not suitable to the stony soil.
- The nuclear method is fast method as compared to the sand cone and rubber balloon method.
- But it radioactive material, so care should be taken while using

Field Compaction

- The compaction in the field is usually done with the help of rollers.
- The types of rollers used depends upon
  - The type of soil
  - Degree of compaction apply
- For high degree of compaction required for important highways, heavy weight roller is needed to achieve the desire dry density.
- The most common types of roller are
- Smooth Wheel Roller
- Pneumatic Rubber Tired Roller
- Sheep Foot Roller
- Vibratory Roller
- Grid Roller

Field Compaction

- **Smooth Wheel Roller**
- These consist of hollow steel drums, one drum on the front steering axle and two on the rear axle.
- The weight of the roller can be increased by filling it with water or sand.
- These are used for all types of soil except when large boulder are present.
- These are widely used for finish rolling of sub grade and base and also for the compaction of asphalt pavement.
- For good bonding the compacted surface must be scarified before applying next layer
- They provide 100% coverage under the wheel with ground contact pressure of about 45 to 55 lb/in^2
- They are not suitable for high dry density when used on thick layers.

Field Compaction

- **Pneumatic Rubber Tired Roller**
- These are suitable for wide range of coarse and fine soil
- The tires are closely spaced mounted on several axles, commonly two axles (4 to 6 tires per axles)
- The rear wheel overlap the lines of front wheels to ensure complete coverage of the soil surface.
- The tires are relatively wide with a flat tread so that the soil is not displaced latterly
- The contact pressure under the tires can range from 85 to 100 lb/in^2
- They produce 70 to 80 % coverage..
- Pneumatic Rubber roller can be used for the compaction of sandy and clayey soil.
- Compaction is achieved by combination of pressure and kneading


BOMAG

Field Compaction

- **Sheep Foot, Tamping Foot or Pad Foot Rollers**
- These rollers consists of hollow drums with a large number of tapered or club shaped feet projecting from their surface.
- Different manufacturer give different name but all have projecting feet.
- The weight of roller can be increased by filling with water or sand.
- The arrangement of feet can vary but they usually range from about 200 to 250 mm in length.
- The area of projection may range from 4 to 13 in^2
- They are more effective in compacting clayey soil
- They are also suitable for coarse soil with 20% fine.
- Due to the penetration of feet it provide strong bonding properties


APAC
CA25

Field Compaction

- **Vibratory Roller**
- Vibratory roller are very effective in compacting the granular soil.
- Power driven mechanism can be attached to it .
- The mass of the roller and the frequency of the vibration must be matched to the soil type and layer thickness
- The lower the speed of the roller, the lesser the number is required.
- **Grid roller**
- These roller has a surface consisting of a network of steel bars forming a grid with square holes.
- Grid roller provide high contact pressure (1400 to 6000 kN/m^2)
- Suitable for coarse grained soil.
- They produce only 50% coverage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Field Compaction

- **Indoor Compaction**
- **Vibrating Plates**
- These consists of steel plates with up turned edges, or a curved plate, on which a vibrator is mounted.
- These are used for the compaction of granular soil over limited areas and are also suitable for other types of soil.
- **Power Rammers**
- Manually operated power rammer generally used for the compaction of small areas, where is access is difficult where the use of large equipment is not justified.


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Factors Influencing the Choice of Compaction Equipment

- It is always very important to choose compaction equipment which is not only suitable for the of material to be compacted , but also well adopted to the hauling and spreading operations.
- The following check list is used as a guide
- **Characteristics of Compactors**
- Mass, size
- Operating frequency
- Maximum compaction capacity m^3/h.
- Transportation of compacting equipment at site
- Facilities available for repairs
- **Characteristics of soil**
- Initial density, water content
- Grain size, Shape
- Climatic conditions

Factors Influencing the Choice of Compaction Equipment

- **Construction Procedure**

1. **Compaction specification**
2. **Frequency of the operation of vibration**

- Maximum range for frequency is 25 to 50 Hz.
- For large volume the frequency of vibration is 25 to 30 Hz (1500 to 1800 Vibrations/min)
- For asphalt 33 to 50 Hz (2000 to 3000 Vibrations/min)

3. **Speed**

- 3 to 6 km/h for compacting soil and rock.
- For asphalt is 6 km/h
- For soil is 5 km/h

Parameter affecting the Performance of a vibratory roller

- Static Weight
- Number of vibrating drums
- Frequency and amplitude
- Drum Diameter
- Driven and non driven drum

Compaction Specification

- Currently three types of compaction specification are in use
- Methods of specification
- End Result
- Combination of Both
- **Methods of Specification**
- Types of compaction equipment
- Number of passes of the roller
- Speed of roller
- Thickness
- Moisture Content
- **End Result**
- In this method a minimum degree of compaction and or relative compaction is specified and checked by field and laboratory tests.
- In most countries' end result are more important for large project.
- These specification provide information to the contractor to use which type of compactor.

Compaction Specification

- **Combination of Both**
- The requirement for minimum degree of compaction is often specified with a combination of compaction equipment, maximum layer thickness, moisture content etc.

Compacting Capability of Roller

- The amount of material compacted to the specified density by a given roller per unit time is known as **"Capability of Roller"**
- It depends upon
- Working Width (W)
- Speed (S)
- Number of Passes (N)
- Thickness of Layer (D)
- **Working Width**
- Working width is equal to the width of roller multiplied by rolling width efficiency
- The rolling width efficiency varies from 75% for asphaltic material, 90% for soil

Practical Capability = Theoretical Capability X Rolling Width X Working Ratio

- **Working Ratio**
- It is defined as how much minutes work is to be done actually in one hour.
- It is commonly assumed to be 0.85 (51 minutes in 1 hour)

Compacting Capability of Roller

- **Theoretical Capability**
- **For Asphalt Compaction**

$$Theoretical\ Capability\ =\ \frac{(W\ x\ S)}{N}xDxG$$

- **For Soil Compaction**

$$Theoretical\ Capability\ =\ \frac{(W\ x\ S)}{N}xD$$

- The heavy roller has high compaction capability. Since they will require less number of passes to produce the specified density

Application

- Highway, roads, Airfield, Street
- Railway embankments
- Earth and Rock fill dams
- Fill used for support of building foundation and floors
- Trench Fill
- Reinforced Earth structure
- Natural soil deposit with low densities
- Fill as a retaining wall

During construction of an embankment, a sand-cone test was performed in the field. The following data were obtained:

1. Weight of sand to fill test hole and funnel of sand-cone apparatus = 870g.
2. Weight of sand to fill funnel = 322g.
3. Density of sand = 98.0 lb/ft^3.
4. Weight of wet soil from the test hole = 750g.
5. Moisture content of soil from test hole = 13.8%.

Given data

As above

Required

Dry density of the compacted soil = γ_d

Weight of sand in test hole = Weight of sand to fill test hole and funnel, minus the weight of sand to fill funnel

= 870 - 322 = 548g

= 548/453.6 = 1.208lb

Volume of test hole = $\frac{1.208}{98.0} = 0.0123\,ft^3$

Bulk density of soil in-place = γ_b = $\frac{750/453.6}{0.0123} = 134.42\,lb/ft^3$

$$\gamma_d = \frac{\gamma_b}{1+m}$$

$$\gamma_d = \frac{134.42}{1+0.138} = 118.12\,lb/ft^3$$

$$\gamma_d = \mathbf{118.12}\ lb/ft^3$$

For construction of an embankment, a soil from a borrow pit gave the following laboratory results when subjected to the ASTM D 698 Standard Proctor test.
Maximum dry unit weight = 120.5Ib/ft^3
Optimum moisture content = 13%
The contractor, during construction of the embankment, achieved the following
Dry density achieved by field compaction = 118.0Ib/ft^3
Actual field moisture content = 12.9%
Determine the relative compaction achieved by the contractor.

Given data

Maximum laboratory dry density ($\gamma_{d\,max}$) = 120.5 lb/ft^3
Field dry density ($\gamma_{d\,field}$) = 118.0 lb/ft^3

$$\text{Relative compaction} = \frac{\textit{Field dry}\ \text{density}\ (\gamma_{d\,\text{field}})}{\textit{Maximum laboratory dry}\ \text{density}\ (\gamma_{d\,\max})} \times 100$$

$$= \frac{118.0 lb/ft^3}{120.5 lb/ft^3} \times 100 = 97.92\%$$

Relative compaction = 97.92%

THANK YOU!