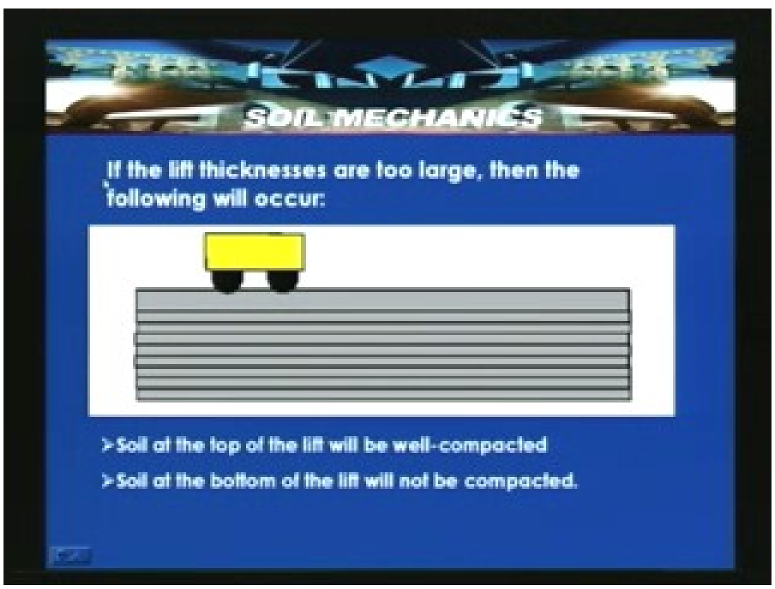
Soil Mechanics
Prof. B.V.S. Viswanathan
Department of Civil Engineering
Indian Institute of Technology, Bombay
Lecture – 16
Compaction of Soils – VI

Welcome to compaction of soils- part 6 lecture. In the previous class we have seen field compaction, specification and different methods for determining the field compaction. We also reviewed different types of compaction equipment which are available for ensuring compaction in the field. In this lecture we will be introducing the in-situ densification of some soils, predominantly granular soils. Then we will see 2 illustrations 1.1 and 1.2 which illustrate the problems pertaining to compaction. Particularly we will be seeing a problem and then we will be solving the problem in the form of a solution.

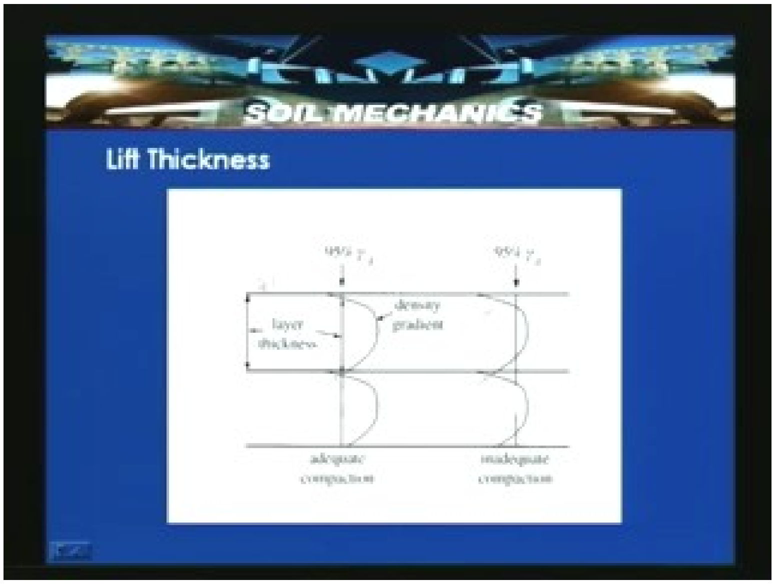
In the previous class we have discussed the importance of the lift in the compaction process, in the field. Let us look how it is actually possible for us to select the lift thickness. If the lift thickness are too large as it is shown in the below slide, then the following will occur.

(Refer Slide Time: 2:06)



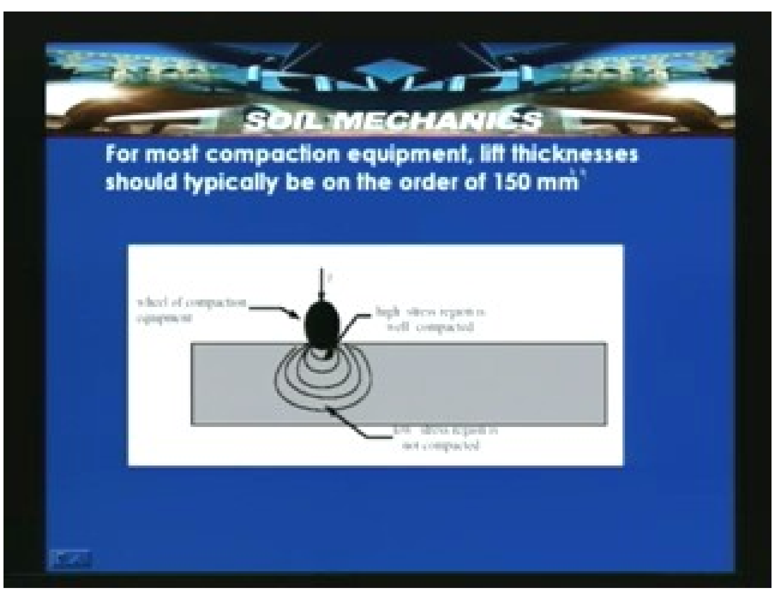
In the sense, soil at the top of the lift will be well compacted that means in the top zone it will receive well compaction. The bottom of the lift will not be compacted at all. The lift thickness selection is a very important criteria in the field compaction. If the lift thickness is too large only the top soil will be compacted and the bottom soil will not be able to satisfy the criteria. There is a certain criteria which is required to be followed to see whether the minimum specified compaction is achieved or not.

(Refer Slide Time: 2:49)



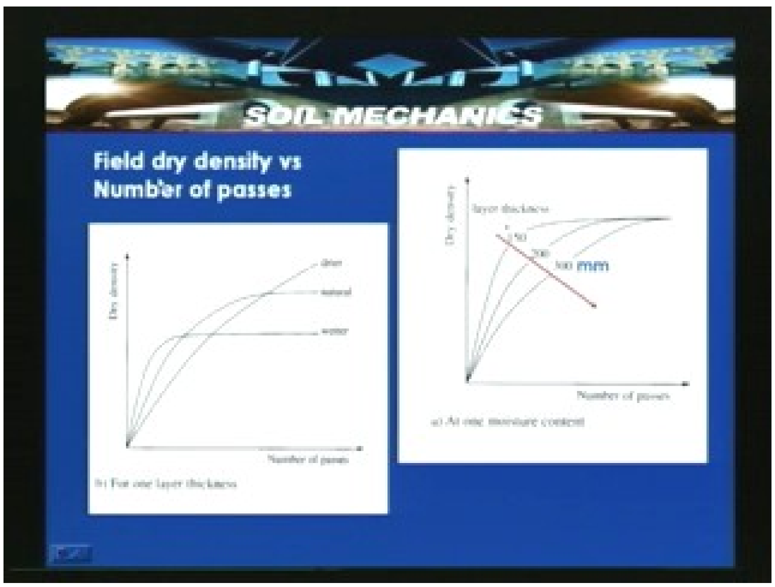
Consider the above slide with a 2 different layers. If you specify 95% density as the required density for adequate compaction. Then at the mid of the layer the density gradient will be high, at the top and bottom it will be less. If I set 95% γ_d that means if the lift thickness in the 2 particular layers is adequate then we say that both the layers have achieved the adequate compaction. In the other case if the set criteria is 95% γ_d that is the straight line. But most of the areas at the edges is falling less than this particular requirement which is the straight line, which actually shows the inadequate compaction. The lift thickness is very much important and to satisfy the required compaction in the layer uniformly.

(Refer Slide Time: 3:56)



For most of the compaction equipment the lift thicknesses should typically be on the order of 150-200mm. The roller is exerting the energy and the bottom of the roller is in the form of a pressure ball. The area which is very close to the roller is something called high stress region and it gets well compacted. Below is the low stress region. The wheel of compaction equipment is shown in the slide which is the darker region and the high stress region is the one which is shown immediately below the dark region and it is the well compacted zone. The last layer is the low stress region, indicating that the layer is less compacted. If the layer thickness is large then the bottom most of the layer will not reach the required compaction. Let us look at the slide below where it shows field dry density versus number of passes. In the previous lectures also we have discussed that the number of passes required for a wetter soil will not make much difference.

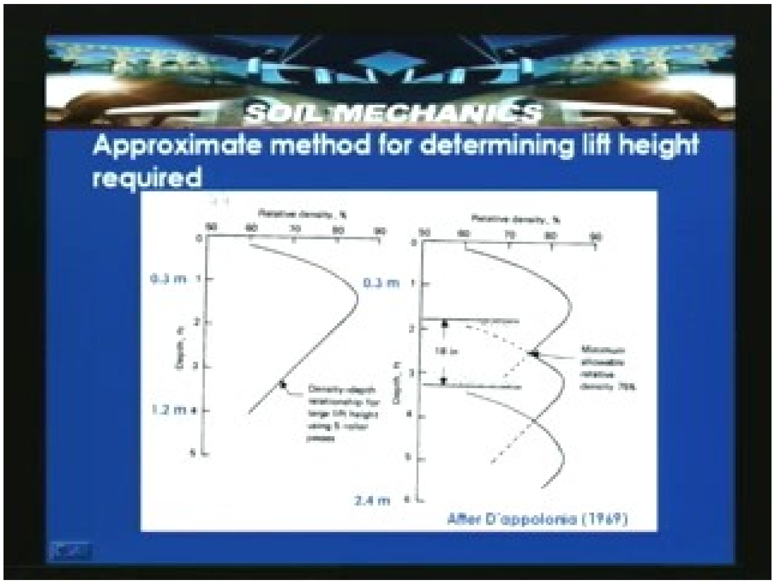
(Refer Slide Time: 4:46)



In this slide if you see for a wetter soil the dry density achieved is very much uniform with increasing number of passes. The increasing number of passes on the wetter soil turns out to be futile because it will not have any effect in increasing the dry density. The dryer soil or some natural soil has got the effect which is shown in the first figure. The figure is drawn with dry density versus number of passes for one layer thickness.

Consider the increasing layer thickness. For example the lift thickness increases from 150, 200 or 300mm. suppose the layer thickness is increasing, for a given number of passes the dry density achieved will be less for a layer with 300mm lift. For a layer with 150mm for a same number of passes, the dry density achieved will be high. This shows the correlation between dry density achieved and thickness of the lift in the field compaction process and number of passes. For any job a trial and error procedure has to be arrived and see that the correct number of passes has been arrived for a given type of soil and for a given type of job, so that the adequate compaction or set compaction can be achieved.

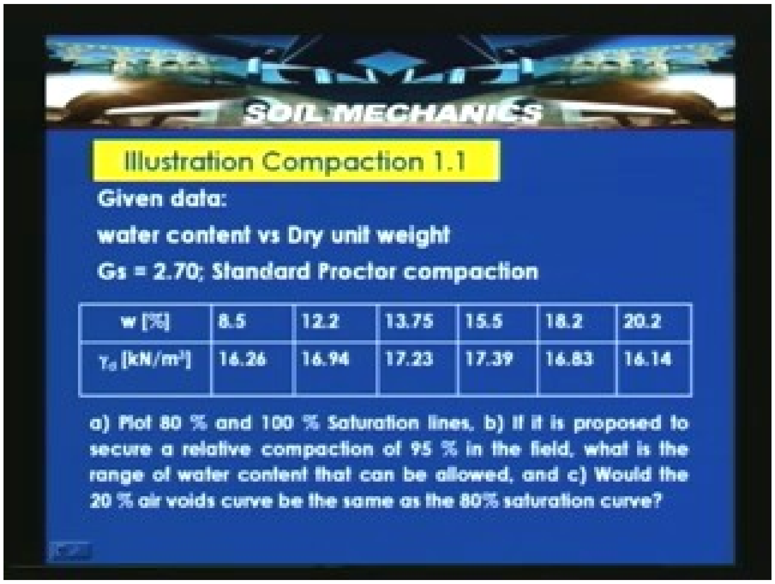
(Refer Slide Time: 6:28)



The approximate method for determining lift height required according to D'apollonia (1969) is present in the slide. In this case the relative density is basically done for a granular soil. The relative density which is plotted for a single layer thickness. The y-axis is the depth in meters that is the thickness of the layer and the x-axis is the density achieved. The maximum density is achieved at 0.3 m with single layer thickness and the density depth relationship for large lift height using 5 roller passes. Whereas the same layer compacted in number of layers. Suppose if I say that the minimum allowable relative density is 75% and this particular thickness is qualified as the required minimum lift thickness for compacting the granular soil in the field.

In the slide we tried to see the approximate method for determining the lift thickness in the field. In the 2nd figure of the above slide we have seen something like each layer is compacted in different zones. Then the field compaction basically the relative density has been accessed and plotted against the depth to see whether it is above the minimum set specification or not. For example in this case a minimum set 75% density is satisfied for a layer which is of 18 inches or so. Let us look into some illustration pertaining to the compaction that is the problem number 1.1. In this case the water content versus dry unit weight data is given for a standard compaction test and specific gravity of the solid particle is given as 2.70.

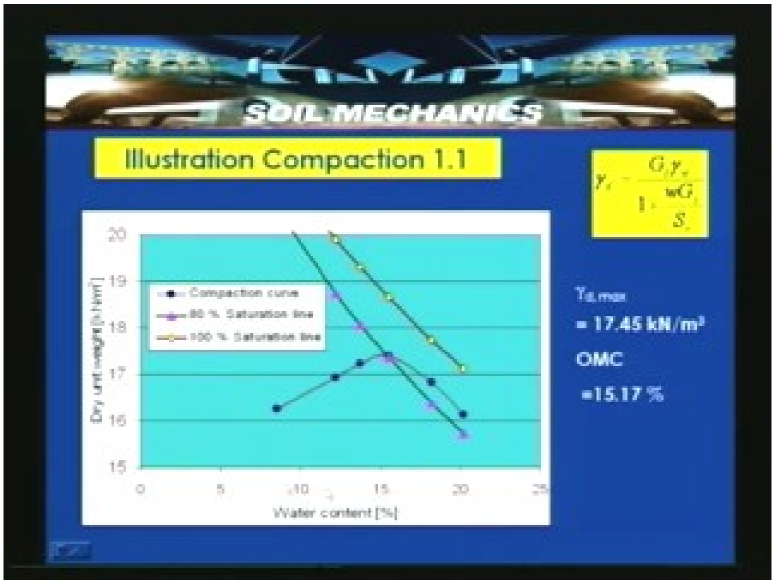
(Refer Slide Time: 8:14)



The standard proctor compaction has been adopted and the data which is given in the slide shows the water content versus γ_d that is the dry unit weight in kilo Newton per meter cube (kN/m^3). The tabulation shows that these are the results which are obtained from the standard proctor compaction test. We should plot 80% and 100% saturation lines, first of all we are required to plot the compaction curve. If it is proposed to secure a relative compaction of 95% in the field, that means 95% of maximum dry density which is achieved in the laboratory. In this case once we plot, we will able to determine γ_d max and Optimum moisture content.

What is the range of water content that can be allowed is asked in part b and would the 20% air voids curve be the same as the 80% saturation curve is asked in part c. So it is a 3 part problem were we are required to solve in steps. Let us try to do the solution. The data given is water content versus dry unit weight. We have to plot water content on the x-axis and dry unit weight on y-axis. We have plotted and the different points on the inverted curve are the result of the standard proctor compaction test.

(Refer Slide Time: 9:44)



So with these results the maximum dry density at Optimum moisture content of around 15.7% is 17.45kN/m^3. We can see with the increase in water content there is a maximum dry density or dry unit weight has been reached. Then at a unique water content for that particular type of soil where the optimum moisture content in this case is around 15.17% and then with the increase in the water content beyond the optimum we can see there is a decrease in the dry unit weight.

$$\gamma_d = \frac{G_s \gamma_w}{1 + \frac{wG_s}{S_r}}$$

Using the above equation draw the 100% saturation line which is in yellow color and 80% saturation line which is in pink color. So 100% saturation line can be obtained by putting S_r =100 or S_r =1 in the equation shown above in which G_s is known to us.

Similarly by putting S_r =80% draw 80% saturation line. The 100% saturation line which is also called zero air voids line which is on the right hand side of the compaction curve. At optimum moisture content the approximate dry unit weight is around 80% or so. Having determined γ_d max and optimum moisture content, we have solved part a of the problem. We also have plotted 100% saturation line and 80% saturation line. Further we examine these results to obtain the results in the field.

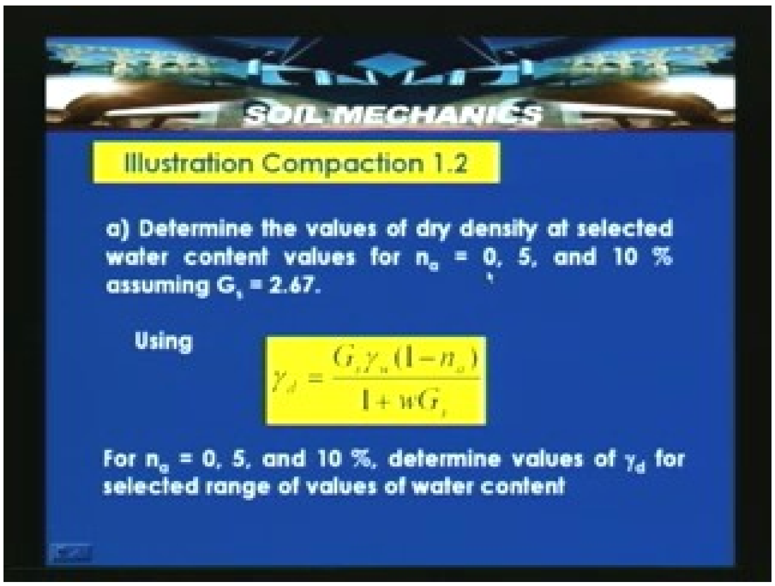
The relative compaction is proposed to achieve around 95% of the maximum dry density obtained in the field. We have obtained maximum dry density in the laboratory around 17.45 kN/m^3. So γ_d field can be obtained as 0.95 time versus 17.45 which is around 16.58 kN/m^3. If you look into the previous plot curve, the 16.58 kN/m^3 which is the field dry density is possible in the field. For that dry density the water content ranges somewhere around 10 to 17%. We have the flexibility to achieve the 17.85 kN/m^3 water will maintained in the range of 10 to 17% in the field. Further it has been asked whether this 20% air voids curve is same as this 80% saturation line. Naturally from the fundamental definition the air content is equal to 1- S_r that is S_r is nothing but the degree of saturation, n_a is the percentage air voids which is n times that is proxy times ac, ac is nothing but 1- S_r . So n_a =n × 1- S_r .

Using the data if you adopt then we will be able to justify the line that the 20% air voids curve is not the same as the 80% saturation line. Using this approach also we can prove the following equation.

$$\gamma_d = \frac{G_S \gamma_w (1 - n_a)}{1 + wG_s}$$

The above equation we have derived in previous lectures. For a given water content w =8.5% that is the starting water content which is the data given to us. The n_a is the percentage air voids which given to us is 20% air void curve that is n_a =0.2 and γ_d is 17.22 kN/ m^3 . With the above given data and using that formula we will get γ_d =17.22 kN/ m^3 . Which is different from 20.56 kN/ m^3 for degree of saturation of 80%. If you calculate for 80% saturation line and a water content of 8.5%, the density or the dry unit weight is around 20.56 kN/ m^3 which is different from the γ_d value. With this also we will be able to say that 20% air voids curve is not the same as the 80% saturation curve. But we can also say 80% saturation line is same as 20% air content line because ac is nothing but 1- S_r , S_r is the degree of saturation. Let us look into illustration compaction 1.2

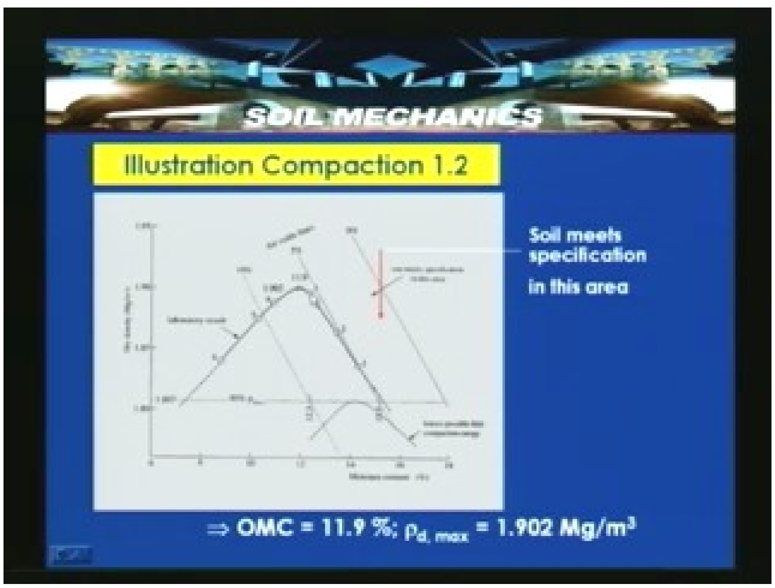
(Refer Slide Time: 15:22)



The problem statement is as follows. Part a is n 4 parts. We were asked to determine the values of dry density at selected water content values, ranging from n_a = 0, 5 and 10% and assuming the specific gravity of the solids as 2.67. Again using γ_d , dry unit weight is equal to a relationship for a partially saturated solid that is $\gamma_d = \dfrac{G_S \gamma_w (1-n_a)}{1+wG_s}$.

For n_a = 0, 5 and 10% determine the values of γ_d for selected range of values of water content. And using the compaction data for standard proctor compaction, plot the results again on the dry unit weight versus water content. The dry density is defined here with the units Mg/m^3 and moisture content or water content indicated in percentage. This is the laboratory result which is plotted in the slide below. From the given data we have generated 0%, 5% and 10% air void lines that is n_a .

(Refer Slide Time: 16:33)

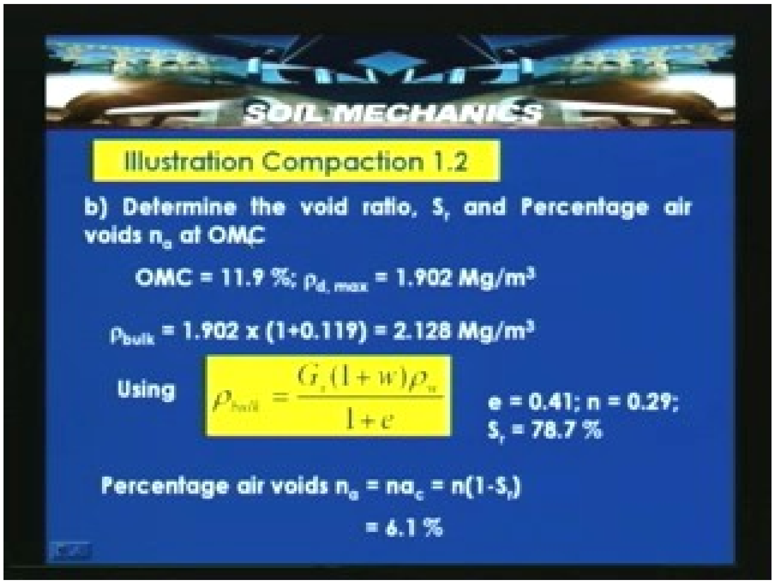


You can see in the above slide that the maximum dry unit weight is around 1.902 Mg/ m^3 and optimum moisture content is around 11.9%. For example if I specify a 5% air void lines, with that as criteria I will be able to decide the range of water content which I have to allow in the field. That is actually very much required to control the soil moisture in the field during compaction. Having set in part a, now let us look in to the problem statement in part b. In part b we have to determine the void ratio, degree of saturation s_r and percentage air voids n_a at OMC. In the previous discussion we have determined maximum dry unit weight and optimum moisture content. We said that optimum moisture content is around 11.9% and $\rho_{d.\max}$ is around 1.902 Mg/m^3. The ρ_{bulk} can be determined as $\rho_{d.\max}$ × (1+ OMC) is nothing but 2.128 Mg/m^3.

ρ_{bulk} =1.902 × (1+0.119) = 2.128 Mg/m^3

Using $\rho_{bulk} = \frac{G_s(1+w)\rho_w}{1+e}$ and with the substitutions we will able to determine the void ratio. The void ratio in this case works out to be around 0.41. Having known the void ratio and by the relation between void ratio and porosity we can determine the porosity of soil. The porosity of soil in this case is around 29%.

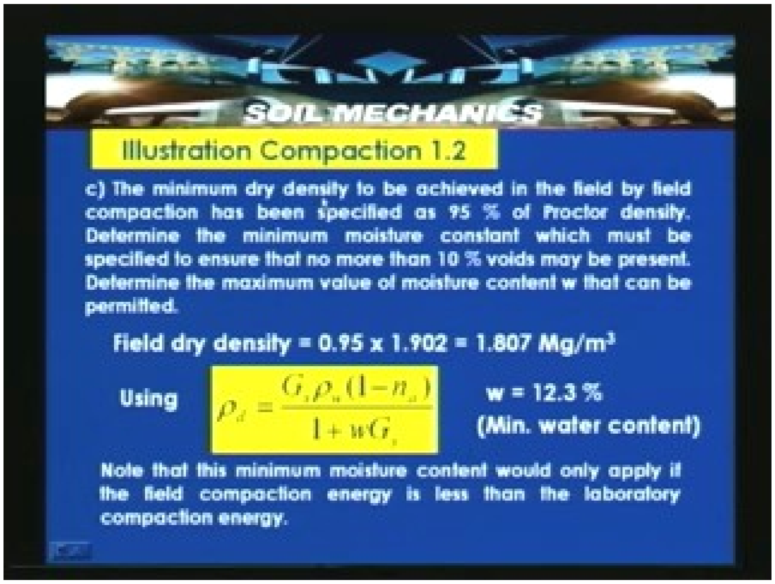
(Refer Slide Time: 17:54)



Then by knowing $e = \frac{wG_s}{S_r}$, the relationship between void ratio, water content, specific gravity of soils and degree of saturation, we can determine the degree of saturation and that comes to around 78.7% which is approximately 79%. We were asked to determine percentage air void n_a at OMC. We have determined the porosity and also the degree of saturation, so with that we will be able to say percentage air void is equal to n times a_c or n × (1- S_r). Having known S_r and porosity, we will be able to determine percentage air void n_a as 6.1%. The percentage air voids at OMC will remain around 6.1%.

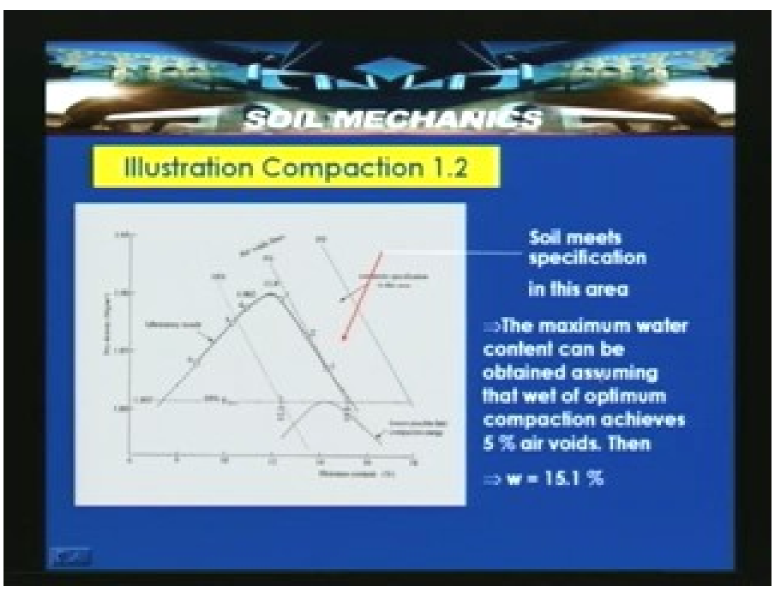
Let us look at part c of this illustration compaction 1.2. We are trying to relate to the field compaction. The minimum dry density to be achieved in the field by field compaction has been specified as 95% of proctor density. That is 95% of the proctor density was given. Determine the minimum moisture content which must be specified to ensure that no more than 10% voids may be present. So 10% voids are to be allowed. And determine the maximum value of moisture content w that can be permitted. The field dry density we can estimate as 0.95 times the maximum dry density in the laboratory which is 1.902 which we have determined from the previous deliberations. The field density is around 1.807 Mg/m^3.

(Refer Slide Time: 20:02)



Using $\rho_{d=} \frac{G_s \rho_w (1-n_a)}{1+wG_s}$ we can determine w=12.3% that is the minimum water content where n_a is given as 10%. Note that this minimum moisture content would only apply if the field compaction energy is less than the laboratory compaction energy.

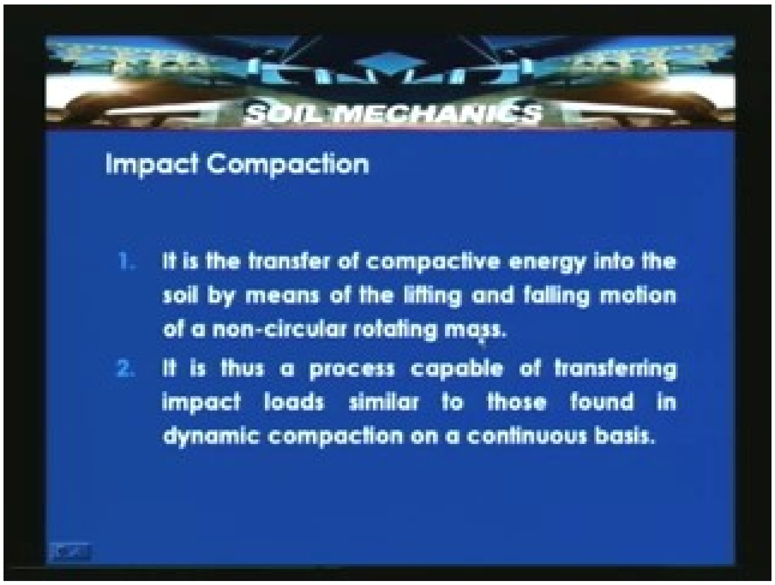
(Refer Slide Time: 21:28)



If we look into it the maximum water content that can be obtained assuming that the wet of the compaction curve achieves with 5% air voids.

So repeat the same process, if you determine for 5% air voids the water content works out to be around 15.1%. If you look into the field for the desired dry density of around 1.807 Mg/m^3, I have a flexibility to vary the water content between 12.3% and 15.1% as per the problem statement. It says that the soil in this zone which is marked in red color arrow meets the specification. This is how we decide that it meets the specification or not. This is about the illustration problems 1.1 and 1.2.We are setting the specifications and trying to see the range of water contents we will be able to allow in the field. That is actually we are trying to estimate and understand.

(Refer Slide Time: 21:56)

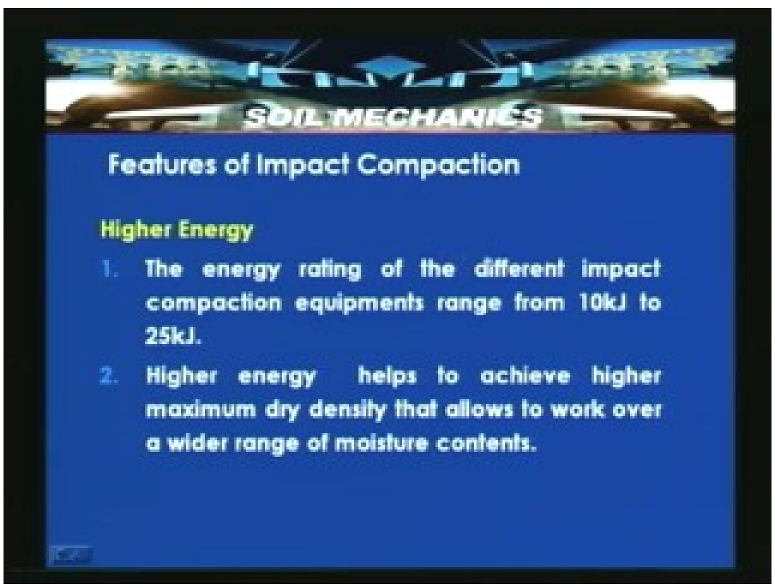


Let us look into another type of compaction method called impact compaction. It is the transfer of compactive active energy into the soil by means of the lifting and falling motion of a non-circular rotating mass. It is thus a process capable of transferring impact loads similar to those found in dynamic compaction on a continuous basis.

In this impact compaction the object called non-circular objects will be able to induce energy to the soil, something very similar to the dynamic compaction. The depth of the extended compaction would be very high. This impact compaction is also another type of compaction method which we have not covered in previous lectures. We are trying to see what types of impact compactors are available and how this depth of compaction is comparable with the other static compaction and vibrability compaction, etc. The following picture given in the slide is a typical impact compactor. The part after the wheel is the impactor which we described earlier as non-circular impact. When this rotates it creates a wave type of energy and tries to compact the soil to the greater extend.

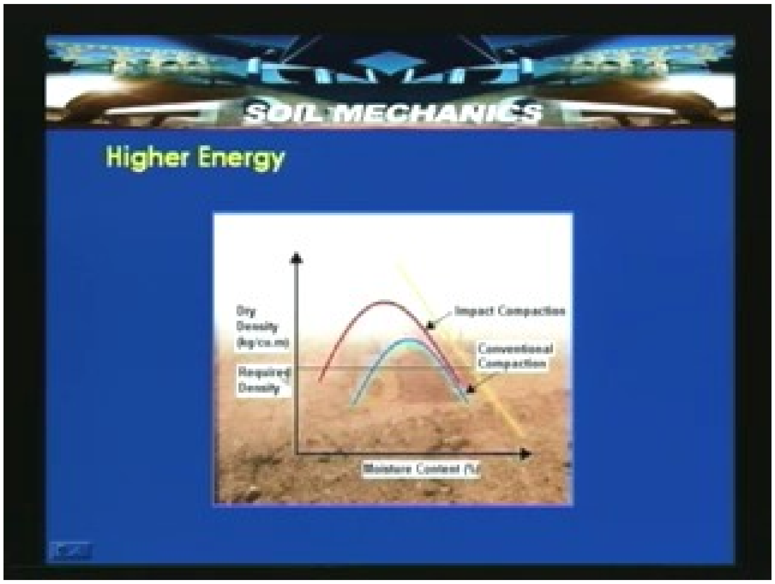
(Refer Slide Time: 23:52)

(Refer Slide Time: 24:20)



Let us look at the features of impact compaction. We can have the possible higher energy that means the energy rating of the different impact compaction equipments range from 10 kJ to 25 kJ. Higher energy helps to achieve higher maximum dry density that allows to work over a wider range of moisture contents. We saw the range of moisture content that we follow. This type of process may allow us to achieve those higher densities in the range of the moisture content which are possible to maintain. So higher energy helps us to achieve higher maximum dry density that allows to work over a wider range of moisture contents.

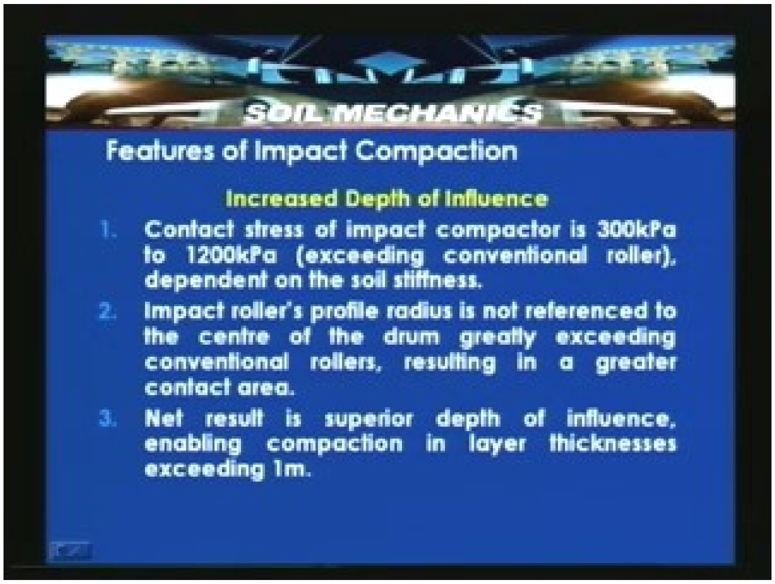
(Refer Slide Time: 25:04)



In the above slide, the dry density versus moisture content is shown. Suppose for the range of water contents I get a curve like which is in blue color which is the conventional compaction and the yellow color line is the zero air voids line. Then the red color curve is due to the impact compaction so that the given range of water contents will be able to achieve the higher dry densities because of the energy produced by the non-circular type of object. Let us list the features of impact compaction.

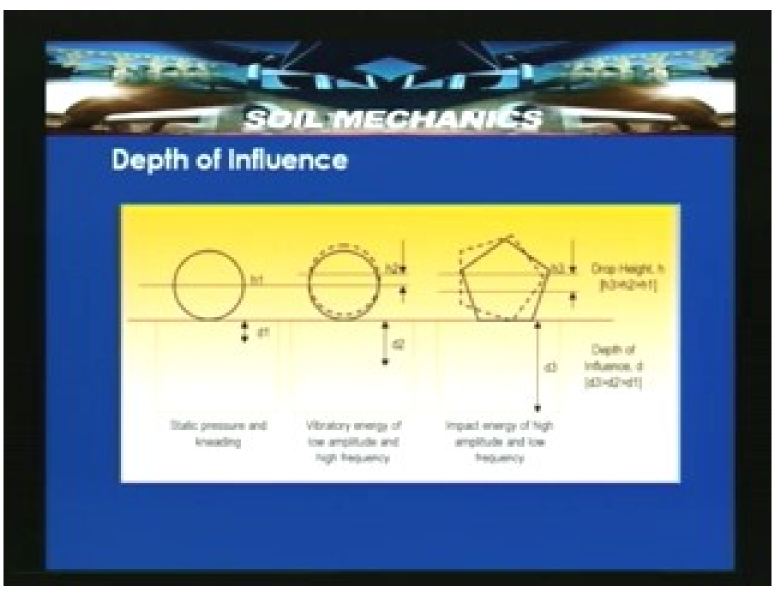
One of the attribute is the increased depth of influence. The contract stress of impact compactor varies from 300kpa to 1200kpa. It is exceeding conventional roller and dependent on the soil stiffness. Impact rollers profile radius is not referenced to the centre of the drum greatly exceeding the conventional rollers, resulting in a greater contract area. As it is not being a circular roller these possess to have a greater contact area. The greater contact area with the field soil is possible with this. That is what actually has been discussed in the second point.

(Refer Slide Time: 25:55)



The net result is superior depth of influence, enabling compaction in layer thicknesses exceeding 1m. With these sometimes the large lifts like 1m also can be compacted efficiently with higher dry densities. In the slide below a typical static roller, vibrating roller and an impact roller has been compared.

(Refer Slide Time: 26:55)



The d1 is the depth of influence for a static pressure and a leading compaction and d2 is the depth of the vibratory energy of low amplitude and high frequency where d2 is greater than d1 and h2 is the vibrating energy produced about vertical axis. Because of the impact energy of high amplitude and low frequency, the depth of the influence is d3.

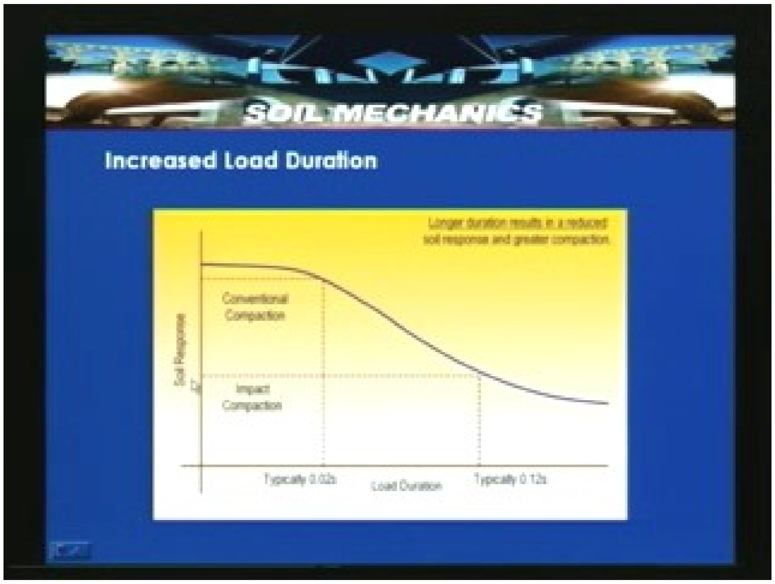
In overall d3 is greater than d2 and d1. Actually the above slide illustrates the superior depth of influence or spreading of compaction energy because of the impact compactor. If you see in the 3rd diagram the drop height h3 is greater than h2 and h1. For the 1st one the drop height is very less and h2 is less than the drop height of h3.

(Refer Slide Time: 28:12)

We will now look at the features of the impact compaction which is increased load duration. The impact compactors load duration has been measured to be 10 to 15 times longer than that of conventional rollers. That is one of the important features which are available with the impact compactors. This allows for a softer soil response and hence enhanced compressibility is attainable.

In increased load duration, the soil response versus load duration is shown in the following slide. For typically 0.02s duration, the soil response is very high. But if you see at the lower part of the curve it is typically 0.12s, the longer duration results in reduced soil response and greater compaction. That means it opposes the energy which is applied because this compaction is less with the longer duration. So here the impact compaction is able to produce longer duration so that a greater compaction can be achieved.

(Refer Slide Time: 28:45)



Another feature of the impact compaction is high operating speeds. Landpac impact compactor is the type of compactors which are used generally in the field. It operates at a speed up to 5 times faster and 10 times greater volume per day than the conventional compaction equipment.

(Refer Slide Time: 29:27)

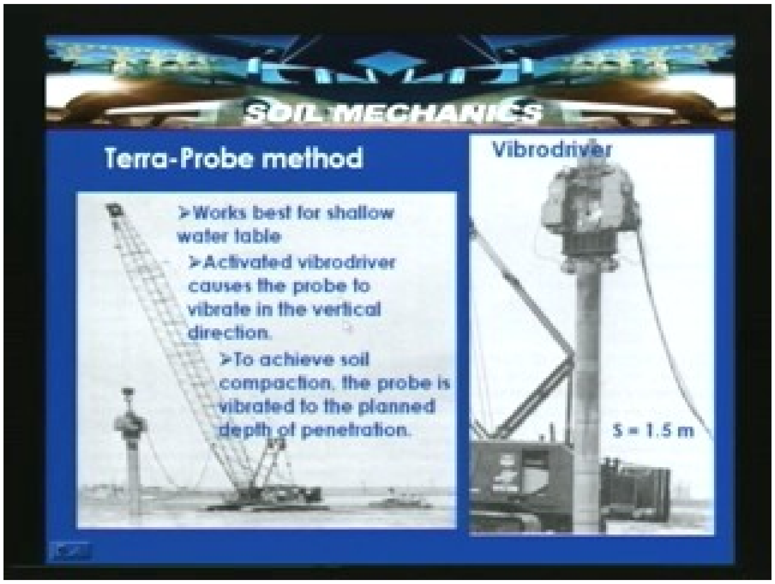
We are trying to compare with the conventional equipment. It says that 5 times faster and 10 times greater volume because larger lift can be compacted, so the volumes of the compaction will be high. Thus we have seen some problems and the solutions for how to control the moisture control in the field. Let us look into the different methods available for In-situ densification of certain type of soils. Many times the manmade structures are constructed on the existing soil deposits. Some time these soil deposits are required to be densified before constructing a structure. For such type in order to attain compaction up to deeper depths then in-situ compaction methods have to be adopted because the roller compaction and other such things will not be affected. It will be effective only up to a certain depth of influence. For that to happen there are certain type of methods. Let us look into the different type of methods which are available for the in-situ densification of soils. In this slide a several new techniques are given. They are terra-probe method, vibroflotation, building sand compaction piles, blasting and dynamic compaction.

(Refer Slide Time: 30:47)

Mostly for loose sandy soils one of the alternatives is to replace some of the loose soils with a column of soil having high relative density. That is when a column of soils which is replaced with high relative density is called a sand compaction pile. This is one method which we can increase the overall load carrying capacity of a soil deposit.

The other one is vibroflotation which is an in-situ technique and building sand compaction piles is also an in-situ technique. The blasting or by explosives or by dynamic compaction or compaction by bounding, basically releasing of the repeated heavy blows on to the soil deposits. These methods have been successfully used for the compaction in In-situ soils especially for the granular or sandy soils. Let us look in to some of the typical methods like vibroflotation, blasting and dynamic compaction.

(Refer Slide Time: 32:16)



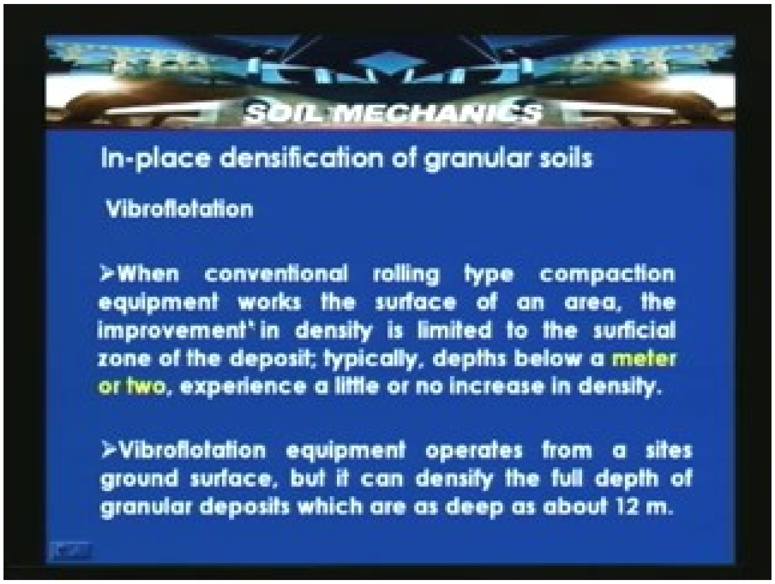
This is a terra-probe method and here it has got a vibrodriver sitting on the probe. It works best for the shallow water table. Suppose the water table is at shallow level that is up to 2 to 3 meters below the ground surface, then this method will be very effective. This method requires densification at spacing which ranging from 1.5 to 2 meters. You can see that s = 1.5 m which is a general thing.

Activated vibrodriver causes the probe to vibrate in the vertical direction. In the above slide the top portion is the vibrodriver and the remaining is the probe. This vibrodriver is nothing but the one which is used for the pile driving equipment. A similar one in which it induces the vibration in a vertical direction. The probe because of the presence of a shallow water table can penetrate in to the ground and densifies the soil.

To achieve soil compaction the probe is vibrated to the planned depth of penetration. This is a terra-probe method which is shown in the above slide. There is a rig which is holding the vibrodriver along with the probe and the above slide is the picture of the vibrodriver sitting on the probe.

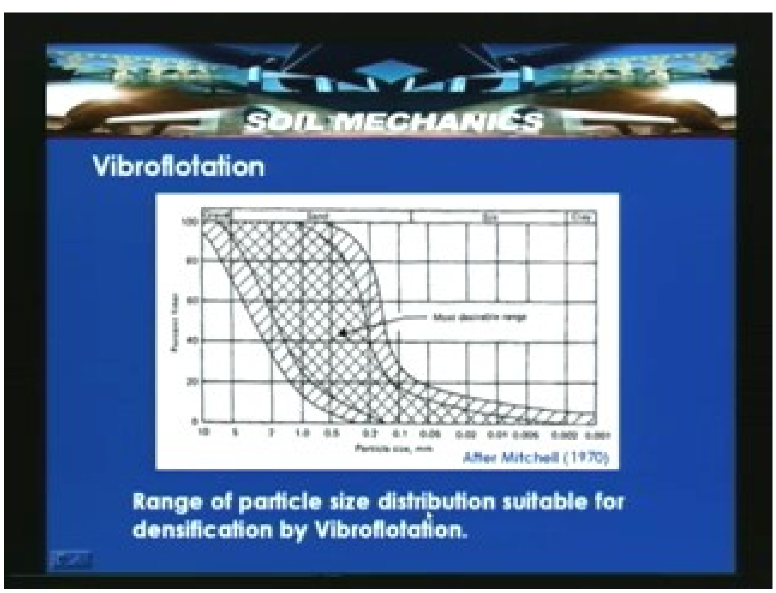
The next method which has been mentioned is the vibroflotation. This is the method which is widely used for in-situ densification of granular soils. With these methods deeper depths of soil can be compacted to a reasonable degree of high relative densities.

(Refer Slide Time: 32:16)



When conventional rolling type compaction equipment works the surface of an area, the improvement in density is limited to the surficial zone of the deposit. Typically, depths below a meter or 2, experience a little or no increase in density. We have also discussed that if conventional compaction equipment is used on a loose sand deposit then or a granular deposit, the energy which can be imparted to compact the soil may reach up to a meter or 2 meters depth. In order to compact the soils at the deeper depths then we have to reserve the method which is called as a vibrofloatation method. Vibroflotation equipment operates from sites at ground surface, but it can densify the full depth of granular deposits which are as deep as about 12 m. Vibroflotation, this particular technique has got a device called vibrofloat which is used in the field very widely and in the depth around 12 m the compaction can be achieved with this particular type of method.

(Refer Slide Time: 35:23)

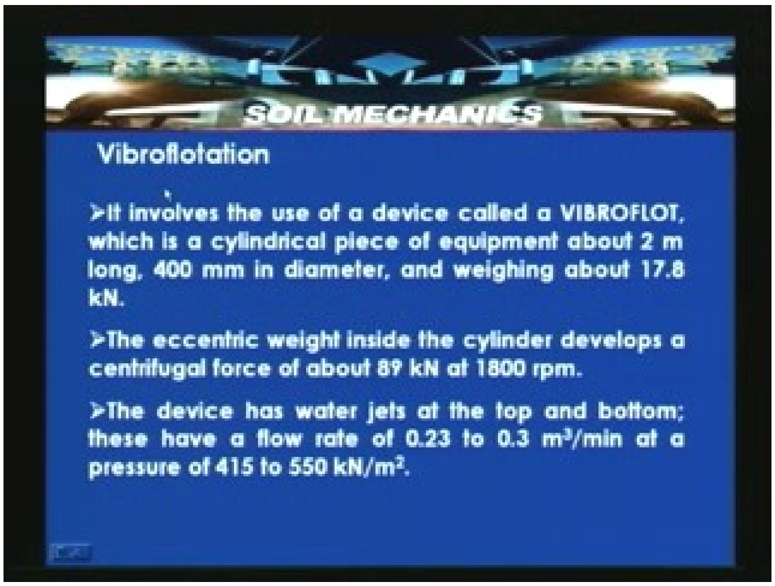


In this vibroflotation method the above slide shows the range of particle size distribution suitable for densification by vibroflotation. Because before selecting any method we have to look in to the type of soils to which this method can be applied. For example this particular slide which shows the percentage size versus particle size for the range of soils and this chart is applicable for compaction by explosive, compaction by pounding as well as for vibroflotation technique.

In the above slide you can see that this is the most desirable range which is shown here with rhombus type hatching. This is after Mitchell 1970, we can see that mostly the gravel sand deposits and partly some silty soils and very less clayey soil.

This is basically for gravel, sand and to some extend silty soil can be used. We can choose this particular vibroflotation method for gravelly sandy soil and particularly to some silty soils but very less for clayey soils.

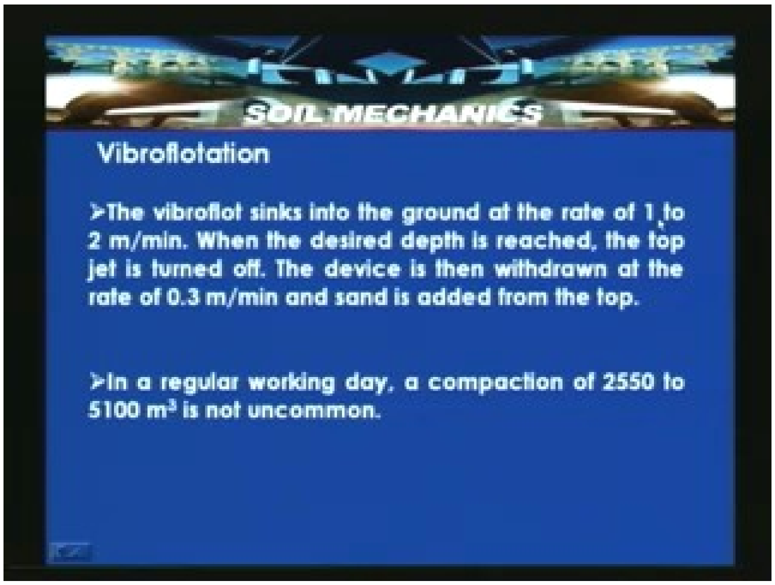
(Refer Slide Time: 36:25)



A vibroflotation involves the use of a device called a vibroflot which is a cylindrical piece of equipment about 2 m long and 400 mm in diameter and weighing about 17.8 kN around 1.78 tons. The eccentric weight inside the cylinder develops a centrifugal force of about 89 kN at 1800 rpm. The device has got water jets all around the periphery or at the bottom and with that it is able to induce and progress in penetrating in to the soil. The device has water jets at the top and bottom and these have a flow rate of 0.23 to 0.3 m^3 /min at a pressure of around 415 to 550 kN/ m^2 . The device has water jets both along the sides and at the bottom to allow it to penetrate into the ground and to reach the desire depth of penetration. The vibroflot sinks in to the ground at the rate 1 to 2 m/min. That is per minute it can sink by 1 to 2 m.

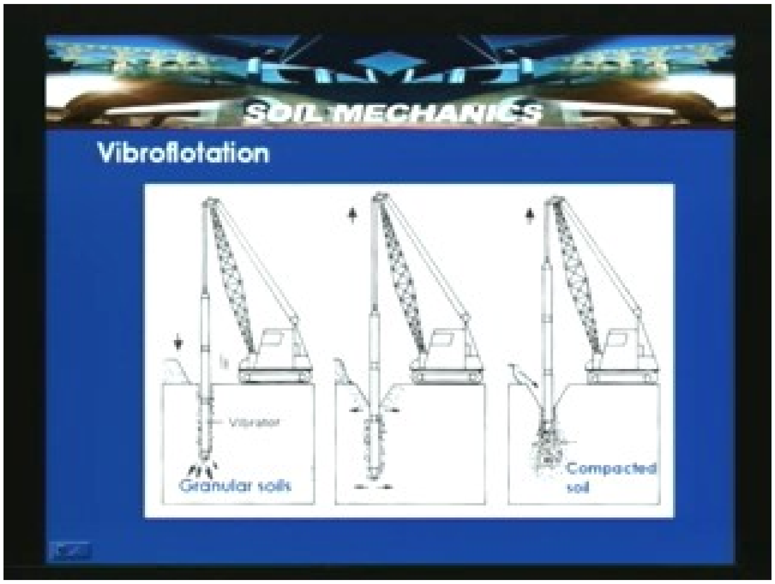
When the desired depth is reached, the top jet is turned off. The device is then withdrawn at the rate of 0.3 m/min and the sand is added from the top. In a regular working day, a compaction of 2550 to 5100 m^3 is not uncommon. Generally in a regular working day about 2550 to 5100 m^3 of soil can be compacted. We are going to see the sequential steps in the subsequent slides where the device vibroflot is allowed to penetrate in to the ground and create the desired compaction at the deeper depths.

(Refer Slide Time: 38:10)



The vibroflotation scheme is shown in the below slide where we are seeing the vibrator which is penetrating into the desired depth and the rig is holding the vibrator. At the bottom are the typical granular soils which are undergoing compaction.

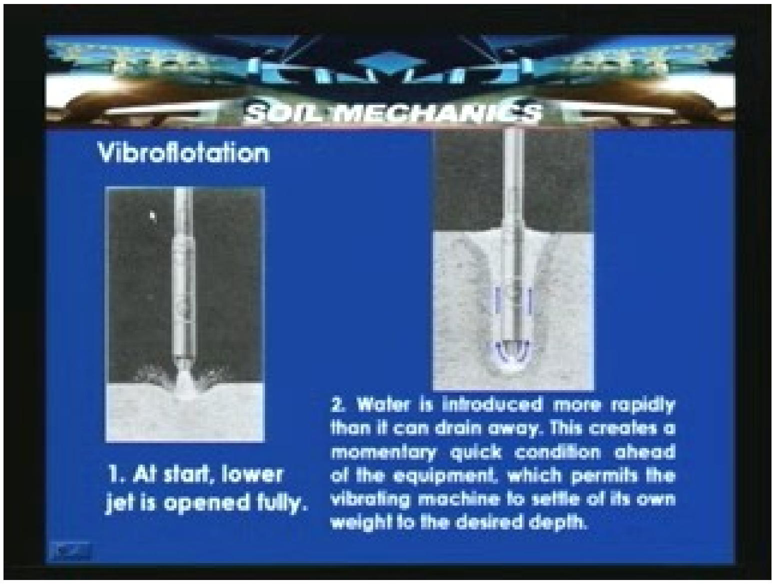
(Refer Slide Time: 39:15)



The 2nd picture in the above slide shows how the water is spreading and creating a densification surrounding the areas and the 3rd one is the compacted soils with the release of the sand from the top. Till this process what will happen is while retrieving, the sand will be sent in to that tube like structure and in this process the soil gets compacted.

In this process the soil within that vicinity of that particular probe gets compacted. Like this it is required to cover the entire area at the optimum spacing so that the net soil deposit which is there is approached to have high bearing capacity or high load caring capacity for desired structure coming on to that soil deposit.

(Refer Slide Time: 39:15)

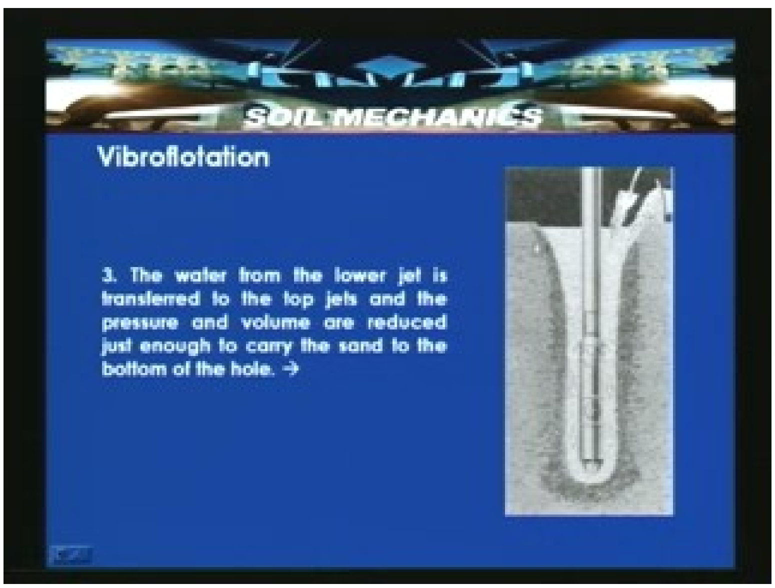


This is the process which is described in the above slide. The 1st picture is the vibroflot device in which the bottom jet will open and at the start lower jet is open fully. When it penetrates in to the ground it has to create a quick sand condition where momentarily the soil loses the strength. For that the rate of flow of water should be more than the water draining rate. If I am able to do that then momentarily a quick sand condition can be achieved.

Water is introduced more rapidly than it can drain away. That is the thing which is followed here and this creates momentarily quick condition ahead of the equipment, which permits the vibrating machine to settle of its own weight to the desired depth.

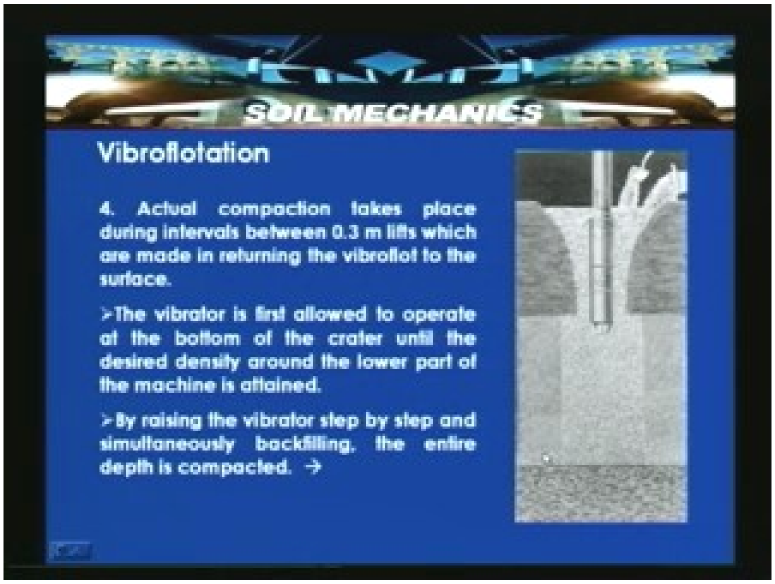
With its own weight it is able to penetrate in to the ground. In this process it momentarily creates something called a quick sand condition where the soil is giving way for the vibroflot to penetrate into the soil at its own self rate. In this slide we can see how the jet is pushing the soil and the progressive penetration of the vibroflot.

(Refer Slide Time: 41:37)



You can see from the slide that the sand is being added. The water from the lower jet is transferred to the top jets. The pressure and volume are reduced just enough to carry the sand to the bottom of the hole. Once the sand supply is started, the bottom is switched off and the water is now opened from the top and sides. You can see the densified soil in the region around the vibroflot.

(Refer Slide Time: 42:13)

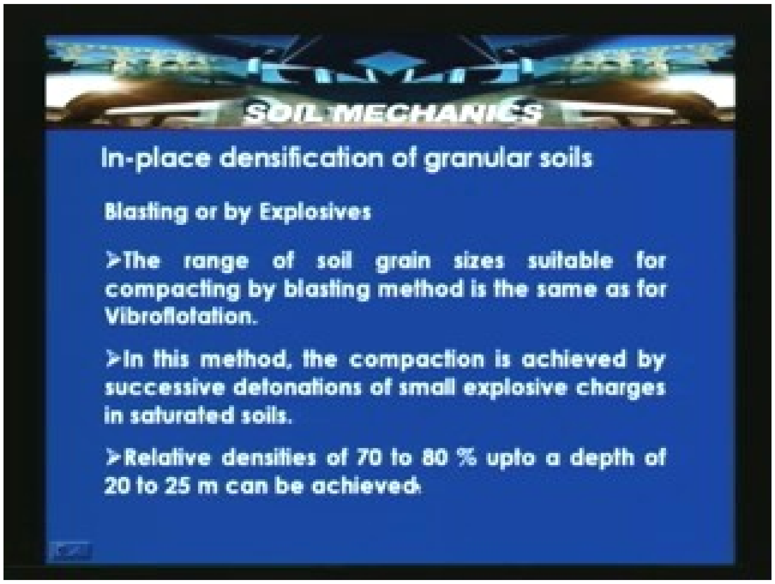


In this slide what we see is the actual compaction taking place during intervals around 0.3 m lifts also and which are made in returning the vibroflot to the surface. During this process what you can see is that the last layer is the strata and the middle area is the compacted zone with the thick soil deposit, which is compact with the desired relative density. Again the same process is repeated to compact this particular stretch also. The vibrator is first allowed to operate at the bottom of the crater until the desired density around the lower part of the machine is attained. By raising the vibrator step by step and simultaneously backfilling, the entire depth is compacted. In this process what we are trying to explain is that it is a sequential 4 step process where a momentary quick condition is created and the vibroflot is penetrated in to the ground and the sand is applied.

With that by switching on the flot to the top jets and allowing water to flow we are able to allow the sand flow to bottom. By creating this condition sequentially, by returning the rate of around 0.3 m/min and by repeating the same process we will be able to achieve the compaction at deeper depths.

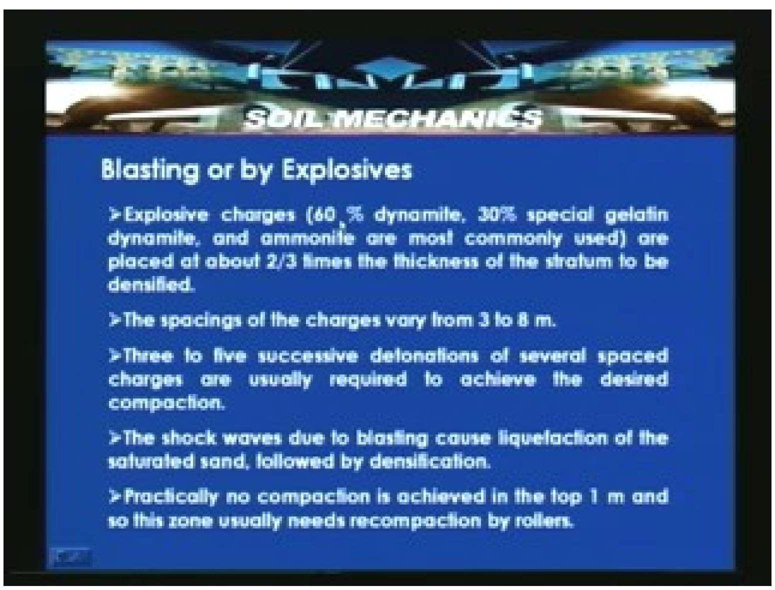
The next method of compaction is by blasting or by explosives. These are also the methods which are used widely. The range of soil grain sizes suitable for compacting by blasting method is the same as for vibroflotation.

(Refer Slide Time: 44:25)



In this method the compaction is achieved by successive detonations of small explosive charges in saturated soils. Relative densities of 70 to 80% up to a depth of 20 to 25 m can be achieved by the method of compaction by explosives. This is the process in which the energy is creating by detonating dynamite which is having a peculiar chemical composition. The range of soil grain sizes which are suitable for this method is same as the one for vibroflotation. Hence predominantly this is used for sandy and gravel soils.

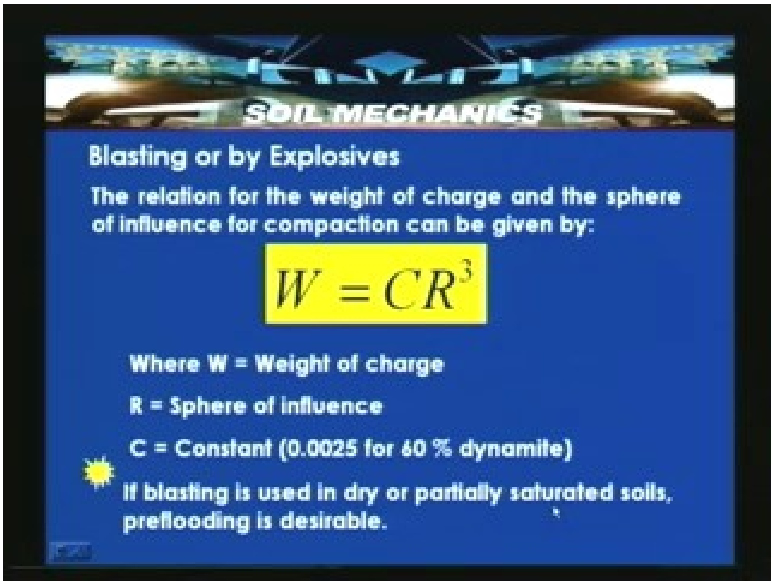
(Refer Slide Time: 45:09)



The explosive charges 60% dynamite, 30% special gelatin dynamite and ammonite are most commonly used, are placed about $\frac{2}{3}$ times the thickness of the stratum to be densified. The spacings of the charges vary from 3 to 8 m. The 3 to 5 successive detonations of several spaced charges are usually required to achieve the desired compaction. A grid of this detonation has to be planned to achieve this degree of compaction.

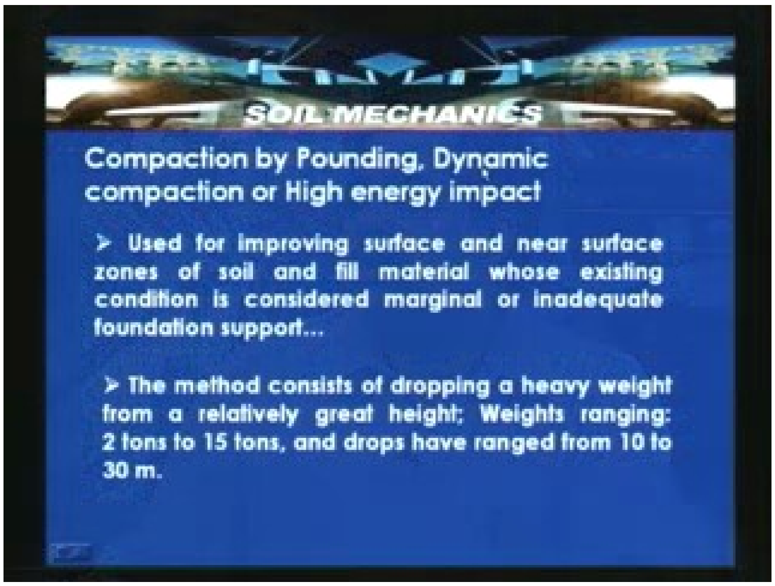
The shock waves which are created due to blasting cause momentary liquefaction of the saturated sand, followed by densification and this is the concept. Because of this, practically no compaction is achieved in the top 1 m of the layer. This top 1 m layer usually needs to be recompaction by rollers. That means both, compaction by explosives and then this roller compaction has to be adopted. The shock waves due to blasting cause liquefaction, which is followed by densification and that is how the compaction process is done.

(Refer Slide Time: 46:50)



In blasting by explosives the influence radius can be defined as $W = CR^3$ where w is the weight of the charge and c is the constant which is 0.0025 for 60% dynamite and r is the sphere of influence. If blasting is used in dry or partially saturated soils, preflooding is desirable. It is possible because we said that the saturated sand deposit or gravel deposit is undergoing blasting. Suppose if a partially saturated soil deposit is required to be densified by this method, a preflooding of the site is required before detecting these explosive charges.

(Refer Slide Time: 47:19)



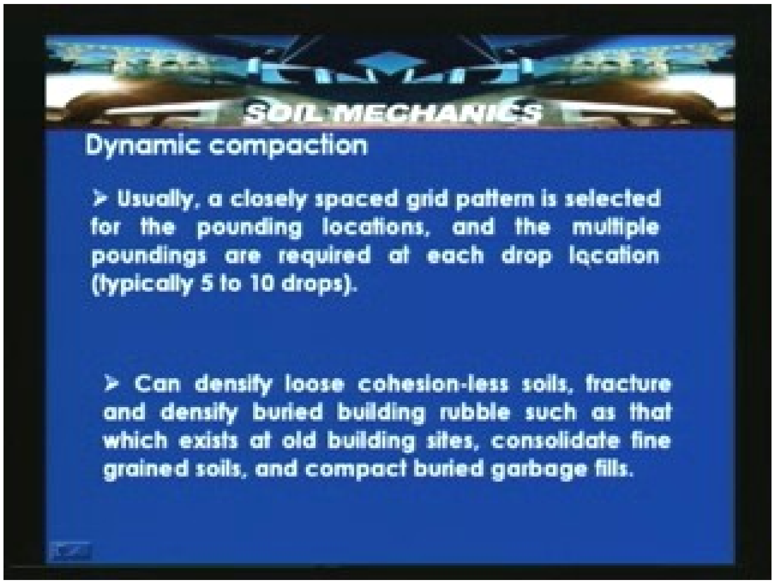
The compaction by pounding, dynamic compaction or high energy impact are used for improving surface and near surface zones of soil and fill material whose existing condition is considered marginal or inadequate foundation support. This method consists of dropping of a heavy weight sometimes ranging from 2 tons to 15 tons at height equivalent to around 10 to 30 m.

During the process the potential energy which is gained is transferred in the form of compaction energy to densify the soils. At each point whenever this repeated heavy tamping of loading is done, the crater is formed and the soil will be displaced. With that process a grid of locations in a particular site will be able to densify the soil in that particular area.

This is basically used for improve the surface and near surface zones of soil and fill material whose existing condition is considered to be marginal or inadequate foundation support. The condition is that it is marginal or inadequate for carrying the load which is going to be induced because of the forthcoming structure.

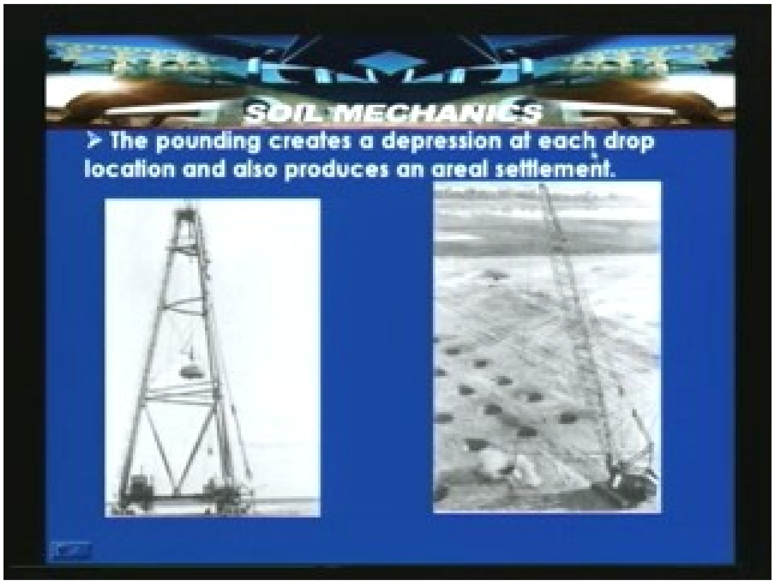
Usually a closely spaced grid pattern is selected for the pounding location and the multiple poundings are required at each drop location typically 5 to 10 drops are required. That means the weights ranging from 2 to 10 tons and drop height ranging from 10 to 30 m are required to be at each particular location of around 5 to 10 drops which are required to be carried out at closed spacings. So that the entire area gets densified and the density can increase.

(Refer Slide Time: 48:35)



This can densify loose cohesion-less soils, fracture and densify buried building rubble or building depry which exist at the old building sites, consolidate the fine grained soil by dynamic compaction process and compact buried garbage fills. This is widely used in compacting the municipal solid waste fills. That is in the land fill sites the dynamic compaction method is widely used.

(Refer Slide Time: 49:49)

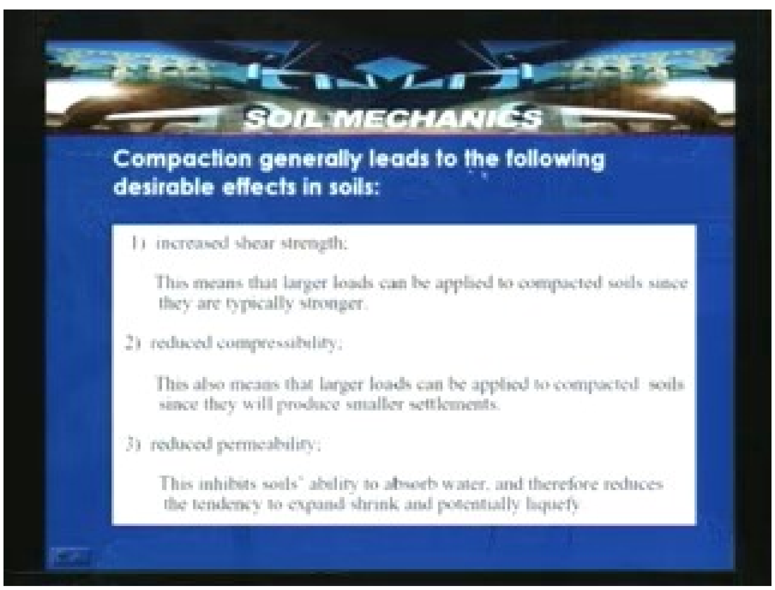


The pounding creates a depression at each drop location and also produces an areal settlement. As you can see in the above slide these are the different craters which are created because dropping a certain weight from a certain height. The rig is shown at particular height where the weight is hanged and about to release. In this particular portion of the 2nd diagram the weight which has been released in the soil can be seen.

In this process when a set of craters have been created in this particular area and this actually creates a sort of depression. This entire area tends to become compacted. We have tried to see different methods of in-situ densification of soils and some other methods for compacting soils for laboratory using both standard proctor compaction and modified proctor compaction.

Then we have discussed about the field compaction specifications, method specification and product specification. Also we have seen some illustrations and problems 1.1 and 1.2 and some problems pertained to compaction. Then we also discussed various factors affecting the compaction process and how the role of water is important in the process of compaction and we brought out the relevance.

(Refer Slide Time: 51:18)



Finally let us look the compaction generally leads to the following desirable effects in field. Our aim is to produce the soil deposit with increased shear strength so that we will able to support the structures with higher loads. This means that the larger loads can be applied to compact soil since they are typically stronger and reduced compressibility also means that the larger loads can be applied to compacted soils since they produce smaller settlements.

The reduced permeability, that enabled the soil to absorb water and therefore reduces the tendency to expand, shrink and potentially for the liquefaction. The compaction process produces increased shear strength, reduced compressibility and improves the performance of the soil deposit in supporting or in deriving the functions for the particular structure. So in this class we have tried to complete and covered the most of the salient aspects of the compaction. With this lecture we are able to complete the compaction of soils.