Ground Improvement
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Lecture 19
Vibro Compaction

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Hi all. Once again, I invite you to this Ground Improvement class. We are now in module 5 and lecture 1. And module four, of course, it was not full week, that does not matter it will be adjusted. And this ground improvement, under this today, I will be taking a new topic that is Vibro-Compaction and this is also a deep compaction generally.

We have already discussed, two three methods shallow densification, deep dynamic compaction, rapid impact compaction and vibro-compaction also almost in the same line, but this is also a different technique. It is generally used for deep densification. This typically, the concept behind this let me take you to the first slide.

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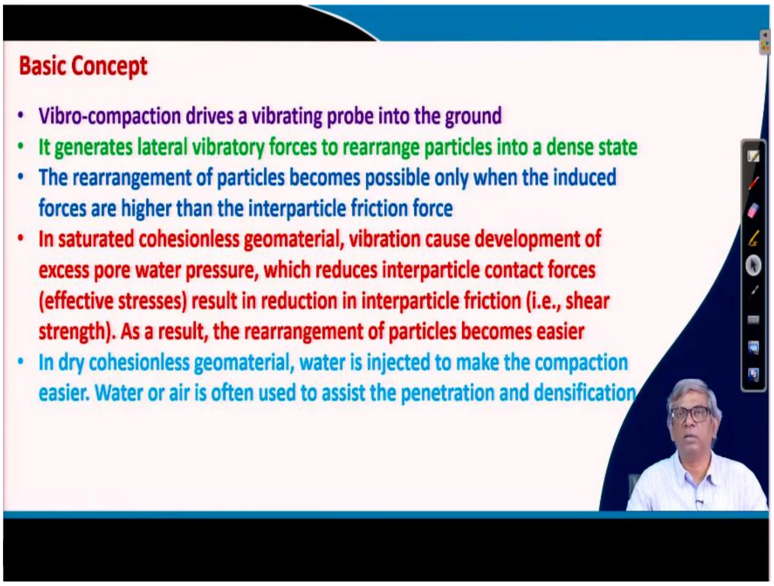

The basic concept in it that is, there is a probe that will be driven into the ground. And then, it will generate lateral vibratory forces to rearrange particle into a dense state. This rearrangement of particles become possible only when the induced forces are higher than the interparticle forces.

The probe which is giving vibration, like this, we have to give that much vibration so that, that induced force will be able to break the interparticle forces that will work on the interparticle forces. Then only particle will be separated and then they can be rearranged.

And in saturated cohesionless geomaterial soil, geomaterial means soil, vibration cause development of excess pore water and which reduces the contact forces and which in turn result in a reduction in interparticle friction and as a result the rearrangement of the particles become easier.

So, if it is a saturated and granular soil, then when you will give vibration and we know, this is a typical well-known phenomenon that is liquefaction. Liquefaction means actually when you are giving the force to the saturated granular soil and immediately the particle let us say, since it is not compressible, so initially, instead of contracting that pore fluids will be pressurized that is in the form of excess pore pressure.

And that excess pore water pressure generally causes the reduction in shear strength and if the shear strength is reduced that contact forces will reduce, and once the contact force reduce, then the particles will be easy to separate from each other. And that when it becomes separate to each other and then continuously vibrations are given, then particles will try to rearrange in a newer and denser state.

That happens when it is saturated soil. But if it is a dry cohesionless material, that time, this should not be there difficult to dry condition to rearrange. So, in that condition, we can inject water and then that will again similar phenomena will cause and that will help to rearrange the particle of granular materials to a denser state.

This is by and large so that means in a what is the concept in the probe? It will be driven in a particular desired depth where the soil is weak and then vibration will be given, enough vibration has to be given so that the forces given by this vibration should exceed the interparticle forces, friction forces and these can be easily obtained when it is a saturated granular material because in granular materials, when you give vibration, then there will excess pore water pressure development would be there.

That excess pore pressure development will cause the reduction in shear strength. That will also cause the reduction in contact frictional force and as a result, it will be easy to separate and rearrange in a more stable and denser state.

And when with dry soil, this can be accelerated by injecting water and when you put water together with vibration, then this again same the similar way, the particle can be separated from each other and they can be forced to rearrange in a more stable and denser state and that way, finally soil will be densified. When a particular place this is done, then it can be slowly come up and it can be densified. So, this is the by enlarge concept in your vibro-compaction.

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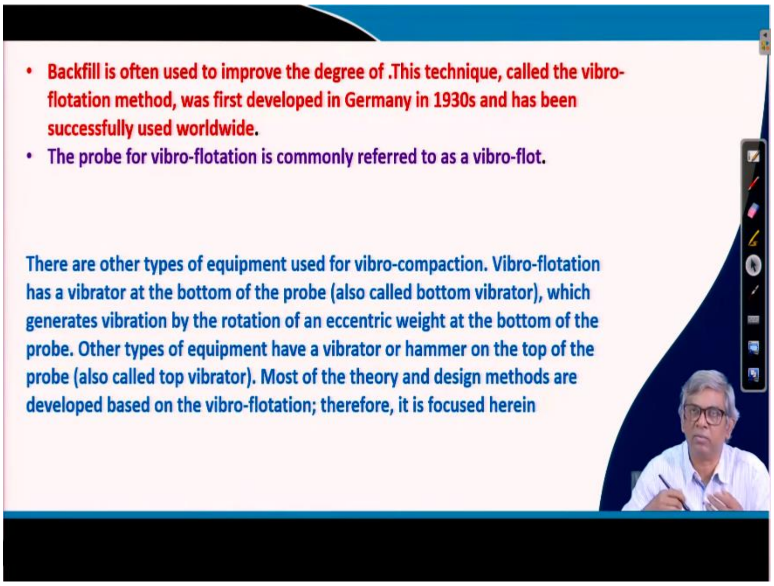

And, sometimes backfill so when this operation will be done, then automatically this will be subsidence and so that to make our soil to be densified at a depth. Sometime, we can backfill it and then backfilling will go that place is vacuum created and that place again, it will be further compacted and further more compact soil can be prepared. Without backfill also it is possible.

Backfill is often used to improve the degree of this technique, degree of densification actually, one word is missing and this technique called the vibro-flotation method and was first developed in Germany in around 1930’s and has been successfully used worldwide.

This is the technique vibro-compaction, it is more than nearly 100 years old and this is typically known as vibro-flotation and during that probe of vibrating and because of this vibration because of the arrangement, rearrangement of the particles, soil can be densified and simultaneously to make more compact, we can backfill it and again compact it and then surrounding soil will be further densified.

That is the by enlarge the concept. And the probe for vibro-flotation is commonly referred to as vibro-flot. Because of that this name is vibro-flotation. There are other types of equipment of course whatever we have mentioned used for vibro-compaction and vibro-flotation has a vibrator at the bottom whatever I have explained, the concept that the vibrator is at the bottom and we generate vibration by the rotation of eccentric weight at the bottom of the probe.

And, other types of equipment have a vibrator or hammer on the top of the probe and most of the theory and design methods are developed whatever we are using and whatever we know most of them based on the vibro-flotation and we will be focussing on that only. So, though there is another method in a vibro-compaction whatever concept I have mention, there can be different types.

One type is which is very commonly used that is, the vibration is given from the bottom and whereas there are some mechanisms where vibration can be given at the top. But though there are different mechanism available but the one which is giving vibration at the bottom, that is called as vibro-flot and that is generally used more frequently, more widely and whatever theories and applications are known, most of them based on vibro-flotation only. So, we will concentrate only or focus on that particularly.

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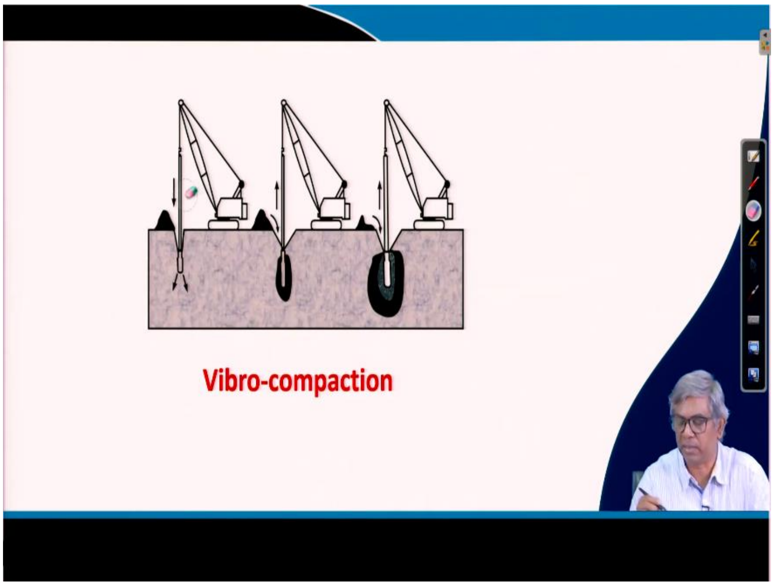

And this is the one whatever I have told, actually you can see here, that the soil maybe weak here at this zone, soil maybe weak in this zone. Because of these through these, this is the probe, a vibro-flot, this one. This has to be driven where actually to be densified. After that, this can be vibration will be given from continuously and because of that surrounding soil will be loosen and because of this vibration again further soil be getting into more stable and compact state, and when this will be done and you can see at the close to the opening, there are some materials, backfill material is kept ready, when it will be desired depth and sufficient vacuum created then this backfill can be poured in.

And you can see this poured here, once this backfill is poured here, then again through this probe, this probe can be lifted and again dropped like that, it can be compact. You can see this zone is actually by backfilled, this by vibration and all this zone is densified further because of this additional backfill material which is again compacted, so this much area is finally getting densified.

Like that you can make another close to that. So, it will be compacted this much like that, I can do here another. So, like that entire area will be densified. So, this is the mechanism of your vibro-flotation or vibro-compaction.

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And suitability where we can use this vibro-compaction and as I have mentioned perhaps in the beginning that vibro-compaction is suitable for densifying deep deposit of cohesionless geomaterial with up to 20 percent fines. Though it is mentioned 20 percent fine but preferably up to 10 percent because with increase which we will discuss later on, with increase of percent of fine the effectiveness of vibro-compaction will become less and this again, out of 20 percent though fine is allowed or permitted or it is effective up to 20 percent fine but most suitable with 10 percent fine.

Again, out of 10 percent fine, fine means actually sealed and clay both considered as fine soil but out of that again if the clay content is more than 2-3 percent, then this method become ineffective actually. I should have a clay content within 2-3 percent. If it is more than that, so total fine content supposed to be 10 percent and or maybe 10-15 percent or 20 percent maximum but no way clay content should exceed more than 3 percent.

If it is so, then your effectiveness of the compaction will be reduced. This is suitable, that means basically vibro-compaction is suitable for cohesionless geomaterial that is more important and there is no issue whether it is saturated or not saturated, in fact, saturated it will be better. If it is not saturated, if it is dry then we have to inject water and we can favourable condition we prepare and then we can apply this method.

So, basically it is cohesionless geomaterial where this vibro-compaction is more suitable. And again, it can have little bit of fine contents, so up to 20 percent but little less will be more effective. So, 10 percent is the preferable one and out of these fine contents, clay content should not go beyond 2-3 percent.

This is the area where actually we can apply effectively this method. And this person, Saito showed that there is a WBC, based on the field evaluation before and after vibro-compaction, the increase of fine content, as I have more than 20 percent densification become less effective or ineffective. So, that is why again and again I am giving importance to this fine contents.

This person has conducted some field test before and after vibro-compaction and he has seen that when the fine content become more than 20 percent, then your effectiveness of densification become less effective or ineffective and it is clearly shown that a low fine content, the increase of the SPT N value is more significant. That I will show you, he has given in a form of a plot that I will show you in the next slide. let me go to the next one.

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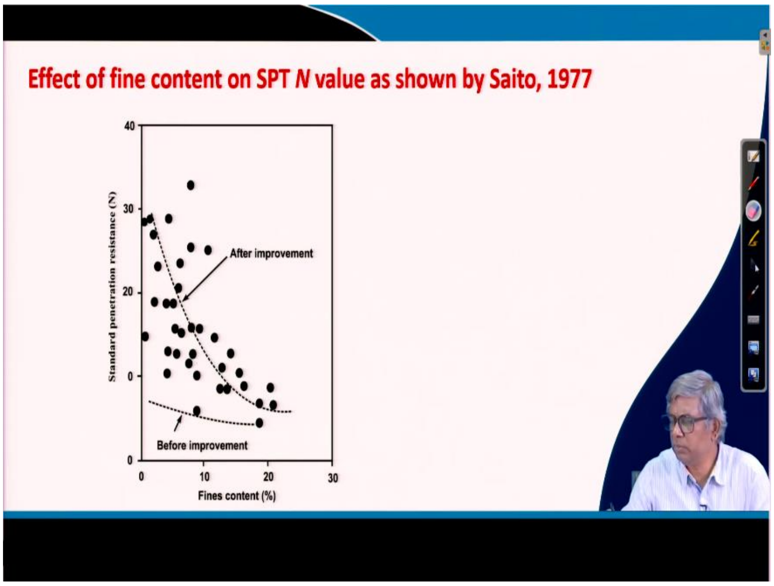

You can see this figure, that here actually standard penetration value and this side is fine content and you can see 10 percent, 20 percent and you can see here that before improvement, the standard penetration value with fine content, this is the line approximately so and after vibro-compaction, the fine content with your SPT value we can see that these are the value and the average line is drawn here, this is after improvement.

This data points are here and this data is actually before improvement. This line is before improvement, so one is less than 10 percent and another is close to 10 percent and SPT value are calculated and obtained and you can see at these two values by I-estimation or average trained line can be drawn.

This is suppose a train line for before vibro-compaction with the fine content, what is the SPT value and the same side with different percentage of fine contents SPT vibro-compaction is conducted then SPT also determined and those SPT values you can see scattered and from this scattered value, we can average train line can be drawn, this one can be considered as average train line and you can see that when 10 percent the increase of SPT value from here to here, whereas when it 20 percent, there is hardly an increase.

That is what it is shown, in fact, if you go beyond 20 percent then there may not be any very minor or nominal or very insignificant increase will be there. So SPT, that is the thing actually with the increase of fine content, the effectiveness of vibro-compaction significantly reduced. So, fine content should be as less as possible, if it is a clean cohesionless soil that will be better.

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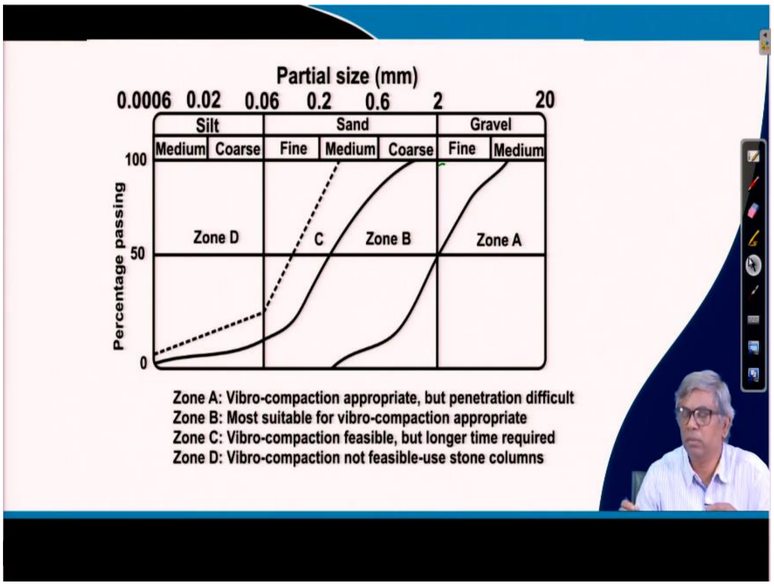

Let me proceed to next slide. You can see here, again we are discussing our suitability and you can see this is a chart given and you can see the grain size distribution there are four zones are divided, zone A, zone B, zone C and zone D.

And out of these four zones, these actually zone 2 and 3 means lot of fines are there, medium sand and fine and this is fine medium sand fine and here actually, mostly gravel and coarse sand and here actually coarse sand and fine sand. This zone B actually is supposed to be more suitable and zone A somehow, a vibro-compaction can be done but it will be little difficult because of large size of particles.

So, with vibration rearrangement by large size particle will be little difficult. But still it is not impossible, something can be done here and most suitable here and these zones also it can be done but it will take longer time because of more fine contents and zone D almost difficult to densify by vibro-compaction method. So, this is the chart given. So, if you have a particular site soil, then immediately you can draw the grain size distribution and you can see where it is falling.

If it falls here, then it should not be chosen. Similarly, if it falls here, we can try but it will not be that effective, lot of energy will be required but if it falls within this zone, immediately this is the best method to densify the soil. So, this is the way actually the method of a particular ground improvement technique, it will be chosen.

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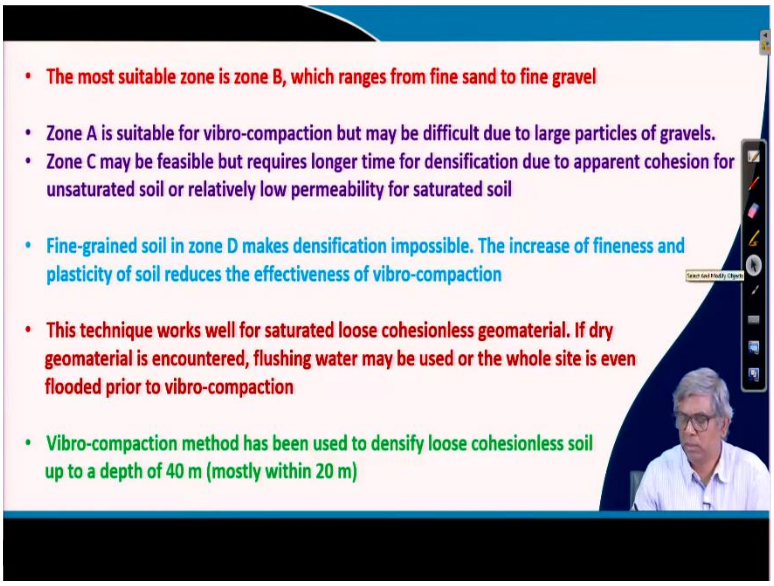

Let me move to next slide. So, still we are talking about suitability. Whatever figure I have told already explained. Once again, I will be explaining with details, written details you can see. As I have mentioned, the most suitable zone is zone B which ranges from fine sand to fine gravel. Fine sand, fine gravel and then it will be easy to rearrange particle and put and force them to be in more stable and denser state.

And as I have mentioned, zone A is also suitable for vibro-compaction but maybe difficult due to large particles of gravels which will be sometime rearranging more energy will be required. Zone C again maybe feasible, it is not good actually. Feasible means if you do not have other options, you can go for it but it will be little difficulty will be there. So maybe feasible, requires large time for densification due to apparent cohesion for unsaturated soil or relatively low permeability of saturated soil.

So, this is the reason why it will be taking longer time. That your apparent cohesion sometime will resist and it will not allow or it will prevent to rearrange after sometime and then only it will be possible. So, that is what and fine-grained soil in zone D makes densification impossible. So, if it is a completely fine soil whatever vibration you give, it will not be densified. So that is what the increase of fineness and plasticity of soil reduces the effectiveness of vibro-compaction. So that is the fine and even plasticity.

When more clay particles are present means plasticity will be increased and these two affects actually reduce the effectiveness of vibro-compaction. This technique works well for saturated lose cohesionless geomaterial. Geomaterial means soil or sand and in dry geomaterial, if it is encountered, the flushing water maybe used or the whole site is even flooded prior to vibro-compaction.

We know that vibro-compaction actually in the saturated cohesionless soil will be more effective and if it is dry soil then we can prepare the site just by flooding beforehand and then you can do it. So that is what is the easiest way to do it and vibro-compaction method has been used to densify loose cohesionless soil up to a depth of 40 metre, that is most important.

So far whatever method we have discussed, that a shallow densification means it will be only in the levee thickness 30-40 and if you buy that way of course levee thickness we can go for 4-5 metre for impact and other things but in general levee thickness is equal to 30-40 metre or maximum 50 centimetre whereas rapid impact compaction, it will be 5-6 metre. Deep dynamic compaction, it is up to 10meter.

So, these are range so far, we have got but this vibro-compaction, you can use up to densify soil up to depth of 40 meter. How it is done actually suppose if in fact surface soil 2-3 layers maybe quite good but at a 15metre depth, soil is loose. In that case actually suppose that soil sometime to be densified, the vibro-compaction will be the best method because this is the ground surface, you can just penetrate and reach probe will be pushed there and then vibration will be created, vacuum will be created and then backfill soil will be poured here and then it will fill and compact and then slowly we can go upwards.

So, this way actually, this maximum depth up to which the compaction, soil can be densified by vibro-compaction method is 40metre. This is actually to be noted because so far whatever method we have discussed was up to 10metre but this is the method where actually you can go up to 40metre.

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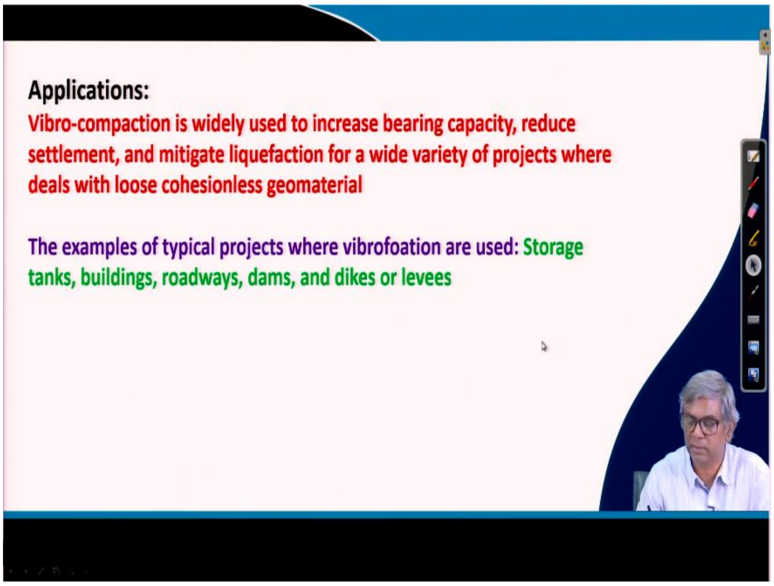

let me go to the next slide. And where we can apply? Application everywhere where this type of soil, this is vibro-compaction is widely used to increase bearing capacity and reduce settlement and mitigate liquefaction for a wide variety of projects where deals with loose cohesionless geomaterial.

Loose cohesionless saturated soil, so you can add saturated cohesionless soil that is more effective because the bearing capacity improvement sometime not that effective. Most of the time all will be done but some area where actually the soil, maybe the certification and there may be different depth and different type of soil is there, so this is the depths of soil. This soil may not be liquefied but this soil will be liquefied.

There is a liquefaction potential is very high. This area actually very effectively can be densified by vibro-compaction. That is why the vibro-compaction is used widely to increase not only bearing capacity, it can reduce the settlement of the foundation and also basically to mitigate the liquefaction potential for a wide variety of projects where we deal with loose saturated cohesionless geomaterial.

Suppose, this is a building here and these are the different layers and suppose one layer is going to get liquefied, then because of the liquefaction of the soil, this building may have some damaging effect. So, because of that if you find such soil then this can be densified by this method. And then examples of typical projects where vibro-flotation are used storage tanks, buildings, roadways, dams, dikes, levees etc. there are different areas can be.

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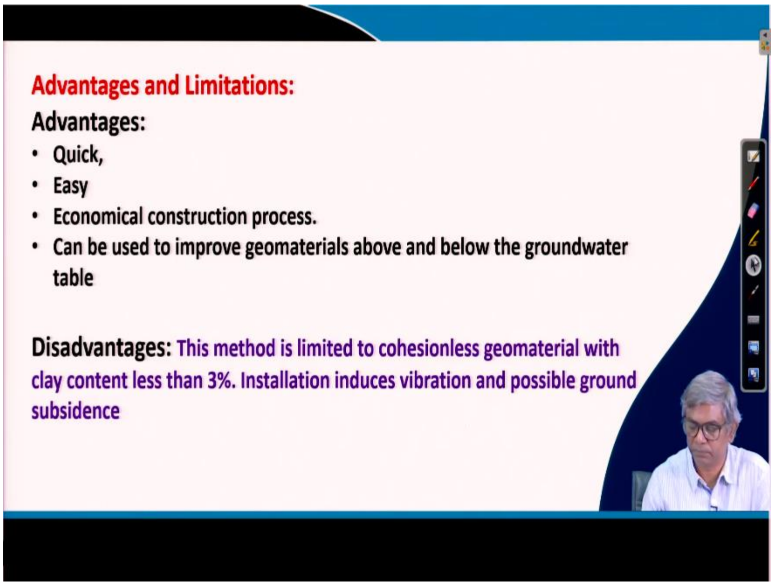

Next slide, advantage and limitations of this your vibro-compaction. Advantages actually most advantage perhaps it is a very quick method. It is also very easy, economical construction process and can be used to improve geomaterials above and below the groundwater.

This is actually whatever method we have discussed previously, if water table is there closed to ground service, it is not good or it is not suitable but here, whether it is below or above groundwater table, both can be used. Also, in addition to that it is quick, easy and economical.

And disadvantage is this method is limited to cohesionless geomaterial. This is important. If the site is fine, so fine grain soil then this method cannot be adopted, that is the advantage and limitation of this method.

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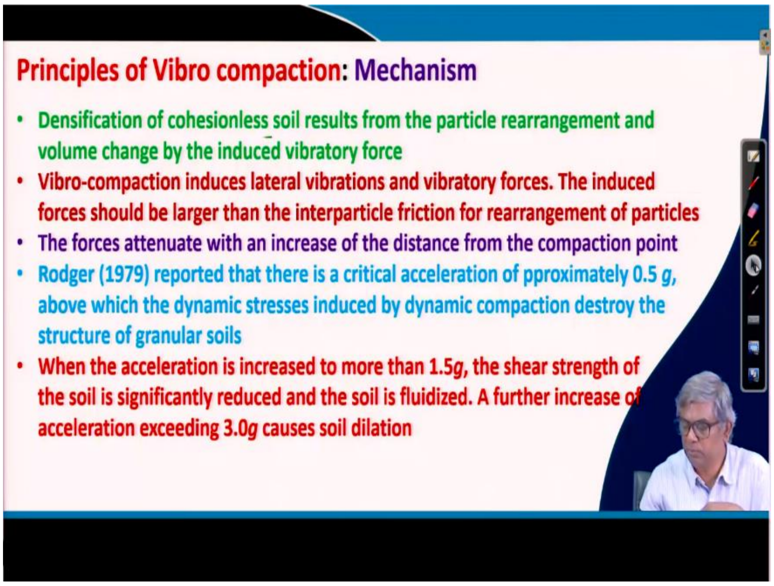

Let me go to the next slide. So, principle of vibro-compaction so mechanism. What is the mechanism here? Mechanism already we have mentioned densification of cohesionless soil result from the particle rearrangement and volume change induced by vibratory force. So, whatever probe we insert in the ground and then because of the insertion in that probe vibration, particle rearrangement happens and because of this particle denser state and then volume change will be there.

That means some additional voids will be removed and voids will be created and that voids actually that means soil can be sent converted into denser state. This is the densification of cohesionless soil results from particle rearrangement and volume change by the induced vibratory that is first thing. And second thing is vibro-compaction will be lateral vibration and vibratory forces. The induced forces should be larger than the interparticle friction forces.

In the beginning itself I have mentioned that you are giving vibratory force how much is required till that it overcome or exceed the interparticle friction force. Otherwise, the particle will not be separated and it will not be and your rearrangement will not take place. And forces get attenuated with distance because we are giving vibration here, close to the soil will be more vibration but we will go away from this then it will be attenuated.

And we can see that this person, Rodger reported there is a critical acceleration of approximately 0.5g above which the dynamic stresses induced by the dynamic compaction destroy the structure of the granular soils. At 0.5g, start destroying and once the acceleration is increased more than 1.5g, the shear strength of the soil is significantly reduced and the soil is becoming fluidized.

Then a further increase of acceleration exceeding 3.0g cause soil dilation, volume change. So, these are the things that means we have to give vibration and then because of that volume change and change will take place. At the volume change actually by that only densification will happen and then the forces get attenuated to distance and there is a particular acceleration is needed that is actually 0.5g is minimum to destroy that frictional force to break the rearrangement contract particles.

And if you go beyond 1.5g then soil shear strength of soil will be reduced significantly and become fluidized and further increase if there will be dilation will take place. So, this is the one by enlarge the principle in which or mechanism in which the vibro-compaction work.

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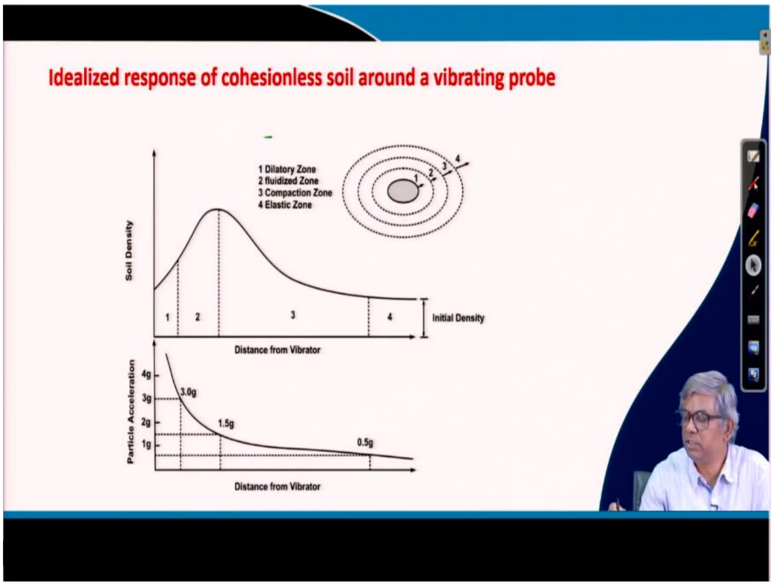

Let me go to next slide. And you can see here, so idealized response of cohesionless soil around a vibrating probe. You can see here, that this is the suppose the probe of the centre point and close to this actually zone 1, it will be 3g. if it is 3g and this zone it will be dilatory zone and zone 2 actually this one, it will be fluidized zone. And this is between 1.5 to 3g and this zone actually 0.5 to 1.5, this is actually compaction zone.

So, this is the area, the most effective to densify the soil. Then 0.5g to 1.5g so this is the fourth is the elastic zone. This soil density, actually it is giving soil density with distance from the probe. So, that means density will be close to this will be less and slowly it will increase and then it will be this one. This zone will be most that is called compaction zone. I will discuss again further elaborately maybe in the next lecture.

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So, perhaps with this I can close here this lecture. I will take again same thing in the next one and try to again discuss further mechanism and then I will go for another necessary requirement for vibro-compaction. Thank you.