Ground Improvement
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Lecture 20
Vibro-Compaction (Contd.)

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Good morning. Let us continue with vibro-compaction mechanism. In the previous lecture we have just mentioned what exactly is the mechanism by which, by vibro-compaction method, soil get densified and what is the vibration level required that we have seen, and then densities, or situation from the probed location to away from the probed location how it varies that we have shown. Just we have discussed but once again I will take from there and I will go further. So let me take the slide again.

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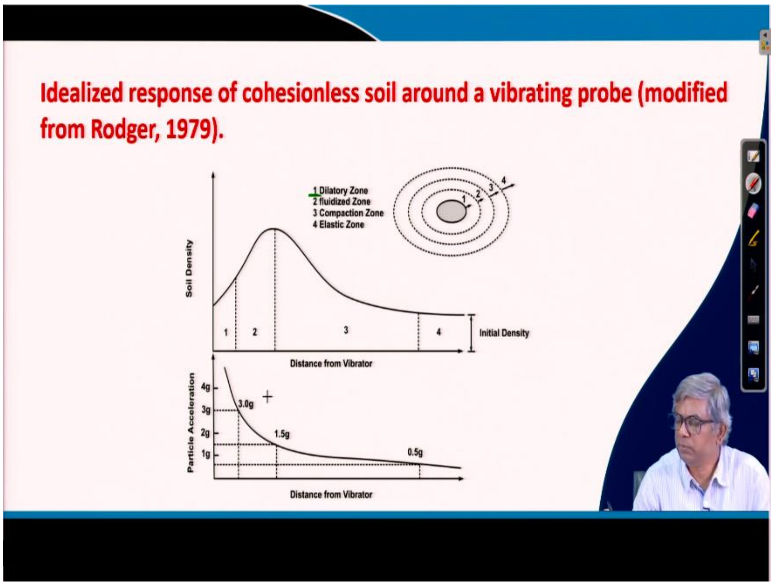

And you can see that the idealized response of cohesionless soil around a vibrating probe and which is given by Rodger in 1979. You can see this, we have discussed already, that up to 0.5g vibration if I do, then it can cause the separation of particles, that means area arrangement will start taking place. And at 1.5g actually beyond 1.5g then your shear strength of the soil will be reduced significantly and then soil will be fluidized. When we go beyond 3g, and then soil will start dilating.

That is what and because of that density will be reduced. So that is why, so this figure actually shows how the density varying actually with centre point because the vibration also attenuated so the distance when you go away, so vibration level will be reduced. This zone particularly more effective for compaction. Zone 1, 2, 3, 4 actually it is mentioned here, you can see and corresponding here different acceleration level that also shown here. This is by enlarge mechanism of vibro-compaction. Let me go to next slide.

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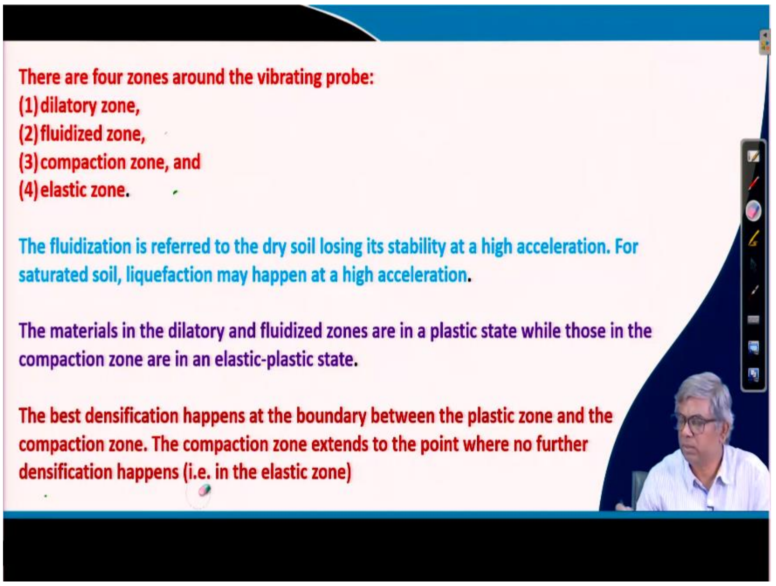

You can see this we can once again explain elaborately, there are four zones around the vibrating probe. That is what I have mentioned that dilatory zone, fluidized zone and compaction zone and elastic zone. The fluidized zone is referred to the dry soil losing its stability at a high acceleration and for saturated soil, liquefaction may happen at a high acceleration.

The materials in the dilatory and fluidized zone are in a plastic state, while those in the compaction zone are in the elastic plastic state. When you do this, the different zone what is the state that is what is mentioned here. And the best densification happens at the boundary between the plastic zone and the compaction zone.

We have mentioned four zones like this. This is the compaction zone and this is the plastic zone, so the boundary, so around this best compaction happens. So that is what is mentioned. So, it is true also because we are getting maximum density here, so this zone actually you can say the most effective zone.

The best densification happens in the boundary between the plastic zone and the compaction zone. The compaction zone extends to the point where no further densification happens. So, that curve that is shown is going like this. Here ultimately no change happens beyond something that is the compaction zone. This is called compaction zone, this is where actually compaction zone extend up to which where there is no change, volume change is taking place. So, this is once again whatever I have shown in the figure that is again clearly written statement is given, what is what and what is the different zone and how it happens. Let me go to the next slide.

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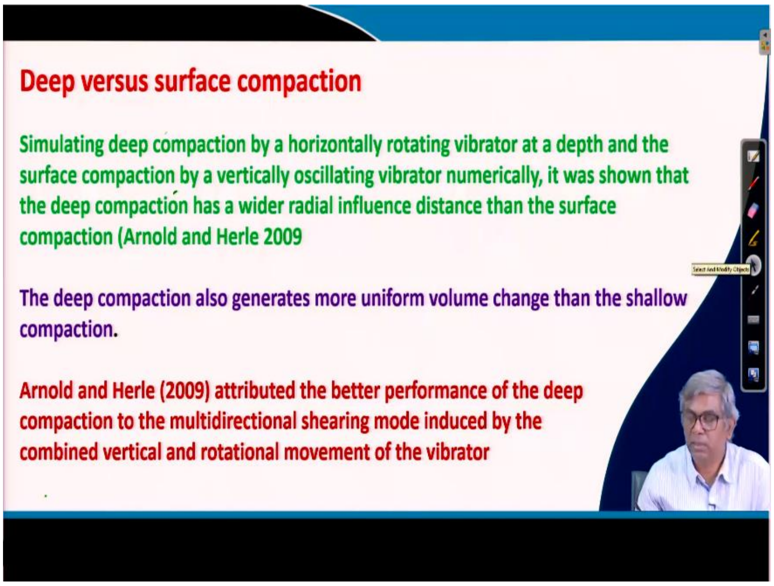

Deep versus surface compaction. You can see that someone simulated by numerical methods and the surface compaction and also deep compaction. And by doing that, it is shown that the deep compaction has wider radial influence distance. That means, if I do a vibration here, then suppose this is the point so the wider radial that is more area will be covered under this. Whereas, if I do at the surface, it will not go that wider.

That is what it is mentioned, simulating deep compaction by horizontally rotating vibrator at a depth and the surface compaction by vertically oscillating vibrator numerically, so simulated by how? Numerically. It was shown that the deep compaction has a wider radial influence distance than the surface compaction and who has shown this, by this person. That means, so this is actually the simulated by numerically and one is vibration given at depth and vibration given at the surface and then what it has shown?

That deep compaction will have wider influence that the surface compaction. That is more precise statement and deep compaction also generates more uniform volume change than the shallow compaction. That is again if I do by the deep compaction, the uniformity within this soil will be more uniform density will be achieved compared to surface compaction. And also, he has mentioned why it is happening, the vibrant compaction why it is affected?

This attributed the better performance of the deep compaction to the multidirectional shearing mode induced by the combined vertical and rotational movement of the vibrator. So, multidirectional shearing mode, that actually is causing more effectiveness. That is the main gist of the statement. By combined vertical and rotational movement, the multidirectional shearing mode happens and that will cause more effective densification. So let me take to next slide.

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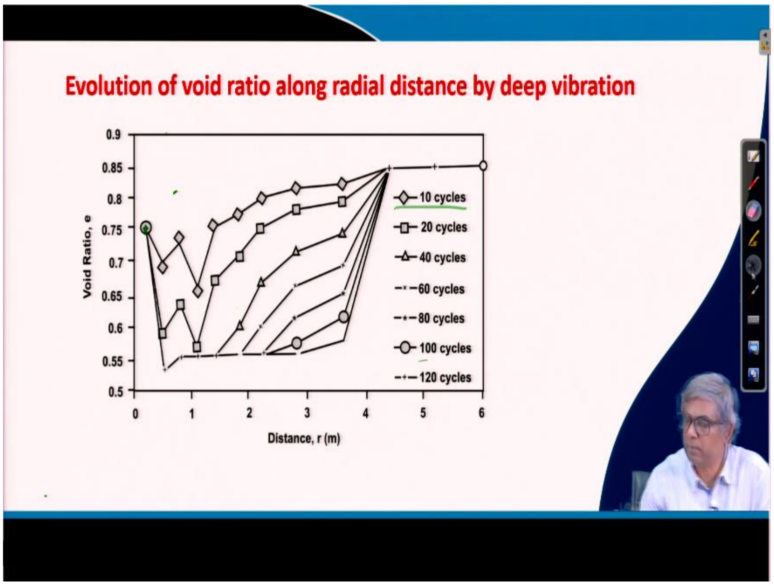

And you can see here, whatever already numerically I simulated and whatever statement is shown same thing is in the form of figure is presented. You can see evolution of void ratio along radial distance by deep vibration. You can see here you are getting distance this way and void ratio this way. Initially void ratio is here and we are giving vibration of different cycles also and you can see that whatever maybe the affect is up to distance, up to this much distance.

So, whatever you can see that the reduction in void ratio, you can see it is reduced. This bottom most line is the 120cycle. So, it become from here to here and then it became almost constant and then it is reduced because beyond that the effect will not be there. It will be reduced and then it will not know effect and then if it is 100cycle, then again from here to here reduced and then this is the way and there is no effect here, then 80 cycle, then this is star.

This is the one, you can see here. From here it is reduced here, this is the way so that means with the increase of cycle again, it is going far away from the location, initial origin. With decrease of cycle actually, the effect is reducing also, distance this is not going that far. But by enlarge, we can see that effect is up to 3.5 to 4 times of radius. Whereas, same thing if you see for a deep dynamic compaction and if I do compaction at this particular location, how far it is going radially that can be seen in the next figure.

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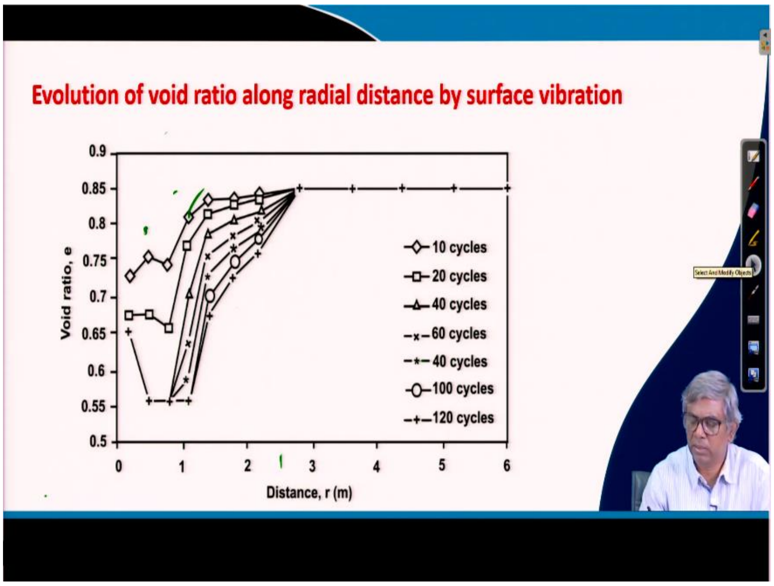

You can see the next figure. You can see here the evolution of void ratio along radial distance by surface vibration and again different cycles are applied and you can see here, void ratio is here and then it is going only one and sometime it is going 2.5 maximum. And again, you can see maximum 2.5 where there is 3.5 and with different cycle again similar effect will be there with 10cycle, 20 cycle. This is 10cycle, this one. This is 20cycle, this one.

With increase of cycle reduction will be more and distance also more and with lesser frequency the reduction of void ratio also will be less and distance are effect, the radial distance also will be less. But by enlarge, what we concluded actually that the deep compaction radial influence will be more than the surface compaction. This is shown by two figures which is actually numerically generated, not experimental data of course. Let me go to the next slide.

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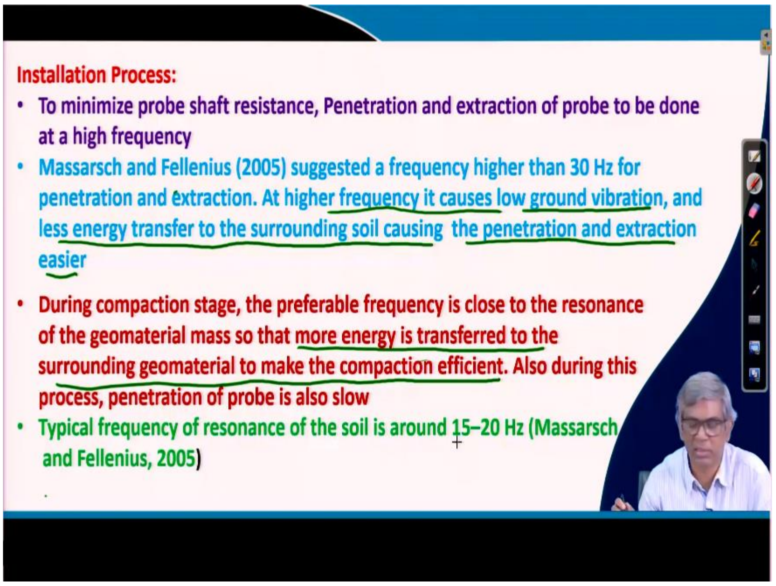

The installation processes. Installation process means when you do vibro-compaction, how will you proceed? First of all, we have to drive the probe and while driving the probe, you should have minimum resistance and to minimise the probe shaft resistance, penetration and extraction of probe to be done at a high frequency.

Only when it will be driving the probe at a high frequency you have to do because at a high frequency, resistance to penetration will be reduced. And this person, Massarsch and Fellenius suggested a frequency higher than 30 hertz for penetration and extraction. Even when penetration high frequency is required, even extraction also high frequency.

Otherwise, extraction time, then if it is low frequency surrounding soil will become closer and it will be more friction will there difficult to extract. So, for extraction and the driving time, penetration the 30 hertz frequency. At higher frequency, it causes low ground vibration and less energy transfer to the surrounding soil causing the penetration and extraction easier. Why it is required at higher frequency?

At higher frequency causes low ground vibration and less energy transfer to the surrounding soil, causing the penetration and extraction easier. So, that means when you give high frequency, this high frequency will be surrounding soil will be there more. More surrounding soil will be excited and will be loosen and so transfer will be less to the surrounding soil further and transfer of vibration will be less and because of that it will be easier to extract and drive. And during compaction stage, the preferable frequency is close to the resonance of the geomaterial mass.

So, your particular soil mass you are densifying, you have definite resonance frequency and if you can set or vibrate at that frequency, it will be more effective because during that soil vibrates with more frequency and then separation will be possible so that more energy is transferred to the surrounding geomaterial to make the compaction efficient.

So, if you make the frequency close to the resonance frequency of material, then more energy will be transferred to the surrounding geomaterial to make the compaction efficient. This is the reason why you need to do that. Also, during this process penetration of probe is also slow.

During compaction stage, if the probe gets penetrated then it will not be effective. It will be particular place it has to vibrate it so because of that if you low frequency, the resonance frequency which will be comparatively lesser and that frequency will be transfer the energy to geomaterial and make compaction efficient and also, the low frequency that the during vibration it should not penetrate easily. That also you have to see.

Typical frequency of resonance of the soil is around 15-20 hertz. That means when you are driving the probe, you are using around 30 hertz frequency. When after reaching the desired depth, where you need to compact then that time you have to again further vibrate the probe. That time when you vibrate the probe you have to keep lower frequency and it is supposed to be close to the resonance frequency of the material which is getting testified and we have seen that for wide range of material the resonance frequency is around 15-20. So typically, you need to vibrate, the vibration stage you need to set frequency around 15-20 hertz. So, this is the installation stage, you have to do this way.

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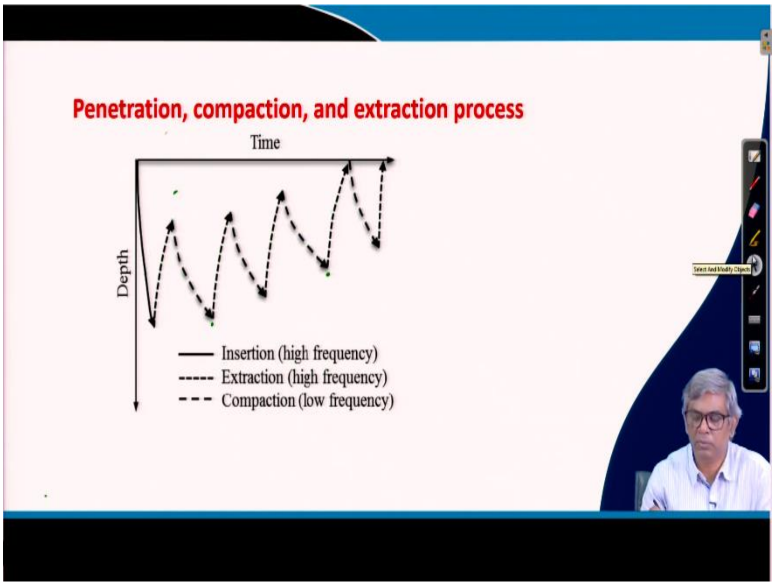

And now we can see here, it is shown nicely in this figure that you can see with time, suppose you have 2-3 hours of operation. Initially, by increasing the frequency you can see depth. By increasing the frequency, you reach suppose this is the depth where you have to densify and then again reduce the frequency and get the densified. I will get densified and then reduce the frequency, then you come here and then again you can see then you can do at this point compaction which will be low frequency compaction and then you will reach at this point with time and again you can extract by this way and reach there and then again compaction, then with low frequency, then high frequency extract then again you low frequency, then you compact and then it will be again high frequency, you extract and then it will be if you give low frequency and compact.

Like that entire with time this operation will continue. So, penetrations, compaction and extraction process how it will be done. This is the way it will be done. Then insertion high frequency, this is the solid line and then extraction. Initially we are in the solid ground we are going. And when you are extracting it is not solid. It is already gone, then you are just lifting up so because of that again extraction, the high frequency both are high frequency otherwise it may have resistance and when it will be compacted it will be low frequency.

This is compaction, this is actually driving, this is extraction, this is extraction, this is extraction and again this is also extraction. Let me go to next slide.

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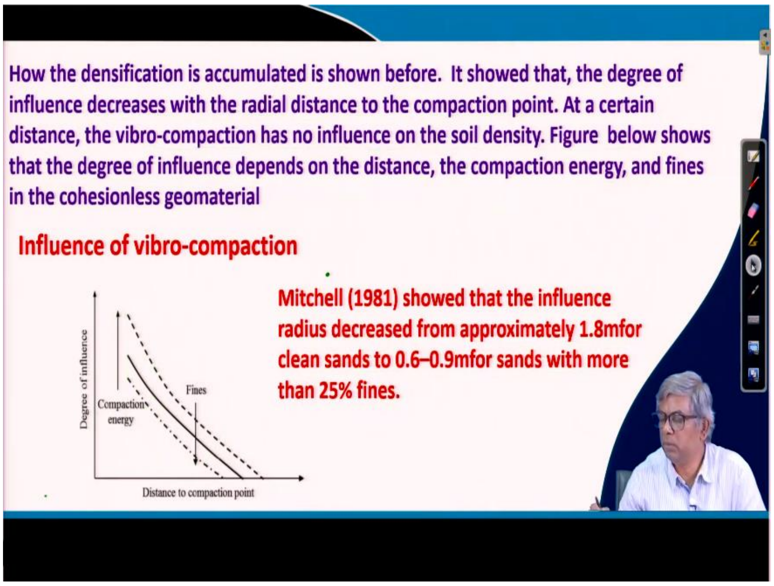

Now, how the densification is accumulated around is before actually we have shown where it is showed that degree of influence decreases with the radial distance. So, density whatever close to some distance, that is there. So, degree of influence decrease with the radial distance to the compaction points. If this is the compaction point and with influence it decreases when you go from the radial distance.

At a certain distance, the vibro-compaction has no influence on the soil density. That means as we have shown like this, there may be no change at all and this figure actually, this figure below shows the degree of influence. Again, already we know that degree of influence when you go away from the compaction part will be reduced but for that there are several other parameters which influence this parameter.

You can see those are actually the influence on the distance, the compaction, energy and fine in the cohesionless geomaterial. You can see here this plot is given degree of influence. In this direction degree of influence is shown in this direction and distance to compaction point, so distance to compaction point at degree of, so from here actually, degree of influence when you go away it is increasing. So, this is supposed average line and again if we have a fine content more, this is the degree of influence.

If more fine content, so degree of influence will be reduced and again if you have compaction energy more, if you have more compaction energy, the degree of influence will be more. Then degree of influence how it will be, so whatever we see general trend again that can be influenced by the fine contents and the compaction energy. Compaction energy it will give the influence increase and if the fine content increase, then degree of influence will be reduced.

That is what this is the three boundaries suppose if I show this is the average line because of the fine content it can fall from here to here and by increasing the compaction energy, it can go from here to here. That is the thing. Average line can be this. This figure actually indicates that not only with the distance from the influence will be there, radial distance, the compaction point, degree of influence decreases with radial distance.

This is the common and again further, degree of influence will be decreasing further if fine content is more and degree of influence will be increased further if the compaction is more. That is the figure shown here. This figure explains that. This person showed that the influence radius decreased from approximately 1.8 metre for a clean sand to 0.6-0.9 metre for sand with more than 25 percent fine.

Suppose when a clean sand is used, this is supposed compaction point, the influence suppose goes up to 1.8 metre and when the same sand contains 25 percent fine, the influence only go between 0.6 to 0.9. So, from this to this, 0.6 to 0.9. So, maximum 0.9 metre so that is half.

That means that fine contents already we have mentioned that when there is a fine content there is a vibro-compaction is ineffective or less effective and here it is indicated that for a particular observation that when a particular clean sand is compacted by or densified by deep dynamic compaction, the influence goes up to 1.8 metre radial distance whereas, same soil added 25 percent fine, the influence reduces to 0.6 to 0.9 metre. It becomes almost one-third to half distance. So, from here actually it can be obviously concluded that fine content is unsuitable for deep dynamic compaction. Let me go to the next slide.

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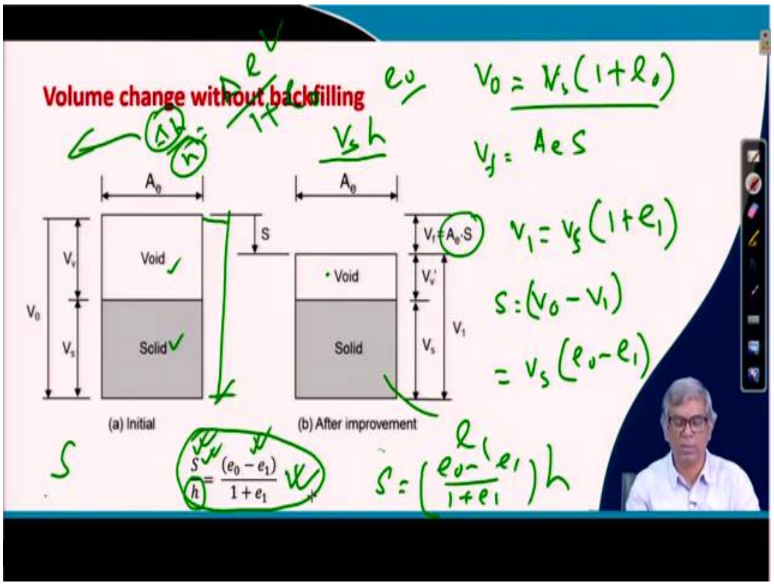

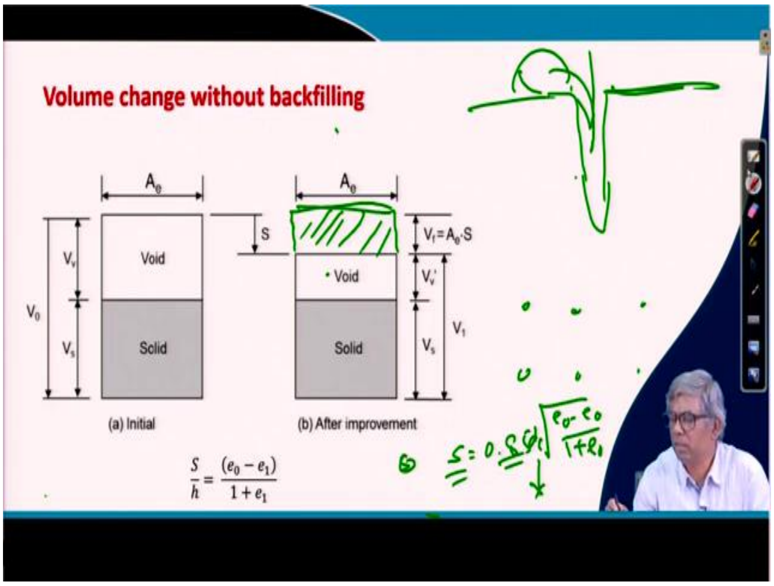

That volume change without backfilling as we have mentioned that when you do vibro-compaction, by vibration particles get rearrangement and then volume change will take place. But if you want to keep the same level and if you want to reach the same level, maintain the same level then backfilling can be done and so, with backfilling if you do, then this is actually typically we can emerge in this, the original volume of soil at a particular site.

This is the solid and this is the void. So V_v and V_s and suppose after vibro-compaction this volume is reduced to this volume and then void V is reduced to V dash and then this V_a become the you can say it is the settlement or subsident and then we can see that what you can do this original V naught, so total this is the settlement, this is noted here and if the depth of improvement is H, the S by H can be converted to or this equation can be derived that S by H equal to this.

So, how it is done? The original volume supposes initially the void ratio was V naught and the amount of solid suppose Vs, then V naught can be expressed as Vs into 1 plus V naught and whereas this one, your finally V_f become Ae multiplied by S and V_1 equal to Vs multiplied by 1 plus e_1. And then, your V naught minus V_1 is nothing S equal V naught minus V_1 and if I do that then it will be Vs and e naught minus e1.

$$V_o = V_s(1+e_o)$$
$$V_f = AeS$$
$$V_1 = V_s(1+e_1)$$
$$S = (V_0 - V_1)$$
$$S = V_s(e_0 - e_1)$$
$$\frac{S}{h} = \frac{(e_0 - e_1)}{1+e_1}$$
$$S = \left(\frac{e_0 - e_1}{1+e_1}\right)h$$

Here V_f actually equal to Ae into S. So, original when the soil was original soil then suppose this has a Vs multiplied by H. So, once again I can show this one. So ultimately, we will get S by H that means settlement divided by depth, that we can find out how much it can be expressed as e not minus e_1 by 1 plus e_1 and you can see here that everything is denoted here. e naught is the initial void ratio of the site and after compaction this final void ratio is e_1, then S by H can be expressed e naught minus e1 by 1 plus e_1 and so, this is actually nothing but whatever consolidation you have seen that delta h by h equal to del e by 1 plus e naught. So, here e naught minus e_1 is nothing but delta e and delta h is nothing but S and H is nothing but the original volume, vertical depth.

Same formula is almost we are getting here. This again I will repeat this part. What we want to express here that when you do your vibro-compaction without backfilling, then this is the relationship can be established that what is the amount of settlement if my depth is this much, original volume is this much. Final void ratio is this much, I can find out what is the settlement will be there or what will be the ground, how much will be subside.

So, S will be equal to e naught e1 divided by 1 plus e1 multiplied by H. H is the depth of improvement. If I know the depth of improvement, before improvement what was the void ratio and after improvement what is the void ratio?

What will be the total settlement I can find out from this equation, in between how it is coming I can show once again in the next class. So, let me go to the similarly second one, when it is done with backfilling. We will repeat this one in the next class without backfilling somehow it is not there. We will discuss in the next class. That means what would be there? Suppose, this same problem what you will do, maybe instead of keeping the same level so we have to backfill this one.

Whatever we have shown that there is a probe and then the soil from where it is giving and then compacting finally, we are keeping the same height. So this much backfilling if it is there, then ultimately, we can find out that the spacing required for this vibro-compaction, what spacing actually you have to do to maintain that. You can find out the spacing. This is not the equation, but different equation. That is small s equal to 0.85 dc under root e naught minus e_1 divided by 1 plus e naught and this dc is the diameter of the vibro-compaction and 0.85 multiplied by dc under root e naught minus e naught by 1 plus e_1. This is the spacing when it will be using in a square pattern and if you use in the triangular pattern, it will be again the value instead of 0.85, it will become 0.95 and everything will remain unchanged. So, this thing actually that means when you do there are two options of doing vibro-compaction, without backfilling and with backfilling.

$$S = 0.85 d_c \sqrt{\frac{e_0 - e_0}{1 + e_1}}$$

If I do without backfilling, then automatically after compaction it will be subside, the ground level will be lowered. How much it will be lowered? How to find out, if I know the void ratio before compaction, void ratio after compaction and if you can find out the depth of improvement.

These three parameters if I know, then I can find out how much settlement is going to take place finally and similarly, alternative option, if you want to keep the level same then simultaneously during vibro-compaction we are backfilling and compacting and then if you do that then at what interval and what diameter, if diameter can be chosen and if a particular diameter is chosen then based on that what spacing to be used so that before whatever void ratio and final void ratio whatever is required, if it is known then I can do from this equation.

So, this of course I will repeat once again, this particular portion how we are getting that. This is a simple one but somehow it is not there and also time is not there. So, we will do in the next class.

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With this thank you today, thank you all.