Ground Improvement
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Lecture No. 23
Application Problem and Quality Control

Hello everyone, let us once again join in ground improvement lecture class and I was discussing and I was in module 5 and it was a, topic was vibro-compaction. And I have discussed various aspects of vibro-compaction including design aspect, construction aspect. And only perhaps I have not taken the application problem, also quality control and assurance this part only I have not taken yet.

Today I will try to address those, these parts that is application problem one or two problem I will be taking discussing on that. And then quality control how what is the involvement in quality control for this type of project like vibro-compaction and let me come to.

Before going to that problem, I am trying to show you why I mean number of times I have mentioned square pattern, I have mentioned triangular pattern, and then we are taking area with respect to spacing. How we are taking? I have told, I will show you later on but I have not done yet, it will come almost many applications. Today I am planning to show that first and you can see this one first slide.

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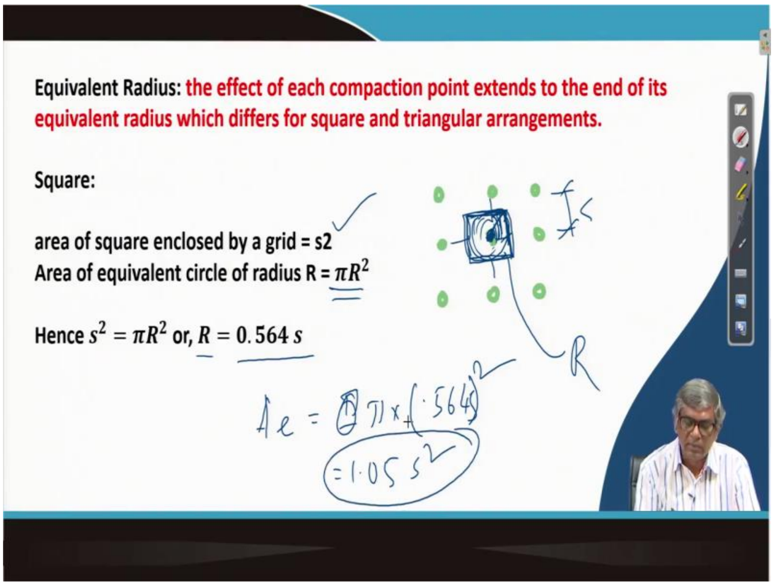

Equivalent radius. You know that a square pattern, suppose this one and this one, this is a square pattern. And then what I can find that area of influence can be of this, of this, and this. This distance will be half of spacing, again this distance again half of spacing, this distance half of spacing, this distance also half of spacing. As a result, this square also will become s by s, but when there is a circular, vibro-compaction is a probe is a circular.

That way it will be this is some centrally column will be there and around that densification is expected. It will be circular, not exactly it will form a square. If I assume this circle, this square into an equivalent circle that is suppose extent of the influence, in that case is area of square enclosed that is that means for this vibro-compaction point this is the influence area suppose, then what will be the area if I consider spacing is s, then it will be s square.

$$\text{Area of square enclosed by a grid} = S^2$$
$$\text{Area of equivalent circle of radius } R = \pi R^2$$
$$\textit{Hence } S^2 = \pi R^2 \, or, R = 0.564S$$
$$A_e = \pi (0.564)^2 = 1.05 S^2$$

And if I consider the radius of this equivalent circle is equal to R, then the area will be pi into R square. And s square equal to pi R square, then R equal to 0.565 s or wherever I am using Ae equivalent area or influence area, then that will be nothing but pi by 4, or I can say pi multiplied by 0.564, 0.564 s square.

So, it will come 1.05 s square, that means, if I get a square pattern and I want to know the influence area, directly I can use this format that is what I wanted to show you, number of times are mentioned that this is the one. Similarly, if you take a triangular pattern and then how it will be, let us see that. Triangular pattern and let me go to the next slide.

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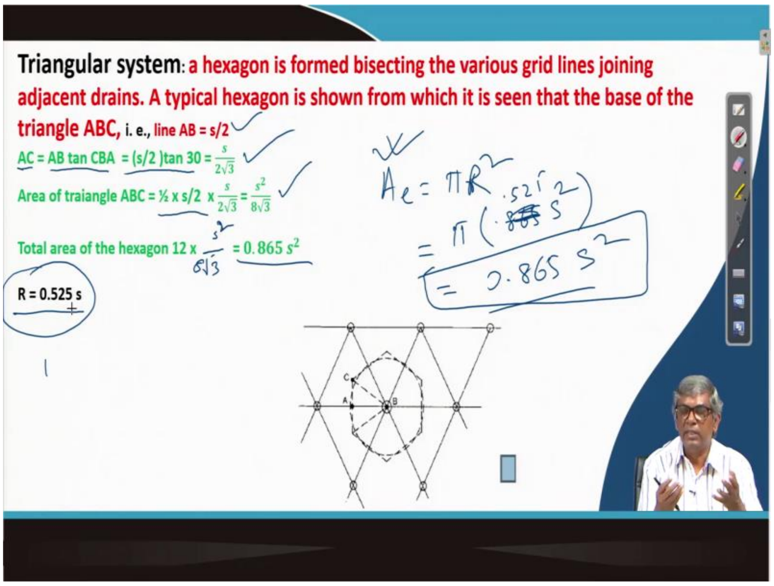

And you can see that triangular pattern, so how it is? We have shown here, you can see this is one point, this is one point, this is one point, this is one point, these are three angle, these three are forming triangle. So, influence of this particular one how I can find out, I can go along this half, I can go along this line half, I can go along this line half, I can go along this half, I can go along this half, I can go along this half.

So, like that perpendicular line I can draw. So, like that I can draw and I can get a hexagon, you can see these hexagons ultimately the influential area for a triangular method will be hexagon, but when as I have told the previous case then vibro-compaction is done by probe, which is cylindrical in shape. So, the cylindrical column will form and then densification is also expected cylindrical.

That means, along these there will be influence that will be area of influence with radius r. That is what I have to find out that means, I have to relate r with s, on area with s, the influence area with s. So, that is what you can see the triangle if I take and line AB if I take AB will be nothing but s by 2 that is what it is mentioned here. And AC equal to AB tan CBA and that can be written from that trigonometry rule s by 2 tan 30.

So, it will be s by 2 root 3 and area of triangle ABC that means a small triangle then it will be half multiplied by height multiplied by another site, base s by 2. So, if I do all together, then this you do not have area equal to s by 8 root 3. And like that, similar to this triangle, we can see how many triangles, there are 12 number of triangles. Total area of the hexagon will be 12 multiplied by s square by 8 root 3.

If I do this then it will be 0.865, 0.865 s square. And then, if I want to find out that, that this dotted line the circular area, so Ae I want to find out that means, pi r square, pi r square equal to, equal to pi multiplied by 0.865 s square and if I do this one, it will be approximately, not this one this is 0.525, so 0.525 to square. So, 0.525 square multiplied by pi that will give you point 8, it will come little more, r equal to 0.525.

So, 0.525 square equal to multiplied by, yeah it will be 0.865 s square. So, this will be Ae equal to 0.865 s square. This one directly I can find out. So, this can be, whenever I require to use area, whenever I require radius or radius of influence of a particular probe, I can use this. And if I want to find out area, I can directly use this.

These are the thing how it has come number of times I have taken perhaps this one and whatever I have shown previously, these two things I have taken, but I have not shown the derivation, this is the one. So, when it is a rectangle, you can see the influence area I can, the tributary area for a particular probe is again, it will be square, if it is a square pattern. But since I am using a cylindrical probe to densifying it.

So, always the influence area also would be cylindrical, that means it have some radius equivalent radius. That equivalent radius can be obtained equating the both areas. When squared area equal to circular area from there we can find out the radius and from there you can find out the area. Similarly, here when you see the triangular pattern, then actual tributary area is a hexagon, that hexagon approximately can be considered as equivalent radius or equivalent a circle and with R radius.

That if you equate the radius become 0.525 s, and that means area will be equal to 0.865 s square. These are the two things to be used frequently in many other topics also. I will not, I may not repeat this one again. A number of times I have mentioned I will show it, today just I have taken before taking the problem. Let me go to the next slide now, to the problem.

$$AC = AB \tan CBA = \left(\frac{S}{2}\right) \tan 30 = \frac{S}{2\sqrt{3}}$$

$$Area\ of\ triangle ABC = \frac{1}{2} \times \frac{S}{2} \times \frac{S}{2\sqrt{3}} = \frac{S^2}{8\sqrt{3}}$$

$$Total\ area\ of\ the\ hexagon\ 12 \times \frac{S^2}{8\sqrt{3}} = 0.865 S^2$$

$$R = 0.525 s$$

$$A_e = \pi R^2 = \pi (0.525)^2 = 0.865 S^2$$

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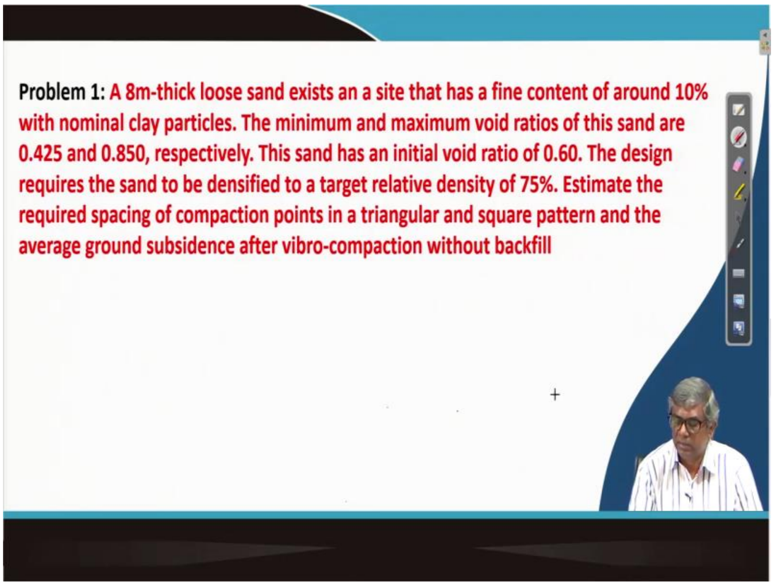

You can see that this problem is described like this, 8meter thick loose sand exist at a site that has a fine content of around 10 percent with nominal clay particles. If there is a too much of clay particles, it will not work. And it has a silty loose sand that is also good for vibro-compaction. The minimum and maximum void ratio of the sand are 0.425 and 0.850 respectively.

This sand has initial has an initial ratio of 0.6. The design requires the sand to densify to target the relative density of 75 percent. Estimate the required spacing of compaction points in a triangular and square pattern and the average ground subsidence after vibro-compaction without backfill. So, that means, first of all, if the soil has this minimum or maximum void ratio is like that and you have to compact and initial void ratio is 0.6.

And then if I want to, for compact at a relative density of 75 percent and from there that means in the compaction stage or after compaction what are the void ratio I can find out. So, after finding out that void ratio, then I know previous before compaction what is the void ratio, during after competition what is the void ratio, and then I can find out the settlement.

That is there is one equation, when you use without backfill there is an equation I will come to that point. And another thing is when I want to find out this mass densification, for that we need to find out the spacing, and that spacing how to find out that also I will try to show you. So, let me go to the problem maybe next page, let me go.

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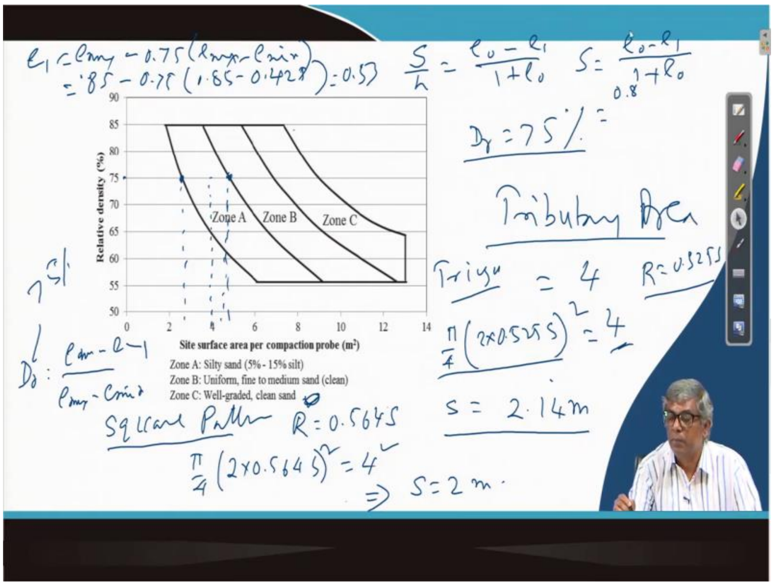

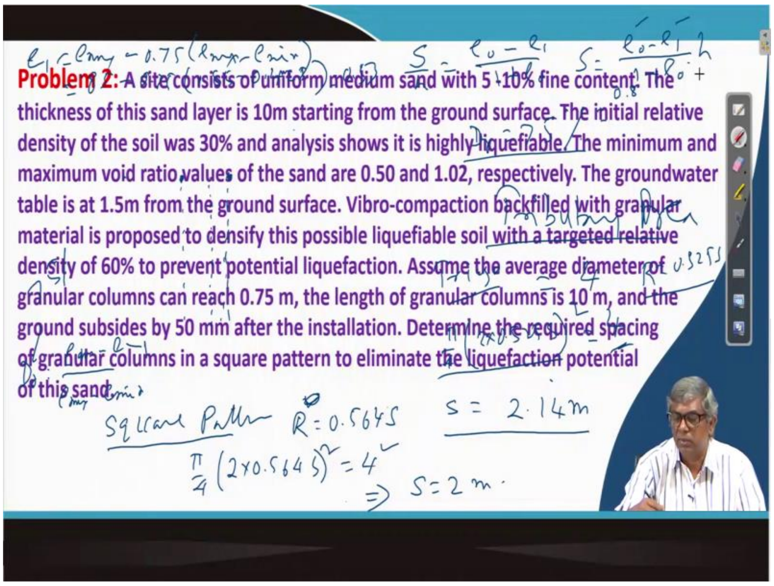

I have shown some design chart at the end towards the end and where I have shown that relative density to the tributary area. And here it is found, here what you can find we can see 75 percent the relative density is required, 75 percent relative density is required. What is here and the silty sand is Zone A and 5 to 15 percent silt. They are at 10 percent of this same soil can be taken.

$$e_1 = e_{\max} - 0.75\left(e_{\max} - e_{\min}\right) = 0.85 - 0.75\left(0.85 - 0.425\right) = 0.53$$

$$\frac{S}{h} = \frac{e_0 - e_1}{1 + e_1}$$

$$D_r = 75\%$$

$$D_r = \frac{e_{\max} - e_1}{e_{\max} - e_{\min}}$$

$$Triangluar\ path$$

$$R = 0.5255$$

$$\frac{\pi}{4}\left(2 \times 0.5255\right)^2 = 4$$

$$S = 2.14m$$

$$Square\ path$$

$$R = 0.5645$$

$$\frac{\pi}{4}\left(2 \times 0.5645\right)^2 = 4^2$$

$$S = 2m$$

That means, I have these two options, the extreme values of area, tributary area for a particular vibro-compaction is this to this. If I read this one, it will be slightly more than close to 3 and if I use this one, it is close to 4. I can take somewhere in between where it will be close to 4.

I can consider corresponding to relative densities 75 percent that you have to choose pacing in such a way that tributary area of a particular vibro-compaction will be approximately 4, tributary area will be equal to 4, if this is the one and then, so we can have, this will be if it is a triangular pattern, then triangular pattern we have seen pi by 4 5 multiplied by 0.525 s whole square equal to 4. And from here I can find out s equal to how much, 2.14 meter.

Similarly, when it is a square pattern, we have seen that the R equal to, we have seen R equal to 0.564. You can do pi by 4 multiplied by 2 multiplied by 0.564 s whole square equal to 4. And from here you can get s equal to 2meter. That means, whatever it is asking the problem that first of all, the description is given, relative density is 75 percent and a tributary area is this much, and so, relative density is this after to be compacted relative density 75 percent, so tributary area from this chart I can get approx. 74.

So, when it is a triangular pattern, as when it is a triangular pattern then we know the influence spacing R equal to 0.525 s. I can find out the area, that area to be equated. I can get from there, what is of spacing required. Similarly, when the square pattern I know the radius with spacing, radius with spacing relationship then I can find out the area of pi this square by 4, equal to 4. From here I can find out the spacing equal to 2. These two things first of all they have asked find out the spacing of the vibro-compaction, this is done.

Next thing it was the find out this displacement. So, we have another equation s by sorry, S by h equal to e naught minus e1 divided by 1 plus e naught. And so, we can find out S equal to e naught minus e_1 divided by 1 plus e naught and e_1 can be obtained Dr equal to e max minus e divided by e max minus e minimum. These e when it is a 75 percent corresponding to that you can say this is e1.

From this equation one can find out the value of e_1, so e_1 can be obtained something like this, e_1 will be equal to e max minus D_r point 75 multiplied by e max minus e minimum. So, if I do that e max equal 0.85, 0.85 which is given minus 0.75 minus 0.85 minus 0.425. From there I can find out the value e1 equal to 0.85 minus 0.425 multiplied by point 75, this one. So, 0.85 minus equal to 0.53. So, this is 0.53, 0.53.

It will be then S will be equal to 0point, e naught means, before compaction what is the value, was given, anyway you have to see the problem. So, before compaction this value, anyway so before compaction this value and during compaction this value and these two values are they multiplied by h, h is the thickness 10 meter. One can find out. This value I can show you once again let me, so spacing already calculated only deformation you need to be calculated.

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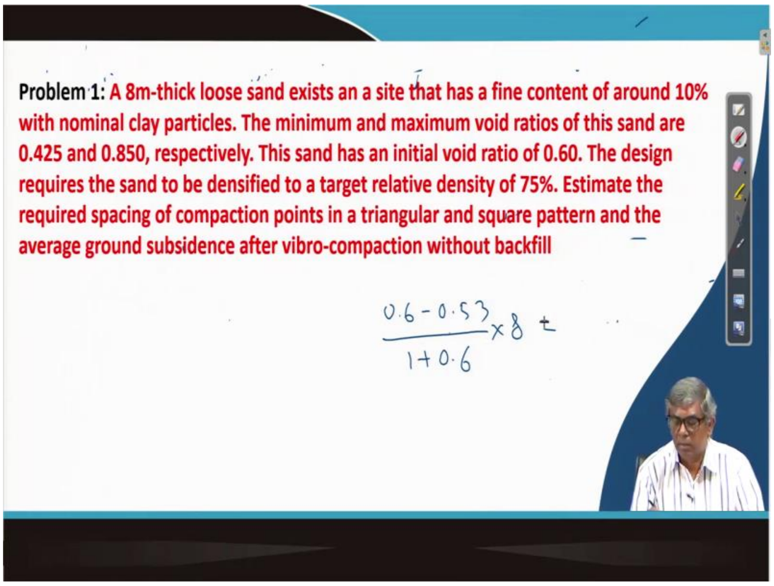

Here you can see the sand has initial void ratio 0.6. So, if you do that that means one 0.6 minus 0.53 divided by 1 plus 0.6 multiplied by 8meter. That become your deformation. So, it will be 0.6 minus 0.53, 0.6 minus 0.53 divided by 1.6 multiplied by 8. It will point 35.

That means point 35 meter will be the subsidence, if I do not use backfill and use vibro-compaction using particular spacing whatever we have shown, then it will be this much settlement will take place. This is the one problem whatever we have discussed in the theory, that the application of that. Next, I will take one more problem.

$$\frac{0.6-0.53}{1+0.6}\times 8t$$

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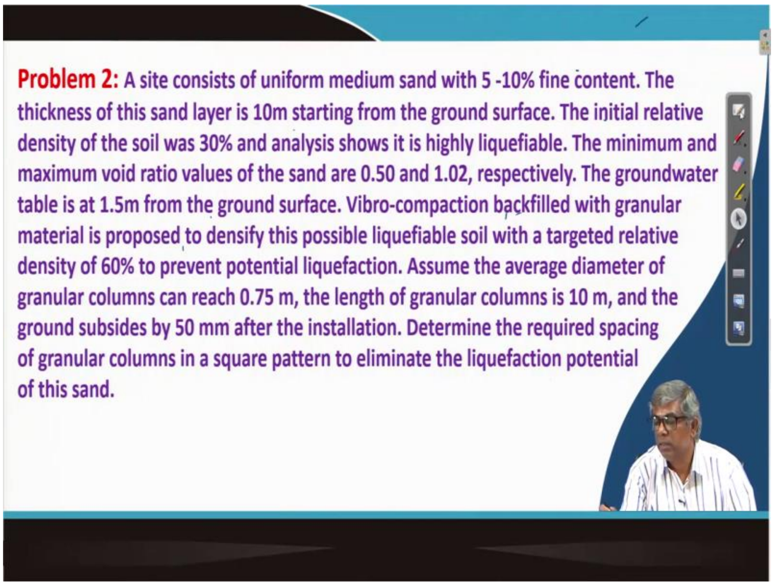

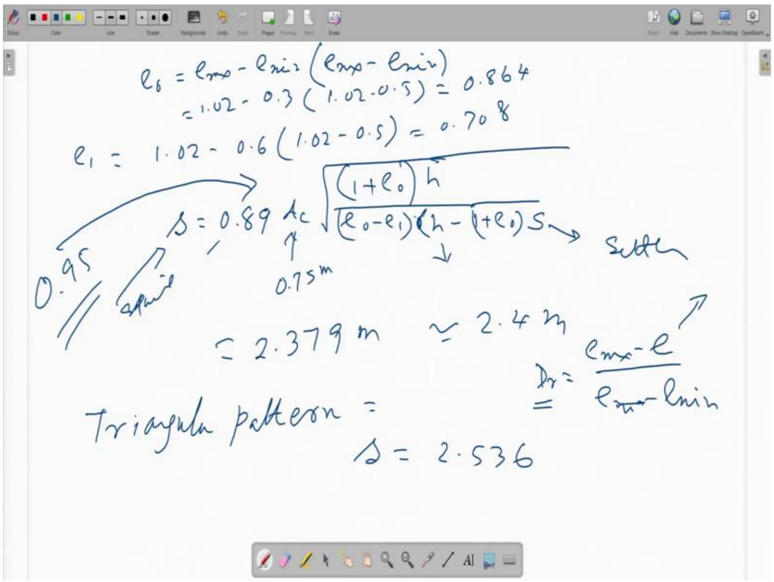

This problem is you can see now, a site consists of uniform medium sand with 5 to 10 percent fine content. The thickness of the sand layer is 10 meters starting from the ground surface. The initial relative density of the soil was 30 percent and analysis show it is highly liquefiable. The minimum and maximum void ratio was minimum and minimum void ratio or max to 0.5 and 1.02.

The groundwater table is at 1.5 meter from the ground surface. Vibro-compaction backfill with granular material is proposed to densify this possible liquefiable soil with a targeted relative density of 60 percent to prevent potential liquefaction. Assume the average diameter of the granular column can reach point 75 meter, the length of granular column is 10 meter and the ground subsidence by, subsides by 50 millimetre after the installation.

Determine the required spacing of granular column in a square pattern to eliminate the liquefaction potential of the sand. So, these one this problem, this problem, let me take better, I take a board and you can see that e naught I could have taken board for previous problem, e naught will be e max minus e minimum multiplied by e max minus e minimum. And if I put all those values that means 1.02 minus 0.3 initially 30 percent relative density, so e max minus 1.0 to minus 0.5 and then you will get a 0.864 initial void ratio.

And e_1 that means, when you are compacting to 60 percent, so it will be 1.02 minus 0.6 multiplied by 1.02 minus 0.5. then it will give you 0.708. And we have discussed in a square pattern, in a square pattern and when backfill is used and there is a subsidence, then there was an equation you can recall the spacing is given equal to 0.89 multiplied by d_c under root 1 plus e naught multiplied by h divided by e naught minus e1 multiplied by, this is h, h minus 1 plus e naught into S, this S settlement, and this s is spacing.

Everything is given e naught is known, e_1 is known, h is known, and S is known everything is known, dc is also known, 0.75 meter. If I do this one in a calculator then I will get a spacing equal to 2.379 meter. And this can be equivalent to 2.4 meter. Similarly, if you do in a triangular pattern, if I do triangular pattern, then if you do a triangular pattern then you will get this one corresponding s equal to, we will get 2.536.

And in that case equation in the square pattern and triangular pattern, only the difference in the equation this instead of 89 there was it is point 95. That is the only difference. These two problems I hope it is clear enough. Always relative density is defined as D_r equal to e max minus e divided by e max minus e minimum. If relative density is given e maximum is given.

You can find out void ratio at any stage, either before compaction what was the, if it is not given and but relative density is given then I can find out. Similarly, during compaction, after compaction what is the relative density is given and density, void ratio is not given you can find out. And if you can find out those then automatically by applying this equation, I can find out the rest of the things. This is the one by a large I wanted to show two problems. So, I hope this is done.

$e_0 = e_{max} - e_{min}\left(e_{max} - e_{min}\right) = 1.02 - 0.3(1.02 - 0.5) = 0.864$

$e_1 = 1.02 - 0.6\left(1.02 - 0.5\right) = 0.708$

$$For \text{ square } S = 0.89 d_c \sqrt{\frac{(1+e_0)h}{(e_0 - e_1)h - (1+e_0)S}} = 0.89 \times 0.75 \sqrt{\frac{(1+e_0)h}{(e_0 - e_1)h - (1+e_0)S}} = 2.379 \cong 2.4m$$

$$For \text{ triangluar } S = 0.95 d_c \sqrt{\frac{(1+e_0)h}{(e_0 - e_1)h - (1+e_0)S}} = 2.536$$

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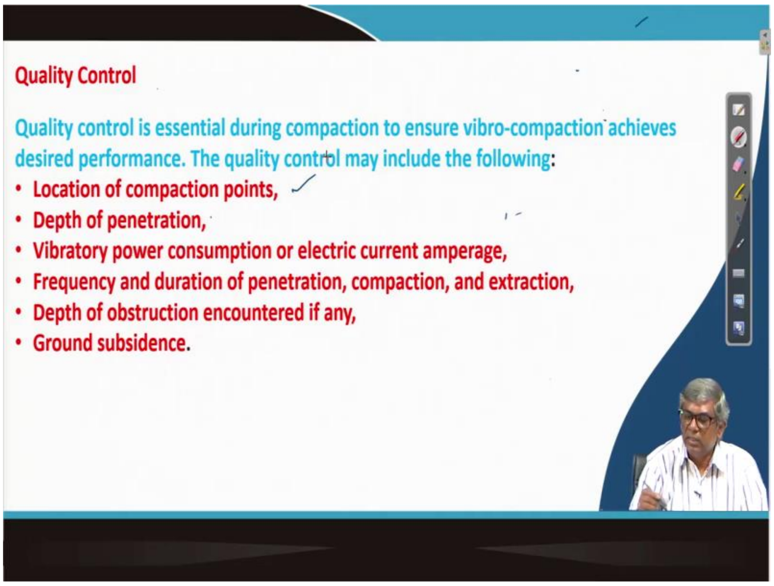

So, now, let me go to the smaller aspect that is quality control as I have mentioned. The quality control for every like any other work here also quality control required, because we have mentioned construction method some of things to be followed and in that there are some specifications is given. Whether it is maintained or not that to be followed.

Under that quality control vibro-compaction to check whether to achieve the desired performance, if we want to the desired performance, whatever desired parameters all everything should be at per during construction also. What are the things to be check that under quality control, what other things to be control that location of compaction point, location of compaction that to be controlled that means that also you have a location decided but when you are doing it is different, then your compaction will not be as good as it was planned.

Similarly, depth of penetration, so we know that compaction is required up to 10meter but if depth of penetration does not happen that then of course, you will not get that densification up to 10meter. Then vibratory power consumption electric current etc. that fluctuation indicates some inadequacy or over compaction. That to which controlled properly.

Frequency and duration of penetration compaction extraction, we have mentioned specifically during penetration some frequency to be maintained, during extraction some frequency to maintained, during vibration or compaction also some frequency to maintained, that all those things to be a controlled.

Depth of obstruction encountered if any, so during the penetration if you find any things that we also monitored and reported and if necessary, some extra measures to be taken then ground subsidence if it is there, how much it is, if your calculation is not there, but if it is happening, then how to or whatever you have predicted whether it is happening or not. That to be or at least you have to maintain that. These are the different controlling parameter to be controlled to achieve your desired compaction.

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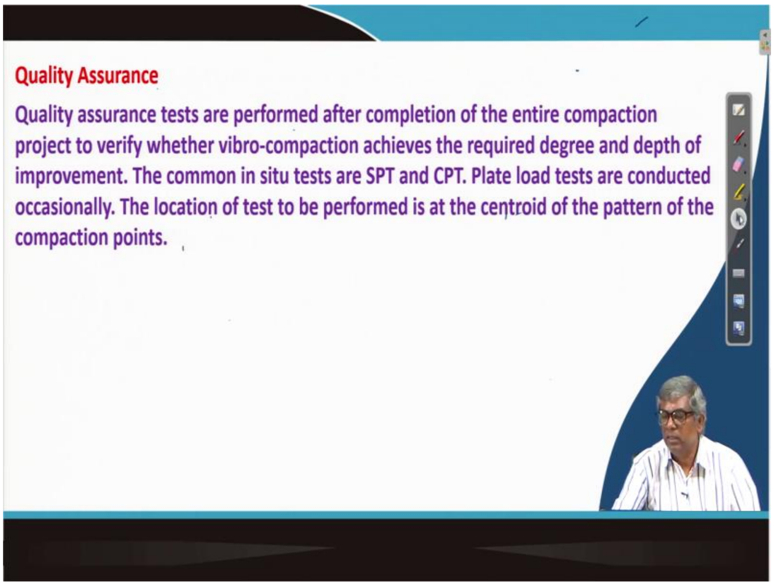

See in addition to that, there are few more things, if your water is used that during the penetration of water use again there should be well planned water flow channels to direct water from compaction points to the into settling points. And again, if backfill is used the quantity and rate of adding backfill that also to be monitored.

And of course, all those things whatever we do, we definitely can monitor but still whatever design parameter and all those things whether based on that, if it is doing or not that to be checked also by a trial test to be done. So, this is part of monitoring work. And of course, quality control means what after all controlling everything whatever we have, end product we have got whether the end product is suitable or whether it is satisfying your requirement all those things to be checked.

And for this checking purpose generally we do a number of field test, the SPT, CPT is generally a commonly used test. Sometimes plate load test also used. And location test and where we want to test that should be chosen as centroid of the pattern of the compaction points. The whatever pattern we are doing, if it is a square pattern, center of a square to be chosen as a testing point.

Similarly, if it is a triangular, you can center of the triangle to be chosen as a quality check point. This is the way once you all satisfy then only you can declare the compaction is satisfactory, vibro-compaction is satisfactory. This is by a large the completion of vibro-compaction and though vibro-compaction is a deep compaction and there are some other deep compaction methods they are similar to this and there are a number of methods, I will not be able to discuss all of them, but deep displacement which is exactly similar to that only the construction checks in minor difference.

Because of that, I may not go up to the design but some basic differences and similarity between these vibro-compaction of deep displacement, maybe two lectures I will take along with this module. So, maybe I will take in the next lecture. Thank you.