Ground Improvement
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Lecture 41
Grouting (Contd.)

Hi everyone, let me continue on design consideration of grouting, number of them already I have discussed in the previous lecture and as I have pointed out that one or two aspects that is what will be the whether it is a single row or it is a multiple rows or and if it is single or multiple again, in the single or multi in the rows itself what will be the spacing, this is important aspect in the in the grouting to improve the overall ground condition, where grouting is used as the ground improvement technique. This part I will try to discuss quickly and then we will take a problem.

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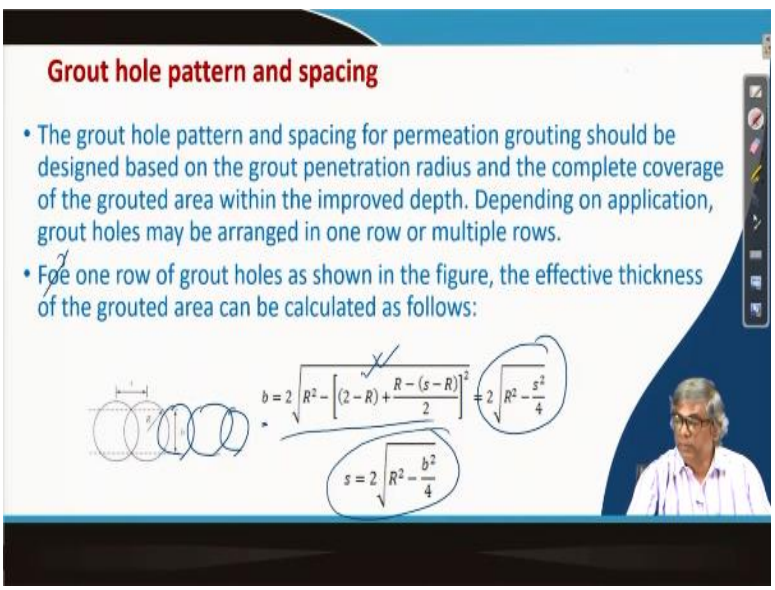

you can see this the grout hole pattern, so that is grout hole pattern and spacing for penetration grouting should be designed based on the grout penetration radius and the complete coverage of the grout area, that means whatever we have discussed in the previous lecture, that penetration radius we can estimate. Based on penetration radius and how much area to be covered and based on that we can find out the spacing and again pattern. The pattern again depending upon application the grout holes may be arranged in a one row or multiple rows, that is pattern and if it is use one row and multiple rows that again then based on that if it is multiple rows then again pattern can be in the square form and otherwise it can be triangular form which we have already learned for other application.

Similar, to that here also if the multiple rows it can be in the square form that one after one or it can be zigzags, a triangular form, first row, first, second and second row the first will be in between this, like that so that is the pattern and spacing. And so here there is a small typo it will be for, for one row of grout holes as shown, this is supposed if the grout holes are like that is like that continued.

And then the effective thickness of the grouted area can be calculated, effective thickness means your this h, this one, this one effective thickness so you can see this equation can be used, s, b your, this is the b effective thickness b can be calculated 2 under root R square minus 2 minus R plus R minus s minus R whole square by 2, so this is some derivation it can be done but I am not going to do that, this is the one finally it can be taken and it can be this is a big expression.

Foe one row of grout holes as shown in figure, the effective thickness of the grouted area can be calculated as follows:

$$b = 2\sqrt{R^2 - \left[(2-R) + \frac{R-(s-R)^2}{2}\right]} = \sqrt[2]{R^2 - \frac{s^2}{4}}$$

$$s = \sqrt[2]{R^2 - \frac{b^2}{4}}$$

But ultimately it is seen that it can be simplified or it can be instead of this if you use this the results are by and large very close. If you want to do exactly a very accurate result then one can use this one but you can accept little error but calculation is efficient, one can use this equation that means 2 under root R square minus s square by 4, R is the penetration radius and s is the spacing.

If this two is known then I can find out what is the effective width of the improvement by a single row of grouting, this is the main theme of this, s equal to again, here s equal to 2 under root R square minus b square by 4, this is the s, this is the single row.

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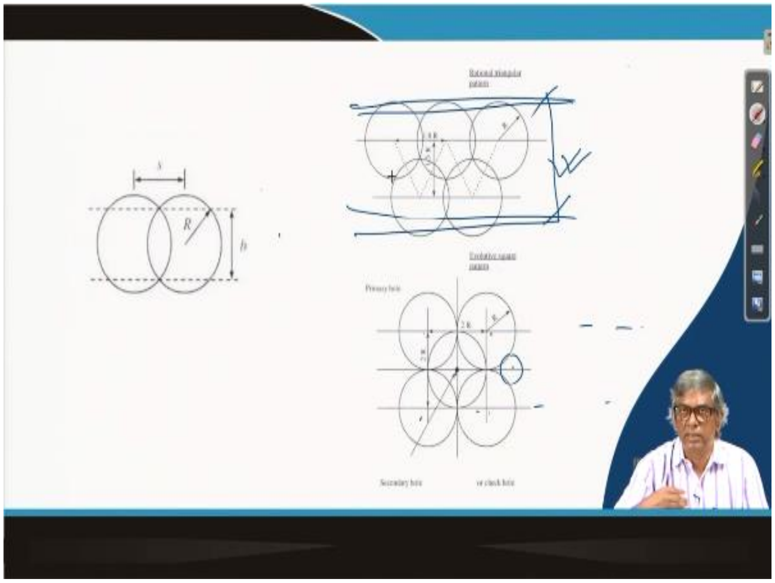

Similarly, if it is a multiple row and multiple row can be of different kind, you can see here this is the single row already we have discussed single row and this is multiple row and again multiple row here two rows are shown, it can be this side again further rows can be there similarly, this further number of rows can be there but by showing two and you can see this is a triangular pattern and in the triangular pattern more effective, you can see by this is getting overlapped everywhere, no additional grout hole is required to cover the area.

by doing this itself it is there is a sufficient overlap, this by two rows the effective width of ground, improve ground may be this much, but whereas if I use multiple rows in this form, that is in the square pattern you can see here this one, this one, this one you this one if you do the middle portion there will be unimproved, because of that you need to do secondary grouting, that means you do like this, this is primary sequence and then to cover or give sufficient overlap you have to give some secondary operation.

Similarly, we may require some tertiary operation also, that is why the grouting may be better most of the cases this triangular pattern, this also can be done but in that case it has to be divided into two part, primary sequence and secondary sequence to cover the areas.

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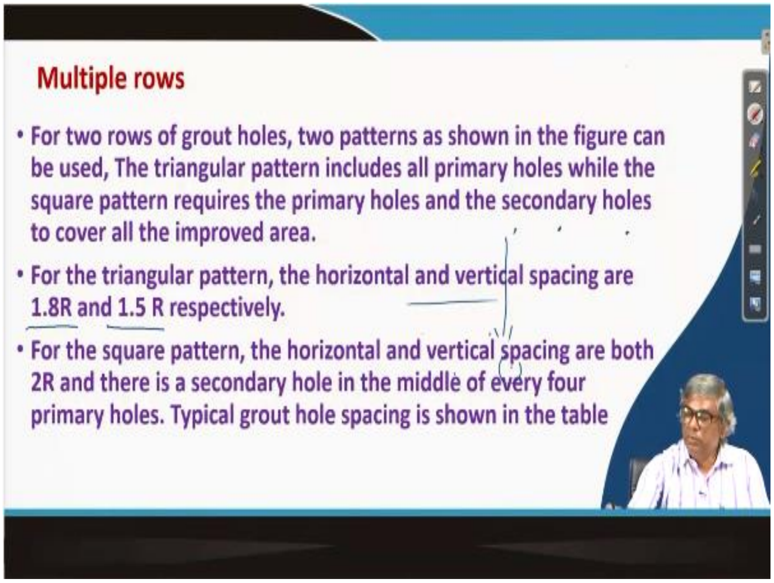

And multiple rows again whatever I said everything is written here, for two rows of grout holes, two patterns can be used which I have already shown and the triangular pattern includes all primary holes while the square pattern requires the primary holes and the secondary holes to cover all the improvement, already I have mentioned that when it is triangular by primary operation itself it is sufficient overlapped is there.

There is no unimproved area, whereas if you use square pattern, the square pattern when you progress then you will see that in the middle of the particular square there will be unimproved, so in the form of secondary operation you have to again grout so one has to keep in mind. For the triangular pattern, the horizontal vertical spacing are 1.8 to 1.5R, for the triangular pattern the horizontal and vertical spacing 1.8R and 1.5R respective.

Horizontal spacing that means this is horizontal spacing and verticals would be in this direction, this direction suppose, so it will be ones is 1.8 another one is 1.5R, R is the penetration radius and for the square pattern the horizontal and vertical spacing are both 2R twice the radial penetration and there is a secondary hole in the middle of every four primary holes.

Typical grout hole spacing is shown in the table again, typical spacing etc., what is recommended which I will be discussing in the next one, otherwise when you use in a triangular pattern then your vertical spacing 1.8 and horizontal 1.5R, when the square fitting it is the spacing is 2R but in every four there will be again secondary grout hole will be required.

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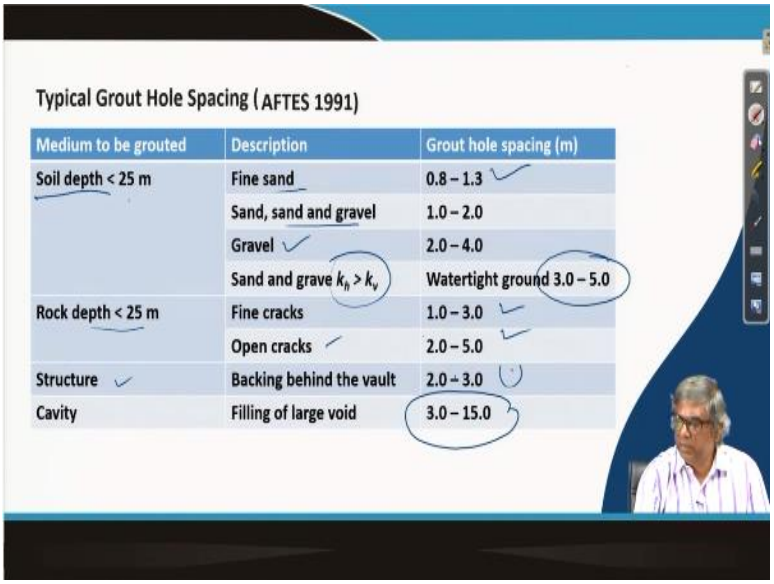

this is typical given the grout hole spacing, you can see here again it depends on though it is based on penetration radius it is given there but it is not how much penetration it depends on soil type, ultimately all including the information there is a recommendation that if there is a soil type is like this, if the soil is like this, then you need to do this is the spacing, this recommendation is in the table form you can see here.

Soil and depth are less than 25meter, that means grouting is done less than 25meter depth below that difficult maybe and in the description fine sand then this will be, it will be fine sand, then grout hole spacing, 0.8 meter to 1.3 meter, with the sand and gravel mixer then it spacing can be 1 to 2 meter and when it is a gravel alone then spacing can be 2 to 4 meter because why it is so?

Because when it is a fine sand the penetration radius will be less, so automatically your spacing will be reduced, whereas gravel actually penetration will be large as a result you can see that the spacing is 2 to 4 meter and sand and gravel where horizontal permeability is greater than vertical permeability, then water tight ground then there spacing can be used 3 to 5.

And where rock again less than 25meter depth, the fine cracks, the spacing can be 1 to 3 meter and open cracks it will be 2 to 5 meter spacing and structure, backing behind the vault 2 to 3 and cavity actually it is filling of large void, if there a in the ground itself there is a voids then filling of that voids one can use the spacing between 3 meter and 15 meter.

This is a tabular form depending upon soil type and the rock type you can choose, though we can do some calculation otherwise if you do not want to do calculation if by approximately if you choose this spacing by a large your work will be effective. With this I will be design criteria or consideration or whatever recommended value to be used for design that I just complete.

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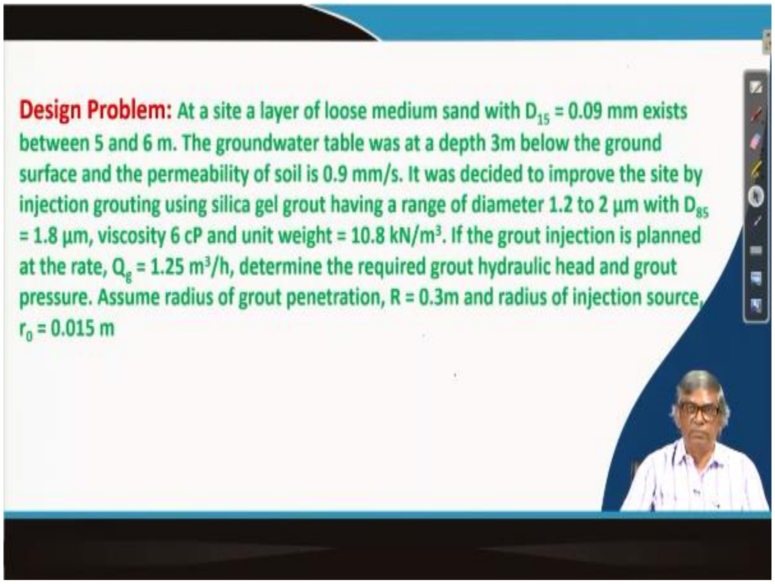

Now I will take the problem and some calculation how to do I will just try to show. this problem is like this, a design problem is given, at a site a layer of loose medium sand with D15 is 0.09 millimeter exist between 5 and 6 meter, that means at a depth between 5 meter and 6 meter there is a loose medium sand whose D15 is 0.09 millimeter and ground water table was at depth 3 meter below the ground surface and the permeability of the soil is 0.9 millimeter per second.

It was decided to improve the site by injection grouting using silica gel grout having a range of diameter 1.2 to 2 micrometer with D85 actually 1.8 micrometer, our viscosity of that grout was 6 centipoise and unit weight was 10.8 kilo newton per meter cube and if the grout injection is planned at the rate of Q_g equal to 1.25 meter cube per hour determine the required grout hydraulic head, grout pressure and we can assume the radius of grout penetration R is 0.3, that means how much volume it will go that radius of sphere is given 0.3 meter and radius of injection source is given 0.15 meter.

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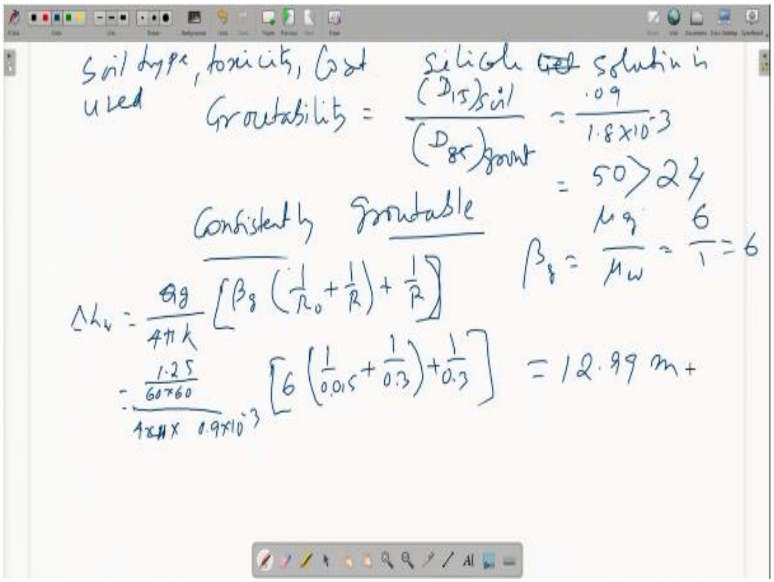

These are the things so whatever the guidelines we have already discussed will try to take that and one by one let us ah try to do it. For example, suppose considering several issues like soil type, issues you consider soil type then we consider toxicity, soil type, toxicity and the cost, after considering all those things suppose silicate which is already mentioned that is a silicate is used suppose, silicate gel is used, silicate solution is used and then the first thing you have to do groutability, groutability will be equal to D15 soil divided by D85 grout.

This is soil it is 0.09 and this is 1.8 multiplied by 10 to the power minus 3, so this will give you 50 which is greater than 24 which is discussed before, this is groutable and not only that it is consistently groutable, consistently groutable. this is first thing is done, now you know that delta h_w which we have discussed today, previous lecture that is Q_g divided by 4 pi k and beta g and then 1 by r naught plus 1 by capital R plus 1 by capital R.

Soil type, toxicity, cost

Solution in groutability$= \frac{(D_{15})_{soil}}{(D_{85})_{grout}} = \frac{0.09}{1.8\times10^{-3}} = 50 > 24$

Consistency groutable

$$\Delta h_w = \frac{Q_g}{4\pi k}\left[\beta_g\left(\frac{1}{R_0}+\frac{1}{R}\right)+\frac{1}{R}\right] \qquad \beta_g = \frac{\mu_g}{\mu_w} = \frac{6}{1} = 6$$

$$\Delta h_w = \frac{\frac{1.25}{60\times60}}{4\pi\times0.9\times10^{-3}}\left[6\left(\frac{1}{0.05}+\frac{1}{0.3}\right)+\frac{1}{0.3}\right] = 12.99m$$

This is the one, so we need to find out beta g, beta g actually equal to your mu g by mu w, this is 6 by 1 so this value is 6, now we can put all those value Q_g is actually 1.25 meter cube per hour, everything is second I can convert 1.25 divided by 60, divided by 60 divided by 4 multiplied by pi multiplied by k is given 0.9 multiplied by 10 to the power minus 3 and then beta g is 6 and 1 by r naught 0.015 plus 1 by 0.3 plus 1 by 0.3, if I do this calculation then I will get, whatever value I put if I calculate this one we get a value equal to 12.99 meter.

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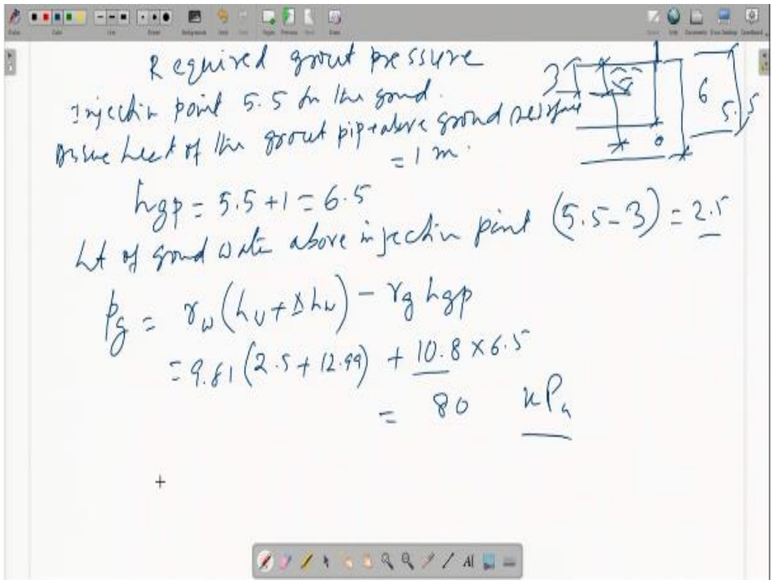

next part is your required grout pressure, so this one the injection point will be, so your ground is here and this is 5 meter and this is 6 meters, the soil layer is between 5 to 6 meter so injection point assumed to injection point 5.5 from the ground and assume the grout injection point that this was above 1 meter above, so assume head of the grout pipe above ground surface, we can take anything so I am taking 1 meter.

So h_{gp} will be 5.5 plus 1 6.5, and the hw height of ground water above injection point, so water was here 3 meter and here it is 5.5 meter so this will be 2 meter so 5.5 minus 3, so it will be 2.5 meter, so the water table this was is this was 3 and this was 5.5, 5.5 minus 3 is 2.5.

p_g will be equal to gamma w hw plus delta hw minus gamma g h gp, so this one 9.81 and hw is 2.5 plus delta is 12.99 and plus this one 10.8 and h gp is 6.5, so we can find out this value equal to I think it will be it will come close to 80, 80 kPa, it will come close to 80 and now effect of Bingham fluid can be applied but since silicate gel is the Newtonian fluid so no yield strength, so no correction will be there.

Required grout pressure

Injectit point 5.5m from the ground

Assume weight of this grout pipe alive in ground well system=1m

$h_{gp} = 5.5 + 1 = 6.5$

weight of ground waste above injectin point(5.5-3)=2.5

$p_g = \gamma_w \left(h_w + \Delta h_w\right) - \gamma_g h_{gp}$

$p_g = 9.81\left(2.5 + 12.99\right) + 10.8 \times 6.5 = 80kPa$

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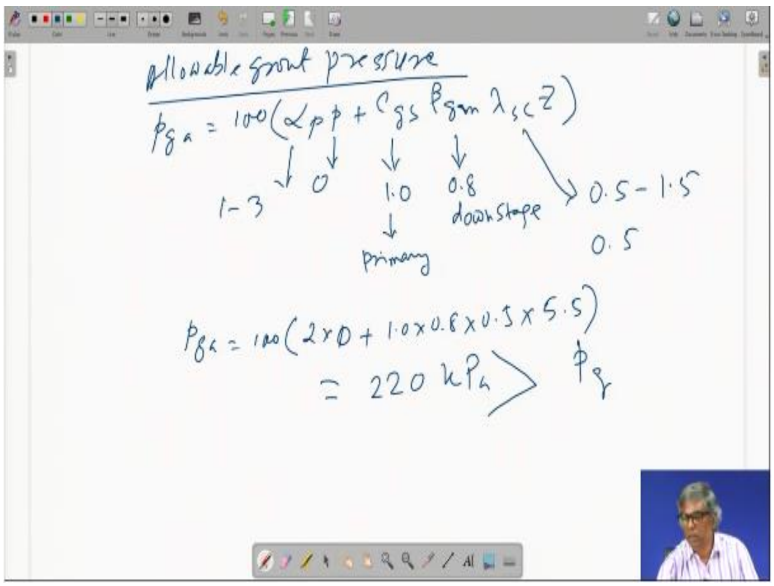

now what you have to do, next part this is the grout pressure it required to grout in this soil but what is the allowable grout pressure that to be checked, so let that equation for this the allowable grout pressure Pga will be equal to 100 alpha p into p plus C gs beta g m lambda sc into z, so here the p surcharge is 0, alpha p between 1 and 3, can be taken 2 but because this 0 will become 0, C gs sequence factor assume is a primary grouting, so we can take 1 and this is grouting method factor.

Allowable grout pressure

$p_{ga} = 100\left(\alpha_p p + c_{gs} \beta_{gm} \lambda_{sc} z\right)$

$0.5 - 1.5 = 0.5$

$p_{ga} = 100\left(2 \times 0 + 1.0 \times 0.8 \times 0.5 \times 5.5\right) = 220kPa > p_g$

So, 0.8 and 0.6 are there so we can take 0.8 here assuming down stage and this is assuming primary and this is soil characteristics factor which is varying between 0.5 to 1.5 we can take 0.5, if you take all those values here then we can see P_{ga} equal to 100 and 2 multiplied by 0 plus 1 multiplied by 0.8 multiplied by 0.5 multiplied by z is how much, z is 5.5 injection point.

If you calculate this value you get a value equal to 220 kPa and we have got P_{ga} around 80 which is much greater than p_g, that means whatever calculation we have done this is acceptable, so with this, so this calculation can be done, that means what pressure is to be applied this is the design, the remaining design is you have to select a spacing and if you select a triangular spacing of course, from the type of soil you can find out what is in meter you can find out if it is square pattern.

If it is a square pattern is used then you have to conduct it in primary and secondary in two sequence and again primary and sequence, they are what should be the radius, the spacing that can be taken from the table. And with this so the design will be completed and nothing else, there are so many other things can be there, for example, that quality control and all, this is already we have taken one extra, for this grouting chapter I am trying not trying to do any that sort of things quality control etcetera.

Maybe at the end if I get some time I can try to show those things and though I have done this problem in the lecture itself but once again my solution also kept in the PPT, so we can refer that also for convenience, both ways it is there but I have step by step to explain the method, I have shown step by step so that is the one may be helpful, with this I will close the grouting method of ground improvement and I hope it will be helpful to you, with this I will close and next class I will start with some new topic maybe chemical modification, thank you.