Ground Improvement

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Lecture – 31

Preconsolidation

Hello everyone, let us continue with ground improvement. And a new topic that is preconsolidation, we have initially the introduction section; we have mentioned different methods of ground improvement. And this is, number of them we have already covered. Now, this is a method called preconsilation. Preconsolidation means, this is applicable for fine grained soil.

And configuration is characteristics of fine-grained soil, saturated fine-grained soil. And we have, I think you all learn from soil mechanics, that that there are two things, two different ways densification can be done. One is actually by compaction; another is by consolidation. That means, you have to remove the voids from the, for air when it is a compaction and remove the water from the void spaces for consolidation.

These are the basic difference, and in addition to that consolidation is a lengthy procedure, it will be slow and whereas, compaction is instantaneous. These are the two different ways densification is possible. And when is a compaction for any soil, we can do by applying instantaneous load. And whereas consolidation, it is only one essential condition is that soil has to be saturated.

And if it, and it is a fine grain soil, saturated fine grain soi, so, when it will apply load, then that load immediately it will be because of that loading that pore pressure will develop and that pore pressure will slowly dissipate and as a result consolidation will take place. That will load transfer will happen from the poor fluid to the fine grain and that will cause soil grain to bring closer. And when it happens, then some amount of water will go out and then it will be densified.

That is a consolidation, soil mechanics naturally when the foundation is built on a sub saturated soil, they know what the time it will consolidate, that is obvious known and how to find out consolidation settlement all those things is discussed in soil mechanics section, soil mechanic subject. Now, if a new area, where we know the problematic soil particularly saturated fine-grained soil, and wanted to build some important structure.

Then after building the call, important structure, it may undergo a huge amount of consolidation, which actually we do not want. Or this, particular structure is not limited to settlement to be insured. Because of that, if that type of fine is there, then it is preferable that we consolidate. That during the loading time, during the service type of the structure that consolidation, the consolidation will be comparatively less.

That means this major amount of consolidation you have to complete before construction of the actual structure. So, that is a pre consolidation. That topic I will be discussing here now.

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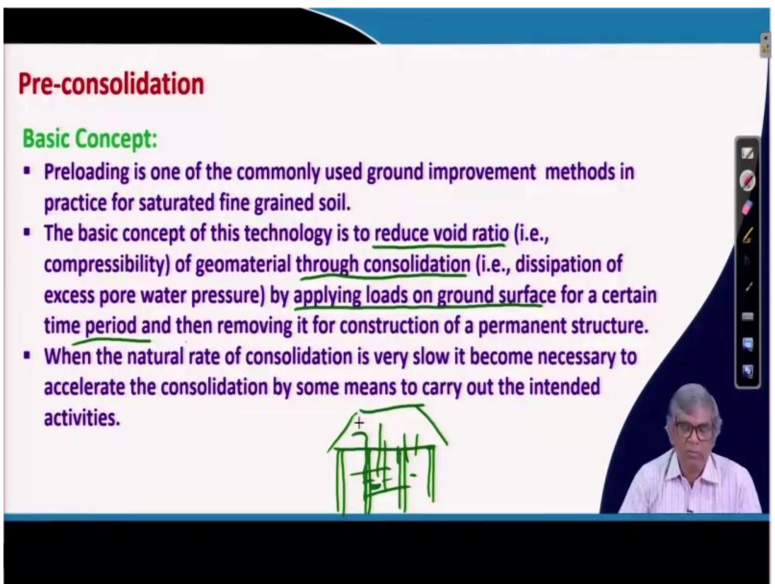

And let us, the basic concept is, what is the basic concept in it? That is actually, this is a pre loading is one of the commonly used ground improvement methods in practice for saturate fine grained soil. This is actually as I already mentioned the introduction itself. That it is common method, which is practice for saturated fine grained soil. And again, the basic concept of this technology is to reduce void ratio, that already I have also mentioned.

And how the void issue is reduced? That is through consolidation. And the consolidation means what exact? That means you can underline those. This is actually the objective is basically reduced, the void ratio, by what? Through consolidation and consolidation means what?

Applying loads on ground surface for a certain time period and that is a consolidation. Once the consolidation is completed, then we can remove the load.

And then of course, after removal of load little swelling maybe there, but they will not come back to original. As a result, this will be consolidation. Then and, and this actually when actually we need to do this, that consultation will be, rate of consultation is very low, very slow. In that case, case it becomes necessary to accelerate the continuity by some means of, to carry out the intended activities.

Suppose pre consolidation, one method we, I will discuss one by one. That is, suppose this is a ground surface, we can apply some amount of structures Then of course, when there is a water in the soil mass, than water will go out from this. And then this will be, if this, this process is very slow then there can be another alternative, that we can provide some amount of drains, vertical drains like this, you can provide vertical drains.

That when load is applied, then water not only will go this direction, water can go in this direction and meet the drain and through this again finally can go. Basic concept is that, you have to reduce the void ratio, and it is, it is applicable for saturated fine grained soil. And it is, main concept you need to actually reduce the void ratio by consolidation.

And consolidation means actually, in the saturated financial we apply certain amount of load, which was not there before. And with time, they should consolidate. And this is the natural way of consolidation. And if the rate of consolidation again become very slow, then some alternative arrangement can be done like that drain or etc. This thing will be slowly discussed in detail one by one. Let us take next slide.

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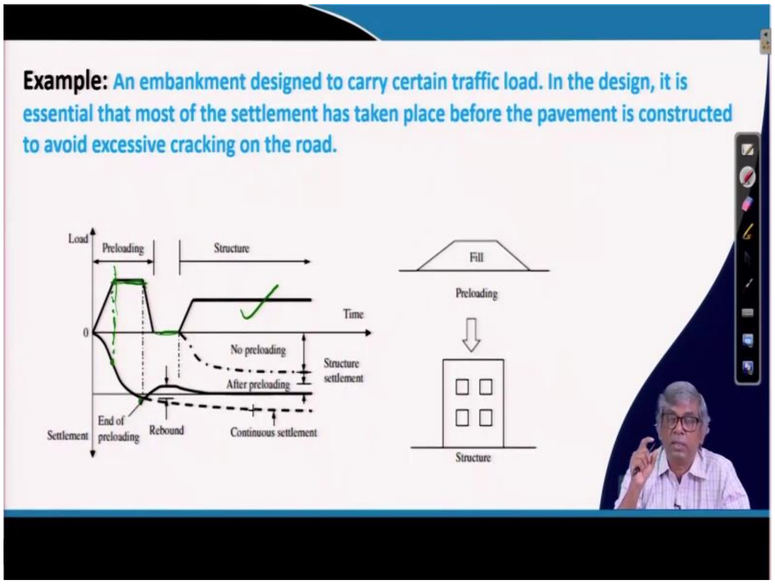

You can see this, and as I have told you that say, suppose, you want to build some structure and which has a limited settlement and we know the soil is problematic. Definitely if you build a structure then it will have much more settlement than the limited that, then it is specified. Because before the, because of that those area actually you have to consolidate. Here actually one good example is given.

That an embankment and which will be designed to carry certain traffic load and, in the design, it is essential that most of the settlement has taken place before the permanent construction, construct permanent. Pavement is constructed to avoid excessive cracking on the road. That means, that means when your final pavement is made, and for the traffic. So, if the below soil is not consolidated before, then during service time it will consolidate.

And as a result, the pavement will damage. Because this is, one good example is most of the time for construction of road, generally pre-loading, a method there is a consolidation is generally completed before construction of embankment. This is the example that is embankment designed to carry certain traffic load. And in that case, it is essential to complete the most of the settlement before pavement is constructed.

If it is not done, then in that case, there will be some cracks and other things and the damage of the pavement will happen, that will cause more maintenance or sometimes rebuilding also may be required. To avoid that you need to do preconsolidation and you can see, how it works. This is the diagram, suppose this is the structure. We can, come back in this figure first, and you can see the loading time, we can suppose you want to put certain amount of load.

The load you cannot sudden, suddenly you can put it, some over, over a times, over this much time over this much time, the full load is reached. And during this loading actually there will be settlement also. Suppose, when is this much load is reached that, by that time settlement is this much? Now, with this load, if I keep this much time long, this much time again this two time, then under this loading then it will become, settlement will be going further.

Maybe sub to some here, here. And you can see now, if you remove the load, to the load is removed now. And then you can see there is a little swelling, and then if you construct the building and because of the building load and all, then again it will be then it will be again, it will, continue this direction, this direction. That means, this much settlement will be there, all the after the construction.

And, and suppose if I applied this much pre load like this, then we could have not done by pre loading, then if you apply this, this much load is applied and our structure is applied this with this much load. Then we could have got this mass settlement. These are the difference how it works. That means, if you, the particular soil if you preload and consolidate and then if you build this structure, you will have this much settlement, only this much settlement.

Whereas, if you do not do the pre loading and you simply apply load from here, then your settlement would have been this much. That much structural settlement would have been there. This is by a larger procedure. That means, you have to, when you know the soil is problematic, then you dump load over a period of time. This is the suppose, this was time was taken to reach the desire suppose.

And then this structure, you have to keep for some time. And if you keep with this much structure, then you can see the settlement will these, this much here. And then again if you remove, then of course, it will go back. And then again if we apply structure, then this will be the final settlement. And so, this is the way actually this, this by preloading method, the settlement in the structure we can reduce.

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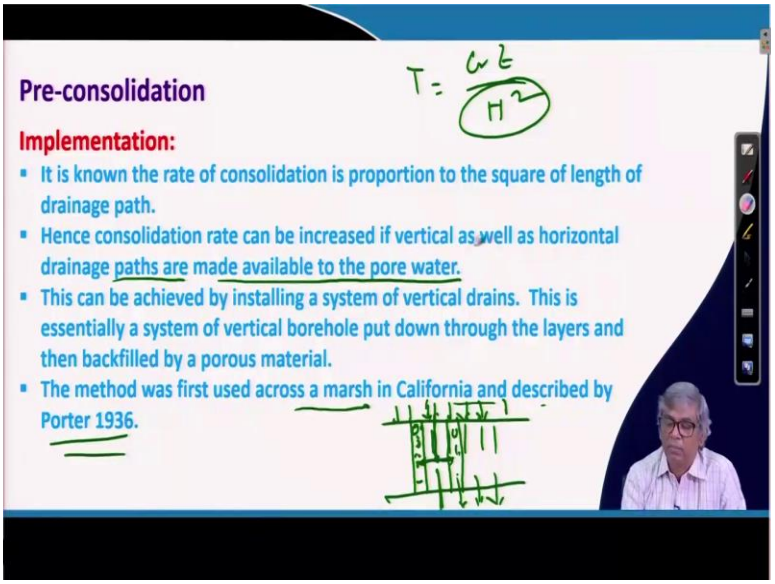

And implementation how we can do? So, this is a, the rate of consolidation is proportional to the square of length of drainage path. Actually see that, T equal to cvt over H square. So, this time proportional to our rate of consolidation, rate means time is only the pro, proportional to the square of length. This is the length of drainage path. So, this is known already through consolidation theory.

$$T = \frac{C_v t}{H^2}$$

Hence, consolation rate can be increased if vertical as well as horizontal drainage paths are made available to the pore water. So, suppose there is a ground and if normal condition, if I apply load from here, if I load apply, apply load from here. And if it is saturated fine grained soil then water will go this direction only. And if there is a drainage there it can go this direction also. This is the way if I do, it will be taken a long time.

To accelerate what we can do? We can suppose, I will put a drain here, vertical drain and drain means it is not really hollow. It is filled up with good permeability of soil, soil with good permeability. If I have, have another drain here, then soil here, water here it can travel this direction it can travel this direction also it can travel this direction. That means and it will be, if that means this is very near compared to this, so it will be faster.

That means to hence consideration rate can be increased in vertical as well as horizontal drainage paths are made available to the pore water. Pore water pressure, pore water is here, it has to, and normally it has to go this way or this way. Now if I put drains like this, then it can go this way also. So, all direction drainage is taking place. Consolidation will be also faster. And, so this can be achieved by installing system of vertical drain.

That is what, already mentioned here. This is essentially system of vertical boreholes put down through the layers and then backfill by porous material, already I have mentioned. The method was first he used across marsh that means sub trials, in California. And it was described in 1936. And since then, things are improving. Now it is well established and one can easily implement the pre consolidation in sub soil by vertical drain. So, let me go to the next slide.

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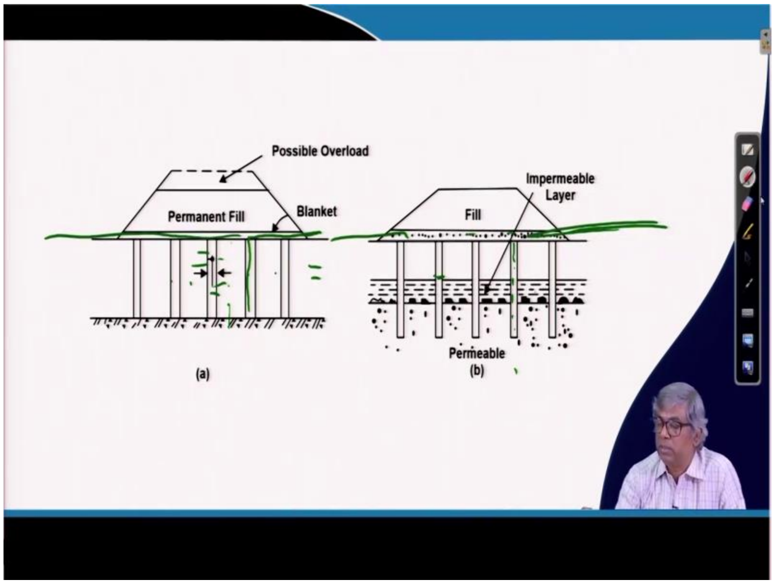

This is the one you can see here. Whatever I have scribble there, it is here actually once again, and nice sketched. And you can see this is suppose comprehensible layer, this is the comprehensible layer. And we can put this much of vertical, this much we can suppose a permanent field is this much. And still that is not enough, so we can put some amount of structures over that also. Then, and if I apply this much, if these trends are not provided, then it could have taken suppose five years or six year or three years or two years.

And suppose, the project to be completed by one year or six months, then to accelerate that, we on, we generally in the industry, it is adopted that vertical drains. And vertical drains in particular spacing, this has to be also designed to make it effective. And when these bore, bore holes or these drains are designed then obviously, the bore water present here or present here, it not only can go this direction or this direction, it can go this direction.

And that way the consolidation will be accelerated and here you can see that permeable layer is this one. And it has to be consolidated and this is the impermeable layer. And if you make vertical rain up to this is no use. What you have to do? You have to penetrate this impermeable layer and go up to this and then you have to apply surcharge. And because of that surcharge load and this well from this layer, water will come out.

And then this will be actually, this is a blanket through which actually after water will be go like this and then enter into this and then it will be taken out. This is the issue here also same thing. The blanket that means water will be going from here and then through these it will be taken out. And by that way, this entire layer will be consolidated.

This is actually schematically whatever I have said in the previous slide, two, three sorry, two three steps I have shown. So, this is the theoretical it is shown. And all the additionally, this diagram is shown that when there is a, suppose that the soil is compressible, layer is there. So, five meters beyond and at three meter or somewhere and one meter thick in permeable, impermeable layer is there.

Then what you have to? You have to prepare or you have to make sand drains or whatever vertical rains, you have to push, go through that impermeable layer and enter into the compressible layer. Then only, this water from this layer will be going out and finally, it will help to consolidate. This is about the method of reconsolidation.

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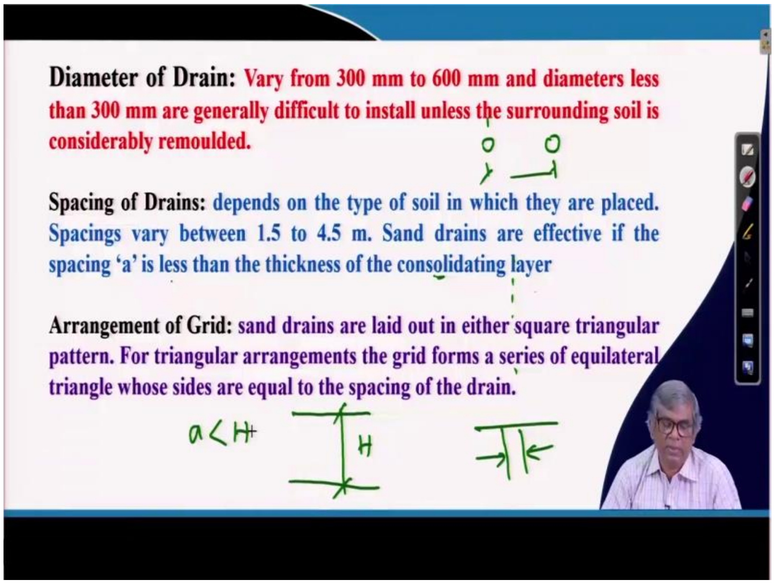

So, when you do this, since it is known now, that, that reconsolidation by surcharge can be done. But if, if it is, if you want to do quickly, then in that case you can provide sand drains. And then that means, it has to be designed. The design means what? The design parameter for sand drains will be that it will be the diameter of the drains. Then it has to be designed, the spacing of the drain and what type of spacing?

Whether the square, triangle, and rectangle all those things are to be designed. Also at the same time, up to how much depth vertical drains to be provided. Depends on the thickness of the compressible layer. All those things are now one by one and there is some guidance. Suppose if you want to design the vertical drain, then what should be the diameter of drain. That actually some guidelines are given here, you can see vary from 300 millimeter to 600 millimeter.

That means, the whatever vertical drains we provide in a soil sorry, whatever vertical drains we provide, the like this, this diameter of this drain can be between 300 to 600millimeter. And diameter less than 300 millimeter are generally difficult to install, unless the surrounding soil is considerably a<H. So, this is the one, lesser than 300millimeter generally difficult to make and generally not practice.

It is generally, so if you want to design a sand drain, then how what initially you have to assume and then you have to satisfy the condition. So, you have to start with maybe 400, 450, 500 like that, not or even if you want hat 350 also lower, but beyond 300 should not be adopted. Then similarly, spacing of drains, spacing of drains again it depends on the type of soil, in which they are placed.

And spacing vary between 1.5 meter to 4.5 meter. And spacing means, you can see the next one is there, that one borehole to another bore hole, this is the spacing actually. So, this is the spacing and it is actually, typically 1.5 meter to 4.5 meter. And sand drains are effective, if the spacing is less than the thickness of the consolidated layer. So, so that means spacing is less than the thickness of the consolidated layer.

Suppose, that a consolidating layer is this. And this is supposed H and then spacing a, spacing should be less than this. This is another way to make it effective. Otherwise, the sufficient pressure will not alive and water will not come out. And then next part is the arrangement of grid. Sand grains laid out in either square or triangular pattern, two pattern generally used.

Previously also, whatever we have discussed, deep dynamic compaction or other method, there are also some patterns, that everywhere are the triangular or square, these two are popular method. This here also similarly, either square pattern can be used or triangular pattern can be used. That means, what it is? I will show you the, it is there in the next slide. I will not do here. So, square and triangular pattern you can see here.

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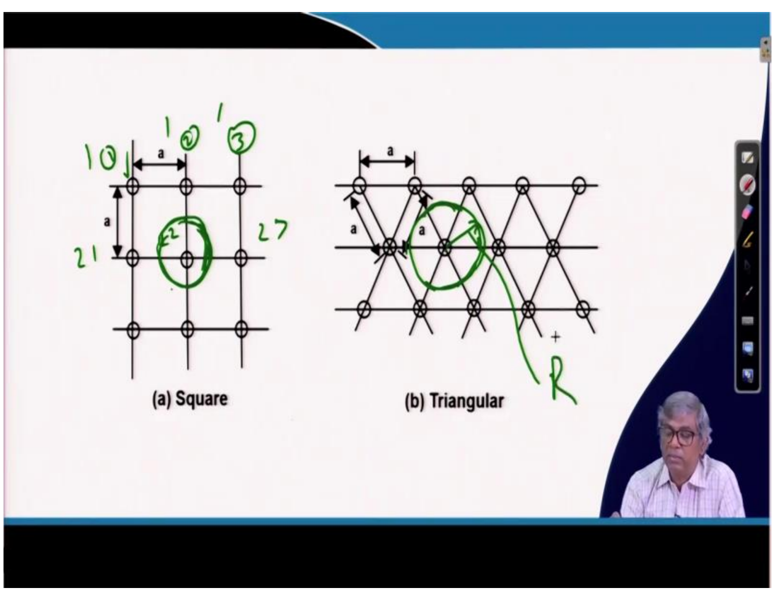

This is the one square pattern that means, this is the 1 borehole, borehole 1 or sand drain 1, this is sand drain 2, sand drain 3, like that. And similarly, here actually you can say 1 1, 1 2, 1 3. This is 2 1, 2 2, 2 3. That means it is, row 1 number 1, row 1, number 2, row 1, number 3, row 2 number 1, row 2 number 2, row 2 number 3 like that, you can put. So, these are the spacing. And similarly, if it is a triangular, then you can see here, then this is one row and this is another row.

Next, the borehole will be in such way we put, that it will form between two rows and the position of the sand drain, the suppose, not necessarily sand drain, it can be any drain. We will discuss instead of sand drain there are some other types of drain. What about vertical drain is a better term here? The arrangement of vertical drain is, it will be done in such a way that they inform equilateral triangle.

If it is done this way, then we can imagine that effect, effective area under, under 1 on drain. And what is the relationship between the spacing and the radius of this influence, that we will see later on. Similarly, here this also we have done, that we can do like this, we can do like this and like this, we can have another, another inference area with respect to this bore hole or sand drain, vertical drain. And then what is the, if this is the R and what is the relationship between R with the small r, that means diameter of the sand drain? So, that also we will be seeing later on.

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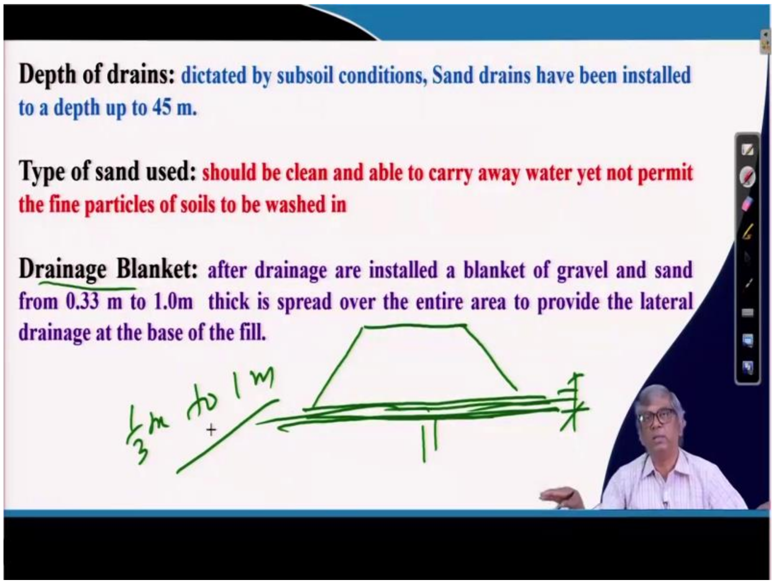

And depth of the drains, actually you can see here dictated by subsoil conditions. That means, depends on subsoil condition, how much depth to be decided. Sand drains have been installed to a depth up to 45meter, that means a comprehensible layer is there up to 45 meter or there may be at as close to the surface there is something quite good, but if you go deeper and deeper then we may find some compressible layer, to consolidate that you have to go deeper

So, up to 45meter, actually sand drains are provided, that much is the record is there. And type of sand used, you can see that in theory it is a requirement is that the through these drain water should pass easily. That is a requirement. Because of that free running sand has to be used, that what is the meaning of high permeability, so should be clean and able to carry away water yet not permit the fine particles of soil to be washed in.

That is a clean sand actually has to be used. And drainage blanket, there is a, as we have shown. That if this is the, soil to be come, consolidate and if you have surcharge, surcharge to be applied like this, then between these there is a drainage blanket. Immediately after water come out from the drain it will go join in that blanket and through this blanket this, the water can flow in the lateral direction.

After drainage are installed a blanket of gravel and sand from 0.33 meter to 1.0 meter. This thickness of the blanket, can be one third meter to 1.0 meter. That means, meter to1.0 meter. This is the range actually thickness to be provided over the entire area to provide the lateral drainage at the base of the field. Once water is then then lateral drainage has to be there. By providing vertical drain, we are bringing the water from inside the surface.

And after surface coming to, water coming to a surface if there is no drainage is provided, then water will not finally come out. We told again, it will be shown either through the drainage blanket, it will help to water laterally it will be drained away from the structure. This is a requirement.

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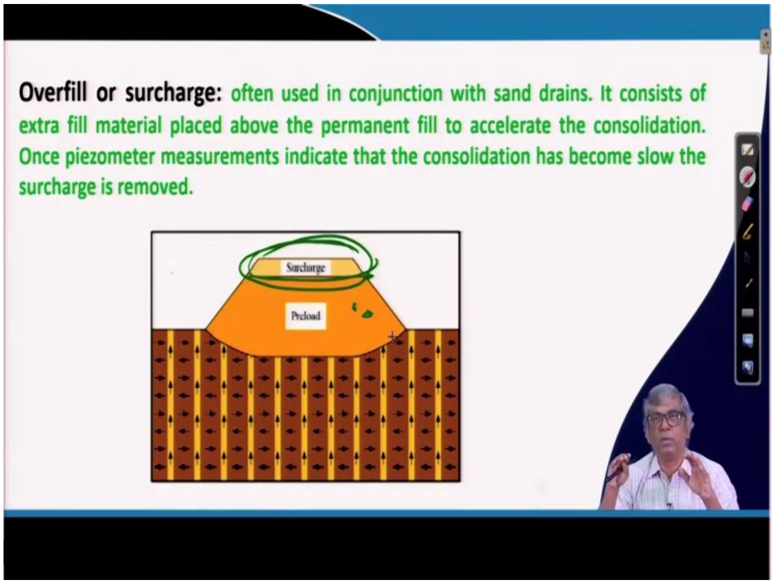

And you can see there is a overfill or surcharge. This is of course, we have seen that if there is the embankment is required, this is the part of embankment but this material went up to this is part of embankment. And by that much loading settlement, whatever permanent consolidation will be, will not be enough. We can additionally, we can put some load which will be removed or taken away and later other places, use in some other places. Often used in conjunction with sand drains, it consists of extra field which are placed above the permanent field to accelerate the consolidation. Once piezometer measurements indicate the consolidation has become slow, the surcharge is removed. That means, there then what will happen that in the consolidation. We are putting this much surcharge and what are coming out and consolidation taking and when you take decision, that consolidation is lower or the soil can be removed.

There will be some measurement also will be there, piezometer will indicates the pore water pressure from there you will know that the consolidation, whether it is always covered 100 percent may not be there, close to 100 percent generally is required to reach. And when, from the piezometer indication, we can close, stop the work. We consider the work is completed and then this amount of soil again to be removed, maybe use somewhere, next stress it can be used.

This is the way actually that is overfill or surcharges, that way this is the embankment normal this much load applied and keep it for some time. Some consolidation will happen, but we know finally the total embankment how much consolidation will take place and how much consolidation is recommended for the road. So, if there is a difference, then that much differential amount has to be completed by additional surcharge. So, that has to be designed. So, this is a part of design again, we will discuss later.

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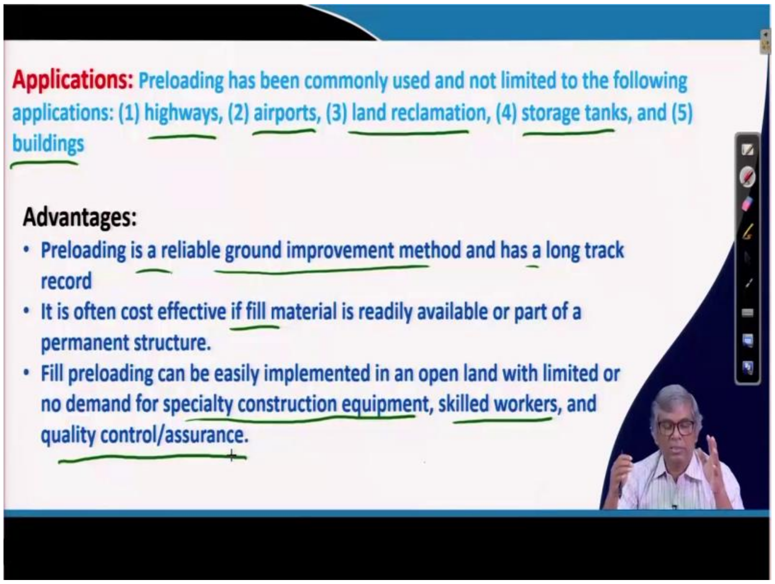

And applications actually here, number of applications that there pre loading can be used in many areas. Every area is almost consolidate, a pre consolidation but most commonly used places actually highways construction, relay construction, airport construction, land reclamation, storage tanks and buildings. They are the areas, actually very commonly pre loadings are done. It has an advantage, it is reliable, ground improvement method and has long track record.

That means, people know about these and I have mentioned, the first this technique is applied in 1936 and then onwards, it is improving. Now it is a quite well-established method and it is often cost effective. If fill material is readily available or part of permanent structure. We are consolidating by surcharge of embankment, the embankment loading itself a maybe 80 percent surcharge, another 20 percent we can add.

That the entire embankment can be consolidated by surcharge. And fill pre loading can be easily implemented in open land with limited or no demand for speciality construction equipment, skill workers and quality control or assurance. It is so simple only dumping material except, when you want to accelerate that vertical drain construction, maybe some skill you will be required.

Otherwise, it is a very simple and easily can be implemented any open area. That is the advantage and of this, next one.

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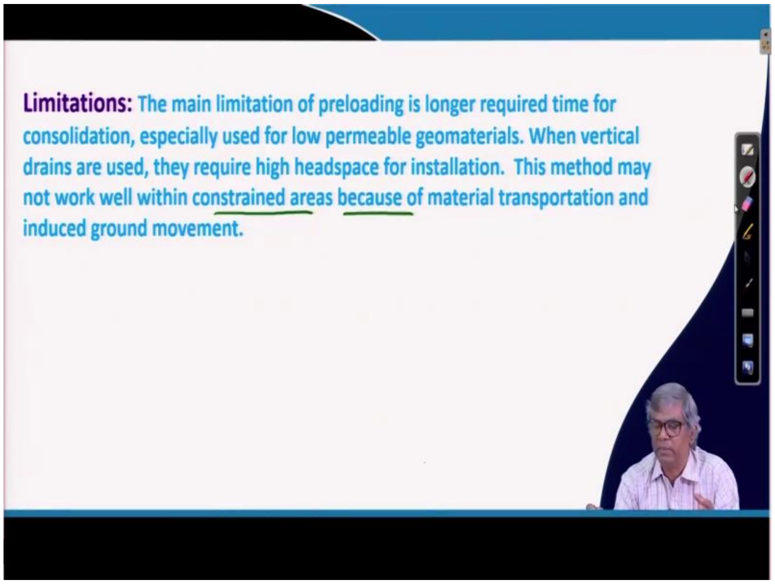

And of course, there is some limitations. Limitations are very little actually, main limitations of reloading are longer, is longer time required for consolidation. That is time required and especially used for low permeable geometry. If the permeability of the soil is becoming, is less, then it takes longer time, that is the only drawback. And when vertical drains are used, they require high headspace for installation that is also another disadvantage.

And this method may not work well within constant areas, because of material transportation and induced ground movement. The constant areas that mean, where we have difficult to move and access all those areas, this is very difficult to use. These are all of course, compact limitations on new areas pre consolidation are done for new areas. Because of that mostly you can say it is the advantageous.

And if of course, the comparability of the soil is less, it cannot be done or it is not effective, that is the only disadvantage I can say otherwise, others are just like those points are added. But otherwise, they are not much disadvantage for this, next one.

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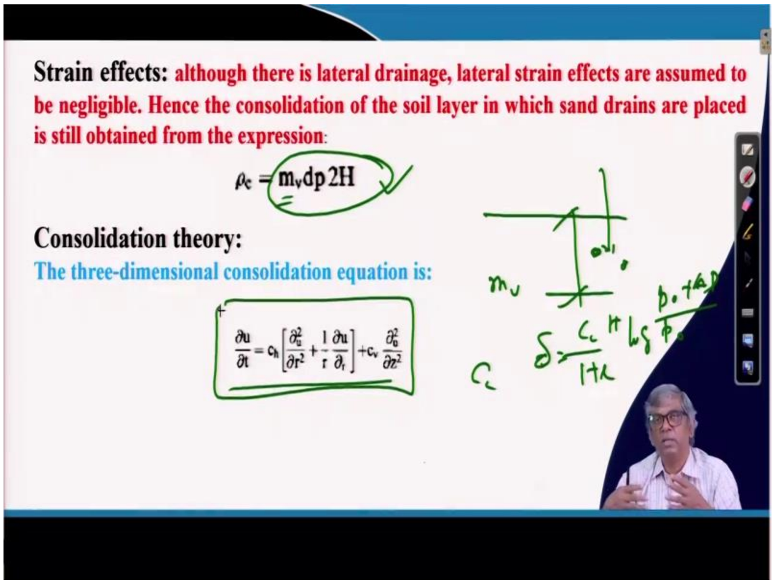

You can see that consolidation theory I do not want to discuss here, and if we coefficient of volume compressibility you know, if I know and then the, if there is a fine layer and if I know the mv of the soil and if I know the thickness of the soil and at the middle of the layer what is the pressure increase if I know, then by this formula, I can calculate the total expected settlement.

$$\rho_c = m_v dp 2H$$

Three-dimensional consolidation equation is

$$\frac{\partial u}{\partial t} = c_h \left[\frac{\partial_u{}^2}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r} \right] + c_v \frac{\partial_u{}^2}{\partial z^2}$$

Otherwise, I can collect a sample, find out cc and based on that I can find out delta equal to c_c multiplied by H by 1 plus e then log P naught plus del P over P naught. That formula can be used, but, this formula also can be. This by this way, we can, if I can find out the consolidation and that is the total consolidation expected and suppose after construction also you can suppose permit 20 or 30 millimeter consolidation, the total console, calculated settlement minus that, that is actually to become consolidated by this pre loading method.

Degree of consolidation will be based on that you can find out and then or design can be, can be done. So, that is the one we will discuss later on. For the time being now, there is a, as we have mentioned that if you apply a vertical drain, if I install a vertical drain to accelerate water movement from lateral direction and vertical direction. There is a three-dimensional consolidation theory, the governing equation is this.

And by this people have solved it and given a finally, it is a highly complicated mathematical solution. But finally, they have provided some chart. By knowing some design parameter, one can use it and design the sand drain or whatever vertical drain system, that I will have come to that part better instead of solving this equation. The solution part of this, can be learned in soil mechanics or advanced soil mechanics or somewhere. But here, I will try to explain the application of it.

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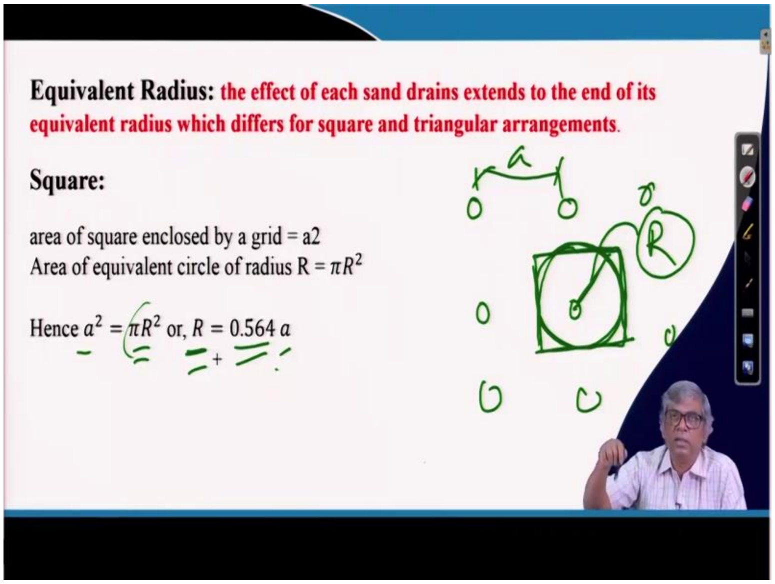

So, for application part actually, as I have mentioned that two things to be if I, if I in a square pattern, then actually like this, like this Like this Like this, then influence area of this actually suppose this is capital R. And capital, and the spacing is suppose a, then what is the relationship between a and capital R?

$$\begin{aligned}&\textit{Square}\\&\textit{area of square enclosed by a grid} = a^2\\&\textit{area of equivalent circle of radius } R = \pi R^2\\&\textit{Hence } a^2 = \pi R^2 or R = 0.564a\end{aligned}$$

That is what it is there. We can imagine that this circular area is pi R square and actual spacing, the influence area of this one is half a, half a then it will be a by a square. This it is equated actually. It is actually your actual influence area is this, this vector this square, but approximately this square can be drawn by a circle.

That circle is pi R square and a. Then R will be equal to 0.564 a, this is also have shown in some other application. For once again I am repeating because we will be using very frequently here, so the relationship between the radius of influence with the spacing is given here. Similarly, if it is your triangular spacing, if it is a triangular spacing, then how, what is the relationship? That I will show quickly.

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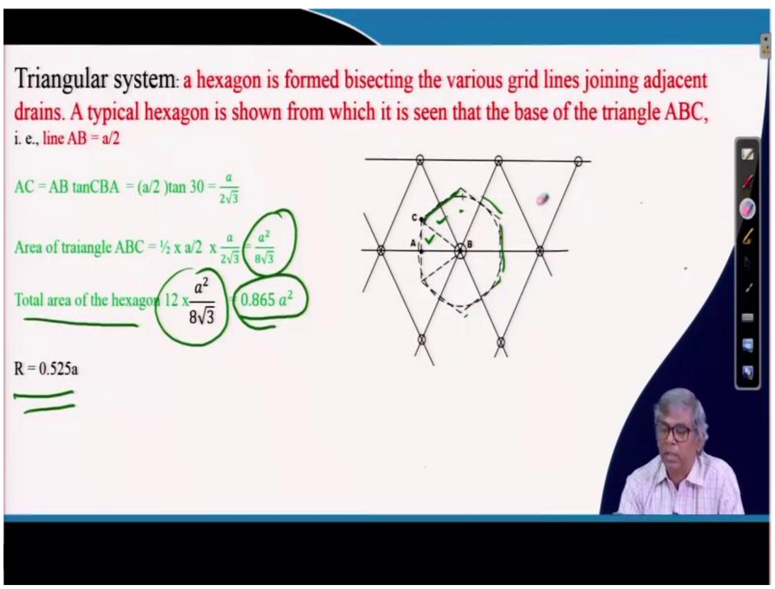

You can see here, if there is a triangular spacing then finally, this is the borehole if I take the natural influence area is this, this, this, this, like that. A hexagon, that hexagon can be drawn in a small either equal in circle. And that circle actually again, twelve small parts are there, you can see, twelve such parts are there. And area of one part actually is a square by 8 root 3. And total area is 12 multiplied by a square by 8 to the 0.865 a square.

And this can be equated with a square and so, R become, so, R become 0.525 a. That is what Here actually when the triangular arrangement. R and spacing 0.525, what is a square, square arrangement then the relationship is little different which I have shown in the previous one. These are actually will be used in design.

Because of that once again I am showing here, otherwise this part actually once I have shown before. This part now, this is the some of the things actually required to apply radial consolidation problem in sand drain application. The actual solution on how to use it, I will go to the next one. And here actually, I will stop with this, this part. Thank you.