Ground Improvement
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Lecture 60
Summary and Concluding Remarks

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Hi, everyone. Once again, I welcome you to this Ground Improvement course. We are almost at the end part in course. We had total 11 modules. Ten modules of five days, and five lectures, and last eleventh module, actually we had ten lectures actually. So, nine lectures already completed. So, this is the tenth one.

And tenth, eleventh module, we are talking about, geosynthetics in ground improvement. But today I do not have much planned to talk about geosynthetics, mainly because today is the last class, in last lecture. So, I want to summarize also. Because it is a vast subject in ground improvement, and some portion of it only I actually taken. But still that portion itself is not a small, quite big.

And when we have a total thing in your mind and when you are in the field, how to take out, from your mind one and apply in the appropriate place, I just wanted to talk in that line only. Basically, I was talking about geosynthetics in ground improvement, I can take one slide maximum and then I can go to the other general conclusion.

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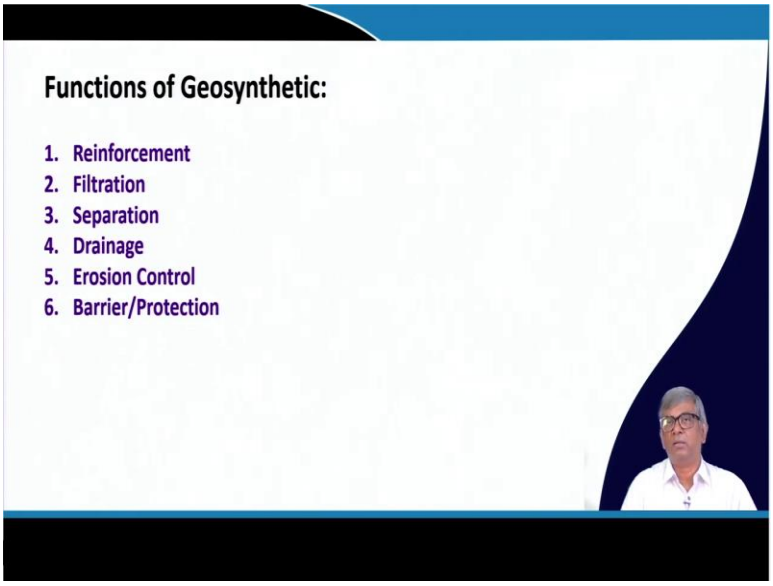

So, if I take this one, you can see that, I was talking about function of geosynthetic and then reinforcement, then filtration, separation, drainage, erosion control, barrier and protection. So, these are all different kinds of geosynthetic application. And in these, all I have briefly shown how they are used, where they are used, and their potential in geotechnical activities.

And particularly the use, reinforcement, application as reinforcement, there are plenty application, and out of that I have taken the example of geosynthetic reinforced wall. That means mechanic, that is actually MSE wall, mechanically stabilized earth wall. Also, also it is called as reinforced earth wall.

So there actually, in the, before application or before advancement of this geosynthetics, generally we are used to make RE wall, reinforced concrete wall, or gravity retaining wall, or similar type of wall, heavy wall. And cost is used to be high. whereas, when this geosynthetics came then different ways, it is used.

And particularly, this mechanically stabilized earth wall, that means instead of making a huge gravity, reinforced concrete wall, we can make just facing element, and that facing element can be connected through the reinforcement, and it would be laid inside the soil.

And when, because of the earth pressure, the facing element will try to move, then reinforcement also will try to come out. At that moment, there will be some friction will

develop between the oil and reinforcement, and that actually helps to bring the wall intact, or with minimum movement. So, that is actually reinforced earth technique.

And this one, actually, I have taken and the theory and design principle I have discussed, also I have shown the design calculation thoroughly. Reinforced earth application also can be there. There are many areas like slope, also I have introduced little bit.

And then it can be used below the foundation, reinforced soil bed. That means foundation on reinforced soil, that means if the soil is weak then we have already discussed different methods of ground improvement. One such method, I can say that you can excavate, and then you can bring good soil and then put, lay the reinforcement, and again put number of layers. And that way very strong foundation bed can be prepared.

So that is also another application, but the use, that application of that type of reinforcement is not that popular, mainly because for, to make the reinforced earth technology, you have to bring good soil, that means sand. And once you will be using sand, and whether you will put reinforcement or not, and that does not matter, actually. Sometimes if you can compact well, it will be useful.

But anyway, there are plenty research paper available on geosynthetics and the foundation on geosynthetic-reinforced bed. So, a lot of people are varying that the length of the reinforcement then the number of reinforcement layer, then depth of first reinforcement, spacing of reinforcement, like that, vary everything, and you will get new results. And that way many people are doing. A lot of publications are available.

The practical application of that is very less. Generally, we do not see the, very frequently that the foundation is built over reinforced soil bed. But of course, it is there, application in road and all, where separation and reinforcement, both are actually, together it will work. So, that type of application, it is there. But otherwise, only for foundation on reinforced bed, is not that popular.

So of course, but if you want to do then a lot of complicated analysis is there. It will take a quite long time. And in fact, geosynthetics in geotechnical application, it is a vast subject now. The complete one or two courses also available in the NPTEL itself.

So those who are interested to learn more about geosynthetics application in geotechnical engineering or ground improvement application, then one can go through those courses or even read some books by Quaner.

So, with this, I will close the geosynthetics chapter, that means whatever we wanted to include in this particular ground improvement course, it is almost, you can say, it is now the end.

But now, as I was telling at the beginning, that after knowing so many things, which might be going to your brain, and information will be there, but now we are in a practical field and you will see the situation, the ground condition, water table condition, soil condition, many other aspects, and finally, how to take out a particular information from your brain which is actually appropriate for that particular situation. How to do that? So, I just wanted to make a very brief discussion on that, maybe a few slides. And then I will just say goodbye. So, let me go to the next slide.

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Already I have mentioned that we had this is the course outline which was circulated at the beginning itself. And you can see we are started with the introduction where we have mentioned where actually ground improvement is required, where actually problematic soil is there. And what is problematic soil, that is actually discussed in the introduction chapter itself.

And there itself we have done some, the easiest method actually, that excavation and replacement, that means if you find a poor soil, the best way to remove that. You just, do not face the problem. Instead of that you bypass. so bypassing is what? Actually, whatever poor soil or problematic soil is there, you just excavate and remove, and bring the good soil.

So that is a, one of the simplest techniques. When it is a small sized work, that type of technique can be used. And it is, many times used. And of course, we have discussed in length how we can design that, how to check whether this type of replacement is required, whether this replacement is suitable, how to check etc. we have given detailed analysis.

Next, I was, we have given a different topic like shallow densification, deep dynamic compaction, rapid impact compaction, vibro compaction, drainage and dewatering, preloading and vertical drain for densification, grouting, chemical stabilization, soil nailing and ground anchors, and use of geosynthetics, that is the last one. So, like that, we have completed the course.

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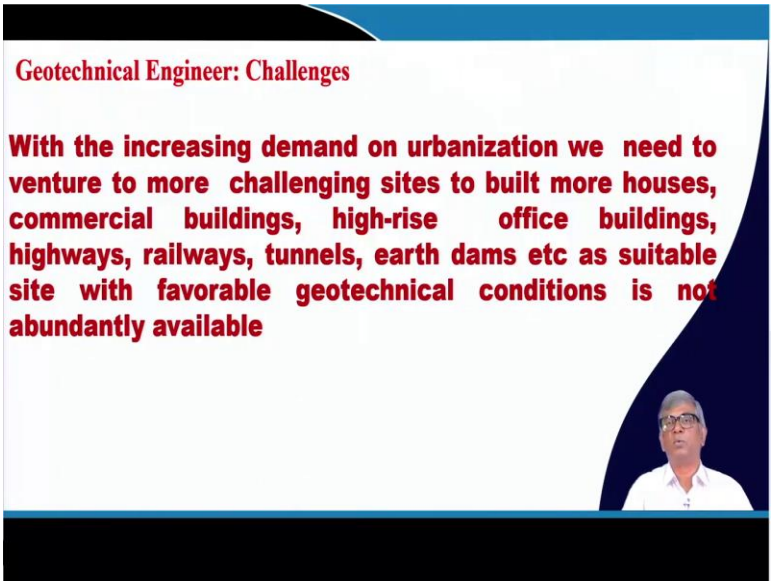

Now, after going through this course what I can summarize is what is the challenge in front of a geotechnical engineer. Geotechnical engineer actually as a civil engineer itself will have the first challenge actually, any civil engineering activity will be started, the first challenge will be faced by the geotechnical engineers.

Because, we know that people will have tendency to settle close to a place where all facilities are available, like near river, because water is available. So, all, you can see, the civilization started close to the river. And then again, many other facilities whenever available, then people will be settling there.

So, when people start settling, then people will look at various other aspects also, the ground condition will be better, no flooding, no extra heat, or no extra cold. Like that people will see. That means at a first instance people will be choosing the best location. Once you are choosing one after one, and then sometimes that best location will not be available. Then, that is the challenge.

So, with time that you have to enter into the challenging side. Challenging side means what? Where actually the soil may not be available to be used as it is, like a, a low-lying area. That which, like maybe wetlands, or something, a forest, or something, deforestation, of course, is illegal. Better not to talk about forest. But otherwise, suppose some sort of bushes or anything is there, we have to clean it and then only you can make it suitable for building suppose.

So, this type of areas is not ready for use. You have a lot of development. For those developments, actually, the first challenge will be faced by geotechnical engineer because land has to be made ready for any building.

Land making ready means what actually? Land should be strong enough, it should not be settled too much, it should not liquefy, many other such requirement is there, which we have discussed over last, almost two, three months. So, that means, what is the challenge actually?

With the increasing demand on urbanization, we need to venture to more challenging sites to build more house, more commercial buildings, more high-rise office buildings, more highways, more railways, tunnels, earth dams etc., as suitable site with favorable geotechnical conditions is not abundantly available. So, that is the challenge.

That means favorable geotechnical site is not available just like that. People are using and finally it will be coming shortage. You have to enter into the challenging site. So, when you are entering the challenging site, there are different types of challenge will be there where soil may be very sharp or soil may be very new fine and lose, there may be underwater.

Those are the challenge, actually. When it will be there with you then you need to know there are solutions. That solution actually, we have discussed through this course, ground improvement course. What solution we are we have talked about?

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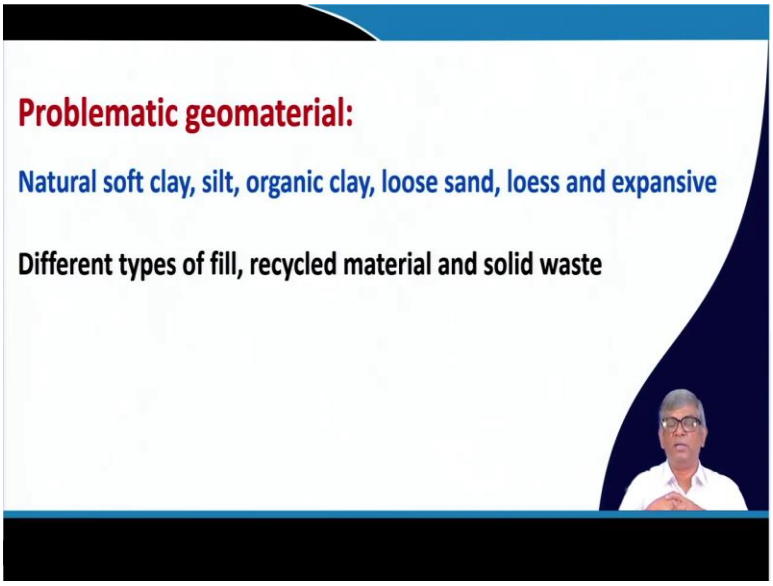

Before, of course talking to the solution, we have discussed about problematic geomaterial. Already I have just now mentioned, problematic geomaterial means exactly what? It can be natural soft clay, it can be natural silt, it can be natural organic clay, it can be natural loose sand, or it can be naturally deposited loess, or expansive soil. They are all expansive, all our problematic soil.

So, when you want to do something or develop something on that type of soil you need some care, or need some improvement. And then, it is another one thing, that is natural. So, those are natural. Sometime, we are actually using or, you are producing a lot of waste, or you are making the after, buildings becoming old we are demolishing and there, we are producing a lot of waste.

Then we are also putting those waste somewhere, mining activities, we are producing water waste, that also we are putting somewhere. like that we are also continuously filling land. There are different types of fills are there. So, those fills also sometimes can be utilized as the site.

Again, different types of fills, those fills also, generally they are not a favorable geotechnical site. You need to have some sort of ground improvement. So, different types of fills also, or recycled material, or solid waste, or whatever we are producing, we are putting somewhere. And after several years it will be decomposed, may be that area can be chosen as the site for development.

If you want to do that, then just ready-made cannot be used. You have to do a lot of improvement activities. That means, first of all, when you are in a site, then we need to know what is the problem, you need to know. Whether it is a natural problematic soil, or it is a fill problematic soil. That to be identified, then accordingly treatment also will be different.

Coming to the next, let us see different type of problems on problematic soil, to improve and make it suitable for the building, what technique we know.

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All these are the things we have discussed. You can see that, these are the methods we have discussed over two months, almost. And that, you can see that the first topic we have discussed is excavation and replacement.

That means, if you find that the topsoil is not good, which is maybe 1 meter deep, and your project site also quite small, it can be some time wise to take a decision to excavate and replace by good material, if good material is available nearby. If you are to bring from several kilometers, again, it will be expensive. So, that will not be wise to use. So, excavation and replacement, we have discussed.

Then we have discussed shallow densification. Shallow densification is a very, commonly used densification technique. This cannot be done for a deep soil densification. This is actually, has to be done in layers.

For example, if you want to make an embankment or dam, suppose dam or embankment of 8 or 10 meter high, or dam 50, 60 meter high, if earth even, it cannot be so high. Suppose 20, 30-meter-high dam, if you want to make by earth, then you have to compact in layers. So, those compactions, whatever we do, that is actually shallow compaction. We do by roller.

Different kinds of roller are there, again, depending upon your type of soil. And so, you know that when it is a sandy loose soil then the, the smooth wheel roller, with vibration is suitable. Similarly, if there is a soft soil, is there, but you need to improve it then sheepsfoot roller is suitable. Like that in between, if there is a silty sand and all, then there is a pneumatic tired roller. There are different kinds of roller depending upon soil type can be chosen.

So those things also, we have discussed, that is, actually, that shallow densification is done by deep thickness. That means if you want to make a 5-meter-high dam or embankment, then what do you have to do? You have to do in a 30, 40-centimeter height, compact, then again 30, 40 centimeters, then compact, then 30, 40 centimeters, like that deep thickness you have to rise up to the level of the embankment. So, that is shallow deterioration.

But when, this is actually when you are making a road or similar type of things, we can make it. But if a particular site, soil is not good up to, suppose, several meter, like 5, 6 meter or 10 meters, then this technology cannot be, or technique cannot be used because the surface rollers cannot reach beyond 0.5-meter depth, or beyond that. So, as a result, you need to look for some other techniques.

That is the one, deep dive densification means, there is a technique where a huge weight will be lifted up from a height and then it will be fall, allowed to fall. And because of that energy applied to the soil, will be densified. And that densification will be extended up to 8 to 10 meters.

And again, all soil cannot be equally densified by deep dynamic compaction. We have also mentioned type of file which can be easily densified, which cannot be easily densified. And in addition to that, what should be the groundwater condition. All those things, we have discussed.

Suppose a soil up to a significant depth improvement is required, and soil is supposed silty sand, and water table is significantly low, then actually deep dynamic compaction will be suitable. If the water table is very close, then sometimes it will not be good. Of course, it can be used, some modification can be done. So, what, we have discussed in the appropriate place.

Similarly, rapid impact, deep dynamic compaction is up to 10 meters, similarly, comparatively lesser energy can be applied, and instead of a few drops, a greater number of drops and more frequent, high frequency. So, that is another type of compaction called rapid impact compaction, where actually what type of soil it is suitable, et cetera, we have discussed.

And particularly water table depth, if it is less than 1 meter, then this method is not suitable. So, in that case you have to use the water, lower the water table, then only it can use. So, that rapid impact compaction can be improved up to maybe 5, 6 meters, and very commonly used up to 4, 5meter.

That is actually shallow compaction means, it is really shallow, 0.5 meter, deep means up to 10 meter, and rapid impact compaction maybe up to 5metres. These are the different ways actually, by applying energy, that is the compaction, we are doing. That is one way of improving the ground.

And there is another type of ground improvement, that is vibro compaction. Vibro compaction actually is quite useful technique, where, actually, suppose top 2, 3 layers may not be that problematic, but below, maybe, 2, 3 layers, there is a particular layer is very loose and also saturated.

You know that saturated, lose, fine grained soil will have tendency to liquefy during earthquakes, so if you have a very good or important facility to developed, then you have to prevent, or you have to reduce the liquefaction potential, or you have to make that resistant to liquefaction.

So, to make that, the vibro compaction is a method, where, actually, we can compact soil quite deep, maybe up to 30, 40meter. And at any depth you can do. Even, leaving the surface, you can do at the bottom.

The technique how it can be done, you have to make a borehole by water jet or air jet, and you have to go up to the depth. And then from the surface you pour good soil, and then finally compact. So, like that, several compacted sand columns that can be made one after another and then finally, the entire ground can be densified. That is another type of compaction technique, that is vibro compaction.

These are all about sand, silt, these are all suitable, but when actually very fine-grained soil, saturated fine-grained soil, maybe 10 to the, 10, 15 meter deep, and if you want to build anything on that, then there is a chance of having very large settlement.

So, to avoid these, after construction this large settlement, generally, soil has to be preconsolidated. So, there is a preconsolidation technique. That is another method of ground improvement. So, that is, which is applicable for fine grained soil.

And this preconsolidation can be done by applying surcharge. And by applying surcharge if you want to do, only, then time may be taken by, very long, and which may not allow many of the project to wait for such a long time. To accelerate this consolidation, again, we can associate with some sort of drainage provision, some vertical drain you can provide, by sand drains, or it can be preplicated vertical drain.

And by installing that, and if you surcharge together, then very fast you can consolidate the fine grained soil. So, that is another ground improvement technique which can be used for soft fine grained soil, saturated fine grained soil.

And then there is a grouting, where, actually, three types of grouting, again, it can be solidification can be made by inserting the, or (penet), the, pumping the grout material within the soil pore. And then after solidifying, then ultimately there will be, strong solid mass will form, which will be sometime useful for improving the ground.

Then there is a chemical stabilization. That, some soil, you know the composition of the soil, and you know the material by which it can be reached. Accordingly, we can choose some chemical material like lime, cement and then you can add to the, to the soil. And over the time it will react and finally, it will be, better soil will be resulted. So, these are all different techniques we have discussed.

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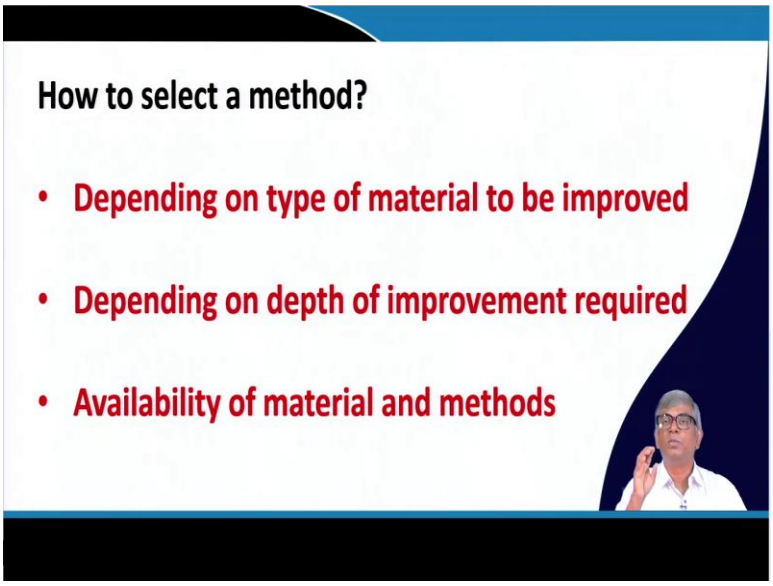

Now, the question is, how to select a method? So many methods we know the selection actually, it can be, depending on type of material to be improved. That means, whether it is silt, whether it is sand, whether it is a clay, so again based on that, again, even if it is a shallow densification, so depending upon soil type we can have different types of rollers. And so, that is another thing.

Again, deep dynamic compaction, rapid impact compaction or preconsolidation or grouting, depending upon soil type, we can choose. So, that means, you have to see the, what type of soil. And again, sometimes depending on depth of improvement required. Then all you have to see together.

Suppose a particular soil, you have seen maybe shallow densification is good, but your densification depth is required maybe 8 meter or 10meter. Then in that case, only choice you have is the deep dynamic compaction. Like, depth of improvement is again another important point. So, you have to see the type of material, the depth of improvement required, and then availability of the material and method.

Suppose deep dynamic compaction, you want to make. If there are no contractors close to you, then better not to use. So, me other thing you have to use. like that, or some other chemical stabilization, or anything, or you want to do by excavation and replacement. You should have a source for a good material.

like that, you have to see type of material, you have to see depth of improvement, and see the availability of technique and methods and equipment, those things also. And also simultaneously, you have to see the groundwater location.

All those things you have to see, and then based on that, and you have to eliminate, because of this particular condition, this is not a suitable, finally, there will be some method which will be suitable for a particular site. So, that is the way you have to select.

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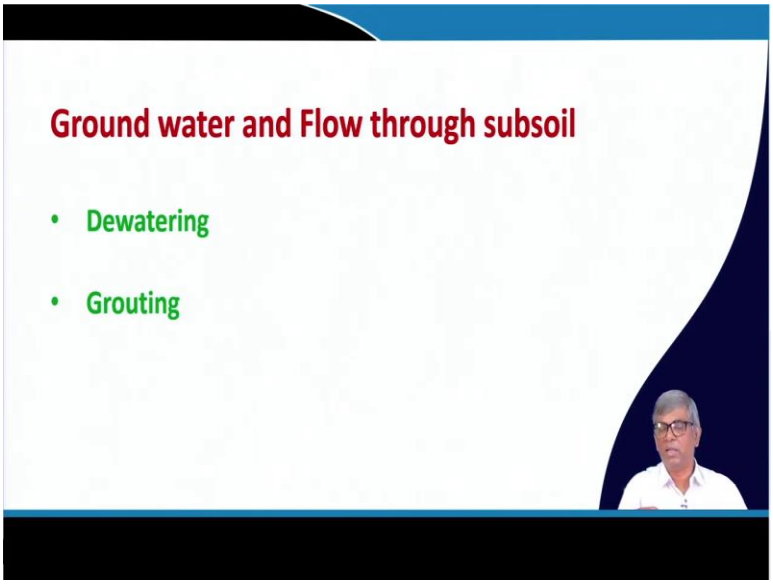

Next one is the, sometime groundwater, and flow through subsoil. So, when groundwater is there, as I have mentioned that, if the groundwater is close to the ground surface, rapid impact compaction is impossible. Similarly, if it is some other activity also, groundwater if it is a close to the surface, then construction activities are very, very difficult.

Because of that, why you need, what do you need? You need to dewater. So, there are dewatering techniques. How to dewater, you have discussed. And sometimes because of the difference in height, water will try to move through, one direction to other direction through the subsoil.

And when this water movement, of through the foundation takes place, then there will be some, initially the path will be narrow, and then path will be, slowly, it will be wider, wider, then finally it may cause collapse. So, because of that we generally try to prevent flow of water through the foundation.

So, when you want to do, sometime we need to use the different types of grouting to seal, actually. The sealing purpose, grouting can be used. These are things also we have discussed in appropriate place. This is the, by enlarge, you had the course.

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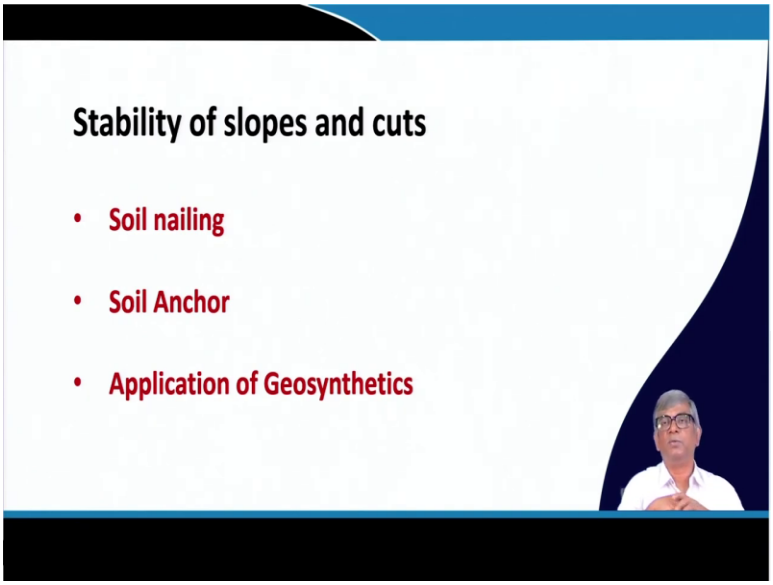

And then, another two topics we have discussed, that stability during excavation, or that, during the road making in the hilly areas. Suppose, hilly areas with a very narrow area, you have to make the road. So, you cannot make particular slope, mild slope. Then you have to do that with a steep slope, to maintain construction activity, we can use some technique called soil nailing. And by that, actually, required access area is less. So, soil nailing, how, what is, how do it is useful, we have shown.

Similarly, soil anchor. When you want to do some excavation, and then, up to some depth only we can do without support. But when you go beyond certain depth, then you need to have support otherwise your, it will collapse. That collapsing can be prevented by providing proper anchoring. That soil anchor also, we have discussed. And finally, we have discussed soil application of geosynthetics for different application.

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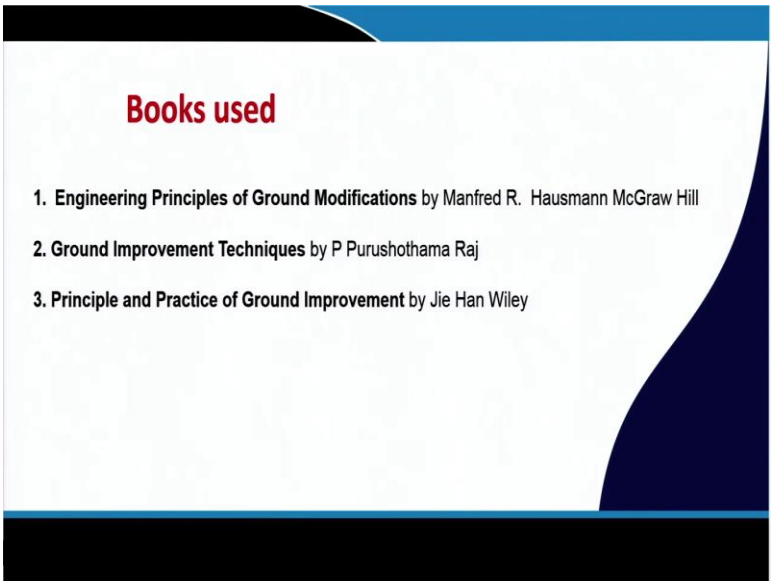

So, this is the way, actually, we have completed the course. And I hope, finally, this is the thing, actually I missed. I have mentioned three books in the introduction itself. And most of the materials are used in the, from the last book, actually, Principle and Practice of Ground Improvement by Jie Han. And this book is by Wiley. But presently it is available in Indian edition.

So, it can be available in 400, 500 rupees. One can have this book, but this book is a huge book. Portion of it only, I have done, but one can have this because whatever I have covered, other than also, other than that there are many other problems, how to solve those problems, one can refer this book and get the solution. So, one book on ground improvement is must if you want to become a geotechnical engineer.

So, these are the things I wanted to tell with this. With this, I will just close this ground improvement. And I will be very happy if it is useful to you. I will be waiting for your feedback at the end. And I think you will appear for exam also, some of you. And if you want to appear in the exam, the exam actually, there are a ground improvement, a lot of design aspects are there, which we have discussed in the class, and there is big design aspect, lot of things to be remembered.

So, but in the exam, we cannot do that, since it is a computerized online exam. We have to make mostly 2 marks questions. And those 2 marks questions, sometimes directly 2 marks question or sometime it will link question. There may be a type of design we have done, so similar design type of question we can ask. And step 1, we can give 2 marks,

step 2, 2 marks, step 3, 2 marks, like that. So, this is the way. 50 to 60 questions will be there for 100 marks question.

So that is all. If there is anything you require, you can raise in the forum, and I had already two live sessions. One more live session is, there but in the past two live sessions, it was quite pathetic. I did not see many attendances. If you want, if I see good questions then I will come in the last live session. Otherwise, I will just keep that. So, I will wait for your feedback. If you need some help then only, I will come. Otherwise, this is the end. So, thank you all. So, I will just close this Ground Improvement here itself. Thank you.