Ground Improvement

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Module No. # 01

Lecture No. # 02

Classification of Ground Modification Techniques

Dear students, I welcome you for this second class on Ground Improvement, which is the NPTEL course.

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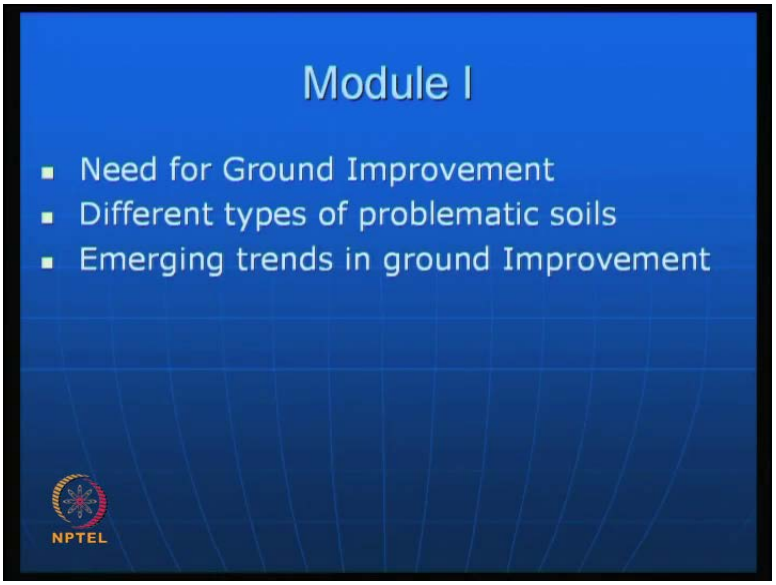

As I mentioned earlier, we should be able to understand the need for ground improvement, different types of problematic soils and also the emerging trends in the ground improvement.

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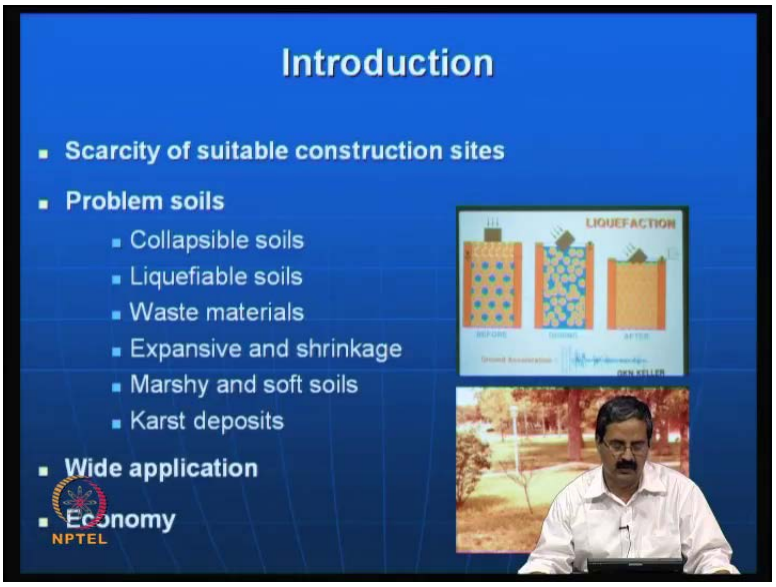

Just to recapitulate what we discussed, this use of ground improvement technique is very essential, because there is lot of growth in infrastructure and we find it very difficult to have suitable sites for construction. When you have this sort of problems, it is always difficult to handle soils – the soils or different varieties of soil we have. We try to say that they are all problematic soils are problem soils. Soils can be collapsible, some soils are liquefiable, some soils are expansive and some soils have a tendency for shrinkage, you have some areas, where you have marshy deposits and also soft soils, and Karst deposits. These collapsible soils are nothing but the soils, which have a tendency to collapse upon loading. Many of the reasons such as, the stable or unstable meta structure or capillary structures nullification are some of the reasons for this collapsible nature of the soil. Suppose the soil is partly saturated and when it comes in contact with water, the moment there is a contact with water all the capillary structures are destroyed. Because of this, there is a volume change; it is in fact a reduction in volume and that leads to collapse.

These liquefiable soils most of the times occur in… They are essentially sandy soils, which have a tendency for liquefaction; means they behave like a liquid under the influence of impact loading and like an earthquake. You can see that the earthquake – for example, before an earthquake occurs and during the earthquake event, which is about 30 seconds to 1 minute, there is a particle rearrangement. The foundation that you have at the top could sink in; in fact, we can call it a quick sand condition also, which is nothing

but static liquefaction; means the soil behaves like a liquid when the effective stress is 0. When this effective stress is 0, the soil loses all its strength and behaves like a liquid. So, these two soils: collapsible soils and liquefiable soils are problematic because it is very difficult to have foundations on these deposits.

Same is the case with waste materials like municipal solid waste or any of the waste, because in soil mechanics, it is possible to understand the consolidation behavior; for example, in terms of primary consolidation, secondary consolidation and all that. However, in waste materials, you have lot of biodegradable material and it becomes very difficult to understand how these materials behave with time. This is a difficult challenge. You have another type what is called the expansive soils, which I can show you the figure here like – I think I am just covering that.

You can see that these expansive soils are also quite common in many of the areas particularly in Deccan plateau and in some parts of Andhra Pradesh, where the soils have a tendency to swell; means they take lot of water and then when you remove all the water, they go to a minimum volume like liquid limit is a highest water content in the range of about 100 percent and the shrinkage limit could be as low as 10 percent. This extreme range of water contents in the case of expansive soils causes significant expansion, also significant shrinkage leading to lot of volume changes. Because of this you have many of the problems like the distress in foundations, then loss of contact, many other things.

Marshy and soft soils are another classic feature in many of the soft soils in India; like all along coastal areas in India, you have these marshy deposits and soft soils. Where the shear strength is so low that you cannot even walk, you are expected to construct a nice port structure there. So, when the soft soil is so poor, it is very difficult to construct anything, because the bearing capacity is very low, shear strength is low, consolidation settlements are going to be very high and permeability is very low. These are all very peculiar. So, this needs to be improved.

Another case what is called Karst deposits. Actually in some natural formations, there are some soils where there is a formation of holes like sink holes; we call them formation of sink holes like… We do not know how it forms, but when there is a contact of soil with water, all that soil is lost and suddenly you find a cavity. So, these are very big risk.

So, you need to fill up those voids or the gaps and then see that the bearing capacity of the soil is there to the extent that we need them and also settlements are minimum, and all that.

The general applicability of the ground improvement techniques is that we should have good shear strength, less settlements and also permeability that will not create lot of problems like pore pressures or seepage and all that. So, we need to do a lot of engineering analyses here. Many of these techniques particularly the ground improvement techniques have very wide application, because the objective is that when infrastructure is growing, people should reach out to smallest villages; for example, you have in Kerala, small villages in maybe 100 members in a village, but you need to construct a road, which goes to lot of soft soil deposits, or it could be a place in Andhra Pradesh, where the soil is totally expansive, or there could be some waste materials that you would like to construct a multi-storeyed apartment in a building in a city. You have liquefiable deposits in the whole of Gujarat. Particularly in the Kutch area, lots of liquefiable soils are there. We know that particularly in the earthquake of 2001, many dams, buildings roads have caved in simply because of these liquefaction problems.

Definitely, all these ground improvement techniques have very wide applications. Economy is a key, because there is no solution here in some places. Maybe in some cases, instead of going for a shallow foundation, one can go for pile foundation, which is again expensive. However, in such cases, one can go for simple foundations, where you have good cost economies achieved with proper design.

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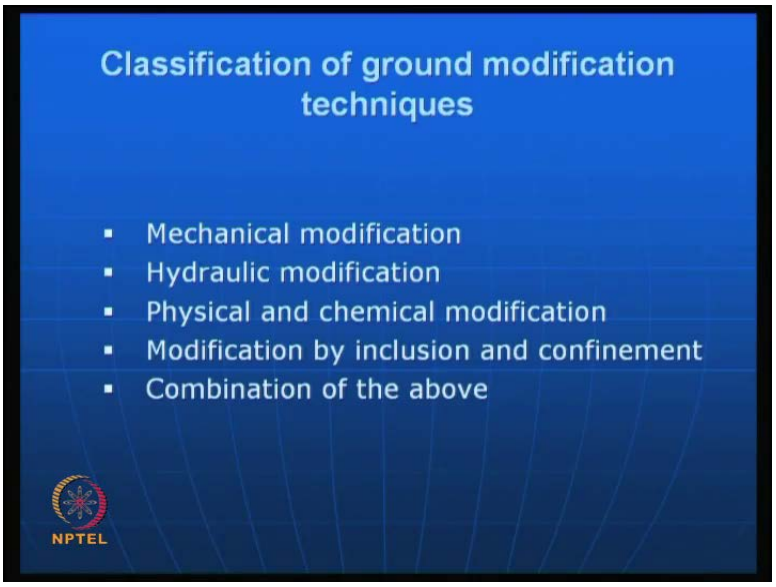

I would like to classify the ground modification techniques or improvement techniques in different ways. One is called mechanical modification in which say for example, by compacting the soil, you can increase the density of the material; like you can put some rollers in a field and then see that compaction is achieved. This is called mechanical modification. Then, the second thing is hydraulic modification, in which, we know that the shear strength of the soil is low when the water content is high. So, you try to remove some amount of water by preloading or by increasing the drainage, by pre-consolve, pre-fabricated vertical drains; we have some pre-fabricated vertical drains that we will discuss. We try to remove the water from the soil and also see that it is consolidated to a very high pressure, so that the existing pressure or the pressure that we are going to place later on, will be very minimum with the reason that it helps the purpose. So, this is called hydraulic modification.

Then, we have another category called physical and chemical modification, in which, for example, the soil is poor; as I just mentioned the case of an expansive soil like the liquid limit of the expansive soil is 100 percent and its shrinkage limit is 10 percent. If I add some sand in the expansive soil, what happens? The liquid limit of the sand will come down say for example, 60 percent and the shrinkage limit will increase to 20 percent. So, what happened is in the first case, the range of water contents is 100 minus 10, means 90 percent is the range of water contents. Then, it leads to lot of settlements because that is a tendency of soil to undergo lot of volume changes because of water content variations.

Now, by adding some sand by physical means, what you did was that the water content variations are brought down; the range is 60 to 20, which means about 40 percent. From 90 percent to 40 percent, you reduce the range of water contents, which means that you are able to achieve some sort of stability in some form using physical means. The same thing can be obtained in the case of expansive soil using say for example, lime; lime is a classical technique in stabilization of expansive soils. So, you add lime, then it reacts, and then it forms cementation bonds and many other things with the reason that even chemically also the same process can be obtained. So, this is what we meant by physical and chemical modifications.

We have another one, very important one – modification by inclusion and confinement. Inclusion means the reinforced soil technique. Say for example, you put some…; we know – we are used to reinforced concrete, where steel is used to take care of the tensile strengths. Similarly, in the case of soils also, we put the reinforcement whether in the form of geo grids or steel girds or geo membranes. There are so many materials here; one can put them in the form of reinforcement in soil, which we call it as reinforced earth or reinforced soil. The advantage would be that whatever is a load that is on the soil, it is taken care by the friction between the soil and reinforcement. We have introduced some sort of reinforcement in the soil; if you apply load, what happens is that the load gets transferred to reinforcement and soil and then, there is a friction between the soil and reinforcement. Because of this friction between the soil and reinforcement, the load that particular component will help in taking additional load.

The other important point is the confinement effect. For example, sands; sands do not have any confinement effect; in the sense, it does not have any cohesion; we know that sand has negligible cohesion. Friction angle is say for example, 30 degrees and I want to increase the cohesion in sand, I can use this reinforcement or what you call geo cells – we will see them. One can improve the ground using these inclusions or confinement effects either in the form of a reinforcement like geo grids or using this confinement using geo cells. So, this is another important aspect. One can use many of these combinations. In fact, I have been working on many of these projects, where we are able to use combinations as well to just improve the soil and get the desired benefit like what exactly we want is what we can get; that is a beauty here.

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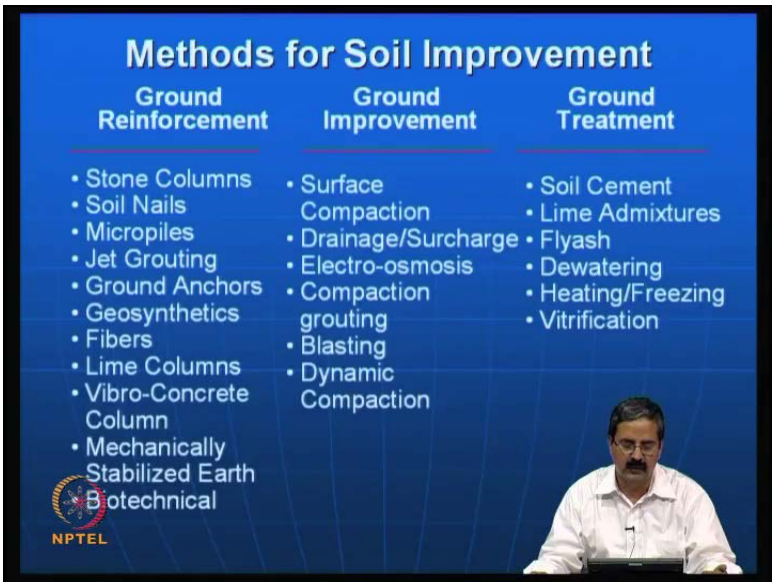

What you saw just earlier was some sort of classification based on the methodology that we do, but in practice, there are many things. You can say that I can call it ground reinforcement, ground improvement, ground treatment. It is just the terminology that we are using here, because all the three things are… Essentially we are trying to improve the ground or its properties. We are trying to be very specific here when we say ground reinforcement, because the reinforcement action will be very dominating here. Say for example, if I say stone columns, this stone column is a technique that is used in the case of soft soils. Say for example, in many of the coastal areas in India, whether it is Vizag port or Kandla port or Cochin port, you use these stone columns. What happens is that normally you apply some load in the case of soft soil, the load is so much, and the load cannot be taken care. However, similar to piles, if you have stones – stone columns made of matrix of stones and aggregates, they will take the load. So, it is a sort of reinforcing the ground. That is a reason we call it reinforcement.

Then, we have what is called soil nailing. Actually we see that many projects we have been doing, this technique has been used; particularly in the case of excavations and all, where there is a tendency for soils to slip, we use soil nailing. Then, micropiling is another technique, where if there is a stability improvement required, instead of piles, we use micropiles, which can be easily driven into the ground. Both: soil nails can be driven or inserted into the ground and micropiles can also be simply inserted to the ground. What happens is that when this stone column or soil nailing or micropiling – they are all

reinforcement techniques, they intersect the failure surface. The moment they intersect the failure surface, then what happens is there is shear strength availability at the point where this material is available. So, that deflects the failure surface. When the failure surface is deflected, the shear strength is going to be…, the failure surface will have higher factors of safety. We will see one of them.

This jet grouting is a similar thing, where grouting is you are trying to put a stronger material into the system instead of the weaker material. Then, we have another terminology called ground anchors. Ground anchors – particularly in the case of excavations and all, I will take you to some construction projects soon, where anchoring is done, so that their retaining walls are stable or the excavations do not collapse. Using ground anchors, we use anchoring mechanism here. That is a very helpful thing.

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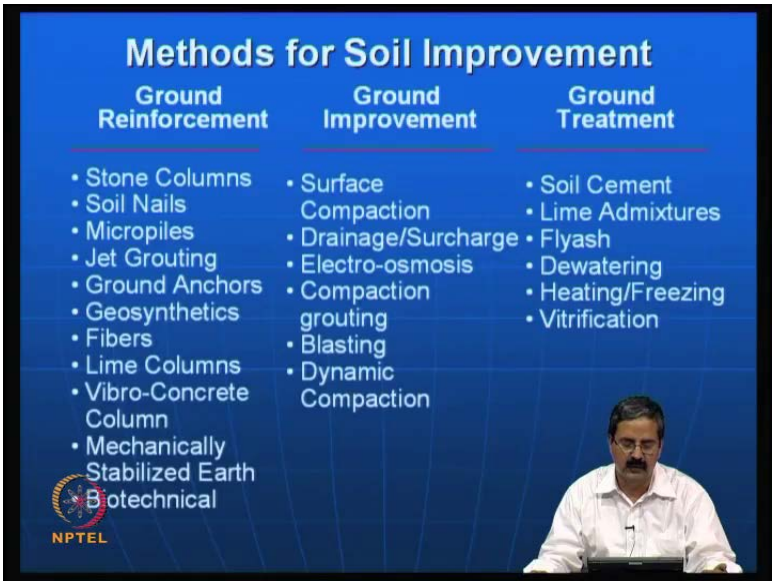

Geosynthetics is something that people have been using to the maximum extent. There is no substitute to this that for example, in a civil engineering sense, we are used to concrete, steel and soil. All these things – if they have any problem like say for example, you have additional dimension here nowadays. Even in RCC, people have been using geosynthetics; even in hydraulic problems, people have been using geosynthetics. So, these geosynthetics have wide applications and they have been significant component in ground improvement or ground reinforcement techniques. Then, fibers – fibers is something that – any of the fibers like coir fibers, steel fibers, we are used to fiber

reinforced concrete; why not fiber reinforced soil? In fact, I will show you some examples today how fibers can improve.

Then, in some places, called lime columns instead of the stone columns. For example, soil is very soft; so, let us put stone columns there. However, if the soil is expansive, let us put lime columns; as simple as that. So, this vibro-concrete column is another variant of this same thing, where you can get shear strength improvement based on what you need. Then, mechanically stabilized earth or reinforced earth wall actually; this reinforced earth walls is a standard technique that we have been… Nowadays, all the flyovers are constructed with this reinforced technique; that is called mechanically stabilized earth. Mechanically means you are using the reinforcement there, because it is mechanical. Because of the mechanics of interaction of the soil and the reinforcement, the stabilization of the earth is taking place. So, by introducing the reinforcement, we are having a reinforced earth walls rather than gravity walls or the other types of walls like counter fort walls and all that.

Even biotechnical stabilization; in fact, the slopes are getting eroded; so, what do we do? We just use some grass and the slopes, which have erosion. Then, what happens? The profile will not get eroded. Gully erosion is a classical problem; because of the influence of water, which forms on the slope surfaces, you will see gully erosions. However, if you have a sort of a grass and some other enzymes, biotechnical stabilization is possible. It is a very challenging area; people have been working on this nowadays to a large extent. Then, that way one can just put under the ground reinforcement some of these topics (Refer Slide Time: 18:59).

Then, ground improvement; for example, one can say that when you do the surface compaction. We know typical rollers that we have, which is used for the rolling purposes and then get some maximum dry density. You normally mix the soil at close to optimum moisture content and allow the rollers to do the compaction. So, this is called surface compaction. Then, as I just mentioned, you remove water from the soil and then it leads to drainage. Because of the drainage or the expansion of water, there is an increase of shear strength. One way of putting that removal of water is by putting lot of load, what is called surcharge or a preload; in fact, we call it a preload. You will be knowing the concept of pre-consolidation pressure; if you have pre-consolidation pressure, below the pre-consolidation pressure, the soils will have less settlement; that is the standard thing.

So, we try to apply a very high surcharge, so that the existing load is less than the surcharge with the reason that whatever settlements or the strength you want, it is there.

In some cases, in clays, sometimes we have electro-osmosis. Electro-osmosis – you must have heard in basic geo mechanics classes, where since clay particles are negatively charged, if you want to really remove the water, the electro-osmosis is one thing that can be effectively used, because the water removal is… Sometimes you have two types of water: one is called absorbed water and then… In the pore water, there is some water; then, there is a water that is adsorbed to the clay surfaces. So, if you want to handle them in a proper way together, electro-osmosis combined with drainage is an excellent option. Then, we have what is called compaction grouting. Compaction grouting is another technique that we use in many of the cases.

Then, blasting; for example, we see that the soil is liquefiable, how do you see that the liquefaction tendency is reduced? we create the blast into the ground. The thing is I have seen some cases; in fact, when you want to break rocks, you do blasting. Similar to that, we introduce some charges into the liquefiable deposits and then blast them. What happens is, because of the energy that is there, the whole soil gets consolidated or compacted in about very short time. So, blasting is another technique people have used. In fact, in liquefaction problems, this is one of the techniques used, experimented actually in a great deal, because it is a very useful technique and simple to use.

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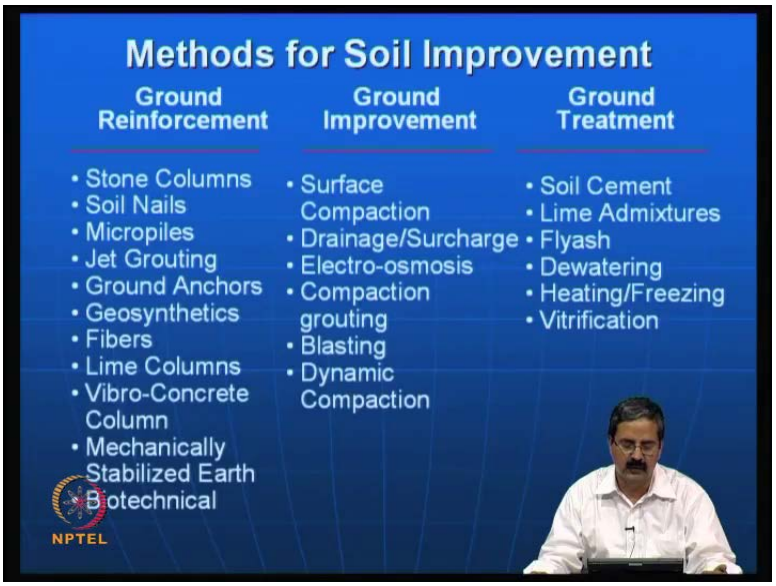

Then, dynamic compaction is another thing. There is a difference between what is called surface compaction and the dynamic compaction. Here in the surface compaction, what you are doing is we are putting rollers there; then, in the dynamic compaction, you are trying to put some tamping from a high like 10 to 15 meters high; you just put lot of weights on to the ground; you dynamically compact the whole soil. Because of the dynamic compaction under a charged weight, there is a possibility that pore pressures are generated already and consolidation occurs. Once the consolidation, everything is complete, we can say that the ground is stabilized or improved. Then, it can be used.

Then, you have some more sets called ground treatment; you try to say use the term called treatment essentially because you add something. Here we treat the soil by using some cement or lime admixtures. For example, calcium hydroxide, calcium oxide – many of these materials can be added. Flyash, if it is available. For example, the clay has very high water content and if you have flyash, it definitely decreases its liquid limit or the high water holding capacity. Dewatering is another one. In fact, heating and freezing; in fact, the leaning tower of Pisa – you will be knowing that the freezing technique was used, because it was tilting; then, they felt that before they start any other new techniques, they wanted to really… They used this freezing technique as well in the stabilization of leaning tower of Pisa.

Then vitrification; vitrification is nothing but making some gas-like material. This is also very popular because suppose there is a contaminated soil area and you do not want that the soil water should go through that e or that influence of that contaminated soil should be there in the nearby fields or areas; so, you totally solidify or vitrify in the form of a glass. However, we will see some examples. In fact, there are one or two case studies in abroad, where vitrification is also done, because the moment… For example, there is a site next to the factory and the factory release lot of hazardous materials; now, that area has to be reused. So, they have done this sort of vitrification in some cases.

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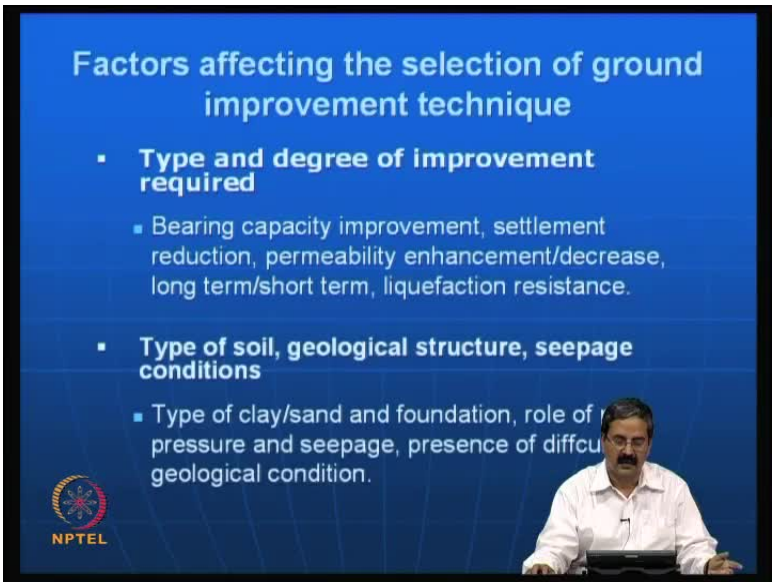

Now, I would like to draw your attention to – what are the factors that influence the selection of ground improvement technique? You have seen in the previous slide that there are many techniques that we have for ground improvement; many techniques like not less than 15 to 20. However, you need to decide what exactly we want. Now, we should understand – what are the factors that influence the selection of ground improvement technique? It is very important because for the same thing, you may have some three or four techniques. For example, you want a bearing capacity improvement; bearing capacity improvement can be obtained by many means like one can use stone columns, one can use reinforced earth, one can use cement slurry injection, one can use addition of flyash, all that. So, the factors affecting the selection of improvement are very important. So, we should look at what is the type and degree of improvement required. Are you looking at bearing capacity improvement, are you only looking at settlement reduction or are you looking at permeability enhancement? For example, you would like to see that the permeability is to be increased, so that there is a good drainage. Is it that what you want or you do not want the permeability increase at all? Then, do you want in long term or short term? For example, do you want a particular improvement technique in long term or short term?

Then, liquefaction resistance; You need to define what is the main purpose. Actually, many of these techniques will result in many things like one technique may result… For example, addition of lime; addition of lime will increase strength, reduce the settlements,

and increase permeability; whereas, some other additive if you add, it may even decrease permeability also; it may help in increase of strength, increase of the reduction of settlements, but it may reduce the permeability. So, one should look for what exactly he want. You have to pick up the primary mechanism of improvement and also understand what you need exactly. So, what is long term? what is short term? It is another important point because a soil is getting consolidated; we know that. For example, I have seen in many places, where you need improvement only for 1 year. So, that is short term. For example, you start loading on a soft soil; say for example, you are constructing on a soft soil area a highway embankment of 3 meters or 4 meters height; you are dumping with sand and all that; the rate of dumping will be so much high that the soft soil area, because of its low permeability, it cannot take. So, what we do is that only during that 1 year time, since we are loading and constructing that embankment in 1 year, you want improvement. After that, once you construct the embankment and traffic comes and it is opened to traffic, then that is a different story. So, we have what is called short term improvements and long term. Long term means they will have to be continuously monitored also; in the sense that particularly they have long term as its life period like for example, 50 years or 100 years.

Then, liquefaction resistance; how does liquefaction resistance beam can be understood by using this technique? One should really look at some of these issues in a careful way and decide on the type; what is the type or the degree of improvement required? The other one important is… Normally, the bearing capacity improvement is explained in terms of bearing capacity factor. For example, in one case, the bearing capacity of the soil is only 10 ton per meter square; then, you would like to make it to 30 ton per meter square. So, 30 by 10 is called bearing capacity ratio. So, I know exactly what I need; I need 30 ton per meter square for that area. So, I will get this, I will design this in a proper way such that I will get that 30 or 35 and even conduct a plate load test to see that I get the same thing, because you have to finally, confirm to the people that you got this number like 30 ton per meter square; otherwise, the technique may not stand at all.

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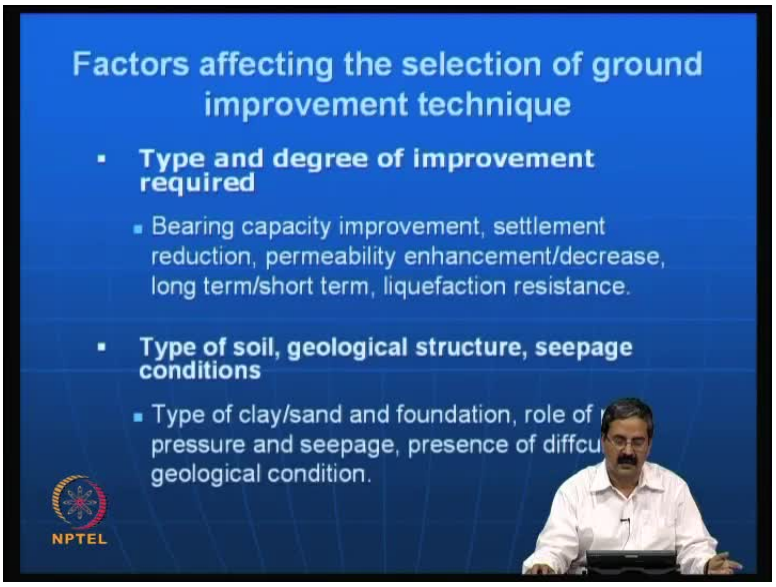

Essentially assume that you are a client or a contractor; for example, you are representing the government of India port trust authorities; some of you may be chief engineers soon. You may just say that I am the chief engineer of this project and I would like to see that the bearing capacity of the soil is improved to say 30 ton per meter square from 10 ton per meter square. So, that can be done. Actually, the settlement is also same thing. Permeability – many of these things; for example, permeability enhancement – initially, it may be 10 to the power of minus 7 centimeters per second; I would like to just increase it to minus 5 centimeter per second. How do you do that? You should do some experiments in the laboratory, also in the field to see that these effects are obtained.

Then, the type of soil, geological structure, seepage conditions; it is a very big variable in trying to decide about what type of ground improvement techniques are required. As we saw – what type of clay is there? What type of sand? What type of foundation? For example, depending on the type of clay say for example, is it a soft soil area or it is an expansive soil area or it has very loose sand? So, the techniques are different. For example, if it is a loose sand, you may use stone columns; like that. For example, you want to do foundation; it also depends on the type of foundation you want. For example, you are looking at pile foundations; pile foundations have one alternative in the original sense. Because the cost of piling is so much high in India and many places, they wanted to reduce the cost of foundation. So, what should be done? Instead of going for pile foundations, one can provide only a simple… It can be in a raft foundation or isolated

footings, so that you can place these both raft foundations and isolated footings on the improved ground. The pile foundations – you will be placing them on the original ground and then you have to compare with the cost of foundations, when you place them on the improved ground using ground improvement techniques, and include the cost of ground improvement also. Actually, in many projects, what happened is that there is a significant effect of these ground improvement techniques in terms of cost, sustainability, ease with which it can be done, confidence to profession; there are many issues here.

Then, the role of pore water pressure and seepage; I just mentioned about the permeability enhancement or decrease. If you just want higher pore pressures to be mobilized or dissipated; in fact, if the water can go faster, the drainage is better. So, when the drainage is better, what happens – pore pressures are less. So, you provide a means of proper drainage and seepage also. For example, if there is a lot of seepage, what happens – the soil particles come out; that is another problem. So, presence of difficult geological condition – I just mentioned about few minutes back that presence of Karst deposits, which have tendency to form holes is another risky thing. So, the type of soil, geological structure, seepage conditions influence the ground improvement technique choice.

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Costs equipment and specifications; this is a very important thing. Size of the project – are you trying to go for a simple multi-storeyed building or you want for a bigger colony? Because ground improvement techniques are all done by number of contractors; many people will do that. If it is a small project, they may not come. So, you may have a very nice idea about a ground improvement technique, but then if the size of the project is too small that the contractor is not ready to come, then it is useless.

Then, availability of the equipment; in fact, this is a very important thing. Many of the ground improvement techniques need some sort of specialized equipment. For example, if you are making stone columns, you have to have some sort of equipment, which can make holes into the ground; then, compact them into the in situ; then, like that. So, you need some good equipment; the contractor will not come if the size of the project is too small. For example, if you have a small house of 100 by 100 area; if you want ground improvement technique for that, they may not ready to come, because the mobilization costs are so high that he may not ready to come for that; otherwise, here the technique will be too high for you also.

Then, the transportation costs as another important variable. Many of the ground improvement techniques need specialized contractors; it is not easy because in soil mechanics or geotechnical engineering, you need to have lot of experience in soils; otherwise, the project will be in a serious problem. For example, I must tell you many examples in our own case – soil nailing – you do not have good contractors; micro piling – you do not have good contractors. However, if you have good contractors, they are very expensive. So, the owner is always worried about – should I go for a contractor, who can give me at a low price and I am not sure about the quality or go for a good contractor, where we are assured of the quality, but at the same time he is expensive. This is a very big problem in many of the projects.

Then, specification of the work; we may understand fundamentals and design, everything is perfect; analysis is also perfect. However, when you want to do the work, you should be in specifications like government of India specification like what should be done and in what form; you should give them the sequence of work right from the beginning – cleaning of the ground to the complete work; you have to initially clean the ground, then bring the equipment, then make some holes at a specified spacing; there is so many issues; it is not easy. So, people should have the specifications properly written – all the

consultants, all the engineers should understand the specifications. In some cases, what happens – many of the ground improvement techniques are well developed in some countries, but in some other countries, if you want to use them, they are not available, because in that country the specifications may not be accepted. So, that is the big problem. For example, in Indian conditions, we do not have too many specifications for ground improvement techniques; we just have one for stone columns and geosynthetics a bit, but it is not complete. So, this is a big problem when the contractor wants to use some of these techniques.

Then, guidance documents; see specification of the work is one thing; guidance documents, for example, when you are trying to use a new technique, the contractor should know completely, the owner should know completely, the engineer should know completely – all parties; in fact, in any of the construction projects, there are at least four people: one is a owner say either it can be a government; the next one is a designer; then a contractor; then, you may also have some supplier also – in some cases, you may have a supplier; you may also have somebody like a quality control supervisor. There are many people in this business and they should know; if otherwise, all should understand the principles of the ground improvement techniques, also how it should work in a given situation and discuss thoroughly. So, the guidance documents will help you a great deal; otherwise, there will be lot of conflicts between the owner, the contractor, the supplier and the actual installer. It leads to project delays, which is again a problem. So, one needs to have good guidance documents.

Then, the construction time; you should be very clear about this construction time because the ground improvement techniques actually were used to save some time. For example, you would like to construct the project in 6 months or 1 year. Normally, we will see that there are different ground improvement techniques. Normal consolidation of the soil for example, takes 9 years for 390 or 90 percent of consolidation to occur. You do not want 8 to 9 years to wait; you want everything in 1 year. So, you can back calculate and introduce the drainage in a proper way. So, within 1 year, which is supposed to be a construction time, I can finish consolidation completely rather than 9 years or 8 years time. So, construction time available should be clearly known and the purpose also should be clearly known.

Then, use of accelerated construction techniques; in some cases, it is possible to use number of techniques to accelerate the whole process. We have done couple of projects on this, where one can do accelerated means of constructing underpasses using box jacking techniques, where certain underpasses were able to be completed within 5 to 6 months time when the normal time itself was 3 years. I will show you those pictures.

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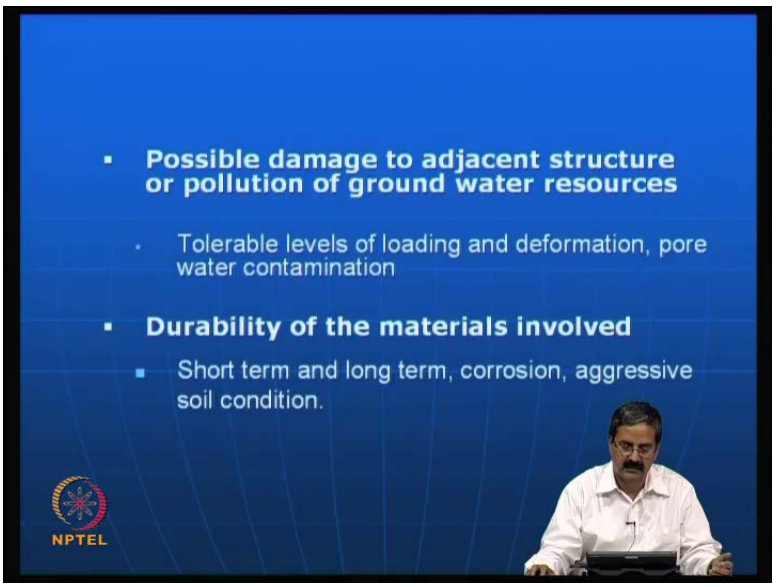

When you are trying to use a ground improvement technique, you should also understand that… For example, you have an apartment and next to that you want to construct another apartment. If you start excavation next to the apartment, what happens? That owner will come and then he will sue you, because the moment you start excavation, what happens – there will be some cracks in buildings and there will be a problem. So, what happens is that one should understand what the tolerable levels of loading and deformation are. For example, you know about the concept of differential settlements and total settlements. If you just remove some amount of soil next to ground, what happens? Actually the apartment is standing because of the confinement effect. Now, you removed some over burden about 5 meters; then, all the failure planes developed towards the excavation side and the whole constructed building starts to tilt; that is a very dangerous situation. So, one should use proper ground improvement techniques.

I will show you in fact in nearby area only; they are using micro piles. Micro piles – one can use for apartments, where there is no problem of deformation at all; just there is a 3

storeyed or 4 storeyed apartment; next to that, they are vertically cutting it, because they have used already some sort of micro piles there. So, that way one should know what the tolerable levels of loading are and deformation.

Then, pour water pressure contamination is something that one should understand because by our operations, we should not contaminate ground water. In any of the ground improvement projects, suppose you are using lime or you are using something or flyash or anything, you should not lead to some difficulties and peoples should not put a case against you later. This is one thing. So, these will influence the choice of a ground improvement technique.

Next is the durability of the materials. For example, there are many materials, which can be used in different conditions both in short term and long term. I will show you the coir fibers; coir fibers or the coir geo textiles; there are two types: one is called coir geo textile and a jute geo textile. Even regular geo synthetic materials like plastics; plastics can be used for long term; whereas, coir and jute geo textiles can be used for short term. Then, there are some materials which will have corrosion. For example, in places like Bombay, because of the sea intrusion and all that, people say that no, I do not want to use the steel, I would like to have a PVC coated materials. Aggressive soil conditions are another important problems, because finally, you are using ground improvement technique and say for example, you are putting some reinforcement, the reinforcement should be there working for about 30, 40 years or 50 years. If the reinforcement is dissolved because of the aggressive soil conditions or some other problems or somebody removes it, then it is a serious issue.

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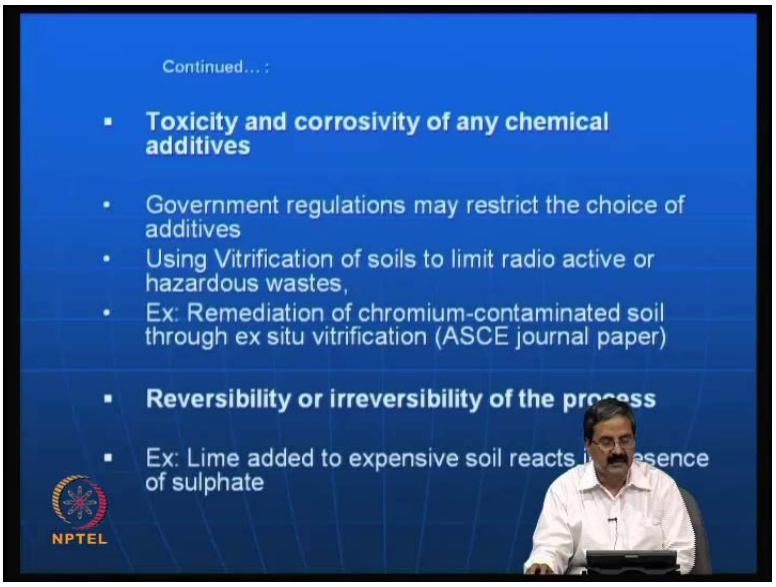

Then, we have what is called toxicity and corrosivity of the chemical additives. Actually, as I just said, the example of what you call contaminated ground; in many countries, you know that this has been a big problem; if the soil has lot of toxic chemicals like chromium, mercury and some of them, then it is very difficult. So, sometimes we do not know what type of additives we should use in those adverse chemical environments. So, if you add some chemicals, the problem is that we do not know the chemical reactions. That may lead to lot of problems. So, it is better that one needs to understand the chemistry of the soil as well as the toxicity and the corrosivity of the additives that we are going to have, so that the problem is not there.

I just mentioned about using vitrification of the soils to limit radioactive or hazardous wastes. Actually, this is one example as I just mentioned – remediation of chromium-contaminated soil through ex situ vitrification; it is an ASCE journal paper. I was just seeing this morning, where they were able to see that the contaminated soil is stabilized using vitrification. Then, there is another classical example. So, one should understand that toxicity and corrosivity of the chemical additives is also very important in ground improvement techniques, particularly when you are using chemical additives.

Another important point that governs the choice of ground improvement technique is reversibility or irreversibility of the process. Actually, people have been using lime for expensive soil treatment. What we hope here is that the soil will not swell when you add

lime. That is our assumption. However, you have seen that particularly when the sulphate is present in the soil, the expensive soil comes back, the nature comes back like the heave will be more than you expect. For example, the percent heave may be 5 percent in one case or 10 percent. When the sulphate soil is present, it is so bad that whatever stabilization you have done becomes useless. In fact, in Texas area; Texas, Arlington and many of the places in US, lot of roads have got damaged. They initially thought that… See the Texas area is full of expansive soils and what happens is that by treating the soil with lime, lime injection and all that, they thought that they can have this problem rectified.

However, what they finally observed was that since the soil has sulphate, heave took place and the problem is it got worsened. Actually, I will show you some of these photos also in a very detailed manner later, because this is a very important thing that people have been addressing in Texas and many other places. Luckily in India, we still did not realize whether this has been a problem in some places. However, one should find out the sulphate content in the soil and then come out to see if it is within some acceptable levels of sulphate; then, one can go for lime treatment; otherwise, lime treatment in the presence of sulphate will be very dangerous and the process gets reversed; you want to reduce expansion, but expansion starts; it is a very risky process.

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Then, there is another important component here. Reusability of components such as steel, plastics, concrete and many places; actually, in many of the ground improvement techniques, the beauty is that you should be able to reuse many of the materials. We are using for example, geo grids in a project; that geo grids can be reused and then you can really form some sort of material like this. In fact, this is a geo cell road; this is all plastic water bottles; this is also waste; this can be used in many cases. In fact, I showed you a previous example where the vitrification of the soil was done. In fact, I understand from that paper that now because of the vitrification, all that soil is such a strong hard material that they have just broken into pieces, and then used as an aggregate in a pavement. So, one should be able to reuse the components in a ground improvement technique also.

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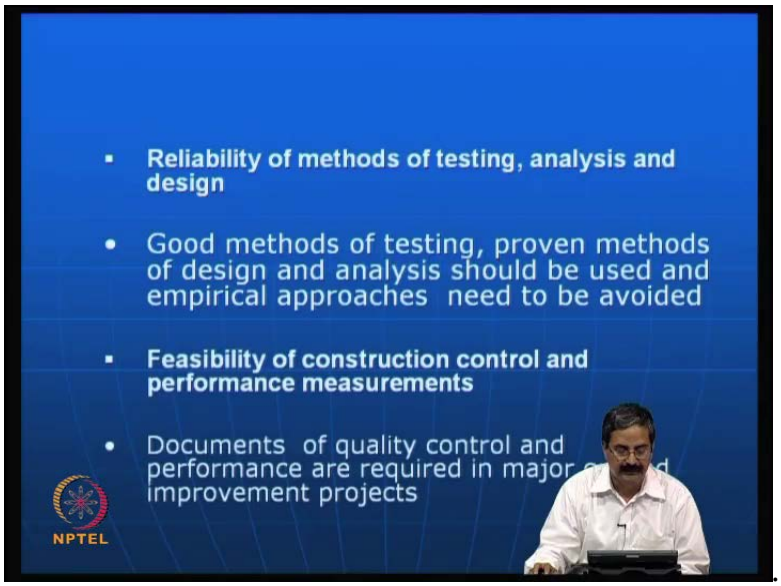

There is another important point that we have – the reliability of methods of testing, analysis and design. Actually, as I just mentioned, the soil is soft we say. How do you test whether the soil is soft? You take a venture test and do a venture testing, and then it will give you some shear strength; or, take some undesired samples; you will get some properties of that soil. For example, you are using a cone test or an SPT test; you should have good methods of testing. For example, the undrained shear strength of soil – you get it as 5 ton per meter square. What is the ultimate bearing capacity of the soft soil? 5.14 into CU. If you know CU – undrained shear strength by 2, will give you the cohesion. So, 5.14 into CU will give you the ultimate bearing capacity. You divide by a factor of shift F3. What do you get? You get allowable bearing capacity. So, you have to

really estimate these numbers in a proper manner; the testing methods should be very good; then, proven methods of design and analysis.

Actually, what is happening in some places is that they do not design the things properly; they use the soil is same as that soil. I have a sandy soil here; in that project also, there they have a sandy soil, they use the particular ground improvement technique; I want to use the same thing here, same spacing here, same length here. That is not correct. Then, they will just justify that because the soil is same, I can have the same design. That may not be correct. So, one should have proven methods of analysis and design, because you have to clearly show that this is the bearing capacity before treatment; this is the improved; this is by means of some analysis and design.

You have to come out with a number; earlier, the bearing capacity is 10 ton per meter square; now, by my method and design, I made it to 30 ton per meter square and I am using stone columns here for the improvement; the design of stone column gives you the length of the stone column, the diameter of the stone column and the spacing of the stone column. So, one should have a proven method of design, which is accepted by codes of practice like federal highway or US codes or many of these things. Even analysis should be thorough; otherwise, it is a big problem. Empirical approaches should not be used to the extent possible because as I just mentioned, in geotechnical engineering, empirical design like whatever they use in some place, they try to justify and then come out with simple equations. For example, I will tell you the classical example of an SPT; you have an SPT value and then there is a connection to the phi value; you have one SPT test result and you will get one phi value, and that equation that you are using is not specific to that area. It is an equation that is derived out of Japanese practice or an American practice. What you are doing is, in SPT test, in some place in India, we do not know whether the same SPT. Actually, there is so many uncertainties in SPT test, because the height of drop, the weight of the hammer, there are so many issues; one should be very careful. So, one should really use scientific approaches to come out with proper methods of design; they should avoid empirical approaches and also come out with good methods of testing, proven methods of analysis and design. This is very important.

Another important point; the thing is the reliability of methods of testing; why it is important is that if the testing is correct and analysis is correct, you can come out with the proper choice. Even the choice of ground improvement techniques depend on this

because I have seen a case wherein the grain size distribution itself can be misleading. Based on the grain size distributions also, there is a thin margin in choosing these materials; particularly the efficiency of the technique depends on many of these properties of the soils that need to be improved. So, one should do proper testing.

Then, very important point is feasibility of construction control and performance measurements. In the field, you may design a ground improvement technique, but how well it is done or executed on the field is very important. When it is not done, you need to have lot of controls also; sequence of control should be there like you excavate, then put a reinforcement, then compacted, there are so many construction controls. One should have a proper construction control operations. Particularly, the ground improvement techniques – soil is so variable that it is very difficult to really say that; based on some few test results, you can say that the entire soil is same. So, one should have construction control because there will be differences in borehole information. So, one should be very careful. So, one needs to have lot of construction control. I have lot of examples on how construction control is very useful. Other important point is performance measurements. You are expecting that settlements will come down. So, you have to measure them. For example, you keep on measuring the settlements; then only, you can say that the settlements are not there. You use a ground improvement technique; if you do not measure and then there is a settlement, then there is a big problem. So, one needs to have this.

Document of quality control and performance are required. For example, compaction control; at what spacing you should take samples or what type of tests? For example, sand replacement test should be really specified and then they should be used in lot of ground improvement projects.

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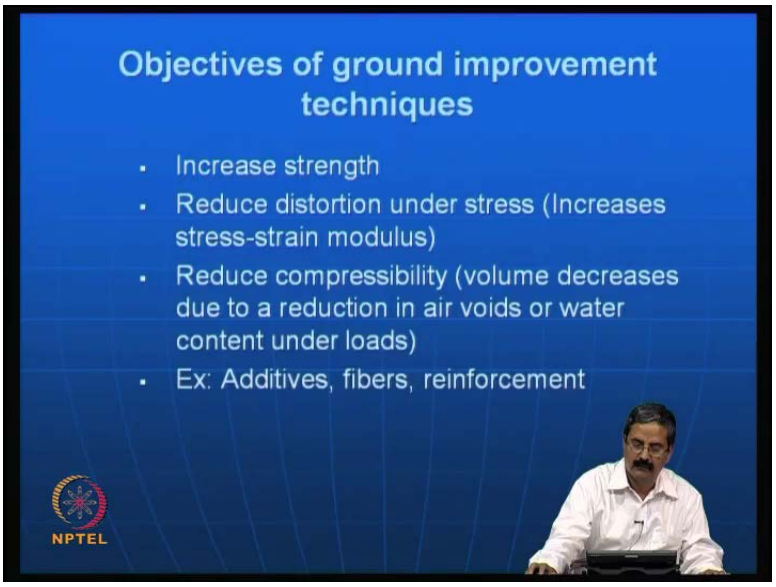

This is another point that I think I would like to cover in the next class. What we covered so far is that we are able to understand the various problems that one can have in geotechnical engineering and also the ground improvement techniques that one needs to choose. We have covered varieties of ground improvement techniques; at least some introduction to them and also discussed about various factors that can influence the choice of ground improvement techniques.

Thank you.