Ground Improvement
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Lecture - 01
Need for Ground Improvement

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Good day to everyone, and I welcome you to this new course that is Ground Improvement. Perhaps some of you have gone through my earlier courses, Soil Mechanics and Foundation Engineering. This is the third one, Ground Improvement, and this Ground Improvement is one of the important courses in Geotechnical Engineering. I always talk about this development of Geotechnical Engineering. And there, we see that the development or existence of geotechnical engineering was comparatively late.

Merely though any system or structure finally raised on the soil, the importance of soil was not given much in the initial stage merely because the understanding was not clear. And when more or more failures were occurring, people started investigating, and slowly the Soil Mechanics and Foundation Engineering and other areas were developed. And ground improvement is from the term itself is quite clear that something to be improved.

What is there is actually? The improvement means ground when not in the condition to use it directly. Maybe if you do some modification or some changes in this, it may be suitable. So, that process by which we do this science or technology is called Ground Improvement. And it has a lot of applications in Soil Mechanics. There will be some application of chemistry, and there is some application of some calculations also.

But in general, when you go through ground improvement, you will see different methods are described most of the time. But there are also when you practice in the field when you apply a certain technique, you have to use some material of some quantity that means some calculation will be there, but most of the time in most of the books, this calculation part is missing.

And then, in this course actually what I will try to do, what about journal aspects? That is the method definitely I will discuss and in addition to that, I will try to show some calculations that means when a particular technique to be applied, how much quantity, how much depth, how much number of blows, a sudden like that, what is the lift thickness like that, whenever it will come in the appropriate place. I will discuss all those things when some calculation is necessary, and I will try to show that in the respective places.

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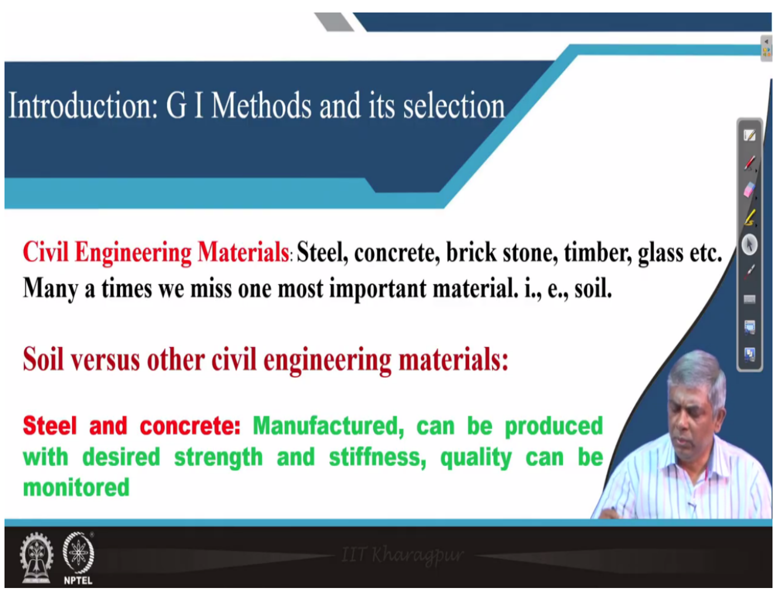

Now, I will start with the first slide of Ground Improvement. In civil engineering, if we ask that what is the civil engineering materials? Many people without thinking they will mention some of the materials namely steel, concrete, brick, stone, timber, glass, etc. But many times, we miss one most important material that is actually soil.

You know that Civil Engineering has to handle the soil. Soil is a material, and it has to be handled properly. It will have definite strength and definite compressibility, which you have learned in the soil mechanics course. And as a result, this soil also has to be considered one of the civil engineering materials. Now, when you look at the soil, the other materials, and with soil, these two materials when you compare and then what you observe?

Mainly steel and concrete is the most significant part of the material component in civil engineering. And these two materials actually how we do? We manufacture in the factory, and it can be produced with desired strength and stiffness, and can also monitor its quality. For example, when you use concrete, the concrete is M10, M15, M20.

Similarly, when you use cement, we started with 33-grade cement and now with a lot of development, that cement grade improved from 33 to 53 grade and concrete that also from M10, M15 to now, it is minimum M20, that means, we can achieve more and more strength at the same time more durable.

So, what are the highlights of the steel and concrete? The steel and concrete are manufactured in the factory, and their strength and stiffness can be changed. It can be developed depending on the requirement, and also its quality can be monitored. So, if I want 500 kPa strength, then with very little variation, we can achieve 500.

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Whereas, when you talk about soil. Soil is natural, and properties are mostly not known or depends on many factors, no control over its quality. That means what I want to mention from here is that soil is naturally developed, and if at a particular site I want to build a structure, then I cannot demand soil according to my requirement; what will be the soil available on the site.

I have to assess what type of soil it is, and I have to modify my design accordingly. If I cannot design a particular soil satisfactorily, then the point of ground improvement comes into the picture. So, what I want to mention here is that when you talk about conventional civil engineering materials like steel, concrete, they are very much under control, it can be strength, stiffness can be modified depending on the requirement. Whereas soil is naturally developed, and its quality cannot be monitored or controlled, and it cannot be according to our desire. We have to use as it is or with some modification that by applying the ground improvement technique. So, these are the things. So, like this is how the soil develops?

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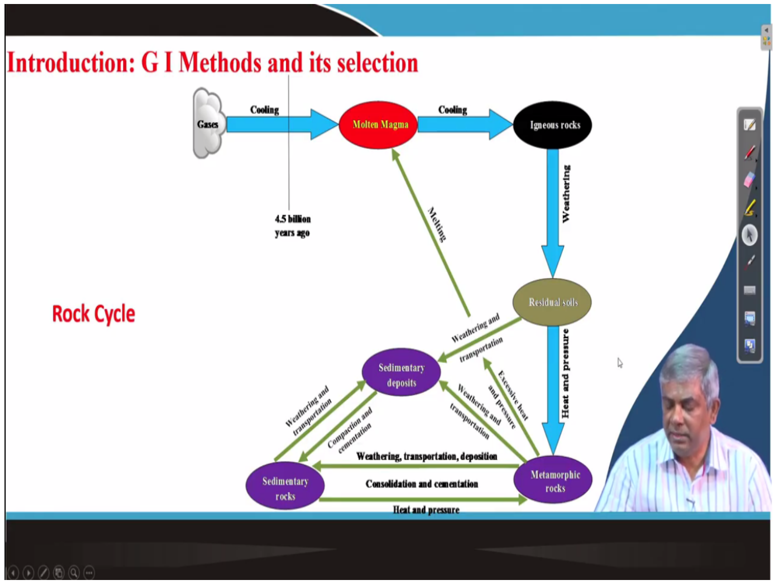

If you look at this particular diagram, and those who have completed soil mechanics, perhaps you have seen this particular diagram. You can see here how the soil form. Initially, it was in gas form in the very early stage (4.5 billion years ago). And then, after cooling, it became Molten Magma.

And then Molten Magma subsequent cooling, it became Igneous rock and then with further weathering, the rocks were disintegrated, and it becomes Residual Soil. So, this is one type of soil, and then again, with further application of heat and pressure, this residual soil again becomes Metamorphic rock. And similarly, you can see from residual soil by weathering and transportation it becomes Sedimentary Deposits.

And from the sedimentary deposit, by further compaction and cementation, it becomes sedimentary rocks and again, weathering and transportation, it will become sedimentary. So, this is a two-way process; it becomes sedimentary rock by cementation, and it becomes sedimentary deposits by weathering and transportation.

Similarly, becoming metamorphic rock from excessive heat and pressure. Again it becomes sedimentary rocks by weathering and transportation and deposition. From this consolidation and cementation and heat and pressure, it becomes metamorphic rock.

Like that it process rock to soil at different stages of rocks forms and final form is soil and characteristics of soil depends on from which type of rock, it has produced and what chemical composition depending on that different soil will have different properties. So, this is the most difficult part of soil mechanics that every soil is new. No soil is similar to other soil.

So, each soil will be different particularly the soil can be of different, it can be a fine grain soil, it can be of course gain soil, it can be again fine grain soil with moisture, fine grain dry, like that several variations are possible and each soil has to be treated differently, there is no generalized way, but ultimately fine, fine-tuning for each soil will be it has to be treated differently.

So, I want to mention here that soil is a difficult material. While handling, it has to be characterized; after characterizing, if you find that it is not suitable for foundation or building, you have to apply ground improvement technique. And again, ground improvement technique means there are n number of techniques depending upon the type of soil, actual area, volume of work. We can develop different types of ground improvement techniques. So, those things will come later on. So, now, let me go to the next slide.

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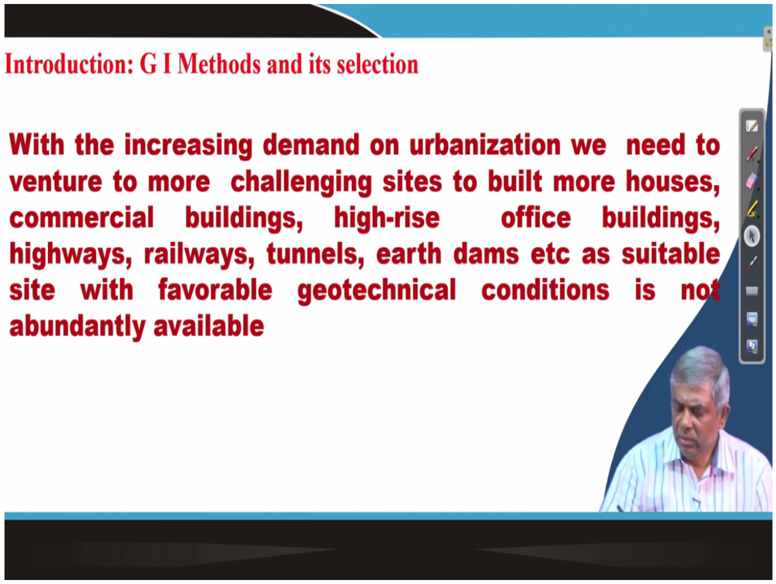

But what is that, though the soil is a very difficult material, but we cannot avoid it. Because with the increasing demand on urbanization, we need to venture to more challenging sites to build more houses, more commercial buildings, more high rise office buildings, more highways, more railways, more tunnels, earth dams, etc as suitable site with favorable geotechnical condition is not abundantly available.

So, that means what, what I want to mention here, we have a demand that we have to build this many kilometers of road, this many houses, this many buildings like that, but when this demand increases, then the supply or availability of good site will be reduced. And that is the challenge actually, when you want to enter into the difficult site that means the site which is not ready for use those areas actually we need to do this ground improvement techniques.

And again ground improvement techniques as I have mentioned there are different types of ground improvement techniques and we can suitably choose depending upon type of material available at a particular site.

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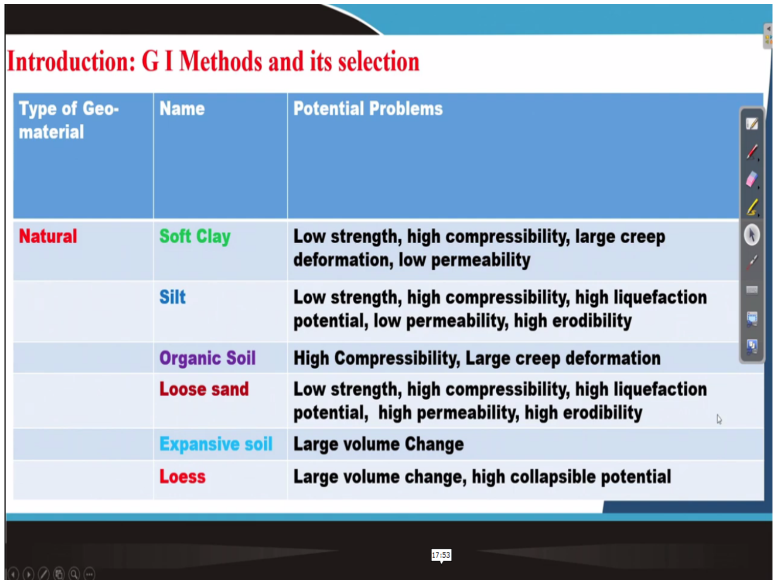

Type of Geo-material	Name	Potential Problems
Natural	Soft Clay	Low strength, high compressibility, large creep deformation, low permeability
	Silt	Low strength, high compressibility, high liquefaction potential, low permeability, high erodibility
	Organic Soil	High Compressibility, Large creep deformation
	Loose sand	Low strength, high compressibility, high liquefaction potential, high permeability, high erodibility
	Expansive soil	Large volume Change
	Loess	Large volume change, high collapsible potential

So, next slide you can see now that geomaterials are now I have mentioned whatever soil that I can name it generalized way I can name it and one type of the geomaterial can say it can of Natural or it can be Fill. So, if I have to talk about natural geomaterial and it can be again of different types, I have listed here. The first one is listed here as Soft Clay.

And so, in this table, what I am trying to show you a number of natural soil and all those natural soil may not be good or all may not be bad, in particular, natural soil and what is their potential problem, when you are trying to build something over it. So, out of natural soil first one is soft clay, and it has different problems.

The first problem is that it has very low strength, the second most important problem is that it has high compressibility and then it has large creep deformation and it also has low permeability. So, where we required suppose the water to be drained quickly, but if there is a soft soil that means fine-grain soil is there because of the low permeability, it is not suitable. Similarly, if you want to make a high rise building and if you have a soft clay, where actually strength is low, then you will not be able to build high rise building because high rise building demands high strength of the soil.

So, this is some example of natural soil and under that the soft clay. The second natural soil is silt. Silt is another type of soil that is coarser than fine clay soil, but it is finer than sandy soil. And when the silt is there in a particular soil site, it has a problem of low strength, and it also has high compressibility, it also high liquefaction potential. What is liquefaction potential?

Liquefaction means it is susceptible to damage during an earthquake that is Liquefiable. So, that means when there is a particular site, silt is there because of low strength and high compressibility, high liquefaction potential, low permeability, and high erodibility. That means, very easily, it can erode. So, that is also a problem if you make an embankment with silt that will be just washed away during the rain. So, this is a second natural material that is silt and these are the potential problems when there is this type of soil in a particular site.

Similarly, the third category of natural soil can be organic soil. This organic soil develops by the decomposition of vegetable material over time. And when a particular site if you find a huge amount of organic soil, it also has a difficult problem. It has high compressibility and large creep deformation; these two aspects are hazardous for a particular organic soil.

Similarly, another natural soil is loose sand. When at a particular site, loose sand is present abundantly, it has a problem of low strength, it has a problem of high compressibility, it has a problem of high liquefaction potential, it has a problem of high permeability, it has a problem of high erodibility.

Similarly, another natural soil is Expansive soil: black cotton soil, which is known popularly as Black cotton soil and even some other soil also when there is a Montmorillonite or Illite clay is there abundantly in a particular site. This soil also will have some problems: it has a typically large volume change that means it will shrink in a dry season. During wet season, it will expand and because of this, that volume changes with variation of season and that building over it generally undergoes some damage.

Another category of natural soil is Loess Sand. Loess is a particular type of soil that is available in the desert. Because of the wind, it rolled and finally, it became rounded grain uniform and it deposits. This rounded grain fine soil is known as Loess. And when this loess is there, it will be having large volume change and high collapsible potentially, and its shear strength is very low. So, this is under different soil, natural soil which has the different types of problems I have mentioned here.

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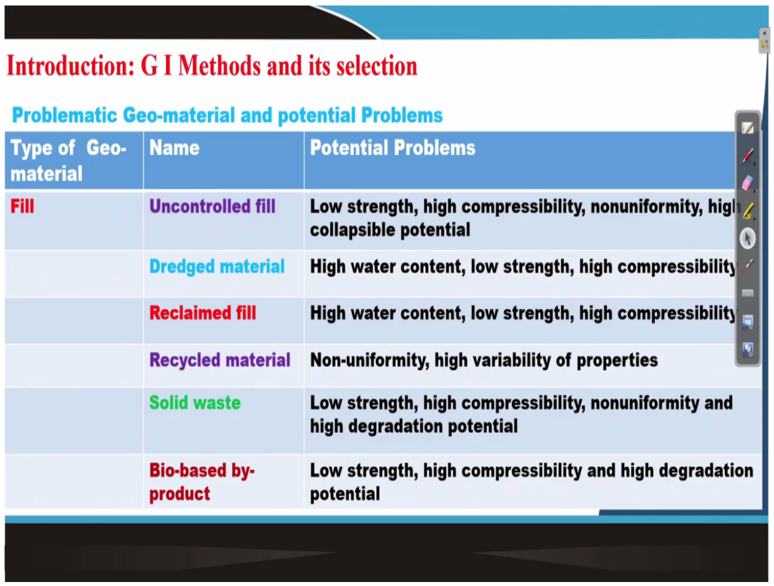

Type of Geo-material	Name	Potential Problems
Fill	Uncontrolled fill	Low strength, high compressibility, nonuniformity, high collapsible potential
	Dredged material	High water content, low strength, high compressibility
	Reclaimed fill	High water content, low strength, high compressibility
	Recycled material	Non-uniformity, high variability of properties
	Solid waste	Low strength, high compressibility, nonuniformity and high degradation potential
	Bio-based by-product	Low strength, high compressibility and high degradation potential

Next go to the Fill soil. Different again where soils at a particular site can be developed by filling material and different types of Fill can be used. One first type of Fill is Uncontrolled Fill, and it has some problems: It will have low strength, have high compressibility, has nonuniformity, high collapsible potential.

So, if it is uncontrolled, then to dump and randomly some waste and finally the site is developed, then this site will have this type of problem.

Similarly, the next fill material is Dredged material. You dredged material from somewhere and dumped it and then developed the site. In that case, this type of soil will have high water content, low strength and high compressibility.

Similarly, Reclaimed Fill means the low land area by filling we can use, fill it, and develop it. This type of site will have high water content, then low strength and high compressibility.

Then Recycled material, there are some material can be recycled in that case, it can be used as a filling and then if you do that, then that type of soil will be highly nonuniform and finally, high variability in properties and because of that very difficult to predict the behavior.

Then next is Solid waste, by using solid waste fill site can be developed and these sites will have low strength, high compressibility, nonuniformity and high degradation potentials. Like that Bio-based by product also can be there in some site, then in that site also will have some problem of low strength, high compressibility and high degradation potential.

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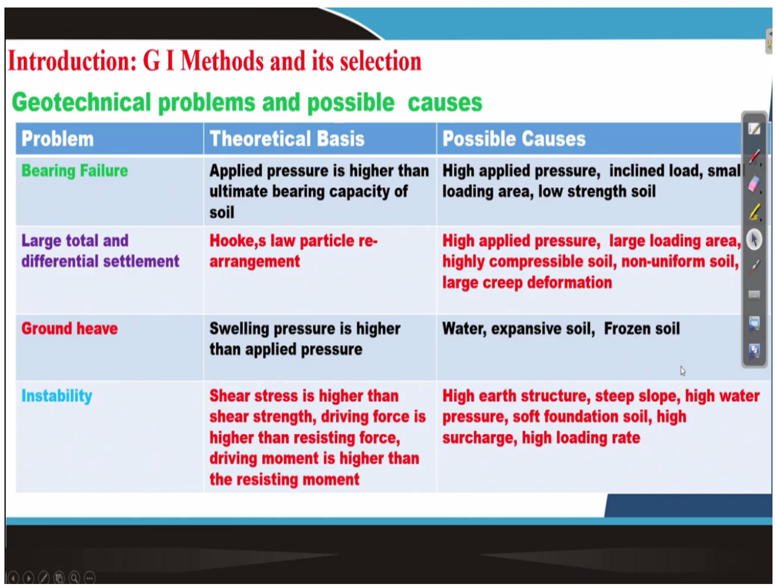

Problem	Theoretical Basis	Possible Causes
Bearing Failure	Applied pressure is higher than ultimate bearing capacity of soil	High applied pressure, inclined load, small loading area, low strength soil
Large total and differential settlement	Hooke,s law particle re-arrangement	High applied pressure, large loading area, highly compressible soil, non-uniform soil, large creep deformation
Ground heave	Swelling pressure is higher than applied pressure	Water, expansive soil, Frozen soil
Instability	Shear stress is higher than shear strength, driving force is higher than resisting force, driving moment is higher than the resisting moment	High earth structure, steep slope, high water pressure, soft foundation soil, high surcharge, high loading rate

Next, see then, typically geotechnical problems and possible causes at a particular site. If you have a bearing capacity problem or it can have too large total and differential settlement, some sites can have ground heaving problems, and some sites have instability problems. So, suppose you have a bearing capacity problem. What theoretical basis we can apply for choosing ground improvement that applied pressure is higher than the ultimate bearing capacity of the soil that is the Theoretical Basis.

And Possible Causes that high applied pressure, the inclined load, small loading area, high strength of the soil or low strength of the soil. So, that means, if you have a bearing capacity if there is a failure occurred because of bearing capacity that means applied pressure is larger than the ultimate bearing capacity of the soil and why this applied pressure is large because of many reasons. It can be high applied pressure, incline load, small loading area, etc.

Similarly, some buildings or structures fail because of large total differential settlement, which means every building will have some permissible settlement amount. And a particular building cannot settle by more than 25 millimeters, and if you find that it is settling by about 60 millimeters or 70 millimeters or 75 millimeters, that is considered a failure.

Similarly, Differential settlement means from one end to the other end if there is a difference in the settlement, then that is a permissible limit. If it goes beyond that, then that can be considered a failure. If it happens, Hooke's Law, particle rearrangement, etc., will be the basis of that failure and why the possible cause will be again high applied pressure, large loading area highly compressible soil, non-uniform soil, etc.

Now, if you find a ground heaving problem at a site, then Swelling pressure is higher than the applied pressure. In some sites, if there is swelling soil is there, and if you construct a building by which applied pressure which is greater than the swelling pressure of the soil, then there will be no chance of heaving, whereas, if you make a building where pressure is significantly low compared to the swelling pressure, in that case, the building will be rising up and down with the variation of the season.

And the possible reason is the presence of water, if the soil is in dry condition, there is no change in moisture content in the soil, if the water enters into this, then this may cause a problem. Similarly, if the expansive soil is present, this is problematic. If there is frozen soil, this may also create a similar problem.

Some substructures may become instable because the Shear stress is higher than the Shear strength, the driving force is higher than the resisting force, the driving moment is higher than the resisting moment. These are all typically due for our retaining wall and in this instability, we can see that high earth structure, steep slope, high water pressure, etc.

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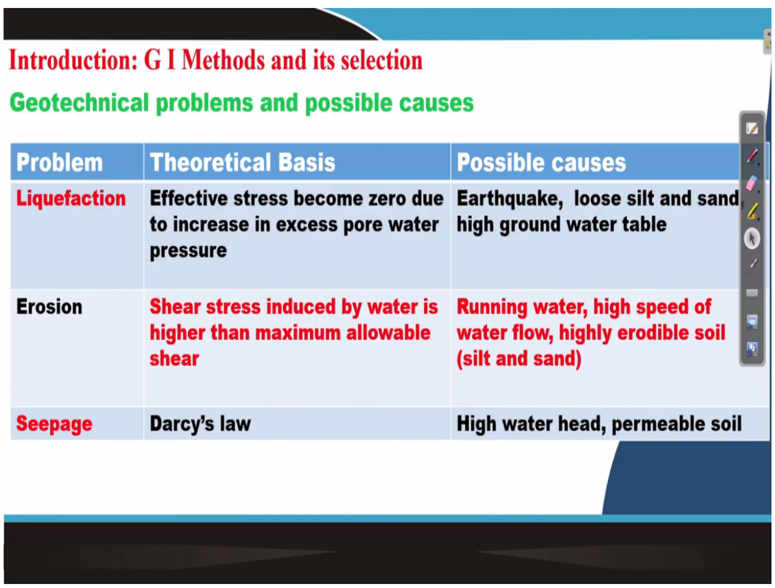

Similarly, some areas may have liquefaction, and effective stress becomes zero due to an increase in excess pore water pressure because of the earthquake, then prisms have Loess silt and sand high groundwater table. Similarly, suppose Erosion takes place at a particular site. In that case, the possible or theoretical basis is that the Shear stress induced by water is higher than the maximum allowable shear of the soil. The possible cause are running water, high speed of water flow, and highly erodible soil.

Seepage happened at a particular site, then the theory behind is Darcy's law and happened because of high water head, permeable soil. If I store water at a very great height and another side is open, then there is a chance of seepage. And if the soil is permeable, then the seepage will be more; if the soil is low permeable, then the seepage will be less.

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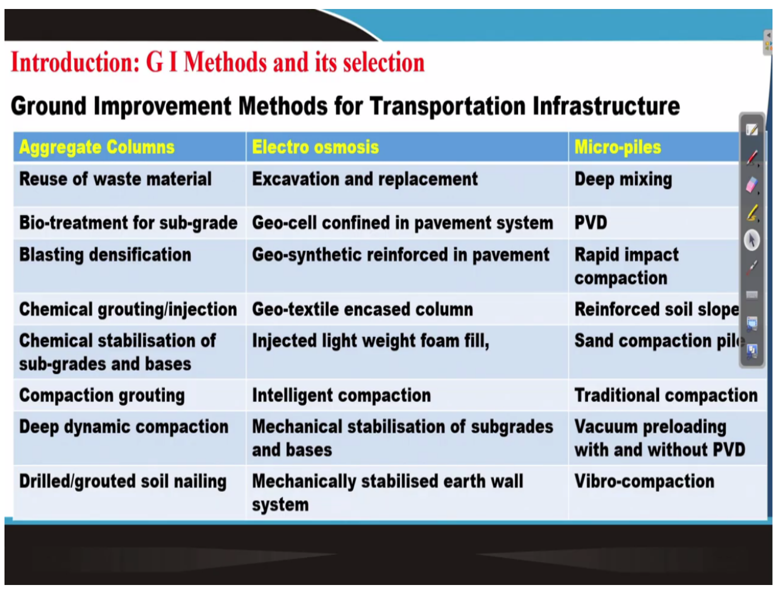

The next Ground Improvement method for Transportation Infrastructure you can see that that ground improvement can be applicable for every area, but very popularly the road infrastructure actually ground improvement technique is used maximum. When there is a multistoried building, if you find poor soil, most of the time we can use deep foundation (pile foundation), but when the road to be built and the road is going through different kinds of soil and these soil is not suitable for road construction, and piles on the road are expansive.

And because of that, we generally adopt different kinds of ground improvement techniques. And these are listed: Reuse of waste material, Bio-treatment for Sub-grade, Blasting densification, Blasting densification means by blasting if I disturb a particular soil by this way of impact generation, the surrounding soil will be densified. Chemical grouting/injection that means in a particular building if you find that is poor soil, we can inject from the side and improve the soil.

Then chemical stabilization of sub-grade and bases by adding chemicals, soil can be improved. Compaction grouting by pushing a good amount of grout inside the soil by which the surrounding soil will be compacted. Deep dynamic compaction means by dropping the heavyweights from a particular height on the soil, and the soil can be compacted and densified.

The Drilled and Grouted soil nailing means, when this particular slope if you find unstable, then we can drill it and then grouted soil nearly can be used. Similarly, Electro Osmosis can be used, then Excavation and replacement which means at a particular site, if you find the soil is not suitable for construction, you can remove some amount of poor soil and replace it with good soil. Next method is called Excavation and Replacement that is the simplest method of ground improvement but it is applicable only for a smaller area which I will discuss later on.

The Geo-cell confined in pavement system, Geosynthetic reinforced in the pavement, Geo-textile, encased column, Injected lightweight foam fill, Intelligent compaction, Mechanical stabilization of subgrades and bases, Mechanically stabilized earth wall system.

Micro-piles, there are smaller diameter piles can be the larger number of, piles can be driven in the soil by which the site can become strong. Then Deep mixing means you can enter into that deep soil and make some chemical by which you can make a ground improve, and you can improve the ground at depth. PVD that means Prefabricated Vertical Drain, pre-consolidation is one of the ground improvement technique and this pre-consolidation can be accelerated by using Prefabricated vertical Drain.

Rapid Impact Compaction, comparatively lightweight from the lower height, can be impacted on the soil by which soil can be densified. Reinforced soil slope, Sand compaction pile, Traditional compaction, Vacuum preloading, Vibro compaction. There are so many ground improvement techniques, and they will be classified differently.

I will discuss these later on each technique will be discussed in length subsequently. So, in this lecture one nothing much to conclude. The one thing I want to highlight is that soil has to be considered as one of the important material in civil engineering and it has to be handled properly, and it has to be characterized, if you find the soil is not suitable, then the suitable ground improvement technique to be applied to make it suitable.

And next is reference, in the end, I will give this reference. So, I have not written here. With this, I will close this lecture one.

Thank you.