Ground Improvement
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Lecture - 02
Ground Improvement Methods

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Once again I welcome you all to this Ground Improvement lecture series and this is the second lecture in ground improvement and we are in the introduction. Before going to a particular technique we are giving you certain information, why ground improvement? And under this, you have seen that I have highlighted that soil be considered as one of the important material in the previous lecture.

And when the soil is there, there will be different types of problems, whether it is Natural or whether it is a Fill. Depending upon the type of soil, what are the problems one has as a geotechnical engineer? One has to assess. If I know that I am a geotechnical engineer at a particular soil site, I should know that site will have low strength or high compressibility. If that is known, then automatically, when I try to build something, I have to take care of that.

See that is what I tried to summarize in the previous lecture. Now, towards the end of the first lecture, I have mentioned a very large number of ground improvement techniques used in road infrastructure. These are all randomly mentioned different methods. Now, I will try to cover the classification of Ground Improvement.

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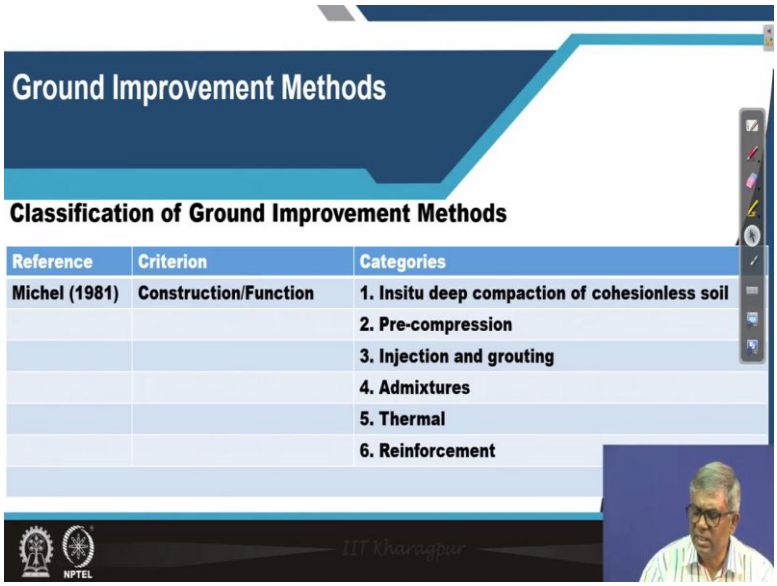

So, some people classify ground improvement techniques based on specific criteria. For example, Michel (1981) has classified his ground improvement technique based on its construction or function; what are the categories? In situ deep compaction of cohesion less soil is one technique. Later on, we will show you or discuss, but for the time being, we are classifying.

So, next is Pre-compression, which means that if there is soft soil and it is one of the problematic soil, and if I want to build something, there will be a large amount of settlement. So, to overcome that, the soft soil is kept pre-compressed or pre- consolidated. So, if I want to pre-consolidate beforehand, that is called another way of ground improvement.

So, he has classified that one as a pre-compression which means we are before constructing any building or structure; we are compressing the soil itself so that for the loading, it will have the minimum amount of compression.

And the third category is Injection and grouting. Injection and grouting, if there is a particular site, particularly below the building or below the tunnel, or above the tunnel. Sometimes, we may find there is a soft pocket, and then there is a chance of collapse. So, in that case, we can inject some material from outside and strengthen those weak soil. So, the third category he has mentioned is the injection and grouting method or technique.

Admixture means in some soil, if you mix something like chemicals or some other things or some other suitable material and mix it then what will happen that material may become suitable. So, that is why it is given another classification that is admixtures. And then thermal modification, that means thermal change by heating and tying, can improve the ground. So, this is a Thermal method of ground improvement. And sixth category is Reinforcement. Since concrete is not good in tension and when you use a particular member where tension is there, then in combination of concrete and steel, if you use the reinforced concrete, then it become good for both compression and tension.

And similar to that, when soil alone cannot take the load, we provide a certain amount of reinforcement inside the soil. Of course, the mechanism for reinforced concrete and reinforced soil is different, but there is a technique that you can insert or include some reinforcement in the form of some strip or some cloth or some fabric inside the soil in the form of reinforcement, then the soil will be strengthened. So, that is how Michel (1981) classified ground improvement in different categories: In situ deep compaction, Pre-compression, Injection and grouting, Admixture, Thermal modification and Reinforcement.

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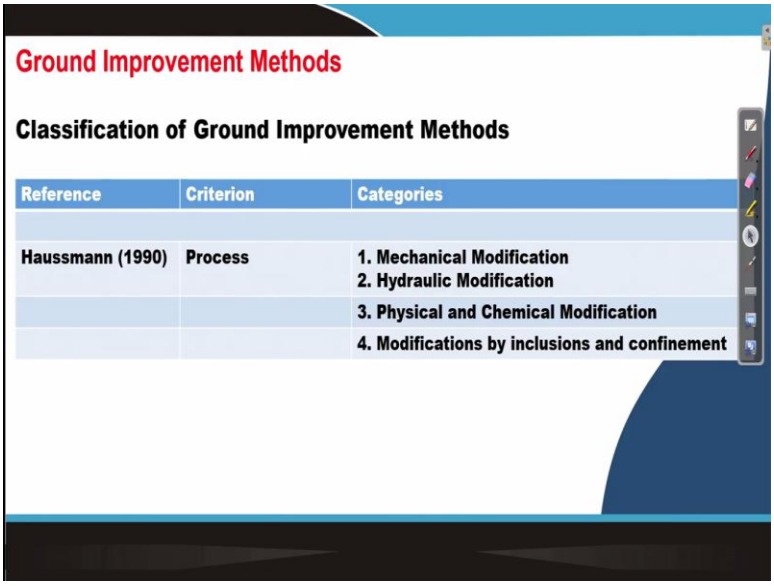

Haussmann does the next classification category, and he has categorized the classification into four categories. What is the basis of classification? He has done the classification on the basis of Process. So, first is Mechanical Modification, which means lose soil improved in dense soil mechanically either by compaction or by mixing with something. If you do that mechanically by some arrangement, strengthen or improve the soil or ground, that Process is called Mechanically Modification.

Then similarly, Hydraulic Modification means, at a particular site, because of the high water table, that may not be suitable for construction. And then hydraulic Modification means that we can draw water or we can extract water from the soil. If you continuously extract water from a particular site, then automatically groundwater table will be lowered. And that is why lowering the groundwater table will actually be good for the soil. So, the strength and other parameters will be improved. And that is why it is called Hydraulic Modification because we are hydraulically modifying.

Similarly, Physical and Chemical modification, physical modification means you can excavate some amount and then replaced by good soil, that is Physical modification. Chemical modification means, you add cement or some other lime to the soil and based on that soil will be modified. So, that is why he has given the process Physical and Chemical modification.

And the fourth category is a Modification by Inclusion and Confinement, which is similar to reinforcement modification mentioned previously by Michel (1981); modification by inclusion means, inside the soil, if you put some amount of reinforcement strip, cloth, or fabric, then it will be improved. Sometimes on a slope, if I put a nail in a rod, you put a rod at a particular angle, and then it will be prevented from collapsing. So, modification by inclusion or confinement is another method of classification, according to Haussmann.

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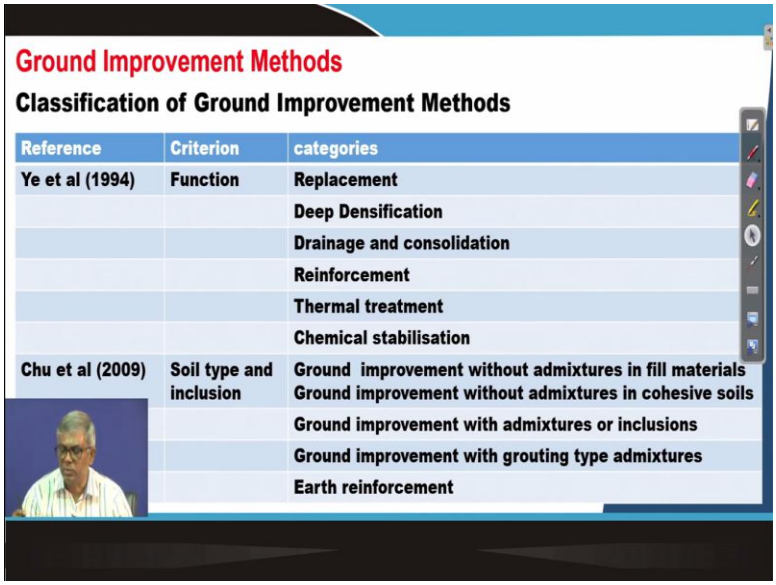

Then Ye et al., he has also classified the ground improvement, and the criteria of classification are the function and according to him, there are six classifications mentioned. First is a Replacement; if you find a particular site is of weak soil, we generally remove the weak soil and replace it with good soil. So, that method is called replacement.

Next is Deep Densification, that means, soil at the particular site, topsoil, maybe because of some reason is quite good, but there may be soil at particular depth it is quite fine but water table or presence of water table may be vulnerable (liquefaction) or some other reason it is not suitable then in that case densification, that is not the deep densification. So, deep densification means actually by dynamic load and all whatever we do which up to 8 to 10-meter depth. If you densify that is another mention at this method is called Deep Densification.

And Drainage and Consolidation, as I have mentioned before that when there is a soft soil and it is saturated, then if we apply load then over the time that water will come out and it will be, it will be a consolidate and consolidate means that ultimately soil will be compressed.

So, because of that many a times as other methods also, it is mentioned that we have to pre-consolidate. So, before construction, the soil will be pre-consolidated, and pre-consolidation can be done only by surcharge sometimes or in addition to the surcharge, you can provide additional drainage or vertical drain to make it or accelerate the consolidation. So, he has mentioned one of the ground improvement techniques as Drainage and Consolidation.

Then another method is Reinforcement which means, within the soil again, if you put in the form of reinforcement different material like strip or geo-fabric. The soil will be strengthened, and it's chemical stabilization in some soil depending upon its chemistry, we can add certain chemicals. The different stronger materials will form by reacting these chemicals with the soil, and finally, soil will be stabilized. So, that is the another way of ground improvement method. So, according to him, Ye et al, he has mentioned six categories of ground improvement technique based on function.

Similarly, Chu et al., also has classified the ground improvement techniques in five categories and he has classified based on soil type and inclusion. So, you can see here ground improvement without an admixture in fill material.

So, ground improvement without admixture in fill material, a conventional compaction that means, by roller and other things, simply you put in layers and then compact then soil will be densified. So, that is actually without inclusion, any chemicals, the ground improvement without admixture in cohesive soil. And then ground improvement without admixtures in cohesive soils.

Then ground improvement with admixture or inclusions. So, here actually admixture means we can add chemicals, we can add something else or you can use reinforcement also by which the soil can be improved that is another method of ground improvement according to Chu et al. The ground improvement with grouting type admixtures. The grouting actually sometime work in different ways, through the pores of the grains, the grout material enters and it cemented together and become a stronger material.

Some soil has fissures through that fissures grouting can be entered, and it may again make a stronger material or sometimes grouting can be injected in a large volume. And the amount of, where the low permeable soil, the grout material is injected within the soil with pressure then that large volume is entering into the soil, where the similar amount of soil will be compressed, surrounding soil will be compressed.

Then Earth Reinforcement again, typically, almost everyone mentioned this as one of the ground improvement techniques that is the below the footing if a particular site soil is not up to the mark for a particular foundation then below the foundation, if you put in some interval 2-3 layers of reinforcement sometimes the foundation become very strong. So, that is the method actually, according to him.

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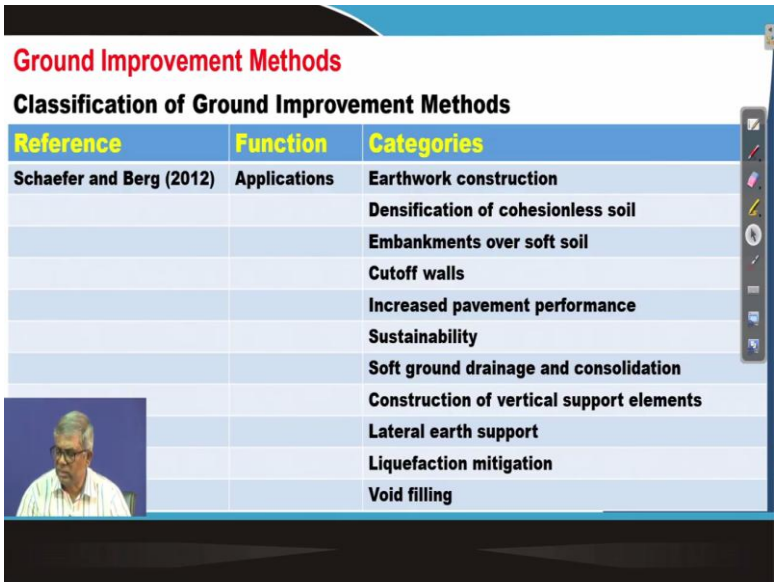

And then Schaefer and Berg (2012), according to them ground improvement classified in different categories based on application, and then he has an Earthwork construction. So, Earthwork construction that we need excavation or filling, how the slope will be made accordingly where ground a soil dwelling will be used. So, the Earthwork construction related ground improvement he has mentioned

The densification of the cohesion less soil is another category, the cohesion less soil means fine soil; how it will be densified is generally reconsolidation or some other deep dynamic compaction. So, that is another classification he has made. Embankments over soft soil he has made another classification by this.

Then Cutoff walls is another method of ground improvement that means to prevent the movement of water through the soil or to make the movement of water slow because when Cutoff wall is there, then the flow path of the water will be longer. As a result, it will be reduced. Then Sustainability is another aspect based on which the ground improvement techniques will be used that some materials may be harmful. So, accordingly, you have to use some material that will not be harmful at the same time. It is helpful to improve the ground strength and stability and other things.

Then Soft ground drainage and consolidation that is another way of classification, he has mentioned. Construction of vertical support elements that is another type of classification. Lateral earth support then Liquefaction Mitigation, and then void filling. So, this type of classification is not very clear and is a very work specific classification. And so, this is not very widely used to classify.

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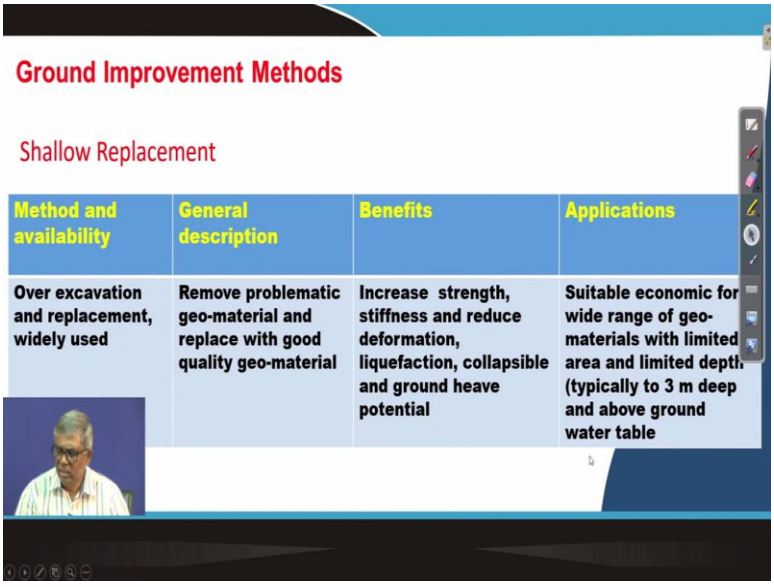

And then finally, I am now discussing different methods, and then a particular method, what its description means, how it is and if you do, what are the benefits, what I will be getting out of it, and where we can apply. So, like that, I will try to list a few of them, for example, methods and availability. So, that means the first column shows methods, what the methods are, and whether they are available.

So, you can see Over excavation and replacement is the method, and this is the simplest method, but it may not be suitable everywhere. When there is a smaller work, this method is suitable. It is widely available and used in the practice and a general description of what is the. This over excavation and replacement means what exactly it is that is described in the second column you can see.

Remove problematic geo-material and replace them with good quality geo-material. So, though it is described, it is not so simple because of how much to be excavated, how much void, if the footing width is two-meter then how wide should be the excavation, and at what slope and depth all those calculations will be there, which we will be discussing later on.

So, by large, the method describes that you have to remove the problematic material and replace it with suitable material. And if you do that, what benefit we get, we will get better strength, better steepness, we will have reduced deformation, it will be less liquefaction potential, then collapsible potential reduced and ground heave potential also because if there is a close to the ground surface, there is an expansive soil and if I remove it, then automatically that ground heaving problem will be removed or reduced.

Why can it be applied? It can be applied for a suitable, economic, wide range of geo-materials with limited area and limited depth within three-meter and if it is above groundwater. If that is below groundwater table excavation, all will be difficult, and when excavated water comes, dewatering is required. So, it can be used widely, but when the work is comparatively small, and the depth is relatively less, this method can be used successfully.

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And then this is excavation and replacement is shown. You can see that the material is excavated and the excavated material is replaced with good material and then finally, it is compacted that is the way it can be done.

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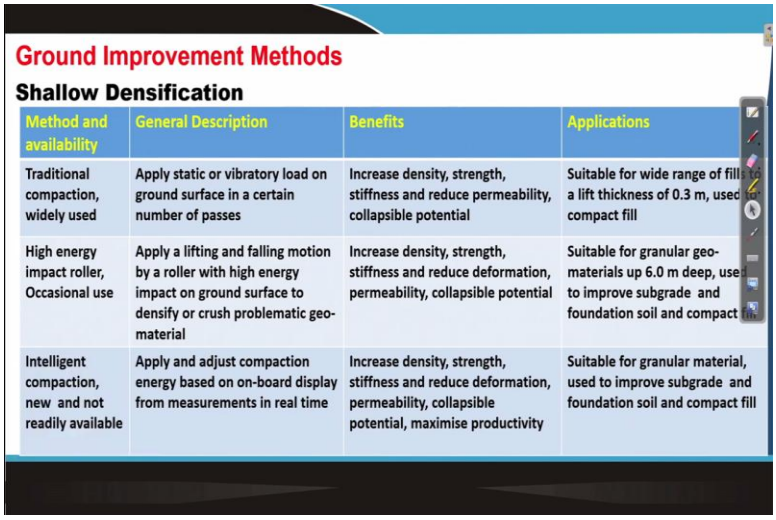

And then we have Shallow densification, and there are different methods for shallow densification. First is traditional compaction, which means we can use roller, and then we can give a number of passes, and if you give a number of passes in a particular soil with a heavy roller, then soil automatically densifies, and this conventional traditional compaction method and it is used widely.

What benefit do we get? We get increased density, we get increased strength, permeability reduced, and it will be less collapsible, and where we can apply that application area is quite wide. You can see suitable for a wide range of fill, lift thickness of 0.3 meters, and compact fill. - So, that means when you use traditional compaction generally of 0.25 to 2.3-meter soil. We provide number of passes. So, that is the way we can densify.

And suppose 1-meter soil if we want to densify this will not happen. So, that is the drawback of this method. So, that is why it is limited to a particular type of work. Then the next one is the High energy impact roller. And it is a roller, but in addition to this in the roller, there will be something added by which there will be some weight lifted and create an impact on the ground.

In addition to the heavyweight, it will create some vibration in the soil, resulting in better compaction. And this high-energy impact roller, again depending upon a particular type of soil, is not very commonly used. Still, when loose sand is there, we can use this vibratory roller, which will be more effective, and the description of the method is already I have mentioned. And what benefits can we get from a high-energy impact roller? We can get increased density, strength, stiffness, reduced deformation, permeability, and less collapsible potential.

And where can we apply it? Suitable for granular geo-material up to 6 meters deep. You can see now that we can get only 0.3 meters deep in conventional roller, but for high impact energy roller, we can get up to 6 meters deep and use it to improve, subgrade and foundation soil, and compact the ground.

Then there is another method of compaction that is the Intelligent Compaction. By the name itself, Intelligent Compaction, one can guess what it is. It is traditional compaction. Still, in addition to that in this, a number of sensors will be attached to it. When you do traditional compaction after giving several passes, you have to monitor whether the desired strength and compaction is achieved or not. And then some test we carry out. Whereas intelligent compaction will monitor during compaction itself, the sensor itself will be receiving data, and based on that, it will signal whether it is compacted if some area is less compaction, then it will direct to move that area like that.

So, it will take you to the area where compaction is required, and it will take you away from the site where compaction has already been achieved. It is a highly controlled way of roller

compaction, and it is a method that applies and adjusts compaction energy based on onboard display from measurements in real-time. That is what that lot of sensors will be there by which it will display specific figures and by that figures and we can decide whether the compaction is achieved.

So, what benefit can we get from these? We can get several benefits similar to others. If the soil density increases automatically, then the increase of density provides better strength. It gives better stiffness than deformation automatically be reduced, permeability also decreased, the collapsible potential will be reduced, and maximized productivity that means it can be maximized, where it can be used.

And where you can use suitable granular materials to improve subgrades and foundation soil and compact fill. So, these are the different areas it can be used, and of course, until unless a very accurate and quick result is required. Since specialized equipment is rarely used unless it is essential, this method is generally not used.

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And you can see here that ground this is the conventional compaction you can see that either you can see the bottommost layer is compacted y. Then you can see there is some thickness of the layer of laid and then over that roller is moving and in the one pass, you can see there is a difference in impression from the figure. When one pass is given, it will be compacted, or depth will be reduced. If you go two passes, then further depth will be reduced; depth reduction means they are getting densified.

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Then similarly, a high-energy impact roller means the roller will be moving horizontally at the same time as the wheel itself, there is extra mass. At a particular frequency, it will be moving. Because of that movement, some amount of vibration will be exerted on the ground in addition to the weight that the dual action of vibration and the weight sometime for granular soil, compaction will be achieved quite easily. And so, that is another method of traditional compaction with some additional features.

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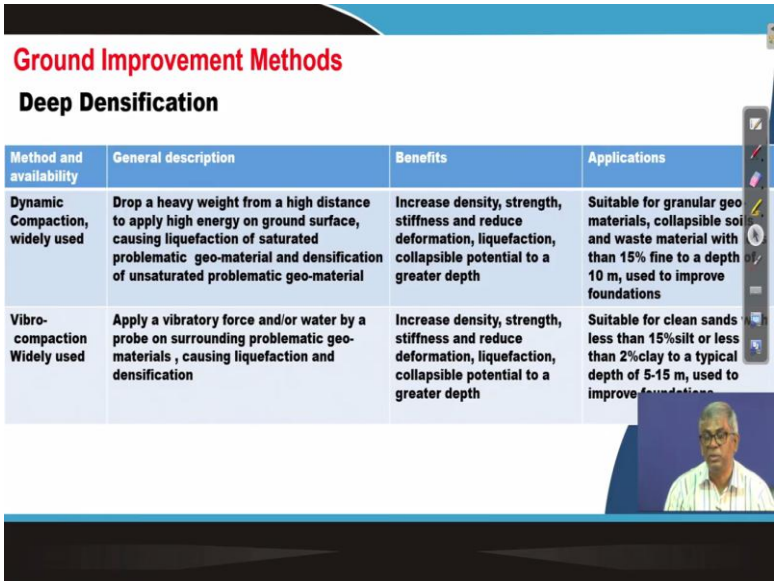

We have seen that shallow densification up to 1 meter in depth can be done. But for deep dynamic compaction means up to, up to 8 to 10 meters deep, we can compact and generally, deep dynamic compaction is a heavyweight, will be dropped from 30-40 meter height and because of this height, drop that weight and then the soil will be highly densified.

Some areas around when the drop will fall immediately below that drop, and surrounding soil will be compacted. You drop a heavyweight from a high distance to apply high energy on the ground surface, causing liquefaction of saturated productivity geo-material and densification of unsaturated problematic geo-material. So, this is the way this mechanism works.

And what are the benefits we get from this increased density? The main target of every ground improvement technique is to increase the density. So, here the density increases, strength also increases, and stiffness also increases the reduced deformation, which means once you densify, then further when we lower the settlement or deformation is reduced.

Then lower liquefaction potential where it can be suitable for granular geo-materials, collapsible soil, and waste material with finer, fine material more than 15 percent fine to a depth of 10 meters. So, deep dynamic compaction can be achieved up to as high as 10 meters deep.

And then Vibro compaction This is also another method, apply a vibratory force and water by so, that means there is a probe and with vibration and water jet, it will cut the soil, and it will go

to a depth. Vibro compaction generally can be done in a different depth. Suppose if you want to compact at the 5-meter depth, then you go by these up to 5-meter depth, and then you fill it with good material, and then this probe water will be closed. This probe will be lifted and dropped a number of times, and in that way, that soil will be densified. Once that particular level densifies, then lower level than above that again, you can repeat the same process and the densify and then go up to the surface.

So, that is the Vibratory compaction and is also widely used, and this benefit is again increased density, strength, stiffness, reduced deformation, reduced liquefaction potential, etc. As you can see, it is suitable for clean sand and less than 15 percent silt and less than 2 percent clay to a typical depth of 5 to 15 meters depth.

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As I have told you, deep dynamic compaction will be dropped, and once you drop heavyweight. You can see here that there are different impressions because of this dropping of weight. Once this deep dynamic compaction is done in one stage, the soil will be disturbed. You may have to drop more than once at a particular place, sometimes the staggered way. So, when you have put here next time, you put somewhere next to this like the entire area will be covered.

And finally, when the deep dynamic compaction is completed, the surface will be disturbed like 1 meter to 1.5-meter soil will be disturbed heavily. Then that soil can be again level, and then a

typical conventional roller can be used to compact the soil. So, that is again, a combination of these two can be used. So, this is deep densification.

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So, in this lecture 2, different people have tried to classify ground improvement techniques on different basis. Finally, we are doing our way of classification, and we have done Replacement one, then we are doing Shallow densification. Then next, Deep Densification and other things I will be discussing in the next class. So, I am not making any specific conclusion here, only classification, and We can say the most important highlight in lecture 2. With this, I will stop here.

Thank you.