Earthquake Geotechnical Engineering

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Lecture 53

Ground Improvement Techniques: Types of GIT

I welcome you again for this NPTEL online course on earthquake geotechnical engineering. We are under module last module of this course which is on ground improvement techniques this is lecture number 53. We are discussing types of ground improvement techniques and here in the types of ground improvement techniques we already started with densification techniques. Today we are going to talk blasting, compaction grouting and areal extents of densification. So, here once densification technique is over then we are going to talk about reinforcement techniques. So, in this case we have already used two types of techniques, one is like vibroflotations and then another we are going to talk about blasting today.

Here in the densification techniques when we talk about blasting you have dynamic compaction. So, we have vibroflotation dynamic compaction. Now, we are going to talk about blasting. In case of blasting, which is for the loose granular soils have also been compacted by blasting.

In case of blasting as the name suggests you use basically some explosive. Blasting densification involves the detonation of multiple explosive charges which are vertically spaced 3 to 6 meter apart which could be in drilled or jetted boreholes. The boreholes are usually spaced between 5 to 15 meter apart and backfilled prior to detonations. So, of course, this kind of techniques, blastings has been stopped nowadays particularly after the you know that some ruling from Supreme Court and the blasting is no longer used like particularly in the hilly areas. But still like this is one of the techniques which is used in some areas which is particularly if some area is inhabited, or it is completely remote area then it could be used.

To increase the efficiency of the densification, processing the charges at different elevations may be detonated at a small time delays. Immediately after detonation the ground surfaces rise, and the gas and water are expelled from fractures. The ground surface then settles as the excess gas and water pressure dissipates. Although the efficiency of densification decreases with each round of blasting, 2 to 3 rounds are often used to achieve the desired degree of densification. So, here is one of the examples where the blasting techniques has been used for the ground improvement.

So, in this figure ground surface shortly after detonation of explosive during blast densification. So, you could see that in this figure that like with this you have this fog is coming out of that, smoke is coming. So, these are the detonators, the smoke is coming out of it. So, these are the explosives, and these are used for densification of loose soil beneath an abutment prior to construction of cold water creek bridge. This is also from Washington states in the US, and this is thanks to the it is taken from the Kramer's book.

Blasting is most commonly effective in loose sands that contains less than 20 percent silt and less than 5 percent clay. Even a small amount of clay or a small clay seams can substantially reduce the effectiveness of blasting. Blasting can be effective in dry soils, but the effects of the capillary tensions and gas bubbles in partially saturated soils virtually negates the its effectiveness. So, the effectiveness of the blasting techniques will decrease if you have partially saturated soil. If you have dry soil good, but if you have the partially saturated soil then there is a problem.

However, if you have completely saturated soil then it is fine. So, the partially saturated soils have the problems for this blasting techniques and the reason being here the there could be effects of capillary tension and the gas bubbles, and they can try to reduce or even eliminate the effectiveness of the blasting. In such soils where you have the saturation, the shock wave produced by the charges produces localized temporary liquefaction. Particularly in saturated soil there could be due to during the blasting there could be temporary liquefaction which allows the soil grains to move into a denser configuration. Although blasting is quite economical, its use is limited by several practical considerations.

It produces strong vibrations that may damage nearby structures or produce significant ground movements and so that is why it cannot be used near the existing buildings or structures. It also requires the use of potentially hazardous explosives for which strict regulations on handling and storage is usually applied. Finally, its effectiveness is difficult to predict in advance because its effectiveness will depend on your type of soil and particularly it may not be effective for partially saturated soils. We continue in the dense friction. We talk about after blasting compaction grouting.

So, the compaction grouting, and dynamic compaction are different things. So, let me put on this slide. We have discussed in the densification technique two of the techniques, one is vibroflotation. Vibro, let me use this. I think so this in general we can say this could be like you know that vibro techniques, in general we say vibro techniques where you use the vibro tactic.

Then you have dynamic compaction. These we discussed in the last lecture. And now blasting has been over and then compaction grouting. So, dynamic compaction and compaction grouting is different. In case of dynamic compaction you are just compacting with using some hammer or prop or you can say impact loading. While in case of compaction grouting you are injecting some material, so where grout is used. So, there are difference between these two techniques dynamic compaction and compaction grouting. So, now we are going to talk about dynamic compaction grouting. Soft or weak soil can be densified by injecting a very low slump grout into the soil. So, some foreign material, very low slump grout is injected into the soil under high pressure because it is a kind of a fluid like and when you inject inside the soil at a high pressure then it can be densified because it will fill its voids and this process is known as a compaction grouting.

Because the grout is highly viscous it forms an intact bulb or column that densify the surrounding soil by displacement. Compaction grouting may be performed at a series of points in grid or along a line. Grout point spacing ranging from 1 to 4.6 meter have been used. So, like these are the range where the spacing means at what spacing you inject the grout inside the soil.

So, this is a typical feature the compaction how the compaction grouting is done. You have pump and pressure gauge to measure. What is done? You have a stem through which you inject the grout inside the soil in the kind of a fluid slurry and when it goes it will automatically frame a grout bulb where you have the loose you know where it have the space to go. If you know at some depth suppose you have the loose, so it will automatically spread out and a grout bulb will be created. So, this compaction grouting though low slump grout is pumped under high pressure to form a bulb that displaces and densifies the surrounding soils.

So, it will displace and after displacing the surrounding soil it will densify also by raising the grout tube while pumping. So, continue with the compaction grouting because high higher overburden pressure allows the use of higher grout pressures. Larger specks are used when treating deeper soils. So, naturally when you go at the deep at higher depth then the larger amount of grout will be there. A shallow depth compaction grouting may be used to lift settled slabs or structures.

Indeed, remediation of foundation settlement is probably the most common application of compaction grouting. So, compaction grouting most of the application is a remediation of foundation settlement. Suppose your foundation settle more settlement within the foundation is not within the permissible limit. So, many times we use compaction grouting for that. The compaction grouting may be performed from the top down.

Top down means basically you start from top and then go towards the down side or it could be down that may called downstage grouting. That means you are going from up to down top to down or it could be bottom up which is called upstage grouting. That means you start from first from bottom and then go towards the top. Upstage grouting is less expensive where upstage in upstage grouting you fill first the bottom and then you come towards the top and more commonly used than downstage grouting. However, downstage process is preferred for underpinning of structures or underpinning basically kind of retrofitting of the structures or for sites where loose soils extend to the ground surface.

By working from the top down placement of an upper grout into bulb reduces the possibility of subsequent grout escaping at the surface. So, once we have prepared the let us say that this upper grout bulb then chances are there that it may not escape like when you start filling continuously. So, then it may not escape some part of the soil. And it provides additional strength and confinement that allows the use of higher grouting pressure at greater depths. The grouting rely on vibration, compaction grouting can be used for all types of soils including the cohesive soils.

It is most commonly used in sands and non-plastic soils. Compaction grouting can be used to virtually any depth and can easily be used within a given range of depths. The size and shape of the grout bulb or column is influenced by the stiffness and strength of the soil and also by the rate and pressure at which the grout is injected. So, the size and shape of the bulb grout bulb will be influenced what type of soil you have, at what pressure you are injecting the grout inside the soil. An important feature of compaction grouting is that its greatest effect occur where the soil is softest and weakest.

So, this is very good it goes in the favor. Where you require the most and its effectiveness is maximum for the type of soil where its requirement is more. Now, in the densification technique because one of the important issue we will see up to what extent your densification technique have worked. So, areal extent of densification techniques that means from the areal you see from the air from the like you know that this how this and this in area how much it is extended. So, this areal is related to area though it can be seen from the top and it is related to area how much area is covered.

An important consideration in the densification of soils for construction of individual structures and foundations is the areal extent of soil improvement which is required for satisfactory performance during earthquake. The areal extent should be evaluated on case by case basis since site specific soil conditions, performance requirements and failure consequence must be addressed. The required areal extent of improvement depends on the mechanism of failure that the improvement is intended to eliminate. So, what is your objective? It will depends on that. For potential stability failures the areal extent of improvement will depend on the degree of improvement that can be achieved and on the extent of the potential failure surface.

By estimating the residual strength of the soil after improvement, stability analysis can be used to estimate the extent of improvement that will produce an acceptable level of stability. To minimize post earthquake settlement of a structure or foundation on loose saturated sand densification is usually performed within a zone which is defined by 30 to 45 degree from the age of the structure. For example, it is shown in this figure. You have the structure. Naturally densification is required just below the structure, but that is not enough.

Rather you draw from the age of the structure two lines either at 30 degree or 45 degree. So, minimum is required is that it should go at least up to 30 degree extent, but if you go up to 45 degree then zone of improvement is enough. So, zone of improvement will lie somewhere between 30 to 45 degree. So, this will be your zone of improvement which is required.

And this is for liquefiable soils. You have on the top water table, so liquefiable soils will be down. Typical area of extent of improvement for densification of potentially liquefiable soils beneath a structure. So, this was about areal extent of densification and this with this we completed with the for the ground improvement densification techniques are over. So, all the four techniques, vibroflotation, dynamic compaction, blasting and compaction grouting has been discussed. Now, there are second types of ground improvement techniques, second category which is called the reinforcement techniques, and we are going to discuss the reinforcement technique.

As the name suggests, in case of reinforcement techniques, the soil will be reinforced by some foreign material. And most of the times there are three types of approaches are used for reinforcement techniques. One is stone columns, then you have second compaction piles, third is drilled inclusions. So, here you include something inside by installing discrete inclusions. These inclusions may consist of structural materials such as steel, concrete or timber and geomaterials such as densified gravels.

So, these are used, and we just said that three types stone columns, compaction piles and drilled inclusions. Stone columns are the most popular particularly for liquefaction mitigation. Soil deposits can be improved by the installation of dense columns of gravel known as stone columns. So, normally these though name is given stone columns, but the material which is used gravel basically though you can say gravel is also crushed stone basically because gravels are also made from the like stones only. Stone columns will be used in both fine and coarse grained soils.

In fine grained soils, stone columns are usually used to increase shear strength beneath structures and embankments by accelerating consolidation and introducing columns of stronger material. For mitigation of seismic hazard, they are commonly used for improvement of liquefiable soil deposits. So, one side your objective using a stone column is increasing strength and stiffness of the soil deposit. On another side objective is also to improvement for the liquefiable soil deposits. Stone columns can be installed in a variety of ways.

Stone columns may be constructed by introducing gravel during the process of vibroflotations. Several other methods of installations are also available. For example, in the Franki method, a steel casing which is initially closed at the bottom of gravel plug is driven into the desired depth by an internal hammer. And at the depth part of the plug is driven beyond the bottom of the casing to form a bulb of gravel. Additional gravel is then added and compacted as the casing is withdrawn.

So, this is shown here. So, methods of stone column installations, two methods are here. One is Franki method, another is vibroflotations. So, in the case of Franki method, you have a casing and in this casing you put using this hopper you are putting gravels here. Gravels are coming here, and this is internal dwarf hammer. Using dwarf hammer whatever gravels you insert it is pushed down compacted.

Then another one is vibroflotations where you use vibroflot which vibroflot we already discussed in detail, and you are using this like tractors or maybe like some vehicle you are putting or like you know kind of JCB. You have the stone columns, gravels which are inserted inside this. And when they are inserted, they are compacted using the vibroflotations and ultimately a bulb like here, this is prepared which is a bulb for use from the made of stone columns, gravels and this will have quite good strength compared to the surrounding soils and it will help in its densification as well as mitigation of liquefaction. Stone columns combine at least four different mechanisms for improvement of liquefied soil deposits. So, two different mechanisms which the stone column helps.

First, they improve the deposit by virtue of their own high density, strength and stiffness. In this sense they reinforce the soil deposit. So, first mechanism, which is like the stone column is helping because their strength and stiffness is better than the rest of the soil and they have high density. So, the strength and stiffness increases of the soil. Second, they provide closely spaced drainage boundaries that inhibit the development of high excess pore pressure.

So, drainage boundaries are provided, so it will help in dissipation of pore pressure. So, you can say it will help dissipation of pore pressure. So, the stone columns will help in dissipating the pore pressure. So, here what you have, the third one is the process by which they are installed, densifying the surrounding soil by the combined effects of vibration and displacements. So, third mechanism.

Fourth, the installation process increases the lateral stresses in the soil surrounding the stone columns. These multiple benefits have made the use of stone columns very popular. So, first of all the material is such that it will help in dense, you know that because it is dense material compared to the soil. So, it will increase the strength and stiffness.

Second it will help in dissipation of pore pressure. Third when you vibrate it, so it has combined effect of vibration and installation. And fourth, it increases, this installation process increases the lateral stresses in the soil surrounding the stone columns. The second reinforcement technique is used is compaction piles. In case of stone columns, you use gravels. Here in compaction piles, granular soils can be improved by installation of compaction piles.

And these are displacement piles, usually pre-stressed concrete or timber that are driven into loose sand or gravel deposit in a grid pattern, and they are left there. So, one thing I will like to point out, you know that pile foundations, different types of pile foundations are there. So, you have pile foundations. In case of pile foundations, different types of pile foundations are there. For example, you normally have two types of end bearing piles, or you can say friction piles, end bearing and friction piles.

These types of foundations carry the load, but when we talk about compaction piles, they are not the load bearing piles, they are exclusively used for the ground improvement. So, you can say not load bearing piles. They are not for designing of foundation, rather their objective is to improve the soil. And naturally, they will be smaller piles compared to the piles which are used for foundation. Here this is a typical figure which shows the use of compaction piles.

Compaction piles driven into the upstream embankment of Sardis Dam to reduce liquefaction hazards. So, what you see here, the contact draw of the piles to this level with a barge mounted conventional hammer. The piles were later driven below the water surface with a different hammer. So, here you have like initially these piles are already driven up to the like you know you can see that these are the driven here.

While the another they are ready to dry. So, these are the compaction piles. They are basically like you know compacted and driven inside the soil. So, they will densify the soil, they will have densification effects and when you have the densification effects as well as they will you know that because the material is different so they will also increase the stiffness of the soil. Compaction pile improve the seismic performance of a soil deposit by three different mechanisms. One is the flexural strength of the piles themselves provide resistance to the soil improvement that is reinforcement.

Then vibration and displacement produced by their installation cause densification. Third, the installation process increases the lateral stresses in the soil surrounding the piles. Then structural reinforcing elements can also be used. So, this comes under the category that is the third type of reinforcement technique.

We already discussed stone columns, then we discussed compaction piles. Third is drilled inclusions. So, in case of drilled inclusions what you have is structural reinforcement elements. They can be installed either by drilling or auguring. Drilled shafts sometimes with very large diameters have been used to establish many slopes. Such shafts may be installed closely enough to form tangent or second pile walls.

Soil nails, setbacks, tiebacks, micro piles and root piles have also been used for the drilled inclusion. The installation of such drilled inclusions can be quite difficult in the loose granular soils that contribute to many seismic hazards. So, installation is not easy for drilled inclusions. So, this completes all the three parts of reinforcement techniques. So, we completed densification techniques as well as reinforcement techniques under the ground improvement techniques.

And now we will discuss in the next compaction grouting and mixing and then we are also going to talk about drainage techniques. Thank you very much for your kind attention. Thank you.