Earthquake Geotechnical Engineering

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Lecture 52

Ground Improvement Techniques: Types of GIT

I welcome you all in this NPTEL online lecture on earthquake geotechnical engineering. Today we are going to start a new module on this lecture that is lecture number 52 and today we are going to discuss the last module of this course that is module number 6 and which is one of the important topics of geotechnical earthquake engineering that is ground improvement techniques. Basically, you have seen that during other modules that there are issues related to soils where the properties of the soils are not up to the mark particularly for the earthquake loading. In that case what we can do particularly for related to liquefaction, how we can mitigate liquefaction all these issues we will discuss during this module. So, this module is planned basically in four chapters. The first one is types of ground improvement techniques where we will have almost three lectures on that.

Then second chapter will be on verification of soil improvement. We need to verify the improvement which we have made, whether they are working or not. Then the last two are kind of a mix like third chapter will be on ground improvement using geosynthetics where geosynthetics you may be aware that this is latest technology which is used for many purpose not only for ground improvement for other purpose also even for foundation and for the dam's design and other purpose geosynthetics is very upcoming area. Then finally, ground improvement using natural fibres will also be discussed and some of the work which has been done by the research scholars will be also discussed.

Coming to the first types of ground improvement techniques, what is going to be covered in this lecture that is a lecture number 52. We will discuss the introduction part that is what is ground improvement and what is its past history, how it have developed all these issues will be discussed in introduction part and during introduction we also cover that what are different types of ground improvement techniques are available. And one of the most widely used techniques is densification techniques and in the densification techniques we will discuss in the four parts one is vibro techniques, dynamic compaction, then we also going to talk blasting and then we are also going to talk the reinforcement techniques. So, all these will be covered on densification techniques. Coming to this vibro techniques it will be covered in two part vibroflotation and vibrorod.

So, let us first talk about introduction part of this, but before going ahead most of this lectures and next two lectures are most of the information is taken from the Kramer's book. Coming to the introduction part, if expected settlement or we say lateral movement for a proposed structure is large then two remedial measures may be implemented, and this is happens most of the times that either settlement or lateral movement are not within the permissible limit particularly when you consider earthquake loading. So, this is the common problem when the soils are subjected to earthquake loading. Then you may have two alternatives, one is soil stabilization, or you say soil improvement, or we say ground improvement techniques are required.

So, this is the first option. The second option could be foundation design is modified to resist the anticipated soil movement that means you look for the alternative foundations. So, these are the two methods to solve the problem, but many times you use a combination of both of these two that you if your soil is very weak then you improve the soil also and then you use alternative foundation particularly deep foundations with this improved soil. So, we will be discussing the first part in detail during next few lectures. So, soil stabilization or soil improvement that is ground improvement technique.

When we talk about improvement of the soils, soils have been modified to improve its engineering properties from hundreds of years it is not today like or a recent phenomena. However, in the last century improved knowledge of soil behaviour and geotechnical hazards that has led to the development and verification of many innovative soil improvement techniques. So, though it is not a like you know that when we talk about ground improvement technique, it is not that a full proof process there are different it is in fact case by case there are different techniques, and one technique may not be enough sometimes like in the different scenario different techniques of ground improvement will be used. So, these techniques has been developed and they have lead to whatever the innovative soil improvement techniques has been led in the past many years many decades. Increased recognition of seismic hazards because of in fact, like you know particularly in our country also our India is seismically very active and improved understanding of the factors that control them how led these techniques to be applied to the mitigation of seismic hazard in the past 7 decades.

In both seismically active and inactive areas soil improvement techniques are commonly used at sites where the existing soil conditions are expected to lead to unsatisfactory performance which usually involves unacceptable large soil movements. When you go for foundation design of the structures there are two most important criteria which need to be satisfied for any foundation one is its bearing capacity should be within permissible the whatever the soil the structures apply the pressure at the base should not exceed the safe bearing capacity of the soil so that is bearing capacity criteria. The second important issue that the settlements or lateral movement of the soil should be within the permissible limit. So, in case you have an unacceptable large soil movements which may occur both in active or inactive areas of seismically it may be even without earthquake also the ground improvement is not necessary that it is required only when you consider the earthquake load. This may require even without earthquake loads if your soil conditions are not good.

The movement which is large soil movement it may include horizontal as well as vertical or it could be both components and it could occur during or before or after earthquake shaking. In the absence of earthquake shaking unacceptable movements result from insufficient soil strength or stiffness. So, basically here when we say which type of soil will require the ground improvement or which may not require naturally it depends on the strength or stiffness of the soil. So, as a result most soil improvement techniques are developed to increase the its strength and stiffness of soil deposits. Basic objective whether you consider earthquake load or you do not consider earthquake load, idea behind the ground improvement technique is to increase the stiffness and strength of the soil.

During earthquake other factors can also contribute to unacceptable performance, in particular the buildup of excess pore pressure can lead to very large deformations. So, when you consider earthquake forces in addition to what is the issues in the static case there is a development of excess pore pressure particularly when your soil conditions are saturated conditions and that need to be also considered. So, consequently commonly used techniques for mitigation of seismic hazard often involved reducing the idea is here whatever techniques is used their objective is to reduce the tendency of soil to generate positive excess pore pressure during earthquake shaking as well as increasing the strength and stiffness of the soil. So, you can target that there are two basic objectives of ground improvement. One objective which is even without earthquake that is to increase the strength and stiffness of the soil that is the first prime objective.

The second objective which is important for earthquake loading that is to reduce the generation of excess pore water pressure. So, advances in soil improvement technology have mostly come from the initiatives and imagination of contractors. So, it is something like were the practice started earlier than the theory most of the things you know it comes first in theory and then it go in the practice. But as for ground improvement techniques are there some it happens for many cases the theory was not developed rather this ground improvement techniques has been developed in the field by the initiative and imagination of contractors which was working on it and then later on it has been come in theory it is reverse way. Research and explanatory theories have followed implementations.

So, it is other way that implementation is done first theories have developed later. And proven theories have yet to be developed in such cases indirect or empirical evidence must be relied upon the study of case histories in particularly like that will be very important that we need to rely for mostly the case histories or implementation part. At present a wide variety of soil improvement techniques are available for mitigation of seismic hazards including the liquefaction or landslides. On the basis of the mechanism by which these improve the engineering properties of the soil the most common of these can be divided into four major categories. The ground improvement techniques can be grouped into four major categories.

One is what you call the densification technique, the second we call the reinforcement techniques, third grouting and mixing techniques and finally, fourth is drainage techniques. So, densification techniques we will be discussing in detail. Densification techniques we will continue in this lecture only with the densification technique and in the second lecture also on the densification technique. Once it is over then we will talk about reinforcement technique, then grouting and mixing techniques and finally, drainage techniques. So, let us start from densification techniques.

So, what is the densification techniques for the ground improvement? And this is most popular technique among all the fours. Basically, here you densify the soil by any means then it is expected that the strength and stiffness will increase. At the same time the chances of development of excess pore water pressure will also reduce. The particles that comprise a particle soil can be arranged in many ways, different ways and however, the strength and stiffness of the soil is higher when the particles are packed in a dense configuration compared to when they are packed in the loose configuration. So, basically you know there is a one term when we talk about soil relative density is also linked, strength is also linked that is what we call the void ratio.

So, when you have the loose packing then void ratio is large and the strength will be small. But when you have the close packing and using densification techniques what you can do? You can reduce the voids inside the soil which is either filled by water or maybe by air. So, if you reduce the voids by densification then you are going to increase strength and stiffness of the soil. Also, the tendency to generate positive excess pore pressure due to cyclic loading is lower when the soil is dense than when it is loose. This we already discussed when we discussed about the liquefaction.

As a result, densification is one of the most effective and commonly used means of improving soil characteristics for mitigation of seismic hazard. So, if you densify in fact, you know that even when the foundations are constructed like you know that the bed or what we call the like the PCC which is called plain cement concrete a bed of this created before and it is compacted by using handheld hammers or like this it is compacted by putting so many times. So, this compaction is also one type of densification where you densify the soil to increase its strength because the voids will be reduced. However, it should be noted if it is important particularly for earthquake engineering when you increase the stiffness of a densified soil deposit due to densification or technique which has been used then it will cause to respond differently to earthquake motions. For example, displacement amplitude are likely to decrease because soil is now densified, but acceleration may be somewhat greater than that for soil without improvement.

So, you have densified the soil conditions. So, soil strata or soil deposit will now respond differently to the same earthquake loading when it was not densified, and two differences have come after the densification this displacement is expected to be less, but the accelerations may be increased. Densification produce permanent volume changes that often results in settlement of the ground surface. Different densification techniques produce different amounts of settlement. So, within the densification techniques are also number of techniques are there and we are going to discuss these densification techniques under these four headings.

One is vibro techniques, second is dynamic compaction which we are going to discuss and continue in this lecture and two more techniques that is third is blasting and compaction grouting. These third and fourth we are going to discuss in the next lecture. So, let us come on vibro techniques. When we talk about vibro technique continue with the densification technique and the vibro technique, the first three out of these techniques which is used for densification are used for tendency of granular soil to densify when subjected to vibration. So, first three techniques, vibro techniques, dynamic compaction and blasting they are successfully used for the cohesion less soils or granular soils.

As such their effectiveness is greatest for cohesion less soils such as clean sand and gravels. However, the fourth one compaction grouting can be used for cohesive as well as cohesion less soils. In case of cohesion less soils as fines tend to inhibit liquefaction during earthquakes, they also tend to inhibit densification by vibrations. So, if fines are present inside the soil, they will try to resist the densification. So, they also try to resist the liquefaction, they also try to decrease the liquefaction resistance, the same way they also inhibit densification which is due to vibration.

So, in case of first technique in the densification that is vibro techniques. In vibro techniques are what is done in there are probes are used, probes are kind of a hammer or some device which is strike from a height that are vibrated through a soil deposit in a grid pattern to densify the soil over the entire thickness of the deposit. Vibro techniques can be divided into those based on horizontal vibration which is normally called vibro flotation and those based on vertical vibration is called vibro rod systems. Vibro techniques are among the most commonly used techniques for mitigation of seismic hazards. So, these are the most commonly used most popular vibro techniques are most popular and they are used for mitigation of seismic hazards.

So, first one vibro flotation as we said that vibro flotation are used for where the vibration is in the horizontal direction and vibro roads are typically used for vertical vibration. So, let us discuss first vibro flotation vibro techniques with vibro flotation. In this case a torpedo like probe that is called the vibro float is suspended by crane is used to densify soil deposit. Vibro floats usually 30 to 40 centimeter in diameter and about 3 to 5 meter long contains weights which are mounted eccentrically on a central shaft driven by electric or hydraulic power.

So, it is here. So, this is systematic for vibro float. So, in the vibro float what you have you have on the top you have two types of pipes one is electric cables are going which will use. So, because it will be operated by electricity or maybe hydro power, this is hydraulic power. Then the second is water hoses that means water is required and we will discuss why water is required in the next slides. Then you have this vibration isolator coupling then vibration vibrator suction is given the down.

So, there is electric motor which is run by the electricity then you have eccentric weight which is here, and this weight eccentric weight is used for putting and this weight eccentric weight is you know like it is fall from a height and height of this weight like diameter is discussed 30 to 45 centimeter while the it is length is about 3 to 5 meter. So, it is quite long. So, 3 to 5 meter you know that it is quite long like almost 2 stories so that. And how it is used? The here vibro floats densifying liquefy also is at a wastewater treatment plant in California. This is photographs taken from Kramer's book and where this is coming from Hayward Baker.

Here what you have in this case you have a crane in fact, you could see in this figure there are two cranes and this vibro flow tensors are suspended from the cranes and this is put down in the grid pattern at different locations. And it is so you will have torpedo like a hammer when it strike, and it will generate the lateral moments in the soil. So, it will then densify not only at the point, but some radius around the point. So, which is like for this horizontal because that is why it is will create the horizontal vibrations and will densify the soil. The vibro float is initially lower to the bottom of the deposit by a combination of vibration and water or air jetting through pores in the pointed nose cone.

So, this we already have shown that there is a mechanism in the vibro like float for the water injecting the water. The vibro float is then incrementally withdrawn in 60 to 90 centimeter interval at an overall rate of over 30 centimeter per minute while still vibrating. So, when this vibro float is vibrating then it is withdrawn. Water may be jetted through pores in the upper part of the vibro float to loosen the soil above the vibro float temporarily and add in its withdrawal. So, why like in the top part when you want to withdraw the vibro float because due to densification other reason it may be stick.

Water may be injected from the top part so that the soil on the top is loose and temporarily and it adds in withdrawal of the vibro float. It becomes convenient to withdraw the vibro float. Vibro floats with bottom feed systems can introduce granular metals through the tip of the vibro float. So, bottom feed system means it should go first to the bottom then it should come towards the top. As the vibro float is removed it leaves behind a densified column of soil.

When gravel or crushed stone is introduced into the soil the resulting stone column provides benefits of reinforcement and drainage in addition to densification. So, what happens? One side you are densifying and in case if you are putting some gravel or crushed stones introducing some material also which will be kind of like a stone column which we will discuss in detail in the next part when we talk about reinforcement techniques. The use of bottom feed system has increased rapidly and vibro floatation is most effective in clay and granular soils with fines content less than 20 percent and clay contents below 3 percent. So, these fines should be basically non-plastic fines. These should be non-plastic fines because if you have the plasticity in the soil then this will reduce the efficiency.

So, basically you can say these are the non-plastic fines and this fine content should be less than 20 percent. Clay content should be less than 3 percent in that case if you have more fines then the vibro this techniques will not be so much effective. In such soils that is the granular soils typically produces high densities that is relative densities is about 100 percent within 30 to 46 centimeter of the vibro float and lower densification at greater radial distances. To densify the entire site vibro floatation is performed in a grid pattern that means you have a prepare a grid and you select the that points on the grids with the spacing. And how much spacing should be between one location to another location where the vibro floatation should be used.

It depends on your soil conditions and the power of the vibration is normally spacing of 2 to 3 meter are very common to use. So, this was about vibro floatations which is used in for the horizontal vibrations. Then vibro rods which we discussed is used for the vertical vibrations. Vibro rod systems use a vibratory pile driving hammer to vibrate a long probe into the soil and the probe is then withdrawn while still vibrated to densify the soil. To minimize the densification induced settlement additional soil may be introduced at the ground surface or at depth.

Several types of probes have been used in vibro compaction. So, vibro road is shown in this figure and this is vibro techniques and this is why in this vibro techniques you have vibro roads. So, here why it is called vibro roads because a road is used you could see there is a road which is in vertical vibration and the roads have the kind of blades wings and these wings are like you know longer wings when smaller wings are there. So, it is combinations like you have.

So, this is vibro wing system. Each pair of wings is oriented at a 120 degree angle to those located immediately above and below. Coming to the continue with vibro techniques that is vibro road. Vibro road systems are also most effective in soils similar to those for which vibro floatation is more effective. That means, if you have the loose granular soils then these techniques are going to be most effective, but in cohesive soils they are not going to be so effective. Because vibro roads are used vertical vibration their radius of influence is usually smaller than that is observed for vibro flotation.

So, the grid spacing for soil improvement by vibro roads is generally smaller than for vibro flotation. That means spacing between two grids should be smaller compared to which is used for vibro floatation. The effectiveness of vibro roads also appears to vary with the depth. So, this was about vibro techniques. Now, the second technique used for the densification that is dynamic compaction.

Dynamic compaction is performed by rapidly dropping a heavy weight in a grid pattern on the round surface. So, you prepare a grid on the ground, and you put a very heavy weight from the top. In vibro floatations or vibro roads you are inserting inside the ground. Here you are not inserting, rather you are impacting from the top and you are striking at the surface rather than penetrating. In case of vibro floatation on vibro road you penetrate something inside the ground.

Here in this case of dynamic compaction you are impact striking from some weight. The weights usually constructed of steel plates, or it could be reinforced concrete generally range from 60 to 30 tons although weights of up to 170 tons have been used. Drop heights usually range from about 10 to 30 meter although weights have been dropped from up to 40 meter. The weights are usually dropped 3 to 8 times before moving to the next point on the grid. So, the weights will be dropped from like know that many times before you go to the next grid.

So, here is thus in the dynamic compaction, here you have the grid pattern and in this grid pattern what you have this is an aerial view of a site which is undergoing soil improvement by dynamic compaction. The grid pattern on which weight is dropped and the need for like you have this for so, what you have? You prepare a grid pattern and one by one you drop this weight, and this weight will be densified that part. The kinetic energy of the weight at impact produces stress waves that travel through the soil. The total energy delivered to the soil is a function of the weight. Naturally it will be weight and height from where it drops then it will also depend on the grade spacing and number of drops if you increase the number of drops naturally this energy which is delivered will increase.

When the groundwater table is near the surface placement of gravel or sand blanket may be required prior to compaction. Although dynamic compaction has been used successfully for cohesive soils, its most common use for mitigation of seismic hazards for potentially liquefiable soils. So, this is also used for the dynamic compaction and has been used for cohesive soils also. Starting to continue with this at each grid point a series of drops causes the pore water pressure to increase.

So, the soil particles can move into a denser configuration. Decapitation of the excess pore pressure results in further densification within a short period that could be 1 to 2 days for sand and gravels or even it could be 1 to 2 weeks for sandy cells after the treatment. Dynamic compaction is generally effective up to the depth of 9 to 12 meter although extremely high impact energies may produce densification which could be at greater depth. Because the process is rather intrusive in case it produce the dynamic compaction can produce considerable noise, dust, flying debris and vibration it is rarely used near occupied or vibration sensitive structures. So, suppose if you have already like you know residential area or you have where already the construction has been done then this technique may not be near the existing building or structures it cannot be used because it will be creating lot of noise, dust and then it may produce vibrations which may have even the cracks in the nearby buildings and others.

So, it need to be used carefully. So, with this dynamic compaction is over. So, we have discussed vibro techniques and dynamic compaction techniques which is a part of densification of the soil. We will continue with the third and fourth techniques for the densification. Thank you very much for your kind attention. Thank you.