Earthquake Geotechnical Engineering

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Lecture 59

Ground Improvement Techniques: Reinforced Fibers

I welcome you all again for this NPTEL online lecture on earthquake geotechnical engineering. We are at the second last lecture of this course that is lecture number 59 and we are at the last module that is on ground improvement techniques. In fact, we have already discussed three chapters on this ground improvement techniques, the types of ground improvement techniques, ground improvement using geosynthetics and in the last lecture we talk about vertical drains. Today we are going to talk about ground improvement using reinforced soils. Though partly it is covered already in when we discuss the first chapter that is types of ground improvement techniques. But today we are going to discuss at least two case studies and which has been done at IIT Roorkee.

So coming to ground improvement using reinforced soils, first when we talk about the reinforcement of the soils, there could be many like you know that one way we could be using fiber reinforced, then other ways could be there like for geogrids or maybe like you have geosynthetics also. So, what we are going to discuss this lecture in three parts, one is fiber reinforced soils that is synthetic fibers and natural fibers we are going to discuss, which will be discussed from the reference like taken from the book by Swami Saran that is title is reinforced soil and engineering application that is the first part of this lecture. Then the second part we are going to discuss a case study on reinforced soil and finally, case study on stones and columns. So, this lecture is totally in three parts, three components.

Let us start from the first component which is fiber reinforced soils. So, let introduction about fiber reinforced soils like fibers could be what we called the it is said to be more effective when they are randomly distributed. So, randomly distributed fibers in soils among the latest technique in which fibers of desired type and quantity are added in the soil, mixed and laid in position. So, fibers are mixed in this one. The method of preparation is quite similar to conventional stabilization techniques.

So, here what you are doing you are mixing the fibers inside the soils. Experimental work has been done by various investigators and it has been established that addition fiber in soil improve the overall engineering performance. So, there is no doubt about that if you add the fibers in the soil they will improve its engineering performance and notable properties

which improves are greater extensibility that means, its durability of will increase basically extensibility that ductility will increase. Then you have a small loss of peak strength, isotropy in strength that means, in all the directions this strength will be kind of similar and then absence of planes of weakness. So, these are the plus points when you add the fibers to the soil.

Now coming to the fibers can be classified in two categories one is called natural fibers which could be like you know coconut or typically also called coir fiber. Then you have sisal which is also like you know in the fiber which is like small cuttings and then you have jute, cotton, wool, bamboo and banana fiber. So, these are all comes under the category of natural fibers because they are naturally available from the trees and then you have synthetic fiber which is you can say kind of a manmade fibers or made from chemicals. So, you have asbestos, nylon, plastic, polyester, polyamide, polypropylene, rubber, metallic and glass fibers and there could be more. So, many varieties are there for natural fibers as well as synthetic fibers.

Now when you have effect of fiber reinforced soils are similar to what we say geosynthetics reinforced soil for both coarse grained and fine grained soils where it helps to increase the bearing capacity and soil strength. So, like the fiber's addition of fibers inside the soil will help you to increase in the bearing capacity as well as its strength will increase. The synthetic fibers are generally preferred than the natural fibers because of their higher strength and resistance also show a great biological resistance. So, if though synthetic fibers may be bit expensive compared to the natural fibers, natural fibers are mostly those kinds of fibers which are kind of a waste and it is waste to wealth. So, it can be used, but synthetic fibers have the advantage because they are high strength and resistance. For example, fibers like propylene, polypropylene are resistant to acidic alkaline and chemical attacks. Further these fibers have tensile strength resistant to sea water and have high melting point that could be as high as 165 degrees centigrade. So, like if temperature is high no problem. Polyamide has inherent defect of getting affected by the ultraviolet rays from sun, but because fibers are normally embedded inside the soil. So, the sun rays they are not may be affected by the sun, sun rays they are not may be affected.

Then polypropylene fibers are made of crystalline and non-crystalline regions though prone to fire and sunlight, but practically cannot reach into the soil. Again, these fibers like if like they are exposed to you know the fire or sunlight then they are they may not work, but because the when you mix inside the soil. So, the that fire and sunlight may not be an issue. The important properties are like versatility, excellent chemical resistance, low density, high melting point we already discussed about these. All these makes fiber important to construction applications.

Continue with these synthetic fibers, fiber spinning and drying may result in crystalline regions. The degree of crystallinity of polypropylene fibers is generally between 50 to 65

percent which is depending on the processing conditions how it is processed. In a case study polypropylene fibers were tested in 8 different media and those medias are including distilled water, iron, bacteria, culture, sea water and soil for 17 months and found no degradation. So, these that means, they are resistant to degradation even if media in which the fibers are like how could be like different types of media not necessarily distilled water, it could be a bacterial water, culture, sea waters, sea water which is normally water or like salty water. Further results showed that there was no change in the tensile strength or plastic fibers show loss in strength with temperature.

So, as for polypropylene is concerned, they are good, but plastic fibers may decrease their strength. As for nylon is concerned, nylon is comparable with polypropylene as far as strength chemical in and dense durability is concerned. Then you have steel fibers are prone to rust and acids. So, that is the issue that there could be rusting. Then glass fiber though costly, but they can be a temperature up to 150 degrees centigrade.

So, the thick glass may go up to higher temperature. Then you have asbestos glass carbon fibers have been found to be resistant to alkyne and other chemical attacks, but asbestos fibers have been found to lead to corrosion damage. So, when we talk about asbestos from fibers the similar issue which is maybe the steel fibers there could be issue related to corrosion. Now coming to the natural fibers, the various types of natural fibers available in our country are coir which is basically coconut fibers which is a kind of a waste and it is plenty evidently available particularly in South India. Then you have jute, cotton, wool, sisal, bamber, hemp, munja which is again kind of a jute, bamboo and banana.

So, many like you know that this is basically coming from the west of the trees and these natural fibers are good point are that like the coast is there very economical. Because many times rather like you know the using those natural fibers are good because it is kind of a in many cases it is completely waste and if this waste can be used to increase the strength of the soil, so that is better. In order to minimize the cost locally available fiber should be considered in design rather than otherwise the due to the transportation cost will increase, but at the same time stability and life of a structure should be given prime importance. Many of these fibers have been tested and found to lose their strength when subjected to alternate wearing and drying environment. In view of the low strength and lack of durability natural fibers are not widely used for reinforcement, but are preferred for example erosion control or maybe in the pavement design due to their environment friendliness and biodegradability.

Here some natural fibers like coir fibers are too strong and durable, so durability is not an issue. They can be made suitable with proper treatment for reinforcement in cohesion less soils and also as filter fabric in cohesive soils. Natural fibers have poor resistance to alkyne environment. So in fact, one of the natural fibers which is using let us say coir fiber or from coconut one case study we are going to discuss in the next slides where that and it was very

good excellent like work particularly for liquefaction mitigation. Almost all natural fibers get damaged and lose their strength in 24 hours after given 0.1 Newton and solution of sodium hydroxide. The only exception to this is coir. So the coir does not have this problem. They are even resistant to biodegradable over long period of time. It has been shown that breaking strength of coir fiber after 15 years of storage in a hangar comes down from only 165 MPa to 160 MPa.

So that means the strength is there is not much change in the strength and elongation is also not much reduced. It is reduced 29 percent to 21 percent, but in a long period of 15 years. It shows that coir fibers become slightly brittle when with the time, but are best among all natural fibers. So when we talk about to increase the strength if the coir fibers is considered to be the best one among the all the natural fibers. Now as I mentioned that we are going to discuss two case study.

One is case study using on reinforced soils, another is using stone sand columns and the objective of both the case studies has been for mitigation of liquefaction that means to increase the liquefaction resistance of the soil. The first case study has been taken from a published paper in ASCE where like one of my peers and Mr. H.P Singh work and with Professor Swami Saran also. The title of paper is effect of reinforcement on liquefaction resistance of solanisand.

And it has been published in Journal of Geotechnical and Geoenvironmental Engineering of ASCE in 2012. Coming to this case study, a number of studies like background is such that a number of studies have been already conducted to examine the behavior of soil reinforced with randomly ratio fibers under static loading conditions. So, most of the studies prior studies before that most was only for the static condition. For the studies on behavior of soils reinforced with randomly distributed elements under cyclic loadings are very limited. So, what has been here? The results of experiments conducted on a shake table in IIT Roorkee for sand reinforced with geogrid sheets, synthetic fibers and coir fibers are discussed.

So, three types of reinforcement has been used geogrid sheet, synthetic fiber and coir fiber. So, this is a case study like reinforced soils. So, this is geogrid sheet. The first of all the sand which is used in this case study has been collected from the bed of the Solani River. Solani River is near Roorkee and it is from the campus of IIT Roorkee hardly it is one one about 1 and 1.5 kilometer away. Three types of reinforcement were used in the case study. The first one the biaxial geogrid sheets of a particular product that is Nelton 121 CE type with a wall thickness, thickness of the this geogrid sheet is about 4 mm and aperture size is 400 mm square that is 20 into 20 mm. So, it is kind of you can say square like kind of aperture with the dimension 20 mm into 20 mm. And the total dimension of geogrid sheet is the dimension of the plan area of the shake table which I will be showing you later.

The second material used is locally available brown coir fibers of random length which is varying from 50 to 150 mm in length. So, length is quite variable. It is and an average diameter is of 0.4 mm were used. So, diameter is also not constant but average diameter is there but there is large variation in the length of these fibers.

Though the coir fibers are biodegradable and may last only for about 2 to 3 years, however, the durability can be improved by coating these fibers with phenol and bitumen. The third reinforcing material used is a fabricated polypropylene type of synthetic fiber with a length of 40 mm was also used for reinforcement to the sand. What has been done the first reinforcement using geogrids has been done in three patterns because geogrids are used in layers. So, in this case what has been done you have three layers in the first case three layers of geogrids are used, in the second case four layers has been used and in the third case five layers has been used. The distance between two geogrids is constant like it is 190 mm in the first case 140 mm and 114 mm in the third case.

So, that means kind of a uniform you have similar uniform pattern here and in this case the arrangement shows for different layers three layers four layers and five layers. The test was performed on a shake table which is here given here shake table used in this study. The dimension of this set this is a basically it watertight tank. Length of the shake table or this tank is 1.05 meter long in the length direction and width is 0.6 meter and height is 0.60 meter. In this soil sample is prepared at 25 percent relative density. So, the relative density of the solanine sand which is used inside this shake table is 25 percent. Desired level of frequency 5 hertz and amplitude which is varying from 0.1 to 0.4 g of excitation was fixed. The duration of second for each test was kept as 40 seconds at a frequency of excitation 5 hertz. Therefore, the total number of cycles was 200 for all test. So, you have 5 hertz is the frequency and 40 seconds is the like total duration. So, because 5 cycles per second, so total number of cycles for the loading which we applied is 200 seconds 200 cycles for all the test. So, this is the shake table used in the study which is in the department like in the soil dynamics laboratory of department of earthquake engineering at IIT Roorkee.

So, in this case what you could see this is a watertight tank as and inside this tank the saturated solanine sand is filled up and then you also place the whatever the reinforcement is done. There are 3 pickups here to measure the pore water pressure using at the time because it was into a long back this studies man done about 15 years back and public. So, in this case what is done you have 3 locations of piezometers and in this piezometer, you use what you do you measure the pore water pressure. And for the measurement of this pore water pressure this bottom this is middle and the top piezometers. So, what is done here in this case these are the results of the measurement of pore water pressure at 3 different locations.

Locations is top point, middle point and bottom point. Top point is that this one this will be treated as a top point T, this is middle point M and the last one will be bottom point.

So, 3 points are there. Now in this case there are 4 results shown here which is different acceleration of excitation. What you do in the shake table you can control the frequency of excitation as well as amplitude.

So, frequency we already said for all the test frequency is constant which is 5 hertz frequency is not varying, but the amplitude of excitation varies from 0.1 to 0.4 g. So, 0.1, 0.2, 0.3, 0.4 are there. So, these are the results A, B, C, D for 0.1 g, 0.2 g, 0.3 g and 0.4 g and this has been from our laboratory. And in this case what you see the pore water pressure versus time. So, in all the results what you see the pore water pressure reach the peak value you are giving shaking, your shaking is only for 40 seconds. So, your 40 seconds will be somewhere here and after 40 seconds you stop the shaking. So, what will happen during the shaking you will get a peak value where you get the maximum value of pore water pressure and after that it get dissipated and then it becomes 0 and your shaking is also stopped at somewhere at 40 seconds then your pore water pressure which is u, u is nothing but you can say excess pore water pressure. This thing we already discussed in many other last lectures.

So, the excess pore water pressure is of pore water pressure which is generated due to the shaking. Now, in this case there are three curves that this is for the dot line top point, this is for middle point and the bottom point. Naturally this excess pore water pressure which will be developed will be minimum at the top and maximum at the bottom. However, because effective overburden pressure is also high at the bottom point. So, what is you find the value for R u, what is R u? R u is nothing but in this case which is R u is u excess pore water pressure divided by effective overburden pressure at a particular depth and effective overburden pressure also increase with the depth.

So, the value of R u the maximum value of R u is listed here which is more or less same it all the three because 0.911, 0.89. So, similarly this was at 0.1, this is 0.2, 0.3 and 0.4 these are the result. Now, this was for the pure sand that means without any reinforcement. Now, what has been done like a case study has been done for three cases of geogrid layers, one is when you use three layers, four layers and five layers. So, because for the any analysis the peak values is important rather than the distribution.

So, we will what we will do in the next results we will examine what happens to these peak values when you put the geogrid. So, you see that the peak values have come down from 0.99 to like 0.66, then 1 to 0.77 and the 0.89 to 0.81. And another thing that the maximum value of R u max is at the top and minimum is at the bottom. This is happening this kind of sequence not only for three layers, four layers and five layers. So, the similar sequence is there. So, the effect of putting the reinforcement is similar. However, when the number of geogrid sheets are increased, what do you get the value of R u max are continuously decreasing.

So, here the initial value was 0.89 from 0.89 to it become 0.81, then 0.74 and then finally 0.72 at the bottom at the top piezometers. So, this is the effect of the geogrid reinforcement. So, that means, if you have a greater number of geogrid sheets, then it is better.

So, in that case if you have five layers of geogrid sheets, then the value of R u max decreases to 72 percent only. This was about geogrid sheet, and these are the results with the coir fiber. In case of coir fiber, it is the percentage by dry weight that has been used.

So, it is 0.25 percent of coir fiber, 0.5, 0.75. So, it was very difficult to mix the coir fiber more than 0.75 percent inside the soil and this is with the weight. So, weight is you know that weight it is lightweight coir fiber is very lightweight. So, even when you have less than 1 percent, its volume is quite high compared to because soil is heavy in the weight. So, what happens when you mix the coir fiber, you could see that the value of R u max is decreasing 0.29, 0.27 and if you use 0.75 percent, it is only left 10 percent. So, the initial value of 0.89. So, initial value you should compare all the values with 0.89. So, it can be observed that coir fiber is more effective than geogrid sheet, even if you use 0.25 percent itself. So, it reduced to 0.29 only. Then the third case, when you use synthetic fibers instead of coir fibers, then the results are shown here that is the value of R u max is goes to 0.77, 0.26 and 0.14. So, these all like here again in synthetic fibers, 3 cases 0.25 percent, 0.5 percent and 0.75 percent are used. So, all these results, 3 cases or rather 4 cases, 1 for first case is pure sand and 3 cases with the reinforcement, first is geogrid sheet, synthetic fibers and coir fibers.

If you compare, you can see the percentage increase in resistance. How you calculate the percentage increase in resistance? You calculate the value of R u. So, R u will decrease. So, the original value of R u minus the decrease value difference and then divide by the like R u max of the original value. So, that will give you the percentage increase in liquid resistance. So basically, percentage increase in resistance you can say percentage decrease in the value of R u.

So, you can put like this one, this is calculated percentage decrease in value of R u. So, R u decreases means the resistance will increase. So, you could see that maximum increase in resistance are coming with coir fiber, if you have 0.75 percent, your resistance increase 91 percent for 0.1 g and for 55 percent for 0.4 g. The result shown in the figures was only for 0.1 g, but here this table is complete where 0.1 g, 0.2 g, 0.3 g, 0.4 g. So, that means the coir fiber is effective not only increasing in liquid resistance at 0.

1 g, but it is also effective at 0.2 g, 0.3 g and 0.4 g. And the percentage increase is quite significant compared to. So, out of these geogrid sheets was like less effective, which is maximum 31 percent even for 5 layers and synthetic fiber 88 percent. So, synthetic fibers and coir fibers are you know kind of comparable, the effect is comparable. However, synthetic fibers are costly compared to the coir fiber. So, the coir fiber was very effective

and that is why this like you know and this was kind of innovation which is published in ASC paper.

The use of synthetic or coir fiber is a better choice as we discussed than geogrid sheet for the substantial increase in the liquid resistance of sand. The coir fibers gives higher liquid resistance value than that of synthetic fibers for all acceleration levels and fiber contents.

So, this is for all four acceleration level 0.1 g, 0.2 g, 0.3 g, it is happening not only one acceleration level rather at all levels. The coir and synthetic fibers are two distinct reinforcing materials with different textures. The coir fiber used were of random lengths varying from 50 to 150 mm. So, the length of the coir fiber was not constant rather it was varying, where is the length of the synthetic fiber was almost average length was 40 mm constant. So, the because length of the coir fiber was varying that also help rather than uniform length of coir fiber the length was varying.

So, it was better in mitigating. So, it was better to increase the liquid resistance. The shear strength parameter of coir fiber reinforced sand was greater than that of the synthetic fibers and the reinforced sand for identical fiber content. Thus performance of the sand reinforced was expected to be better than the sand reinforced with synthetic fibers. In addition coir fiber is locally available and cheaper than synthetic fiber and is geogrid sheet therefore, coir fiber is most effective among three reinforcing materials considered. First of all the effectiveness of coir fiber was better compared to synthetic fiber and far better than the geogrid sheets.

Then second, they are locally available and third they are economical. So, that is why it was going in the this the fear of coir fiber. So, the proposed ground improvement method can be used in many field applications. For example, the proposed technique may be useful and cost effective in the constructions of roads, embankments, dams and low rise residential buildings. For the construction of roads, the properties of the subgrade may be improved significantly by mixing available soil with fibers especially in the way the soil is expected to be saturated at a later stage. So, this coir fiber at least can be directly used in case of increasing the strength for the pavement design.

So, that was the kind of recommendation coming out of it. But one of the issue was that these coir fibers could be biodegradable. So, that comment have come in the like you know journal paper also. But like their strength can be increased by coating them with this like for example, using bitumen and other things. Similarly this can be done easily for when you are using it for the road construction. So, this was the case study using synthetic and as well as natural fibers and with the pure sand as, so it help you to increase the liquid resistance of the pure sand.

Now, another case study has been done by sing et al. and it has been published in International Journal of Geotechnical Engineering and the publication have come long

back in 2010 about 13 years back. The title is improvement in liquid resistance of pond ash using stone sand columns. Here the objective was to improve the strength not only the sand but rather it is objective was to increase pond ash. So, you know the pond ash is a kind of a waste, pond ash is a sometimes it is also called fly ash. So, the ash which is coming out of the thermal power plants, and which is in the dumps and like you know their shear strength is very weak.

So, the challenge was how to improve their soil property and in fact, we got a live industrial project for related to that in department and which was from the like Anpara site. So, aim of this paper is to demonstrate improvement between liquid resistance of the pond ash which is also called fly ash due to its strengthening with stone sand columns. And here what has been used for strengthening, stone sand columns has been used. Stone sand columns we discussed when we talk about the first chapter of this module that is different types of ground improvement technique. So, the stone column it is kind of reinforcement technique, it is one of the reinforcement technique, stone sand columns as well as the second technique was the granular piles.

Test were carried out on a shake table. Again the test was conducted on a shake table to relate the liquefaction resistance of the pond ash without and with stone sand columns. So, the test has been conducted without and then with also. The proposed techniques of improvement is simple and has very much practical significance. Experiments set up used in this technique is same as discussed in the previous case study that is the shake same shake table has been used. The pond ash which is used in this test were collected from the site of Anpara D thermal power plant and this Anpara D is near Varanasi in Uttar Pradesh like it is in the eastern part of the Uttar Pradesh near like between.

So, when you go away from the Varanasi there is a district called River sganj and so it is coming, and this power plant was from NTPC thermal power plant in that site. All the tests were performed keeping the relative density of pond ash as a 20 percent. For the preparation of the pond ash sample with stones and columns the mild steel, hollow open ended pipes, the mild steel pipes and both sides it is hollow as well as open ended both sides. The size of the pile pipe was 750 mm long, that is 0.75 meter and the 50 mm was the diameter of the pipe were inserted at the desired locations in inside the shake table.

The bottom end of the pipes were plugged with a detachable wooden cones while inserting in the tank. Now, so you what you do a number of pipes are installed inside the shake table in the tank. First you put the basically your soil fly ash and then you install these pipes. These pipes were filled with a mixture of stone chips and what are the stone chips? 10 mm downsize that means the size of the gravel should be less than 10 mm and fine sand. So, it is a mixture of fine sand and gravels where size of the gravel is less than 10 mm. In proportion of 2 to 1 so that means you have the 2 times quantity of gravels and one quantity you take for the sand, and this is by weight and mix thoroughly in a mixture in 5 layers.

Each layer was given 25 blows on the using the 2.5 kg hammer which is dropped from a height of 450 mm. So, you have a hammer which will be dropped from so much height and the weight of the hammer is 2.5 kg and this is for compacting. After each layer was compacted the pipe was withdrawn by the same amount thus finally whole pipe was withdrawn. The center to center spacing between pipes was kept 4D.

What is D here? D is the diameter of the pipe or 3D where D is the inner diameter of the pipes. The tests were performed at an acceleration of 0.3 g and a frequency of 5 hertz. The shake shaking was imparted for 60 seconds. So, you have total number of cycles n number of cycles n will be basically your f into t time f is 5 hertz 5 cycles per second time is 60 seconds.

So, in this case total shaking given is for 300 cycles. The excess pore pressure were recorded at the interval of 10 seconds till these completely dissipation. So, the results are presented in a similar way as we discussed when we talk about for the Solani sand in the last case study. This is the arrangement shown for the stone sand columns like you have stone sand columns. So, in this case as the total length of the tank is 105, 10, 1.06 or roughly 1050 in millimeter all the dimensions are in millimeter. Here the center to center spacing is 200 mm in this side both the directions. So, you have 3 rows of stone sand columns, in each rows you have 4, 5. So, all together you have how many stones and columns your total 15 stones and columns here.

So, number of columns in this case is 15 columns 15. If I decrease the spacing that is instead of 4D it is 3D. So, instead of 200 mm D is diameter D is the diameter which is 50 mm given to you. So, diameter is again kept 50 mm and if you keep the spacing 3D. So, it will be 150, but now in one row you have 7 columns and 4 rows. So, number of columns will increase columns will be here in this case 28.

So, the fifth here you the size of the column is same. So, only 15 columns are used while here 28 columns are will you are used. So, now the see the effect what the effect is of the when you increase the number of columns what is the effect on the results we are going to see it. So, this is the excess pore water pressure with the time for pond ash without the stones and columns that is pure sand. This result is for pure sand that means no pure fly ash for pond ash.

So, you could see this at the top point you get the maximum pore water pressure R u max 0.71 0.68, 0.69. So, we are interested in the maximum value.

So, R u max is 0.71 and when you install stone columns with 4D spacing, then this value 0.71 come down to 0.53. If the spacing is reduced to 3D, then it have come down to simply 0.017 even not like 0.02. So, that means it is not even less than 2%. So, if I convert into percentage, this is 71%, this is 53% and this is 1.7%. So, that means the when you increase the spacing though your number of columns stones and columns are increasing, but it is

very effective, and the liquefaction resistance increase drastically where the value of R u max have come down to 1.7% which was the initially 71%.

So, that means this stones and columns are very much effective. So, this what is the conclusion of this study. The liquefaction resistance of pond ash increases due to addition of stones and columns. In case of 4D spacing the average increase in liquefaction resistance was about 22%. If the spacing is decreased from 4D center to center to 3D, the liquefaction increases tremendously and average is about 92%, the effectiveness is 92%. Proposed investment improvement technique is very simple and can be effectively applied to the instip pond ash without any complication of mixing, compacting, placing etc as required in others. So, this was in fact we have suggested to use this technique at Anpara because they want to improve the ground before they are putting their plant and in fact what we suggested they should improve the ground using the stones and columns number one and then second thing they should use pile foundations for the like particular their heavy structures.

The structures are like you know the power plant which are very heavy should be you put for their foundation first ground should be improved and then pile foundation should be used. So, both like ground improvement technique as well as alternative types of foundation was suggested for their construction. So, this was about two case studies and in general about like geosynthetic and natural like fiber reinforced soils or in general reinforced soils. So, thank you very much for your kind attention. Thank you.