Earthquake Geotechnical Engineering

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Lecture 60

Ground Improvement Techniques: Verification and IS Code

I welcome you all for this NPTEL online lecture on Earthquake Geotechnical Engineering. And this is the last lecture that is lecture number 60 on this course. What we are going to talk is the some part of ground improvement techniques which is verification and IS code. So, in the as we discussed the 6th module of the course which is on ground improvement techniques and all those listed here in the black color has been already over. In the last lecture today, we are going to talk in two chapters, one is verification of soil improvement and once it is over, then we also going to talk about bit about IS 1893 part 1, 2016 particularly what are the given things in that code related to soil. So, let us talk what are going to talk is the verification of soil improvement first that is a chapter number 5 for this module.

In this chapter what topics to be covered that is first verification of soil improvement which can be done either using laboratory testing techniques, in-situ testing techniques, geophysical testing techniques and then we are also going to have the other considerations and the information for verification and other consideration has been taken from the book by Kramer which is on Geotechnical Earthquake Engineering, another reference and this is gratefully acknowledged. Coming to the verification of soil improvement, all the terms done to improve the soil should be checked to confirm that the desired improvement has taken place or not. So, we have a number of techniques for soil improvement, but it is always not only desirable, but it is also must that once you improve the soil, then you need to again confirm whether the improvement which you have made is enough or not. Many times there could be improvement in this like shear strength and other things, but that may be enough or may not be enough for the given requirements.

So, it is must to check. The most direct way of verifying the effectiveness of a particular soil improvement technique is to measure the soil characteristic that was considered deficient both before and after improvement. So, there could be some soil characteristics which was weak. For example, you may require soil improvement for some specific purpose. For example, shear strength could be weak or there could be more development of pore water pressure.

So, what we need to do in this verification, you check on one side there is a condition where you have the soil or let us say like the strata which is without ground improvement. Then again, you improve the site and check again if there is a sufficient difference, then you can say yes, soil has been improved. For example, if the improvement was undertaken to increase the strength of the soil, measurement of the strength before and after improvement would provide the most direct verification of the effectiveness of the improvement process. However, it is not always possible to measure the deficient characteristic directly. In such cases, verification usually accomplished using related characteristics that are more easily measured, but that is you can say indirect method.

Verification may be based on the results of laboratory or field test. In many situations, a laboratory test have been commonly used for verification of soil improvement. Field testing techniques may be divided into institute testing techniques and geophysical testing techniques. So, for the verification, you could use what you call the field testing techniques, which could be in two categories institute testing techniques which is mostly geotechnical engineering, and another is geophysical. So, first of all, we have two categories, one is using laboratory test, another is field test.

Coming to the laboratory testing techniques, laboratory testing techniques have a number of advantages over other methods for verification of soil improvement. So, they have a number of advantages compared to institute testing techniques, but at the same time, they also have some certain drawbacks that can significantly limit their usefulness for certain types of soil improvement. The requirements of obtaining a sample, if you are wanting to like you know test in the laboratory, naturally first of all, there will be requirement of sample, sample need to be collected from the field. And the collection of the sample from the field, it could be advantage for many of the laboratory testing or it could be even disadvantage also. So, it goes in the favor as well as in favor which we are going to discuss later.

Obtaining a sample of improved soil allows visual inspection of the effects of improvement. So, first of all, the like you know that the good point that like if you collect the sample of the improved soil, so what do you do? You collect a sample from the site which is not improved and another which is improved and that test in the laboratory. So, while you can have the visual inspection, the good point once you collect the sample, you can there find their index properties, you can have visual inspection also and then test and then compare. So, the disadvantage is there that this how good this sample is representing the field condition, how it is representative. It is okay when you have undisturbed sample particular for cohesive soils, but for cohesionless or sandy soils, it is difficult to get the undisturbed sample.

Laboratory test allows greater control and more accurate measurement of stress, strain and environmental control conditions than that are possible in field test. So, this is the advantage that means you can control many of the parameters which you cannot control in the field. That means a parametric study can also be conducted in the laboratory, but that is in the field whatever condition is there, you need to test in the accordingly. In some cases, this flexibility may allow more accurate characterization of the properties of the improved soil. On the other hand, laboratory tests only provide verification of discrete points because in laboratory test what you do collect? You collect a small sample which is tested in the laboratory.

Now, there is a problem that how this small sample which you are testing in the laboratory represent the actual condition on the ground. So, when soil improvement is used to improve or eliminate localized zones or seams of weakness verification by methods that require discrete sampling may be ineffective. Laboratory test may also be influenced by the inevitable effects of sample disturbance, a problem that is particularly significant in the improvement of liquefiable soils. So, the density changes produced by even thin walled samples can lead to considerable uncertainty in the evaluation of improvement effectiveness. So, what you are, we want to judge in the lab whether yours the conditions which you have at the field is effective or not.

In that case, first thing is that the sample which you are testing in the laboratory, how good it is representing the field conditions. So, that is also the issue. So, many of the disadvantage of the laboratory test goes in the favor of field test or we called in-situ testing technique. So, here verification effectiveness may be overcome by the use of in-situ test. Therefore, the use of in-situ test for verification of soil improvement effectiveness has increased dramatically in the past 7 decades.

So, in like many decades now, the in-situ test or field test are preferred than the laboratory test because they are the highest test. Because many geotechnical seismic hazards are evaluated using in-situ test parameters, those parameters can provide direct evidence of hazard mitigation. And in in-situ test, what are the different tests? Most popular is SPT that is Standard Penetration Test. And you have Cone concentration test, CPT. Pressure meter test that is called PMT in the short can also be used for verification soil improvement and effectiveness.

The SPT and CPT tests are performed relatively quickly and inexpensively compared to sampling and laboratory testing. The CPT is useful because it provides a continuous record with a depth. The PMT is more expensive, but it also allows measurement of lateral stresses and direct measurement of strength. So, like compared to SPT and CPT, PMT is expensive, but it is providing the measurement of lateral stresses in better way. Interpretation of soil improvement effectiveness from in-situ test results must be performed carefully.

Penetration resistance of granular soil for example, is influenced not only by density and overburden stress, but also by lateral stress. So, in fact, you may know that in SPT, the corrections are applied for what we call the overburden pressure and then also correction is also applied for dilation, dilatancy which is for the particular for saturated sand when the fines and seals are there in the and when the n values is greater than 15. Soil improvement techniques that result in increased lateral stress may produce in unconservative estimates of the density of the improved soil if the post improvement stress state is not carefully considered in the interpretation of penetration test results. So, we need to consider the stress conditions also while interpreting these results. Because time dependent changes in strength, stiffness and penetration resistance are often observed after densification.

That means with the time actually like today you may have different condition of the field, after few days it could be different condition. So therefore, in-situ test perform immediately after densification may not reflect the actual degree of improvement of the soil. So here, verification testing is usually performed at least 72 hours after densification is done. Because you have done some, let us say densification at the site. Now this densification to be effective some minimum time is required, and it is suggested at least wait for 72 hours because after like time passes, the densification might be effective.

So, as a result, first of all minimum times recommended is 72 hours, there is 3 days and another thing that this could be the densification should be with respect to time, how long it has passed since the improvement has been made. So, many of the soil improvement techniques are applied at a grid of treatment points and the degree of improvement usually decreases with the resistance from the treatment plant. This is particular for densification. When you do the densification, you do in the grid pattern. You apply load here densified and another point.

So, naturally the densification will be more effective near where you are doing the treatment. So, as you go away from the point of the treatment, then this effectiveness will decrease. The relationship between the location of the institute test and the location of treatment points should be considered in the interpretation of soil improvement effectiveness from the institute test. So, particularly these tests will have limited effectiveness if you want to verify the grouting effectiveness. So, the two points to check, one is the time which is elapsed after the improvement and the second thing is the distance that is location of your testing site with respect to the point where the improvement has been done should need to be considered while we use the institute testing technique.

Now another category that is the third category, we discuss about laboratory test, then institute test and the third one is called geophysical testing techniques where geophysical equipment like methods are used. And what is geophysical methods? We already discussed when we discussed dynamic soil properties in very much detail. Many soil improvement techniques increase the stiffness of the treated soil. The effectiveness of these techniques can be verified using seismic geophysical techniques. In most cases, it is desirable to perform seismic tests both before and after improvement.

So, the same test need to be performed, what was the condition before the improvement and what was the condition after the improvement. For example, some of the test which is used is called cross-hole and down-hole and when we talk about this cross-hole and down-hole test including seismic cones, we already discussed in detail about this test when we discuss the ground, the dynamic soil property. They are most commonly used for verification of soil improvement using these P or S wave velocities which is like you know that you have seismic reflection test, seismic reflection test also come in this category, then you have SASW or MASW test. So, using the P or S wave velocity which is Bode waves can be measured over considerable distance thereby providing stiffness measurement. However, each require at least one borehole.

When you use the cross borehole, at least one borehole will be required in up-hole and down-hole. So, overall minimum two boreholes are required which we also discussed earlier. For sites where soil improvement has been performed over a large area, seismic reflection and seismic reflection test may be useful for verification purpose. So, if you want to have on the large area, then two test which we have discussed, seismic reflection and seismic reflection, both test has been discussed when we talk about dynamic soil property and they could be useful for verification purpose. Then there could be SASW, Spectral Analysis of Surface Wave and the most popular version of SASW is called MASW that is Multi-Channel Analysis of Surface Wave.

This provides similar information without the need for the boreholes. So, the good point with the geophysical techniques are there that you do not require the like you know borehole except in the cross borehole test. So, for cross hole you require the borehole, but for seismic reflection and seismic reflection or SASW test, borehole is not required. At sites where stiffness changes irregularly in two or three dimensions, the result of SASW may be very difficult to interpret. Such test may also perform when background noise will not adversely affect their results.

So, while conducting SASW test, if it is isotropic condition, fine, but if your strength are varying not only in one direction, let us say along X direction, along Y direction, of course, it varies along the depth. In that case, it is difficult to interpret their results. Now this was about ground like very friction of ground improvement techniques. There are other considerations also which need to be discussed. So, what is in the other consideration? The application of soil improvement techniques to the mitigation of seismic hazard particularly against liquefaction is increasing.

So, that is the technique which you use, and the techniques are used for mitigation of seismic hazard. For example, the threshold underpinning of many soil improvement techniques are poorly developed and empirical observation of the performance of improved soil in actual earthquakes are rare. Because of these factors, it is particularly important to review the relevant geotechnical engineering literature before attempting to mitigate seismic hazard by soil improvement. So, using the soil improvement your objective is to mitigate the seismic hazard, but what type of seismic hazard you want to mitigate, then relevant the literature should be quoted. For example, one of the seismic hazard which is like you know use for and we do for seismic hazard is liquefaction and your objective when you improve the soil, your objective is not only increase simply increase the shear strength, but one of the objective in many cases is to mitigate liquefaction or you can say to increase the liquefaction resistance of the soil.

The effectiveness of many soil improvement techniques can be difficult to predict in advance for a particular site. Furthermore, the equipment, procedure, experience and skill of the soil improvement contractor can strongly influence the soil improvement effectiveness. So, here this is the issue. First of all, sometime it is difficult to predict in advance before you do actual soil improvement. The second thing and it depends like also what type of equipments are used, what type of procedure, what type of experience and skill development.

For these reasons, it is frequently beneficial to construct test sections before beginning production work or even before final selection of a soil improvement technique. Track sections allow site and protective specific evaluation of soil improvement at a moderate cost. Their use is advisable wherever, whenever possible. So, now coming to here, like this was what we have discussed in the first part of the chapter number 5, we talk about verification of the soil improvement techniques and other considerations. Now, the last chapter of this module 6, that is chapter 6 on IS 1893 part 1, 2016 and this is the last topic which I am going to discuss related to this code.

And the reference for this is code which is titled as a criteria for earthquake resistant design of structures that is part 1, general provisions and buildings and like published by Bureau of Indian standards, New Delhi. And this is you know, many of you already may be aware that is this map, this map, what this map is saying, this map is nothing but seismic micro zonation, this shows seismic zonation for our country and published in 2016. For the purpose of determining design's seismic force, the country is classified into 4 seismic zones and these zones are different colors like orange color is zone 5. So, you could see our the whole of the northeast area, all the 7 states come under zone 5.

Then Andaman, Nicobar Islands are in zone 5. Then you have different pockets in the country and these there are 5 pockets, one is in Bihar which is near Dharbanga. Then you have in Almora and the Pithoragarh region in case of Uttarakhand that is the eastern which is the parts of the Uttarakhand state which share the border with the Nepal. Then if you go in the in case of Himachal Pradesh, Mandi for example, IIT Mandi is in seismic zone 5.

Then the capital of J and K which is Srinagar is also in zone 5. Then the Kutch region of the where the Bhuj is located, where Bhuj earthquake occurred is also in zone 5.

So, 1, 2, 3, 4, 5 pockets beside the northeast in comes in seismic zone 5 and whole of the Himalayan region that is including starting from Ladakh, J and K, Himachal Pradesh, parts of the Punjab, then Himachal Pradesh, then you have Uttar Pradesh, parts of the Uttar Pradesh and then Sikkim, Bihar. So, all these Himalayan belt falls in seismic zone 4. So, whole of the Himalayan region either will falls in seismic zone 5 or seismic zone 4. So, whenever you like and that is why a lot of earthquakes and the simple reason is that many of the earthquakes are originating in the Himalayan region.

So, which is seismically very active. Our capital of country that is New Delhi falls in seismic zone 4, capital of Uttarakhand, Dehradun, capital of your that is Himachal Pradesh, Shimla, then Chandigarh, they all falls in seismic zone 4. And then Gujarat is interestingly one of the state where all four zones of seismics 4, 5, 4, 3rd and 2nd zones are there. So, this was about seismic donation of our country. If you see in general, the Himalayan belt in seismic zone 4 and 5, but if you go in peninsular solar India in southern part of the country, you find mostly zone 2nd and 3rd only, only small pockets for example, here near Goa, zone 4 or in Gujarat.

So, otherwise in zone 2nd and 3rd only. So, all, whole of the countries are southern parts in either in 2nd or 3rd. When you design the structures of using this code, there is called design seismic coefficient, and this design seismic coefficient is calculated based on design horizontal seismic coefficient Ah and this seismic coefficient Ah is dimensionless. So, this design horizontal seismic coefficient for design of a structure is given by this relation z by 2 S a by g R by I. What is z here? z is called the seismic zone factor. I is called importance factor, and this will depends on your structure, and it may be specified in the given there are 5 parts of this code.

So, different parts of the code 1, 1st, 2nd, 3rd, 4, 5. It may be specified what should be the value of I should be taken. If it is not given, then I should be taken 1.5 for critical and lifeline structures. For example, you have the bridges or hospitals or dams, the value of I should be taken 1.5. 1.2 for business community structures, for example, industrial areas, then 1 for the rest of the structures, for example, residential building. So, the value of I importance factor varies from 1 to 1.5. Minimum is 1, maximum is 1.5. Even z will be taken as a zone factor from the given zone which we will discuss separately for different zones and R is called response reduction factor. So, the zone factor is given here, seismic zone factor z in this slide. So, for zone second, for zone highest zone 5, the zone factor z is taken 0.36 while for the lowest zone it is 0.1 and for other 0.24 and 0.16. For in fact, these are the values, so like the data like four zones are there and for each zone what is the value of zone factor, it should be remembered by heart. And we in the design philosophy, we use two types of like that philosophy, one is called equivalent static method, and another is called dynamic analysis method. And we will discuss for both the methods what is the value of SA by Z taken.

So, we already discussed Z, we discussed importance factor. What is R here? R is called response reduction factor which is also given in the different parts of the code 1 to 5 for the corresponding structure. And this R response reduction factor will basically indicating the ductility and if you have the reinforced condition, then the value of R is expected to be taken more. And finally, what is SA by Z in this equation? SA by Z in this equation is called design acceleration coefficient for different soil types normalized with P ground acceleration corresponding to natural period T of the structure that is considering SSI if required. So, depending on the SA by Z values, it depends on two factors, one is period, natural period T and the second is type of soil for different soil types. And it shall be given as given in a parts 1 to 5 for IS 1893 for the corresponding structures.

$$A_h = \frac{\left(\frac{Z}{2}\right)\left(\frac{S_a}{g}\right)}{\left(\frac{R}{I}\right)}$$

When not specified, it shall be taken as that cell corresponding to 5 percent damping given by expressions as follows. So, before expression let us discuss that this is the like know that is for equivalent static method. The value of SA by Z variation of SA by Z with natural period T is shown in this figure. And here what you could see when the natural period is increasing from 0 to 6 second, the SA by Z is also like here. So, up to certain value of period T which is in any case less than 1 or even quite less than 1, so it remains 2.5. And these three curves are for three different types of soil, type first is for rock or hard soil, second is medium soil and third is soft soil. So, if you have the weak soil for the given natural period, for example, 1 second, you will have the highest value of SA by Z and lowest value will be for type first. So, this curve is for type first, this is for type third soil and this is naturally for type second. So, the value of SA by Z remain constant up to certain value of T depending on your soil types that value is also constant 2.5. And further, so this curve can be divided into three parts. Let us say for if I discuss this curve for third case type of soil, this is the first part. The second part in all the curves become constant value after 4 second. So, in this case, three parts are there curve and this is listed here.

So, for up to 2.5 second like the value for SA by Z 2.5 up to 0.4 seconds. So, this is for type or rocky site. Let us say for soft soil, it is going up to 0.42. So, this is corresponding 0.4. This is up to 0.67 second. So, here this value I can put it the numbers here on the curve.

It is like up to 0.4, 0.55, 0.67. So, this is 0.44, this is 0.40 and then 0.55. This value is correspond to 0.55 and here this number is related to 0.67 second. So, in this case, up to 0.4 seconds, this is 2.5, here up to 0.55 and 0.67 second. So, this value is shown here and the value is also constant 2.5. Then if your value is between the time period is 0.4 to 4 second, then you can find using 1 by t, the reverse way. If it is more than 4 second, then it becomes constant and the constant value you get is 0.25. This is similarly for medium soft soil sites and the third is for soft soil sites. For the given period except for less than 0.4 second, if I draw less than 0.4 second is this value, this is less than 0.4 second. So, less than 0.4 second irrespective of your type of soil, the value of SI by g is constant which is 2.5 and then after this it depends on your type of soil. If you are weak soil, you will get higher value of SI by g, for the rock or hard soil, you will get the less value. So, this was equivalent static method. Another method which is called response spectrum method, the curve for SI by g and t is quite similar except that you get like you know instead of 2.5 flat, there is between this, this varies between this one. So, now what is this axis if I draw, what is the value of this time period and this time period is given here, this is 0.1 second. So, up to 0.1 second, it is different 0 to 0.1 second, rest of the things are same as we discussed in the response. So, up to 0.1 second for rocky or hard site, it is 1 plus for all 3 sites 1 plus 15 t, 1 plus 15 t, so this remain constant, the first row is constant. So, now your response spectrum has been divided into 4 parts, one part, the second part is here, third part is goes here. So, second and third part, third fourth part is similar as we discussed 0.1 in the last case also.

Now, there could be a question that how we define this code, what is rock or hard soil, what is medium soil and soft soil that is also given in the code itself. So, determining the correct spectrum to be used in the estimate of the types of soil on which the structure is placed shall be identified by classification given in the table and the soil types. First type is rock or hard soil, second type is called medium or stiff soils and third type is called soft soils and these are defined like here. Type first simply if you have SPT n values are available for type first the value of n should be 30. So, for first type of soil the value of n should be equal to 30.

While for type second soil the value of n should be between 10 to 30. If it is false between 10 to 30 then you say the type second. Similarly for type third the value of n should be less than or like this is 10. So, if n is less than 10 then you say that is this is the medium like the weak soil or soft soil. So, how this is defined? The values of n which need to be used using this table shall be the weighted average of the n of soil layers from the existing ground level to 30 meter below the existing ground level. So, you calculate the values from top to the up to 30 meter, but if refusal comes then you need to count that layers only.

Here the n values of the individual layer shall be the corrected values and they should be corrected values that means those values which are already corrected for overburden pressure. So, in this case now we have discussed all the things in the this design horizontal seismic coefficient z has been discussed, s a y g has been discussed, r and i has been discussed all the things have been discussed and that this value of a h can be calculated for calculating the seismic weight. One of the important issue which is given in the code also in a table that has been the minimum value of n which is required if the n the desired value of n is less than these values listed in the table then ground improvement is must and particularly for liquor and this has been divided into two categories. Seismic zone third, fourth and fifth has been clubbed in one category while zone second is another category. For third, fourth, fifth seismic zone it says the n minimum n value up to a depth of 5 meter should be 15.

If your depth is more than 10 meter then minimum n value is 25. However, between 5 and 10 meter the values of n which is a minimum n value required it can be found out from the interpolation. For example, for depth of like you have the depth z equal to 7.5 meter. So, 7.5 meter the n minimum n required will be 20. So, it will be between 15 and 20. So, this was for zone second, third and fourth. While on zone third, fourth and fifth, zone third, fourth and fifth for zone second these values could be up to 10 and 20. So, that means in any zone any seismic zone the core suggests the minimum n value should be 10 not less than 10. If it is less than 10 then ground improvement technique is required to be must. If soils of lower n values are encountered, then those specified in the table shown above then suitable ground improvement technique shall be adopted or default should be used.

And these values are particularly must minimum value to avoid liquefaction. If your soil conditions are liquefiable and n values are low, then if any values are less than the values which is given in this table then that means the soil is going to be liquefied. So, this was about the like for the minimum values are required for ground improvement technique. Now, this code also have a one map which is approximate not very accurate like in the this shows map in general showing principal lithological groups in our country. So, you could see the yellow in this region is allium soils which is gangetic belt and this one and this is liquefiable soils. Then if you go in the like particularly in the southern part of the country then you have Christian metallic rocks are there.

Then in the Maharashtra region you have volcanic rocks and minor. So, basically yellow then you have the this green and then red colors and blue also sedimentary rocks are there. So, one and then laterites with the black color. So, you have which is a small portion 1, 2, 3, 4, 5 and the 6 is data not available which is most like you know the some of the sites including in much a land. So, this was what has been given regarding the soil or ground improvement techniques or for the geotechnical earthquake engineering point of view in the code IS 1893.

So, with this I conclude this course and thank you very much for your kind attention. Thank you very much for patience hearing and as I already acknowledge during my promo like you know this lecture also as well as during initially that many of the material in this course like has been taken for this from the Kramer's book. So, that is gratefully acknowledged, but this has not been used for any commercial purpose, it is just for the educating the masses and it is with the full credit is given to the Kramer's, S. L. Kramer. Thank you very much for your kind attention. Thanks. Thank you very much.