Earthquake Geotechnical Engineering

Prof. B. K. Maheshwari

Department of Earthquake Engineering

Indian Institute of Technology Roorkee

Lecture 12

Field Tests

I welcome you again for this NPTEL course on earthquake geotechnical engineering. And we are discussing the module 2 that is on dynamic soil properties. Now, we will have the second chapter of this module which is on the field test. And as I mentioned earlier that this module this chapter second will be divided into three lectures. So, today we will have one lectures and then another two lectures again. So, in this module dynamic soil properties, we already discussed the concept of stresses and stress path.

Now, we will talk about field test, then we will talk about lab test. When we talk about lab test, it will also include the model test and then finally, constitutive relationships of soils. So, let us discuss the second chapter that is on the field test. But before we move, let us have like recap from what we have done in the lecture 11.

In the lecture 11 last lecture, we have discussed the representation of stress conditions, Mohr circle of stresses, principal stresses and stress paths. And now in this lecture that is on the field test of chapter 2, we will be covering these topics. First introduction of the field test, what are the advantages and limitations and then we will talk about low strain as well as high strain test. But today we are going to talk about low strain test only. Once low strain tests are over, then we will talk about high strain tests.

So, in the low strain test, today we are going to talk two test, field test, one is called seismic geophysical test, another is called seismic reflection test. So, even low strain test, field test will not be completed today, and we will be covering only these two and then in the next lecture 13, we will discuss the remaining test on the low strain field test. And once all low strain tests are over, then we will talk about high strain tests. Here, so for the field test, let us have some general things about. First of all, soil properties which influence wave propagation and low strain phenomena, low strain testing when we talk about low strain testing, what are the properties which are important for low strain testing, it include stiffness, damping, Poisson's ratio and density.

Out of these, stiffness is the most important parameter. While the stiffness and damping characteristic of cyclic loaded soils are critical for the evaluation of many earthquake geotechnical engineering problems. However, not only low strain, but at the intermediate and high strains also, the behavior of the soil is required to be determined, which we will do later. Continue with this, the difference in low strain and high strain. At high level of strain, there will be influence of rate and number of cycles of loading on the shear strength may also be important and that also need to be considered, particular for high strain testing.

For high strain testing, volume change characteristics also become important and that also need to be considered. Now, the issue with this one, when whether we conduct the field test or lab test, how we select which type of test we should use. So, therefore, the selection of these testing techniques for measurement of dynamic soil properties require careful considerations and understanding of the specific problem at hand. So, the basically issue is here, what is your objective? Depending on your objective, you will select type of test to be used for the field test for dynamic soil properties. And one should make effort to use test or test processor, which can replicate the initial stress conditions.

That means, if I repeat the test, then I get back the same condition. So, that is the preferred mode of testing. When we replicate the test, then these should be able to reproduce for under the anticipated cyclic loading condition as closely as possible. Now, regarding the field test, what are the important issues with the field test? Field test allow the properties of the soil to be measured in situ. In situ means in the field, that is in their existing state, where the complex factor of existing stress, chemical, thermal and are reflected in the measured properties.

So, the good point with this field test are that you are finding the properties in the field itself. So, whatever condition is there in situ condition, field condition that will reflect whether it is related to thermal, chemical and structural condition. While the measurement of dynamic soil properties by field test has a number of advantages. What are the advantages? So, we are going to talk about that. So, three issues are here.

First, field test do not require sampling. That means, you no need to collect the sample from the field and then you go in the lab and test. So, because you are testing in the field itself. So, what happens sampling when you do the sampling, sampling can alter the stress chemical, thermal and stress condition in soil specimens. So, particularly and this other change occurs for what we call the cohesion less soils or granular soils or the sandy soils. Many field test measure the response of relatively large volume of soil. So, as a result, the chances that whether your sample is representing, when you take some sample from the field and test in the laboratory, then the sample which you are collecting from the field may not be representing the real stress scenario. But in the field, we are testing in the large ground. So, as a result, that will be more representative. In many cases of the field test, the induced soil deformations are quite similar to those of the problems of interest which are expected during the wave propagation foundation design problems.

So, in the field, the conditions are similar to what is expected during the loading. So, these are the advantages of this. But then there are some limitations also. The one of the limitations of the field test is that you are testing the conditions whatever is existing in the field and suppose for parametric study or for research or for other purpose, you need to change some parameter and the second disadvantage is the control of pore water pressure is not allowed in the field test, which is possible in the laboratory test, but in the field test, the control is not possible. So, that is also disadvantage.

In many field tests, property of interest is not directly measured, but it is indirectly determined by some theoretical or empirical relations. One of the example I give you, like many times suppose you use the geophysical test for measurement of shear velocity or measurement of that. So, in the geophysical test is not a direct test where you are collecting the shear velocity directly, rather it is indirect test where you find first some relative velocity and then using some process you find the shear velocity. So, we will discuss these issue in detail further. Now, before I move to the surface test, whether we should use the field test or laboratory test for the sampling that will depends on your soil samples. Normally for the sands or granular soils, sands or I say granular soils or sometime what you can say cohesion less soils where the sample will get disturbed, the field test is preferred. So, preference is field test. But if you have the clay or cohesive soils, then laboratory test is preferred. However, it is recommended that for the important each projects, you conduct both field test and the lab test. In fact, using the field test you collect, do some testing in the field, collect the soil sample and those soil samples should be further tested in the laboratory.

So, that should be the way. Now, in the field test there are some tests which can be conducted from the surface, from the ground surface rather than drilling is not required without drilling. So, if drilling is not required, then it becomes easy drilling of boreholes without drilling of boreholes and there is advancement of probe into the soil. Surface tests are less expensive and can be performed relatively quickly. So, when you conduct the surface test, they can be performed quickly.

And these tests are particularly useful for materials in which drilling and sampling or penetration is difficult. So, if you have like you know particularly those type of strata where drilling is difficult, then these they are particularly very useful. Now, in the field test, there are surface tests which are conducted from the surface, but there are some tests for which you require drilling and borehole is required. So, you know conducting a drilling or like you know drilling a borehole that may be expensive, that may normally expensively compared to what when you do not require the drilling and it is laborious also. However, the good advantage of drilling is that you are able to collect the samples from the soil which can be further tested in the laboratory.

So, the good point is this and beside that you are able to judge the characteristics, water table location and so on. So, many things are known from out of the drilling. And the interpretation of borehole test is usually more direct than that of the surface test. Now, coming to the in the field test, as we discussed, we have low strain test and we do have the high strain test also. So, let us discuss first low strain test.

And the behavior of the soil in normally in the low strain range are not large enough to induce significant non-linear stress stress behavior. So, we say this strain is not large enough to create significant non-linear stress strain relations behavior. So, this is important to know and understand. That means, in this type of test are based on that we assume the stress strain behavior is linear. And it has been observed if the level of shear strain is less than 0.001 that is the gamma which is denoted shear strain 0.001 in percentage or in absolute terms it is 10 to power minus 5. So, if it is less than this value, then it can be safely assumed that your behavior of soil can be expected to be linear. As a result, because these tests work in the low strain, most of these tests are based on what you call theory of wave propagation in linear materials without considering the non-linearity of the soil. These tests involve the measurement of body waves, velocities of standing wave and you can get the information related to modulus and its frequency characteristics. So, how we get this information from these tests, we are going to discuss further. When we talk about field test, one of the like you know the series of the test is called seismic geophysical test. And the seismic geophysical test you do not require any drilling and in many seismic test what is done, a source produces a pulse of waves. You have a source hammering or something and once it will create a source of disturbance, it will produce some wave and what is done when these waves travel, its travel time is recorded at distant receivers. Suppose I put a disturbance here and my sensors are little away and then with the waves travel, so at which is called receivers.

At the receivers you find out how long it took time to reach from this source to that point and distance between these two is known, time is known, so as a result you can find the wave velocity. The source which may range from a sledge hammer blow to the ground surface to a buried explosive charge will generally produce P waves, S waves and surface waves. So, what type of waves does this produces? P, S and surface wave. The relative amplitude of each will depend on how the impulse is generated. So, you have three types of wave, one is P wave, S wave and the surface wave.

P is primary wave, S is shear wave and thus you have the surface wave which is normally we consider the Rayleigh wave. The relative amplitude will depend that how impulse is generated. For example, in case of seismic geophysical test, it represent an important class of field test for determination of dynamic soil properties and this involve creation of what we call the transient or steady stress waves. And here are like some of the sources which may create different types of wave. Different methods for creation of impulsive disturbance for seismic geophysical test are discussed here.

One source could be explosive source which are normally rich in the P wave content, then you may have vertical impact source, again it is rich in P wave content, then you can apply the horizontal impact sources which may be as such waves are produced more sufficiently by striking the end of a beam. So, here like these three sources are there. What in this figure is shown is the source of disturbance, how you create the disturbance of the wave for doing this test. In the first case, when some like some explosive is done here and this explosion is done below the earth, so this P wave will be generated.

So, using this P wave is generated. So, this is rich in P wave content, P wave will be generated. Again, if this is vertical impact, impact loading. In this case, what I say, hammering, so you are using the impact loading. In this case also, P wave is generated. Now, in the third case, I have a horizontal bar here, it is normally may be metal and I strike one end of this bar using some hammer one time, then I strike another time. So, what is done here, when you strike one of wave, one end of this bar, a wave is generated which is a combination of P and S. So, let us say P and S. When I strike another end, then another is this end is strike, this is fixed, then this is P minus S is generated. So, because S wave will change its direction. Now, if I subtract these two out of these, so what you get, if I subtract minus plus, so you get 2S.

So, difference is these two, you will get S wave and where S wave, its amplitude will be also increased because now you are getting two times of S what is you have. So, here whatever we have discussed is already like in the next slide. Continue with this. In the seismic geophysical test, we already discussed this. First of all, the P wave is the fastest to reach at a point.

So, their arrival at distance receivers are most easily detected and most easily measured because these P waves are the first wave types of waves coming on any station. So, the first wave which is coming is P wave. S wave's resolution can be improved if we reverse the polarity. So, we already said we strike one time this end, another time is this end.

So, this is called reverse of polarity. Since polarity of the trend P wave is not reverse, so as we discussed the P plus S, P minus S, so difference of these two you will give you 2S that is the amplitude of S wave has increased. Wave arrivals can also be enhanced by adding or striking records from multiple impulses and the random noise portion of the records tend to cancel each other while the actual waves are reinforced. So, with this, this was about introduction about geophysical test. But if water is present, then the water create little issues and what are the issues which are created by the water we are going to discuss. So, first is for proper interpretation of seismic geophysical measurements, groundwater effect should be considered.

We cannot ignore what is the effect of groundwater and what is the philosophy here. The P wave or primary wave can travel through the water and this groundwater P wave can travel even at a speed of high speed 1500 meter per second and this depends on the temperature and salinity. However, if you have soft saturated soils may propagate P waves at high velocities even though velocity is not often indicative the stiffness of the soil. So, this was about P wave. But if you pass S waves, then S wave will not pass through the water, it does not have the velocity because the water does not have the shear strength, it have the compressive strength but not the shear strength.

So, as a result, failure to consider groundwater effects can result in significant overestimation of soil stiffness and the groundwater problem can largely be avoided by using S waves which are propagated by the soil skeleton and not the groundwater. If we use the S wave, then good point will happen, thus S wave will give you the velocity of the solids only, it will not give you the velocity of the water. But if you use the P wave for your analysis, then even the P wave is passing through the water, still you may get some velocity. So, that is the difference. So, instead of P wave if you use S wave, then shear wave, they will pass through the only through the solids not through the water.

Now, there are different tests, geophysical test and we are going to talk about two tests, the seismic reflection test and then refraction test and then cross bore hole, MASW test, we will discuss in the next lecture. So, let us talk about seismic reflection test. What is done in the seismic reflection test? The seismic reflection test allows the wave propagation velocity and thickness of surficial layers to be determined from the ground surface or in offshore environments. So, you have wave propagation velocity and thickness of surficial layers. The test for reflection test, the concept is simple, and interpretation is also simple.

And this is this test is most useful for investigation of large scale or very deep stratigraphy. Continuing with this seismic reflection test, it is performed by producing an impulse which is usually rich in P waves. So, the impulse which you have is rich in P waves, P wave contents are rich in impulse at the source S and measuring the arrival times at the receiver R. So, you have one source which is denoted by S, and you have the receivers. So, what is done? You at the source the wave is generated and move, and it is received by the receiver.

The impulsive stress waves that radiate away from the source in the R directions is with hemispherical wave front and as some of the wave energy follow a direct path and some are the reflected one. So, I can explain using this slide. Here for the simplicity, we assume there is a one layer and then there is interface between these two layers. So, this is the interface here, this is what we call interface between two layers. Now, thickness of layer H is known to you, H is unknown, this needs to be determined, this is not known to you.

So, this is the question mark. While the distance between the source, so disturbance and receivers which is X, this is okay, X is known to you. So, X is already known because you know where you are putting your instrument and where your receiver is there. So, the source distance between the source and receiver is X which is known. Now, when the wave come from this point wave front and then it is passing through the medium and hit what is called the interface. So, when it is at the interface, when it hit the interface then what will happen? It will reflect back to the medium.

So, normally suppose you do not have the interface in between which we have deliberately considered then what will happen? This wave will keep going, going down and until like this becomes 0. So, this will continue and as a result when it goes far away it will start attenuating and its amplitude will decrease because it is spreading due to what you call radiation damping or geometric attenuation. Now, here X distance between source and receiver is known. So, this R will receive the wave from two front, one is called direct wave, and another is called reflective wave. Direct wave will be that wave which is coming directly from S to R without truing.

So, what happens? So, it is not this is coming, this is coming S to R and another path that a wave front start from here and it goes, and it hit the interface boundary between two layers. So, this is the boundary interface boundary between two layers and once it hit at this point then it gets reflected back to the medium because this interface may be fixed or whatever is this one. So, as a result when this is fixed then it cannot go, this wave will not pass through this one rather it will reflect towards the receiver. Now, in the receiver we have two waves one is with X covering distance coming from S to R another is from this route to this going this way. Now, for both the cases we need to derive some relations which we are going to talk in the next slide.

Here, let us say time taken from S to R you have recorded. So, as a result the velocity at the surface, surface velocity will be find out if we know that distance of travel that is X divided by wave velocity. So, because TD is known here, X is known so you can find the value of VP1. So, the velocity can be found from this relation. Now, by measuring X and TD the wave velocity of upper layer VP1 can be easily determined so that is there. Now, another portion of the impulse energy travels towards the stoichiometric layer and angle of incidence iota here I if I say this angle of incidence 2i so it will be the so you can find out like this angle of incidence this will be this divided by the basically what you have X by 2 if I draw a perpendicular here.

$$t_d = \frac{distance\ of\ travel}{wave\ velocity} = \frac{x}{v_{p1}}$$

$$i = tan^{-1}\frac{x}{2H}$$

So, this distance will be X by 2 and then i will be X by 2 by h. So, as a result i can be calculated from this relation. So, this iota the angle can be calculated from this relation.

So, TR is the time taken by the direct wave. Similarly, you have a reflected wave what so here direct wave will come directly from S to R while reflected wave will go long path here to here. So, the time taken by the reflected wave will be two times of the distance from here to here divided by the wave velocity.

So, here TR is given by 4h square plus x square divided by VP1, VP1 is the P wave velocity, which is same as we discussed in TD, TD equal to x over VP1. So, VP1 is calculated from this equation actually. You calculate and you put it here x over TD because x is known TD is known. So, this way you can find the VP1. Once VP1 is known then we can find out like another equation total distance by VPn should be the time. And as a result here this in using this formula we can find the thickness h which is not known. Let us say thickness h is not known in this case. Thickness h of this layer need to be determined and this can be determined simply using this relation half of TR VP1 square VP1 is already known and minus x square half of that. So, that is the like how to find this using the seismic reflection test.

This says how to find the thickness of the soil stratum. One of the issue is not only the finding using this test finding the you know the wave velocity or like this, but rather another thing that using this what will be the thickness of the soil layer that can be also determined. Now on the right hand side you have what we call the distance versus distance you know x axis. So, you have distance versus time curves here. So, what happens? Time is increasing here continuously.

So, this will be the distance covered 2h over VP1 will be the time. So, and this is distance here. So, this is time on x axis t is 10 for time and this is distance. So, initially what happens actually your direct wave will start from 0 there is no distance if I put my source and then as the time increases the distance will increase. So, the time like you are like you have here with the time passes. So, here this is x distance. So, accordingly the slope of this opposite of the slope will be the p wave velocity. Here there will be a trade-off if I have a 2h over VP1 what is 2h over VP1 you can find out from this equation and if x equal to 0 if I put x equal to 0 in this equation what I will get? I will get tr equal to twice h over VP1. That means what it says? It says that two times of h so this will be the scenario which is hypothetical scenario where you do not have any angle rather than this wave have gone along this and this have passes through. So, it have directly come vertically down and then move again in the same direction in that case. So, this is the and this is corresponding time this time is at least lagging time which is the minimum time will be required for this wave to reach to the receiver.

So, I think with this I have completed this 12th lecture. Thank you very much for your kind attention. So, we will continue in the next lecture with the field test, and we are still dealing with the low strength testing. So, we will talk about a field test, low strain test. Thank you very much.