Earthquake Geotechnical Engineering

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Lecture 13

Field Tests (Conti.)

I welcome you for this course on earthquake geotechnical engineering. So, today we are on lecture 13. From lecture 11 onwards we have started module second which is on dynamic soil properties. So, we already covered in dynamic soil properties, stress conditions in the lecture 11 and in the lecture 12 we started with the field test. So, we are continuing with the field test today in lecture 13 as well as lecture 14.

So, this was the module for dynamic soil properties. We are at the second chapter of this module that is field test which consists of three lectures, and this is the second lecture of this module 2. We talk about introduction of the dynamic soil properties. We also discussed the field test what are the advantages and limitations of the field test and then we started field test for low strength test where in the low strength field test we have already discussed two test that is seismic geophysical test and seismic reflection test. Now, today what we are going to Continue with the field test which is on the low strength test. Here we are going to talk seismic reflection test, steady state vibration, spectral analysis of surface wave that is SASW test, then we do have seismic cross hole test, seismic down hole, up hole test and seismic cone test. So, these six test we will discuss and all these test fall first of all they are in the field test and the second thing they are on the low strength test.

So, before I go move ahead let me acknowledge that most of the information during this lecture is from the book by Kramer on geotechnical earthquake engineering. Coming to the seismic reflection test, the seismic reflection test eliminates the most important limitations of the seismic reflection by using the arrival times of the first waves regardless of the path. So, it will use the first wave and as a result this test involve measurement of the travel time either of P wave or S wave that is basically on body waves, and which is created through an impulse source on a linear array of points where you can have receivers or geophones at different distances from the source.

So, in case of seismic reflection test, greatest earthquake engineering application is delineation of major strategic unit that means you have a number of layers. I can explain it like this one. So, when the waves passes in the refraction any wave which is coming from the like you know that from the ground and then it passes through this like then it changes its path.

So, this is refraction. So, it will not be going the same path rather there inclination it get changes at the interface of two layers. So, these are the interfaces. So, in the refraction it happens and if you have the homogeneous material then refraction will be out of question, but normally you do may not have homogeneous layer rather than what we call the layered soil. So, this is the layered soil in that case when it hits the layer then there will be change.

So, for this test an impulsive energy source which can be mechanical, or explosive is used which is located at the near ground surface. A series of receivers which is usually called geophones are placed in a linear array one receiver is located at the source. So, how it looks let me like explain with this. You have this seismic refraction setup here. What do you see? Let us see first the bottom figure where you have a source here explosive charge it could be a source, source of disturbance and then you have recording equipments which is connected through the geophones.

So, you have a number of geophones, and these geophones may be spread, but normally we try to keep them on equal spacing. So, for example, here this is like 50 meter feet 100 feet and like this. So, every 50 feet one geophone is placed and then you have recording equipment and what is done? We try to find when the waves go from the source towards the receiver because the distance between source and receiver is already known which is fixed and then you do after this once you have then distance is fixed. So, you note down the travel time what is the travel time taken from the source to a receiver and the travel time like once you can plot what you call the distance like arrival time versus distance. So, this you can see on the graph here.

So, on x axis you have distance which is same along the you have the different geophones and arrival times. Naturally arrival times will be more as the distance increases, but it is not linear. Why it is not linear? Because travel time like you know that we will keep varying from you go to here. So, like you know that little bit change. So, you have this arrival time versus distance and continue the output of all the receivers recorded when the impulse load is triggered from these recording arrival times are noted.

So, we already discussed this. Now continue with the seismic refraction test like you can calculate what we call the shear velocity the v s. So, that can be calculated. So, this is about the seismic refraction test. Now we discuss the second that is what is called steady state vibration that is Rayleigh wave test because Rayleigh wave is a surface wave.

The last one seismic refraction test was based on the body waves whether you use P wave or S wave. However, in case of a steady state vibration we use surface wave and one of the type of surface wave is Rayleigh wave. So, in this case the problem of detecting wave arrivals and measuring arrival times becomes is eliminated and in test that interpret properties from the characteristics of a steady state vibration. So, means steady state vibration that means your amplitude become constant after certain time so that you get a steady state state. And in this case the displacement along the ground surface which is adjacent to vertically vibrating circular footing and it is primarily caused by Rayleigh wave.

So, here this is Rayleigh wave and you know already that this is a surface wave. So, this test is based on the surface wave. And the Rayleigh wave produce both vertical and horizontal displacement for a constant loading frequency so the ground surface will be distorted as shown here. So, what happens? Like here you have a Rayleigh wave which is induced deformation surface. So, this is a source of disturbance and then you have wave.

So, this is peak value down peak the down peak the distance between two peaks value are called wavelength the lambda r this is wavelength here. So, what is done here? You have both vertical and horizontal displacement. The displacement actually one side it is propagation and another side you have the particle motion another direction you have particle motion. So, you as a result you have both vertical and horizontal displacements in this case for the Rayleigh wave which is surface wave for a constant loading frequency. So, the ground surface is distorted as seen by placing a receiver at the center of the footing and moving another receiver to points at different distances from the receiver. The location of point vibrating in phase can be determined.

So, here is this. Continue with this. So, in case of a steady state vibration you have the horizontal distance between points are equal to the wavelength of the Rayleigh wave. So, by measuring the wavelength the Rayleigh wave phase velocity can be calculated using this relation where you have Rayleigh wave velocity and you have this relationship frequency multiplied by the wavelength. So, ultimately here the Rayleigh wave phase velocity can be calculated and this you have this lambda r divided by 2 pi omega divided by 2 pi. So, basically you have frequency multiplied by wavelength. Frequency multiplied by wavelength give you the Rayleigh wave velocity and you already know that there is a relation like Rayleigh wave velocity is less than the shear velocity or shear velocity is roughly for the soils 1.09 times v r. So, this is for the soils you have this. So, Rayleigh wave velocity is approximately 92 percent of the shear velocity and in any case for any Poisson's ratio or for any material you know that this v r will be always less than v s. So, depending if you increase the Poisson's ratio then this difference will like with the increasing the Poisson's ratio difference will decrease. So, like this. So, here like this Rayleigh wave velocity in fact, this will be for even for the rocks also because it may go for the soils it v r may be around 0.96 v s.

$$v_R = \frac{\omega \lambda_R}{2\pi} = f\lambda_R$$

For many soils $v_s = 1.09 v_R$

Or $v_R = 0.92 v_s$

So, this is for the soils, and this could be for the rocks. So, with this like we go then the for soils whose stiffness varies with the depth dispersion will cause the Rayleigh wave phase velocity to vary with the frequency. We already discussed in the last lecture what is dispersion. Dispersion is a property through which the velocity or wave velocity is a function of frequency and the state-state vibration is useful for determining the near surface shear wave velocity and cannot be easily provide detailed resolution of highly variable velocity profiles. The shape of a dispersion curve, what is the shape means here? That is a plot what is the dispersion curve? A plot of Rayleigh wave velocity versus frequency or wavelength that is called the dispersion curve.

At a particular site is related to what we call the variation of body waves velocity with the depth. So, ultimately our objective is to find out how the body waves particularly the S wave varies with the depth. So, here we have the shape of the you prepare a dispersion curve and dispersion curve is nothing but a plot between the Rayleigh wave velocity which is surface wave velocity versus either frequency or wavelength. Using that data, we process that data and then we find out the body wave velocity and particularly when we talk about body wave velocity is mostly shear wave velocity. Then steady state can be used to generate a dispersion curve by repeating the test at different loading frequencies.

So, the test is repeated at different loading frequency and here. Now continuing with this steady state vibration there is another version what is what called we call a spectral analysis of surface wave which is called in the short SASW. And as we discussed as there is another version called MASW. MASW is basically multi-channel SASW. So, number of channels are more in.

So, if I have MASW and SASW are the same only difference that you use number of channels in MASW. So, what you have the output of both receivers here you use in SASW test two vertical receivers on the ground surface in line with an impulse or random noise source. So, for example, here you have a setup for SASW test. In this setup you have a source and then you have receiver, receiver 1 and receiver 2. There is distance of receiver 1 distance of receiver 1 from the source is so, let me put the receiver 1 and receiver 2 here.

So, d1 is the distance of the receiver 1 from the source and d2 is the distance of the receiver 2 from the source. Normally as far as possible the equal spacing is kept. So, that means, d2 minus d1 will be the same as d1. So, it is d1 d2 will be almost approximately two times of d1. So, that is how it normally kept here.

So, you have two vertical receivers, which is on the ground surface, and they are in line with an impulsive source. So, that means, all three source receiver 1 and receiver 2 all three should be lying in one line only. The output of both receivers is recorded and transfer to the frequency domain using the what we call the fast Fourier transform. Also transformation the phase difference can be computed for each frequency. Now in this case you have this typical configurations here.

The corresponding travel time between receivers can be calculated for each frequency using the data here. What data we have? We have delta t phi f divided by 2 phi. So, what is this delta t denotes? This denotes the travel time and this denotes the travel time corresponding to a phase lag. Phi f we already discussed was nothing, but in this case it was a phase lag. So, what you do? You have the output of receiver and then you transfer those output into a frequency domain using the fast Fourier transform.

$$\Delta t(f) = \frac{\emptyset(f)}{2\pi f}$$

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And once after transformation phase difference is noted phi f, once phase difference is noted then we can have using this phase difference we find the corresponding time lag. So, this is delta t f is the time lag here corresponding travel time and this travel time will be varying with the frequency. Why? Because this phase lag is a function of frequency and then you divide. So, basically what is this? This is simply phi f divided by omega.

$$v_R(f) = \frac{\Delta d}{\Delta t(f)}$$

$$\lambda_R(f) = \frac{v_R(f)}{f}$$

So, this is there. So, when the frequency changes here on the right hand side both numerator and denominator both are varying. So, this is directly varying and this is a function of frequency. So, that means, time lag will depends on your frequency content. So, once you get the time travel time, travel time is noted the distance between two receivers that is delta d and this delta d is nothing, but difference d 2 minus d 1. So, this is known once delta d is known then you can find the relative velocity which is given by this relation that is distance divided by time simple.

But again, because your travel time is varying with the frequency. So, this Rayleigh wave velocity will be also frequency dependent at it will keep varying with the frequency. Corresponding wavelength simply find out dividing the Rayleigh wave velocity with the frequency. So, this way we find out the corresponding wavelength. Now, continue with this one with modern electronic instrumentation are these calculation can be done in the field virtually in the real time and this SASW test have a number of important advantage over other field test. First of all, they can perform very quickly, they require no borehole, they can detect what we call the low velocity layers and can be used to considerable depth which is about 50 meter.

Now, the next test is seismic cross hole test which is again the lowest strain test and what is done in the seismic cross hole test. This also uses two or more boreholes. See that so far in geophysical test which we have discussed no borehole was required because there was the surface test. For example, SASW test, steady state vibration test, seismic reflection, seismic refraction.

In all these test borehole was not required, but in seismic cross hole test borehole are required and number of boreholes are more than it could be two or more. So, minimum is 2, two boreholes one of which will contain an impulsive energy source and other will be receiver. So, this is the like it looks like this. In the seismic cross hole test you have a source and receiver. So, minimum is requirement is 2, but you could have more number of holes for example 3 that then you have may have two receivers, receiver on the source 1 and then you have point is here what you do you put an impulsive source in first borehole at certain depth and at the same depth you put your receiver.

So, when the waves travel from the source then they will travel assuming that if they are traveling horizontally and then they will reach to the same level. The same thing is here. So, the level of source and receivers in this case is kept same. So, they are on the same level horizontally they are on the same level. So, in the one borehole it will be source and another in another borehole you will put the receiver.

By fixing both the source and the receiver at the same depth as we discussed in each borehole the wave propagation velocity of the material between the boreholes at the depth is measured. So, you know the distance between these you if you calculate the travel time what is the travel time taken by the wave from coming from so to the receiver then distance divided by travel time will give you the velocity which will depend on the material. Now coming to the continue with this since the impulsive source must be located in the borehole variation of the P wave or S wave content is more difficult than for the methods in which it is at the source. So, the variation here will not be easy because both are lying at the same level. So, that is the beauty of this seismic cross hole test particularly where you use number of boreholes that your source and receiver they are at the same level.

If you use explosive sources, then wave content shift towards higher P wave content and where large changes are charges are used particularly when denoted if you detonating above the ground. So, this is we already discussed that how it works for first is direct measurement using two hole configuration and the second one is using three hole configuration. By testing at various depth a velocity profile can be obtained. Velocity profile what is velocity profile? In the velocity profile you have with the depth, depth is going increasing this side and you have a shear velocity v s here.

So, this is normally done with the v s. So, the profile looks like this it may be like with the different layers and then. So, you get this kind of profile which is called shear wave velocity profile, and this is basically the output of cross bore hole test as well as MASW. So, this is output. So, this is from this cross, cross bore hole.

But what happens when use more than two bore holes is desirable why because it will minimize possible inaccuracies which may be resulting from different regions including measurement, casing and backfill, material place between the casing and the bore hole wall and thus anisotropy of the soil. So, those could be the reasons of inaccuracy which can be avoided if you use more than two bore holes. The cross hole test often allows individual soil layers to be tested since layer boundaries are frequently nearly horizontal. So, one of the most important advantage of this cross hole test compared to SASW or MASW test is that it can also detect hidden layers that can be easily missed by seismic refraction surveys. So, it can also suppose if you have a small layer and thickness of the layer is very small then your other test may not able to detect but using this we can detect because we are conducting this test at different layers, different thickness.

So, you can select where you want to put your source and then receiver the depth can be selected. And this cross hole test can yield what reliable velocity data to depth of 30 to 60 meter using mechanical impulse sources and to greater depths with explosive sources. Now another version of this cross hole test is called what is called using the single bore hole we can also conduct, but then it is called either seismic down hole or seismic up hole test. And it is depending on the location of receiver if your receiver is located on the ground surface then it is called up hole test. If it is located in the inside your bore hole receiver then it is called down hole test.

So, let us first talk about down hole test then we will talk about up hole test. In case of seismic down hole it can be performed first of all the both in using a single bore hole you do not require two bore holes. In the down hole test impulsive source is located on the ground surface which is adjacent to the bore hole and receiver is kept inside the bore hole and you keep moving the receiver. That means, source of disturbance which is on the ground impulsive source that remain at a fixed place, but you are moving inside the hole along the depth this receiver is kept moving or a string of multiple receivers at predominant depths is fixed against the walls of the bore hole. So, here all receivers are connected to if you have a number of receivers that could be also possible instead of source could be like you have.

All receivers are connected to a high speed recording system so that their output can be measured as a function of time. In the up hole test it is opposite your receiver will be up that means, it will be receiver will be at the ground surface while your impulsive source is located inside the bore hole and this will be movable. Whatever like you know if you say up hole test then receiver will be on the ground surface. If you say down hole test then receiver will be inside the bore hole, but irrespective of up hole or down hole test whatever is inside the down bore hole that will be moving. So, for example, in seismic down hole test your energy source which is inside the hole will be moving.

The objective of the down hole or up hole test is to measure the travel times of P or S waves from the energy source to the receiver. So, how up hole or down hole test looks that is here. So, this is seismic down hole and up hole test. So, you could see here, here instead of cross bore hole where we require at least two bore holes only one single bore hole is used. In case of first one is up hole, so it is the location of the receiver.

So, receiver is kept at up that is on the ground and so depending on the location of receiver you can decide whether it will be up, or it will be down hole test. So, the first one is up hole and the second one receiver is at down so it is called down hole test. Now, in the first case your source will be moving because it is inside the hole bore hole you can move the source. But in the second case your receiver will be moving and like when we use this like receiver will be kept moving. In the first case your receiver is on the ground surface you can use a number of receivers because it is not moving and you can have another receivers and then we can connect in this case.

So, this was about seismic down hole and up hole test. Then continue with this S waves can be generated much more easily in the down hole test than the up hole test. As a result the down hole test is more commonly preferred. So, down hole test is preferred in down hole test you kept your receiver in the hole while your source is at the surface and S waves can be generation of S waves is rather more convenient. While potential difficulty with the down hole or up hole test and their interpretations can result from disturbance of the soil during drilling which you drill because you require a bore hole in this technique. Casing and bore hole fluid effects insufficient or excessively large impulse sources, background noise effects and groundwater table effects.

So, these are the like issues which may cause inaccuracies. So, there are so many issues which may cause inaccuracy in the results and we need to look after that how we can reduce that. Then another the last part is called seismic cone test and this seismic cone test is very similar to what we call the down hole test except that no bore hole is required. Though it is similar to the seismic cone like you know the but you do not require boring like in SPT we need to do the boring, but in CPT you directly like insert inside that like. So, a seismic cone penetrator meter consists of a conventional cone penetrator meter which is outfitted with a geophone or accelerometer mounted just above the friction sleeve. So, seismic cone test is basically linked with what we call the CPT which is a field test, and we will discuss in later.

So, earlier CPT or SPT which we are going to discuss in the next lecture they are high strain test. So, that we need to understand this is a high strain test that is the level of strain is high, but seismic cone test it falls under the category of the low strain like category and you use seismic cone penetrator meter which consists of a conventional cone penetrator and this is fitted with a geophone or accelerometer is fitted where it is fitted? It is fitted on the friction sleeve. You have the penetrator meter and you have the sleeve. So, your this geophones or pickups will be fixed here. Continue with this at different stage in the cone penetration sounding, penetration is stopped large enough to generate impulses at the ground surface and how it is done? It is often done by striking each end of a beam and that is pressed against the ground by the out ring of the cone rig with an instrumented hammer.

So, you have an instrumented hammer using that this can be carried out. Travel time depth curves can be generated and interpreted in the same way as for the down hole test. That means, you have travel time how with the depth you have the depth and when that you have the record of travel time the travel time is varying with the depth. So, once travel time is known then you can find because distances are already known. So, and if for certain depth how long it took to go from one depth to another depth.

So, distance is known travel time is known. So, you can find what we call the velocity in this case. Although down hole or up hole test have usually been performed to complement other test or to provide redundancy, the efficiency of the seismic cone test may lead to its more common use. So, what is done like they are complementary basically. This is done with the borehole like you have the shear velocity and seismic cone test will also give you another.

So, they are complementing that already done. Cross hole seismic test using two seismic cones have also is performed. So, rather than having on one you can have two locations and then that is called cross hole seismic test where two seismic cones will be used instead of one. So, this was all about the low strain testing for the field test. So, we complete with this lecture field test for low strain case. In the next lecture we are going to talk again about the field test, but in the high strain category. Thank you very much.