Earthquake Geotechnical Engineering

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Lecture 17

Laboratory Tests (Conti.)

I welcome you all for this lecture number 17 of this course. So, as we discussed, we have three lectures on the laboratory test for dynamic soil properties and this is the third lecture for the laboratory test. So, in fact, with this lecture, third chapter of dynamic soil properties that is on laboratory test will be completed. So, this is chapter 3 on the laboratory test and what we have done in the last lecture number 16, we talk about two low strain test, ultrasonic pulse test, piezoelectric bender element test and three high strain element test that is cyclic triaxial test, cyclic direct simple shear test and the cyclic torsional shear test. What we are going to talk in this lecture, special shear test, modal test that is shake table test, centrifuge test and summary of all the test will be also discussed.

So, first let us talk about special shear test, then we will talk about modal test. In the modal test, two test that is shake table and centrifuge will be discussed. So, in a special shear test, which consists of plane strain test, it could be true or cuboidal shear test, simple shear test, how are these tests are mostly used for research purpose. So, like these tests will not go in much detail.

So, with this special shear, they are used for finding the dynamic soil properties. We come to now to the modal test. In contrast to element test, modal test usually attempt to rephrase the boundary condition of a particular problem by subjecting a small scale physical model of a full scale prototype structure to cyclic loading. So, what happens? In element test, you collect a small sample of soil, and you test in the either cyclic triaxial, or in resonant column test. However, here you are not collecting the specimen, rather you are preparing a modal which is representing the larger body that is prototype.

So, physical model is created, and this modal test may be used to evaluate the performance of a particular prototype or to study the effects of different parameters on a general problem. In this case, while modal testing is very useful for identification of important phenomena and verification of predictive theories, it is being developed to the point so that it can be directly used for the design of significant structures or facilities. So, the modal tests are nowadays have gone from modal test to mostly like particular for the structural engineering, even prototype itself can be tested which is called large scale test. So, the large scale tests are used now, so the testing is gone beyond modal test. The behavior of soils is sensitive to stress level, soils that exhibit contractive behavior under high normal stresses may exhibit a dilated behavior at low stress level.

So, how the behavior of soil, it is not the same soil sample behavior will be different under two types of stresses. If you apply high normal stresses, then it may contract, it may shrink, contractive behavior may happen. But if you apply the low stress level, then there could be dilation, it can expand. So, the behavior depends on the level of stress. And two types of modal tests are popular, one is called shaking table test which is 1g that is acceleration due to gravity is 1, 1g that is 9.81, 1g means you know that 9.81 meter per second square. However, centrifuge tests are conducted at higher g that is certainly more than 1g. It could be 100g, it could be 50g or 10g or 1000g or like. So, it is quite high compared to 1g.

So, let us first discuss the this model tests. One of the most significant challenge in a modal testing is the problem of testing models. Stress dependency matches that of full scale prototype. That means stress dependency, this is important issue. Level of stresses in case of modal and prototype should be the same.

If that is same, then it is okay. But what happens when you test at 1g level which is in the shake table, then the level of stress in the modal and prototype is not the same. As a result, we need to use for the higher value of g to compensate this. Because this is very difficult under the gravitational field of the earth, one common approach involved testing under increased gravitational field. So, why you want to test at higher g? Because so that level of stress and strain is same in modal and prototype.

So, we will discuss it in detail further. Both shaking table and centrifuge share certain drawbacks and among the most important which are similitude and boundary effects. So, in both the test whether you have the centrifuge, whether you have the shaking table or centrifuge modal test, there are boundary effects. Because different aspect of the response of a 1 by n scale model are governed by different test scale factors, similitude cannot be assured for all parameters simultaneously. So, like you know, if you want to simulate all the parameters, perhaps that is not possible.

So, we need to fix stress and strain parameters. Then boundary effects are usually associated with the metallic beams or bug size in which shaking table or centrifuge models are usually constructed. So, in shaking table you normally use a tank, and you fill soil inside the tank. But in the field, the soil is not restrained the similar way what you are doing in the tank. In the tank, your soil specimen is restrained by the boundary of the tank, but this is not the real scenario.

And the soil wall can withstand soil movement and reflect energy that would radiated away in the prototype. So, what will happen? You have a tank, soil is there when the wave propagate, it hits the wall of the tank and it get reflected back. But in the real field, there is no wall rather it goes away, it will radiate away and will not come back. So, this is the typical example of the shake table test. In this case, you could see there is a bin or tank. So, inside this tank you fill out the soil sample and this typical size of course, it could be more or less. So, you have 8 feet, which is about 2.5 meter and you have the 6 feet, which is about less than 2 meter and 4 feet is the height of the tank. And in this shaking is applied in using a mechanism in the horizontal direction, an actuator is used. An actuator apply the load in the horizontal direction, it try to shake it. Then you have shaking table base and then you have side walls with raised plastic boards. So, that is there. Shaking table with soil been used for dynamic earth pressures. So, this is like. The next one, continue with the shaking table test.

So, this is the shaking table apparatus, which is in the soil dynamics laboratory of at IIT Roorkee. So, you see here in this mechanism, you have a tank, rectangular tank in the cross section. Length is more than the width. Length is about 1.05 meter, and the width is about 60 centimeter. And the height of the tank is also 60 centimeter. Here using this mechanism, you apply the horizontal loading. The tank moves and using this mechanism, you can control its frequency and amplitude. So, you control amplitude and frequency. And you can measure at what amplitude and using these piezometers, you measure the pore water pressure in this test. The shaking table research has provided valuable insight into liquefaction, earthquake settlement, foundation response and lateral earth pressure problems. Most shaking table utilizes single horizontal translation degree of freedom but shaking table with multiple degrees of freedom have also developed. That means, you can apply simultaneously one horizontal, one vertical, that is two-dimensional or both horizontal direction shaking as well as vertical direction. So, three-dimensional shaking is also possible, multi-directional shaking.

These are usually driven by what you call the servohydraulic actuators. And the capacity of these actuators depends on the capacity of the hydraulic pumps. So, the servohydraulic actuators are used inside the shaking table. And if you have the hydraulic pumps with higher capacity, then you can shake with a higher acceleration and higher input. So, the capacity of the actuator will depends on the capacity of servohydraulic pumps. Large pumps and large actuators are required to produce large displacements of heavy models at moderate or high frequencies. So, if your objective is to produce large displacement, then you require the large pumps and large actuators will require. Shaking tables can offer, utilize actual prototype soils rather than rest of the smaller particle size which is often required for a smaller scale model test. So, because the tank is quite big size, so you can see the soil samples, particularly it is quite visible when you carried out the liquefaction testing, where water comes on the top of the soil specimen, the visibility is very good in this test. They can be easily viewed from different perspective during testing, including for liquefaction.

On the other hand, high gravitational stresses cannot be produced in a shaking table test. As we discussed, the shaking table tests are conducted at 1g. The level of gravitational stress is only 1g only rather than the higher stress. Though the contractive behavior associated with high normal stresses at significant depths can be simulated by placing soil very loosely during model preparation, the process of preparing soil models is quite difficult. So, here if you have very loose sample, then it is difficult to maintain the relative density because once you poured out, then that there may be the relative density may be changed.

Because of the low normal stress levels, the contribution for factors that produce a cohesive component of strength will be greater in the model than in the prototype. So, the contribution of cohesive component in model is higher compared to its contribution to the prototype. So, these are the some of the issues with the shaking table test which required attention. Now, the second model test which is called the centrifuge test as we already discussed, in the centrifuge test are conducted at higher value of g that means gravitational field inside the chamber of the centrifuge chamber is increased n times. As a result, in the centrifuge test 1 by n scale model stress is located at a distance r from the axis of centrifuge is rotated and this is rotated at a speed omega, this is the large value of like you know the greater bigger omega.

So, n, this is n times of g, it should be treated like this. So, this is omega square r that means basically n g is if I say roughly omega square into r n times of gravitational field. So, this is basically n g here, this numerator is n g, which is sufficient to raise the acceleration field at the location of the model to n times the acceleration of gravity.

$$\Omega = \sqrt{N/r},$$

So, n times of the acceleration of gravity. So that means, it depends your if you want to get the higher value of n, then either you need to increase the lever arm or you need to increase the speed of that. So normally, once you design a centrifuge, the value of lever arm become fixed. As a result, when I rotate, I increase the value of omega, so n is going to increase. So that means n, in this case, the n which you get will be proportional to omega square, the square of the angular frequency of rotation, where angular frequency of rotation is of the centrifuge at what speed it rotates. So let us say typical example of a centrifuge is shown in this figure.

So let me explain different components. This is the rotor of the centrifuge and it rotate at a high speed. As you increase its speed, the gravitational field which is generated inside the chamber increases. Now you have, it is the center point, the r, radius, naturally the radius will be from here to the center of this, this is r, lever arm, this side. Inside you use bucket, inside this bucket you put your soil sample, this is sample here which you want to test at higher value g. And on another side, the counterweight is used, so the counterweight is coming here, this is counterweight, and this is test bucket where the sample is kept.

So why it is called centrifuge? Because the g value is increased due to what we call the centrifugal force, due to centrifugal force the g value is increased in this equipment. In principle the stress conditions at any point in the model should then be identical to those at the corresponding point in the full scale prototype. So here if you prepare a model which is 1 by n times of the prototype and you rotate the centrifuge at a speed n times of g, then the stress condition in the model and prototype remains same, that is the important issue related to centrifuge. The overall behavior, for example displacement, failure mechanism should also be identical for the model and prototype. So you increase the value of g and you get in the benefit that the level of stress in model and the prototype is same, even the model is prepared at a very small scale.

So, this figure shows the geotechnical centrifuge in the Solidynamics Laboratory of IIT Roorkee. So you could see this is the power unit which is applied in the front, but this is cylindrical, this box, in the cylindrical box you put the soil like in buckets are there, so a rotor moves and inside this chamber the gravitational field is increased and this could be increased up to n times ng. These centrifuge tests are restricted to much smaller models than even moderate size shaking tables. So because you require for the, because a small model is enough rather than a big shaking table is used for the testing here. Since the gravitational field increases with radial distance that is r, if you increase the value of r it will increase.

The gravitational action at the top of the model is lower than that of at the bottom of the model. So, there may be at the model because little bit distance at the top and bottom is different, so there may be small discrepancy in the gravitational field there. Since the gravitational fields act in the radial direction, the horizontal plane is curved by an amount that decreases with increasing centrifuge radius. So, if the radius is decreased then this gravitational field will also decrease. Simulated considerations are very important in the planning and interpretation of centrifuge tests and which we are going to discuss. The scaling factor show how dynamic events are speeded up in the centrifuge, so it is here. So what in this table are given scaling factors for centrifuge modeling? So let us first concentrate on the last column. Last column is nothing but the ratio of modal dimension to prototype dimension. So what you can do using this ratio because prototype dimension is already known you can find what will be the modal dimension. For example, if we talk about different events, stress and strain they have the one unit.

That means stress and strain will remain same between modal as well as prototype. So what required for modal is 1 times of n, 1 by n of modal dimension. So if you have like you know the modal dimension n equal to n is 100, so you require only 1 by 100 length compared to prototype. Mass because all three dimensions are reduced not only one dimensions, so it is like you know the volume will be 1 by n cube and the mass will be also reduced to 1 by n cube. So mass is quite much reduced which is required to be tested in the modal.

So, gravity in the modal and prototype is the same because we are using the same material. Force required in the centrifuge testing is 1 by n square that is you require a small force for conduction of the test. Gravity remains n times. So only the acceleration due to gravity is increased n times and there are other factors like time is 1 by n, frequency is n, acceleration becomes n times. So, these are there and let us discuss some of the examples here.

For example, the stresses and strains in a 30 meter high prototype earth dam could be modelled with a 30 centimeter high centrifuge modal which is accelerated to 100 G. Here what you have done that you have a dam, earth dam, height of the dam is 30 meter. Now you cannot construct a modal in the lab of 30 meter height and then test it for that. So what is done? The modal is scaled out by using the scaling laws that is 1 by 100 of the prototype. So as a result, you get in the for modal only 30 centimeter that is roughly 1 feet.

So a modal is prepared, the height of the modal is 30 centimeter only and that is tested in the centrifuge modal. And this modal which is 1 by 100 of the original prototype it is accelerated to a very high speed which is called 100 G. And in this case when the same modal which is of 30 centimeter is undergo in the field of 100 G then the level of stress and strain in the modal and prototype is the same. So that is the idea here in the centrifuge modal. A harmonic 1 hertz base motion which is lasting 10 second, another example, in the prototype scale would be modal by 100 hertz motion which lasts only 0.1 second in the modal.

So suppose in prototype you are subjecting 1 hertz frequency then in modal the frequency increases acceleration due to gravity increases. Many things are remain same and many things get decreased. But in the centrifuge testing inside the modal many things are greater than in the prototype. For example, the prototype is subjected to only 1 hertz frequency but in the modal we will apply 100 times that is 100 hertz motion and this 100 hertz have come when you are considering n equal to 100 in this modal to prototype. Then another problem comes the dissipation of any generated pore pressure however would occur 10,000 times as fast in the modal as in the field.

So, it will be the very fast in the modal compared to in the field. So to overcome these limitations instead of what are some materials which are for example viscous fluids which are such as glycerin or silicones are used, oil are used as a pore fluid in the centrifuge modal. Then improved estimates of prototype behavior can be obtained using the modeling of modal technique which involves comparing the response of modals of different size at the same prototype scale. Then you use what we call the high speed transducers and data acquisition system. They are required to obtain useful results in dynamic centrifuge test.

One thing is that you may run dynamic centrifuge with some modal but that is no use until you measure, and you collect the data using this one. So for collecting the data high speed transducers are used and data acquisition systems is also used. Because the scaling law applies to all parts of the modal, the miniature transducers and cables are required. Rather like while using transducers, small cables should be used rather than very long cables which will interfere. So, the small, the minimum, they should be used minimum size. Now with this we have come to the end of the both like field test as well as the laboratory test or with the centrifuge we have to also run with the modal test. So we will like before we close this like module, I will like to summarize what we have covered both in the field test as well as in the laboratory test. In the field test we have two categories, low strength test and high strength test. In fact, the same categories in the for the lab test also. In the low strain test we have discussed a number of test which is first was seismic reflection, seismic refraction, steady state vibration, then seismic cross-hole test, then seismic down-hole or up-hole test and seismic cone test.

So, all these seven which comes under the category of low strain field test we have discussed. Similarly high strain test we have discussed four test, standard penetration test, cone penetration test and dilatometer test and pressure meter test. So, four test has been discussed in case of high strain test which is from the field. Now to talk about laboratory, in the laboratory test we have specimen test, low strain element test, three test that is resonant column, ultrasonic pulse test, piezoelectric bender element test, three has been discussed. While high strain elements again three test that is cyclic triaxial, triaxial test, cyclic direct simple shear test and cyclic torsional shear test has been discussed.

So this was the list of the field and lab test. But then there are two model test has been also discussed which is shaking table test and centrifuge test. So, with this we are done with the chapter third of the module and we will discuss tomorrow the last module of this chapter which is on stress-strain relationship. Thank you very much for your kind attention.