Earthquake Geotechnical Engineering

Prof. B. K. Maheshwari

Department of Earthquake Engineering

Indian Institute of Technology Roorkee

Lecture 14

Field Tests (Conti.)

I welcome you again for this NPTEL lecture on earthquake geotechnical engineering. And today we are at the lecture number 14, and this is related to dynamic soil properties. This is the fourth lecture on the dynamic soil properties, and it is on the field test and third lecture on field test. So, today we will complete the field test, and, in this lecture, this is a part of the module 2 of dynamic soil properties and we are under the chapter second. There are four chapter in this module.

So, chapter 2 on field test will be completed today. As a part of the chapter 2, this is a lecture 14th here and what we have covered in lecture 13 they are listed here. We talk about low strain test which includes seismic refraction test, steady state vibration test, then we have SASW test, seismic cross hole test, seismic down hole and up hole test and seismic cone test. What we are going to be covered in this lecture? Field test that is high strain test that is standard penetration test, then we have cone penetration test that is CPT, dilatometer test that is DMT and pressure meter test that is PMT.

And let me acknowledge that most of the information in this lecture is from book by Kramer on geotechnical earthquake engineering. Coming to the high strain test, we already covered the low strain test. At the higher strain rate, behavior of soil is elasto plastic and it produce what we call the irrecoverable permanent deformations. When you have the low strain that deformations may be recovered elastic deformation, but at high strains the deformations may be irrecoverable, and we have the permanent deformations. For geotechnical earthquake engineering problems, the following tests are of particular interest which is one is SPT standard penetration test, then we have CPT cone penetration test, dilatometer test and pressure meter test.

So, these 4 tests are there which we are going to discuss one by one today and all 4 are the field test, all 4 are kept finds in the category of high strain test where you have permanent deformations. So, let us talk, we start with the first one standard penetration test SPT. SPT test is very widely used worldwide. So, this is a quite oldest test and most popular. So, you can categorize this is oldest in the field test and most popular. If we talk about soils, any test data is available worldwide not only in our country India, but in even in US or Japan that is this is SPT. And in the SPT this is a standard penetration test and the oldest and most common. It is also commonly used in the number of geotechnical earthquake engineering applications for example, liquefaction. When we discuss the liquefaction, you can correlate the liquefaction resistance using the SPT data n values. And there is a code IS code number 2131 1981 which is called method for standard penetration test for soil which deals with procedure involved for SPT.

So, what you have in this test in the SPT a standard split barrel sampler is driven into the soil at the bottom of a borehole by repeated blows and these blows are 30 to 40 blows per minute of a hammer. The weight of the hammer is 63.6 kg, and it is released from a height of 76 centimeter. So, you have a hammer why it is called standard because many things are standardized the weight of the hammer is standard 63.6 kg it is fall from a height of 76 centimeter and number of blows rate of the number of blows is about 30 to 40 blows per minute.

The standard SPT sampler should have a constant inside diameter. The use of sampler designed to accommodate internal sample liners can understand that penetration resistance by 10 to 20 percent when the liners are not in place. The sampler is usually driven 450 mm. The number of blows required to achieve the last 300 mm of penetration is taken as the standard penetration resistance n. So, when we actually penetrate what is done in this SPT you drive your sampler total depth 450 mm, and this depth 450 mm is divided into three layers each layer is of 150 mm. So, this is three layers.

So, I start from top, and this is 150 mm then another 150 that is 15 centimeter and the last one is another 150 mm. So, the first layer 150 mm this is called the seating drive and last two layers this is 150 and 150 mm the number of blows required for example, in the first layer number of blows required is n 1 in the second layer n 2 and then n 3. So, n will be simply n 2 plus n 3 we do not count the number of blows required to penetrate the first layer which will come under the seating drive. The n value is a function of the soil type confining pressure and soil density but is also influenced by the testing equipment. So, here basically n will represent this n value will represent your strength.

So, here strength will be represented, and this is basically strength which is shear strength and this will influence that means, if you have better n in that case your shear strength will be high. In the standard penetration test you have here a sampler you can see the setup of a SPT here given. So, you have like this is donut hammer and the slip or guide. So, what you do, and you have the rotating like what you have this rope in fact, this is chain this is, and this goes from the pulley and when you move it, it go up and down when you release it here it will come down when you stretch it then it will come up. So, what is done here you lift the SPT hammer up to certain height and you drop it and again drop it one blows second blows third blows like this and then you count the number of blows to go that this part at certain depth. So, you have the borehole inside this one and this is an anvil where a strike is done and then you have drill rod. So, this way the SPT this is the systematic of the SPT. Now continue with this the data which you get from SPT requires some corrections for different purposes and it is very common to normalize the n values to an overburden pressure of 100 kilo Pascal because the overburden pressure in the field will be different particularly at different depths. So, what we do we normalize this overburden pressure to what 100 kPa there which is roughly one bar and to correct to and what you call the and then we apply correction and energy ratio of 60 percent, and this 60 percent ratio is what is this ratio the average ratio of the actual energy delivered by SPT hammers to the theoretical free fall energy. So, you have actual energy and the free fall energy.

So, you have n 1 60, n m c n and so this is the way here this equation is. So, in this case you have this number of measured penetration resistance and c n is overburden correction factor and what is you have in this case penetration resistance and overburden. So, this is the measured value n m, n m is the measured value from the field, c n is the correction factor and then this correction is for overburden, this correction c n is applied for overburden. The last correction this is due to the energy. In this case E m is the actual hammer energy and E f f is free fall.

$$(N_1)_{60} = N_m C_N \frac{E_m}{0.60 E_{ff}}$$

So, suppose you have E m equal to 0.72 E f f if I have this case. So, this factor will becomes 1.2 and for the conservative side minimum will be 1. So, normally this energy correction will not be less than 1 then overburden correction will give you the values of how c n varies with the depth and c n will be different at different depths.

So, the values of c n and this is also like in this code also there is a code for that and that also says about these corrections. These n 1 60 values which is recorded from this SPT they are after correction they are used for the liquefaction analysis. For gravelly so is another test what is called Baker hammer penetration test can be used and it is used in the same way as the SPT for sands. The BPT resistance is taken as the number of loads per foot of penetration corrected for diesel hammer or in the bounce hammer which reflects the effect of soil and the combustion. So, this is about a Baker hammer.

So, with this complete SPT. Now the second test which is called cone penetration test. One thing I would like to point out here about the c n which is I think somehow it is missed here in the slide. When you have the with the depth what will happen your c n values are like if I have here when I increase the overburden pressure if my overburden is about 100 kPa then the c n should be 1. So, this is one value, and this is the lowest value. So, this like you have it varies like it will go 1 and then it may be more than 1. So, it may be 2 here. So, this curve goes like this one with the. So, this is this value is roughly this is c n on x axis.

So, this is 0.4 and this value is about 1 which is at 100 bar 100 kPa depth and if you go at the most it can go up to 2. So, c n typically like taken the value of c n correction should be between 0.4 to 2. It should not be less than after applying the corrections and there is equation for the c n which is for calculation of the c n equation.

So, 0.77 log 10 then you have 2000 sigma v 0 this is the equation. So, use this equation what is in this equation sigma v 0 is like I can write it here only is effective overburden pressure and this effective overburden pressure should be in kilo Pascal. What you have in the second test after once we done with this. So, you use c n and then these corrections and then you find n 1 60 value. Now coming to the CPT which is called cone penetration test.

The CPT involves the steady penetration of a standard cone penetrometer into the ground and this standard cone penetrometer has a conical tip of 10 centimeter square area and 60 degree apex angle immediately below a cylindrical friction sleeve of 150 centimeter is surface square surface area. So, like SPT in the CPT also many things are standardized and what you have the cone which have a tip and the area of the tip is 10 centimeter square and this is an apex angle of 60 degree and this area and apex angle they are immediately below a cylindrical friction sleeve and the area of the friction sleeve is 150 centimeter square. The penetrometer is pushed into the ground at a constant rate of 2 centimeter per second. So, we push like penetrometer in the ground, and this will be pushed at a like you know that at a like in the SPT also number of blows rate of the number of blows was constant. Similarly, in the CPT you have a number of rate of this penetrometer is 2 centimeter per second.

A typical example of CPT is given here. So, in the CPT you use some mechanism like a truck or like on the top, which is used for rig with hydraulic pushing system, but even it can be done without you know the truck also but then machine will be like loading a penetrometer goes inside this or the inside the ground. So, what you have here in this figure, which is enlarged, and this enlargement has been done for a cone showing the detail for the cone. You have the cone, and, in this cone, you have sleeve friction resistance, which is Fs, you have cone measured tip resistance which is denoted as Qc. So, you have Qc what are the parameters which is measured, then you have Fs sleeve friction, and you get the total cone tip resistance where and then another item which is pore water pressure.

Pore water pressure to measurement for the pore water pressure you require what is called piezo cones. Piezo cones are used for the seismic piezo cones which are used for measurement of pore water pressure. So, to measure u in the field at different Fs. So, that is also possible using CPT. In the CPT the tip and friction sleeve are each connected to load cells that measure the tip resistance Qc and sleeve friction resistance Fs during penetration.

$$\mathbf{FR} = \boldsymbol{f_s/q_c}$$

The friction ratio which is denoted by this ratio Fr which is Fs divided by Qc, friction ratio will be this ratio, and this is also a useful parameter, and this ratio is high for cohesive soils and it is low for cohesion less soils. The absolute and relative magnitudes of the penetration resistance can be correlated to the many of the same properties of the SPT and also to soil type. So, many data like you have the correlation with the data with the SPT and CPT data which is like some correlations are available in the literature. How the typical results for CPT looks which is given here. In case of like CPT, cone penetration test, you have different results of the like friction resistance, how the friction resistance is varying with the depth which is shown in this figure and then you have which is tons per feet while bearing resistance also given in this figure which is tons per feet square. Friction ratio will depends on sleeve friction and cone penetration. So, Fs is sleeve friction and Qc is tip resistance. So, if you divide sleeve friction by tip resistance then you get the friction ratio and you see the friction ratio also varying. In this case, it is varying from 0 to 6 and with the depth variation is quite large. The CPT can be performed rapidly and relatively independent inexpensively because in CPT you are just continuously pushing inside you are not taking it out like the because no sample is collected in this case. So, you are just pushing your penetrometer with certain rate inside the ground. It provides a continuous profile of penetration resistance that can detect the presence of layer thin layers or sand that are easily missed in the SPT testing. The capabilities of cone penetrometers can be enhanced by adding additional transducers to measure additional variables such as pore water pressure, piezocone or wave propagation velocity. So, this can be done.

Now continue with cone penetration test. How the CPT cannot be used at sites with very stiff or very dense soils without damaging the probe or roads. So, if you have very stiff site what will happen? The cone will get damaged when you push it inside, for example, in the rock then it will damage its cone and it is difficult to conduct this test. The presence of gravel size particles can also limit the use of the CPT. If you have the large gravels, then no sample is collected like what is done in SPT. And there is an IS code for the CPT also 4968 part third of 1976 which is method for subsurface sounding for soils that is involved for CPT. So, this was about CPT. Then the third test for the high strength testing in the field is called dilatometer test that is in the short called DMT. The dilatometer test or DMT use a flat dilatometer and dilatometer is nothing but a stainless steel blade with a thin flat circular expandable steel membrane on one slide. The dilatometer is jacked into the ground with the membrane surface with the surrounding blade surface. At intervals of 10 to 20 centimeter penetration is stopped and the membrane inflated by pressure is gas. So, in this case pressurized gas is used and this pressurized gas is used after once penetration is stopped and the membrane which is there that will be inflated by this using the gas.

Continue with the dilatometer the pressure at which the membrane moves by 0.05 mm that is what is called the lift of pressure denoted as P naught. So, one is the lift of pressure P naught and the pressure at which its center moves that is 1.1 mm about that is P 1 they both are recorded. So, you are recording two things the lift of pressure and another pressure which its center moves by a certain distance. So, one pressure is P naught another pressure is P 1, and these are used with the what is called a hydrostatic pressure U naught and the effective overburden pressures sigma v naught to compute various indices to its soil properties can be correlated. So, you have lift of pressure P naught you have the pressure P 1 by which the center moves an amount of 1.1 mm, hydrostatic pressure and effective overburden pressure. So, these four will be used to calculate the indices in the dilatometer test. These indices are given here. So, in these indices you see the most commonly used indices are the material index, which is called ID, the horizontal stress index which is called KD and the dilatometer modulus ED.

$$I_D = \frac{p_1 - p_0}{p_1 - u_0}$$

$$K_D = \frac{p_1 - u_0}{\sigma'_{vo}}$$

$$E_D = \alpha(p_1 - p_0)$$

And in the first case you have P 1 P naught and U naught 3 are involved in KD effective overburden pressure is also involved and in ED this is alpha multiplied by P 1 minus P naught. So, you see the ID dimensionless, nor it is ratio same thing is KD is dimensionless, but ED which is a dilatometer modulus it have will have the same unit as P 1 or P naught alpha is dimensionless. So, dilatometer test how it looks this is given in the figure. So, you have flexible membrane which is about 60 mm in diameter. So, diameter of this is like 60 mm and then you have 90 mm is the outer shaft.

So, this is the elevation first part is the elevation and the second side views are there. So, two side views are there. So, in this case you have a wire, and you have a pneumatic tubing which goes inside this and like thickness which is basically diameter of this your cone which is here it could be about 14 mm is there and then you are applying the pressure is this from the side and similarly. So, this is what you call the flexible membrane is there and these are the pressure measurement.

So, this is side views of the flat dilatometer. So, this was and then in this equation ED which is for dilatometer modulus alpha is equal to 34.7 for a 60 mm membrane dilatometer and a membrane deflection of 1.1 mm. So, if dilatometer is 60 mm and 1.1 mm deflection then you get the alpha value 34.7. Dilatometer parameters have been correlated to low strength soil stiffness and liquefaction resistance. So, they have been used for that. The last part for high strength testing is what we call the pressure meter test. In the pressure meter test PMT is the only in-situ test capable of measuring the strength stress strain as well as strength behavior. The pressure meter is a cylindrical device that uses a flexible membrane to apply a uniform pressure to the walls of a borehole.

So, you have this in the pressure meter test. A cylindrical device is used, and the cylindrical device was used in there also in the dilatometer and it uses a flexible membrane which is to apply a uniform pressure. So, let us see how it like this looks pressure meter test. Deformation of the soil can be measured by the volume of fluid which is injected into the flexible membrane or by filler arms for pressure meter that use compressed gas. After correcting the measured pressures and volume changes for system compliance, elevation difference and membrane effects a pressure volume curve can be developed. So, when you want to develop the from the output of the pressure meter will be pressure volume curve that is how much because there is a fluid is used and that fluid volume of that fluid is used for the measurement of like the pressure measure.

So, to generate pressure volume curve you need to apply corrections and that corrections are related to changes for system compliance, elevation differences and the membrane effects. So, these are done, and this pressure meter test setup is given here. You have a control unit on the top, you have a borehole and cylindrical flexible membrane which pressurize by the fluid and so it goes, so volume is known and the pressure which goes inside this borehole that is also measured and by these calculations we calculate the level of because at this high strain and it is happening at the high strain so we can calculate the properties of the material. Using cavity expansion theory, the pressure volume curve can be used to compute the stress strain behavior. So, this will be used for the stress strain behavior, characteristics.

Self-boring pressure meters which minimize soil disturbance and push in pressure meters which can penetrate soft soils very quickly have also been developed. So, with this we complete the field test using high strain test. So, in fact, with this we complete chapter 14, and we completed two chapters of the module 2, one is stress condition, another is on the field test. So, now in the next lecture which chapter 3rd on the laboratory test and in the chapter 3rd we have again three lectures including in the laboratory test both low strain as well as high strain test. So, thank you very much for your kind attention. Thank you.