Soil Dynamics
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Module - 4
Lecture – 21
Dynamic Soil, Properties
Estimation of Gmax, Modulus Reduction Curves,
Variation of Damping Ratio, Cyclic Plate load Test

Let us start today's lecture on Soil Dynamics, we are continuing with our module 4 that is dynamic soil properties.

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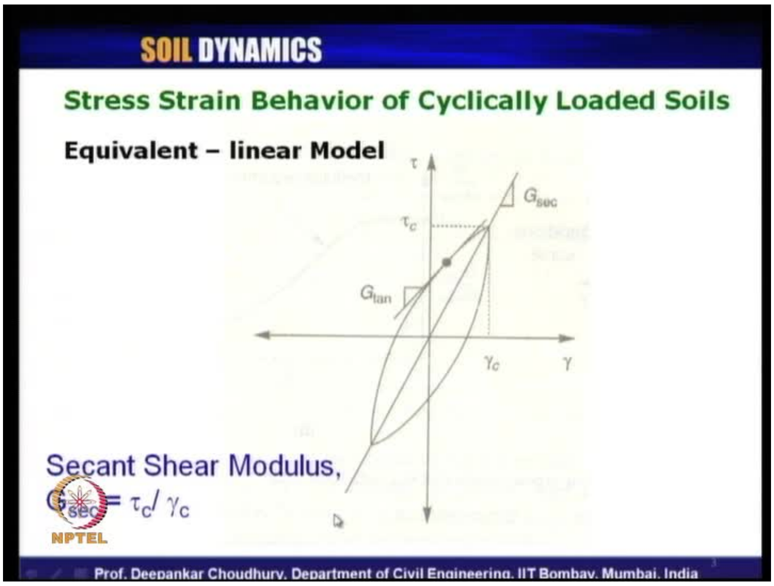

So, a quick recap of what we have learnt in the previous lecture.

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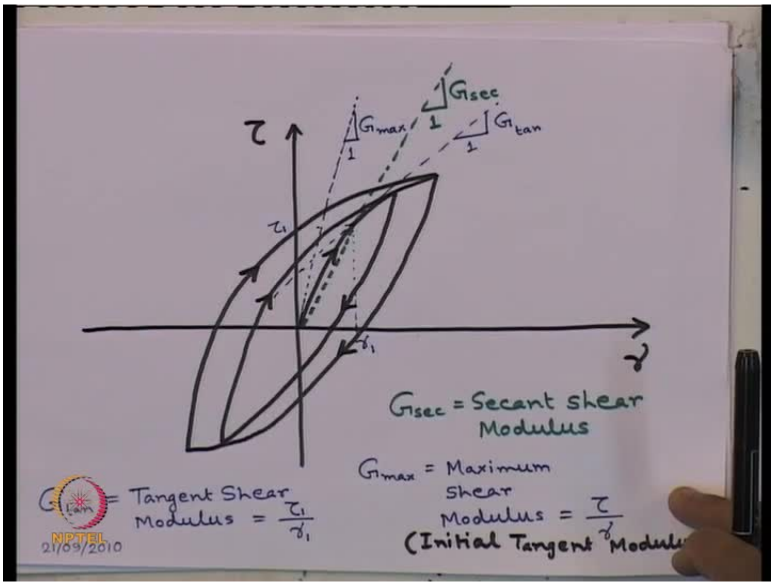

First let us look at this page that is any cyclic test in the laboratory, we can get the data for cyclic shear test versus shear strain. So, the plot of shear test versus shear strain we will start from this point origin 0, 0; it will go up in the loading curve, then if we release the load because this is a cyclic load, this is unloading curve and then again reloading curve. So, like that these are the cycles as per different cycles, we will get different envelope of this tau versus gamma plot.

Now, from this we have identified that the slope of the curve is not a constant value, but it is changing and we have learned that if we draw tangent at the initial portion of the curve that is called G max. G is nothing but the shear modulus which is given by this tau and gamma, shear stress is by shear strain is shear modulus. So, the initial tangent modulus is nothing but maximum shear modulus the slope of the curve at this point. Now, if we take slope of the curve at any point with any other cyclic shear strain value say gamma 1.

So, we can draw tangent at that point and the slope of the curve whatever it will give us the value of G is called tangent shear modulus. And another shear modulus we have seen which is if we join this point to the origin, the slope of that line will give us another shear modulus, which is called secant shear modulus. And what are the application of this three different types of shear modulus that also we have seen in the dynamic analysis.

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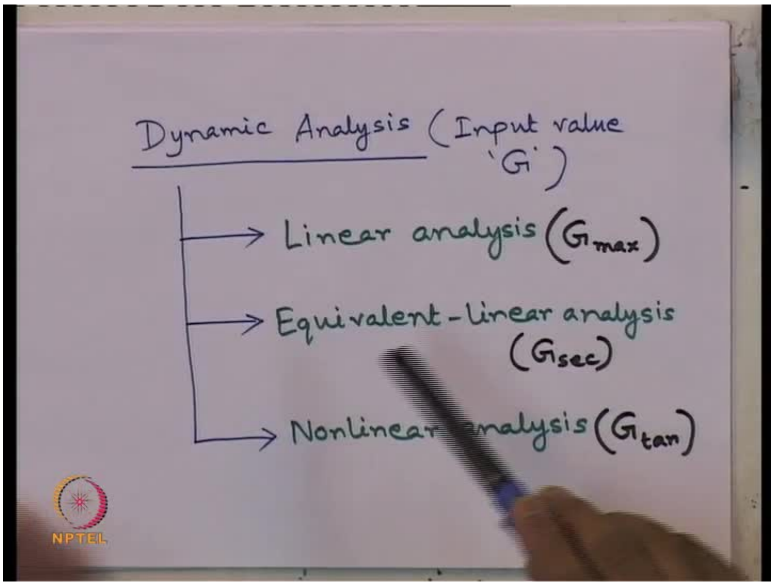

We can sub classify the any dynamic analysis into three categories linear analysis, equivalent linear analysis and non-linear analysis; based on what is our input value of the shear modulus we are using for the analysis. When we are using the maximum shear modulus it is linear analysis, which we have seen that it is the most easiest or simplest analysis, because he had the value of g max remains constant throughout the analysis.

And easily we can estimate this through any field test also because G max is correlated with the shear way velocity of the material through the equation rho v a square. Whereas, most complex analysis but most accurate analysis is non-linear analysis, where we are able to capture the behavior of the soil material that is shear modulus of the soil material at any value of its cyclic shear strain.

So, we should use at that point G tangent shear modulus, the tangent shear modulus as it is keep on changing with change of the curvature of the tau versus gamma plot. So, in your entire analysis this is a completely variable parameter throughout the analysis which is non-linear in nature. So, that is why this is the most complex but gives more accurate result.

Now, depending on the accuracy required for a problem, we can compromise in between these two extreme cases that is simplest analysis and the complex analysis. The in between one is called equivalent linear analysis, where we can use the secant shear modulus. If we aware of that up to a particular level of cycling shear strain our soil model is going to subjected to then in that case we can simply use the equivalent linear analysis by using secant shear modulus.

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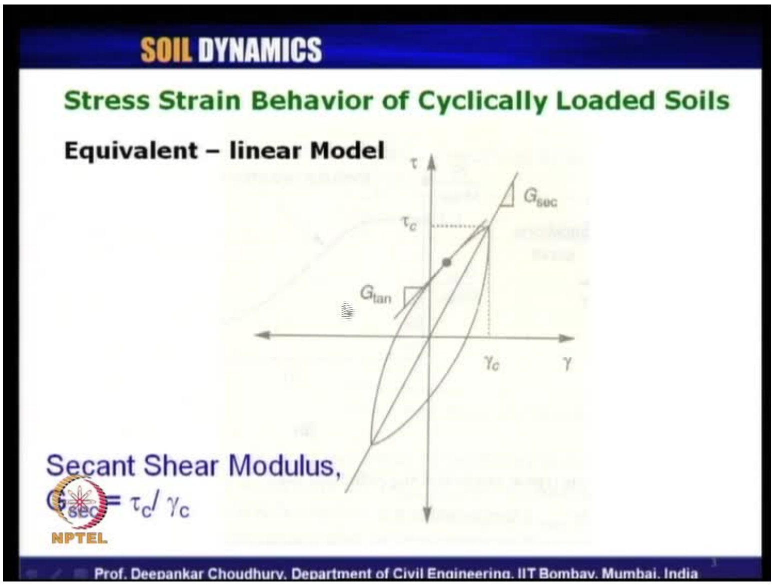

So, coming to the slides the stress strain behavior for any cyclically loaded soil, this is the equivalent linear model with G secant modulus.

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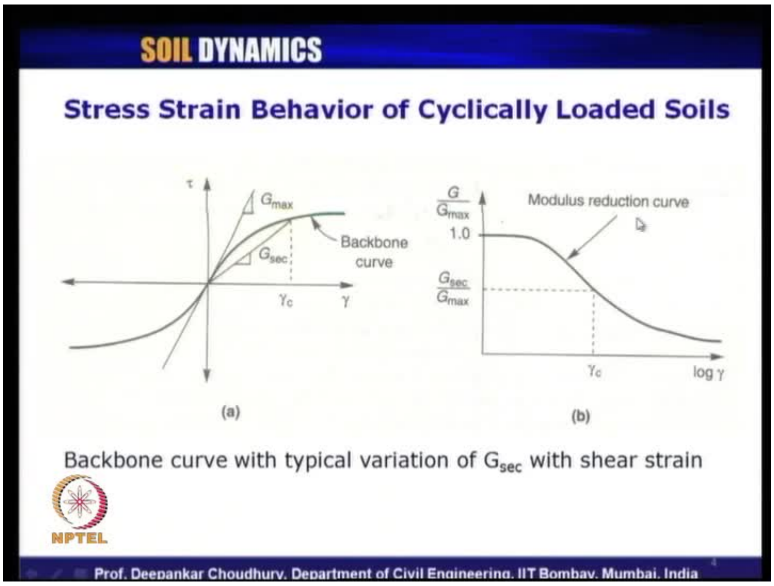

And from that we have seen what is called backbone curve, the plot of tau versus gamma is known as backbone curve. And if we represent it in a non dimensional form of G by G max versus the log scale of the cyclic shear strain and if we plot any data. The typical behavior for any kind of soil material will be something like this it should start from one because at very low strain the value of G is nothing but G max. So obviously, it should start from one and then with increasing cyclic shear strain the tangent shear modulus decreases. So, that is why this G by G max ratio is less than one it is keep on decreasing which known as modulus reduction curve.

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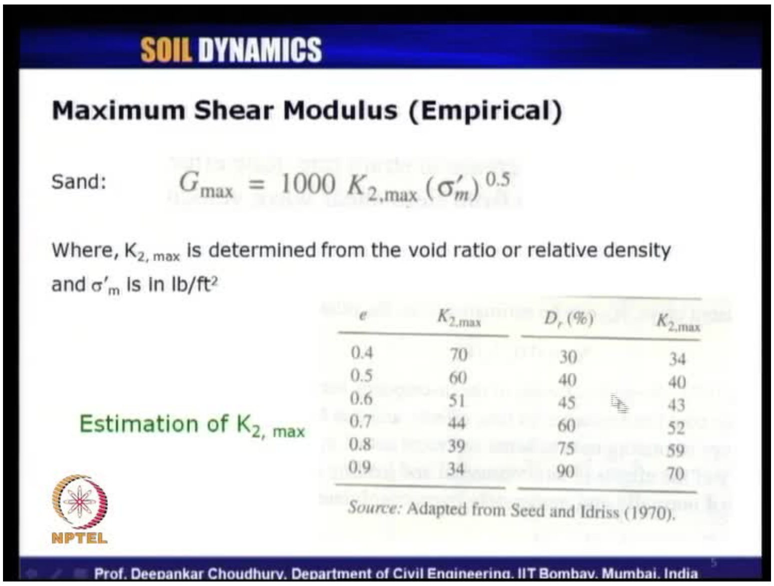

Then we have seen several empirical relations to compute the maximum shear modulus and caution also I have mentioned in using the empirical relations. First of all we have to very careful in which unit they are propose, because all empirical relations are unit bias. Another caution is that this empirical relation derived by several researchers, though mentioned for sand it may be because of only the local regional soil, for a particular soil it may be valid, for other regional soil it is still questionable. Whether it will be valid or not that needs to be checked, so this is the equation proposed by Seed and Idriss in 1970.

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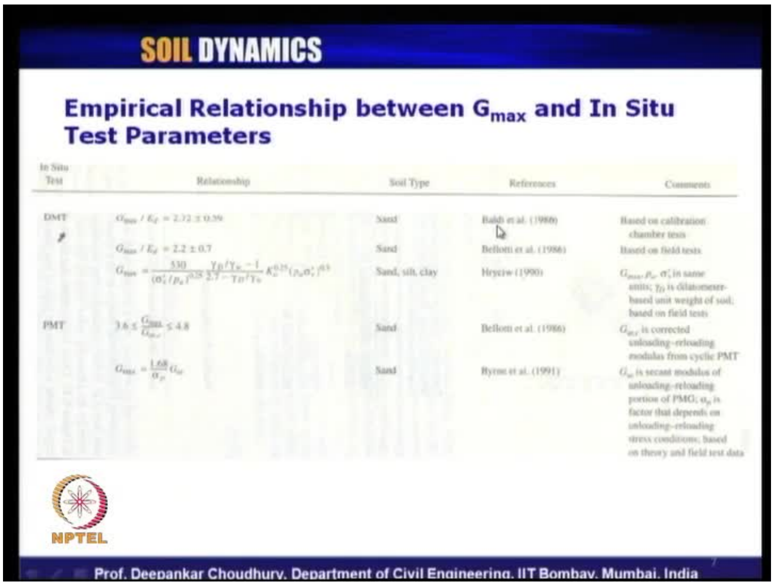

Other relationship have been proposed by several other researchers also depending on in situ test parameters that is standard penetration test value or cone penetration test value to compute the G max. Also the dilatometer test value or pressure meter test value also the G max can be computed as was proposed by several other researchers for different types of soil.

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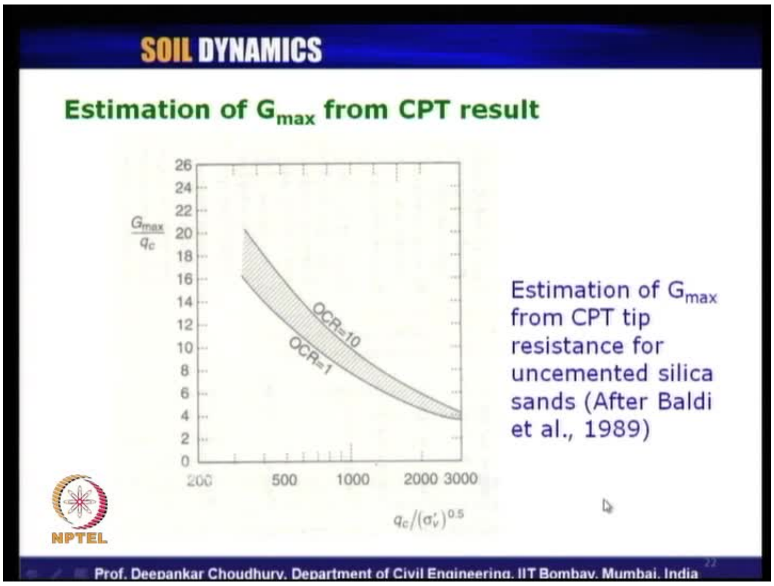

Now, some more estimation of G max value from cone penetration test result, as was proposed by Baldi et al in 1989, that they have used not only normally consolidated soil that is with OCR value 1 but also over consolidated soil with OCR value of 10. So, different values of OCR they have used and then they have plotted in y axis the variation of G max by q c which is of course, non dimensional. So, when you are getting in literature this kind of non dimensionalize result they are much better than the equations which are involved with dimensions.

And in the other x axis it is q c by sigma v dash to the power 0.5. So, the typical variation for different OCR levels is like this they have proposed for un cemented silica sand. These are the strains of the results, that is with increase in over consolidation ratio for a soil, the G max value will increase that is where they have shown through the experimental results.

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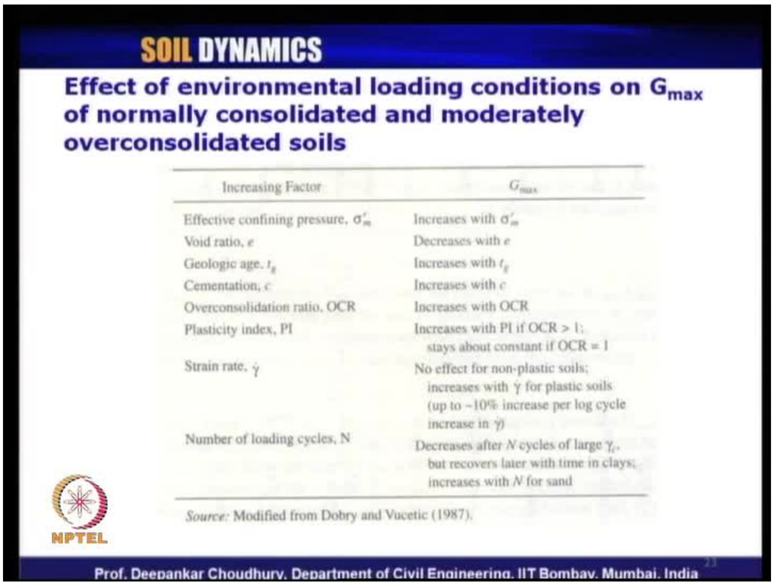

Now, this is one important aspect let us see what are the effects of environmental loading conditions on this value of G max for both normally consolidated and moderately over consolidated soil. So, look at this table what it says if effective confining pressure that is sigma m dash, if this value of effective confining pressure is increasing what will happen to G max that also increases, which is quite understood. Physically also we can understand this one that, as we keep on going much below from the ground surface that is if we go deeper and deeper in a soil straighter, if everything all other parameters remains same.

And soil obviously, we are considering the homogeneous soil then as we go deeper the G max value will keep on increasing. So, that is why it is mentioned effective confining pressure increases means G max value should increase. What happens if void ratio of soil is increasing, then the G max value will decrease this also we can understand physically, void ratio increasing means what happens, that is soils becoming more loose, more loose means strength of the soil will be much lower.

So, that is why void ratio increases means G max value should decrease, then let us look at another environmental factor that is increase in geologic age. Geologic age means like formation of soil if it is geologically very, very old ancient soil or what we sometimes called the parent soil is present at any particular location. Rather than a transported soil or field of soil material from one place to another, if we do the test any the of these cyclic fractions or cyclic simple shear what we will get.

The value of g max with increasing geologic age, there will be increasing g max value which also we can physically understand. But, older the soil obviously, the strength of the soil will be much more than the transported soil or field of material. What happens if the cementation of the soil changes a cementation of a soil increases, cementation means; obviously, the bonding between the soil particles are much more. So obviously, it is suppose to give higher strength.

So, there will be increase in the value of g max with cementation what happens if over consolidated ration increases, just now we have seen. Obviously, if over consolidated ratio increases the G max value also will increase because over consolidation ratio increases means, earlier the soil was subjected to higher load that is what means by over consolidated soil. Obviously, that will give a higher strength of the soil rather than a normally consolidated soil, which was not subjected to higher magnitude of the load.

Now, what happens if plasticity index increases, what is plasticity index we known for fine grain soil, we know plasticity index liquid limit minus plastic limit. So, if that value increases the G max value increases with pi only if it is a over consolidated soil but if it is a normally consolidated soil, then plasticity index hardly is having much effect on the value of g max. That is where is found out by all these observations were made by Dobry and Vucetic in 1987 that is the source.

Now, what happens if the strain rate you know that all test not only the dynamic test also the static test like, if you take fractal test or paraxial test these are strain rate based that is if you change the rate of application of your strain. Obviously, you will get different results or different modulus of the soil. Similarly, for the dynamic test also, if you keep changing the application of your strain rate that is at which the rate of strain applied to the soil sample is changed.

What happens to the g max value it says almost no effect for non plastic soil, that is mostly sandy type of soil are the cosine less soil. But, for plastic soil or for fine grain soil it increases with increase in the strain rate, that is if we increase the strain rate, then the G max value increases up to about 10 percent per log cycle with increase in the strain rate. And what happens if the number of loading cycles increases, what is meant by number of loading cycles.

When we are doing the dynamic testing as we have seen we are doing loading unloading loading unloading. So, that gives us the how many times or how many numbers of cycles of load we are applied to a sample, if we increase numbers of cycles of load to a particular sample, what will happen the G max value will decrease with increasing number of cycles, at large value of shear strain. But, if you stop the experiment then it recovers the G max value whatever I have lost due to the number of applied cycles of load. It will recover later with time in case of only clays, but with increase in number of cycles the G max value decreases for sandy soil.

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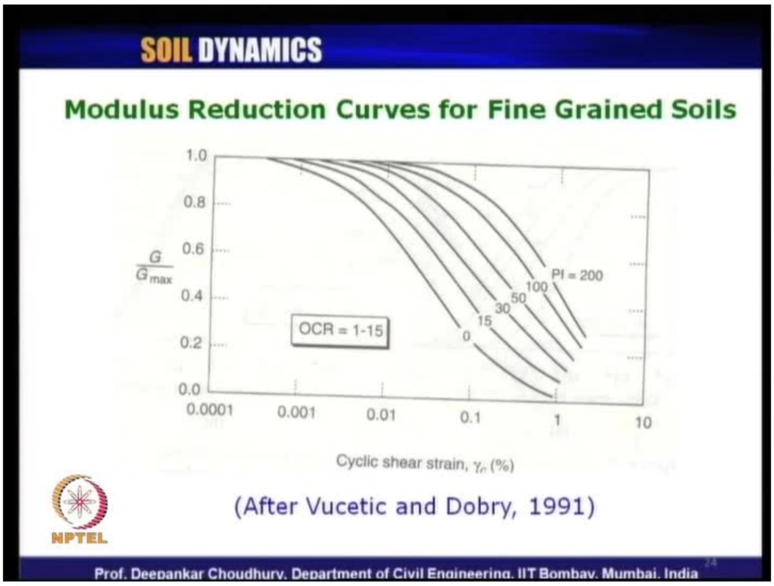

So, let us look at modulus reduction curve for fine grained soil, this is also proposed by Vucetic and Dobry in 1991. Modulus reduction curve means we know g by g max in the y axis and x axis is log scale of the cyclic shear strain which is applied to the sample. So, this the lab test result; obviously, as we know the curve should start at this G by G max at one at very low strain level and then with increase in strain they will keep on decreasing.

So, strain is known now to us, what happens they observed for OCR value between 1 to 15 as the plasticity index increases for the soil, the variation will be like this. But, remember I am coating here the observations by Vucetic and Cobry in 1991 through their lab test; do not consider any of a particular test as universally truth, all these are open under research problems. So, what I want to mention look at this value of P I what does P I 0 means, P I 0 refers to it is a cohesion less soil, not a fine grained soil right.

So, that is why there is no plasticity index but now if we think logically if you want to apply your mind logically does it mean that for different types of sand. Whether it is dent sand or medium sand or loose sand the modulus reduction curve will remain same a single line no. Then what does it mean it is meaning that G value at G max value that ratio remains constant for irrespective of type of cohesion less sand, which is not correct.

So, that is why this is a cohesion later on by several researchers this mistake was pointed out by researchers like Brey et al that this is not a correct graph only for P I equals to 0.

So, whenever you are using this graph for your designer analysis make sure that you are not using the line P I equals to 0 but other graphs are correct. So, that is why limitation of any particular test exerted must be known, rather than using blindly this curves for analysis are design.

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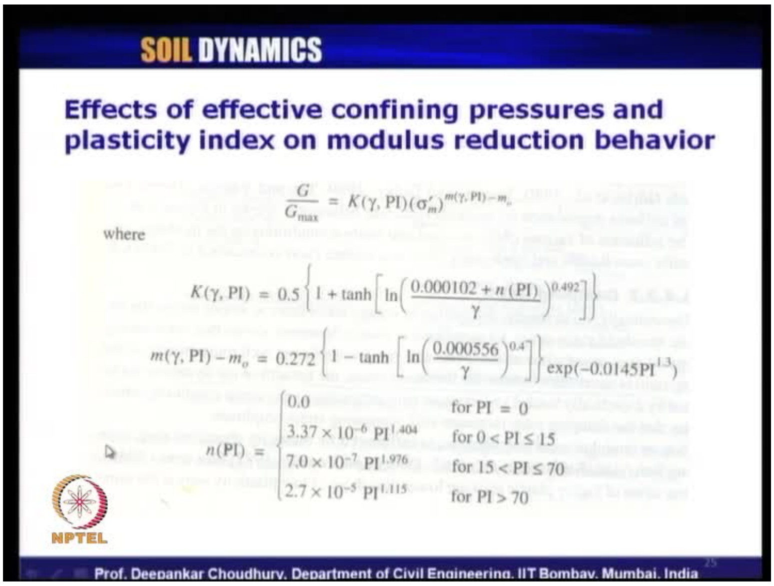

Now, what is what are the effects of effective confining pressure and plasticity index on the modulus reduction behavior. So, this relation has been given G by G max can be computed using this expression K, K is a function which is function of the shear strain and plasticity index. And another function of this effective confining pressure to the power some factor of m which again a function of this shear strain and plasticity index minus m naught.

Where the expression for this function k, which is the function of gamma and P I is given by this and this coefficient that is m which again a function of gamma and P I minus m naught is expressed like this. And this n of pi this function n of P I you can look at here, for different values of P I values are listed with respect to this. So, these are the relationship obtained from the laboratory test results, which we have shown just now, from those curve they have plotted. And formulated a generalized equation to compute the value of g by g max at any strain level and for any particular value of plasticity index.

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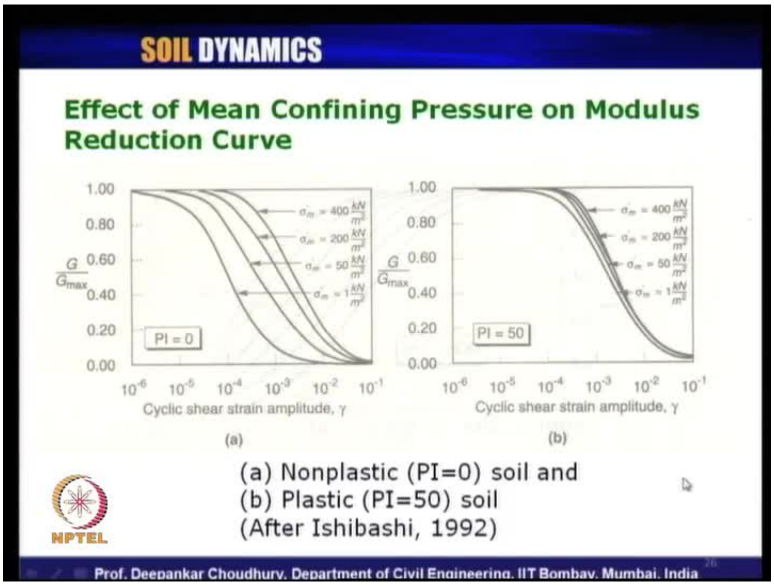

And effect of mean confining pressure on modulus reduction curve it is given by Ishibashi in 1992 mostly for Japanese soil. So, G by G max earlier one was for mostly the California region soil. The Vucetic and Dobry's work is from California soil they are from UCLA and Ishibashi's work for Japanese soil they also proposed the effect of mean confining pressure that is sigma m dash. If it increases what we have learned just now, if sigma m dash increases G max value will increase or strength will increase right.

So, strength should increase that is why there is a shift of the modulus reduction curve in this direction as we are increasing the sigma m dash value for P I equals to 0 for different cyclic shear strain amplitude. And at high value of P I they have showed almost that is no effect of mean confining pressure on the modulus reduction curve. So, when it is non plastic soil, the effective tremendous when it is plastic soil, highly plastic soil the effective very marginal.

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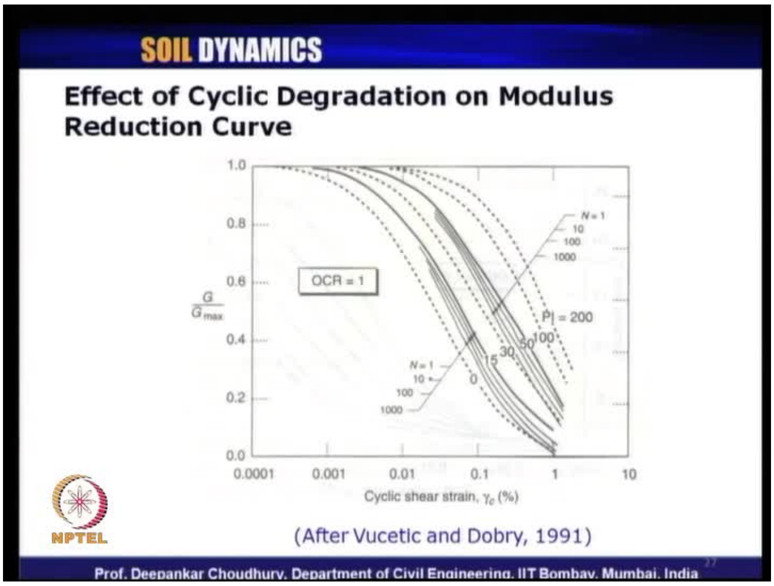

Also Vucetic and Dobry from their same results at proposed this is actually the PhD thesis work of professor Vucetic, who is a now professor at UCLA Los Angels; and he did PhD with professor Dobry. So, another set of results they have proposed how the degradation of this modulus reduction curve occurs at different numbers of loading cycles. So, this n denotes the different cycles number of loading cycles and this P I denotes already we have seen for different plasticity index with the constant OCR of 1.

And as I have already said P I 0 later on has been proved by several researchers of you see Berkley that these are not correct or should not be used. So, with this concept of effect of cyclic degradation on modulus reduction curve, and how to estimate the different shear modulus and to apply them in the dynamic analysis. We have seen in the next lecture we will continue our discussion with the damping ration that is another important soil property.

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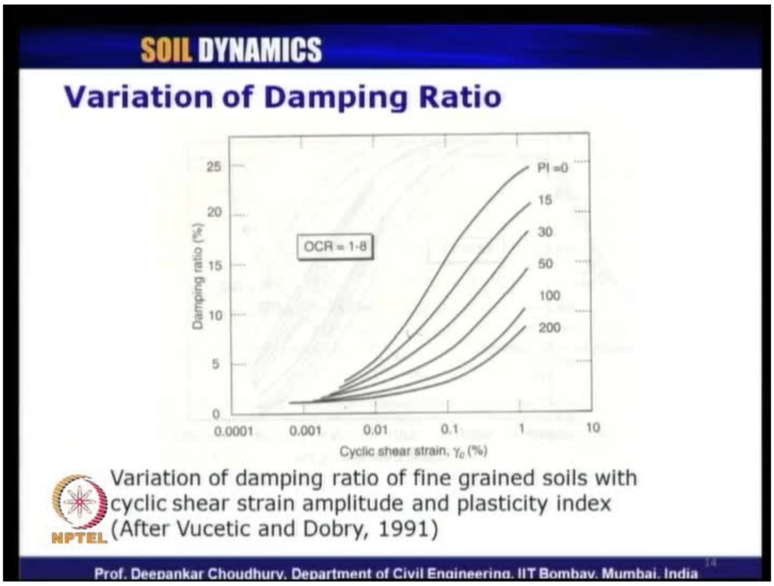

Now, coming to the next important parameter dynamic soil property is damping ratio. So, the most important dynamic soil properties are a g value shear modulus and damping ratio. Now, coming to the damping ratio how to estimate the value of damping ratio.

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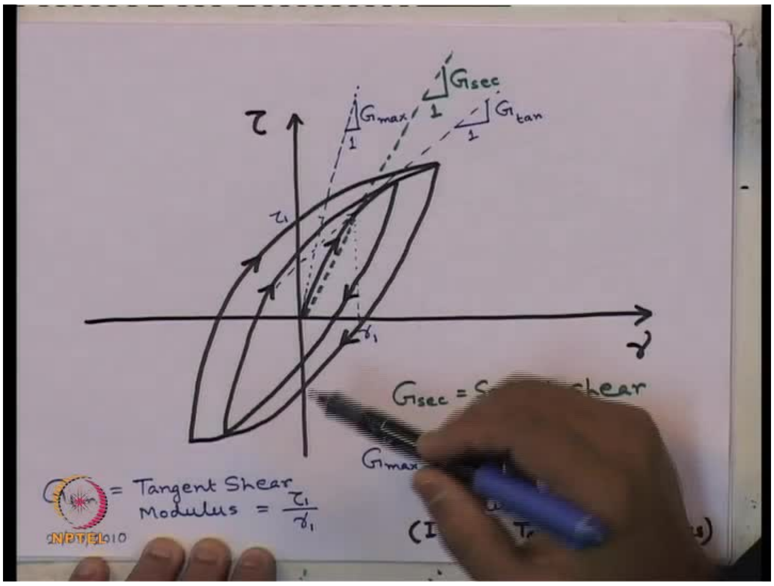

Let us look at this picture once again from any cyclic load test we are getting a typical curve like this, which is known as hysteresis curve, this tau versus gamma plot for different number of cycles of loading. Now, among these curves the third cycle is called the representative cycle.

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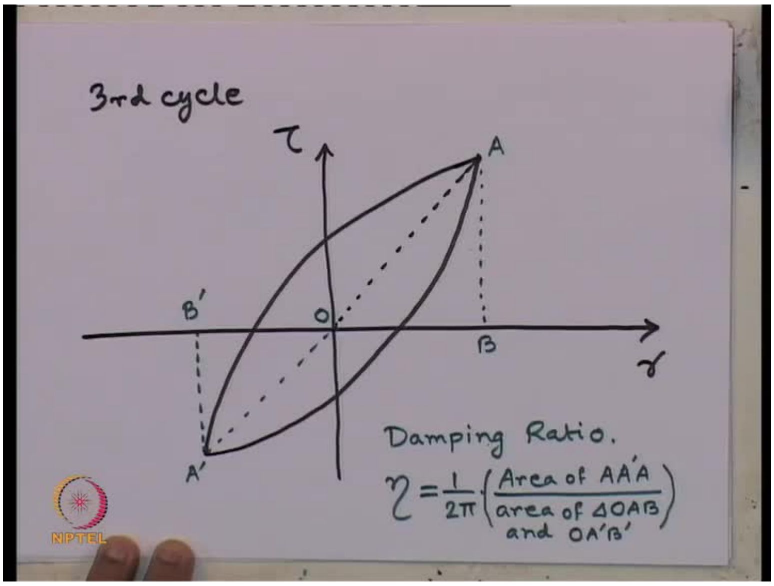

Third cycle of the hysteresis curve is called a representative cycle to compute the value of damping ratio. So now, let me plot the hysteresis curve for a typical third cycle let us say the hysteresis curve looks like this, this is for third cycle am using. So, let me give the nomenclature of various points, because it will require for us to compute the damping ratio of the system; let us say this is the origin, this point is say A, this is B, this is A dash this one is B dash.

So, damping ratio if we express is by eta that is given by 1 by 2 pi times area of this hysteresis loop that is area of A A dash A, so area of A A dash A that hysteresis loop divided by area of triangle OAB and O A dash B dash. So, this is the expression to the damping ratio for any soil from the cyclic load test, how to obtain a g value that we have seen this is the way we compute the damping ratio. For representative cycle, which mostly taken as the third cycle of loading 1 by 2 pi area of this loop divided by area of this triangle and area of this triangle. Now, let us see what are the different effects of various of this damping ratio with change of cyclic shear strain as proposed by various researchers.

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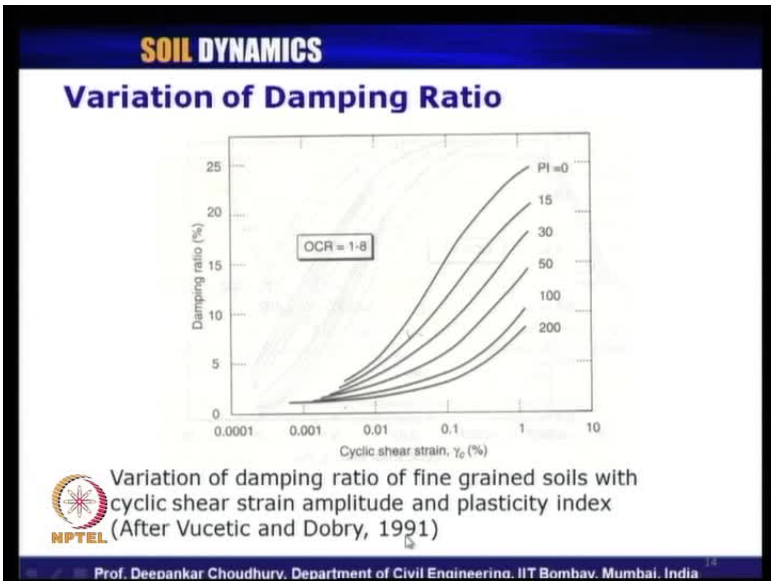

So, again the work of Vucetic and Dobry in 1991 for fine grained soil as been reported here for different values of cyclic shear strain how the damping ratio behaves it is represented in percent. And for various soil they have considered OCR value between 1 to 8 and for different value for plasticity index they have plotted the curve.

So, as you can see if the cyclic shear strain applied on a soil sample increases the damping ratio of the material also increases. Also if the plasticity of the soil decreases then the damping ratio increases for the case of fine grained soil, once again the quotient that is later on several researchers have proved that do not use this curve for P I equals to 1, because it is not actually the representative curve for non plastic soil.

Because, for sand also we can have a set of curves depending on their density, it is not that it will be a single curve for all types of sand. But, for non zero values of P I the trend will be like this. So, it is better to observe the trend that is with increase or decrease with pi what is the effect on damping ratio as well as on the change of cyclic shear strain, what is the effect on damping ratio.

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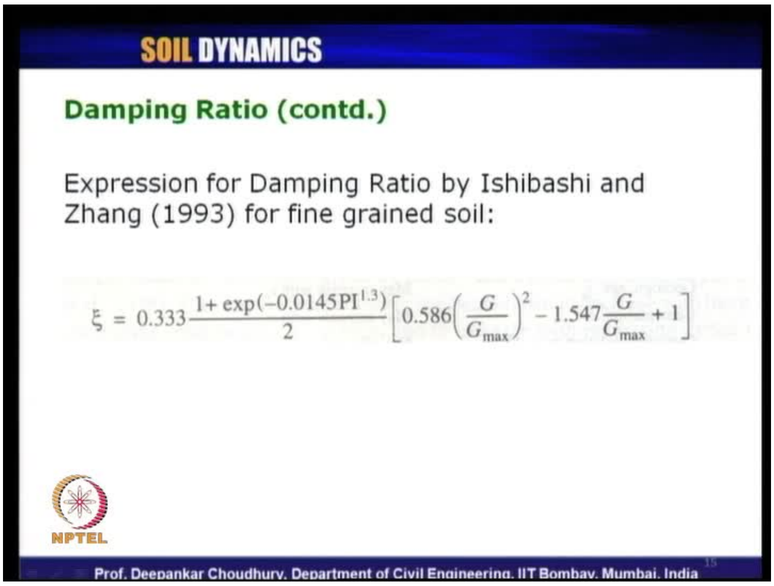

And the expression to compute the damping ratio value is proposed by Ishibashi and Zhang in 1993 for fine grained soil they again used mostly the soil from the Japan region. So, this is the symbol for damping ratio they have been used is given by this expression it is depended on the value of G by G max and the plasticity index. So, that is why when you are taking the G by G max at which particular value of cyclic shear strain you are using that automatically is taken care that effect.

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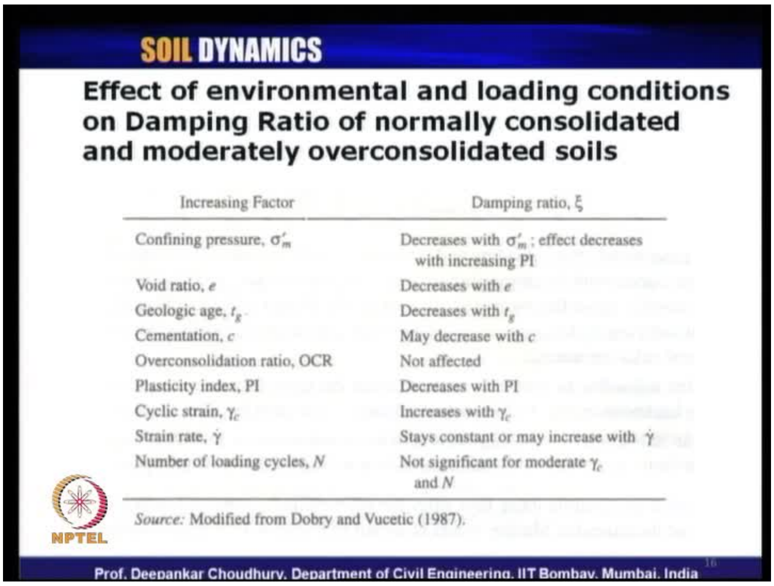

Now, let us see what are the various effects of environmental factors, and loading conditions on this damping ratio for normally consolidated as well as moderately over consolidated soil. If the confining pressure effective confining pressure sigma m dash increases, in that case the damping ratio decreases with increasing in the sigma m dash value. And effect decreases with increasing P I that we have seen with increasing the value of P I the effect of sigma m dash on G by G max curve as well as the damping ratio decreases.

Now, what is the effect of void ratio, if the void ratio increases the damping ratio decreases, what is the effect of geologic age. If geologic age of the soil increases damping ratio decreases, what is the effect of cementation with increase in cementation in the soil the damping ratio may decrease with the cementation but it is not, so significant.

So, effect of the cementation on the damping ratio is not very significant the trend is mine or decrease in the value of the damping ratio with increase in cementation. What is the effect of over consolidated ratio it was observed by this researchers Dobry and Vucetic 1987 that OCR is hardly having any effect on the values of damping ratio. So, for different OCR values of soil, we can expect the damping ratio remains to be almost same. What is the effect of plasticity index if plasticity index increases damping ratio decreases that we have seen just now in the plot also.

What is the effect of cyclic strain with increase in cyclic strain damping ratio also increases we have seen the curve the pattern of the curve. And strain rate the rate at which the strain is applied cyclic shear strain with the damping ratio remains constant or very insignificant amount of it can increase with the increase in the value of the cyclic shear strain rate with which it is applied. And with number of loading cycles the change in damping ratio is not significant for a moderate value of the applied cyclic shear strain. So, these are the effects of environmental and loading conditions on the damping ratio value of normally consolidated and moderately over consolidated soils.

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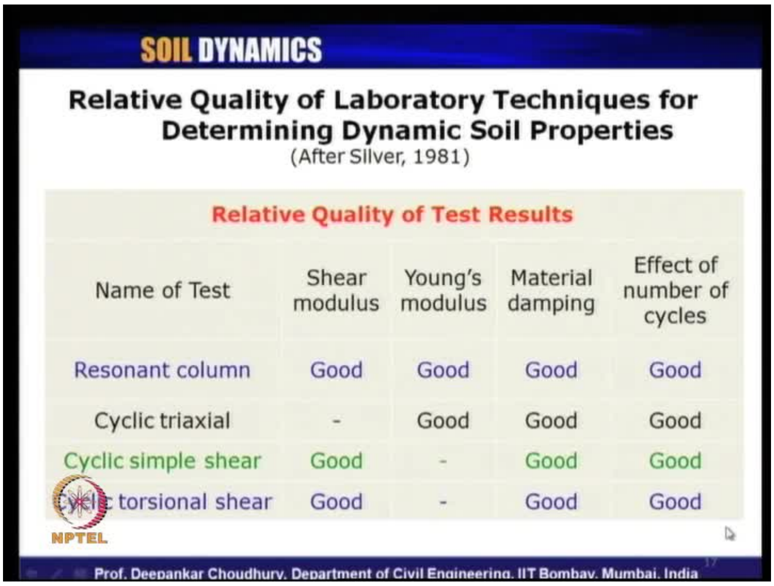

Now, let us come to the relative qualitative assessment for various laboratory test, what we have seen to determine the dynamic soil properties. It is given by silver in 1981 this column gives the various names of the laboratory test, that is resonant column test, cyclic triaxial test, cyclic simple shear test, cyclic torsional shear test. And these are the parameters which we are obtaining shear modulus, young's modulus, material damping and effect of number of cycles.

So, it has been observed that for resonant column test we get a good estimation of shear modulus and young's modulus and also a good estimation of the material damping and effect of numbers of cycles is pretty well represented for resonant column. In cyclic triaxial test, the shear modulus means directly we are not measuring, we measure through it young's modulus value. In material damping it represent a good representation of the material damping and effect of numbers of cycle is also good.

In cyclic simple shear, shear modulus directly we are measuring that is good material damping is also good and number of cycles is good. In cyclic torsional shear also directly we can get the shear modulus and material damping and number of effect of number of cycles is also good on the test.

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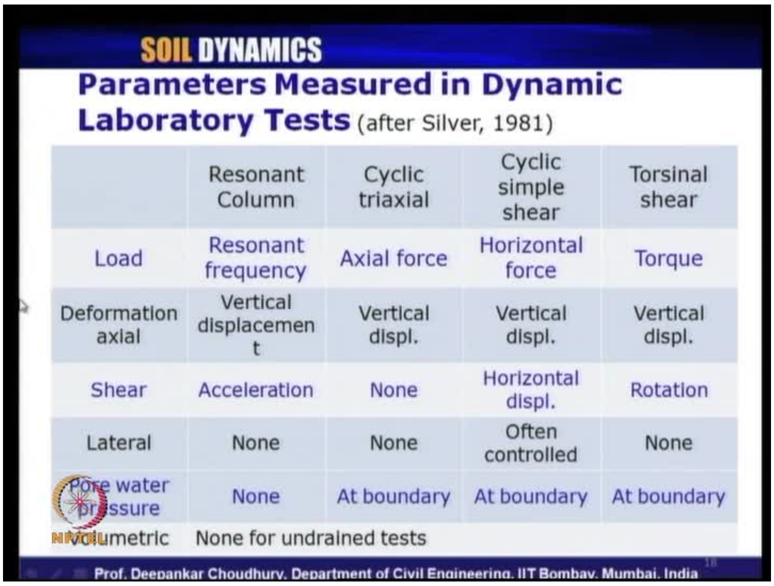

	Resonant Column	Cyclic triaxial	Cyclic simple shear	Torsinal shear
Load	Resonant frequency	Axial force	Horizontal force	Torque
Deformation axial	Vertical displacement	Vertical displ.	Vertical displ.	Vertical displ.
Shear	Acceleration	None	Horizontal displ.	Rotation
Lateral	None	None	Often controlled	None
Pore water pressure	None	At boundary	At boundary	At boundary
Volumetric	None for undrained tests			

Now, various parameters which are measured during the cyclic or dynamic laboratory test in different test procedure are listed in this table it is also given Silver 1981. The summary of the different laboratory test like resonant column test, cyclic triaxial test, cyclic simple shear test, cyclic torsional test and these are the parameters, which are measured are not is mentioned in this way. So, load in resonant column test we measured the resonant frequency, in cyclic triaxial test we measured the cyclic axial load provided in cyclic simple shear test we measured the cyclic horizontal force applied.

And in cyclic torsional shear test we measured the cyclic torque applied to the system. Regarding the deformation axial deformation for resonant column test we measured the vertical displacement in cyclic triaxial test also we measured vertical displacement, in simple shear test we measured vertical displacement and as well as in torsional shear test also we measured vertical displacement. Regarding the shear in resonant column test it represented a measure through acceleration, in cyclic triaxial we do not measure shear in cyclic simple shear test of course, we can measure it through the measured value of horizontal displacement.

And in torsional shear test we measure it through the amount of torsion then coming to the lateral load in resonant column test nothing is involved as such, in cyclic triaxial test also nothing is involved. In cyclic simple shear test the lateral load which is applied often they are controlled lateral load and in torsional shear test nothing is involved. Regarding the measurement of pore water pressure in resonant column test, we do not have any chance or scope to measure the pore water pressure.

Whereas, in all other three test that is in cyclic triaxial test we can measure the pore water pressure at the boundary of the soil sample. In cyclic simple shear test also we can measure the pore water pressure at the boundary and for cyclic torsional shear test also we can measure it at the boundary. And about volumetric strain none are measured in all this test for the un drained test, because when we are doing the un drained test we are not concerned about this aspect.

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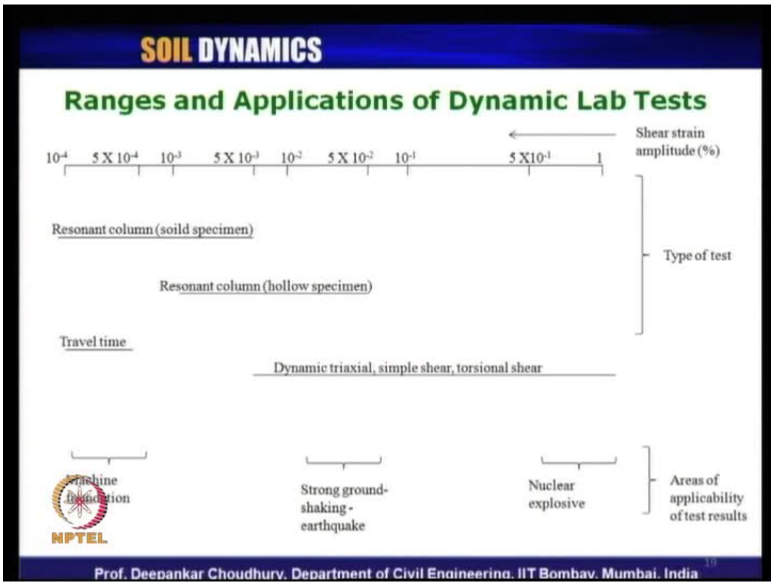

Now, let us see what are the various ranges of the cyclic shear strain amplitude, which are used for different dynamic test. So, ranges and their applications of dynamic laboratory test these are the this is the scale of shear strain amplitude strain, amplitude is here 1 percent, it is 0.5 percent, it is 0.1 percent like that in this direction it is decreasing. So, 10 to the power minus 4 percent very small value of the cyclic shear strain.

Now, what are the different types of test which are used for typical which ranges of the cyclic shear strain are mentioned here, like when we say resonant column test with a solid specimen. Then generally it is used in the test range for the shear strain in between about 5 into 10 to the power minus 3 to 10 to the power minus 4 percent of cyclic shear strain amplitude. That is the range which is applied to the soil sample while testing for a solid specimen.

Whereas, if we use a hollow specimen in that same resonant column test, generally we can go little higher value of the cyclic shear strain amplitude, which is about 5 into 10 to the power minus 2 percent to above 10 to the power minus 3 percent of the value of the shear strain amplitude. We can apply to our soil sample and results will get which are pretty good. And what we have seen all the geo physical test using the travel time method that is the basic concept those are effective only at very small strain values.

So, the shear strain amplitude ranging between about 5 into 10 to the power minus 4 to 10 to the power minus 4. So, these test are good in these range only means the values whatever we will observe from the test is good in this range of the shear strain. Whereas, the dynamic or cyclic triaxial, cyclic simple shear, cyclic torsional shear these test are good in the range of about 1 percent of shear strain to about 5 into 10 to the minus 3 percent of shear strain amplitude.

So, the application of the cyclic triaxial cyclic simple shear and cyclic torsional shear is pretty wide. So, they cover at high strain level as well as moderately low strain level also that is why when we had classified our laboratory test we have classified them in small strain test and high strain test. So, small strain is basically this resonant column travel time these can be classified as the small strain testing procedure whereas, these test of dynamic triaxial, simple shear, torsional shear these are classified as high strain testing procedure. Another in this small range comes the peso electric bender element test which also we have discussed they are also you are effectively measuring the travel time.

So, that is again a small strain laboratory test now what are their applications of these test of or what kind of dynamic load we should use. So, this is very important for a designer to understand that which test will be good for a particular design when they are taking care of under a particular type of dynamic load. So, it may not be universally true or generalized. So, this is very important these are areas of applicability of test results. See, the nuclear explosion nuclear explosive whatever strain shear strain they will induce in the system or induce in the material of soil they are of very high magnitude.

So, the nuclear explosion problems related are when you are dealing with design related to the nuclear safety related issues and loads are coming from nuclear explosion in that case it must be in the high strain range. What does it mean, which type of test we should use in that case, the results which we are getting from cyclic triaxial or cyclic simple shear or cyclic torsional shear. Only those results are correct results to be used for design of nuclear structures; subjected to nuclear explosive or a nuclear explosion type of dynamic load.

If you use suppose the value of G or value of damping ratio obtained from resonant column test for nuclear explosion it will be again a disaster in your design. Because in that case you have estimated value of G which is a small strain value of G is not at all applicable for the range of in which the soil and the structure is subjected to during the dynamic load of nuclear explosion. So, be very careful about the selection of type of test as per the area of application.

Now, coming to the next type of dynamic load which we commonly use as a designer the structures or soil which are subjected to ground shaking or earthquake loading. So, for earthquake loading the typical range is given here about 5 into 10 to the minus 2 about 5 into 10 to the minus 3 percent of shear strain that is a typical range I am telling. So, for that strong ground earthquake motion, when you are using the laboratory test results dynamic shear modulus and dynamic damping ratio value.

In that case again it should come from either dynamic or cyclic triaxial test or simple shear or torsional shear value or may be at most resonant column, if you have used hallow specimen. But, resonant column of solid specimen if that value if you used for earthquake analysis again it will be giving a wrong design procedure, your input value will be wrong then; obviously, your further calculations will be not correct.

As well as if you use the peso electric bender element values or any travel time values, which where you are computed the value of v s, which is the case for saw test also which you estimate the G max only. So, using that for earthquake analysis most of the time it is questionable. So, you should not only have an estimate through a field test of G max through v s value but also you should do a cyclic test for your sample at laboratory better to use the triaxial or simple shear or torsional shear with cyclic loading.

Whereas, if you handle the problems relate to machine design, in machine design problem your machine foundation and corresponding soil mass they are subjected to very low value of shear strain amplitude compared to the other two cases. In this range of 10 to the power minus 4 to 5 into 10 to the power minus 4 percent of shear strain typically.

Why because in case of machine foundation we do not want the foundation or the entire assembly to move by or to displace by a large amount.

So, displacement displacement amplitude is always restricted to a very, very small amount that is the reason why your machine foundation is subjected to very low value of the shear strain. So, for machine foundation design which are the good test laboratory test you can use resonant column test, travel time test, bender element test, peso electric bender element test. All these values of dynamic soil properties of g and damping ratio you can effectively use for the design of machine foundation.

So, only for design of machine foundation this test will be proper, again this test when you are using from the cyclic triaxial, cyclic simple shear you have to use a very high value of g max at the initial stage. So, application of cyclic, triaxial cyclic simple shear and cyclic torsional shear is not that, so good for machine foundation but can also be used.

Because, it is always you are estimating on the lower end, as a designer this is most important observation one should have what are the typical ranges of shear strain amplitude for different laboratory test to determine dynamic soil properties. Based on that, we know for different types of applications, which test suitable for us to apply.

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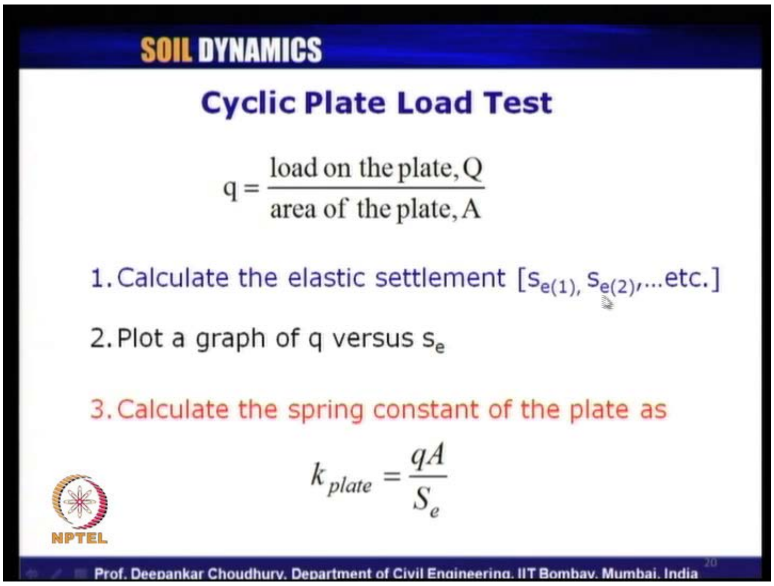

Coming to another type of test, which is pretty commonly used in static case also plate load test, in this case to determine the dynamic soil property we will use cyclic plate load test. So, in cyclic plate load test what are the procedure, let us note it the force per unit area acting on the plate is nothing but total load applied on the plate. So, capital Q by area of the plate, generally square type of plate are used for plate load test you are aware of the static plate load test.

So, same is used in case of cyclic plate load test only change is instead of a static loading we will apply load in cycles we will see that. So, what are the steps, we need to calculate the elastic settlement by applying cyclic load on that plate. So, these are the elastic settlements in the next figure we will show what it this elastic settlements are, plot a graph of that q versus the elastic settlement.

And calculate the spring constant of the plate using this expression, the spring constant of the plate is nothing but this force per unit area, which we have measured from this plot. Times the area of the plate divided by the average elastic settlement, I will show that what we have doing in the plate load test.

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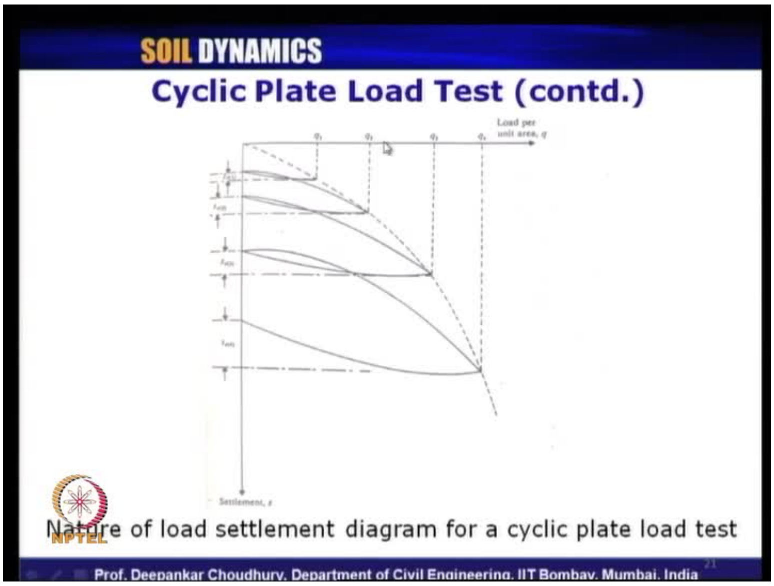

So, through a static plate load test you are aware of we can draw the distribution of load per unit area that is small q versus the settlement. That is for any plate load test we can easily draw load settlement curve this is nothing but load settlement curve in your x axis you can draw load per unit area also or the load itself also versus the settlement. In cyclic plate load test what we are doing, we are starting from here graph is coming this is the loading curve then we remove the load completely take out the full load.

So, as the soil is fully elastic it will not trace back the same path it will go in some other path like this, then you again apply a higher value of load to the plate. So, the curve will come here, then in the next cycle you take out that load also completely. So, allow the load to come to zero. So, that is the point allow is take out the load fully do not keep that load partially take out the load fully.

Then in the third cycle again if you apply a higher value of load then take it fully then again in the next cycle you apply a higher value of load take it out fully. So, what does it mean, when we are applying a load here and then taking out the load completely whatever the settlement it remains that is the settlement with the load applied. Say small q 1 was this much and after taking out the load the soil has come back to this settlement. What does it mean this amount of settlement is nothing but the plastic settlement which the soil material could not regain.

Whereas, the amount of settlement which the soil material could regain is this amount this difference. So, from here you draw parallel line intersecting the settlement axis and this value you know. So, the difference between them is nothing but the elastic settlement component for the applied load of q 1. Similarly, in the next cycle what is happening when you are applying load q 2, the total settlement is this much up to this. So, draw horizontal line from there next after taking out the load completely the settlement remains up to this.

So, the amount of settlement it could recover is this much value, so this is the elastic settlement under the load q 2. So, this is S e 2, so this is s e 1 corresponding to load q 1, S e 2 is the elastic settlement corresponding to load q 2. Similarly, in the third cycle this is the full settlement after taking out the load the remaining settlement is up to this. So, elastic settlement is this much S e 3 is the elastic settlement corresponding to load applied q 3.

In the fourth cycle for the load applied q 4 the total settlement is this much and after taking out the load completely the settlement remains up to this. So, this much is elastic settlement. So, S e 4 is the elastic settlement for the applied load q 4. So, we got the estimation from this load settlement curve from the cyclic plate load test, that what are the values of corresponding elastic settlement to this applied load.

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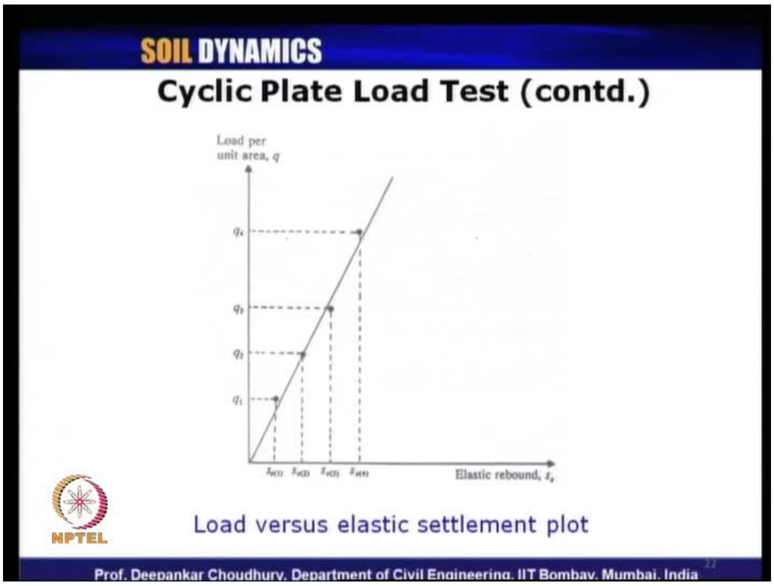

So, what we are doing next, next we are drawing another plot with this y axis has load per unit area that is small q and this x axis has elastic rebound or elastic regain or elastic settlement, which we have just now estimated from the original load settlement curve of the plate load test. So, this is s e 1 corresponding to q 1, S e 2 corresponding to q 2, S e 3 corresponding to q 3 and S e 4 corresponding to q 4. So, these are the different numbers of point.

So, as you use different cycles of loading you can get several numbers of point and obviously for a particular test it is desired that you use at least more than three numbers of test points you should get. So, from that now you should do or you should draw an average line of this q versus elastic settlement, as this is a elastic settlement; obviously, the relationship must be a linear relationship through the origin. So, you draw average line through this test points which passes through origin and which can represent this all your test points very effectively. So, the slope of this curve is nothing but what is mentioned as the let us see that.

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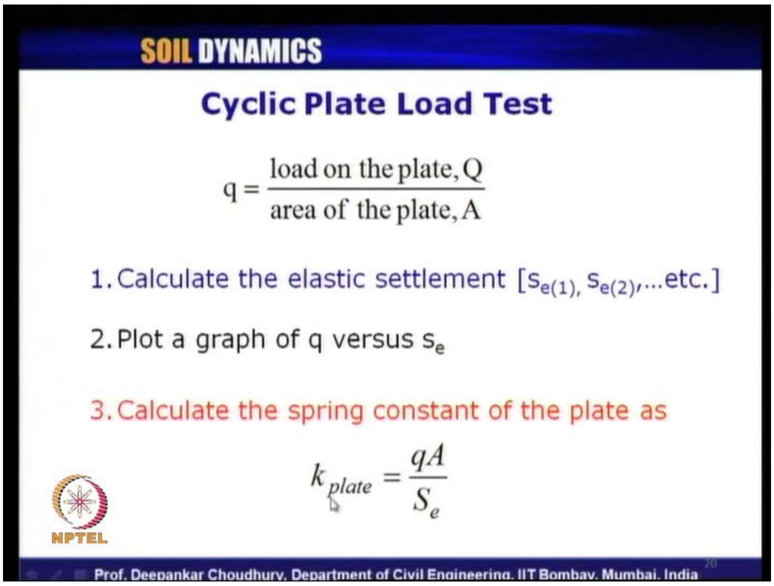

So, let me go back once again in the calculation. So, the spring constant of the plate is estimated like this k of plate is given that q by S e is nothing but the slope of that curve times the area will give the spring constant. So, in this way the stiffness of the plate material is obtained. Now, we need to convert this stiffness of the plate to the actual footing or actual foundation which we are going to use, the same thing what we have done for static load test here also for cyclic load test we need to apply.

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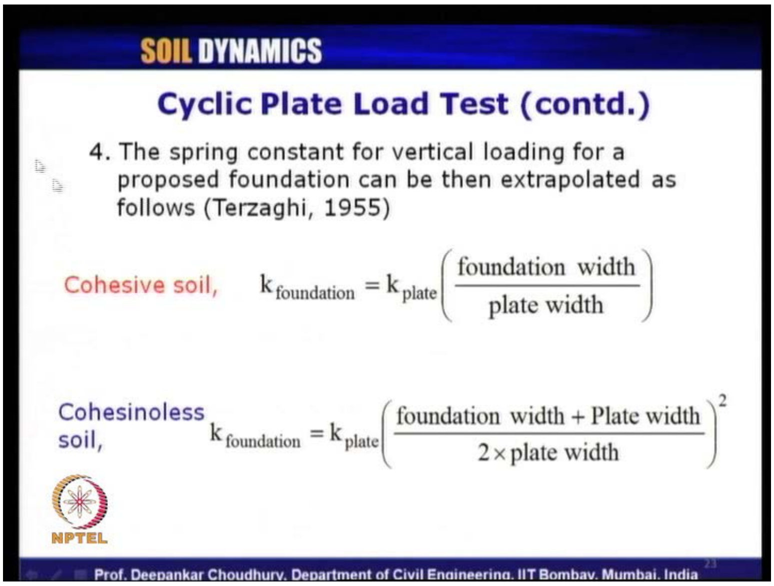

So, let us see what way we can compute the stiffness of our footing because for any design we should know what is the stiffness of our material? So, the spring constant for vertical for a proposed foundation can be extrapolated from the plate load test as proposed by Terzaghi 1995 for cohesive type of soil. The stiffness of the foundation a spring constant of the foundation is given by k of plate times foundation width by plate width.

Whereas, for cohesion less soil it is given by the stiffness of the foundation nothing but stiffness of the plate times foundation width plus plate width divided by 2 times plate width whole squared. So, in this manner we can find out easily what is the stiffness of our foundation to be designed and then using this value, we can further do our dynamic analysis. Because in our all dynamic analysis we need this value of spring constant that is one of the basic input we require. So, this is the way in a simplified manner we can compute the stiffness of the foundation.

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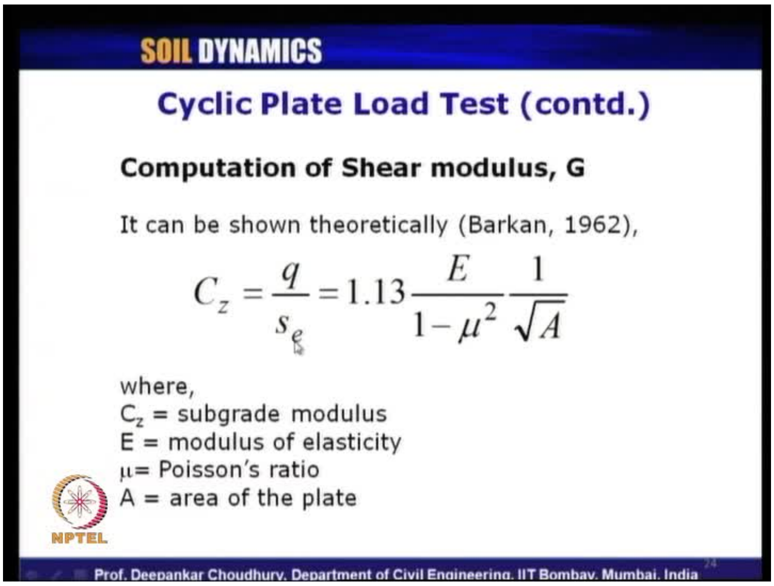

Now, how to compute the shear modulus from the cyclic plate load test it can be shown theoretically as proposed by Barkan in 1962 that C z, C z is defined as sub grade modulus similar to our static case of soil sub grade modulus. What is sub grade modulus the unit of sub grade modulus is nothing but pressure per unit displacement right. So, in this case from the cyclic plate load test the sub grade modulus, dynamic sub grade modulus what we are computing is nothing but that slope of the curve q by S e. So, what does it mean, let me go back to the picture once again.

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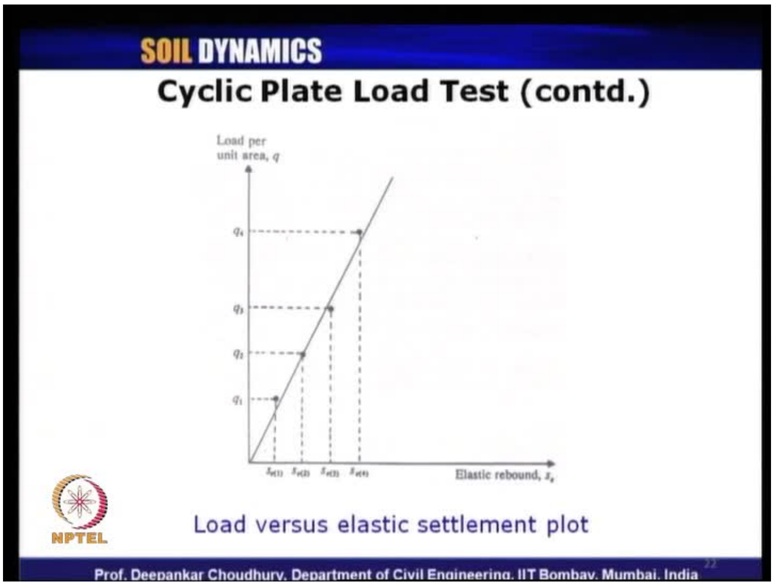

The slope of this curve is not but the dynamic sub grade modulus and what will be the unit of that if q is in kilo Newton per meter square. And this settlement is in meter unit that is all s i units if you use the unit of the sub grade dynamic sub grade modulus will be kilo Newton per meter cube and what is the unit for the k of plate that should be kilo Newton per meter.

So, this is kilo Newton per meter cube times meter squared the plate area you are getting kilo Newton per meter and for foundation k of foundation also it should remain the same kilo Newton per meter in S I unit. So, dynamic sub grade modulus is computed from the slope of the curve which is represented by this expression 1.13 times E by 1 minus mu squared times 1 by root over of A, where this E is nothing but young's modulus mu is Poisson's ratio and A is the area of the plate. So, as kindly note that this expression is valid for only vertical vibration.

So, please note it down it is valid only for vertical vibration for other modes of vibration that is horizon through rocking, pitching, etcetera. We will see other expressions available to compute or to correlate between the dynamic shear modulus with the young's modulus. So, this expression is truly speaking valid for vertical loading only or vertical vibration only as it is mentioned in the previous slide also that this is also valid for only vertical loading.

So, using this cyclic plate load test we have already obtained C z in this case Poisson's ratio of soil if it is known area of the foundation or area of the plate, whatever you are calculating correspondingly you can get the value of the E modulus elasticity.

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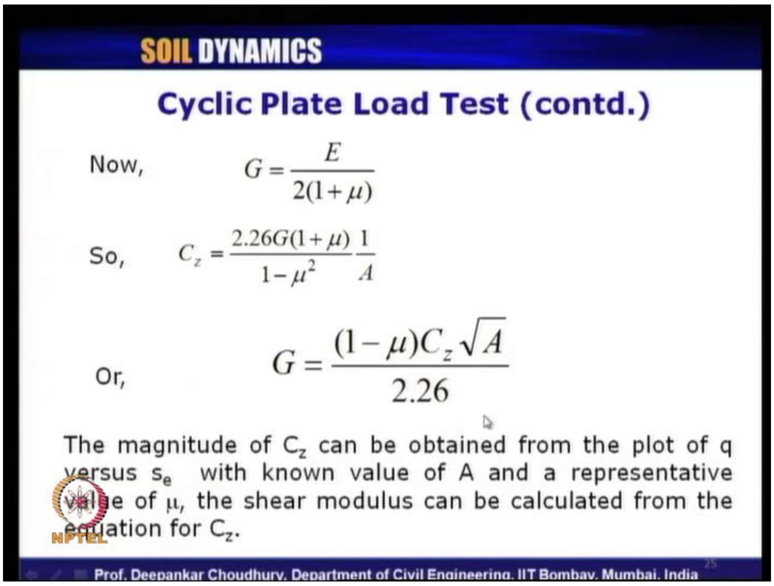

How you can use it to obtain the value of G of the soil? This is the expression or relation between G and E as we know from the basics of the Lenin's constant this is the expression or relation between shear modulus and young's modulus. That we can use in this expression of C z which on simplification will give us this is the expression to compute the value of g. So, the magnitude of dynamic sub grade modulus C z can be obtained from the plot of this q versus elastic settlement with known value of area and a representative value of the mu for the soil. The shear modulus can be calculated from this equation, so this is another way to calculate the dynamic shear modulus. So, with this we have come to the end of this lecture we will continue our lecture in the next class.