Soil Dynamics
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Lecture 33
Liquefaction of Soils – Part 3

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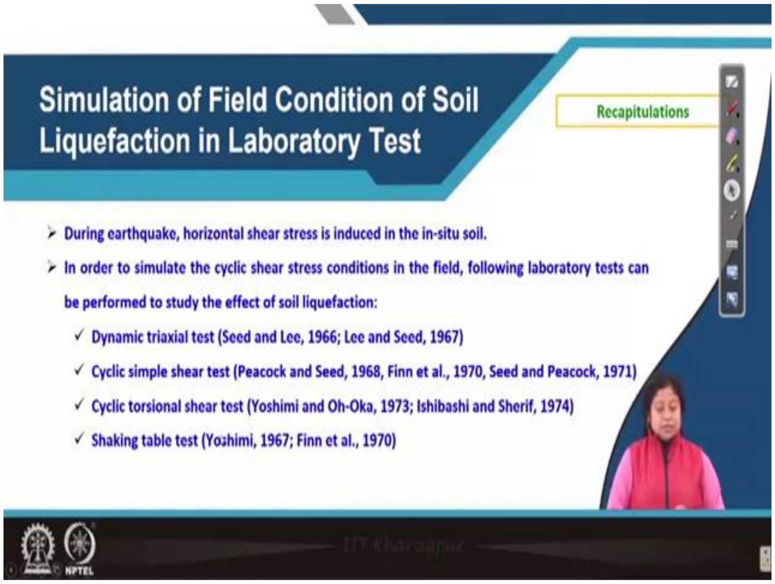

Hello friends, today I will continue our discussion on liquefaction of soils. So, what we have studied in last class first let us see that. We have studied how to simulate the field condition of soil liquefaction in laboratory, there are four tests which we can any one of these four tests can be chosen to simulate the field condition of soil in lab. What are those four tests you can see here dynamic track shear test, cyclic simple shear test, cyclic torsional shear test and shaking table test.

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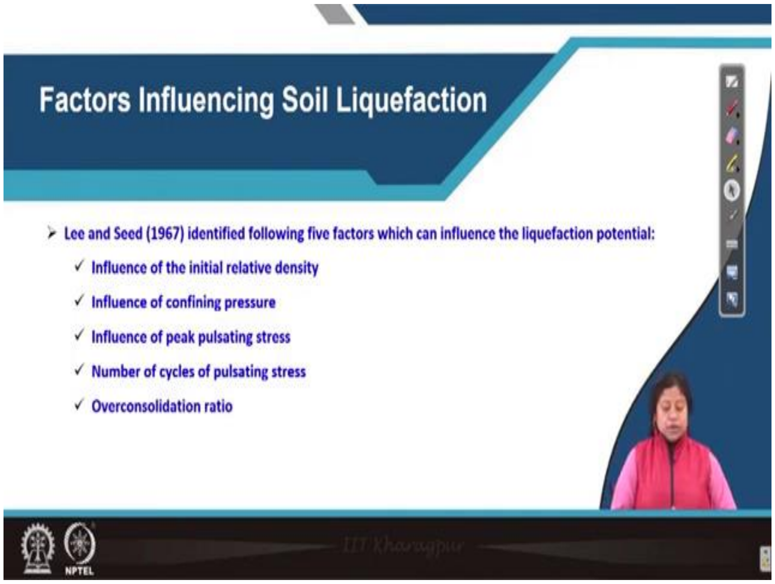

Let us see what are the different factors that influence soil liquefaction Lee and Seed 1967 identified five factors which can influence the liquefaction potential of soil. First one is initial relative density, then confining pressure, then peak pulsating stress, number of cycles of pulsating stress and over consolidation ratio of soil.

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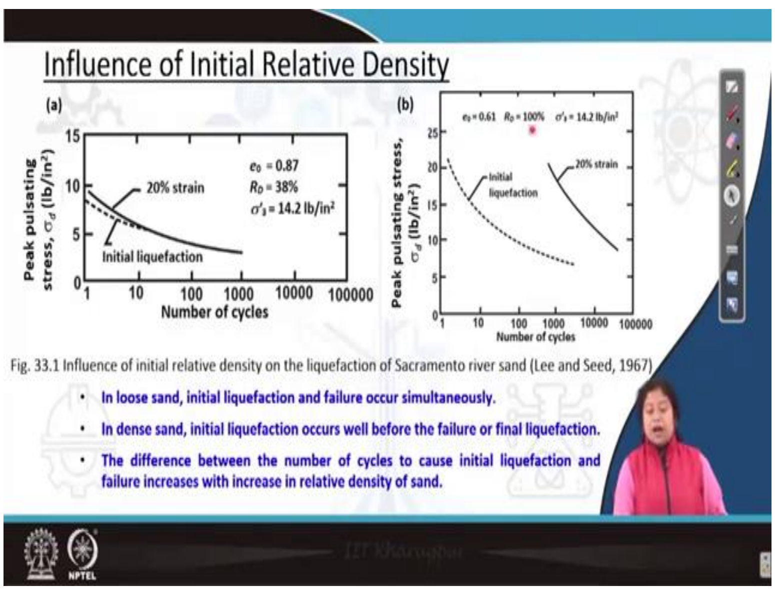

So, first we will see the influence of initial relative density here. So, in Figure a is for loose sand where Lee and Seed has taken a Sacramento river sand and the characteristics of this sand in loose state which was considered at the time of experiment was given you can see here e0 is the initial void ratio Rd is the relative density and sigma 3 dash is the effective confining pressure.

So, in this case what is found is that for loose sand initial liquefaction and failure that means 20 percent strain or I can say 20 percent double strain amplitude both are occurred simultaneously. You can see till 1 to 11 cycles there is some gap between initial liquefaction and 20 percent strain but after 11 cycle you can see both occurs simultaneously.

But, for dense sand the scenario is different. In dense sans initial liquefaction occurs will before the failure or final liquefaction which is for which is at 20 percent double amplitude strain and the difference between the number of cycles to cause initial liquefaction and the failure increases with increase in relative density of sand. Obviously, in figure a if you see their relative density is low 38 percent only.

So, the difference between initial liquefaction and failure is very less whereas, in figure b where relative density is 100 percent almost you can see a wide gap between initial liquefaction and failure.

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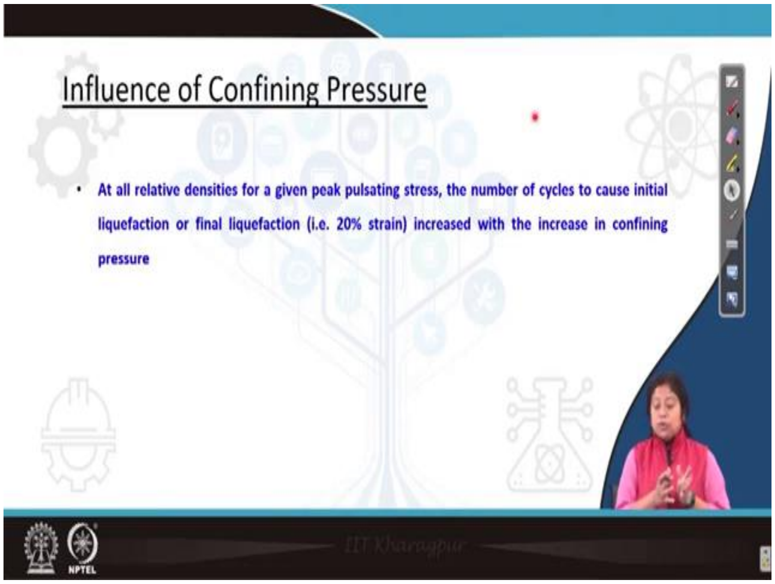

Next is influence of confining pressure. So, at all relative densities of sand for a peak for a given peak pulsating stress, the number of cycles to cause initial liquefaction or final liquefaction increased with the increasing confining pressure. So, if confining pressure increases, then it results an increase in the number of cycles required to start initial liquefaction or final liquefaction.

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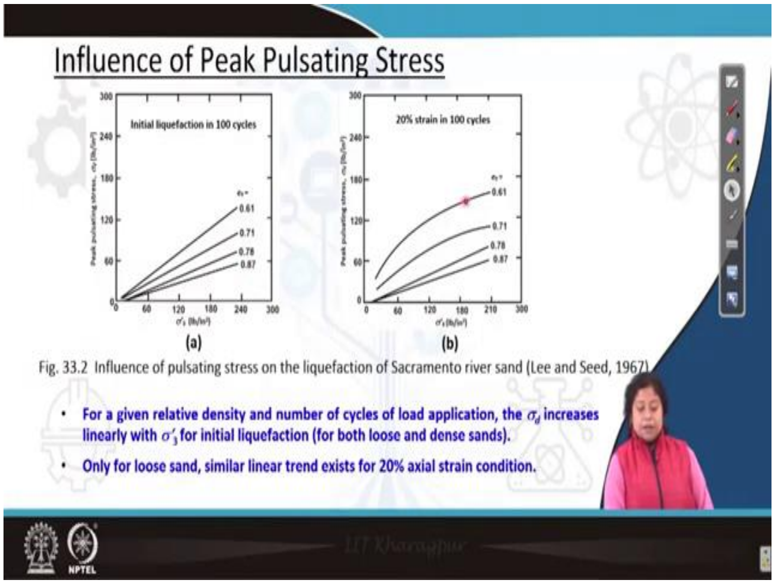

So, in these two figures you can see that influence of peak pulsating stress figure a for initial liquefaction after 100 cycles, figure b is for 20 percent strain after 100 cycles of application of pulsating stress.

Now, in Figure a what we can see for initial liquefaction we see that for a given relative density and number of cycles of load application, which is 100 in this case, the peak pulsating stress which is sigma d increases with increase in sigma 3 dashed that is for initial liquefaction and that is true for all types of sand that means, if it is loose sand then also it is applicable if it is dense having low void ratio then also we can see the same linear relationship.

So, the top curves represents the relationship for the dense sand having low initial void ratio, bottom curve shows the relationship for the loose sand having very high initial void ratio. Now, what is happened for 20 percent strain only for loose sand these type of linear relationship exists. For dense sand if you see the relationship is no more linear.

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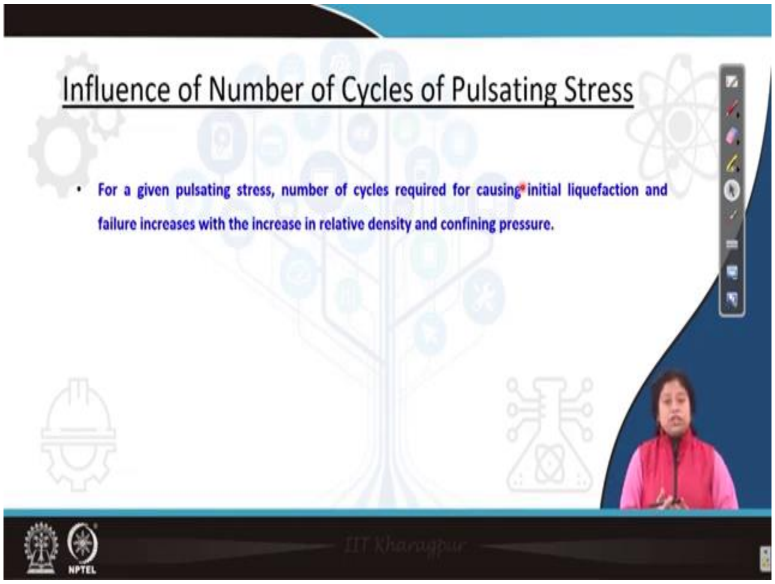

Now, let us see the influence of number of cycles of pulsating stress. For a given pulsating stress number of cycles required for causing initial liquefaction and failure increases with increase in relative density and confining pressure. What does it mean? It means, suppose, I have taken loose sand with relative density 38 percent and also, I have taken another sand sample of relative density say 80 percent, then number of cycles required for causing initial liquefaction for loose sand if it is let us take 25, then for dense sand this value should be more than 25. Maybe 50, maybe 60 maybe 100 also.

And these for loose sand I have chosen a value 25 say. So, now, if the confining pressure will increase, then this number of cycles required for causing liquefaction will no more be 25 but that will also increase with the increase in confining pressure.

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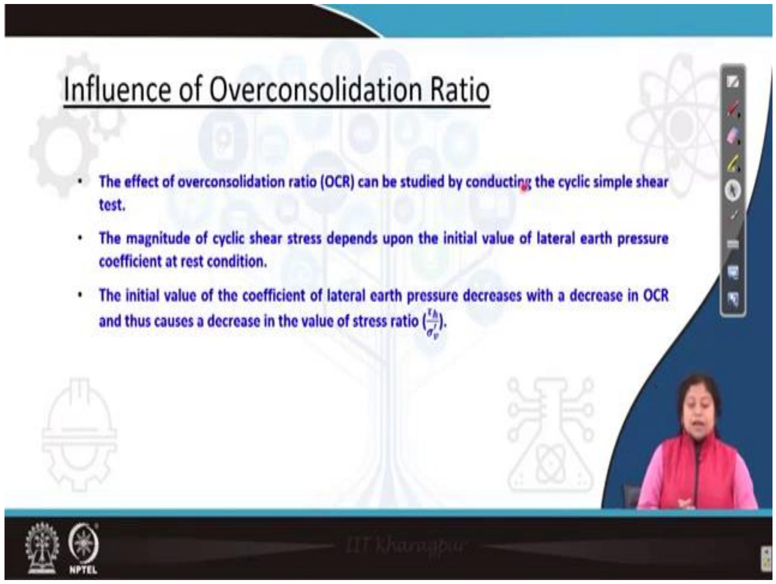

Let us see that influence of overconsolidation ratio. What is over consolidation ratio? Generally, it is the ratio of the pre consolidation stress to the current vertical effective stress in the soil. So, the effect of overconsolidation ratio can be studied by conducting cyclic simple shear test not by dynamic triaxial test.

The magnitude of cyclic shear stress generally depends upon the initial value of the lateral earth pressure coefficient at risk condition that initial value of the coefficient of lateral art pressure decreases with a decrease in OCR that means overconsolidation ratio and thus causes a decrease in the value of stress ratio. In case of simple cyclic simple shear taste stress ratio is defined by a ratio of tau h which is shear stress to the effective vertical stress which is sigma v dashed.

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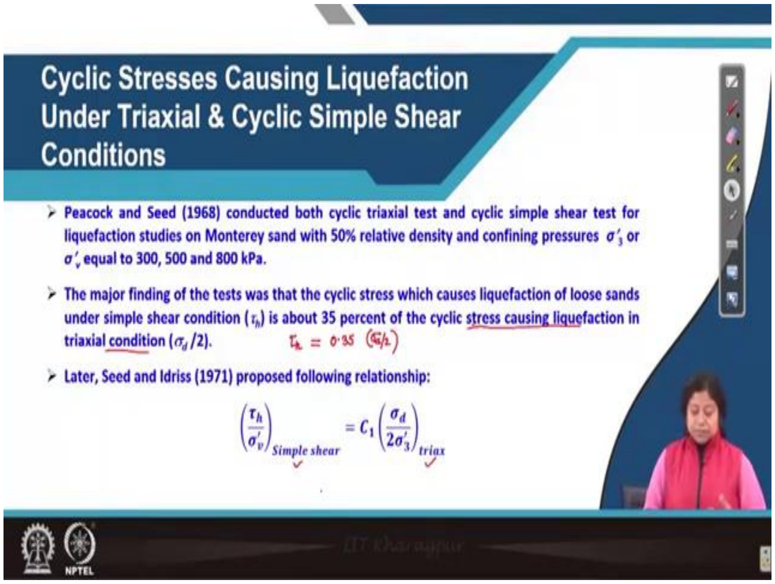

Now, we will see cyclic stresses causing liquefaction under triaxial loading condition and under cyclic simple shear condition. So, Peacock and Seed in 1968 conducted both cyclic triaxial test and cyclic simple shear test for liquefaction studies for a particular sand and it is they have done the experiment at a particular relative density and confined three different confining pressures, which are mentioned here.

So, the major finding from these tests where that the cyclic stress which causes liquefaction of loose sands and the simple shear condition is about 35 percent of the cyclic stress causing liquefaction in traction condition. That means, I can see tau h is equal to 0.35 of sigma d by 2. Later Seed and Idriss 1971 proposed following relationship that the cyclic stress ratio for simple shear is equal to a factor C1 times the cyclic stress ratio for triaxial test.

So, for triaxial test cyclic stress ratio is sigma d by 2 divided by sigma 3 dashed whereas, for simple shear test, the cyclic stress ratio is tau h divided by sigma dashed V or sigma V dashed you can say.

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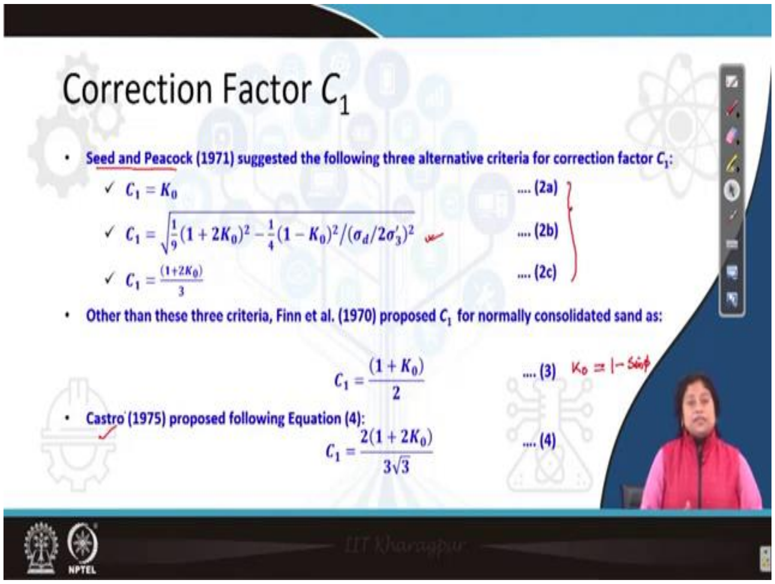

Now, how we can find out the correction factor C1? C1 can be determined in different way, first one Seed and Peacock suggested that any 3 of any one of these 3 relationships can be considered either we can take c1 is equal to k0 which is the coefficient of our pressure at rest condition or we can take this one shown in equation 2 b or 2 c other than these 3 criteria Finn and others in year 1970 proposed C1 for normally consolidated sand where he they said C1 is equal to half of 1 plus K0. Now, in this case K0 is equal to 1 minus sin phi. Later Castro in 1975 proposed equation 4 to find out C1.

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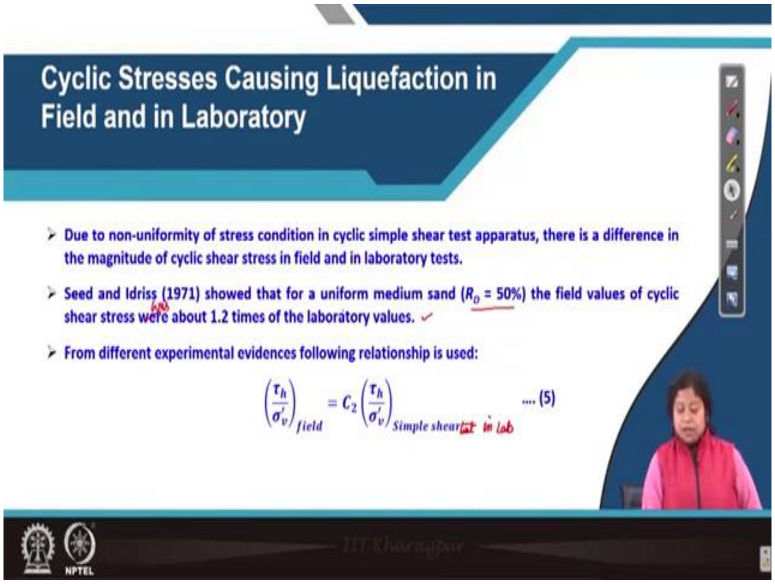

Now, we will discuss the cyclic stresses causing liquefaction in field and in laboratory. What is happened when we are doing (sim) cyclic simple shear test in the lab, because of some constraint in the apparatus non uniformity of stress condition in cyclic simple shear test apparatus is noted and consequently, there is a difference in the magnitude of cyclic shear stress in field and in lab test.

So, in order to correlate these two cyclic shear stress there are we can use one empirical relationship which is shown in equation 5, where we can see that tau h divided by sigma sigma v dash 2 it is cyclic stress ratio in simple shear test. So, if it is field is equal to C2 times cyclic stress ratio in simple shear test in lab better I just write it here add it testing lab. Interestingly, you can note here one point that Seed and Idriss in the year of 1971 showed that for medium dense sand with relative density 50 percent, the field values of cyclic shear stress that means, tau h at field was about 1.2 times of the laboratory values that means tau h determined in the lab.

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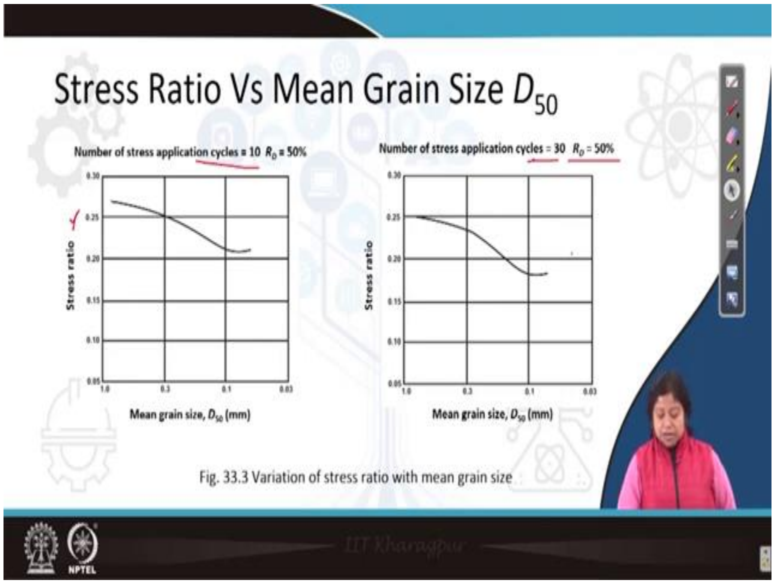

Now, let us see what is the effect of the mean grain size on stress ratio. The mean grain size has significant effect on the stress ratio that you can see here the first figure is for now, for relative density 50 percent and number of stress application k whereas, the second figure relative density is same at 50 percent and number of stress application cycles increases to 30.

So, what we can see here with decrease in mean brain size that is d 50 value stress ratio decreases, but that reduction is not a linear function it is a nonlinear function and beyond 0.1

millimeter these stress there is no change, no significant change I can say in the stress ratio value.

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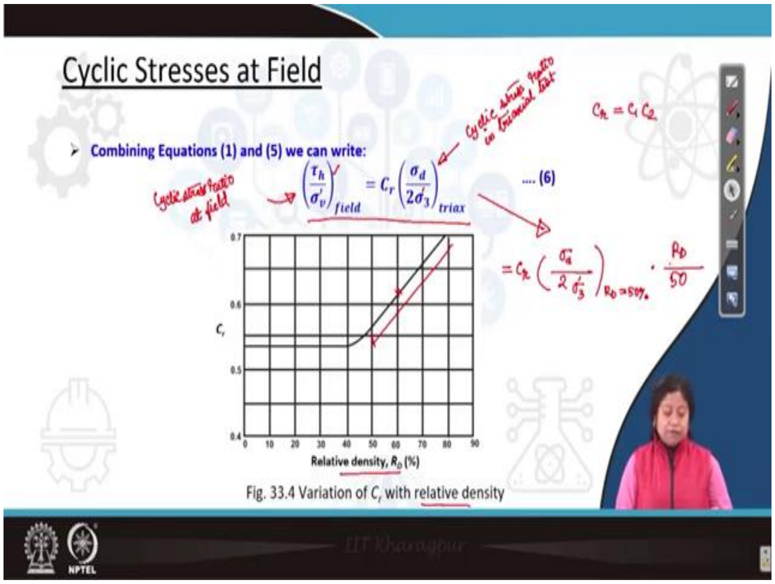

Now, if I combine the equation 1 and 5, then what we can write, we can write this that means, field cyclic stress can be represented by the cyclic stress field cyclic stress ratio this one can be represented by the cyclic stress ratio the triaxial test, so, this is our cyclic stress ratio in triaxial test and this is the same cyclic stress ratio at field. And what is Cr? If we see the equations 1 and 5, then Cr is actually the product of C1 and C2 and Cr is called as the stress is called as a reduction factor which depends upon the relative density of the sand.

Now, interestingly if you see the variation of Cr with relative density you can note relative density more than 50 percent for this case that means, for this region I can say Cr linearly increases with the relative density Rd and before that the value of Cr is more or less equal you can take 40 or 50 approx. So, bit generally we take it 50. If so, then you do not need to do the cyclic triaxial test for all different relative densities, but if you have the data for 50 percent for sand having 50 percent relative density, then also you can get the cyclic stress ratio at field how.

So, this relationship I can write also as Cr now, cyclic stress ratio please correct here this is sigma dashed 3 times. So, this is for relative density 50 percent times let us take right now, relative density is our D1 or some other value which is represented by Rd divided by 50. So, if we have a data of cyclic stress ratio from the cyclic triaxial test of sand specimen with 50 percent relative density, then using that data we can find out cyclic stress ratio at the field.

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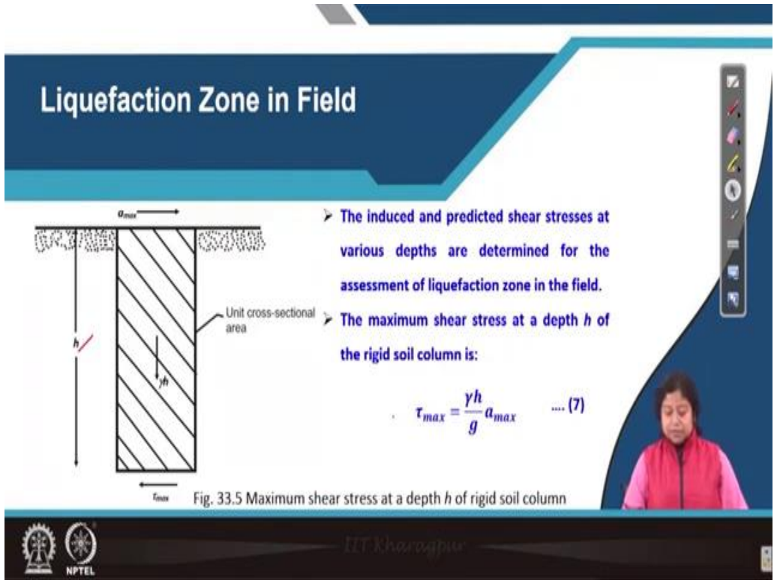

Now, how we will find out liquefaction zone in the field whatever we have studied so, far that says how we can find out liquids, how we can find out the cyclic shear stress that is tau h. But what about liquefaction zone? Let us take a soil column which is a rigid soil column and it is height let us take h the width part unit cross sectional area of these soil column is gamma h tau max which is equal to gamma h divided by g times a max what is a max here a max is the peak ground acceleration and as I said gamma is the unit weight of soil.

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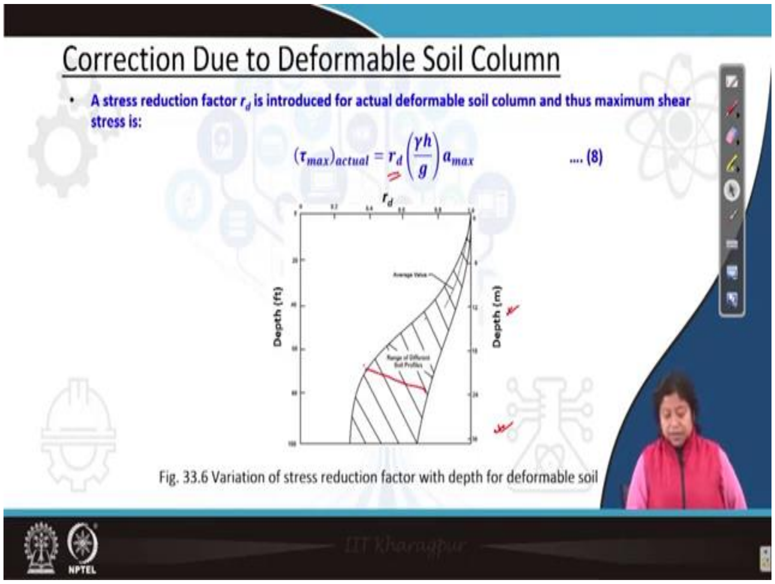

But actually soil is not rigid, but it is a deformable body. So, the so, we need to introduce one stress reduction factor which is our d here to get the actual maximum shear stress at a depth h in the deformable soil column. Now, how do we find out these stress reduction factor Rd? For that we can use these figure where Rd depends upon the depth in this figure, if you see the left hand side there depth is given in feet, if you see the right hand side axis these here death is given in meter. So, this is the range of different soil particles, you may take the average value of for Rd to calculate the actual value of maximum shear stress in the deformable soil column.

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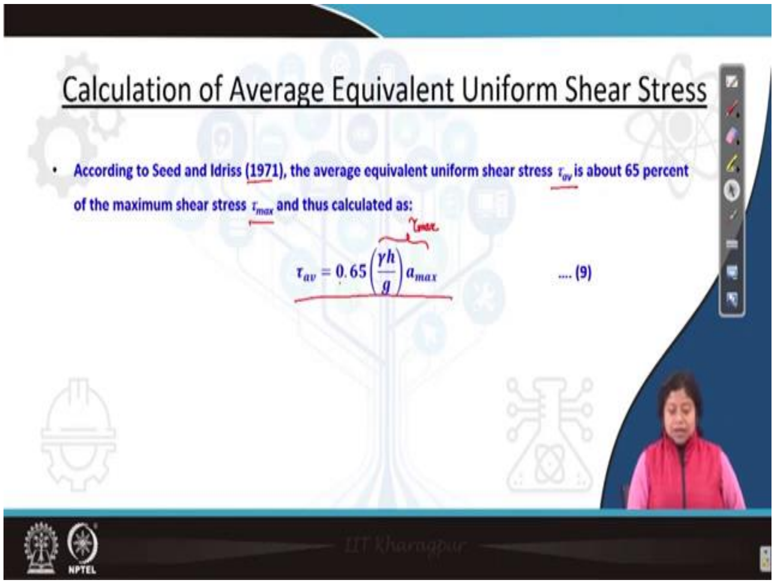

Now, according to Seed and Idriss, 1971 the average equivalent uniform shear stress which is tau average is about 65 percent of the maximum shear stress tau max and that can be calculated by using this equation. So, here if you see basically, this is tau max and tau max is multiplied by 0.65 to consider the average equivalent uniform shear stress.

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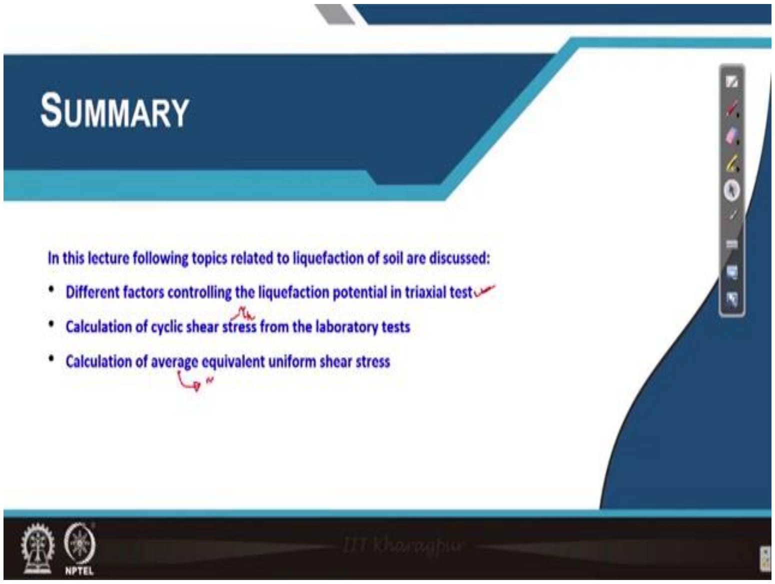

So, let us see the summary of today's class. In this lecture, we have discussed different factors that control the liquefaction potential in triaxial test also we have seen another controlling factor which is OCR over consolidation ratio related to cyclic simple shear test, which also controls the liquefaction potential of soil. We have studied how to calculate the cyclic shear stress that is tau h from the laboratory test we have learned how to calculate the average equivalent uniform shear stress which is tau average. With this, I am stopping today.

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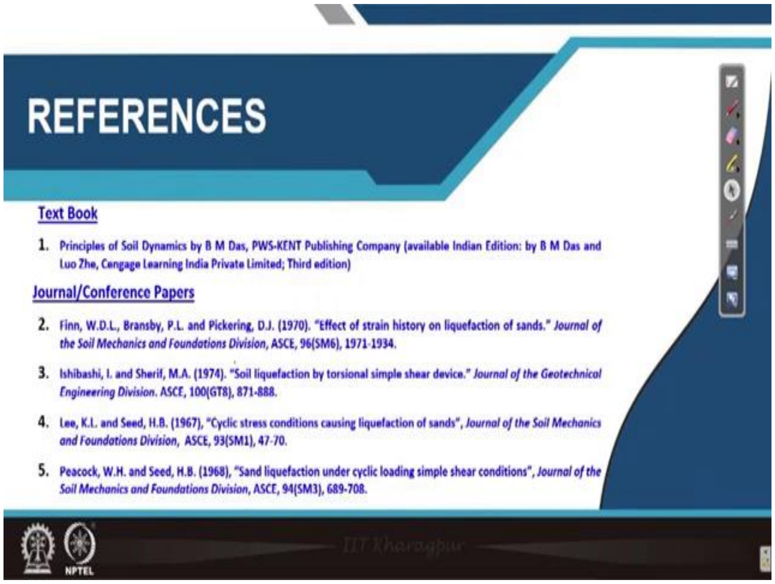

These are the references that I have used for today's class. Thank you.