Soil Dynamics
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Lecture 31
Liquefaction of Soils (Part 1)

Hello friends, today we will start a new topic which is called liquefaction of soils.

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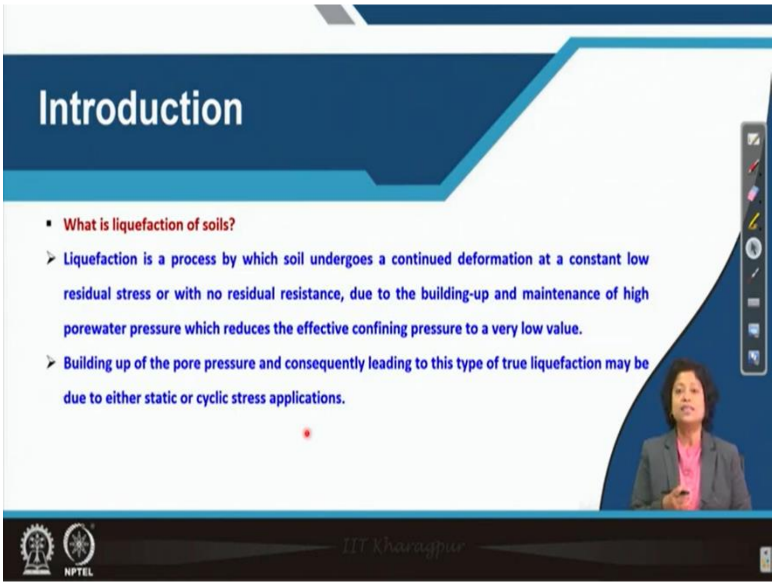

So, first we need to know what is liquefaction of soils. Here you can see the definition of liquefaction. Basically, liquefaction is the process by which soil undergoes a continued deformation at a constant low residual stress or no residual resistance that means either the residual stress is very low or it may become zero also and when it is happening or why it is happening because of the building up and maintenance of high porewater pressure that reduces the effective confining pressure to a very low value.

We all know what is effective confining pressure. Basically, this defines the contact pressure between the soil grains and how we can get it if we know the total stress in the system and if we know the porewater pressure of the same system, then we can calculate effective confining pressure or effective stress particularly by subtracting porewater pressure from the total stress. So, if porewater pressure increases, then what will be happen, effective stress will decrease. So, that is happened in case of liquefaction.

Now, this building up of the porewater pressure and consequently leading to this type of true liquefaction may be due to either static or cyclic stress application. So, when these porewater pressure generally we call it as excess porewater pressure when these things builds up in the system when because of the static or cyclic stress application.

Here, I would just like to mention one more thing, just now, I have used the term excess porewater pressure. So, why it is called excess porewater pressure? I hope all of you know about the porewater pressure in your geotechnical engineering course. So, what is exactly the porewater pressure what is the reason for the porewater pressure of course, this is the pressure which exerts by the water present in the soil void, however this pressure is triggered because of the gravity load or action of the gravity.

Now, in addition to the gravity load, if external load or additional load is applied to the system, then additional porewater pressure will be developed and that porewater pressure is called as the excess porewater pressure.

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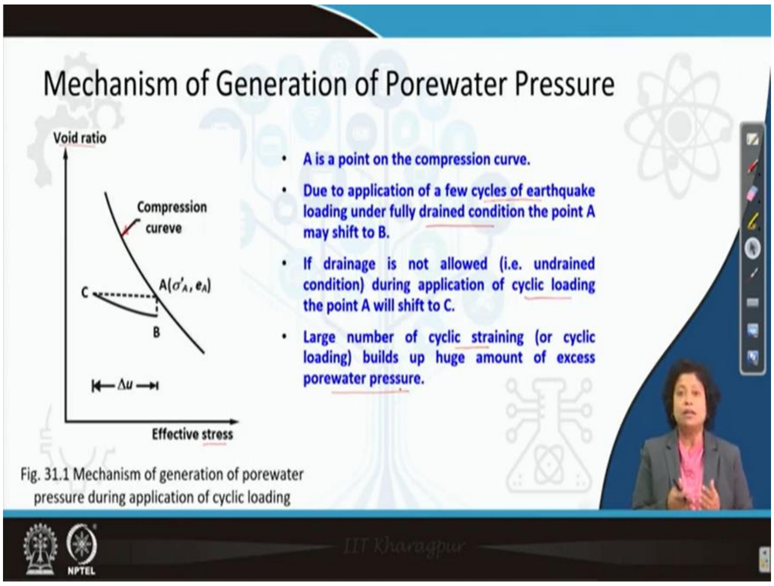

Now, let us see the mechanism of generation of porewater pressure. So, in this figure, you can see the mechanism of generation of porewater pressure you can call it as also excess porewater pressure during application of cyclic loading. So, if so, this curve is the compression curve. We all know the compression curve. So, and in this figure, you can see the horizontal axis is representing the effective stress whereas the vertical axis representing void ratio.

Now, if the soil state on the completion curve is at A, then there are two possible cases. First one, due to application of a few cycles of earthquake loading under drained condition, drained condition means, we are allowing porewater pressure to dissipate. What will be happened? This point A will shift to the point B. Why so? Since we are allowing drainage, so the amount of excess porewater pressure or if I call it as delta u that will be 0 and the what will be happened, then there will be no change in the effective confining pressure or effective stress in the system.

However, because of the drainage, what will be happen, the void ratio will be reduced. So, that is the reason that point A will shift to the point B. Now, if we do not allow the drainage that means if we carry on the testing under drained condition or we can call it as we are applying cyclic loading under undrained condition, then what will be happened? Since the system is undrained that means we are not allowing the porewater pressure to dissipate from the system.

Now, because of the application of the cyclic loading, what will be happened? Porewater pressure will be building up in the system and with time the amount of the excess porewater pressure will increase. So, now, what will be happened to the effective stress that will be reduced and if effective stress will reduce, then the point A will shift to C. And in this case, what we need to note here is that when pore pressure will build up that means under undrained condition of cyclic loading, what will be happened? That time there is no change in the void ratio. Void ratio will remain same.

Now, that large number of cyclic straining or we can call it as cyclic loading also builds up huge amount of excess porewater pressure. So, as a consequence, what we can see? We can see that effective stress or effective confining stress will approach to 0 or it becomes very low value.

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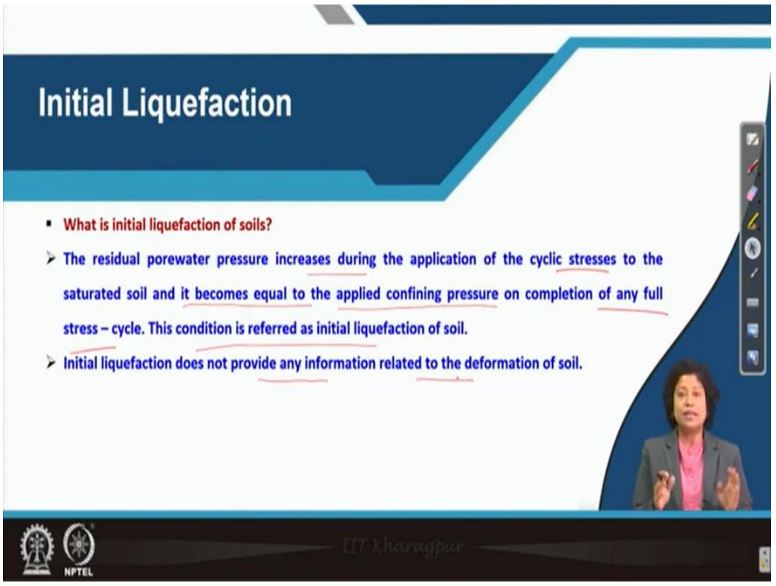

Now, the next thing which we need to know is initial liquefaction. So, what is this initial liquefaction of soil? Here you can see the definition of initial liquefaction of soil. The residual porewater pressure increases during the application of cyclic stresses to the saturated soil and what is happened? Because of this residual porewater pressure increases because of this what is happened? It becomes equal to the applied confining pressure on completion of any full stress cycle.

So, that means that the residual porewater pressure or you can call it excess porewater pressure which increases during the application of the cyclic stress becomes equal to the applied confining pressure and as a consequence, if you think about the effective confining pressure that becomes equal to 0 or very close to 0 and this condition is referred as initial liquefaction of soil.

Now, this initial liquefaction of soil does not provide any information related to the deformation of the soil. This is the limitation of the initial liquefaction data, we cannot get any information related to the soil deformation.

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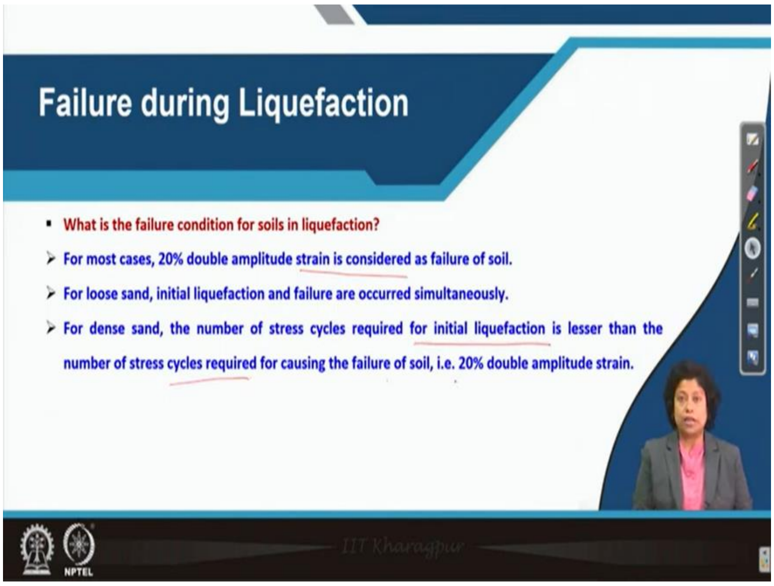

Now, after knowing the initial liquefaction, next is to know what is failure condition for soils in liquefaction. So, let us see the definition. For most cases 20 percent double amplitude string is considered as failure of soil. Now, for loose sand initial liquefaction and failure are occurred simultaneously. What about dense sand? For dense sand the number of stress cycles required for initial liquefaction is lesser than the number of stress cycles required for the failure of soil or we can call it 20 percent double amplitude strain.

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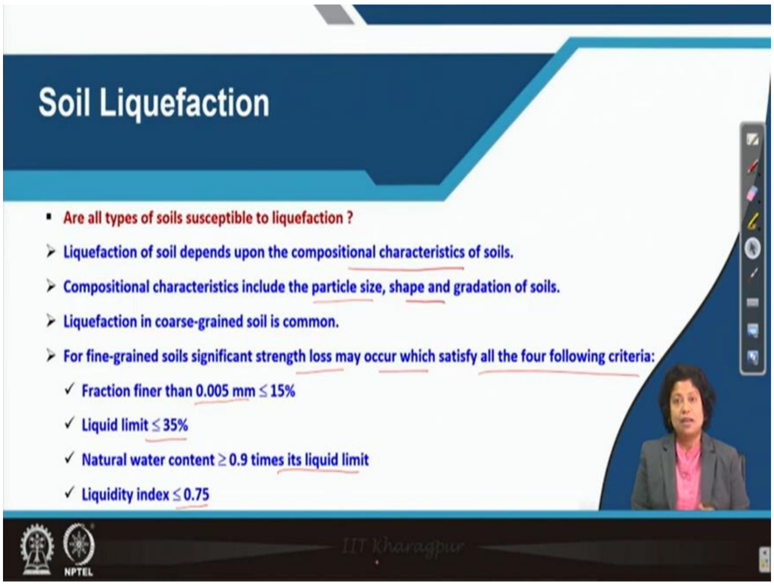

Now, the question whether all types of soils are susceptible to liquefaction or not? Let us see the answer. Liquefaction of soil depends upon the compositional characteristics of soils. Compositional characteristic means the particle size, shape and gradation of soils.

Liquefaction in coarse grained soil is common. Coarse grained soil means what? Coarse grained soil means gravel, sand etc. Generally, for fine grained soil significant string loss may occur which satisfy all the four following criteria.

What are those four criteria, let us see. First one fraction finer then 0.005 millimeter, that fraction should be less than 15 percent. Second one is liquid limit is less than 35 percent less than or equal that means the upper limit of the liquid limit is 35. If it is more than 35 but satisfying the first criteria that means fraction finer than 0.005 millimeter is less than 15 percent, then the soil is not susceptible for liquefaction. Third important criteria is the natural water content is greater than or equal to 0.9 times its liquid limit. What does it mean? The minimum value of that natural water content should be 0.9 times that liquid limit of the soil.

For an example, if liquid limit is 20 for the soil having fraction finer than 0.000 sorry 0.005 millimeter, then minimum value of the natural water content will be how much? That will be 0.9 times 20 that is 18 percent. So, natural water content should be more than 18 percent that is say in the third criteria. Fourth criteria say liquidity index is you can see here is less than or equal to 0.75 that means that maximum value of the liquidity index is 0.75. So, if any fine grain soil satisfies all these four criteria, then that soil is susceptible to liquefaction.

Generally, what is happening? Earlier people believe that only coarse-grained soil is susceptible for liquefaction. Now, after several laboratory tests by Ishihara and the group what they have found, they have found that non-plastic seals also is susceptible to liquefaction. So, the main thing is whether the soil is plastic or non-plastic rather than to think on the grain size. So, if the soil is non-plastic, then it may be susceptible to liquefaction.

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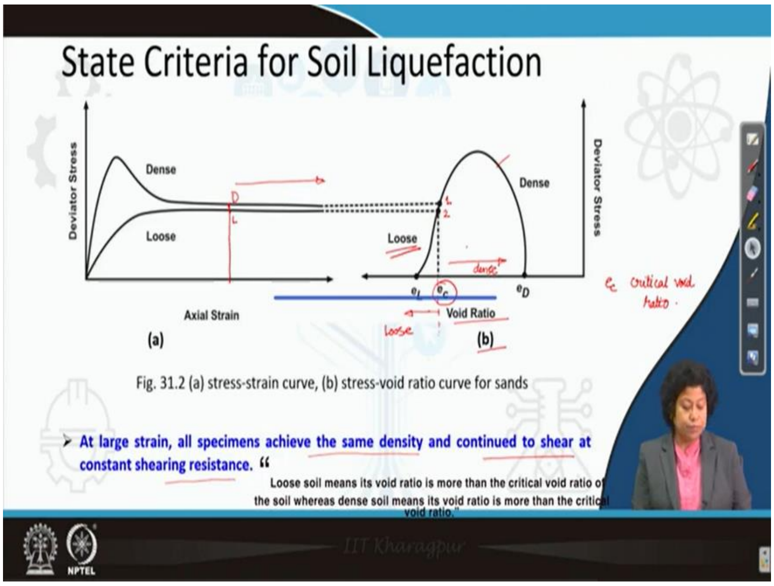

Here now, we can see that state criteria for soil liquefaction. What it says? It says at large strain, all specimens achieve the same density and continue to shear at constant shearing resistance. What does it mean? If you see the figure a, 31.2a, at large axial strain that means somewhere here at large value of axial strain, if I will erect one perpendicular on the deviatoric stress versus axial strain curve, I will get two points, this one and this one. So, let us take first one is A and the second upper one is D. So, D is the point on the deviator stress versus axial strain curve for dense soil and L is the point on the same curve for loose soil.

Now, from D and A, if I will draw two lines on void ratio on these curves, these curves means deviator stress versus void ratio curve this one, what we will get? We will get two points on this curve. This is 1 and this is 2. So, 1 is related to that dense soil and 2 is related to the loose soil. Now, these two points 1 and 2 if you see these two points represents the same magnitude of the deviator stress however, that soil is different 1 is for dense sand and 2 is for loose sand.

Now, if from 1 and 2 I draw two perpendiculars on horizontal axis of the second figure that means, figure b, then what I will get? I will get that eC. eC means critical void ratio. So, eC is critical void ratio. So, in this case what is the observation then? Observation is that at large strain the soil whether it is loose or whether it is dense, it does not matter. It reaches to the or its void ratio it reaches to the critical void ratio or I can say its void ratio becomes equal to the critical void ratio and what else we can see from these curve? When it reaches to the for both the soil if void ratio reaches to the value of critical void ratio that means their density become same.

So, now I can see that both dense and loose sand achieve the same density at large strain and what else and continue to shear at constant shearing resistance. Of course, beyond this point the shearing resistance is constant. So, it whatever written here that continued to shear at constant shearing resistance that we can see here.

Another thing in figure b you can note that the soil on the left hand side of the critical void ratio that means, the void ratio of the soil if it is less than the critical void ratio as you can see here. So, this is the value of critical void ratio. So, on the left-hand side of this soil is in loose state actually it is already written here. Likewise, on the right hand side of the eC that means, critical void ratio soil is in dense state. So, here it is dense. So, that we can note from figure b.

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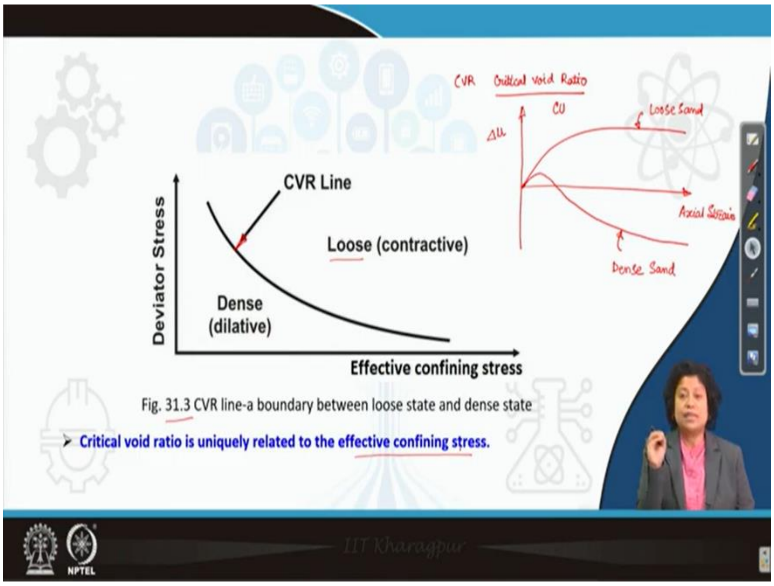

Now, here you please see the figure 31.3 where CVR line is shown. So, in this figure what is CVR line? C stands for critical, V stands for void and R stands for ratio. So, the full form of CVR is critical void ratio. So, if you can find out critical void ratio at different effective confining stress you will get CVR line as shown here. Now, if the soil state is above the CVR line then soil is in loose state that means soil can contract at large axial strain. In case of dense sand what is happened? In case of dense sand when you will start straining initially it will contract but at after some time it will start to dilate and at large straining, we can see that dilation in dense sand.

So, because of these different because of this type of behaviour of dense sand and loose sand now, if we do any kind of undrained test like CU triaxial test the what we will see in porewater pressure. So, let us take horizontal axis represents axial straining, axial strain. Vertical axis represents delta U. Now here what will be happened in case of loose sand? So, loose sand will show contractive behaviour that means when we will apply load or when we will apply axial straining on loose sand it will contract.

So, because of contraction, if we do the test with the saturated loose sand sample, then at large deformation or at a large axial strain, what we will see, we will see pore pressure will build up and that pore pressure is positive and at large strain it becomes constant like this. So, this is the behaviour of the loose sand.

Now, in case of dense sand what we will see? Initially dense sand contracts then it starts to dilate. So, accordingly if we are doing CU test with dense sand specimen, then initially positive pore pressure will develop and then the when at large strain, we will see that negative porewater pressure in the dense sand. So, this is the behaviour of the dense sand under undrained condition loading condition. Undrained loading condition means drainage not allowed in this case.

So, from this what we can say? Critical void ratio is uniquely related to the effective confining stress actually that we have seen in the previous figure itself that critical void ratio is uniquely related to the effective confining pressure. Now, another thing is that with the definition of CVR line we can say CVR line is a boundary between loose state and dense state right that is also written here.

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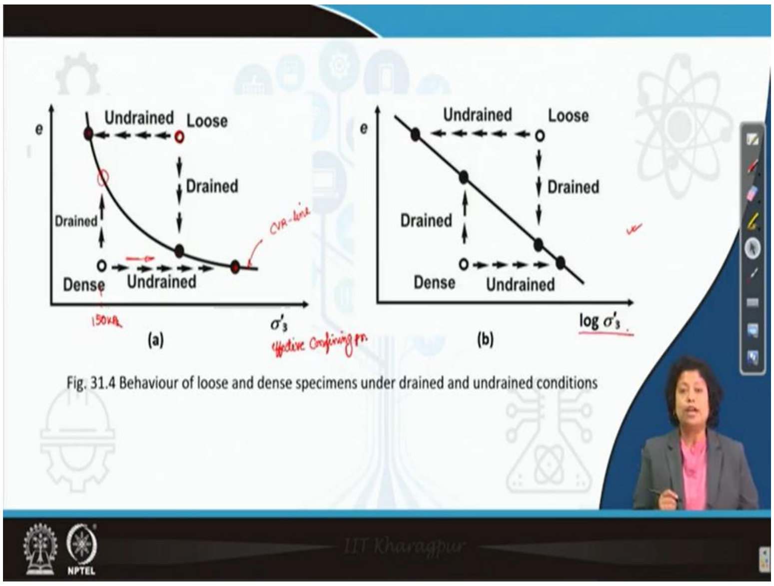

Now, see this figure. In this figure the behaviour of loose and dense specimen under drained condition and under undrained conditions are shown. So, if you see this is the CVR line. Now, if you are using loose specimen that means it somewhere here and now, if you are keeping the effective stress constant and allow loading under drained condition that means, you are allowing poor water pressure to dissipate from the system that time what will be happened? The void ratio will be reduced and it will reach to the critical value that means void ratio will how long this condition will continue up as long as E value is greater than E critical.

Now, once it returns to the critical state, this thing will be stopped there. Now, in case of dense sand what will be happening? In case of dense sand, the void ratio at constant confining effective confining pressure sigma 3 dash is the effective confining pressure. So, at effective at constant effective confining pressure what we can see under drained condition that means we are allowing porewater pressure to go out from the system that time what will be happened?

Void ratio will start to increase the cause the void ratio starts to increase mean sample dilates that is the reason its void ratio increases and how long it will increase as long as void ratio is less than the value of the critical void ratio that means as long as it does not reach to this point because this points is the critical void ratio at this confining pressure. It may be let us take 50 kPa or 150 kPa that may be possible. I am just saying a random number here.

And what we have seen in case of loose sand the void ratio will increase that means sand will densify. How long? As long as the void ratio of the loose sand is higher than the critical void ratio at that confining pressure. This is about the drained test. What will be happened in case of undrained test?

In case of undrained test, we have already discussed that porewater pressure will build up at constant when porewater pressure will build up consequently, the effective stress will decrease. So, you can see in case of loose sand where positive porewater pressure builds up that case effective confining pressure decreases under undrained condition and how long it will be continued as long as it reaches to this point that means at a critical void ratio.

Now, in case of dense sand what will be happened? In case of dense sand what we have seen? Negative porewater pressure is developed. Consequently, the effective confining pressure will increase in case of dense sand. So, you can see here under undrained condition dense sand if we are using dense sand then effective confining pressure will increase and how long? As long as void ratio will remain constant because we are doing undrained test. But how long as long as we do not reach a does not reach to the critical void ratio line.

I think in previous case also I may make mistake to mention that critical void ratio line for loose sand if so, please correct it. So, in case of loosen the under undrained condition effective confining pressure will be reduced as long as it does not reach to the CVR line at this point and in case of dense sand, it will we will see that effective confining pressure increases as long as it cannot touch to the CVR line. Once it touches to this point, the event will be stopped.

Now, in figure b what we can see the same thing is shown in log scale same thing means that effective confining pressure is shown in log scale that is the only difference that you can see here.

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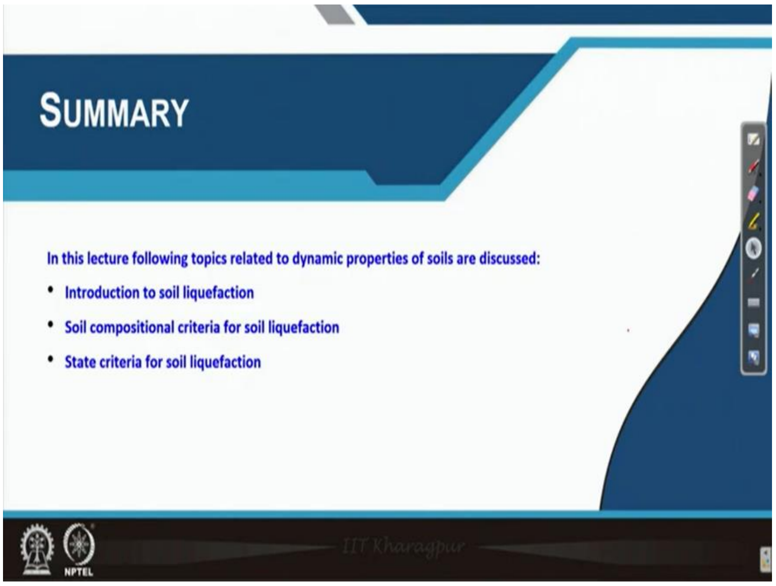

So, come to the summary of today's class. In this lecture, we have discussed a few things. First one we have discussed what is liquefaction. Then what is initial liquefaction, what is failure for soil in liquefaction that we have studied. Then we have discussed the soil compositional criteria for liquefaction and that time what I told you is that earlier people believe that liquefaction is possible only for coarse grain soil but later it is found that for non-plastic fine grain soil liquefaction is possible and four criteria were given if the fine grain soil satisfy all those four criteria, then it may be susceptible to liquefaction.

After that what we have seen, we have discussed state criteria for soil liquefaction where you are introduced to critical void ratio line and what will be happening to dense sand and loose sand when it is under on print when it is loaded under undrained condition. So, what we have seen in case of loose sand liquefaction is possible because of the increasing positive porewater pressure or we can call it as positive excess porewater pressure. Whereas, in case of dense sand, liquefaction is not possible because of the development of negative excess porewater pressure in the large axial strain level.

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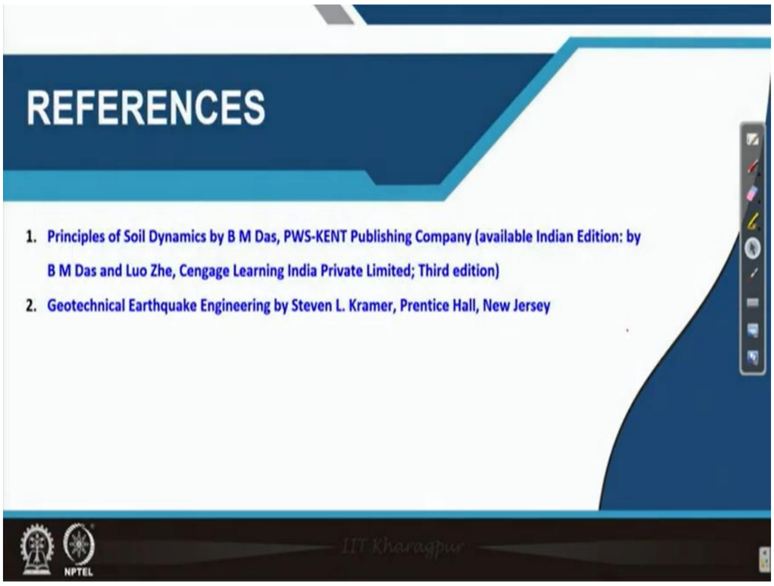

So, these are the references that I have used for today's class. So, thank you.