Soil Dynamics
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Lecture 32
Liquefaction of soils (Part 2)

Hello everyone, today we will continue our discussion on liquefaction of soils.

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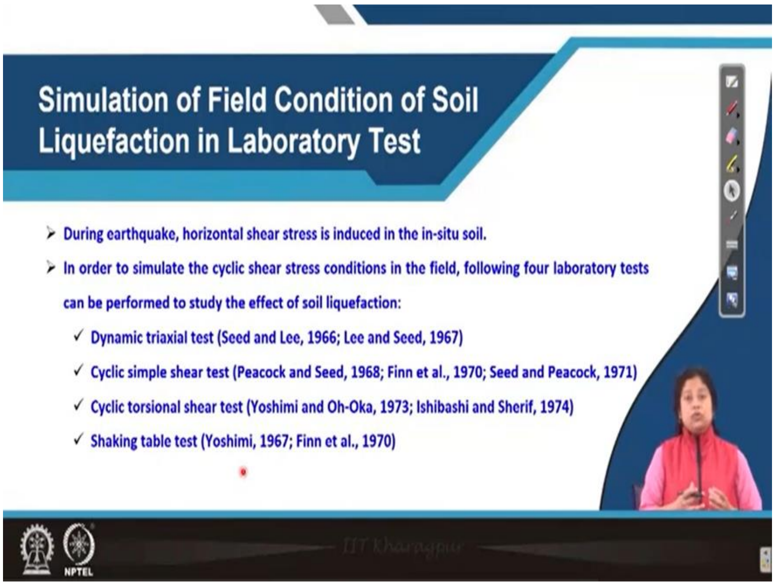

So, first we will see how we can simulate the field condition of soil liquefaction in laboratory. So, what is happened during earthquake? During earthquake horizontal shear stress is induced in the in-situ soil. In order to simulate the cyclic shear stress condition in the field following for laboratory tests can be performed to study the effect of soil liquefaction.

So, first test is dynamic triaxial test, second one is cyclic simple shear test, cyclic torsional shear test is the third one and we can also carry on shaking table test which is proposed by Yoshimi in 1967 and also done by Finn and others in 1970 to simulate the liquefaction in the lab.

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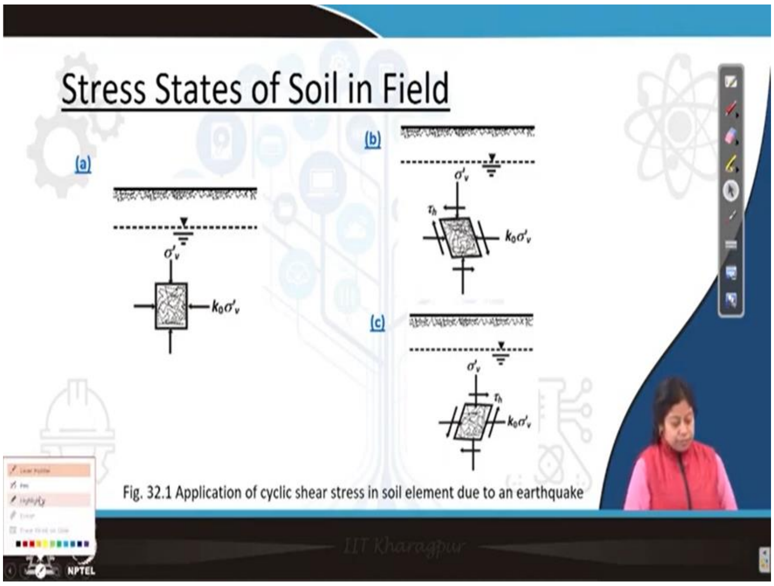

So, what is the stress states of soil in the field when there is no earthquake and when there is earthquake. So, when there is no earthquake, we can see the figure a what is happened? Vertical effective stress is acting on the soil element. Also, since the soil is at rest condition, so, lateral stress having magnitude k0 times sigma v dash acts on the soil element. Now, what is the how we can calculate sigma v dashed?

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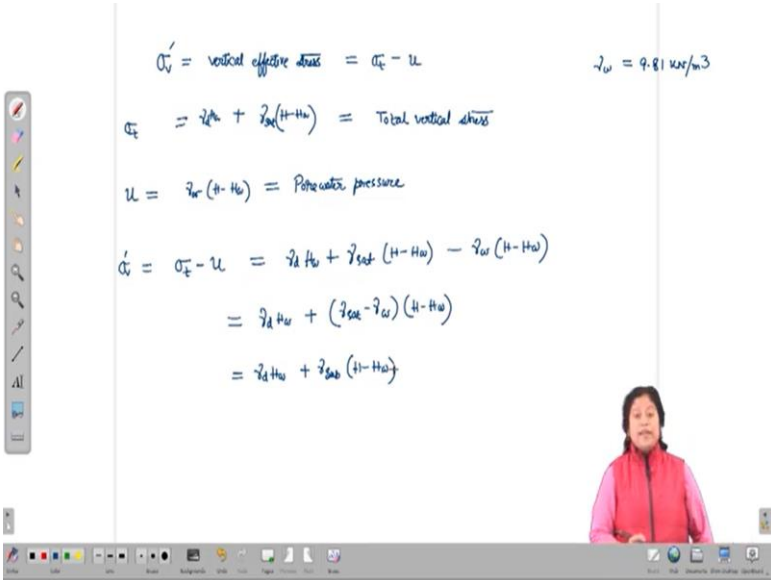

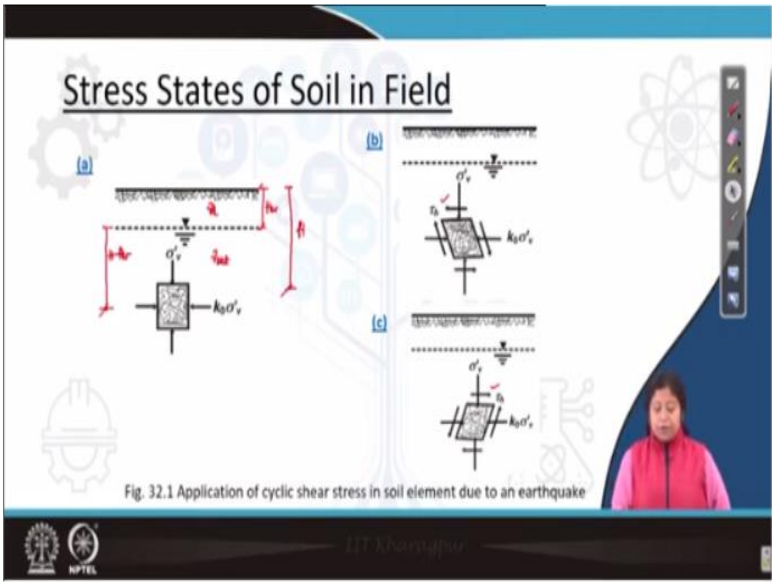

So, sigma v dashed I am writing on the board. So, here you can see sigma v dashed is the vertical effective stress. Effective stress means total stress minus porewater pressure. So, in this figure, if I consider that the water table is at a deep small hw from the ground surface if we consider the depth of the soil element from the ground surface is approximately capital H, then I can do one thing instead of small hw, I am taking here capital HW. So, capital HW is the depth of the groundwater table measured from the ground surface. H is the height of the or depth of the soil element or the point at which we are interested to find out the value of sigma v dashed.

Then, sigma v dashed which is the vertical effective stress is equal to total stress. So, total stress means gamma bulk times capital H I can take or here it is better to write above the groundwater table soil is in dry state if there is no capillary action, so, I can write it as gamma dry times HW plus gamma sat that means saturated unit weight of the soil time H minus HW. So, gamma d is the dry unit weight of the soil above the water table and gamma sat is the saturated unit weight of the soil below the groundwater table.

So, with this we can get the total stress which is equal to gamma sat times H minus HW that means H minus HW means this height plus the stress from the soil above the groundwater table which is gamma d times HW. Now, how much this is the total stress sigma T or I can write it as total vertical stress. This is not our vertical effective stress.

Now, vertical effective stress means what total stress which is sigma T minus pore water pressure which is u. So, in this figure, how much is the pore-water pressure? Pore-water pressure is gamma w times H minus HW, then I can write here u is equal to gamma w times H minus HW. What is this? It is pore-water pressure where gamma w is the unit weight of the water which is if I am using SI system, then in SI system gamma w is 9.81 in kilo Newton per meter cube.

Then sigma v dashed which is the difference between sigma t and u is equal to how much gamma d times HW plus gamma sat times H minus HW minus gamma W times H minus HW. So, what we can get from this gamma d times HW plus gamma sat minus gamma w times H minus HW. What is gamma sat minus gamma W? Gamma sat is saturated unit weight of soil below the groundwater table and gamma W is the unit weight of water.

So, the difference between these two parameters give us the submerged unit weight of the soil. So, I can right here next line as gamma d times HW plus gamma sub times H minus HW. So, in this way we can find out the effective vertical stress or vertical effective stress which is acting on the soil element at a depth age from the ground surface.

Now, this condition we can see when there is no earthquake. Now, during earthquake what is happened? Ground surface shake in horizontal direction also. So, horizontal shear stress is induced in the soil and the nature of the stress in half cycle, if it is acting in this direction, then in the next cycle it is next half cycle it is acting in the other direction. So, that time now, one additional stress is present or acting on the soil element.

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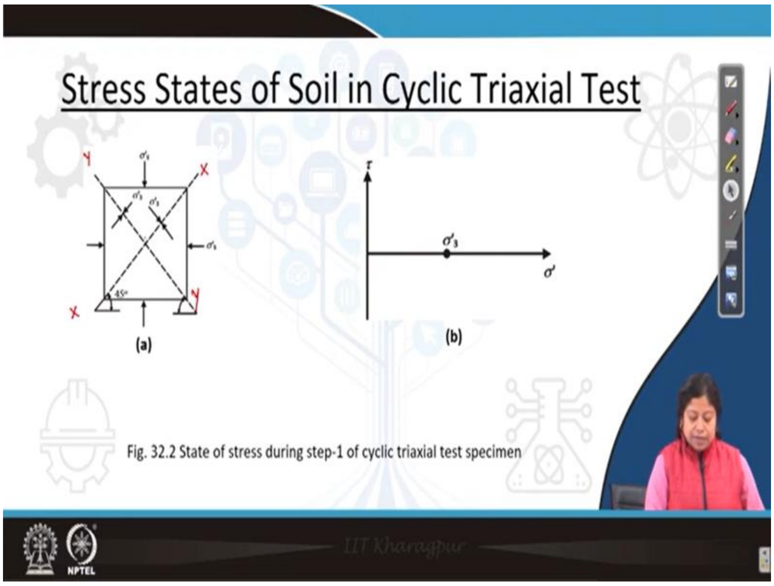

Now, for this we can find out now, we can show these stress state on Mohr circle, we all know how to draw the Mohr circle. So, on sigma tau plane or sigma dashed tau plane we get the we plot the state of states of stresses at on different planes of the soil elements. For an example in this case there are two planes shown you can see here this is our xx plane this is our yy plane likewise, we can take some other plane data I should show here.

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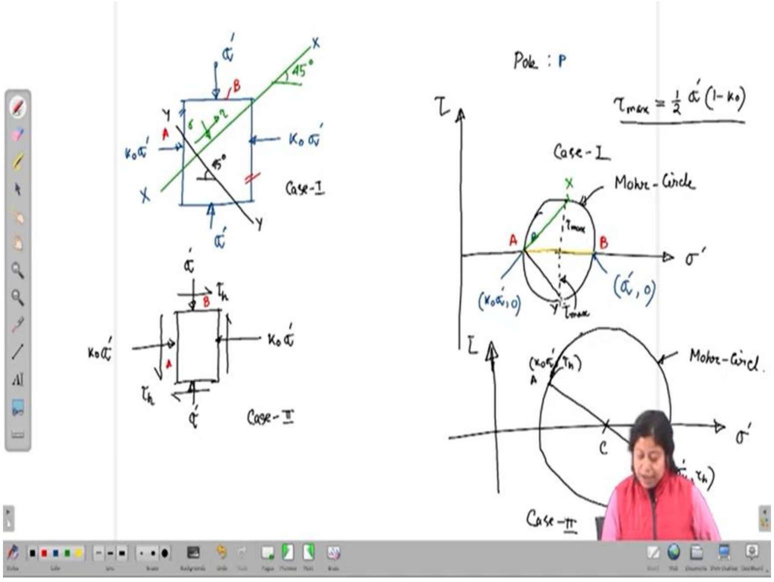

So, if this is our soil element so, on any plane we can get the state of stresses. So, we can expect one normal stress and one shear stress component. So, one component related to the normal stress the other one related to the shear stress like this we can get same thing here also, same thing here also.

And if we know that then we can join those states of stresses and by a circle or in other word I can say if I know so, what I am saying if I know the states of stresses on any two mutually perpendicular planes, let us take these two planes this is vertical planes where sigma 3 is acting or I can take it instead of sigma 3 I am writing K0 sigma v dashed and on vertical plane, this is sigma v dashed.

Then from these information, we can draw a Mohr circle. So, first thing we need to level the two axes, this is our normal stress axis this is shear stress axis. Now, on vertical plane what are the stress components acting? Only normal stress is present on the vertical plane and that magnitude is K0 sigma v dashed and there is no shear stress. So, 0. Likewise, on the horizontal plane that means on this plane only normal stress sigma dash v is acting, so, I can get sigma dash v and shear stress is 0.

Now, if I will draw a circle this is a full circle so, this point is K0 sigma v dashed comma 0 and this one represent sigma v dashed sigma 0 and the two axes are sigma dashed and tau. So, this is our Mohr circle, I am sure all of we have studied Mohr circle in solid mechanics course. So let me write here. So, this is our Mohr circle.

Now just for demonstration, I would like to draw another soil element here, let us take this soil element. Now, in this case, let us take shear stresses are also acting on the vertical and the horizontal plane. So, this is let us take tau H. Let us take this is sigma dashed V and lateral stresses is K0 sigma dashed v. So, for soil K0 is the coefficient of earth pressure at risk condition.

Now yeah. So, for these cases, how we will get the Mohr circle? This let us take case 1. So, this Mohr circle four case 1. Now for case 2 how we will draw the Mohr circle. So, the procedure is same. First, we will mark the two axes then we will mark the states of stresses on vertical plane. So, on vertical plane, it is how much on vertical plane it is K0 sigma v dashed comma tau H. Here, tau H is considered positive in this direction. So, this is one point and the other point is sigma v tau H, sigma v dashed tau H.

Now, what we can do we can join these two points by a straight line. So, this is our one point this is our other point. Now, this straight line intersects the sigma dashed axis at a point let us take C. So, with C as centre we can draw a circle with radius AC and that circle will be the Mohr circle for this case. If we will draw a circle then that circle is the Mohr circle for this case.

So, here also I think it is more or less looking like a circle but not good at all that I accept. So, this is point A and this is point B. So, point A represent stress state for the vertical plane that means for these planes and B represent stress date for horizontal plane that means this one and this is our case 2. So, in this way we can draw Mohr circle from the known states of stresses.

Now the question whether I know case 1 or case 2, but from that how I can find out stress state on some other plane for an example, if I consider case 1, then for this plane let us take it is an angle 45 degrees with horizontal how I will find the state of stress that means there is one normal stress and one shear stress that how I will find out that is the question now.

So, for these, we need to use our property of Mohr circle. There is one unique point on this Mohr circle and that end point is called pole. So, I am writing here pole. So, first I need to mark the pole on Mohr circle. How do I do so? So, I know, since I am right now discussing case A, so, let us mark this point A and B here. So, let us take case 1. So, in case 1 what do we know we know the stresses acting on plane A and the stresses acting on plane B that is horizontal plane.

Now, if I will draw from point let us take B on the Mohr circle, if I will draw a line parallel to the plane on which this sigma v dashed comma 0 that means the stress state at point B is acting then that line will intersect the Mohr circle at one point other than B or maybe only at B. So, that point is the pole. So, in this case, from B if I will draw a line parallel to the horizontal plane then it will intersect the Mohr circle at A. So, here it is the poll, so I am marking A as P, P stands for pole.

Now, let us see this definition in another way, let us take the plane A on which what are the stresses acting normal stress is K0 sigma dash v and shear stress component is 0. So, from A that means stress state on plane A is represented by point A on the Mohr circle 1. Now, from A if I will draw a line parallel to the plane A that means parallel to this plane that will be tangent to this Mohr circle at point A only. So, A is the point at which that plane or the line parallel to the plane A will intersect the Mohr circle and that point itself is the pole of this Mohr circle.

So, with this knowledge, now we can also find out. So, pole is identified now. Now I am interested to find out that stress is acting on plain xx. So, for that what I will do on P or at P I will draw a line parallel to xx. So, let us do this exercise. So, a line parallel to xx. So, this line starting from the pole of the Mohr circle touching another point on the Mohr circle and this point says the stress state on plane xx. So, eventually for case 1 what is stressed state? You can see this is the tau max. So, in this case that means case 1 tau max is half of sigma dash v times 1 minus K0.

So, in this way, we can find out the stress state on any plane by using the Mohr circle. Once again I can show you the stress date on another plane, let us take this yy. Let us take these yy is also making an angle 45 degree to the negative x direction, then what we need to do from pole we will draw a line parallel to yy which will intersect the Mohr circle at some other point and that point will tell us the stress state on plane yy. So, from P if I will draw a line parallel to yy where it will intersect let us see.

So, this is the point. So, this is again tau max for this one yes that we can get the maximum shear stress on the plane xx or y. Now, the direction also important in this case. So, what is the direction in this case that now we will check. So, what is the direction in this case on yy?

So, this is this point is marked yy? So, on yy? Let me go open a new page. So, I am writing here.

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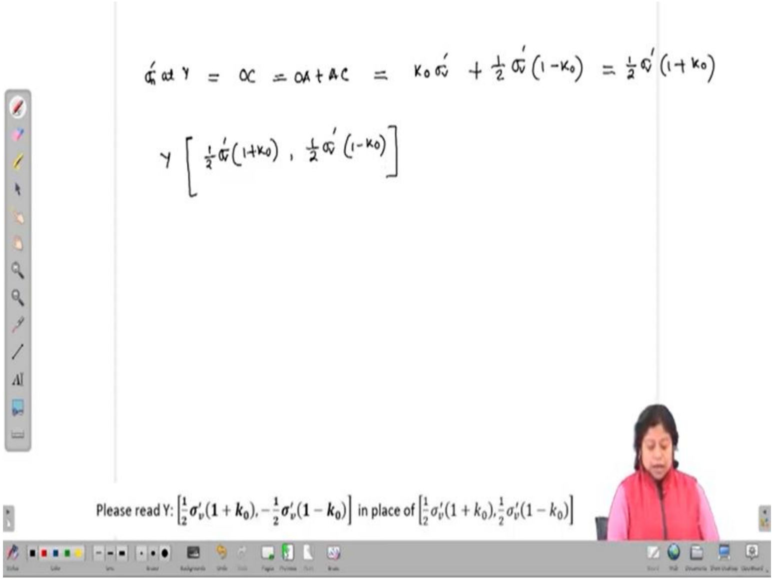

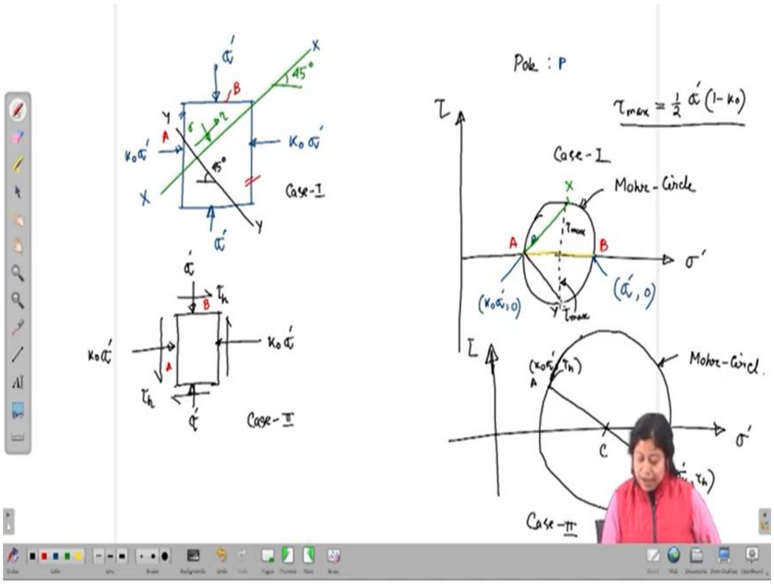

So, now if I am interested to find out the value for the stresses acting on yy plane then that I can get from this dad diagram itself shear stress you can see that is tau max. So, in this case the magnitude of tau max is already calculated. What is the magnitude of the normal stress at this point y on the Mohr circle?

So, let us find it out. So, I am interested to find out normal stress at y. So, that is nothing but the distance of the center of this Mohr circle for case 1 from the origin O, that means OC. So, if we know OC, then we can calculate. OC means OA plus AC. OA means K0 sigma dashed v, AC sigma dash v times 1 minus K0. So, from this what we can get that I am writing one plus K0 times sigma v dashed divided by 2.

So, it means here if I need to write the coordinate for y, that is half of sigma dashed V times 1 plus K0 this is normal stress component and shear stress component is this one. So, in this way we can calculate or we can find out the stressed state on any plane in the soil element.

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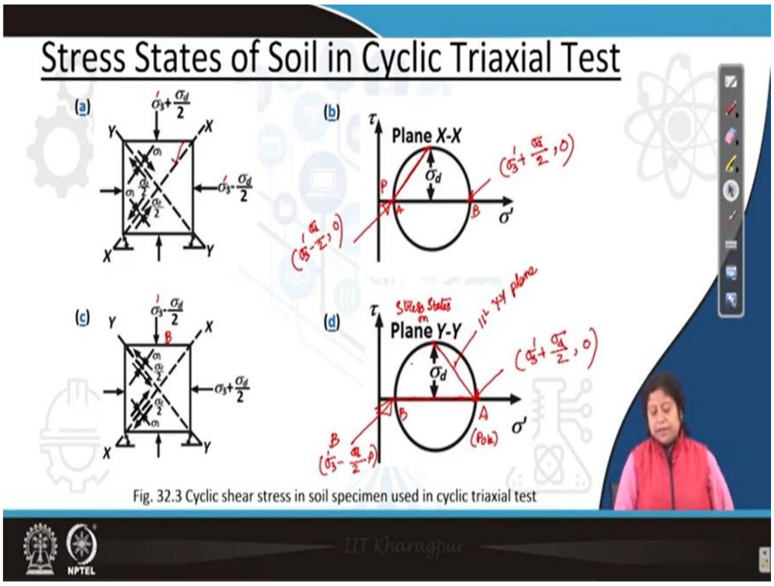

So, now, using this concept of Mohr circle, we will try to continue our discussion. So, for the first case, our first step of the triaxial test is to apply the confining pressure to the soil or soil specimen and the magnitude of the confining pressure is sigma 3 dashed and this pressure is acting all around the soil specimen. So, if we will try to draw a Mohr circle on sigma dash tau plane what we will get we will get a single point only from this data.

Now, here you can see if during triaxial test, we simulate the vertical stress equals to sigma 3 plus sigma d by 2 and you lateral stress is equal to sigma 3 minus sigma d by 2 or you can since, I consider earlier the symbol for the effective stress, so, better you make it sigma dashed 3. So, sigma dashed 3 plus sigma d by 2 on the horizontal plane that means this is the in this case it is the major principle stress.

Lateral stresses sigma dashed 3 minus sigma d by 2 this in this case it is the minor principal stress. So, on xx plane explain that means this plane what will be the value of stresses that we can easily calculate. So, here stress is sigma 3 dashed plus sigma d by 2 and here stress is okay let me write comma also to see that there is no shear stress and on this at this point it is sigma 3 dash minus sigma d by 2 comma 0.

Now, eventually this point itself is the pole in this case pole of the Mohr circle. So, from P, if I will draw a line parallel to xx plane that will intersect the Mohr circle at this point. So, this is the from the we can find out the stress state on xx plane. Likewise, for the second case, if I am interested to find out the stressed state first what I need to do?

First, I need to mark the stresses at these two points straight stress components. So, at these (comp) here it is now, this is B point in this case it is A it is B. Now, this case this is B and this is A. So, this is your sigma 3 dashed minus sigma d by 2 comma 0 and here it is sigma 3 dash plus sigma d by 2 comma 0. So, this is B this is A.

So, this time where is pole that is the first question. If from B I will draw a plane or line parallel to the plane B that means, horizontal plane then that will intersect the small circle at A. So, at A pole of the Mohr circle is located now from the pole if I will draw a line parallel to yy plane, then this is parallel to yy plane and this will give stress states on yy plane.

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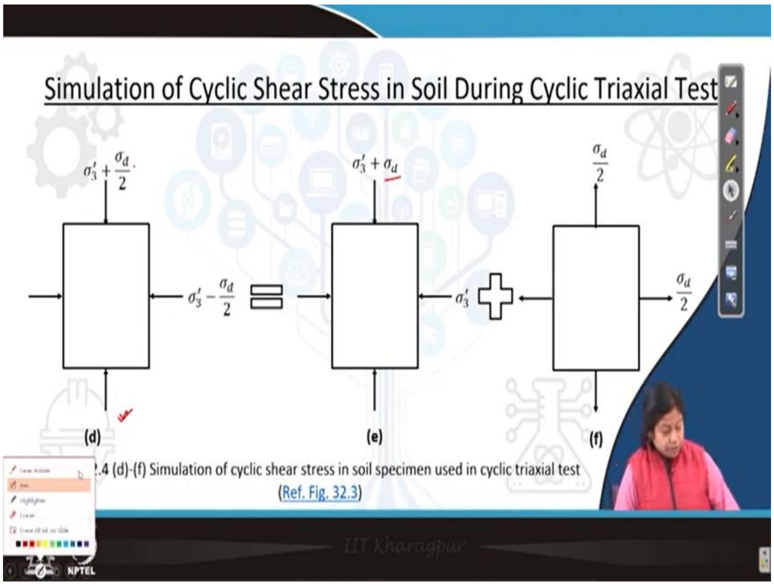

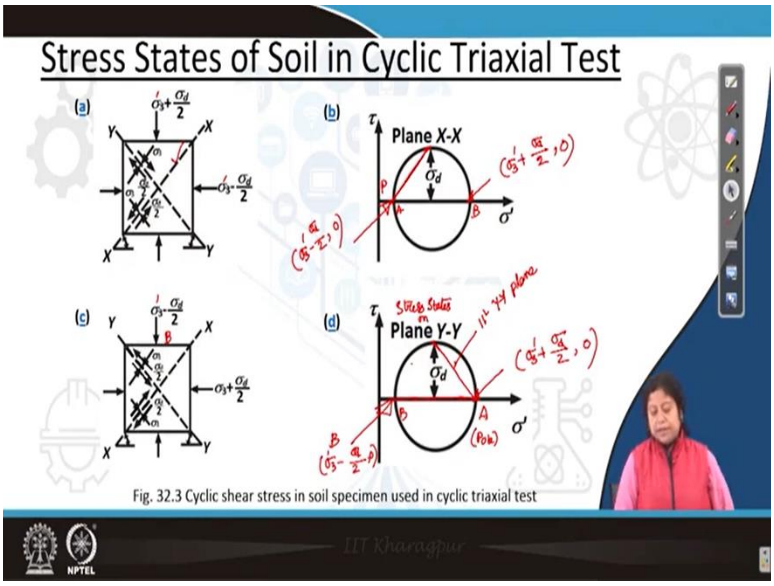

Now, in triaxial test, how we can simulate this condition? In triaxial test what we can do first we can apply the all-round pressure then we can apply axial stress additional axial stress. So, due to that reason, what we can do here is that first we will apply sigma 3 dashed which is the all-round pressure then, we will apply the axial load in such a way that the total actual stress on the horizontal plane that means total vertical actual stress becomes sigma three dashed minus sigma d.

So, if sigma three dashed is comprehensive in nature and if I am applying additional axial stress which is tensile in nature, then the sum of these two is sigma three dashed minus sigma d. Now, I need to simulate this condition for which what I will do now, I will add sigma d by 2 amount of all round pressure to the soil specimen as shown in figure c. So, if I will apply this much amount of the all round pressure, then what we will finally get we will finally get the state of stress shown in figure 4a.

Similarly, for when that additional actual stress is comprehensive in nature that time what we can do, we can simulate these figure d by applying first the additional axial stress which is comprehensive in nature that amount is sigma d and we can also subtract pole pressure from the specimen or add just so, that the all round pressure this time is subtracted sigma d by 2 amount.

So, in this way, we can simulate that condition which is shown in figure you can see this is shown in figure 32.3. So, these state of stress we can simulate by conducting the cyclic track shear test.

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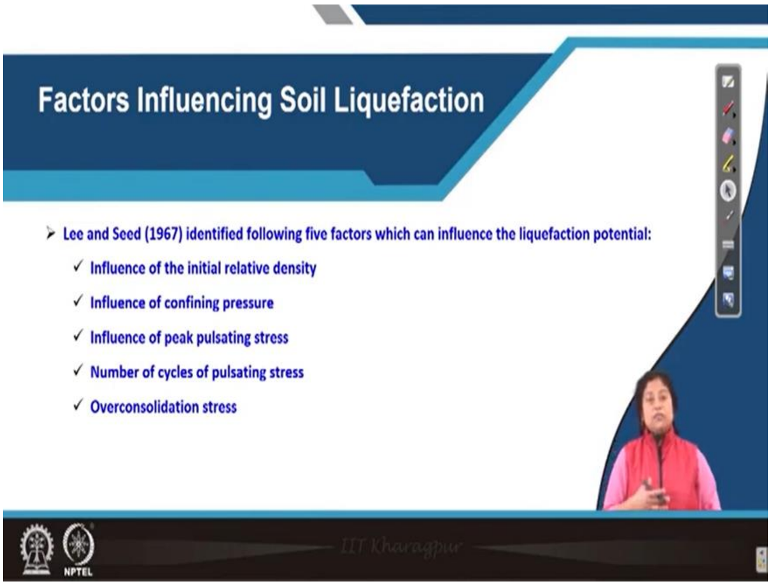

Now, let us see what are the factors which we need to take care or consider during study of soil liquefaction by conducting cyclic triaxial test or dynamic triaxial test. Lee and Seed identified five factors, second one is the confining pressure applying to the soil. Third one is peak pulsating stress, fourth one is number of cycles of pulsating stress and final one is over consolidation stress. However, the fifth one is not related to the cyclic triaxial test but is related to the cyclic simple shear test that these the effect of these five factors we will study in our next class.

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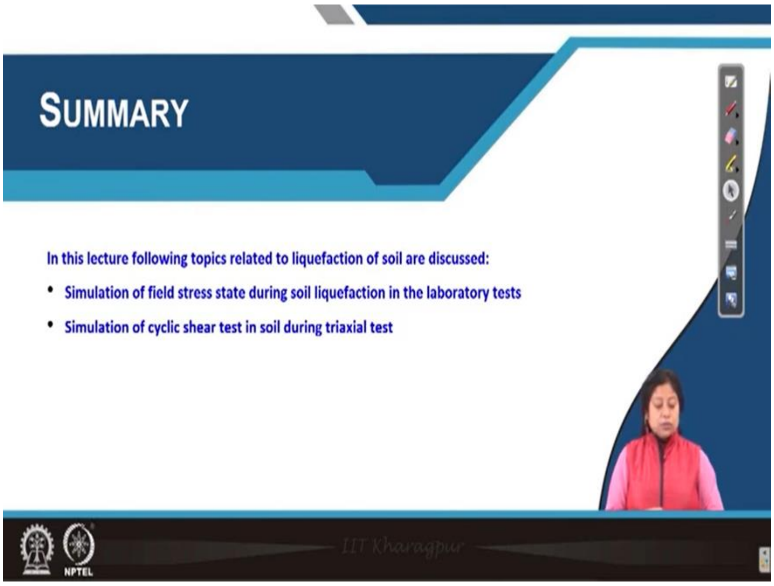

So, here you can see the summary of today's class. We have studied the two major things one how to simulate the field stress state during soil liquefaction in our laboratory test and simulation of cyclic shear test in soil during triaxial test alright and also, we have studied that Mohr circle and how to get the how to know the stress date on any plane if we have the more circle.

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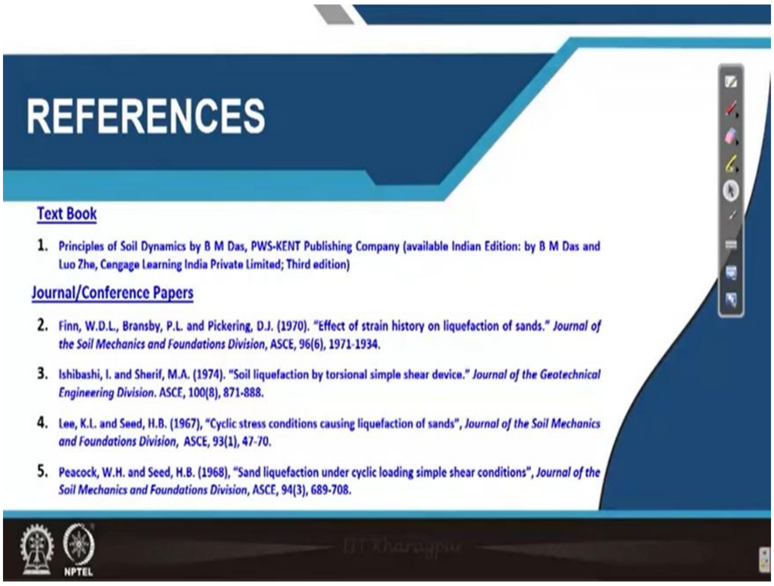

So, these are the references which I have used for today's class. Thank you.