Soil Dynamics
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Lecture 34
Liquefaction of Soils – 4

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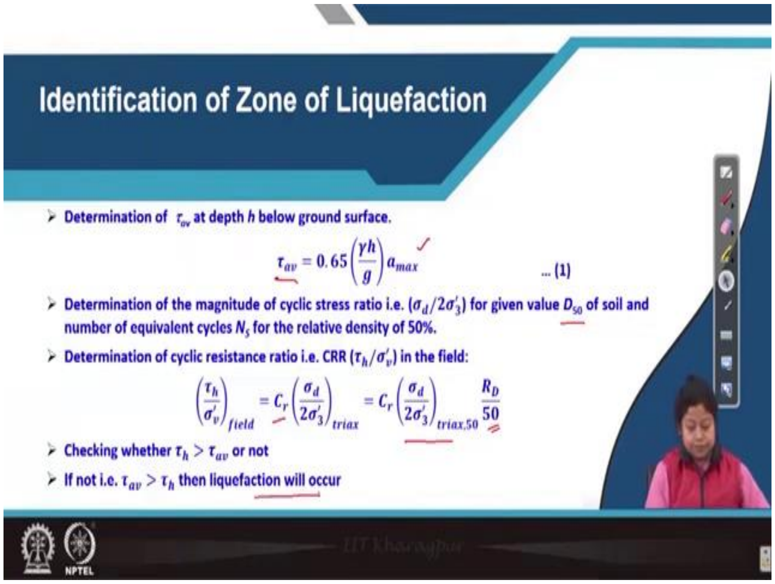

Hello friends, today we will continue the lecture on liquefaction of soils. So, in last class we have studied how to find out the shear stress maximum shear stress that soil can take under cyclic loading condition that means, tau h, we can also call it as a peak cyclic shear stress recurred for the liquefaction. Today, we will first see how to find out the shear stress induced due to an earthquake event.

So, first task is to determine the tau av which is the shear stress induced due to an earthquake at a depth h below the ground surface, we can find it out by using this equation that tau av is equal to 0.65 times gamma h divided by g times a max. So, here a max is the peak ground acceleration or maximum round acceleration gamma is the bulk unit weight of the soil h is the depth at which we are finding out tau av, and we are considering 65 percent of the maximum shear stress that is the reason multiplying by the factor 0.65.

Our next task is to determine the magnitude of cyclic stress ratio, which we have learnt in last class how to find out the cyclic stress ratio which is sigma d divided by 2 times of sigma 3 dashed from the cyclic triaxial test or we can call it also as dynamic triaxial test for given value of d 50 of soil. What is D 50 here here D 50 is the that mean grain size or we can call it also as the diameter of the soil grain corresponding to 50 percent finder and also we need to know that number of equivalent cycles which is NS for the relative density of 50 percent, then, what we will do?

We will find out the cyclic stress cyclic resistance ratio which is also called as CRR, this is nothing but the ratio of tau h divided by sigma v dashed, tau h is the peak cyclic stress recurred to cause liquefaction or in other words, we can call it as the shear strength of the soil under dynamic loading condition. What is sigma v dashed here? Sigma v dashed here is the effective vertical overburden stress and that is in the field we need to find out that means tau h divided by sigma v dashed in field now, we need to find out.

So, for that, we need to use the triaxial data sigma d divided by 2 times of sigma 3 dashed and that triaxial cyclic stress ratio, if we will multiply it by a factor Cr from that I can find out the tau h divided by sigma v dashed in the field. Sometimes what is happening we cannot find out the sigma d divided by 2 sigma 3 dashed for all relative densities of the soil. So, we can just find it out for the relative density of 50 percent and then we multiply a factor RD divided by 50 where RD is the relative density at that soil layer and 50 is the 50 percent or its relative density and that when we will multiply when we are using the value of sigma d divided by 2 sigma 3 dashed at a relative density of 50 percent that means, this value.

So, basically what we are doing here, we are actually finding out the cyclic stress ratios which is sigma d divided by 2 sigma 3 dash from that dynamic triaxial test of a soil for the soil sample at 50 percent relative density and then that cyclic ratio is multiplied by the factor RD divided by 50 here.

Next step is to check whether these tau h which we have determined from the laboratory test that not directly from the laboratory test actually with the help of the laboratory test finally, we have find out the tau h. So, in the field and that tau h whether is greater than the tau av or not. If tau h is greater than tau av, it indicates that the strength of the soil is higher than the shear stress induced during the earthquake event. But, if tau av is greater than tau h, it means that the shear stress which is induced by an earthquake is higher than the shear strength of the soil under the cyclic loading condition. So, what will be happening we will see the liquefaction.

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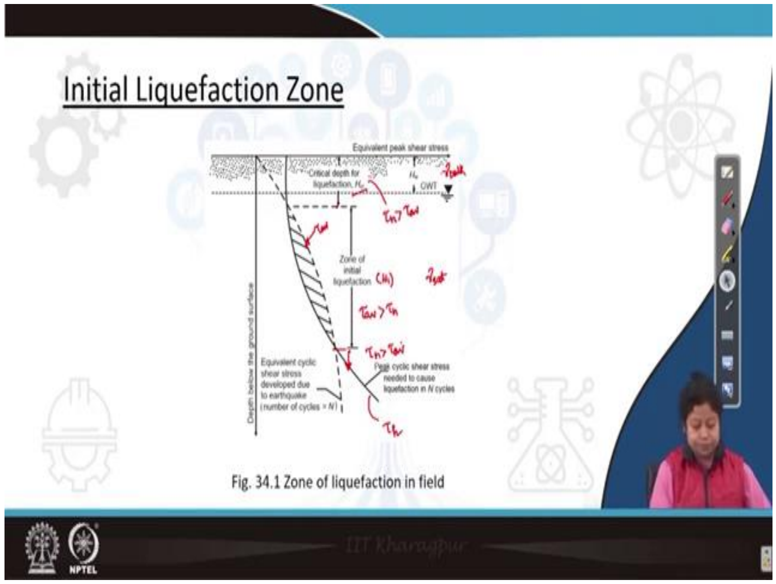

So, in this diagram you can see that our soils deposit, so, groundwater table is located at a deep you can see it is located at a deep hw from the ground surface. Now, below the groundwater table, we know the suppose so, at least obviously soil is in saturated condition. So, we know that gamma set and above groundwater table whatever soil is there we know gamma bulk for that soil. So, with this information what we can do we can find out tau av and also we can find out tau h this is the plot for tau av and this is the plot for tau h.

So, here you can see from ground surface to the depth h Cr. So, up to this point what we can see tau av is greater than tau h. So, here tau av is greater, I just say the reversing let be correct. So, what we have seen from the ground surface to the depth Hcr, we have seen tau h is greater than tau av that means, we soil have sufficient strength. So, there is no liquefaction up to the depth Hcr from the ground surface.

Now, below Hcr, what we can see up to our depth these you can give these as h1. So, below the critical depth for liquefaction to up to h1 depth, what we can see in this region tau av is greater than tau h, it means that the cyclic stress shear stress induced by the earthquake is greater than the strength of the soil. That is the reason initial liquefaction can occur, again below this point that means, this region you can see again tau h is greater than tau av then there is no possibility to there is no possibility for initial liquefaction.

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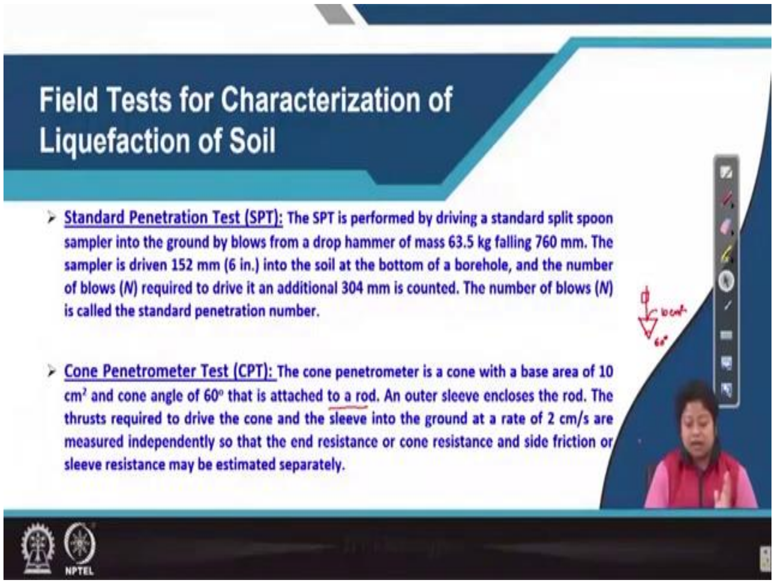

Now, we will see a few field tests also conducting which we can find out the zone of liquefaction what are those tests, there are 2 popular tests one is standard penetration test and the second one is Cone Penetrometer test. So, let us see the definition of standard penetration test or SPT. I hope all of you have studied SPT in your undergraduate geotechnical engineering subject. So, here I am just repeating the definition of SPT or standard penetration test value.

So, the SPT is performed by driving a standard split spoon sampler of course, there is a standard dimension of this sampler into the ground by blows from a drop hammer having mass 63.5 kg falling 760 millimeter. Now, the sampler is driven 152 millimeter or 6 inches into the soil at the bottom of a borehole and the number of blows you can call it you can write it by capital A. So, the number of blows required to drive it an additional 304 meter 304 millimeter is counted.

So, I am repeating just the number of blows required to drive the sampler an additional 304 millimeter is counted and this number of blows is called the standard penetration number, sometimes we call it as SPT value also. So, this is one test field test conducting which we can find out the strength of the soil or I can call tau h of the soil in the field.

The other test is Cone Penetrometer test we in short, we call it as CPT. So, I hope all of you are familiar with CPT as well what is Cone Penetrometer the cone penetrometer is a cone with a base area 10 square centimeter and the cone angle of 60 degrees. So, this kind of cone so, the base this is the base which is 10 square centimeter and the cone angle is 60 degree.

And this arrangement that is cone is attached to a rod and outer sleeve encloses this rod the thrust required to drive the cone and the sleeve together so, there is a sleeve here. So, the thrusts required to drive the cone and the sleeve into the ground at the rate of 2 centimeter per second are measured independently to, that the end resistance or cone resistance and site friction or sleeve resistance can be estimated separately.

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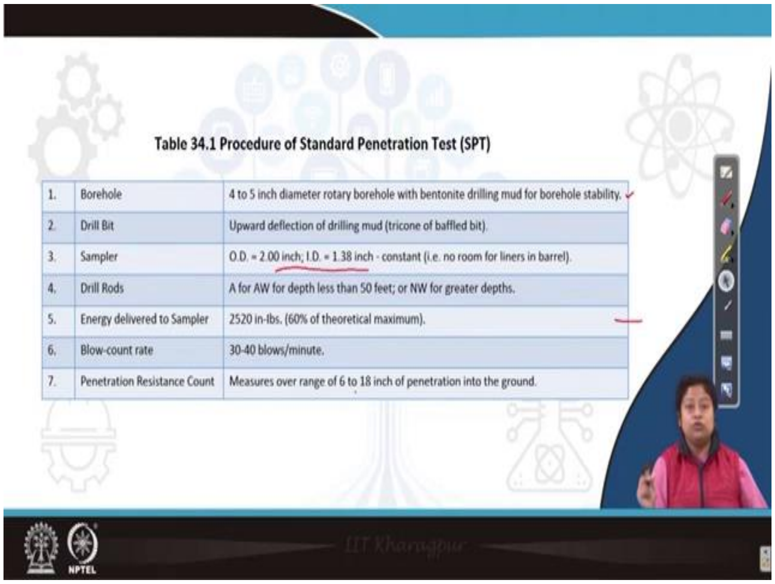

Table 34.1 Procedure of Standard Penetration Test (SPT)

1.	Borehole	4 to 5 inch diameter rotary borehole with bentonite drilling mud for borehole stability.
2.	Drill Bit	Upward deflection of drilling mud (tricone of baffled bit).
3.	Sampler	O.D. = 2.00 inch; I.D. = 1.38 inch - constant (i.e. no room for liners in barrel).
4.	Drill Rods	A for AW for depth less than 50 feet; or NW for greater depths.
5.	Energy delivered to Sampler	2520 in-lbs. (60% of theoretical maximum).
6.	Blow-count rate	30-40 blows/minute.
7.	Penetration Resistance Count	Measures over range of 6 to 18 inch of penetration into the ground.

Here in this table, you can see some standard, some descriptions of procedure of standard penetration test that means SPT so here you can see what is that standard diameter of the borehole which varies from 4 to 5 inches. You can see the standard dimension of the sampler that is there that should be of outer diameter 2 inches and inner diameter 1.38 inches. Likewise, you can see how much the energy delivered to the sampler 2520 inches pounds. Also, you can see the blow count rate which is 30 to 40 blows per minute also, you can see the penetration resistance count. So, this standard procedure should be followed during our SPT test.

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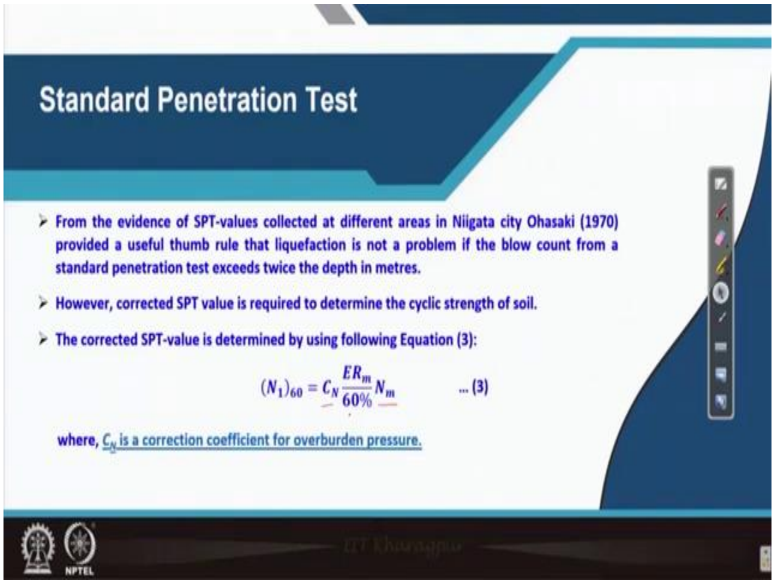

Now, how we will use SPT test to find out the zona liquefaction actually what is happening from the evidence of SPT values collected at different areas in Niigata city or Ohasaki in the year 1970 provided a useful thumb rule what it is said, it said that the blow count from a standard penetration test if exceeds twice the depth in meter then there is no liquefaction.

So, you can see the in the word how I have written here is that liquefaction is not a problem, if the blow count from a standard penetration test exceeds twice the depth in meter that means, if the height or depth of the point at which I am interested to know whether liquefaction is occurred or not, if that is at a depth 4 meter from the ground surface, and if the blow count of SPT is 8 more than 8, which is 2 times the depth, then there is no liquefaction or I can say liquefaction is not a problem at that point.

However, corrected SPT value is required to determine the cyclic strength of soil. The corrected SPT value is determined by using the following equation 3. In equation 3, N1 60 can be calculated by multiplying Nm to Cn and the ratio E Rm divided by 60 percent where Cn is our correction coefficient for overburden pressure.

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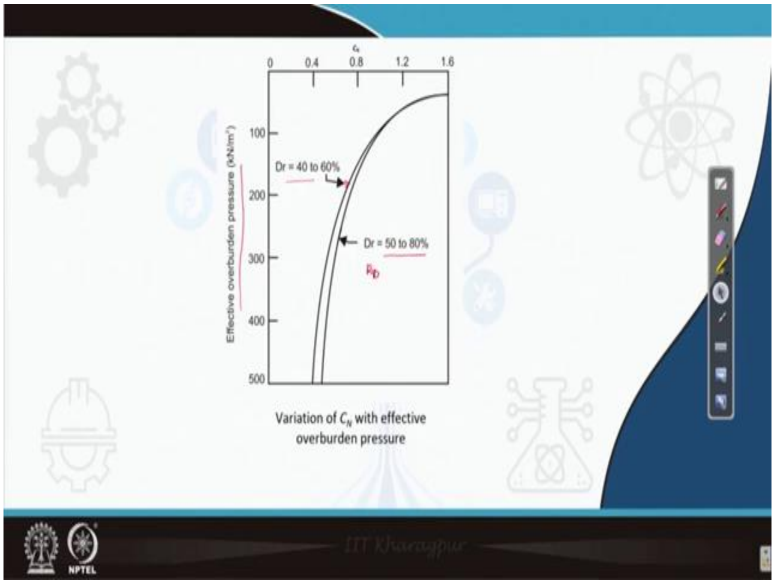

Now, how we can get Cn? Cn can be calculated using this equation cn is equal to 9 point 78 times 1 divided by sigma v dashed where sigma v dashed is the effective vertical stress or we can call it also as effective overburden stress, we can also calculate Cn by using a this curve. So, what is this curve in these curve if we know the value of effective overburden pressure in kilo Newton per square meter, then we can calculate Cn based upon the value of relative density.

If relative density of the soil is in between 40 and 60 percent, then we will use this left hand side curve. If the relative density of the soil is 50 to 80 percent, then we will use the right hand side curve. Here the R represents the relative density sometime instead of Dr we use the symbol RD for relative density.

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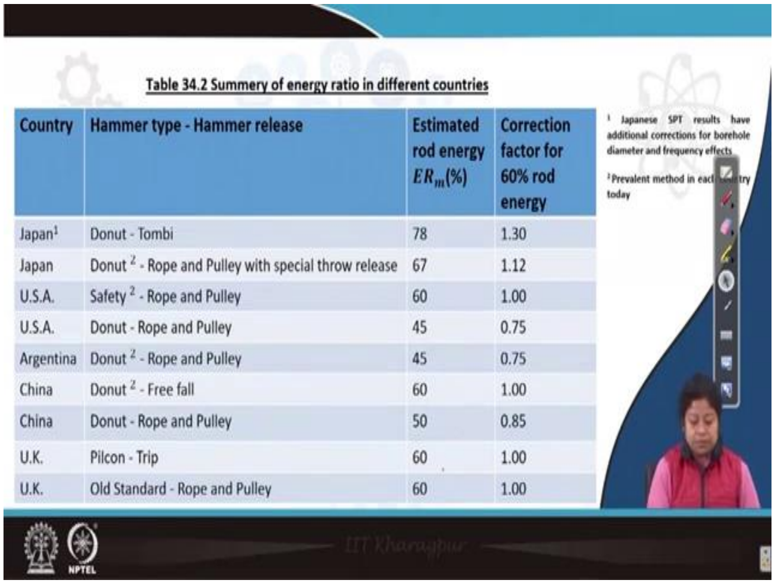

Country	Hammer type - Hammer release	Estimated rod energy ER_m(%)	Correction factor for 60% rod energy
Japan[1]	Donut - Tombi	78	1.30
Japan	Donut [2] - Rope and Pulley with special throw release	67	1.12
U.S.A.	Safety [2] - Rope and Pulley	60	1.00
U.S.A.	Donut - Rope and Pulley	45	0.75
Argentina	Donut [2] - Rope and Pulley	45	0.75
China	Donut [2] - Free fall	60	1.00
China	Donut - Rope and Pulley	50	0.85
U.K.	Pilcon - Trip	60	1.00
U.K.	Old Standard - Rope and Pulley	60	1.00

Now, E Rm is that actual energy efficiency delivered to the drill rod from table 34.2. So, so, here you can see the value of E RM for different types of hammer and ha it also depends upon how the hammer is released. You can see and this value for ERm varies from one country to another country for an example, if you see here Japan used 78 78 or 67 whereas, USA consider 60 or 45 depending upon what type of hammers they are using. Likewise, in UK you can see for all types of hammer, they are considering ERm value 60 percent.

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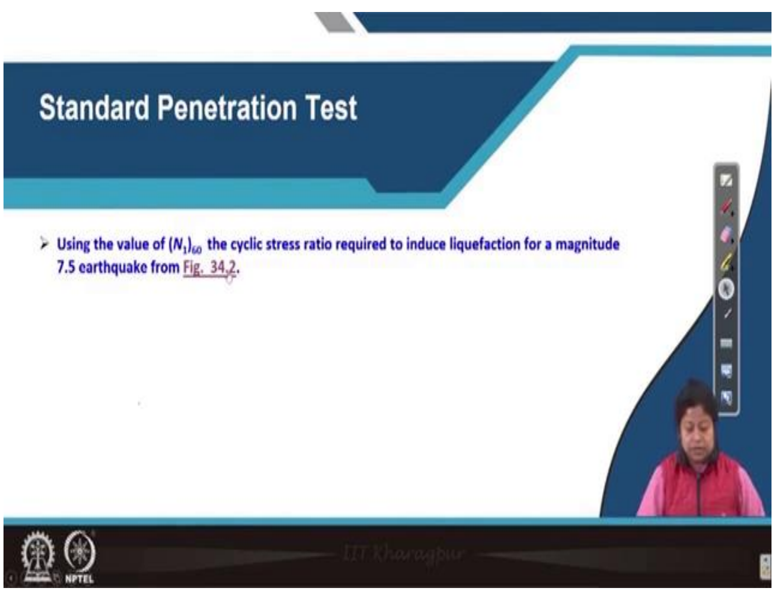

Now, what we will do in the next step. So, from equation 3 we have calculated N1 60, which is corrected already for the overburden pressure. Now, using the N1 60 value so, now, using the N1 60 value the cyclic stress ratio required to induce liquefaction for a magnitude of 7.5 earthquake we can calculate.

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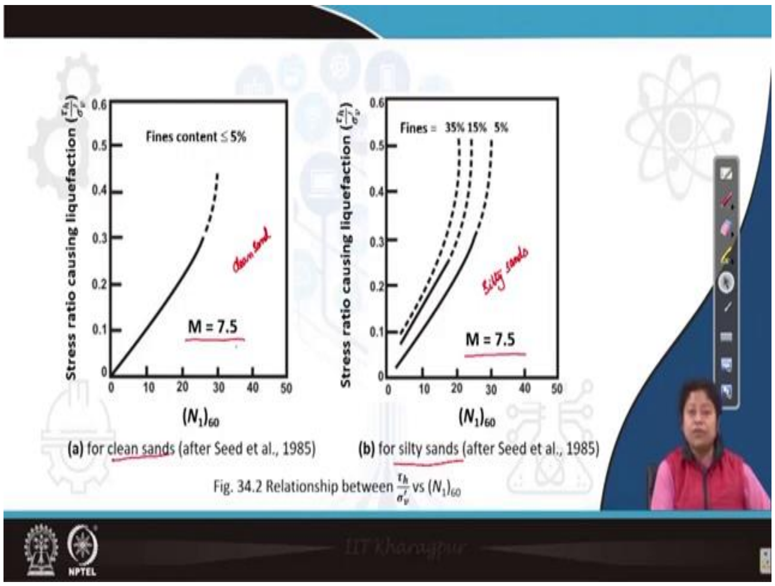

So, here you can see just a minute yes, so, here you can see if we know the N1 60 value using that value we can calculate the stress ratio causing liquefaction that means, tau h divided by sigma v dashed. Now, in this case, what we need to remember is that we can we are using m is equal to 7.5 that means, the magnitude of the earthquake in Richter scale this is 7.5 and also you can see these figure a for clean sand.

So, this figure is for clean sand whereas, this figure B is for silty sand it is already written here. So, we can use any of these 2 figures depending upon what type of soil we are dealing and using these figure if we know the value of N1 60 we can calculate the stress ratio causing liquefaction. Likewise, we need to correct you can you have already seen in previous figure that the earthquake magnitude considered 7.5. So, if the magnitude of the earthquake is other than 7.5, then how we will find it out that is also required. So, for that what we need to do?

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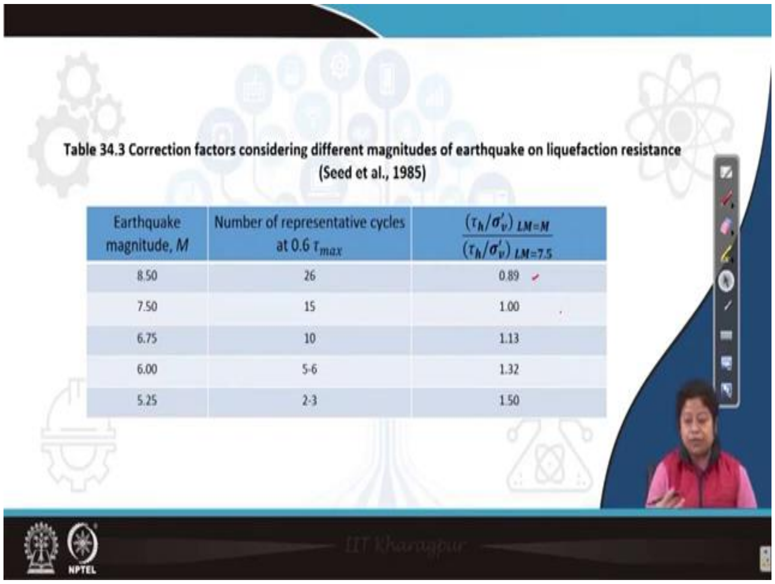

Earthquake magnitude, M	Number of representative cycles at 0.6 τ_{max}	$\frac{(\tau_h/\sigma'_v)_{LM=M}}{(\tau_h/\sigma'_v)_{LM=7.5}}$
8.50	26	0.89
7.50	15	1.00
6.75	10	1.13
6.00	5-6	1.32
5.25	2-3	1.50

Let us see. So, we will use this table, what is this table this table says what is the ratio of tau h divided by sigma v dash for an earthquake of magnitude other than 7.5 to the same ratio for an earthquake of magnitude 7.5.

So, if we know this ratio from that we can calculate the value of tau h divided by sigma v dash which is the cyclic stress ratio for any earthquake of any magnitude. So, what we can see here obviously, for 7.5 magnitude this ratio should be N if the magnitude of the earthquake is higher than 7.5 for an example 8.5 here, so, this factor is less than 1 that means, the strength of the soil will be reduced or the chances of the liquefaction is more

Likewise, you can see if the earthquake magnitude is less than 7.5, then the value of these ratio increases. increases means we will see that the magnitude of tau h divided by sigma v dash that any other magnitude of earthquake other than 7.5 that means, lower than 7.5 in this case is increasing.

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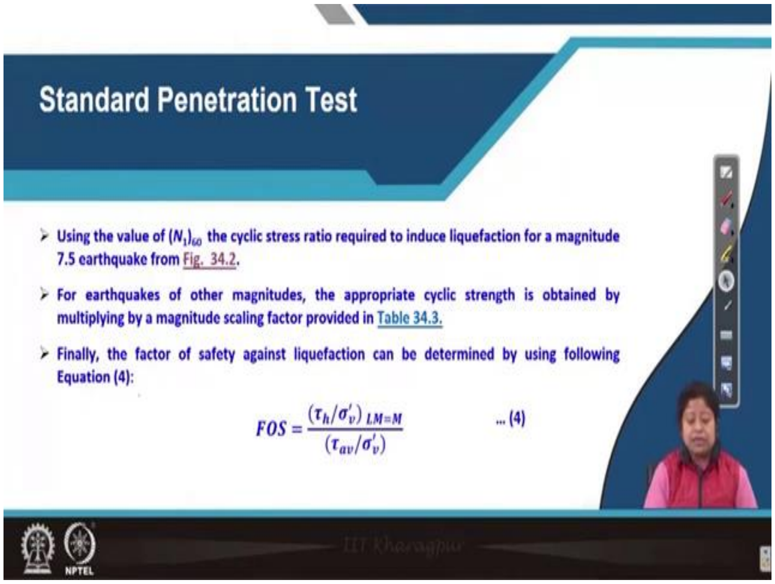

So, now, the next step after knowing the value of tau h divided by sigma v dashed for an earthquake of any magnitude other than 7.5 or 7.5 if we know this, then our next step is to find out the factor of safety, how factor of safety is defined here, factor of safety is defined by equation 4 which says that we need to find out tau h divided by sigma v dashed divided by tau av divided by sigma v dashed or I can see it also as tau h divided by tau av safety.

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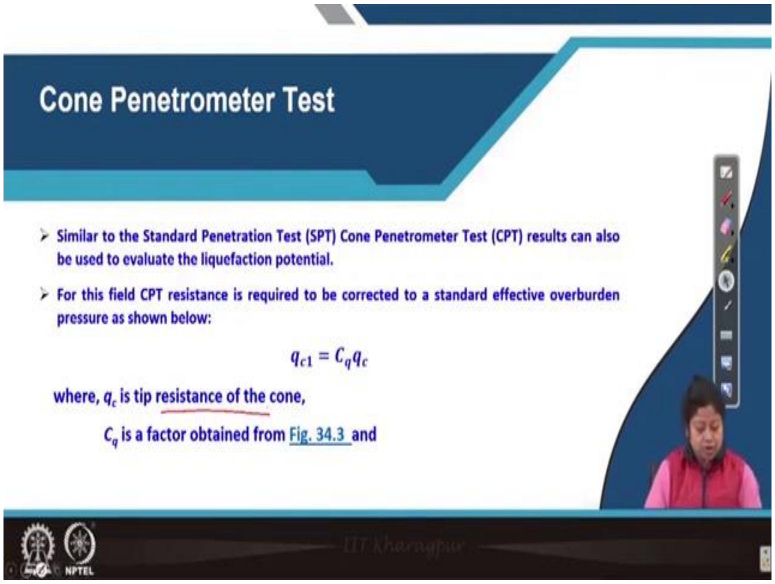

Now, let us see Cone Penetrometer test. So, similar to SPT Cone Penetrometer test we can call it also as CPT results can also be used to evaluate the liquefaction potential for these fields CPT resistance is required to be corrected to a standard effective overburden pressure the standard effective overburden pressure is equal to 1 kg per square centimeter.

So, whatever CPT value we will calculate from the field test that should be corrected for the standard effective overburden pressure which is equal to 1 kg per square centimeter by multiplying these field CPT value to a factor Cq where, as I already told Qc is the field, CPT value or I can call it as also deep resistance of the cone CQ is a factor that we can obtain from figure 34.3.

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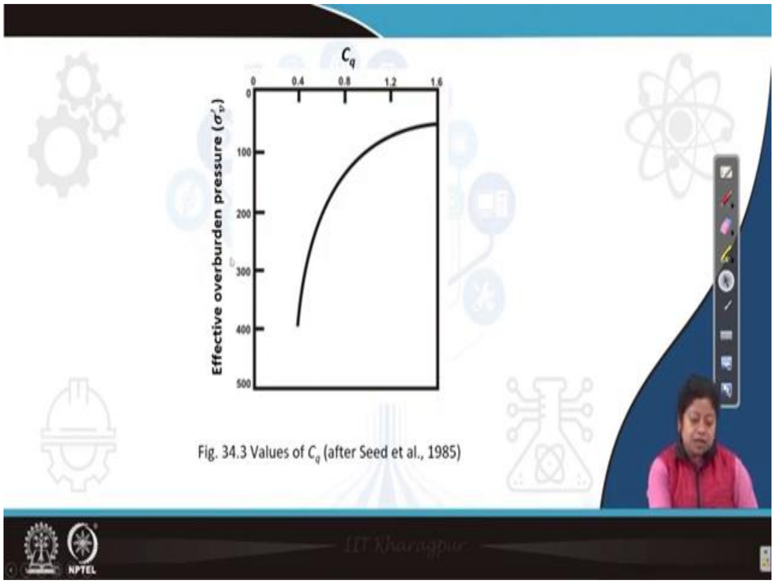

So, you can see figure 4, 34.3. So, if we know that effective overburden pressure, you can see these figure if we know that effective overburden pressure from that we can calculate CQ value and this is given by seed and others in the year 1985. So, in this way, if we know CQ and deep resistance QC, we can calculate QC 1, which is the corrected CPT resistance. As I already mentioned, QC 1 is the corrected deep resistance for effective overburden pressure of 1 kg per square centimeter. Now, we will calculate the cyclic strength ratio, which is tau h divided by sigma v dashed from figure 34.4. Let us see the figure 34.4.

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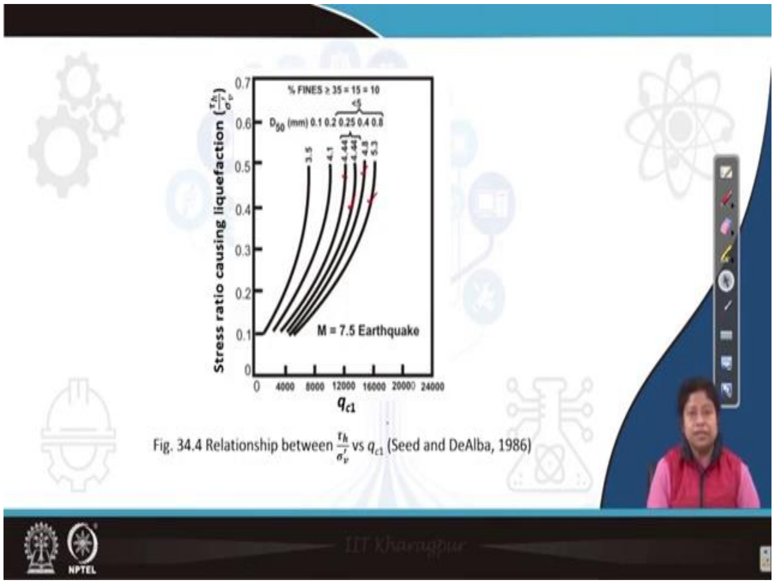

So, this is our figure 34.4. In this figure you can see, if I know the value of q c 1 which is the deep resistance corrected for the effective overburden pressure equals to 1 kg per square centimeter if we know this value, then from that we can calculate the cyclic stress ratio causing liquefaction which is tau h divided by sigma v dashed.

Now, in this diagram, you can see there are 6 lines or 6 curves, what are the meanings of these 6 curves. So, the first one corresponding to fines greater than 35 percent, second one corresponding to the fines content equal to 15 percent, third one for 10 percent and the last three one for the fine times lesser than 5 percent and the queen finds is less than 5 percent that time we need to check also the value of d 50 in millimeter.

So, if the value of d 50 is 0.25, then we will use this curve if the value of D 50 is equal to 0.4, then we will use this curve and if this value is 0.8, we will use this curve. So, using these figure we can calculate the value of tau h divided by sigma v dashed.

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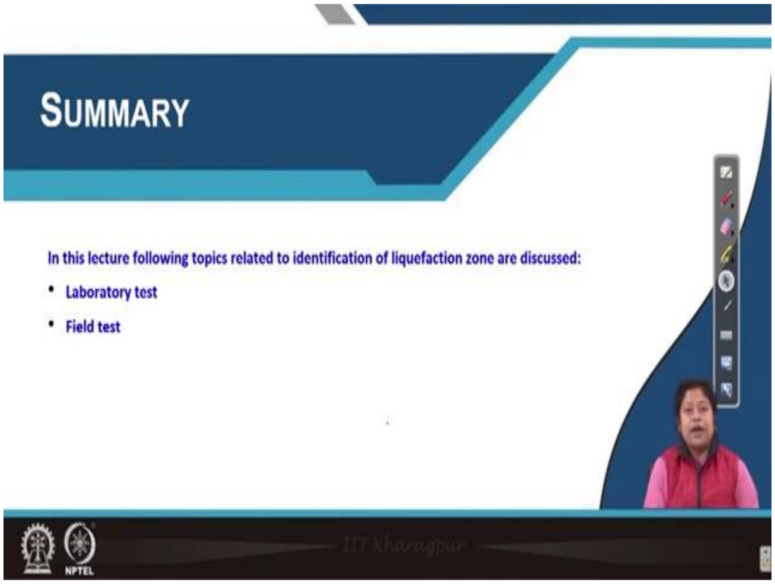

And if we know the value of tau h divided by sigma v dash from that we can calculate tau h and can cross check whether the tau h is greater than or lesser than tau av and accordingly we will reach to a conclusion whether the soil is susceptible to for liquefaction or not.

Now, come to the summary of this class. So, today we have discussed how to know whether the soil is in the zone of liquefaction by conducting laboratory test and by conducting field test. So, under laboratory test, we have studied on the cyclic triaxial test or dynamic triaxial test. Under field test we have studied SPT and CPT. Let us see the summary of today's lecture.

So, today we have discussed how to find out the zone of liquefaction by conducting laboratory test and field test in laboratory test we have studied on the cyclic triaxial test or dynamic triaxial test, in field test we have studied is how to use that data from SPT and CPT. For all the cases, we are getting the information of the shear strength of the soil or we can call it as the peak shear stress required to cause liquefaction of the soil and earthquake induces shear stress in the soil which is tau av.

So, now, if peak shear stress required to cause liquefaction which is the shear strength of the soil tau h is greater than tau av tau av is the shear stress induced by an earthquake, then what is happened, then there is no liquefaction. However, if tau h is less than tau av, then liquefaction will occur and we will see the zone of liquefaction in the soil deposit. So, with this I am stopping today's class.

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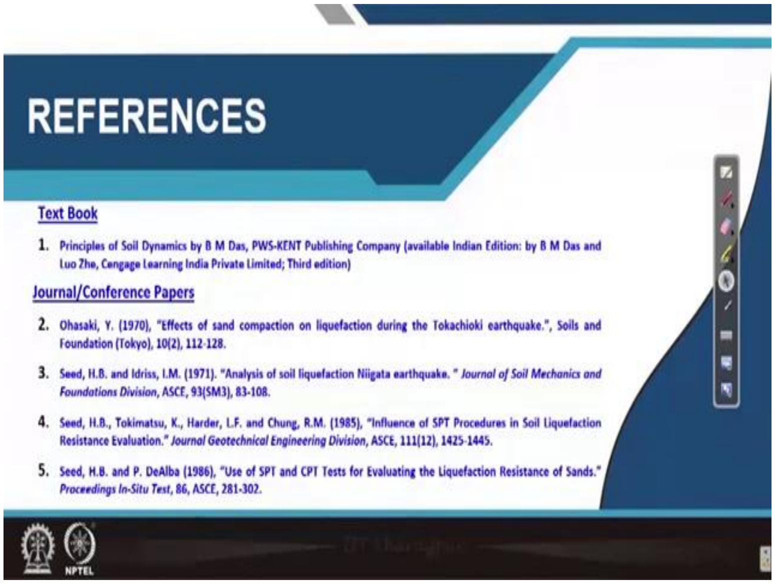

These are the references that I have used. Thank you.