Soil Dynamics
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Lecture 35
Liquefaction of Soils (Part -5)

Hello friends, today is the last class on liquefaction of soil. So, far we have discussed the mechanism of liquefaction, how to find out the shear stresses induced by an earthquake, how to find out the peak shear stress required to cause the liquefaction. Then we have discussed how to find out the zone of liquefaction knowing the value of tau h and tau av. What is tau h? Here tau h is the peak shear stress required to cause the liquefaction and tau av is the shear stress induced by an earthquake.

So, knowing these two values we how to find out the liquefaction potential susceptibility of liquefaction of soil deposit that we have already studied. So, today what we will do today we will solve one numerical problem where we will learn how to do the calculation to find out the zone of liquefaction or to determine the susceptibility of liquefaction of a soil deposit.

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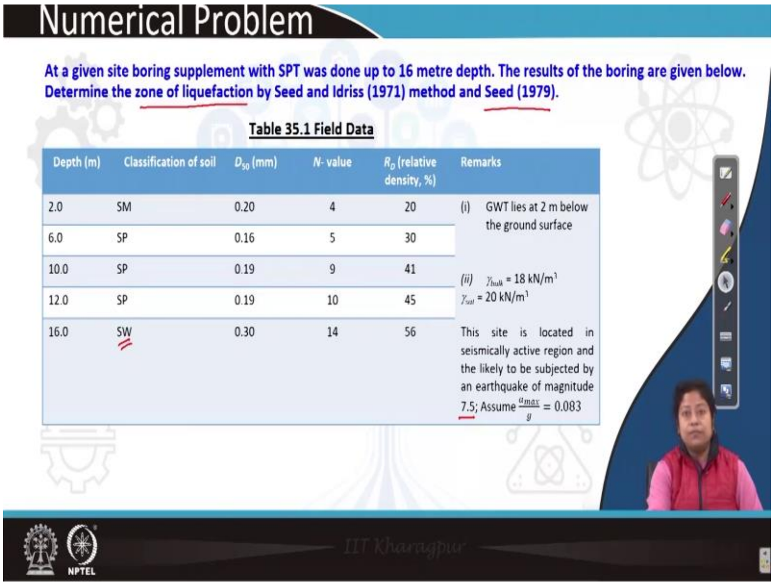

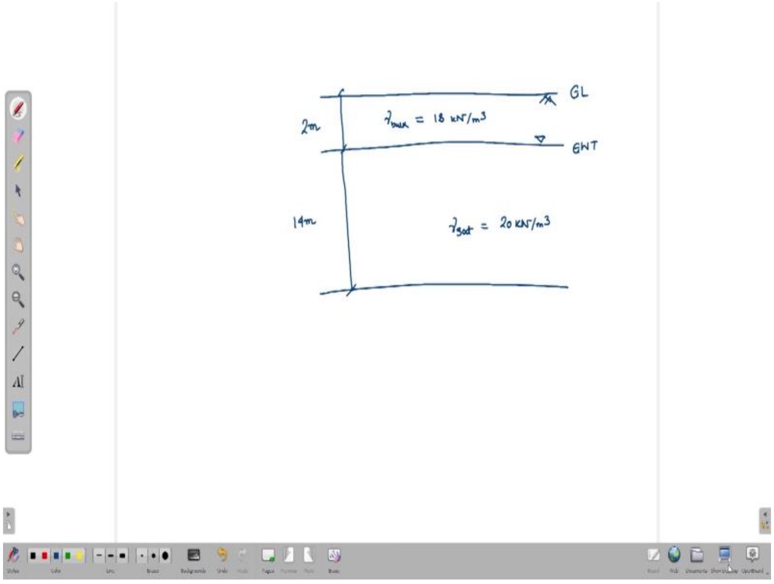

So, let us see this numerical problem what it is said in this problem. At a given site boring supplement with SPT was done up to 16 meter depth. The results of the boring are given below. You can see here. Determine the zone of liquefaction by Seed and Idriss method and Seed 1979 method. So, in this case, what is given date is given and at that depth what type of soil is noted that is also mentioned.

For an example, you can see up to 2 meters depth is same that means, silty sand is found below that after 12 meter you can see SP that means poorly graded sand is identified and below that is the W that means, well graded sand is found the corresponding D50 value for each day also provided N value that means SPT results also provided and relative density also given.

In the remarks column, we can see it is said that the groundwater table is located at a depth 2 meter below the ground surface and bulk unit weight of the soil is 18 kilo Newton per meter cube and gamma sub that mean saturated unit weight of the soil is 20 kilo Newton per meter cube. Also, some information related to earthquake is provided. It is said that the site is located in a seismically active region and they are likely to be subjected by an earthquake of magnitude 7.5. We can assume the value of a max which is peak ground acceleration is 0.083 times g.

So, if I will try to draw the soil deposit. How does it look? You can see here, this is the ground surface at a depth 2 meter groundwater table is located so this is the location of groundwater table and this is our ground surface and this depth is 2 meter. Now, from the ground surface to the 2 meter depth the unit weight of the soil is bulk unit weight of the soil is

18 in kilo Newton per meter cube, below the groundwater table, the saturated unit weight of the soil is 20 kilo Newton per meter cube.

And it is continued up to 16 meter depth that means, these depth is 14 meter from the groundwater table. Now, we need to find out that zone of liquefaction you can see here by 2 different methods, one method which is given by Seed and Idriss in 1971, where we can use the data of the cyclic triaxial test to find out sigma d divided by 2 sigma 3 dashed value and the other method which proposed by Seed in 1979, when we will use the SPT values, I hope the problem statement is clear to all of us.

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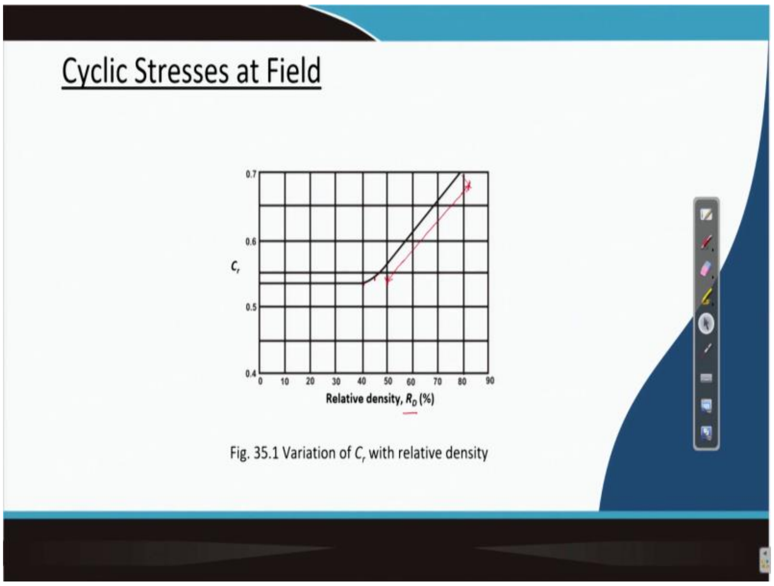
Table 35.2 Cyclic stress ratio

Depth (m)	Effective stress (σ'_v) kN/m^2	D_{50} (mm)	R_D (relative density, %)	C_r	$\frac{\sigma_d}{2\sigma'_3}$
2.0		0.20	20	0.55	0.22
6.0		0.16	30	0.55	0.215
10.0		0.19	41	0.559	0.218
12.0		0.19	45	0.565	0.225
16.0		0.30	56	0.588	0.24



So, first what we will do? We have the information about the depth we have the information about D50 in millimeter, we know the relative density also which is given here you can see this column. Now, from this we need to find out Cr and cyclic stress ratio, actually to reduce the time to get to the Cr value and sigma d divided by 2 sigma 3 dashed which is the cyclic stress ratio, value, I have already written the these two, I have already filled these two columns, but your task is to find out Cr and cyclic stress ratio from the two figures, which I can show here.

Cr you will get by using these figure too, so in figure 35.1, we can see the variation of Cr with relative density RD is the relative density. So, what we can see here? We can see up to some relative density you can see here 40 or you may take up to 45 also that the value of Cr remains constant as these are, the value of Cr is almost equal to 0.5 vote for relative density less than or equal to 40 percent you may take up to 45 also there is no harm. However, after that what we can see? We can see the value of Cr increases linearly with an increase in the relative density. So, in this portion, we can see that the value of Cr increases linearly with an increase in relative density.

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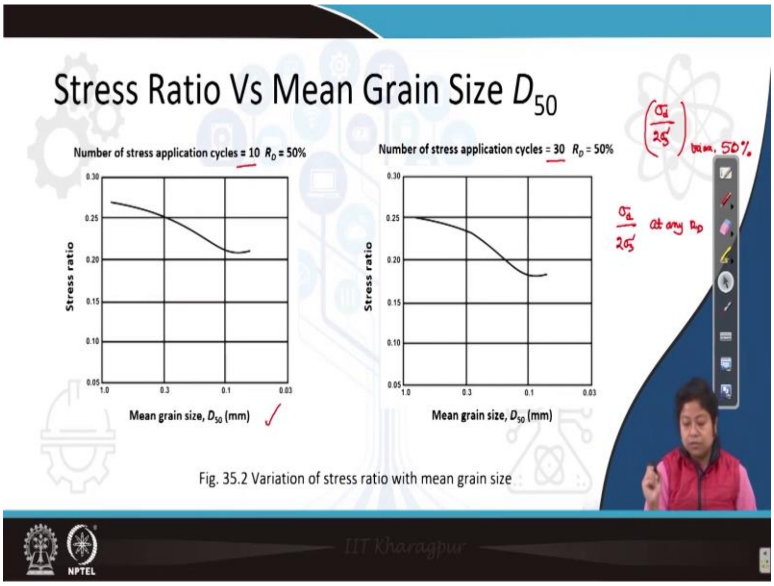

Likewise, using these two figures, you can find out the value of cyclic stress ratio that means, sigma d divided by 2 sigma 3 dashed. Now, that left hand side figure says that the number of stress application cycle is changed and second figure that means right hand side figures says the number of streets application cycle is 30.

So, if the number of stress application cycle is 20, then what we need to do? We need to find out the average of these two figures to know the value of sigma d divided by 2 sigma 3 dashed and that is corresponding to 50 percent relative density, 50 percent not 5. Let me correct this value so, it is 50 percent, then you can multiply it by RD divided by 50 for to get the sigma d divided by 2 sigma 3 dash at any RD value.

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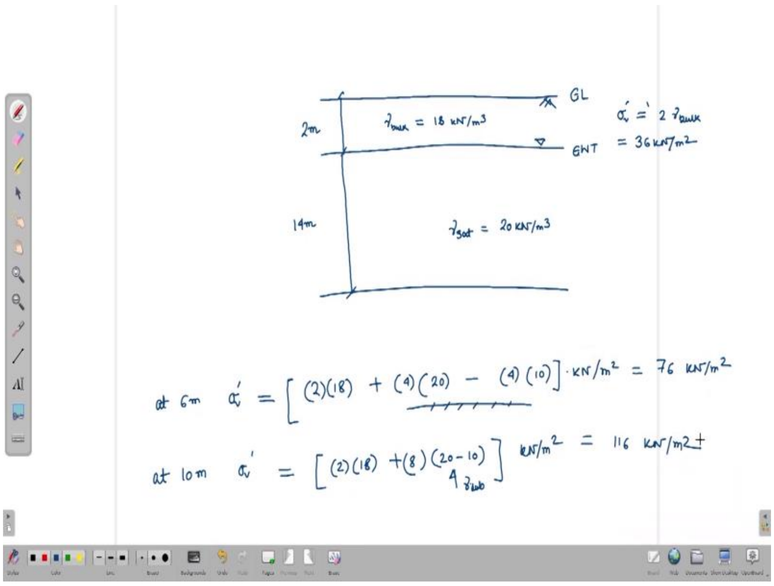
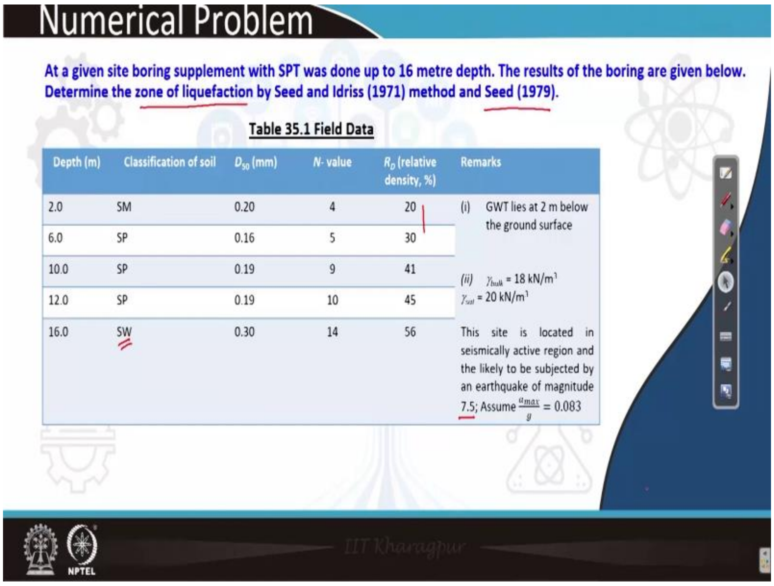
Table 35.2 Cyclic stress ratio

Depth (m)	Effective stress (σ'_v) kN/m²	D_{50} (mm)	R_D (relative density, %)	C_r	$\left(\frac{\sigma_d}{2\sigma'_3}\right)_{50\%}$
2.0	36	0.20	20	0.55	0.22
6.0	76	0.16	30	0.55	0.215
10.0	116	0.19	41	0.559	0.218
12.0	136	0.19	45	0.565	0.225
16.0	176	0.30	56	0.588	0.24





So, let us do this exercise to find out the effective stress. So, using the 2 figures which I have already shown first you will find out Cr for each date which I have already filled here you can see and also you will find out sigma d divided by 2 sigma 3, 2 sigma dash 3. So, this is actually corresponding to 50 percent relative density.

Now, please find out the effective stress. So, for the first 2 meter depth, what will be the effective stress? Sigma dashed v, I can call it here. So, this will be or, this will be how much 2 times gamma bulk there is no water so, no question to subtract the pore water pressure in this case. So, at a depth 2 meter the value of effective stress is 36 kilo Newton per meter square. I can write it in next line so, this is 36 kilo Newton per meter square.

So, here I will write 36 unit is already mentioned at the top. At 6 meter, how much will be effective stress? So, 2 times gamma d, gamma bulk here which is 18 plus remaining, for remaining 4 meter, it is 4 times gamma sub minus 4 times gamma W which is I think mentioned here pain in the question, nothing is given we can just take 10 also or you can take the exact value which is 9.81 also, both are alright.

So, I am just taking 10 here. So, this is in kilo Newton per meter square. So, how much we are getting? Let us see 36 plus 80 minus 40. So, it is coming 76 in kilo Newton per meter square. So, I am writing here 76 at a depth10 meter, how much it will be? At 10 meter sigma dashed v is 2 into 18 plus 4 times instead of writing it this way.

Now, what I can do? I can write directly 4 times gamma sub also. So, gamma sub means here I have taken 20 minus 10 that is our gamma sub. So, this way also we can directly write. It is not 4 meter, it is this time 8 meter. So, let us see 36 plus 8 into 10 which is coming 116 kilo

Newton per meter square. So, I am writing here 116. Likewise, for 12 meter, how much it will be for 12 meter? It will be 136 and for 16 meter, it will be 176 kilo Newton per meter square. So, in this way we can find out the effective stresses at different depth.

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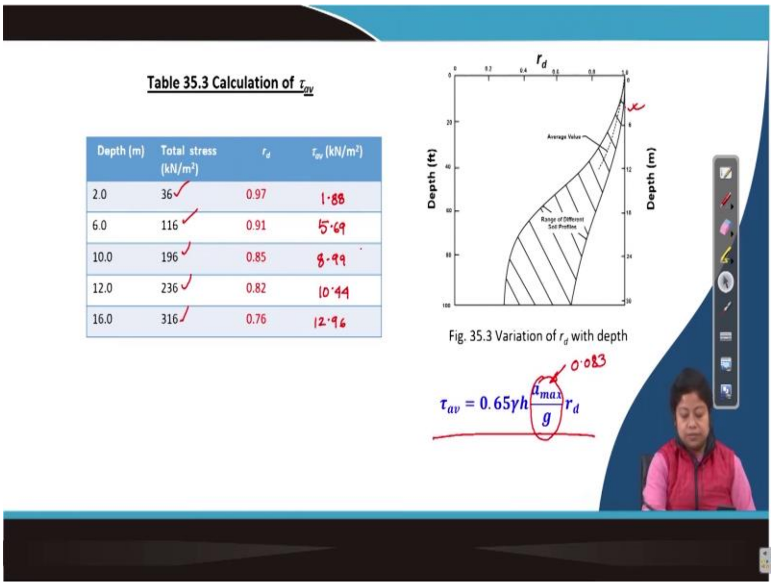

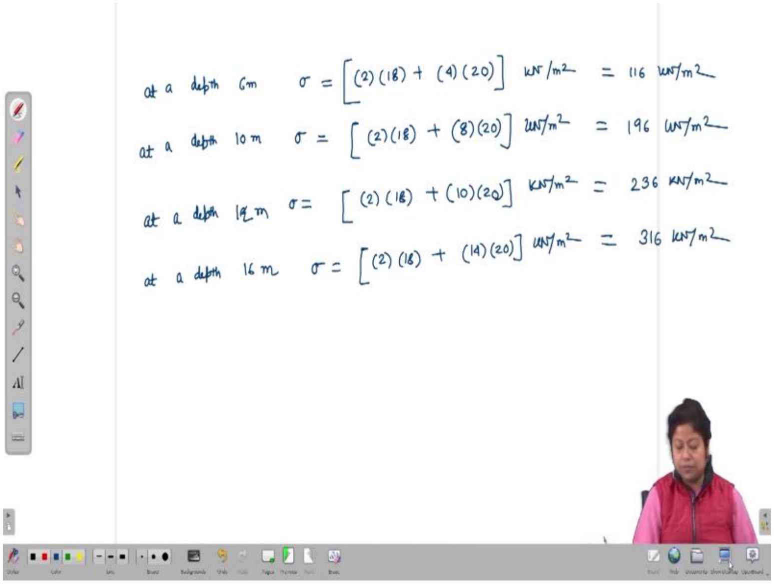

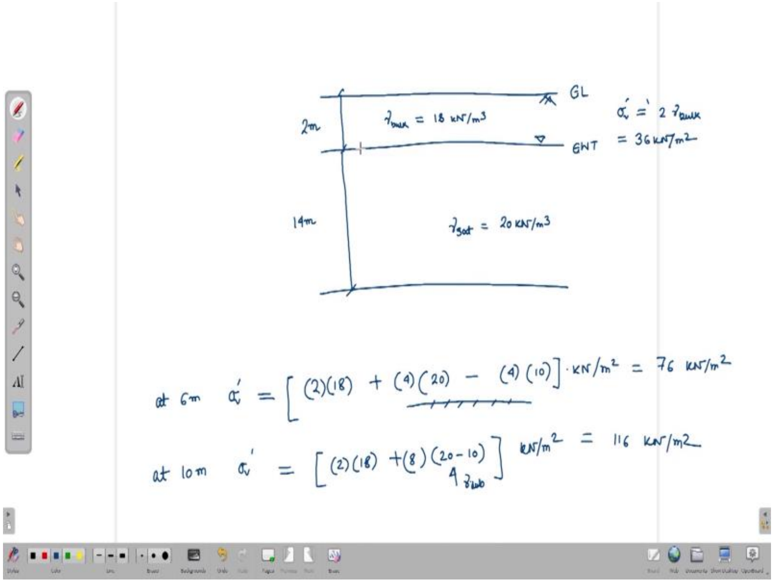

What is in the next step? So, the next step is to find out tau av. What is tau av here? Tau av is the shear stress induced by an earthquake how we can calculate it? By calculate, by using this equation where a max represents the peak ground acceleration of that particular peak ground acceleration caused by that particular earthquake and rd is a reduction factor that is already explained to you and we need to take the average value by multiplying 0.65. We consider 65 percent of the maximum shear stress.

So, let us do this exercise also. So, for firstly are gamma h is how much? Gamma h is 2 times total stress is 36 obviously, I can show here hear it is whatever is sigma v dashed for depth 2 meter that is also equal to the total stress because there is no water table up to 2 meter depth. So, that is the reason here we have written 36. Now, at a date 6 meter what will be total stress? At a depth, in the next page I am writing, at a depth 6 meter total stress sigma is equal to 2 times 18 plus 4 times 20. And this is in kilo Newton per meter square. So, how much you are getting 36 plus 80 which is 116 in this case.

Likewise, we can get it at a depth 10 meter. So, at a depth 10 meter total stress is how much 2 times 18 plus 8 times 20. So, how much it is 36 plus 160 which is 196 kilo Newton per meter square. Now, at depth 40, 12 meter or 14 meter, 12 meter and then 16 meter. So, at a depth 12 meter, sigma is 2 times 18 plus 10 times 20. So, how much it is then? 36 plus 200 which is 236 in kilo Newton per meter square.

Finally, at the depth 16 meter, sigma is how much? 2 times 18 plus 14 times 20. So, how much it is 36 plus 280 so, it is 316 in kilo Newton per meter square. So, that is mentioned already in this table. So, now, from this we need to calculate tau av at 2 meter 6 meter 10 meter, then 12 meter and 16 meter depths. So, let us do this exercise. So, 0.65 into 36 times a max divided by g is given which is 0.083 and rd value given and that you can take from this figure not given actually, I have already noted down using these figure to this table.

So, for 2 meter depth, rd is 0.97. So, I can use this value also. So, tau av is coming 1.88 in kilo Newton per square meter, I am approximating the value up to 2 decimal place here. For 6 meter depth how much it will be? It will be let me check it will be 5.69 again up to 2 decimal place I have considered.

For that next case that means 10 meter depth it is coming 8.99. So, at a depth 10 meter tau av value is 8.99 in kilo Newton per meter square. Let us see at 12 meter depth total stress is 236 and rd value is 0.82. So, that tau av is 10.44 and the depth 16 meter which is the last result last data given to us they are we can see total stress is 316 then, rd value is 0.76. So, using this. rd value, we are gating tau av is 12.96 kilo Newton per square meter. So, in this way, we have the information of tau av. Tau av is the shear stress induced by the earthquake.

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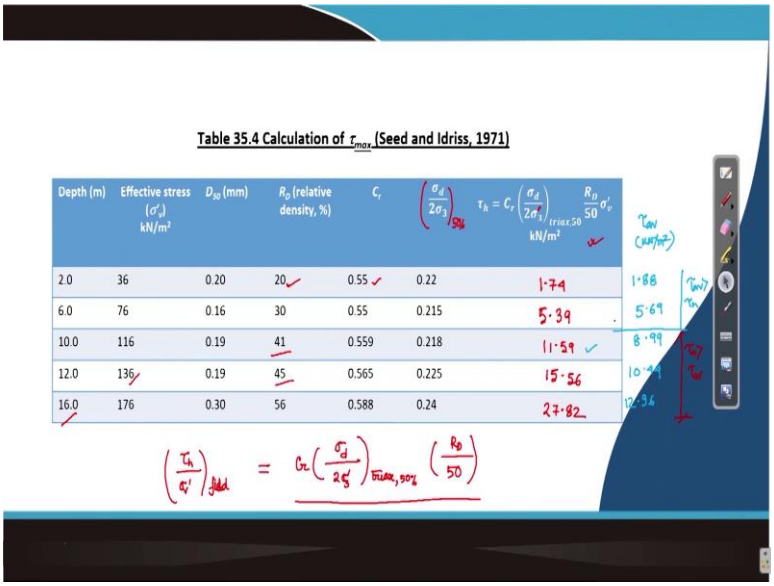

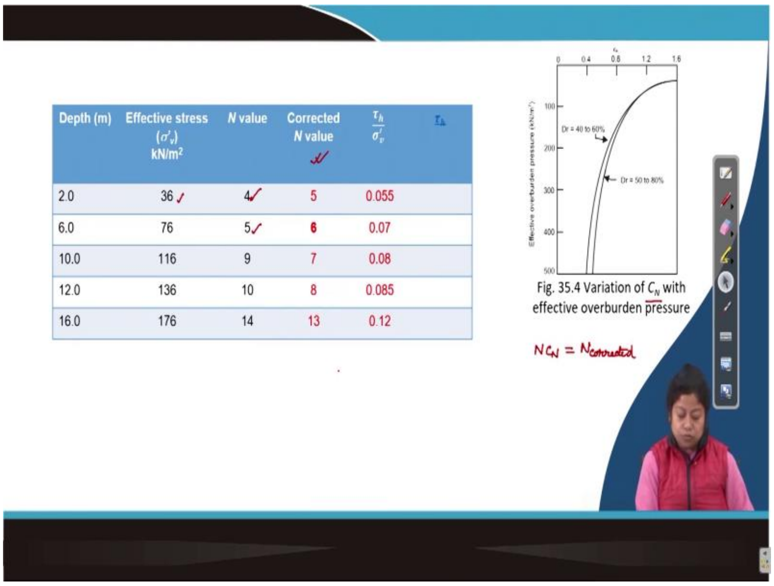

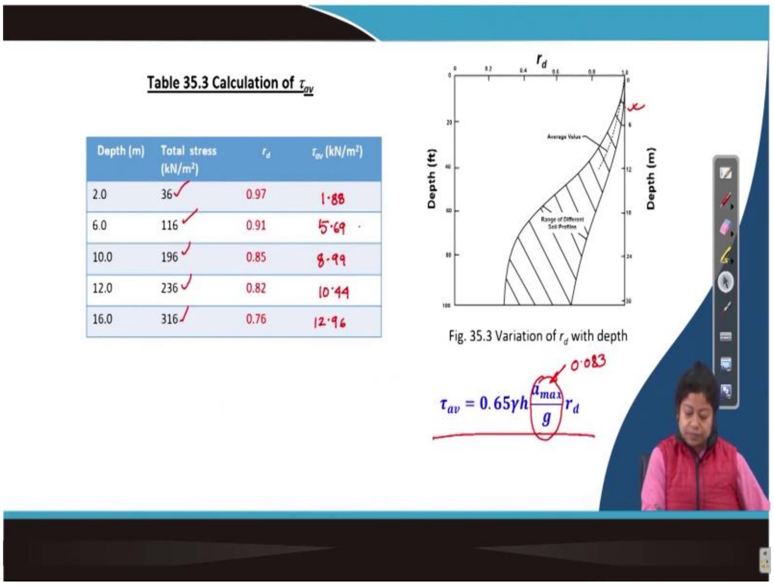

Now, what do we need to do? We need to find out tau h in the field. So, for that we need to multiply what was our equation for tau h divided by sigma v dashed in the field? Cr times sigma d divided by 2 sigma 3 dashed. Please correct here there is a sigma 3 dashed and this is when we are using to triaxial data with 50 percent relative density of the sample.

And since, we are taking sigma d divided by 2 sigma 3 dashed corresponding to 50 percent relative density so, we need to multiply it with the value rd divided by 50, to represent, to get the sigma d divided by 2 sigma 3 dashed which is the cyclic stress ratio at any other relative density. And fear for converting the lab result to the field value. So, this is the equation.

Now, from this if I am interested to get tau h. What we will do? We will multiply this right hand side by this sigma v dashed that is given in this column. So, let us find out the tau h value also. So, here what is that tau h value for the first layer. Let me correct this thing, this is for 50 percent relative density. So, for at a depth 2 meter you can see Cr is 0.55, see stress ratio is 0.22, relative density is given that is 20 percent and sigma v dashed is 36.

So, the value of tau h is 1.74 in kilo Newton per square meter in this context, I would just like to show the value of tau av you can see tau av is 1.88 in kilo Newton per square meter. So, likewise at a depth 6 meter what will be the value of tau h? At a depth 6 meter the value of tau h is sigma d, k, relative density is 30 percent And what else we need to consider here is sigma v dashed which is 76 so, it is becoming 5.39.

Likewise at a depth 10 meter, how much it is let me calculate. At a depth 10 meter you can see relative density is 41 percent so, and total stress is 116. So, tau h is 11.59 kilo Newton per square meter at a depth 12 these values, this value will be 0.565 Cr times these ratio 0.225 relative density is 45 divided by 50 times total time effective stress which is 136 here. So, it is now 15.56. And for the last depth that is 16 meter, we can see this Cr value is point 588 The value of the stress ratio is 0.24 and relative density is 56 percent and total stress is 176. So, with this we can get tau h is 27.82.

Of course, I have approximated it at 2 decimal place. Now, if I will go back to the previous slide, you can see 1.88 for the first layer. So, this for this layer, I am just writing what is I am just making one more column here 1.88 is the value of tau av that is in kilo Newton per meter square.

For the second layer, what is the value? 5.69, 5.69. For the third layer 8.99. I am writing for the fourth and last layer 10.44 And this is 12.96. So, what we can see from these last 2 data that means, if we compare tau h and tau av we see that up to 6 meter, if you see up to 6 meter that means, till here tau av is greater than tau h. Now, from 10 meter onwards we can see that tau h is greater than tau av.

So, here I can write it this way for this layer we are seeing tau h is greater than tau av that means, our zone of liquefaction is located above 10 meter not below 10 meter. So, if we get that data of 8 meter, then probably we will be in the beta stage to comment on whether 8 meter depth is also in the zone of liquefaction or not, but, from these data we are assuming that 8 meter depth may be in the zone of liquefaction or may not be since that difference is very least at 6 meter the difference between tau h and tau av. So, I am expecting that that 8 meter depth is also not in zone of liquefaction.

Now, in this slide you can see that using SPT value. How we can find out the zone of liquefaction? So, using SPT value that means, this one first thing what we need to do is that we need to correct the N value for overburden correction by multiplying N to CN. How we will get CN? If we know the effective stress, then that means, if we have the information of this column, then we can find out the CN value and if we will multiply N to CN, we will get corrected N value. So, this is our corrected N value. In this way, I have already calculated the corrected N value. Now, from corrected, after this what we can do?

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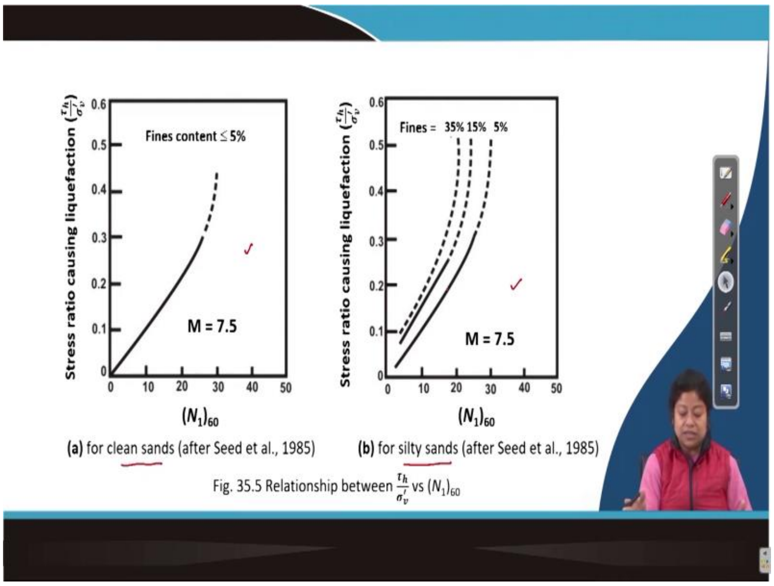

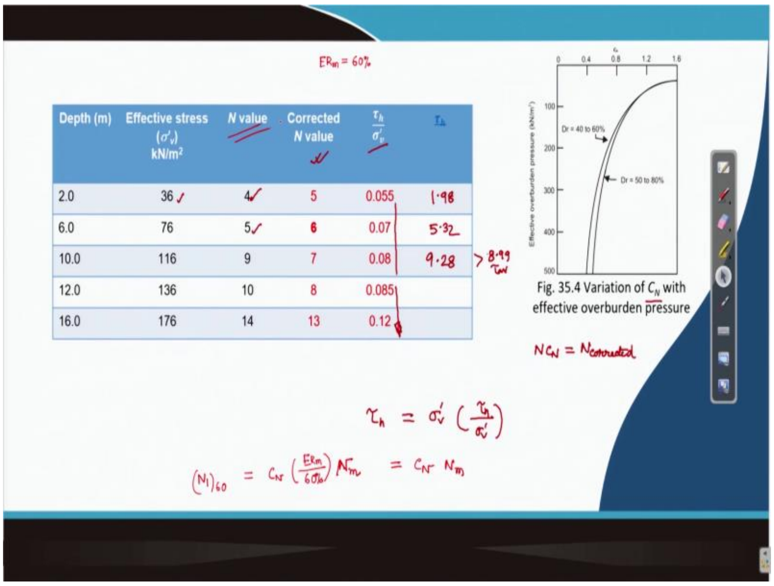

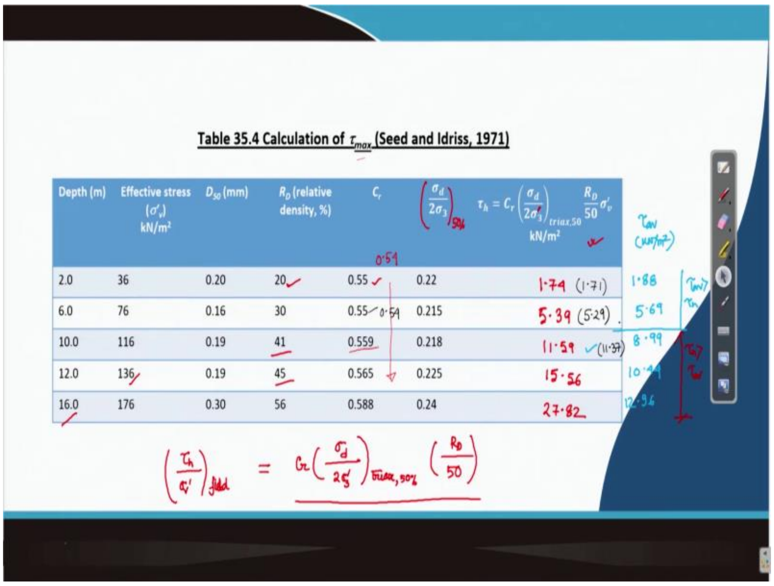

Table 35.4 Calculation of τ_{max} (Seed and Idriss, 1971)

Depth (m)	Effective stress (σ'_v) kN/m²	D_{50} (mm)	R_D (relative density, %)	C_r	$\left(\frac{\sigma_d}{2\sigma_3}\right)$	$\tau_h = C_r \left(\frac{\sigma_d}{2\sigma_3}\right)_{triax,50} \frac{R_D}{50}\sigma'_v$ kN/m²
2.0	36	0.20	20	0.55	0.22	
6.0	76	0.16	30	0.55	0.215	
10.0	116	0.19	41	0.559	0.218	
12.0	136	0.19	45	0.565	0.225	
16.0	176	0.30	56	0.588	0.24	

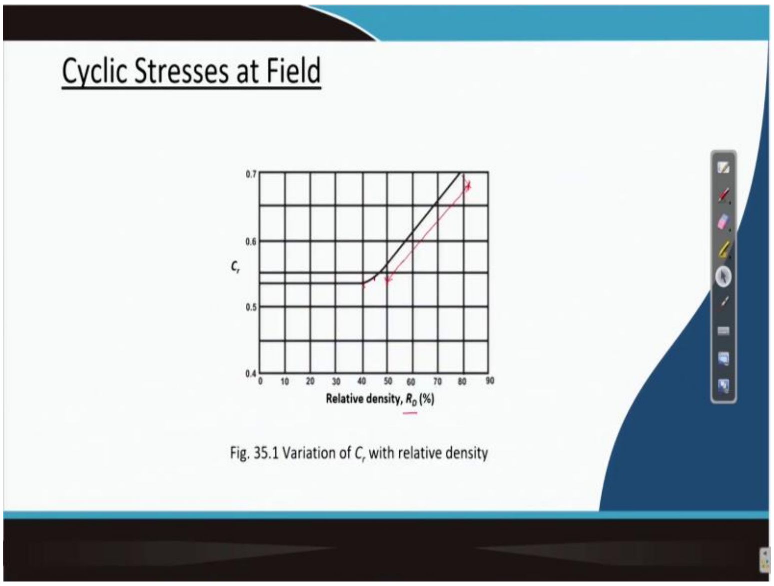

Fig. 35.1 Variation of C_r with relative density

We need to find out tau h divided by sigma dashed, sigma v dashed. So, here there are two curves depending upon fine content and also what type of soil we are getting, way if it is clean sand then we will use this curve if it is silty sand, we will use this curve and if we are using the curve b, the figure b, then depending upon fines content, we will choose any of these three lines and using these any of these four curves what we can do, we can find out the value of tau h divided by sigma dashed v corresponding to the value of N1 60 that I have already done here, you can see for different, at different depth what is the value of tau h by sigma dashed v that I have already provided. So, from this our next task is to find out the value of tau h.

Obviously, tau h which means, we are multiplying sigma dashed v to this ratio tau h divided by sigma dashed v. So, just for an example, what is the value of tau h for the first layer? Let us see, for the first layer, it is 0.055 times 36 which is coming 1.98. Now, if I will go back to previous slide in previous slide it was 1.74 So, the value is more or less close to the value, which we get from the triaxial test, cyclic triaxial test that will be the better phrase.

Now, at 6 meter depth, what is the value? At 6 meter depth this value is approximately 5.32. So, this is also close to 5.39 and here also I can see that tau h here also if you see that tau h is less than tau av, tau av is 5.69 and tau h is 5.32. So, tau h is lower than tau av at 6 meter depth. What about 10 meter depth? At 10 meter depth tau h is how much? It is approximately 9.28, if I will go back to this slide, you can see here tau av is 8.99. So, tau h is greater than 8.99 which is tau av. So, what we can say that 10 meter depth is not under the zone of liquefaction.

So, here before concluding this class, I would like to mention a few things first of all, when I have calculated corrected N value, that time I have considered ERm is equal to 60 percent. Last class you have seen how using table we can find out ERm. So, since nothing is mentioned about the country or Mr type related to the testing, so, I have taken Erm is equal to 60 percent.

So, if you recall in the equation how we calculate incorrect it in that case actually, that equation was something like N1 60 that is equal to CN times ERm divided by 60 percent times Nm. So, since ERm is 60 percent, we can then write it as CN times Nm is this N value. This is the one thing which I would like to mention here other than that, another interesting thing in this table 35.4 were I have calculated tau max probably you have noted that I have taken the value of Cr if you see for relative density that means 20 percent 30 percent and 41 percent I have taken Cr close to 0.55. Even I have taken it 0.55 time.

Now, if I will show you the. What we can see? Till 40 or 45 actually the Cr value for relative density 40 percent or below that it is 0.54 If so, then what basically we will get in this table. Let us see that, because I have taken slightly higher value to calculate tau h. Now in place of 0.55, if I will take 0.54 for relative density up to 45. That means, I am not including 45 or I can include 45 also with this same value, then what will be the tau h, let us just check it that tau h value that will be 1.71 in kilo Newton per square meter.

Likewise, for the second case that means, at a depth 6 meter when I am taking that value of Cr 0.54 in place of 0.55 that time what I will get let me check it, I will get 5.29 for the depth 10 meter, we are getting 11.37 value from the. So, from this what we can note is that, if we will use the figure, which is shown you if we will use that figure to find out Cr using the value of relative density then we will get Cr 0.54 up to 10 meter depth because at 10 meter depth the relative density is 41 percent.

So, corresponding Cr value from the Cr from the figure is 0.54 and using that value we will get tau h is 11.37 in kilo Newton per square meter and that value at 10 meter depth, tau h is 11.37 kilo Newton per square meter and that value is always greater than tau av which is the average shear stress caused by the earthquake event.

Same way you can see that conclusion. Same way you can see the value. Although the value of tau h is reduced up to some extent, but tau h is less then tau av for depth 2 meter at 6 meter as well. So, the conclusion, the result remains same that that zone of liquefaction up to 6 meter depth or above 10 meter depth zone of liquefaction lies above 10 meter depth. And in this case actually if you use if you try to get for 8 meter depth using the same data, you will see that 8 meter data is also not under zone of liquefaction.

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So, with this I can stop today's class, these are the references that I have used in today's class. Thank you.