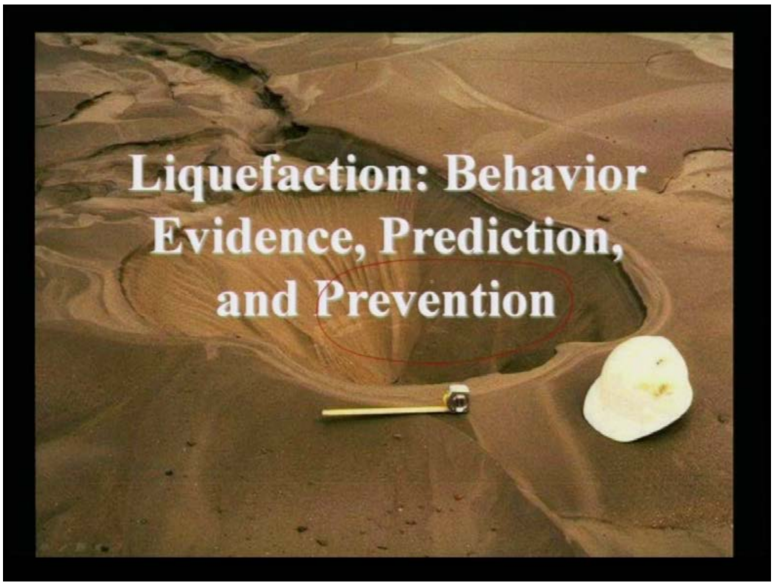
Geotechnical Measurements and Explorations
Prof. Nihar Ranjan Patra
Department of Civil Engineering
Indian Institute Of Technology, Kanpur

Lecture No. # 40

This is last lecture just though this is area is completely different, but it is related to how from soft soil exploration or may be field test data, how to predict this liquefaction and what are the prevention though prevention is not part of this course, this is different.

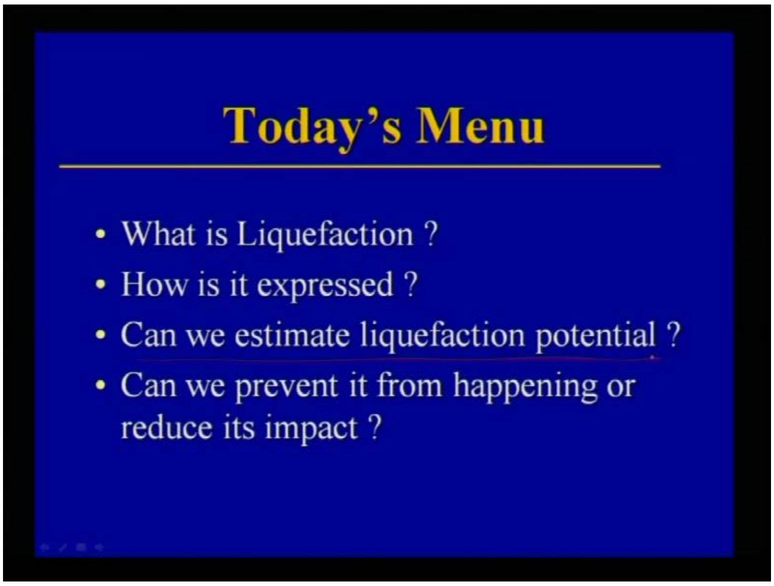
(Refer Slide Time: 00:40)



How do you predict basically? And if you look at this liquefaction particularly in India, we are standing particularly along the indo gangetic belt starting from Jammu Kashmir to Bihar along the indo gangetic plain belt. This fine grain soils are all available, and sand fine sands are there generally what happen during the earthquake. As I said earlier it loses its complete strength. So, then soil will flow like water flow like water, so this is called the phenomenon liquefaction, and this is a hot topic nowadays over the world. So, there are some correlation something has been lot of research has been done for last few years.

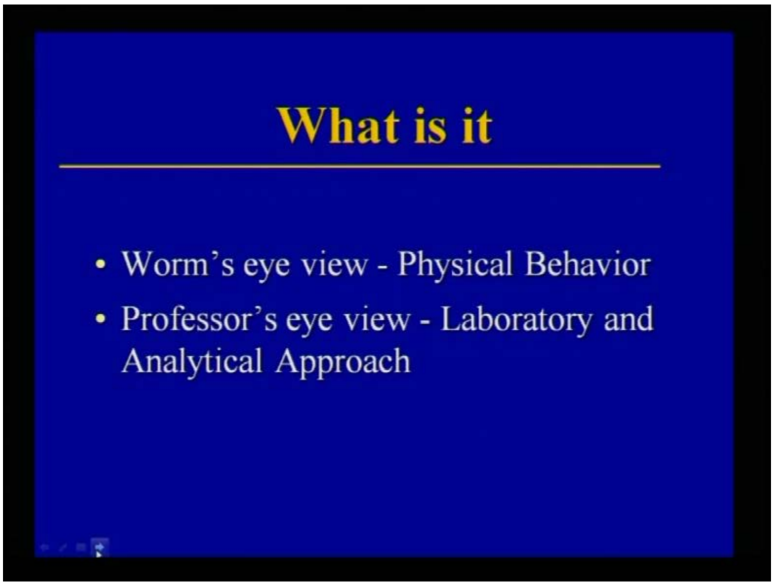
So, based on this soft soil exploration or may be field test like standard penetration test, and cone penetration test can I predict this liquefaction yes, means it is kind it is a kind of indication or indicative you can say that there is a chance of probable chance of liquefaction, and you can do the necessary preventive measures. Of course, for liquefaction prediction a detail laboratory test also you need as I have already explained my previous classes, this liquefactioned prediction laboratory test by means of cyclic triaxial both stress, and strain control and bender element test, and resonant column test this has been explained earlier, these laboratory test require time and also money. So if you have field test in your hand can you predict your liquefaction behavior or not? Yes, we can predict.

(Refer Slide Time: 02:45)



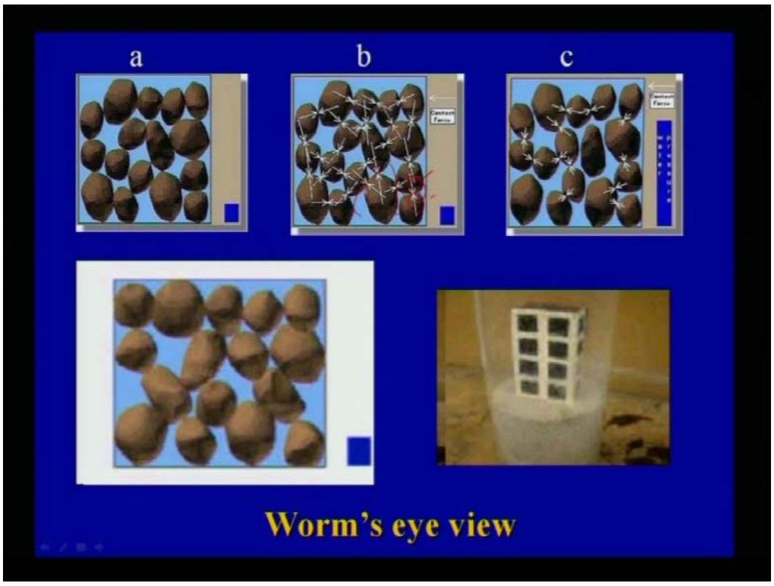
Means if I can say what is the menu? If I go to go back to daily life it means what do you mean by liquefaction? What is the liquefaction? How is it expressed the as I said can I estimate the liquefaction potential from your field data field testing data. Yes.

(Refer Slide Time: 03:07)



Means how it looks a general manner, means there are two two path I am an engineer. How a an engineer can see, how an engineer can visualize as a liquefaction? How a general man how he he will visualize, what is a liquefaction?

(Refer Slide Time: 03:25)



In worm's eye if you look at here, it is a ground shaking, because of shaking what will happen in a oil grains, generally what will happen a, b, c, I have given. Soil grains initially, it will be intact in the ground surface by means of interfrictional force, by means of inter or intra frictional force. If you look at here soil grain one, soil grain two;

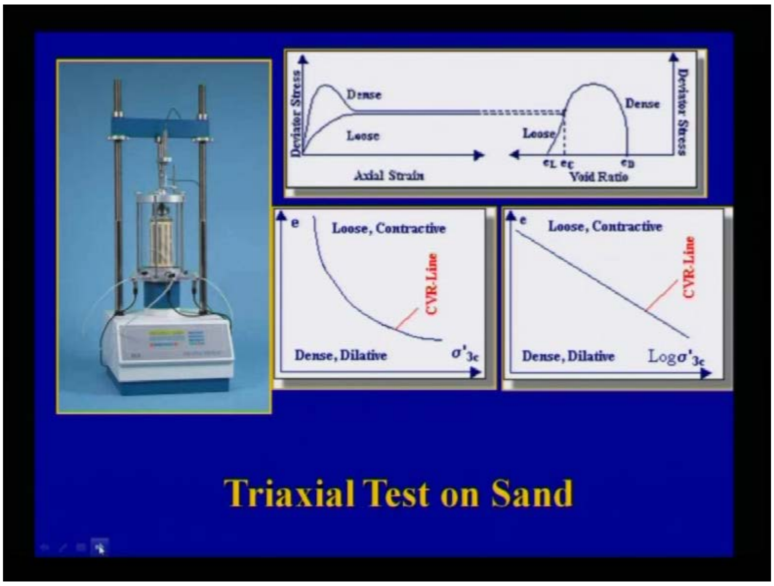
these are all contact forces, inside the ground they have their own contact forces, so that soil grains are intact.

The moment water table, water is there inside, so loading or ground shaking occurs what will happen? The pore water pressure inside the soil increases, so the moment pore water pressure increases, this inter friction between the soil particle it completely loose or it completely lost. So, if you look at here, the soil means a layman how do you understand, what is the phenomenon of liquefaction? You can say that below the ground soil is intact in position, because of technical term very simple thing you can say that friction between particle to particle will be very high, inter frictional force, because of water table, because of pore water pressure developed inside the soil particles, so this inter frictional force completely lost.

So if you look at here, from this to this, this to this; it is completely lost here, and this to this it completely lost. That means, each grade or each particle in the soil, it will behave like an independent particle. Earlier entire particle will be all mix of it will behave like a one soil - complete soil, here each particle will behave like a independent particle, it is no more a mass of soil.

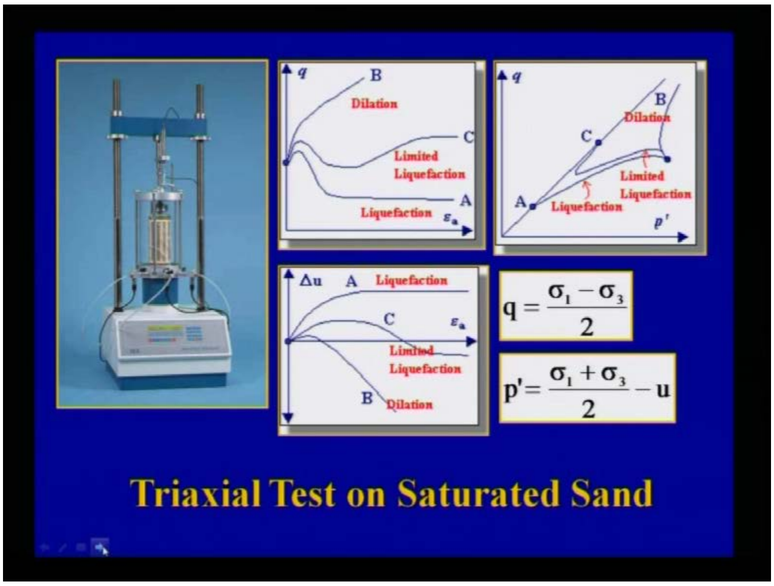
So slowly slowly all forces distract, it loses the moment shaking will be there, pore water pressure increases, first here some forces will go at the end complete force will, it will means no frictional resistance between particles, no forces between the particles, all forces it lost. So, what will happen? Then as good as like liquid, so soil each particle along with the water it will try to flow, so that is the condition where it is called liquefaction; liquefaction is a term, it comes from liquid. Liqui faction, that means soil will completely lose its strength it will flow like a liquid.

(Refer Slide Time: 06:21)



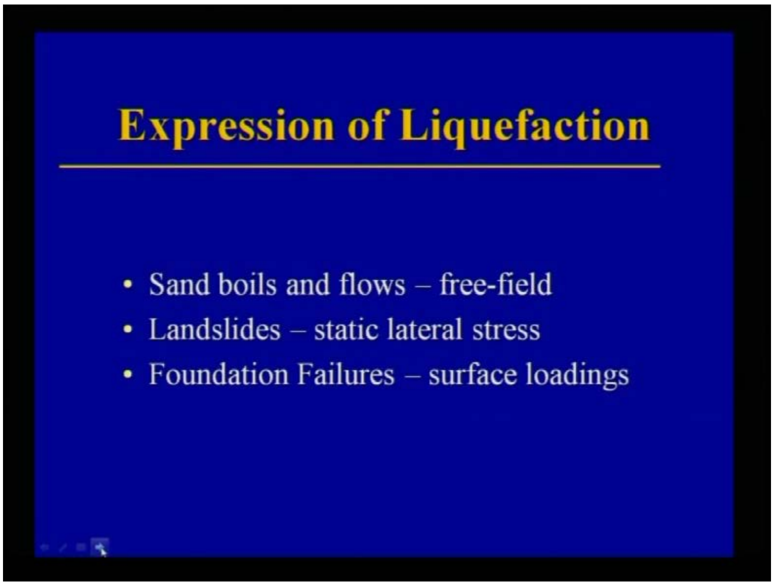
So, this is a general overview, now in technical you can say that as I explained how the triaxial, how it is moving from one state to other detail triaxial test.

(Refer Slide Time: 06:35)



And you can find it out number of cycles versus your change in volume you can find it out initial liquefaction or dilation behavior, all you can do as an engineer. You will have to do all detail study, means how this behavior, how the phenomena occur when this earthquake loading is coming in to picture; these are all I discussed earlier. So, no need to discuss it again.

(Refer Slide Time: 06:58)



Now expression of liquefaction: Sand boils and flows - this is means there are three terms, three cases generally it happens, this is called free field. Second one is landslide, if you go to hilly region - hellish region, there are lands like sloppy grounds are there. What will happen? Due to earthquake, due to liquefaction entire land will slide you might be heard from the news paper like this complete landslide occur some people died during the earthquake, this is because of your lateral stress, static lateral stress.

Third one is your foundation failures that is your surface loading, so these kind of things you will observe means expression liquefaction in terms of this kind of ground reality, what exactly you want to observe if this liquefaction occurs what will happen? In a very simple meaning, soil is loose, soil is going to lose its entire strength; second is your soil will flow like a liquid fine, that is I understand this this is the mechanism. Then what will happen? Soil will flow like a fluid, so in case of sand is there, sand boils - sand boils is means, if this is the ground surface, there is a sand is there, so it will flow like a liquid.

So, what will happen? It will comes out like a liquid in a boil, like water is coming from a aquifer pump; like this it will comes out from this. So what will happen? There will be a hole kind of things, shrinkage hole will be there enter, so boiling phenomena you can see it. Second phase is your landslide, if there is a hilly region like this, if there is a liquefaction, entire land will be fail, entire part will be fail. This is because of your lateral strain, and there will be also foundation failure, this is called surface loading.

(Refer Slide Time: 09:10)

Look at the case one. What is your case one? Sand boils and flow free field, this is entirely sand particle sand this field, all of sudden this because of earthquake liquefaction occurs. Liquefaction occurs means, here sand boiling occur; that means entire sand water come out, entire sand water come out from the ground means it will flow here, and there.

So, once it will come out means what we will we will find it out. There will be a gap there will a gap, there will be a hole, look at here. This is the symbolic view, you can see you can say by looking at this; this is a kind of sand boiling. Once there is a sand boiling, sand from the ground surface along with water will come out from the ground surface like a liquid, and it will flow outside. Once it will come out this will be entirely completely a gap or a hole will be formed, this is called your sand boil.

(Refer Slide Time: 10:15)

Look at your second case of sand boil. In the ground entire sand will come out from the ground, and it flow; these are all sands flow around the periphery of the ground. It comes out, because of liquefaction it loses its strength, it comes out it flows and there is a hole, where this sand boiling has occur? Second case.

(Refer Slide Time: 10:39)

Look at your third, just typical photographs I am showing that pre failures in terms of liquefaction, the moment liquefaction you say how the failure mechanism occur, look at here. It is not necessary that a ground is there, liquefaction is there, sand will come out;

that means only one hole will be there, no look at series of these; recently bhuj earthquake, where the liquefaction occurs in 2001, that is your Gujarat. If you find that these are the cases 1, 2, 3, 4, 5, 6; it is continues this side this side, that means every places sand along with the water it comes out how its spread, look at; these are all your spread all around the spreads - this spreads. So, you will find it out a complete hole in case of sand comes out, this is the phenomena we are discussing about sand boiling.

(Refer Slide Time: 11:49)

Now second phenomena, what is your second phenomena? That is your landslide, because of your lateral stress, as I said in a hilly region, entire land will be slide; that is called landslide, because of liquefaction look at here, complete hilly region. This entire area complete land comes down and it slide, and a disaster happen, look at here. Everything whatever building material it has come down complete landslide, this is your because of your lateral stress, that is your second failure.

(Refer Slide Time: 12:27)

Now come to look at here. What is the case? This is the case, this is your third foundation failure, complete inside the soil it become like big holes complete foundation failure

(Refer Slide Time: 12:43)

Case of landslide: Case of the landslide hilly region building is there, how the building is coming down? Entire land from here to here, it is sliding from here to here, how it is coming down case of landslide.

(Refer Slide Time: 12:59)

Foundation failure, a bridge entire bridge is there foundation failure.

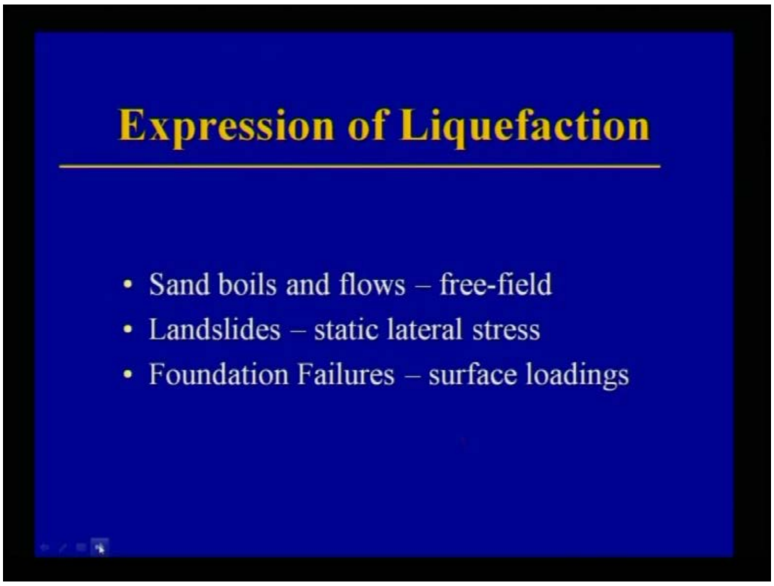
(Refer Slide Time: 13:04)

Again, foundation failure.

(Refer Slide Time: 13:08)

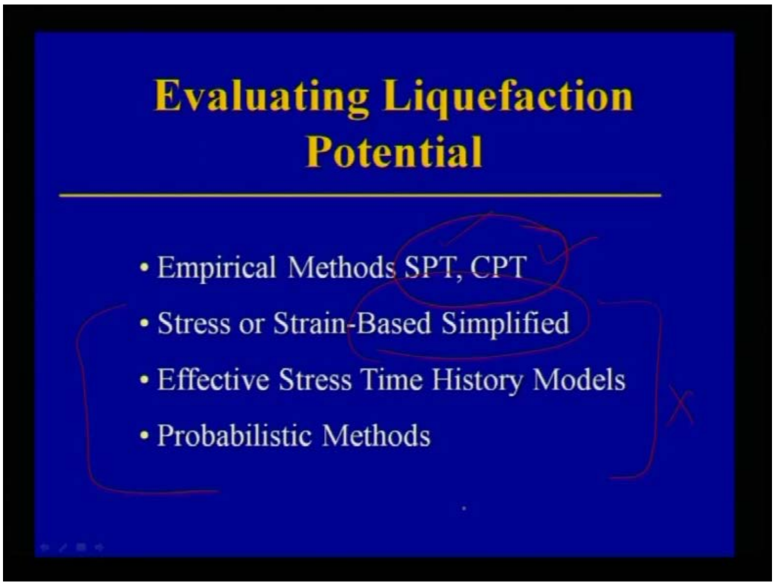
See entire bridge is there, in terms of liquefaction foundation failure, this this I have shown you.

(Refer Slide Time: 13:14)



That means, if there is a liquefaction; there are three kinds of failure we will get it sand boiling, landslides, foundation failure, because of your surface loading.

(Refer Slide Time: 13:27)

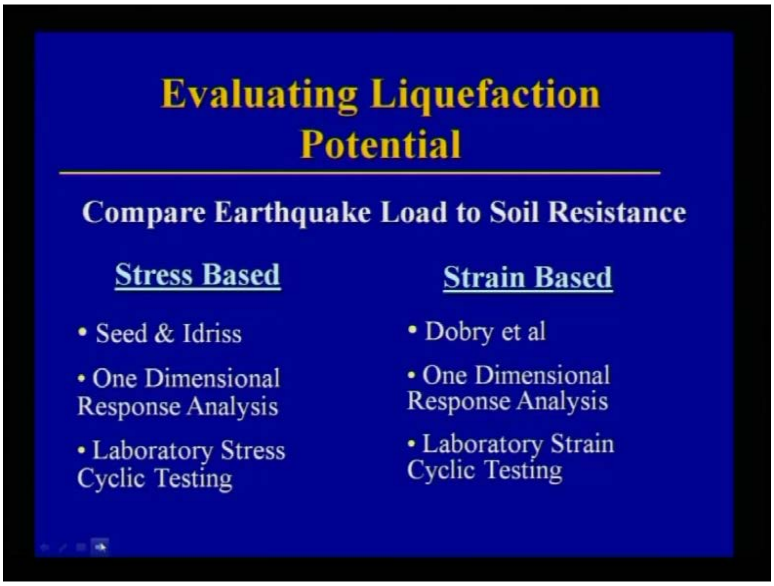


Now, these are really a challenging job, because this is a catastrophic means it would not give time, means earthquake is a very short period of time within that short period of time, this soil this loading will come earthquake loading. Then it will completely fell, because of this once ground surface fells whatever super structure is there it will fell now over the period of time.

So, it has been a debate how to find it out? How do I evaluate? Can I evaluate from this field test yes I can evaluate, there are many empirical relationship has come up, this is one is the best method empirical relation methods based on standard penetration test, and cone penetration test; these are we have already discussed in our particularly geotechnical exploration, and measurement. If I know standard penetration test and cone penetration test from there I can predict the liquefaction potential, another one is stress strain relationship effective stress time history probably, these are slightly in details in the course of soil dynamics and earthquake engineering I do not want to.

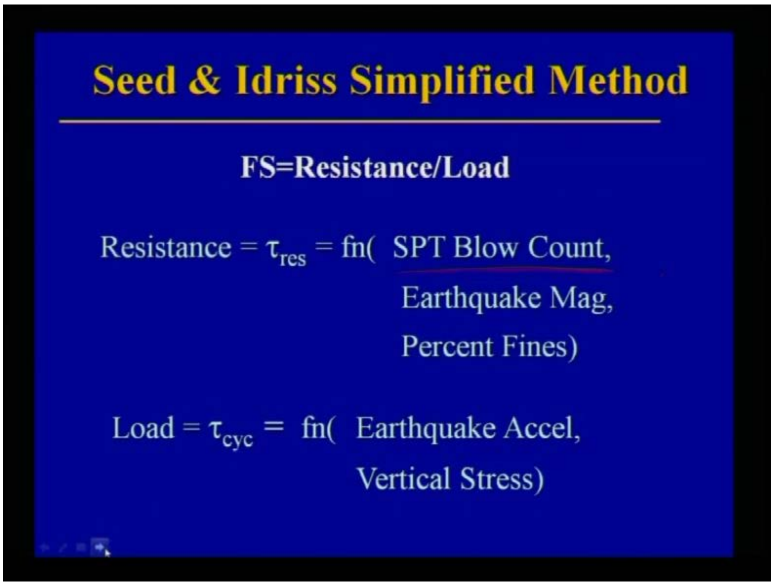
So, but our concern is that whatever field test we are going to do whether based on that will it be possible to find it out, one is your for this from SPT, CPT what we are going to do? Foundation design and other things from this SPT, CPT will it be possible to evaluate the liquefaction potential or not yes. How?

(Refer Slide Time: 14:57)



So, there stress based and strain based correlations they have given by seed and idriss and dobry et al, and one-dimensional ground response analysis, one-dimensional response analysis, laboratory test cyclic testing, laboratory strain cyclic testing; these are all stress based means this is your load based, this is your displacement base. Strain means displacement base, stress means your load based.

(Refer Slide Time: 15:21)

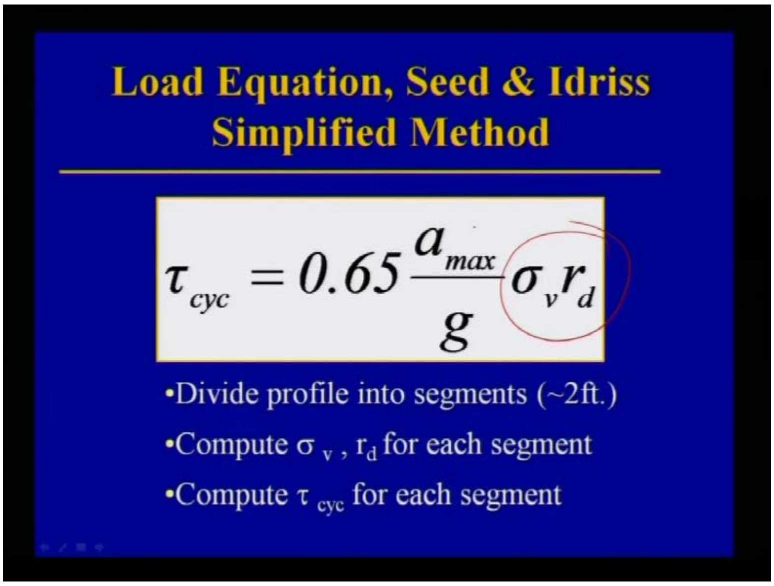


Now, simplified approach means simplified correlation given by seed and idriss, it is most popular. If I say factor of safety you should know little bit slightly, so that once you do the SPT, CPT, then how you are using this SPT, CPT particularly this that also you should know. If I say factor of safety what do you mean by factor of safety? Factor of safety in a simple term I say resistance by load, I say resistance by load very simple for a layman. What is your resistance? Resistance is a function of ground resistance, remember resistance is a function of ground resistance, load is a function of how much load is coming.

Now here in resistance, if a function of if you see SPT blow; from SPT what what you are supposed to get? SPT, I am supposed to get n. How it is a function of ground from n, I can find it out phi strength parameter of soil, so definitely this is a function of ground. Earthquake magnitude, how the earthquake will come? Below the ground surface earthquake will come, so this is a magnitude of earthquake. And in the soil, how much generally liquefaction where will occur? If fine as I said fine soil is there, so percentage of fines, so resistance is a function of if I summarise, SPT blow count, earthquake magnitude and percentage fines, this is your resistance.

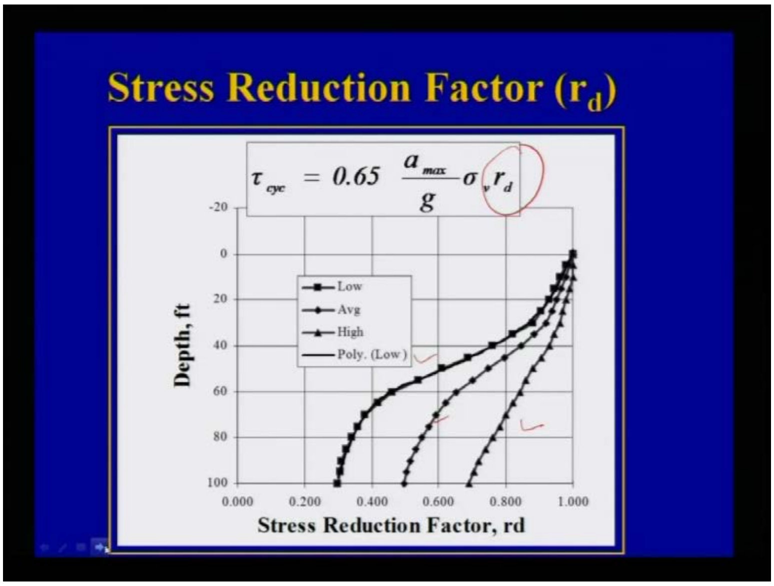
Now load, what is your load? How how the load is coming means how much is your vertical stress? How is the earthquake oscillation? How it travels inside the soil, this is your load. So, this load is your tau cyclic it is called resistance is called tau resistance, if I know these then I can find it out factor of safety. From where I can get it resistance as I said I can find it out from SPT, standard penetration blow; this is nothing but your soft soil exploration from where you can find it out n blows, we will see.

(Refer Slide Time: 17:32)



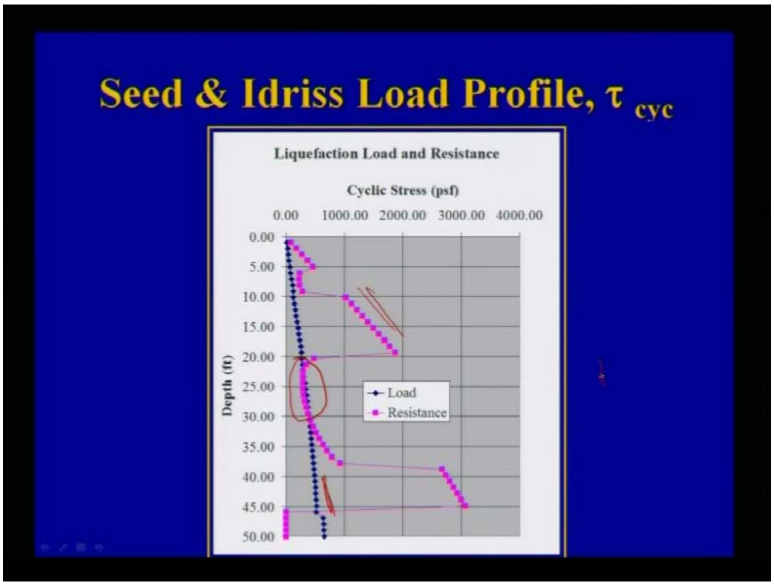
Load tau cyclic these are all empirical relation you can get it 0.65 a maximum by g gamma v r d. So, sigma v is your over burden pressure, r d is your reduction factor; these are well established they have given by seed and idriss, I do not want to discuss much a maximum is your peak ground acceleration or oscillation ground oscillation, this you can also find it out.

(Refer Slide Time: 17:56)



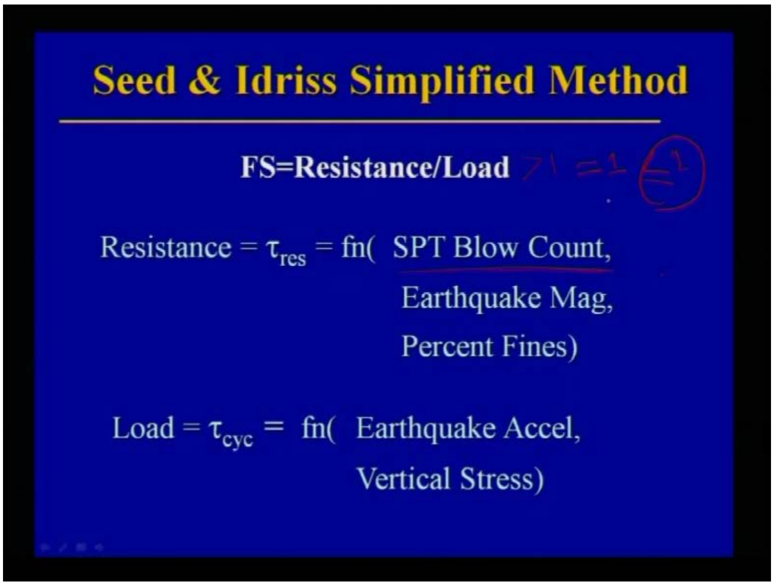
So, how tau cyclic is varying along this depth, this is your low value, this is your high, this is your average for particularly stress reduction factor r d for different depth, how it is varying this is given.

(Refer Slide Time: 18:16)



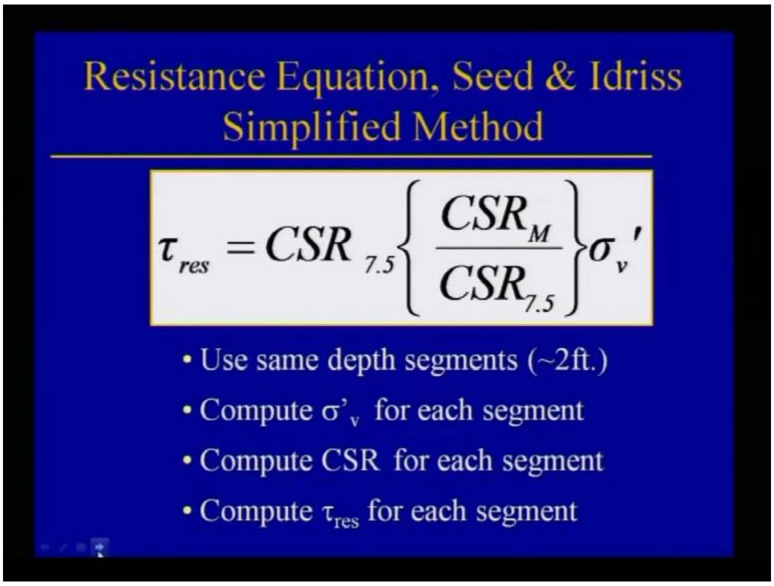
Now liquefaction load and resistance if you see this is the load, and this is the resistance by ground surface. Now, as a layman if you look at here as long as resistance is more than load, then the ground is safe. As long as the resistance is more than the load then the ground is safe, if resistance is less than the load then what will happen? Liquefaction will occur, in a simple. So, where is your resistance is less than your load or equal to load, I plot it load as well as resistance both, so here depth between 20 feet to 30 feet there is a chance of kind of resistance equal to or less than load liquefaction factor of safety means, it means factor of safety if you look at here, resistance by load.

(Refer Slide Time: 19:10)



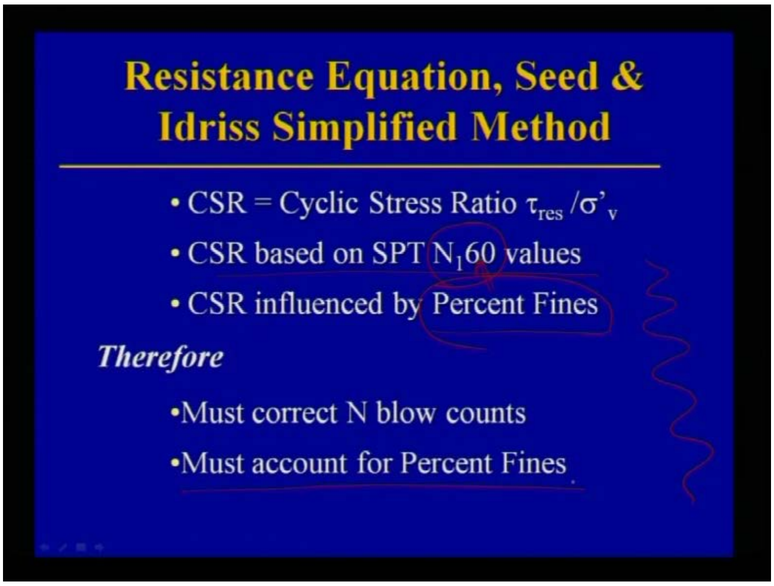
If resistance is more than load, then factor of safety will be greater than one. If resistance is equal to load then factor of safety is equal to one, if resistance is less than load factor of safety is less than one. That means, if it is less than equal to one, that means resistance equal to load or less than load in that case liquefaction will occur. So, some part it is between 25 to 30 it is less than 20 to 25 it is almost equal, so this is a zone this between 25 to 30 there is a high chance of liquefaction may or may it will it will be resistance is less than your load. So, they may be soil will fell by means of liquefaction.

(Refer Slide Time: 20:09)



Now, how do I find it out though this is related to completely soil dynamics tau resistance how I will get it, this is CSR 7.5, CSR M by CSR 7.5. So, cyclic stress ratio SR is your cyclic stress ratio magnitude from there you can find it out.

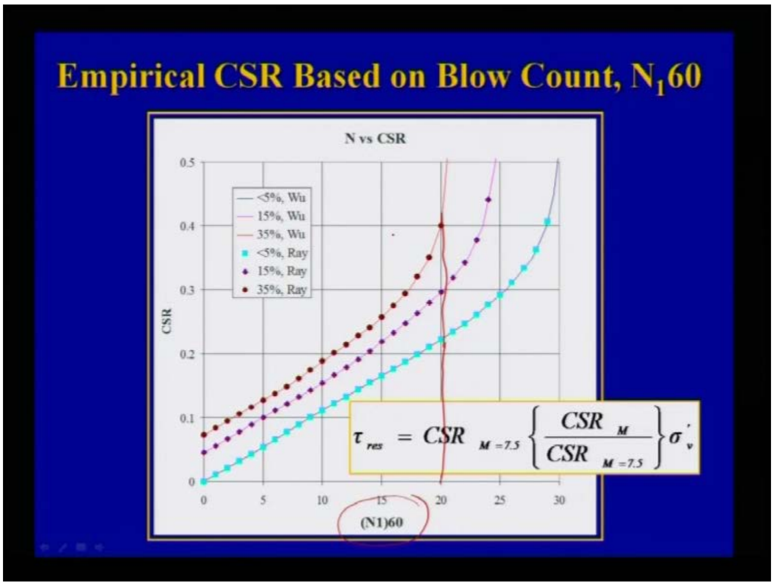
(Refer Slide Time: 20:31)



Cyclic stress ratio and CSR based on SPT N, as I said it is a resistance, so resistance of the soil how they correlate. If you have SPT N corrected N value N value from there you can find it out CSR, and based on the percentage of fines you can find it out N 60, the moment you will get N 1 60 means, what we will get penetration profile. This is you are not corrected uncorrected, then you correct it; once you correct it from there you can find it out your resistance value of the ground based on the magnitude.

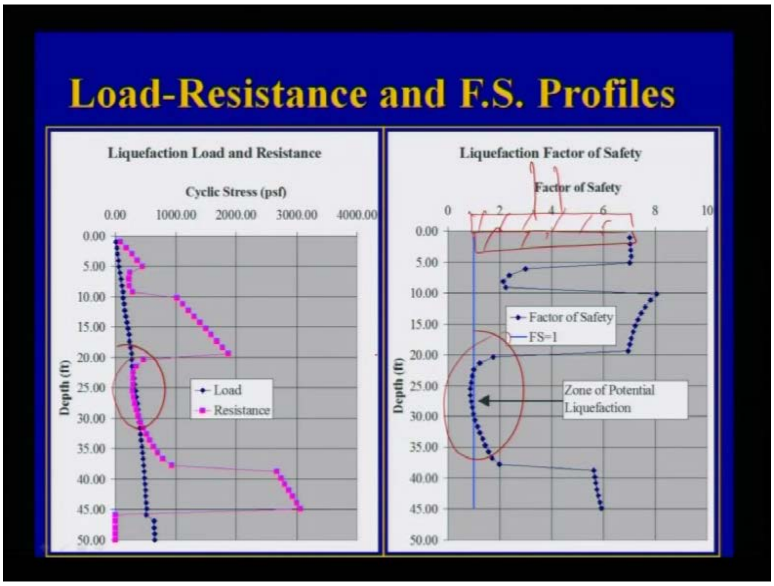
So once you know, then you can able to say by empirical relation means just you can say that whether this this will liquefaction phenomena will occur or it will not occur. So therefore, you see it is written must correct n blow count, must account percentage fine, because it says the definition says fine soil. What is the percentage of fine? 10 percent, 20 percent, 30 percent, 40 percent, 50 percent based on that you can, this is an indication it is not total predicting or not not you are not going exactly, because you will get exactly from laboratory data - laboratory test. So, this is an indication based on your kind of field test.

(Refer Slide Time: 22:00)



Some data has been given by seed and idriss, if you see if I have penetration blow I can directly find it out resistance; these are the empirical curves is there to take out the penetration blow corrected penetration 20 for different percentage fines you can find it out less than 5 percent less than 15 percent, 35 percent, 5 percent. Easily you can if your percentage fines are 10 percent, and penetration blow is penetration blow is say 20 that means 10 percent is lying between 15 and 5. So, where is your 15 and 5, this is your 15, this is your 5 from there you can find it out all these predictions has been given means once you know penetration blow, then you can find it out your resistance.

(Refer Slide Time: 22:53)



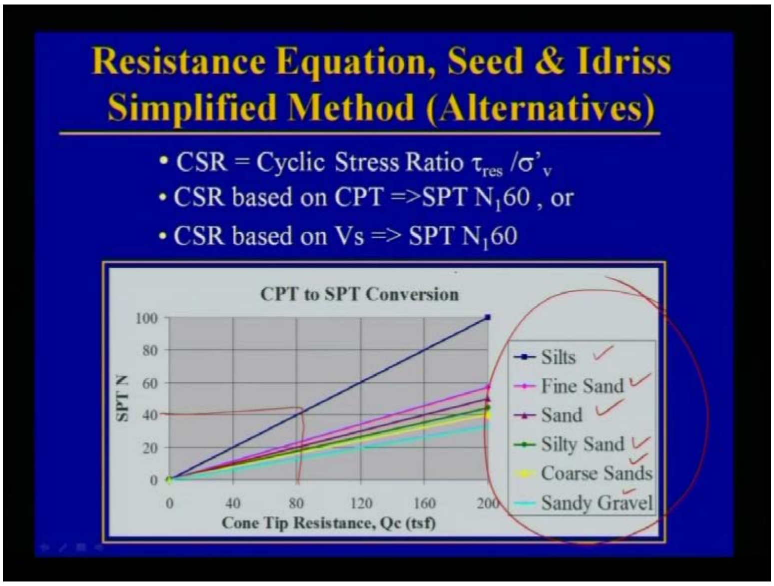
Load resistance and factor of safety profile: Sometimes geotechnical engineer based on also SPT value, sometimes they have been asked to check once you do the soft soil exploration every depth, every 2 meter, 4 meter, 6 meter, 8 meter, 10 meter depth to check whether the soil will liquefy or not just provide some some data some preliminary data soil will liquefy or not. This is a typical kind of factor of safety over the depth - 50 meter depth look at here, how do you get the factor of safety once again, resistance and load; it has been plotted as I said between 20, 22 to 30 meter, the resistance is less than equal to your load. So that means factor of safety less than equal to 1, this region.

Now, if you take it extrapolate it, then plot your factor of safety versus depth like the way you provide your SPT blow versus depth plot your factor of safety versus depth entire ground, soft soil exploration up to 50 meter, here it is up to 50 feet up to 50 feet you provide. So, it has been done, factor safety look at here it is 6.7, here look at it it is between 2 to 4 look at here, it will 8 to 7 look at here, it will 5 to 6. So, all the between the depth of like 0 to 5 feet greater than 1 between 5 to 10 greater than equal to 1 between this to this greater than one, between this to this greater, but the moment you are coming here. Only one point, if I take it show it very, very carefully if I show you only two points, this is the point this is the point, where the factor of safety is equal to 1, that means at this case what will happen? Load is equal to your or resistance is equal to your load, but all other points these, these, these, these, these, these, these; the factor of safety is less than 1, that means load is more than your resistance.

So, this zone is completely called liquefaction zone, this is remembered this is based on your field testing, this is based on your field testing, it may not, it may be true, it may not true, but this empirical relationship you are giving; you are giving an idea look, this is my soil profile. So, 25 feet to 30 feet is the zone of liquefaction, it may possible if there is a sand soil is there, sand boiling may be occur may be occur.

So, as a design there will be a liquefaction, if there is a building here, then there will be a building here, I will take sufficient precaution. If there is a putting hear nearby or may be the building construction, it is 25 feet. So, I will take certain precaution, so that sand boiling may not occur or foundation may, may not fell by means of this particular liquefaction. So, how your SPT, CPT, how it is how you are you are just correlating with your CSR, and resistance how you are getting this is my idea to show.

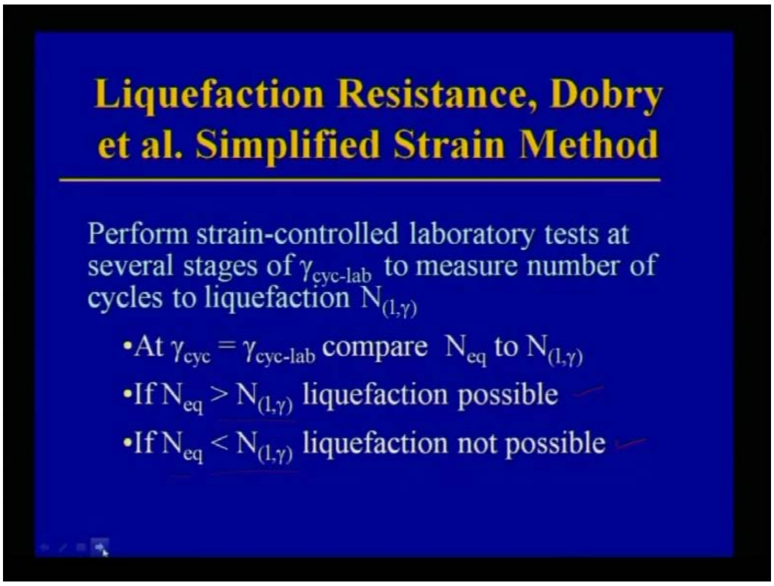
(Refer Slide Time: 26:51)



Now, the way it has been done for SPT standard penetration test also from cone penetration test, you can also find it out resistance. This is the case, if I plot it SPT to cone penetration resistance - cone tip resistance, if I have a cone tip resistance value. I do not have the SPT value, this cone tip resistance from this cone tip resistance, so I can find it out SPT N. The moment I will find it out SPT N from there I can find it out resistance indirectly I can find it out resistance for different soils, this this is the correlation has been given CPT to SPT conversation. That means cone tip resistance, if you have a cone tip resistance you convert cone tip resistance to SPT standard N value from N to we find it out your resistance factor.

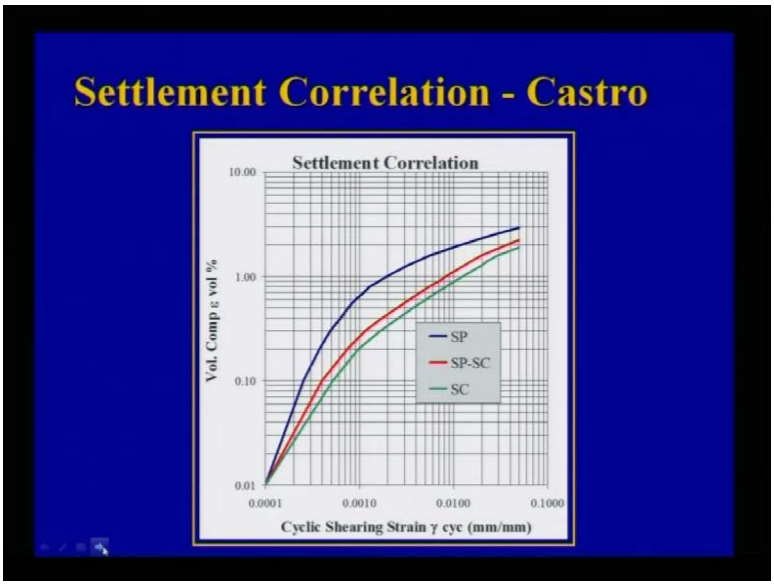
Once you find it out resistance factor compare with your load, then you can find it out whether there is a liquefaction or not liquefaction. You see SPT, and cone tip resistance for various soils, silt, fine sand, sand silty sand, coarse sand, sandy gravel; these are all correlation almost all kind of soils. All kind of soils has been taken into consideration; silty sand, fine sand, sand sandy, coarse sand, so based on these if I have cone tip resistance I will convert cone tip resistance to SPT N from SPT N to you convert it to resistance from resistance you compare with resistance with your load. They can then you can say that whether there will be a liquefaction or not.

(Refer Slide Time: 28:35)



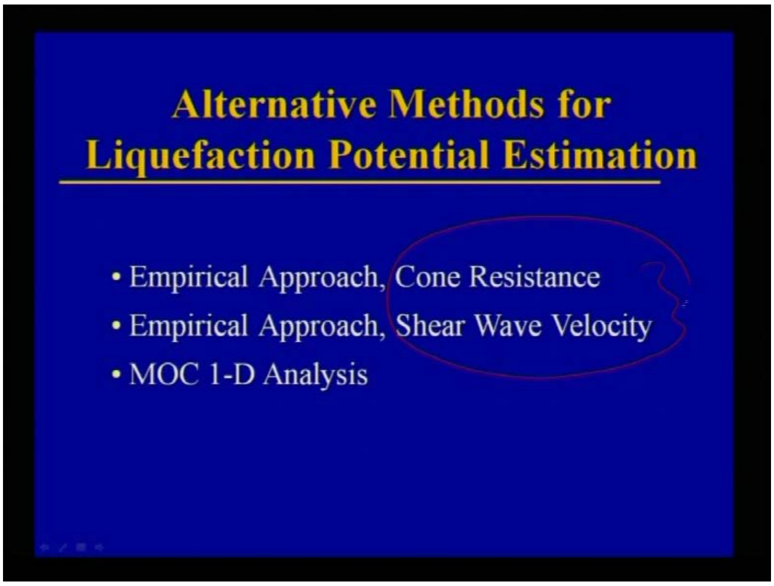
Another liquefaction resistance by strain, these are the stress. Dobry et al has given, so they have given this N equivalent is equal to N 1 gamma based on this N; it will be a liquefaction is possible, and N equivalent is less than N 1 gamma liquefaction is not possible they have given some correlation.

(Refer Slide Time: 29:09)



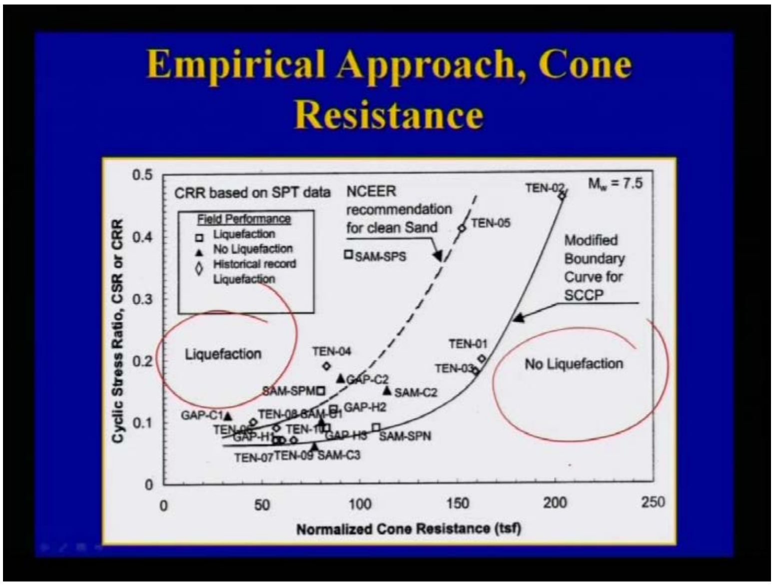
So, use this correlation of this for dry and saturation sand, so from there also you can find it out if you look at here.

(Refer Slide Time: 29:15)



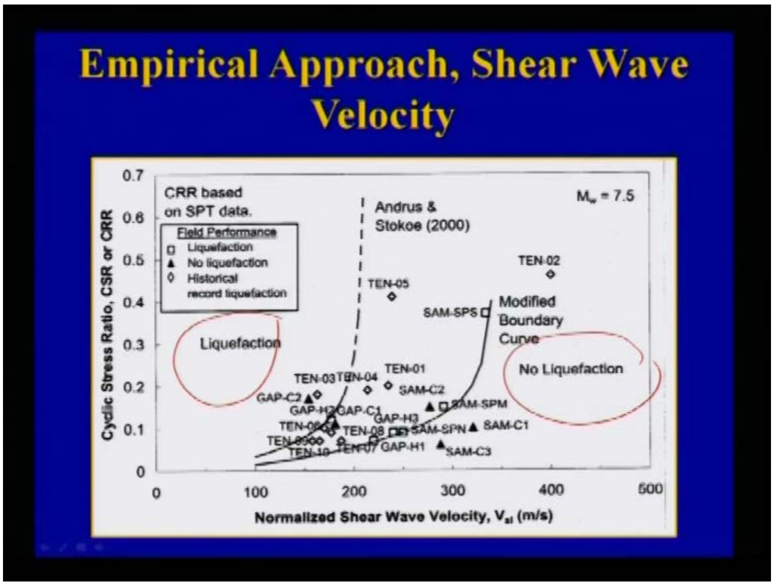
These are all laboratory test, they have given then which I do not want to discuss, I more or less I am interested what is the In-situ condition or field test from there whether, because we are doing this course for soft soil explorations. So, empirical approach by cone resistance, empirical approach by shear wave velocity; both these shear wave velocity also another field test, where you can once you measure shear wave velocity we can also find it out whether there is a liquefaction or not you can also determine.

(Refer Slide Time: 29:43)



Look at here, normalized cone resistance versus shear resistance, once you know cone resistance instead of by seed and idrissay from cone tip resistance to convert N 60, N 60 to convert the resistance, no directly from cone resistance you can find it out also cyclic stress ratio you can from there also you can predict whether it is a liquefied or non liquefied you see no liquefaction zone, liquefaction zone how the curve is going where it is from the cone resistance whether it is no liquefaction zone or liquefaction zone, you can directly find it out.

(Refer Slide Time: 30:21)



Similarly, normalized shear wave velocity profile by field, if you have a normalized shear wave velocity profile, you can plot cyclic stress ratio versus normalized shear wave velocity, and from there you can find it out resistance. So you can classify into no liquefaction zone or liquefaction zone, which is coming this side this part of the depth will be liquefied, this will not be liquefied. So, this is the case my idea is to basically show you, if you have if you have field test data like SPT and CPT will it be possible; will it be possible as I say that earlier in Borlaug profile - in Borlaug profile can you show some indication whether it will liquefy or not liquefy, because this is most important parameter also, yes it is possible some correlations has been given. So, in that Borlaug profile you also provide your factor of safety, you also provide the factor of safety, where the factor of safety is less than one. Then the design engineer he can understand that point there will be liquefaction, this is your additional topic I added, and this is the end of the syllabus. Thank you.