Geotechnical Measurements and Explorations
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Lecture No. # 26

Next part of this is a determination of dynamic property of soil by laboratory test. So, there are different techniques.

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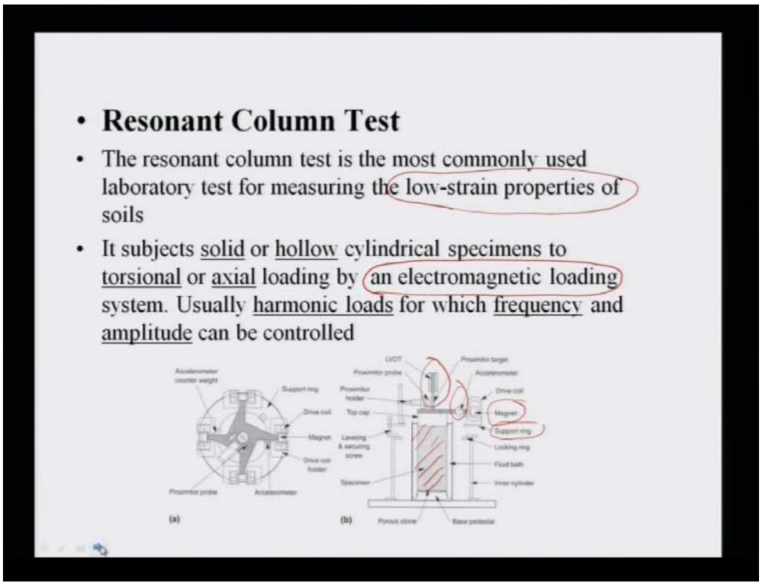

One of the technique is your resonant column test, in resonant column test it is mostly used in laboratory test measuring and it is for low-strain properties of soil. It subjects solid or hollow cylinder specimens to torsional by an electromagnetic loading by means of torsional moment by electromagnetic loading. If you look at here, here is your triaxial cell. In this triaxial cell this l v d t top cell with this proximeter target and this is accelerometer. And with this accelerometer this is a driving coil with this magnet is there and this is your support ring and locking ring and in between this is your soil. And it makes it by means of this dynamic property of shears has been measured by means of making it by torsional.

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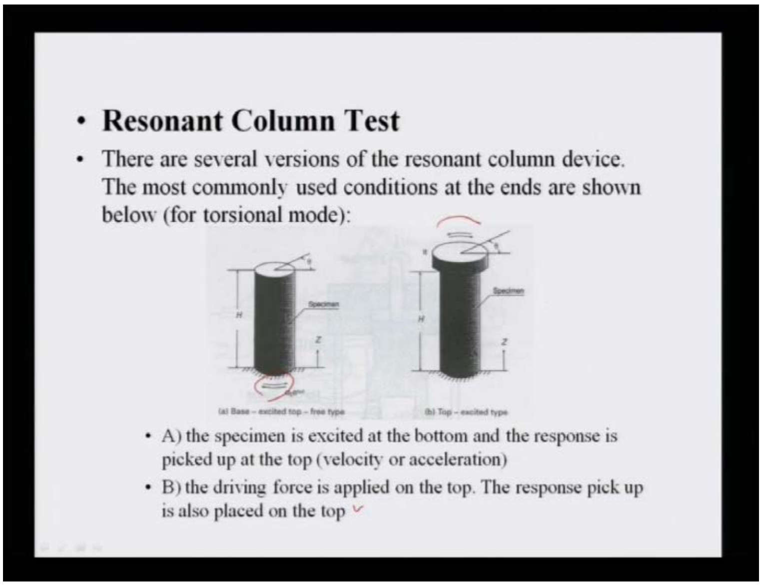

If you look at here several versions of resonant column device, the most commonly used condition at the end are, that is called specimen is excited at the bottom and response is picked at the top that means, excitation in resonant column it has been made at the bottom and response measure at the top by driving force is applied on the top the response pick up is also placed on the top. Here is your driving force excitations at the end this excitation has been made so, that by making excitation at the end and measuring at the top this response you can find it out the dynamic properties.

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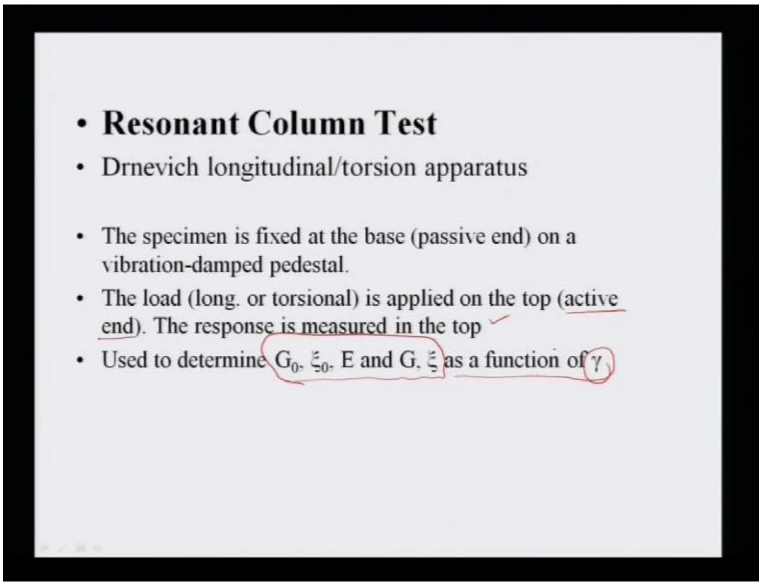

As I said this specimen is fixed at the base this is called passive end on vibration damped pedestal and load is applied at the top this is called active end and the response is measured in the top, it has been used to find it out G 0 (( )) as a function of gamma, unit weight of soil.

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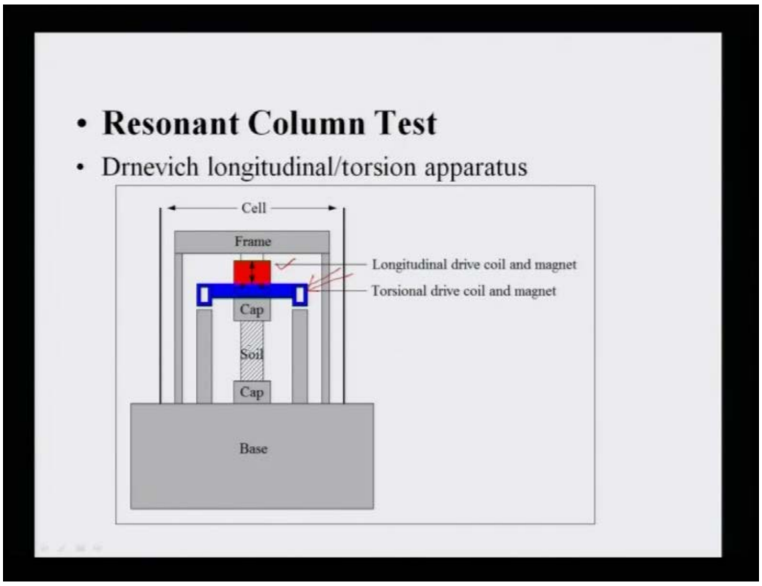

Now, it is a bigger picture if we look at here this is our loading frame. In this loading frame, this in between is your soil column and below is your cap bottom cap or top cap this is called pedestal above the pedestal soil has to fix, mount it and then this is your top cap, this is basically triaxial cell. If you look at here this is your base pedestal and this is your top cap and with this porous stones are there bottom and top and torsional drive coil and magnet. This is the magnet by means of this torsional drive has been made and longitudinal drive coil and magnet here. By means of torsional you can measure this response from the, at the bottom excitation has been made. At the top torsional has been applied so that shearing is there, so with the excitation you can find it out your dynamic properties in terms of gamma.

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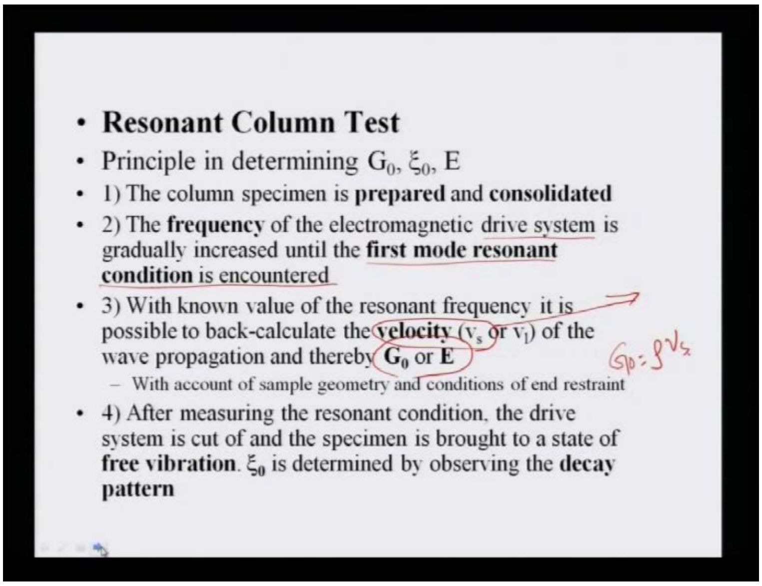

So, principle in determining G 0 (( )) 0 and E, the column specimen is prepared and consolidated. The frequency of electromagnetic drive system is gradually increased until the first mode resonant condition is encountered. With known value of a resonant frequency it is possible to back calculated the velocity that means you apply a known value of frequency. Then back calculate your velocity that is your Vs, this V s is nothing but your shear wave velocity. Then once you get your velocity of wave propagation or shear wave velocity, once you get it then you can easily find it out G 0. G0 is nothing, but rho into shear wave velocity V s. After measuring resonant condition the driving system is cut off and this specimen is brought to the state of free vibration. (( )) 0 is determining, determined by observing the decay pattern.

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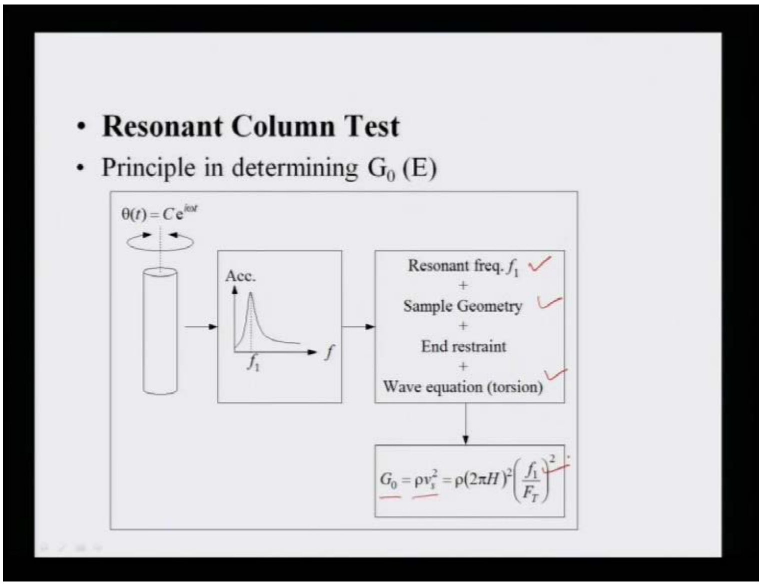

Look at here, in principles of G 0 in E, here is your known frequency has been applied. First your resonant frequency you apply f 1,then sample geometry, then end restraint, in the end then you find it out your wave equation from these you can find it out G 0 is equal to rho v square is your nothing, but your shear wave velocity which is in terms of f 1, which is your resonant frequency and f t.

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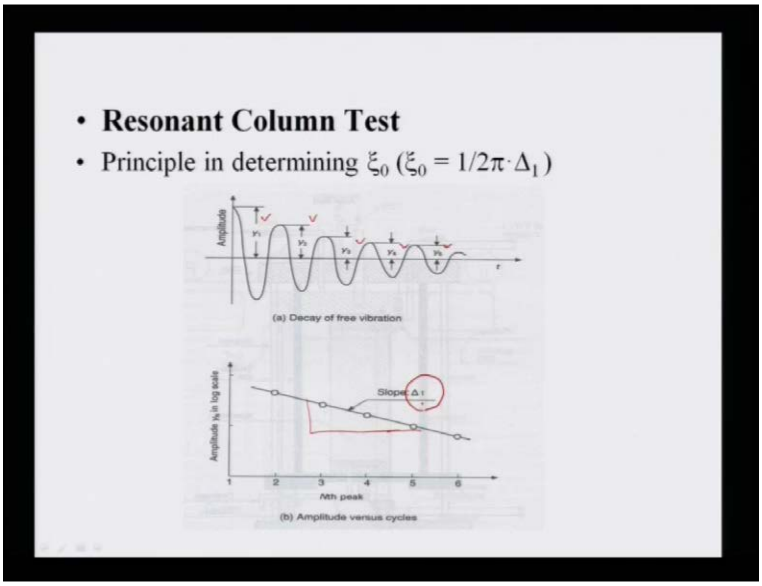

Then (( )) 0 from this you can find it out 1 by 2 pi into delta 1, delta 1 is nothing, but your amplitude in y n in log scale by nth peak. If this is my amplitude versus decaying free vibration then what will happen? It will decay it the free vibration will stop somewhere else, then this is your amplitude in y n in log scale, you take your amplitude y 1,y 2, y 3,y 4,y 5. Once you take the amplitude that means, for first peak this is your y 1 that logs scale. Then you plot it the slope, slope is nothing, but is your delta 1. So, from there you can find it out (( )) 0 is equal to 1 by 2 pi into delta 1, just go to the basic principle once again.

First you prepare the soil column, then allow in the triaxial cell, place in the triaxial cell and apply confining pressure, then allow for your consolidation. It may be isotropic consolidation or anisotropic consolidation, then the frequency of the electromagnetic drive system is increased. That means, if you look at here electromagnetic drive system is here electromagnetic drive system is there. The frequency it has been increased until first mode of resonant condition is encountered. That means frequency applied is equal to natural frequency of soil, when it same, at that time resonant condition will come in to picture. So, first mode of resonant condition is encountered that with known value of a resonant frequency, then you calculate what is your travel time or velocity shear wave velocity. After measuring the resonant condition the drive system is completely stopped that means, the specimen is once you start this resonance then you drive system completely stop. That means the soil specimen will go to a state of free vibration.

Then it will free vibration will start, then will decay it will stop somewhere else, it will decay this is once this free vibration will start it will go, go and stop. This is called decay of free vibration. Then you plot this free vibration measure y1, y2, y3 decay amplitudes y 1, y 2, y 3, y 4 and y 5.Then amplitude in y in log scale by nth peak. What is that peak you are getting then from the slope is nothing, but your delta 1 and that from there you can find it out (( )) 0. Once you get your share wave velocity then you can find it out G 0, that you can convert in terms of frequency applied resonant frequency in terms of sample geometry you can find it out G 0.

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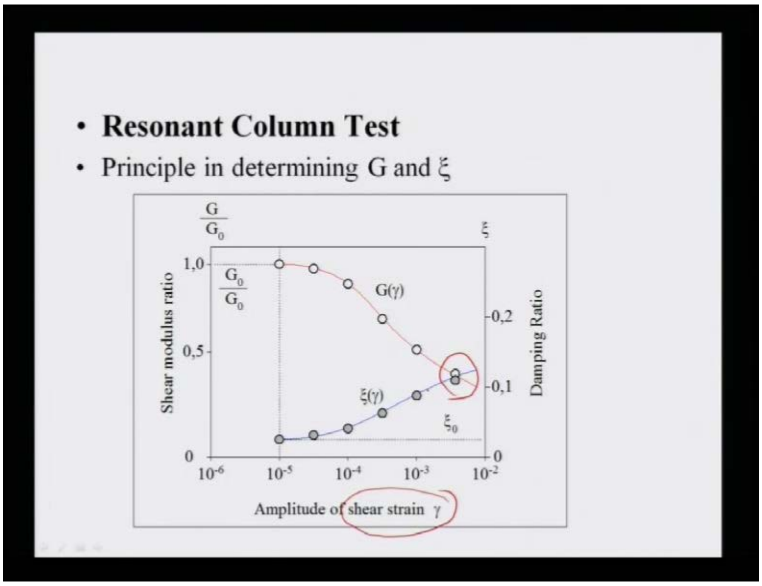

Principle finding G and (( )), if I plot G 0 by G 0 and in terms of amplitude of shearing strain or dynamic property of soil then, if you look at there our (( )) increases, G decreases. Here you can find it out, your shearing modulus ratio where it overlap you can find it out.

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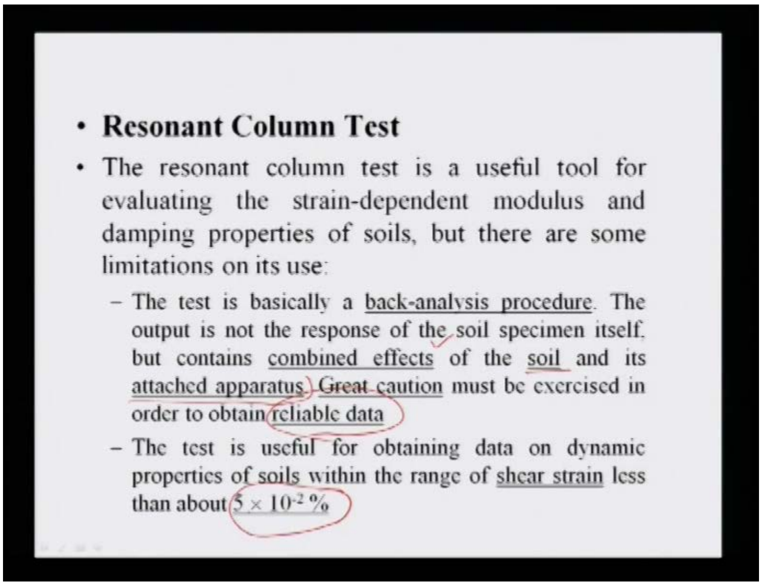

The resonant column test is useful tool for evaluating the strain dependent modulus and damping properties of soil and there are some limitations.

This is basically a back analysis procedure, the output is not the response of soil specimen itself and contains combined effects of the soil and its attached apparatus. Great caution must be exercised in order to obtain reliable data. The test is useful for obtaining data on dynamic properties of soil, with the range of shear strain less than about 5 into 10 to power minus 2 shear strain less than equal to 10 to power minus 2. If this is one technique that means by means of resonant column you can find it out dynamic property of soil, that to the strain limitation is 10 to the power minus 5, you cannot you will, you will measure this accurate data with the strain of 10to the power minus 5.

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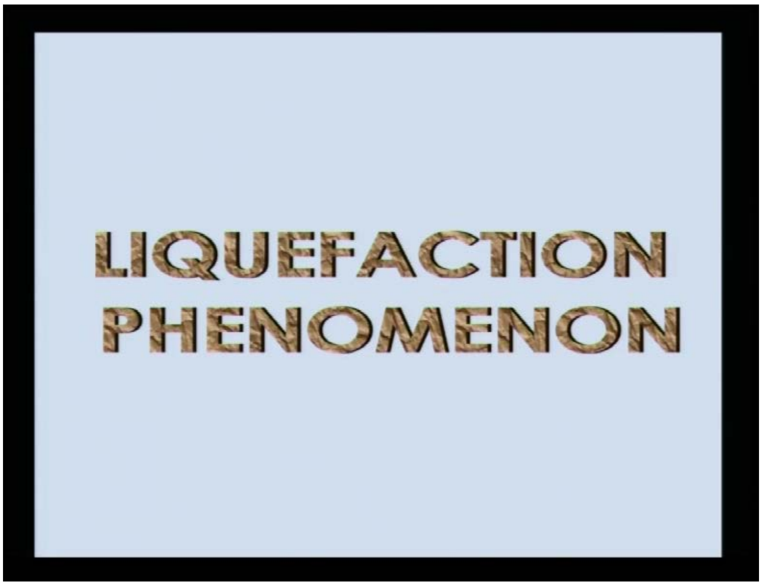

Next part is your cyclic triaxial, where it has been used to find it out cyclic triaxial. The cyclic triaxial has been used to find it out dynamic property, as well as to determine the liquefaction phenomenon. Before you start the cyclic triaxial test apparatus and its use to find it out dynamic properties of soil, let us start with brief introduction of liquefaction phenomenon.

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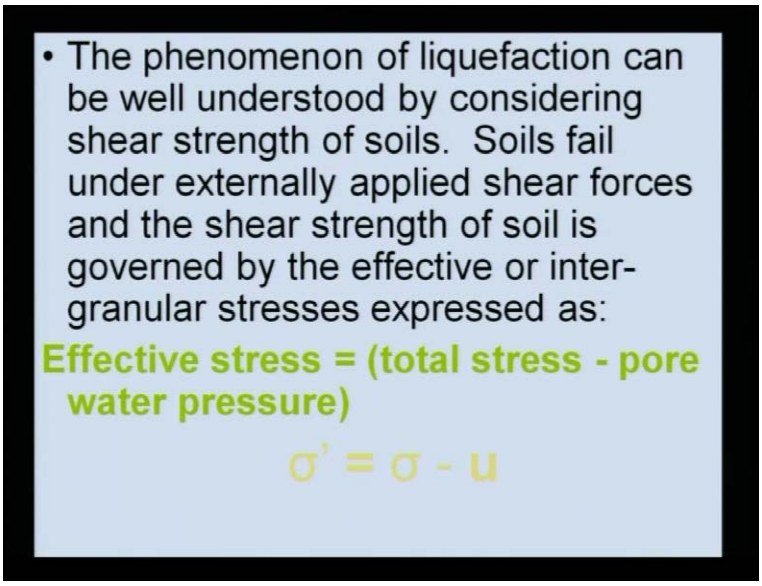

The phenomenon of liquefaction can be well understood by considering shear strength of soil. Soil fail externally applied shear forces and the shear strength of soil is governed by the effective, that means sigma prime is equal to sigma minus u.

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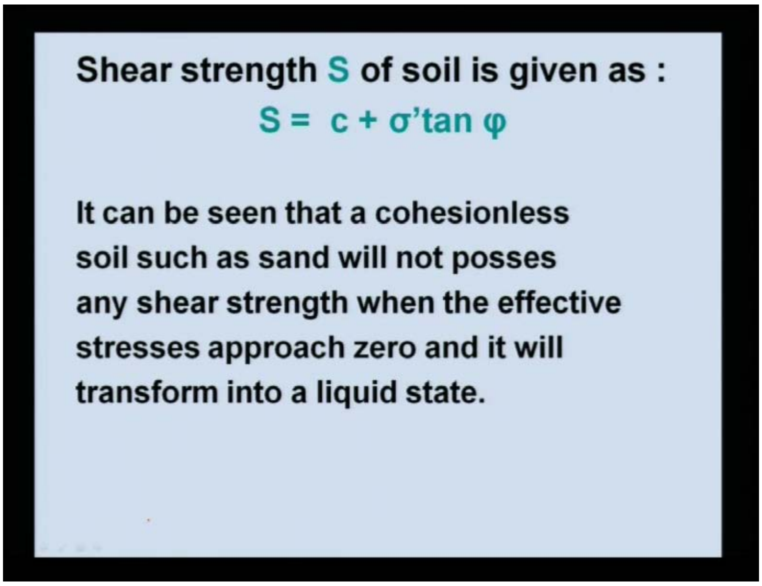

So, shear strength of soil that is given.

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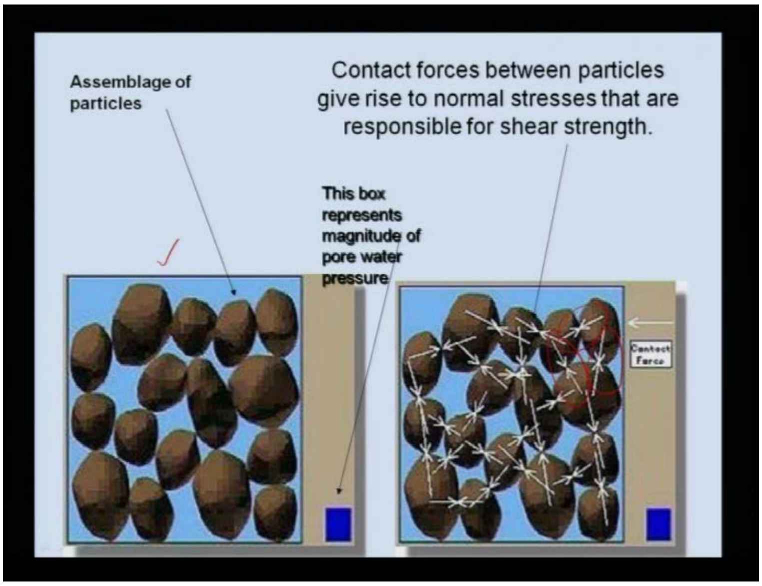

If you come back to soil element showing this assembly of particle then this contact force between the particles give rise to normal stress that are responsible for shear strength. The shear strength because of your intergranular friction c plus sigma tan phi this is your contact force. So, initially this is your pore water pressure.

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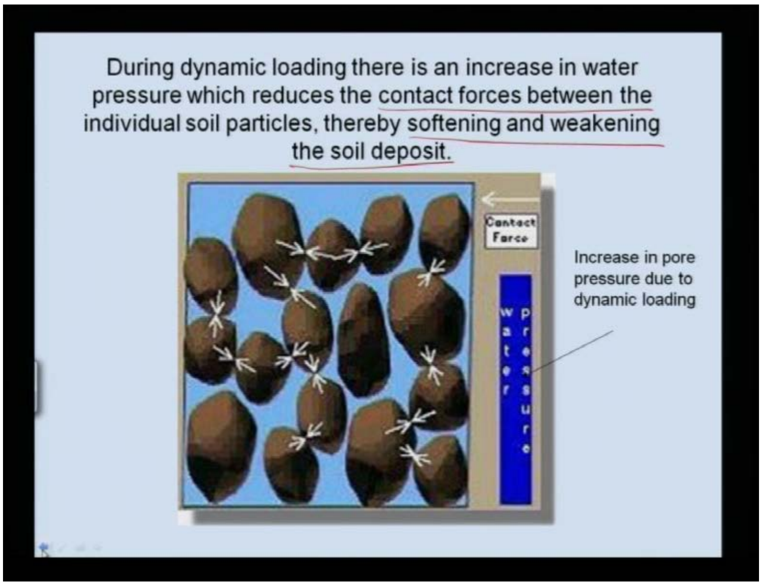

Now, due to dynamic loading the increase in pore water pressure, what will happen? The contact force between individual particles, it lost or it is become weak. That means softening or weakening of soil deposits that means, it lose this contact force between the soil particles. This contact force between each soil particles among themselves. If you look at this, if this is a soil particle it has contact force with this particle, this particle, this particle even if you, if I take with this it surrounded by 1, 2, 3, 4 contact force with this, with this, with this, with this, all this has been contacted with contact force then by means of dynamic loading, this contact force has lost or maybe it will slowly, slowly it will go because of that the softening or weakening of soil deposit happens. This is called nothing, but your liquefaction and what are the history if you come back to 1964 like Nigata.

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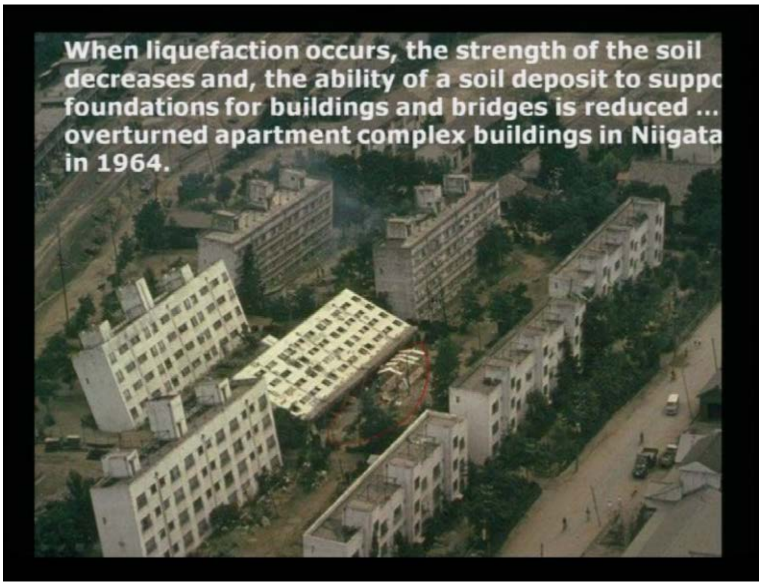

These photographs we can see that, that when this liquefaction occurs, this strength of soil decreases and the ability of soil deposits to support the foundation for building and bridges is reduced. If we look at here it is Niigata earthquake in 1964 because of this failing because of your liquefactions.

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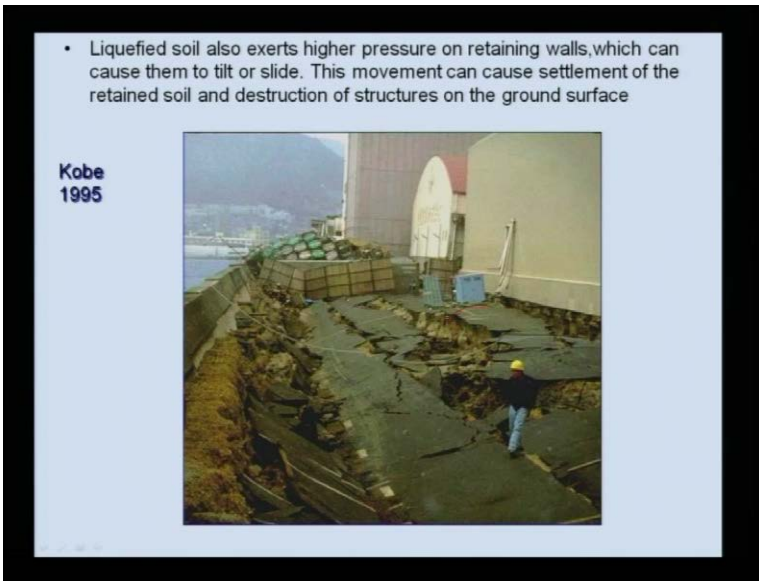

And liquefied soil also exerts higher pressure on retaining wall. This is a retaining wall failure in Kobe 1995 retaining wall failure.

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Then retaining wall damage also lateral spreading, there will be also lateral spreading that happen in Kobe 1995 earthquake.

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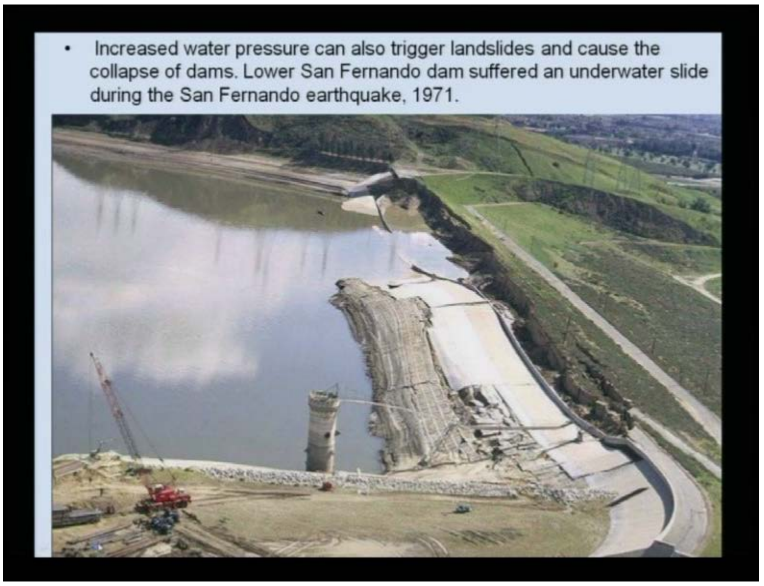

Then if you look at here, San Fernando earthquake 1971, if we see that there is a landslide it flow of landslide.

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Then you see Niigata earthquake 1964 sand boils ground fissures these are the property you observed. If you look at here your sand boils is there, sand boils also ground fissures are there, this is because of your cyclic earthquake loading it becomes liquefied that means it happens in course particularly cohesionless soil fine, fine cohesionless soils.

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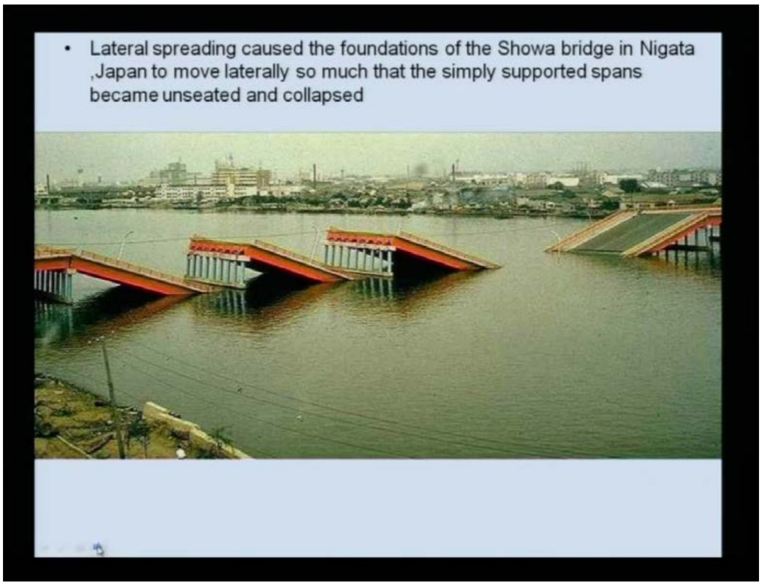

Also lateral spreading caused the foundation of bridges in Niigata in1964. These are all some examples before we are going for cyclic triaxial test.

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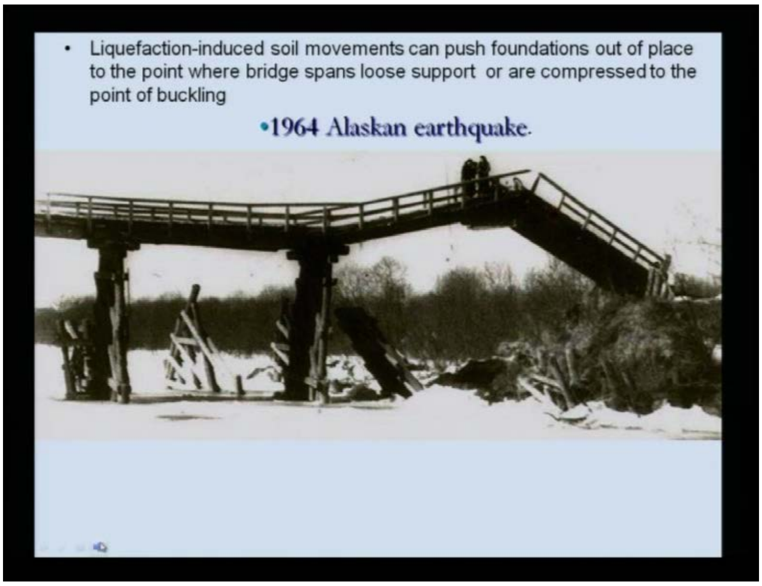

1964 Alaskan earthquake, look at this bridge it completely collapse.

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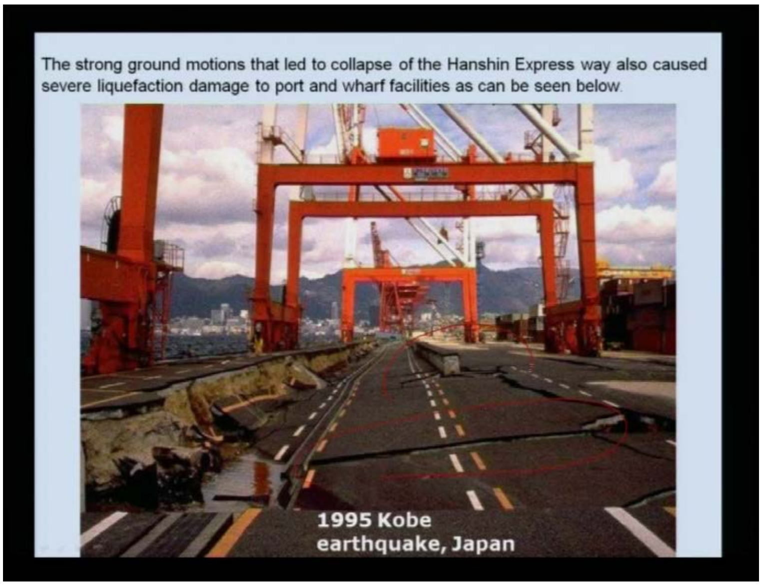

Similarly, 1995 Kobe earthquake Japan. See, this collapse of this bridge.

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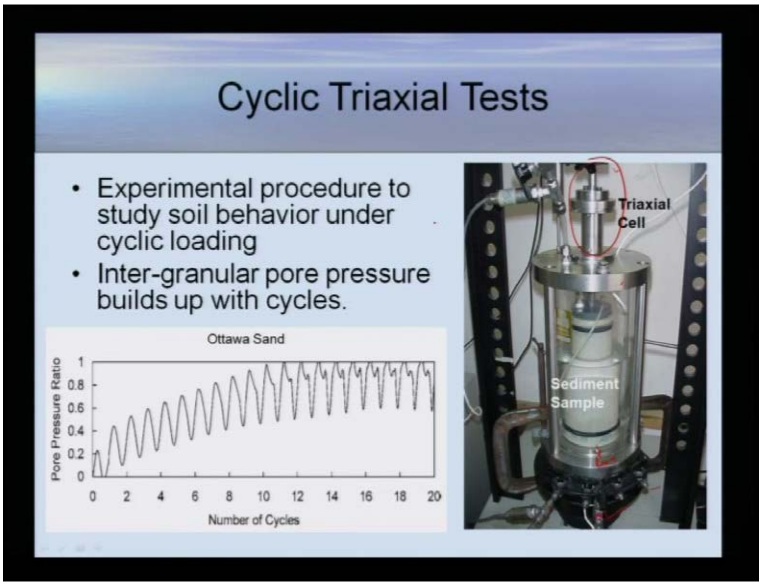

Now, come back to cyclic triaxial test. This will give the cyclic triaxial test, this is a triaxial machine. Basically this is a triaxial machine. With this triaxial machine, what happen the cyclic loading has been applied. If you look at here this is a triaxial cell and soil sample inserted and whatever, earlier static triaxial cell it was there it will be same. The pore water pressure, volume change and applying the confining pressure you can apply and below the soil sample there is a load cell you can measure the load coming to the soil and this there is a pedestal with this pedestal, here you can apply excitation.

Here, you can apply give this cyclic force. It is a periodical, it may be sinusoidal, it may be trapezoidal. So, depending upon your actuator you can place it here by means of actuator you apply cyclic load. Cyclic load again it is 3 types. It may be purely compression that means, if I am saying that what kind of load I am going to apply. This is purely compressive repeated loading. Generally, this kind of loading comes in where, it comes in transportation means particularly roads and highways by means of traffic and train loads, then give another set of loading this is called trapezoidal loading. This kind of loading also in compression also you can provide, these are all repeated loading that means you give this loading at certain interval of time.

Another 1 is your negative positive, negative positive, negative positive give this cyclic loading (( )), once you give the cyclic loading that means the soil sample will be it will be amplitude positive and negative. It will compress and as well as extend, it will truly reflect. What will happen in during earthquake the soil will be positive and negative, positive and negative that means compression and extension. So, it will truly reflect not you cannot say that truly reflective or earthquake loading. We assume that it is an repeated, it is a repeated loading. So, the assumption is that it may be a sinusoidal or you can provide triangular loading kind of repeated loading you can apply. In this machine particularly, this sinusoidal wave has been sinusoidal wave excitation by means of at the top actuator this can be generated.

So, what will happen this will give the soil sample back move and back, if this is my soil sample what will happen initially it will try to compress. Then it will try to extend compression and extension will be there. So, it gives what will happen in cyclic behavior that means if earthquake load is repeated loading and unloading. There what kind of loading will be what type of soil, how it will behave.

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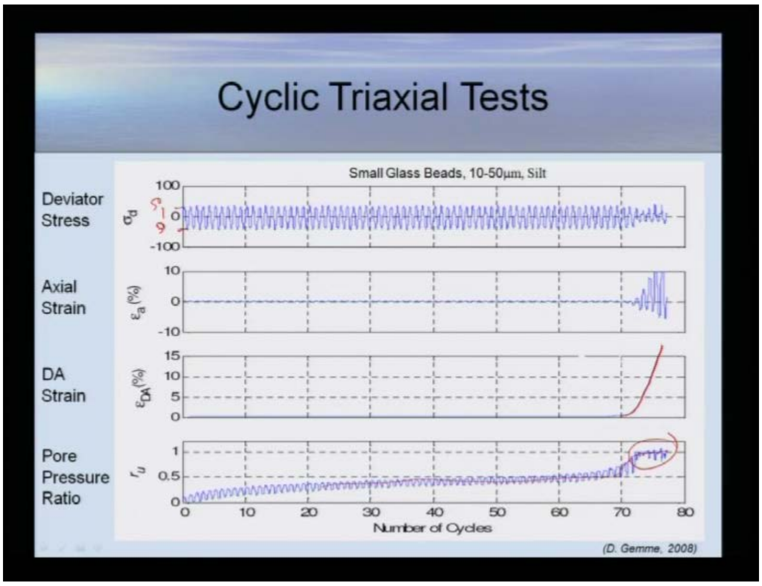

Now, look at these this kind of deviatoric stress will apply. As I said, this is a sinusoidal the moment by means of actuator at the top you excite by means of cyclic loading the deviatoric stress will be suppose it is 50-50 sigma d it will be here, it will be 50, here it will be 50, it will move positive negative, positive negative throughout. Then axial strain will be, what happen and your pore water pressure so, as it is in untrained conditions. So, what happen once you will give negative and positive so, this pore water pressure ratio, it will increase it will strive to increase, increase, increase, increase, increase. All of sudden it reaches at 1 that means the moment it reach to the value of 1 at that time we say that, it is complete liquefaction. Complete liquefaction, then your double amplitude strain, if you look at the double amplitude strain there are single amplitude strain, double amplitude strain I mean if you say double amplitude strain means that means negative and positive.

This strain with this negative and positive what is a strain double amplitude. If I say single amplitude strain that means it is only either positive or negative side. What is that strain if I plot the double amplitude strain. If the plot the double amplitude strain the strain will go all of sudden during the liquefaction, that means liquefaction is a phenomena at which soil loses its strength. It will become asymptotic, it will steep rise and it will become 100 percent or 1 it will steep rise.

These are all parameters how, what is the output you are going to get once you apply cyclic loading to the soil. What kind of what kind of data you can get it just I am showing then can I find it out dynamic Young's modulus.

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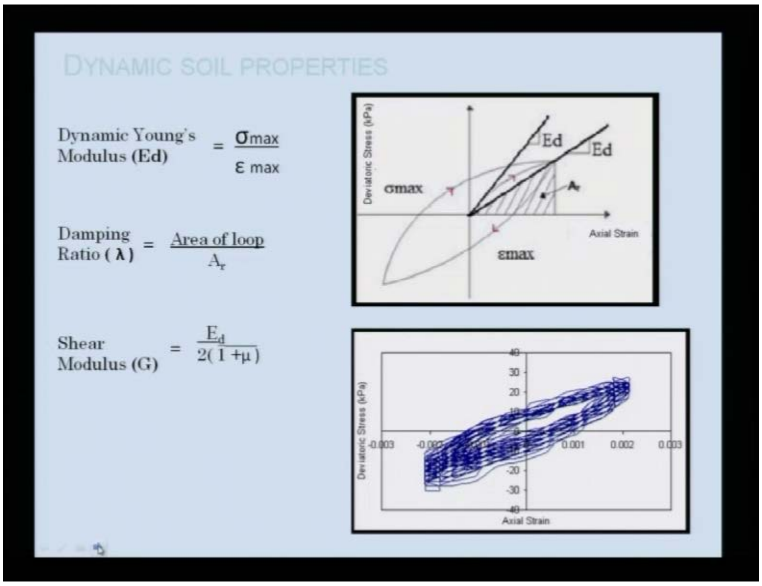

Can I find out dynamic Young's modulus? Can I find out damping ratio? Can I find out shear modulus? Yes, we can find it out.

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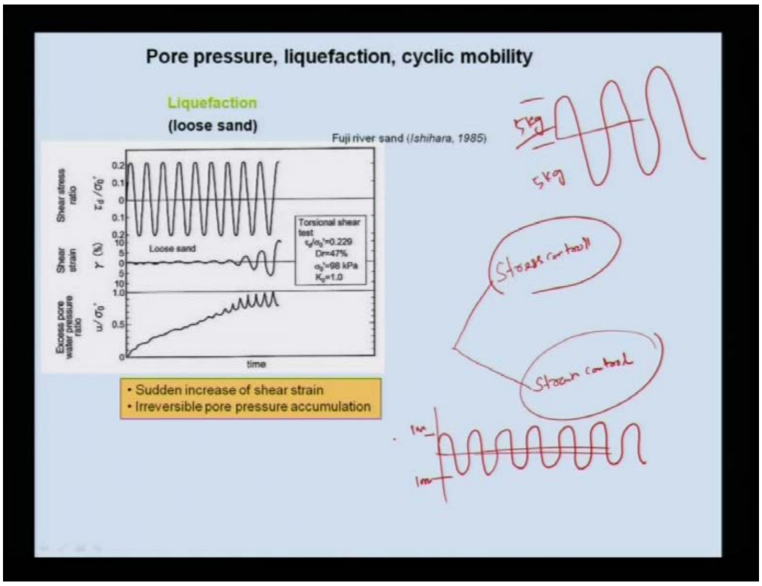

Look at here before we discuss that there is some example Ishihara, in 1985, they have conducted with this cyclic test on Fuji river sand. So, this stress ratio they applied some stress ratio they put it so, there are 2 kind, 2 types of cyclic triaxial test. 1 is your stress control, other is your strain control. So, in case of stress control what happen? At the top you fix in such a way that it will apply load kind of 5 kg like it will apply 5 kg, 5 kg,5 kg, 5 kg that means it will apply load of 5 kg that means stress of 5 kg divided by area.

The moment you say that it is a strain control you apply this you set in such a way that it will apply a displacement. Suppose, I say it is a strain control I will set the displacement should be maximum 2 mm or 1 mm so, it will go always with this the cyclic load will be applied always this. This is 1 mm, this is 1 mm, that means this strain rate strain has been fixed in case of stress control distress has been fixed. So, there are 2 test basically stress control as well as strain control. So, later on I will show you this stress control independently strain control photographs.

Now, this is your shear stress ratio applied and shear strain, how you are getting then excess pore water pressure.

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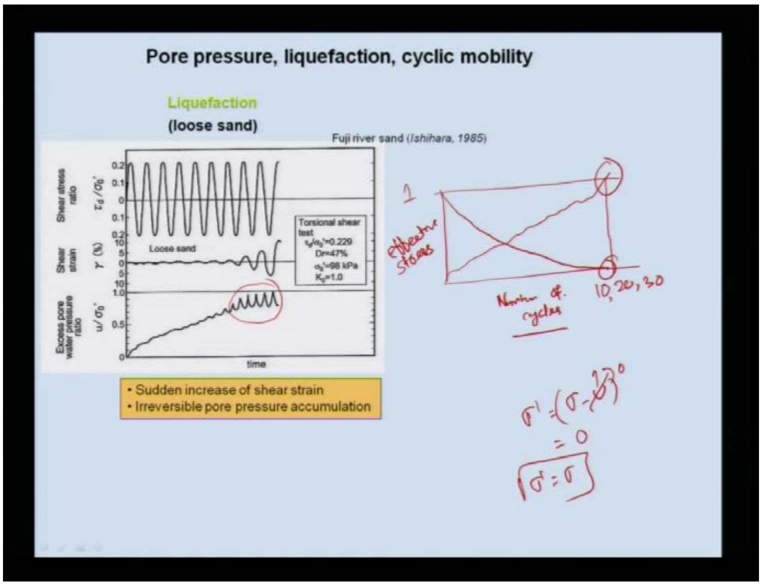

It has gone with the time it all of sudden it increases. What we are suppose to get? We will get either cyclic shear stress ratio versus number of cycle what will happen the moment you apply either cyclic shear stress. If it is a stress control, if it is a strain control or cyclic shear strain that means if it is a cyclic shear strain or cyclic shear stress the moment you apply what happen, this pore water pressure will increase, increase, increase, increase it become 1. The pore water pressure become 1 at what number of cycles say 10, 20, 30 or whatever may be number of cycle, the moment pore water pressure become 1, ratio 1 that means, pore water pressure achieve 100 percent. 100 percent means pore water pressure that means sigma prime is equal to sigma minus u.

Once it become pore water pressure is equal to 100 percent that means this is 0. At that time soil loses its strength. At this at the same time if I plot effective stress versus number of cycle what will happen? This effective stress initially it will be there then what will happen it will decrease, decrease, decrease and it will become 0. So, this is a kind of, kind of confirmation you can find it out from the test that means where, this effective stress initially it is 100 percent so, that means this effective stress is equal to initially pore water pressure is equal to 0. So, effective stress is equal to sigma so, all of sudden it will build up pore water pressure and it will become 0. At what point effective stress is equal to 0? At that point your pore water pressure will become 100 percent.

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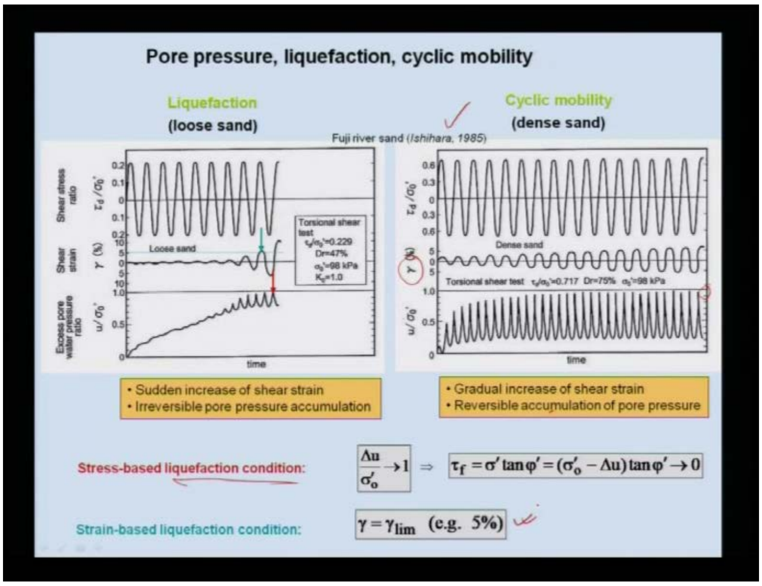

Look at this delta u by sigma 0 is nothing, but your pore water pressure ratio, change in pore water pressure by sigma 0 prime, when it tends to 1 that means your shear strength tends to 0.

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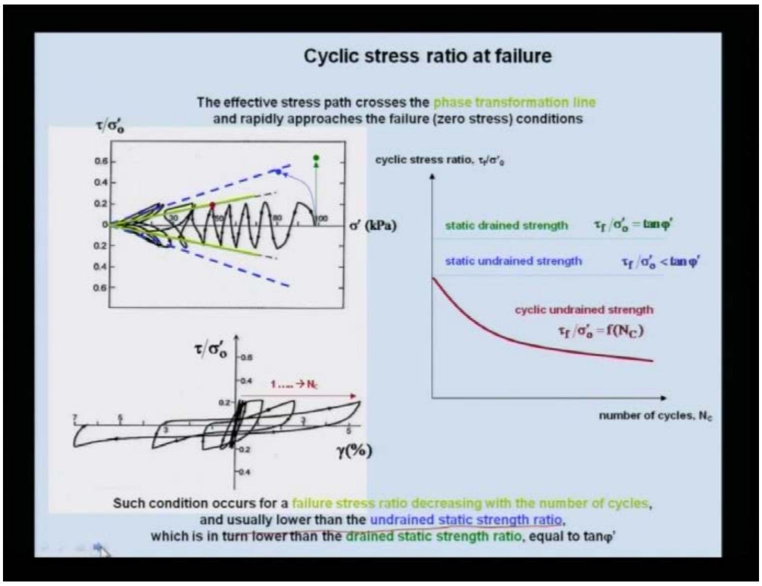

If you look at here this is my shear stress ratio apply, this is your shear strain, shear strain this is your change in pore water pressure ratio, pore water pressure ratio and it will go it will become 100 percent. This is based on stress control test to find it out liquefaction as given by Ishihara 1985. So, strain based liquefaction condition is equal to that is your gamma is equal to gamma limiting that is your 5 percent strain, 5 percent strain you can consider. Look at here cyclic shear stress at failure as I say so, cyclic shear stress it will go and it become either 0 or may be less strength will be there means it will be asymptotic somewhere else it will come, it will like this asymptotic there is no further. So, at this point you can say that number of cycle you can take it. So, the effective stress path across the phase transformer line and rapidly approach the failure 0 stress condition.

You see effective stress path approaches to 0 during failure conditions, static undrained strength tau a pi sigma 0 prime, less than is equal to tan phi. So, such condition occurs for a failure stress ratio decreasing with the number of cycles usually lower than the undrained static strength ratio. It is lower than the undrained static strength ratio, which is in turn as I said it is lower than the undrained strength ratio.

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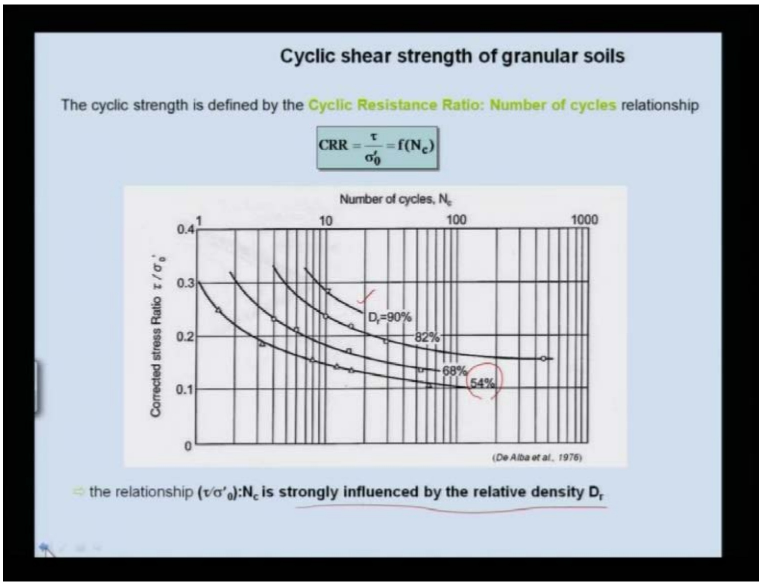

Then cyclic resistance ratio as I say CRR it will be tau by sigma 0 (( )) which is a function of number of cycles. If I plot the cyclic resistance ratio, if you see the versus the density influenced by the relative density. The cyclic resistance ratio for 90 percent relative density it will be higher as density goes down lose to medium dense it will be lower.

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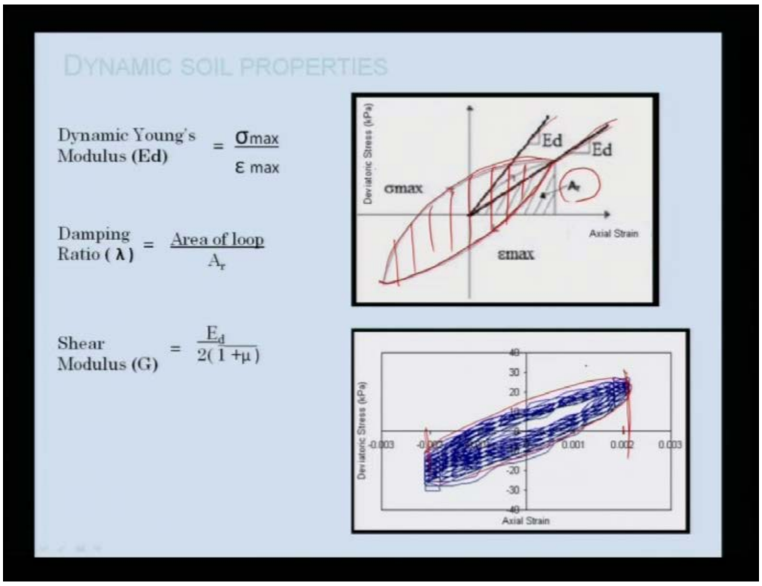

Now, can I find it out dynamic Young's modulus E d? Yes, we can find it out sigma maximum by E maximum. So, from where we can get it this is your hysteresis loop this is a 1 loop, if you look at this is loading and this will start with this loading then unloading. This is 1 loop, with 1 loop E d will come you take this from here or here depending upon the loop you can take it and this is your area of loop. So, we can find it out damping ratio is equal to area of loop into divided by area of loop means this is your area of loop divided by A r where you find it out E d this is your A r. Similarly, shear modulus G we can find it out G is equal to E d by 2 into 1 plus mu.

So, these kind of if you look at here deviatoric stress versus axial strain, if it is strain control. We applied a strain of say 2 mm. So, if you look at here both the ends, the maximum displacement achieved is 2 mm and this is loading unloading, loading unloading that means each cycle, each cycle you can find it out damping ratio and shear modulus, each cycle you can find it out then these shear modulus suppose it fails suppose it fails say by 10 cycle or twentieth cycle or may be by thirtieth cycle, at thirtieth cycle at failure what is your shear modulus? What is a damping ratio? That is your input parameter for your design.

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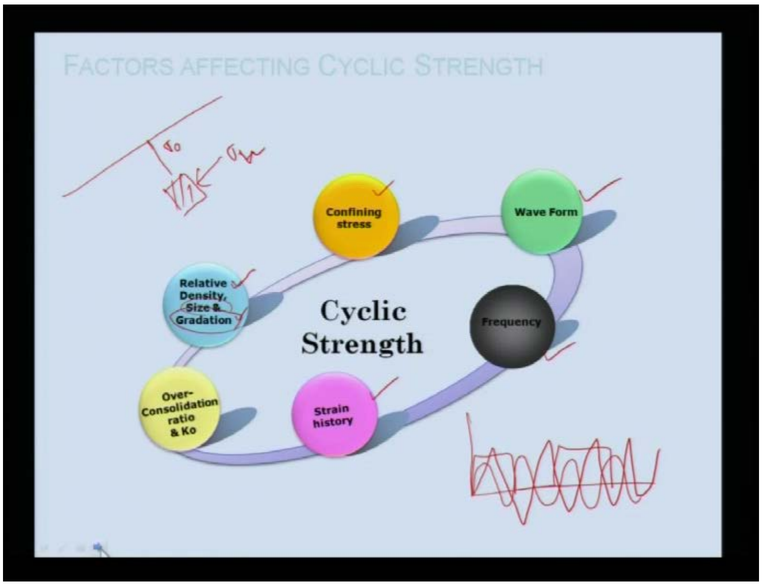

Now, cyclic strength what are the parameters factors affecting the cyclic strength. If it is said, definitely it is strain history means what kind of loading and frequency. Of course what kind of frequency it is applied, strain history waveform as I said, how you are applying this wave is it a sinusoidal, is it a trapezoidal or it is a triangular. What kind of wave you are applying it depends upon that wave then over consolidation ratio and k 0 over consolidation ratio and earth pressure at rest, it depending upon that how you are consolidating, it is a normally consolidated or may be isotropic, non-isotropic or over consolidation ratio or what is a lateral earth pressure? It depends. Also, it depends a relative density size and gradation. It is not necessarily that liquefaction will occur all size or all gradations, liquefaction may occur, may not occur also course grained soil. In course grained soil generally liquefaction is not going to occur because the accumulation pore water pressure buildup has less chance. It depends upon size and gradation and relative density, also confining pressure means if it is a very dense.

Relative density means, if it is a very dense soil there is a less chance of occurring liquefaction also confining pressure. What confining pressure if the confining pressure that means this is ground below this the soil sample is there. If this is your overburden pressure, overburden pressure this is your lateral pressure or may be horizontal pressure. What confining pressure? It all depends upon these are the all factors may be we can discuss later on some something about this.

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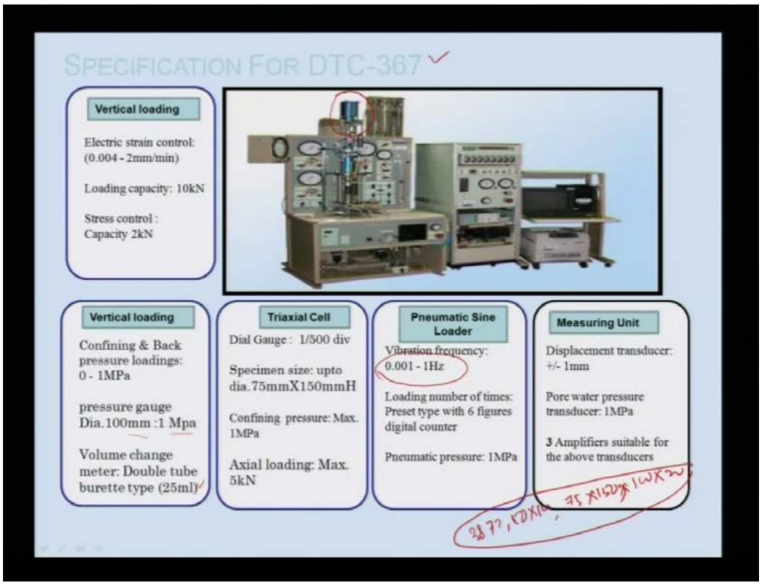

This particularly this factors, how it affects. Once I will show that strain control as well as stress control. Now, vertical loading generally load capacity generally gone. In standard this is a like 10 Kilonewton with this stress control of capacity 2 Kilonewton, then in case of pressure gauge means diameter is like 100 mm, 1 Mpa and volume change is your double tube burette like 25 ml. You can change your volume. These are all specification as per as per this ASTM (American Society of Testing Material), triaxial cell you can use any sample means sample size of 38 by 72, 50 by 100 or 75 by 150 or 100 by 200.

There are various ranges of you can use the sample size. Confining pressure, you can maximum, you can go to 1Mpa, axial loading is your 5 Kilonewton, frequency vibration of frequency for soil for particularly soil it will varying from 0.001 hertz to 1hertz. If it is soil. If it is not soil, if it is a ballast or any other things it may possible that this frequency may vary much more than that. Loading number of times like preset like 6 figured digital or pneumatic pressure and displacement transducers are there, pore water pressure transducer 1Mpa, 3 amplifiers for this (( )), This is a typical test, typical testing arrangement. It has been shown if this is your triaxial cell with this and this is your as I said may be clear picture I can show you later on it as I said this is your actuator, with this help of actuator the dynamic or cyclic loading cyclic loading has been applied.

So, you can set your range if you are interested for soil, you can go for pavement, you can go for concrete, you can go for steel, means depending upon that particularly soil generally you go for a low frequency, maximum we can go up to 1 hertz frequency. And this is all about your cyclic triaxial, may be next class we will discuss more about your, how to find it out dynamic property of soil in lab.