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ADVANCED GEOTECHNICAL ENGINEERING

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Lecture No. 57

Module – 7

Lecture – 8 on Geotechnical Physical Modelling

Welcome to lecture on advanced geotechnical engineering course.

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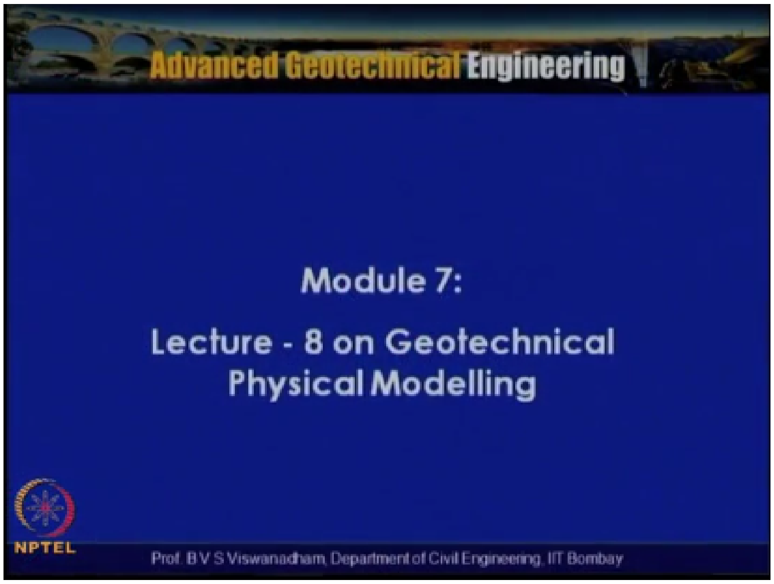

This is module 7 on geotechnical physical modeling lecture 8, so in the previous lecture we introduced ourselves to two aspects which are required for verifying the scaling loss or particle size effects the one is that modeling of models are other one is that modeling of prototypes.

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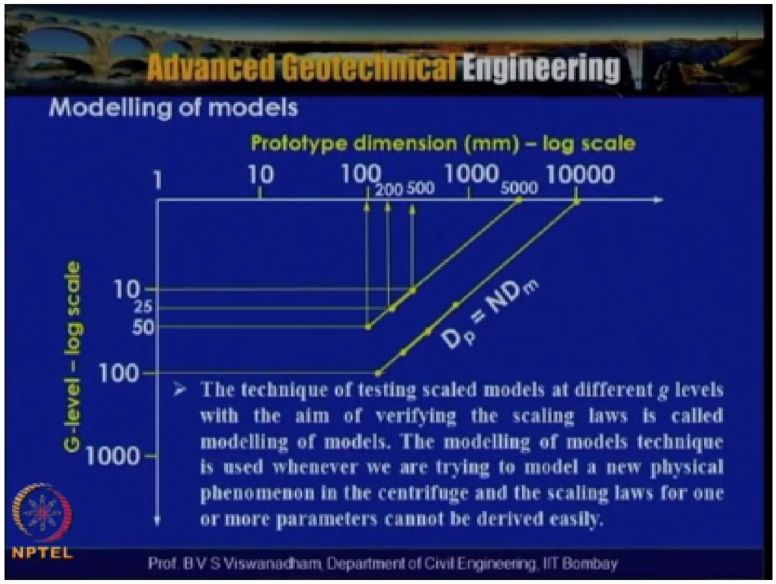

So in this particular slide the schematic representation of the figure which is actually used for you know explaining the modeling of models is given again so here on the x axis we have the prototype dimension so this can be it can be a footing size or it can be a wall-size or it can be an embankment size so anything in prototype dimensions particularly at 0 = 1 they represent the prototype dimensions in if they are in full scale then here it is on the x axis on the G level so here what we have discussed is that the technique of testing this modeling of models with the different G levels and this is basically done with the aim of verifying this carrying loss you know is called as the modeling of models.

And we also have deduced a number of scaling loss of scaling relationships between different parameters and they require a validity or sure that they follow the scaling laws and that can be done by using the principle of modeling of models so the modeling of models technique is used whenever we are trying to model a new physical phenomenon in this centrifuges and the scaling laws for one or more parameters cannot be derived easily so this is applied when we actually try to derive test a model which is a new phenomenon in the centrifuges and the scaling laws for one or more parameters cannot be derived easily.

So if you are having a prototype of say 10 meter dimensions and we can actually have the you know the model different models at different gravities so that they represent all these models represent a prototype which is actually projected here at 1g similarly when you have you know a particular prototype of 5000 units size then we also have three different models representing the behavior.

So what does it mean is that it means that if you are having the same prototype with same soil tested with identical boundary conditions then the performance of these models which are tested model one model two model three and they are models of this particular prototype they represent the identical behavior has that in the prototype so this is a you know interesting you know option for centrifuge based physical modelers for verifying the scaling laws and also to check the models whether they are free from particle size effects in case of geo ornamental engineering whether they it is free from the characteristic length effect.

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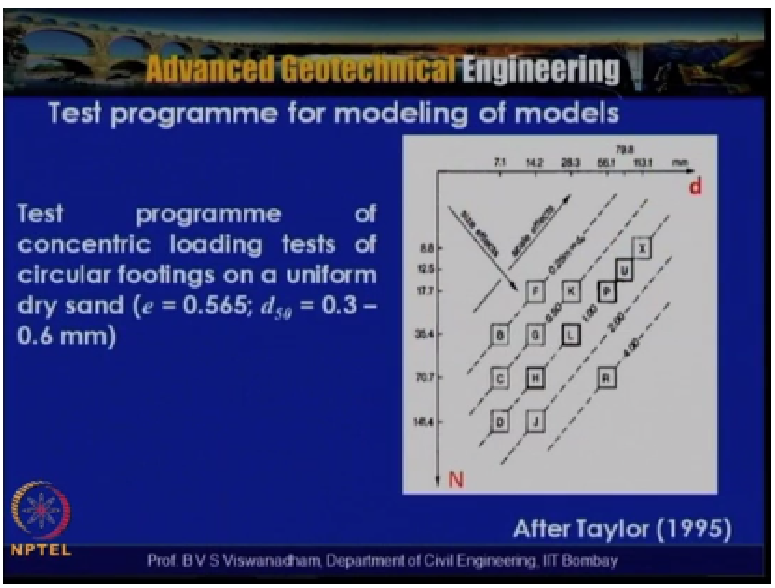

So let us look into the example which is a you know on the test program for modeling of models which was this was originally carried out by this ocean in 1980 this was reported by Taylor 1995 wherein they have tested the test program basically consists of concentric loading of you know sir circular footing tests on the circular footings on a uniform dry sand so here the void ratio more or less is actually has been maintained in all the tests as e = 0.565 and the average particle size is between 0.32.6 mm.

So it can be looking to is what has been done is that the number of you know models have been formulated and basically to see where the size effects are there and where the scale effects are going to be there so in this particular chart here this is a footing dimensions are given on the x axis on logarithmic scale and here also the g level which is actually given on they-axis so this particular you know line indicates that dP = 0.25meter diameter footing and this is 0.5 meter diameter footing and this is 1m diameter footing and 2 m, 4m diameter footing.

Now when you go down from this side then we can see that the footing sizes increases and the stress levels are different and when you go in this direction the footing sizes are same and to present the identical prototype in the field but they actually have you know the different G levels say for example here this particular model tested at 7.1 mm footing diameter is subjected to you know certain g of 35.4 basically to simulate a you know 250 mm diameter of footing.

Similarly here when we take you know the one meter size so this 28.3 mm diameter footing subjected to 35.4 to model you know a one meter diameter circular footing in the field so this particular series of tests which are actually named as series BF and Series C and G and K and DHLNPUX these represent you know 1 meter diameter footings and the test J and then tests R which are actually for 2 meter and 4 meter size footings.

So for say test J in order to model a 2m footing a footing diameter of 14.2 mm was considered but the g level is maintained as 1.1 41.4 so that means that in order to get TP = 2 m what we have to do is that 14.2 mm into 141.4 it yields 2m you know the diameter footing so the results were actually compared for you know the prototype footing having diameter 1m and all tests corresponding to you know 1 m when we see and the normalized load settlement curves for modeling of models are given.

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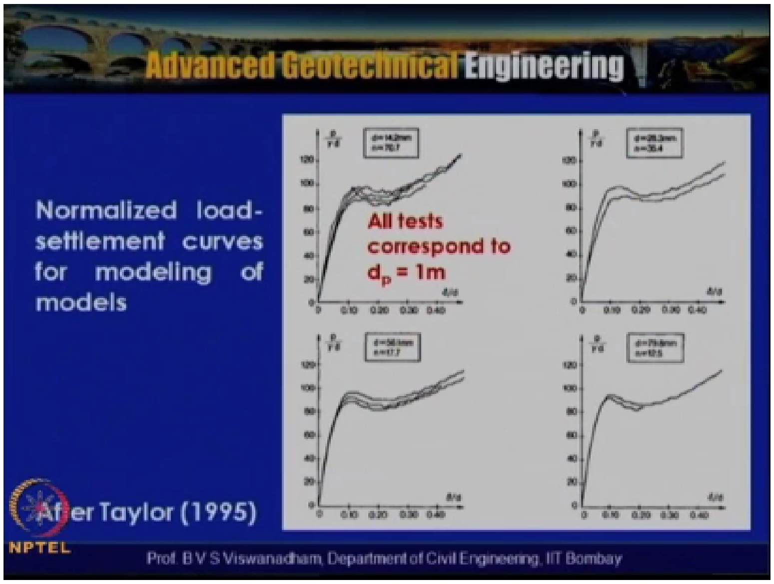

So we know that when we have you know load carrying capacity of a footing found to depend upon several parameters and we said that p / γ D is the you know principle π which actually has to be identical in modern prototype so when we have seen that you know one particular dimensionless π term called DG / D that is you know which is not similar in modern prototype even in centrifugal based physical modeling.

So in the in order to see whether what to what extent these effects will be there so in order to verify that what has been done is that you know this p / γ d are which is actually for so this test data is for diameter of 14.2 mm tested at 72.7 to yield a floating of diameter of 1m size similarly here this is 28.3mm diameter tested at 35.4 to yield a footing of diameter 1 m similarly here 79.5 mm.

And tested at 12.5 to yield a prototype diameter of 1 meter is here also 56mm tested at 17.7 to yield a you know footing of diameter of 1 meter so it can be seen that most of the values which are a number of tests have been carried out and they reproducibility and repeatability of the test was found to be very good and you know at Δ/ d = 0.1 and at p / γd is found to be in the range of 495, 200.
Similarly here also a Δ / = 0.1 0 and with the you know this p / γ d is found to be in the range of 95 200 so these tests indicates that the model actually in the modeling of model holds very good and also for the type of the size of the footing which is actually considered the particle size effects are actually μ1 or you know not it can be said that they are negligible.

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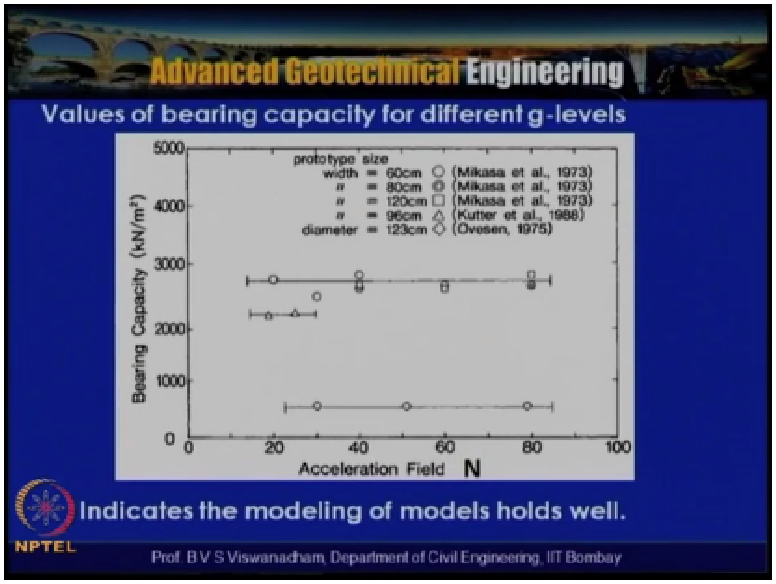

So here what has been done is that the value of the bearing capacities for different g levels were actually plotted and the Overs on 19 75 79 work is actually compared with Mikasa at al.1973 and Kutter at al. 1988 and here it has been found that the x axis has actually has got an acceleration field n and bearing capacity is plotted in kN/m^2 on the y axis so the horizontal horizontality of these lanes which are actually tested by the several investigators this indicates that you know the modeling of the model holds good well.

So and then one more interesting thing we need to do is that it is not that you know all the tests are actually free from you know scale effect.

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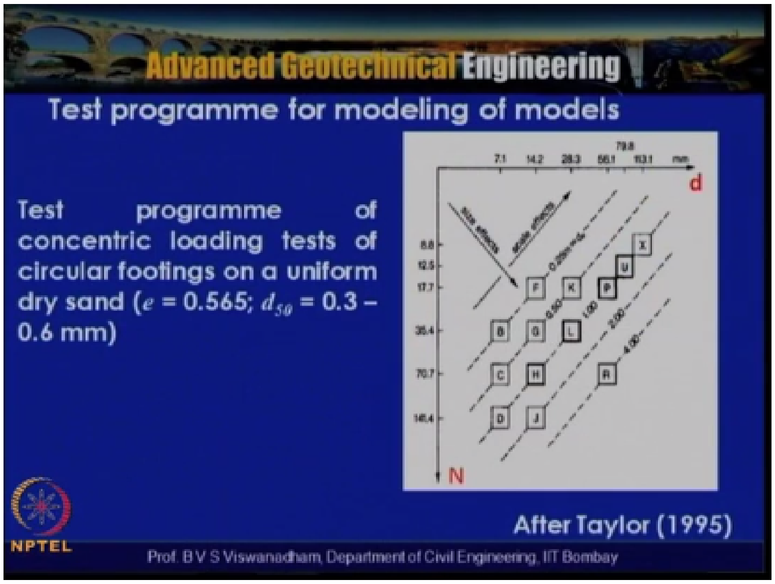

There are some tests for example when you are having you know say 7.1 mm diameter a footing which is almost like the size of a button then you know when you these footing size is actually supported in a given horizontal line with let us say 0.5 mm diameter is the average particle size then you know about 50 number of particles, so in the field when you have say 250 mm diameter you know footing resting on the you know soil in the field same soil the field there are innumerable number of particles are actually going to support the footing.

So that indicates that you know if in order to avoid the size effects in order to avoid the scale effects there is a requirement that you know the footing size that is the d /d50 has to be you know they found that you know as to be in the range of 30 to180 and if this range is actually maintained they said that you know the scale effects you know particularly due to particle size can be eliminated.

So while selecting the dimensions particularly like a footing diameter or tomorrow life somebody is interested in modeling a pile then pile diameter to the you know average particle size need to be understood and if this ratio is found to be having adequately higher number or higher ratio that is a dimension / a dimension of the particular model like pile diameter D or footing diameter D / d 50 has to be adequately large and then you know it implies that you know the symbols the conditions you know similar to that in the field.

So in such situations we can say that the model is actually free from particle size effects so like this and this modeling of models was actually applied for verifying the consolidation laws that means that you know the time of consolidation we said that TM / TP = 1 / n ^{2} so in that situation when we actually model you know the different clay layers of different thicknesses tested at different gravities and representing the you know a certain thickness of the layer in the field then you know the consolidation or time settlement behavior about to be identical.

So this was actually if we are able to get the identical performance with you know identical response then we can say that you know the particular scaling law for example for time of consolidation in model in prototype that is TM /DP = 1/ n ^{2} is found to be validated so and then you know while discussing you know the dynamic scaling considerations we said that you know there will be a conflict between diffusion and dynamic events.

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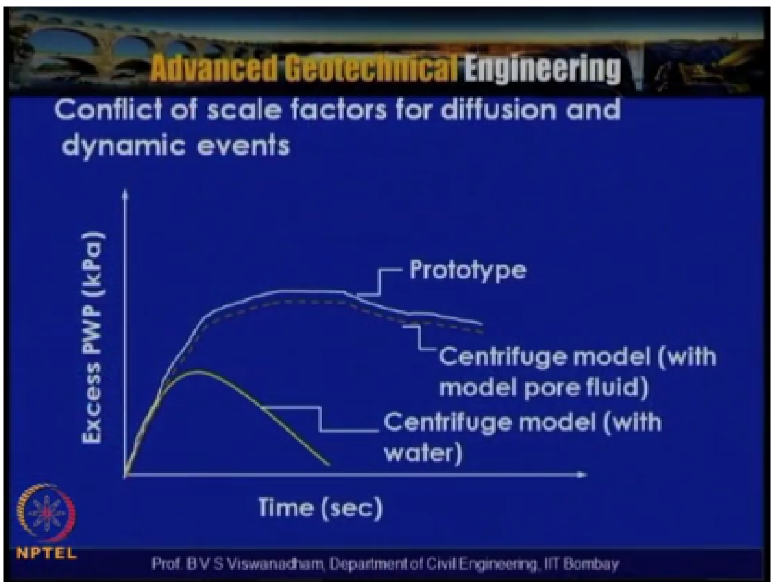

And this is actually arises because the scale factor for the time which is you know for diffusion is you know 1 by n square times faster and that is the time in prototype is 1 by n time in model is 1by n square times in that in prototype so because of this what will happen is that the excess pore water pressure will not generate to the initial set total stress or the total stress at a particular point then what will happen is that there is a you know you know the partial raise of the excess pore water pressure and then a rapid dissipation of pore water pressure takes place.

But in principle in the in the prototype when you actually really monitor this it is difficult to get this data but if you are actually having this excess pore water pressure with time recorded in the prototype when at a location at the onset of say earthquake then it will have like this it will be rise up to a certain level do the target desired total stress then it will be dissipation so you can see that the slope of this line is much flatter than the slope of this line which is actually shown here and here and this indicates that you know this is the you know curve which we may get if you are actually you are having the centrifuge model with the model pore fluid.

So we said that in order to you know avoid the conflict two schools of thoughts were discussed one is to you know reduce the gradation of the particle size the other one is to you know to replace the conventional pore fluid with water fourth grade water with a pore fluid having higher viscosity then we said that you know there are a number of you know different types of poor fluids have been used and but one thing is that you know we have to see that the pore fluid will not actually affect the strength properties.

And also you know will not actually alter the constitutive behavior of the soil and also you know the damping characteristics and secondly is that you know we also have to see that how these are this is a you know very rated R is required so in this case you know what we do is that we will have a detailed discussion about a particular pore fluid and then we will try to verify the requirement of this thing so from theory point of view what we said is that you know this is required and this actually stimulates the situation of you know the what exists in the field.

So once again you know the quality of qualities of an ideal substitute poor field one is that the density has to be close to that of water.

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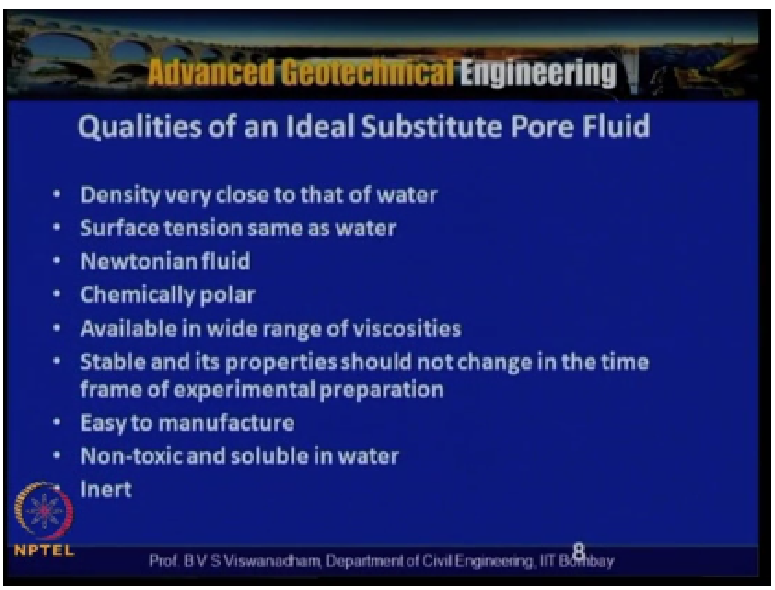

And this is very much required because to have identical effective stresses you know as that in the prototype suppose if you are actually selecting a you know pore fluid which is actually heavier than water then you know for example like chloride solution if we take then you know we cannot we cannot actually simulate you know this you know identical T in the effective stresses and the surface tension will be same as that in water and it should be Newtonian fluid.

So were you know the and then also it should be chemically polar and available in the you should be available in the wide range of viscosity and the viscosity should not change with the age of the you know the preparation of this solution and it should be stable and it should properly should not change in time from the from the experimental from the time frame of experimental pressure and easy to manufacturer and non-toxic and soluble in water and should be in it so these are the you know the you know qualities of an ideal substitute pore fluid.

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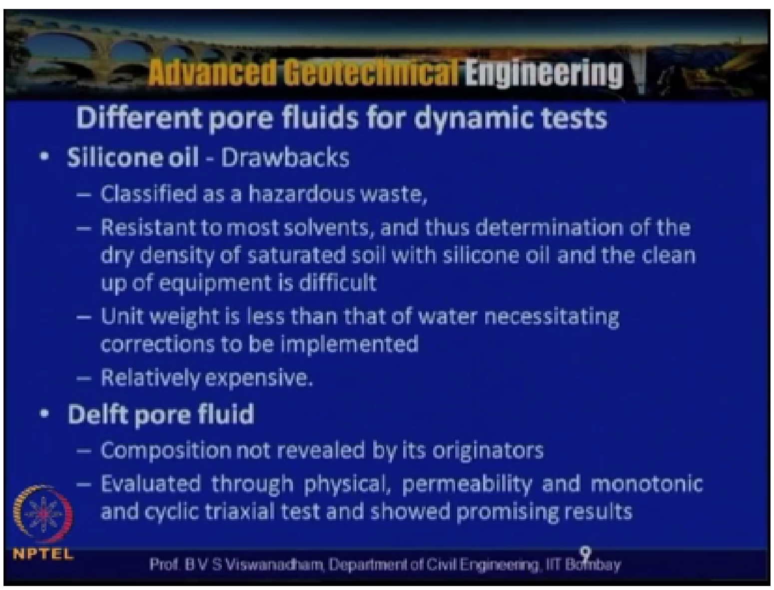

Then number of for fluids actually have been in a you know the first one to be used is that silicone oil and classified has hazardous waste and resistant to most solvents and does determination of the dry density of saturated soil with silicone oil and the clean cleaning up of the equipment is difficult and unit weight is less than that of water necessitating the corrections to be implemented and relatively expensive and in the some laboratories they actually have you know their own trademark poor fluids.

And for that one example is that technical university delft the nether lands the composition not known but evaluated through physical permeability and monotonic and cyclic tri-axial test and said that you know the delft pore fluid fulfills the required qualities of an ideal poor Fluid then glycerin and water mixtures which were actually also used non-toxic and easily mixable with water in any concentration so different combinations of glycerin and water were actually tried.

And this is also one of some investigators have actually used so in the recent past methyl cellulose which is a methyl ether and which is biodegradable and relatively easy to clean up and available in the wide range of viscosities and unit weight of the solution will be identical to that of pure water and the components are inexpensive readily and available and not subjected to any proprietary products so this methyl ether are a metal which is popularly called as is you know the food pore fluid which is off discussion.

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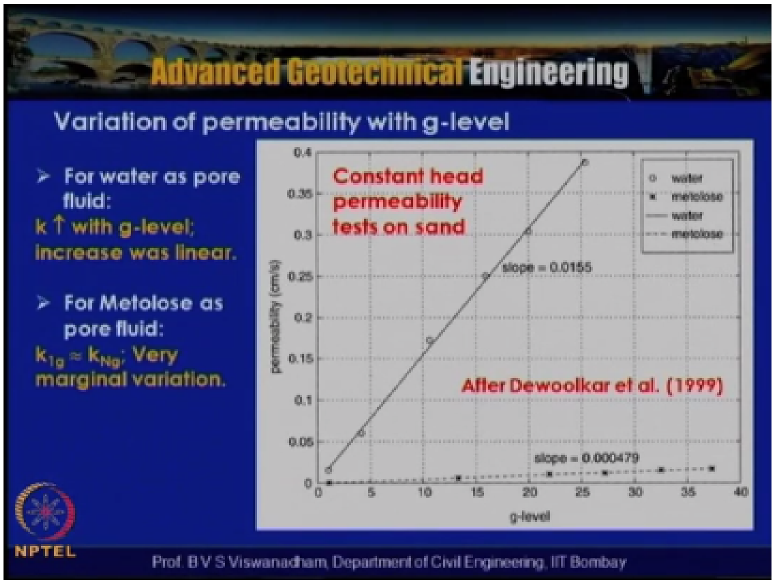

So we also said that you know particularly when we have you know replaced the model pore fluid we have that is conventional pore fluid with a model for frame having a viscosity then you know we actually have said that the permeability will remain the same that is km = KP and when km = KP with then vm = VP and with that what will happen is that you have got time in model prototype TM / TP =1 / n that means that we have slowed down the diffusion event by replacing conventional pore fluid with a pore fluid having higher viscosity.

So if you are actually scaling down model by say 50 times then we need to replace the pore fluid that is conventional pore fluid with a pore fluid having you know viscosity of 50 centistokes because water at a standard temperature it actually has got one sent a stroke you know the kinematic viscosity. So if you look into this year the constant head permeability test given by presented by Dewoolkar et al, 1999 on sand which are actually conducted.

And then it says that you know for example water as the pore fluid when it was actually taken then the as the g level increases either because of you know either because of the IM=nIP or because of kb=nKP which we have discussed earlier what actually happens is that with increasing g level the permeability increases. So for water has pore fluid k increases with g level and increase was found to be all more linear. And if you are looking for a metal arrows as a pore fluid then you can see that k1g whatever we have is found to be equivalent to k and g and very marginal variation can be noticed here.

The slope of this line is 0.0155 so if you take the inverse of that you will get as 32 so this is the test which is actually carried out at you know they it should be you know this marginal differences could be due to you know the difference in the differences in the preparations of the sample. So you can see that this is very the slope of this line is 0.00047 and this is 0.0155 so it can be seen that you know by replacing you know the conventional pore fluid with a model pore fluid having higher viscosity that is particularly here metolose has been tried.

Then you know the permeability value which is coefficient of permeability was found to be you know marginal xa having marginal variation.

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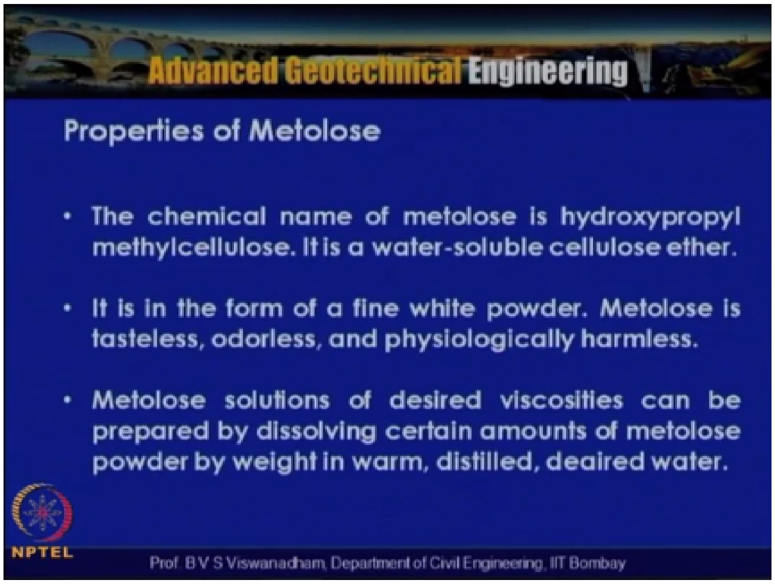

So the properties of metolose in particular the chemical name of metolose is hydroxypropyl methylcellulose and it is a volume it is a water-soluble cellulose ether, and it is in the form of fine white powder and metallosis tasteless odorless and it is also homeless. And metalloid solutions of desired viscosities can be prepared by dissolving certain amounts of metolose powder by weight in warm distilled and deaired water.

So generally what is done is that you know the metolose with higher concentration is actually prepaid like for example 500 centistokes of metolose and then you know suppose if you wanted at a concentration of say with the viscosity of 50 cent stokes then it will be diluted by mixing warm distilled and deaired water. So, metal solutions of desired viscosities can be prepared by dissolving certain amounts of metals powder by with by weight in warm distant and deaired water.

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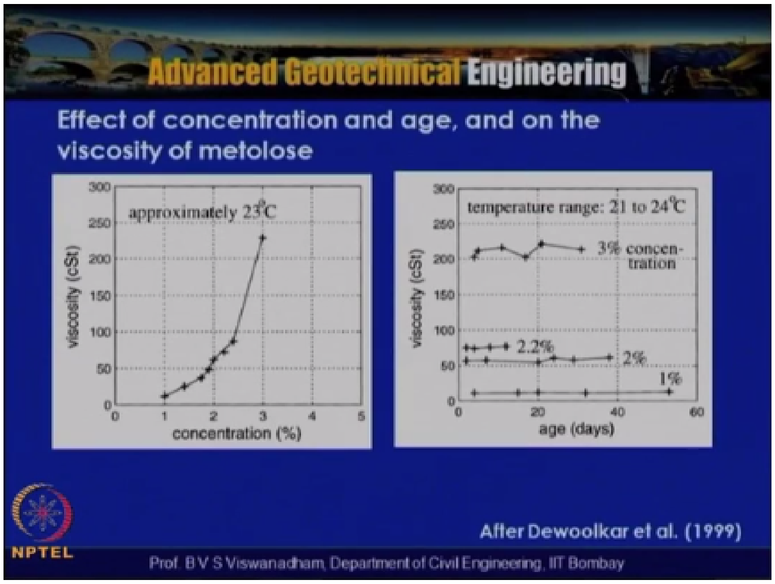

So here in this particular chart effect of concentration age on the viscosity of metolose is shown here. So if you see here you know viscosity which is actually measured by using visco meter and the concentration that is 1%, 2%, 3% so you can see that with increase in concentration there is an increase in the viscosity. Of course it is not linear but is found to have a certain variation. but as can be seen here viscosity when it is actually plotted with the age in days for 1% concentration, 2%, 2.2%and 3% concentration.

At 2% concentration itself you know the most of the you know tests which can be done at 50g can be achieved and here it is about 75 this is about 75 g that is 2.2% and 2 and 3% concentration yields very high in a viscosity like 200 g. So most of the dynamic centrifuge model tests are carried out between 50 and you know 75 so it seems that 2 to 2% concentration is sufficient and another thing is that the marginal variation of viscosity indicates that it can be stable and will not actually alter its viscosity properties with the time.

And when we are actually having the ambient temperature of 21 to 24˚C whereas in you know the beam centrifuges which are actually there in the world so what will happen is that because of you know the cooling systems and because of the ventilation which are actually provide the temperature will remain in ambient conditions when the you know the test is in progress.

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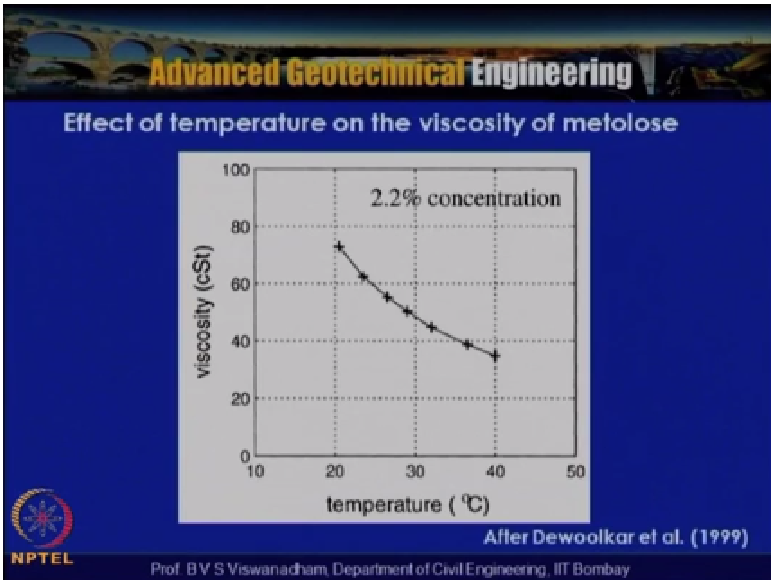

And here the effect of temperature on the viscosity of the model metolose so here it is says that with an increase in temperature definitely there is a decrease in the viscosity this is for 2.2% concentration which is shown here and it implies that you know if the temperature increased to 40 that is that there is you know a fall by about 30, 40%. However as said earlier when we are actually having the you know suitable ventilation systems in the beam certifies equipments in the world this particular you know factor is not every because the ambient temperatures will be maintained.

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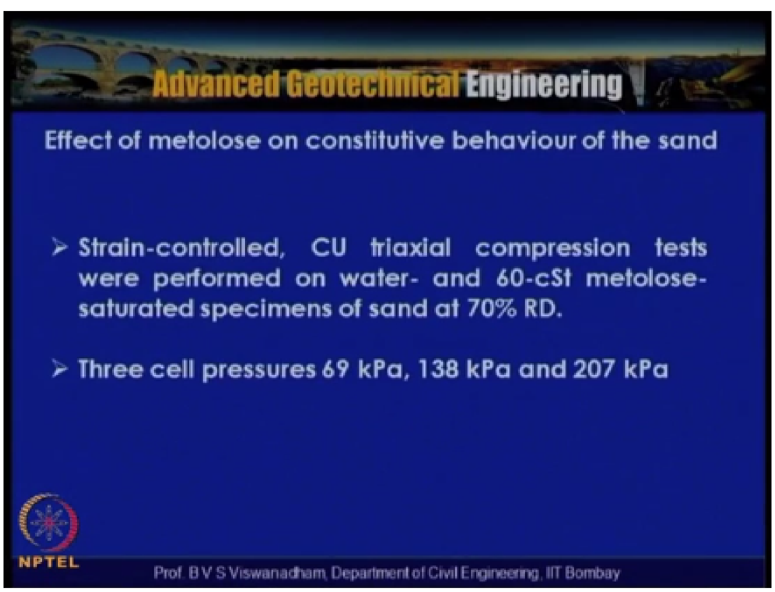

So the effect of the metolose on the constitute behavior of the sand was actually investigated and then strain controlled see you try axial compression tests were carried out on water and 60 cSt metolose saturated specimens of sand at placed at 70% into density the fine sand placed at 70% radio density and three cell pressures of 69kPa, 138 kPa and 207 kPa were actually maintained.

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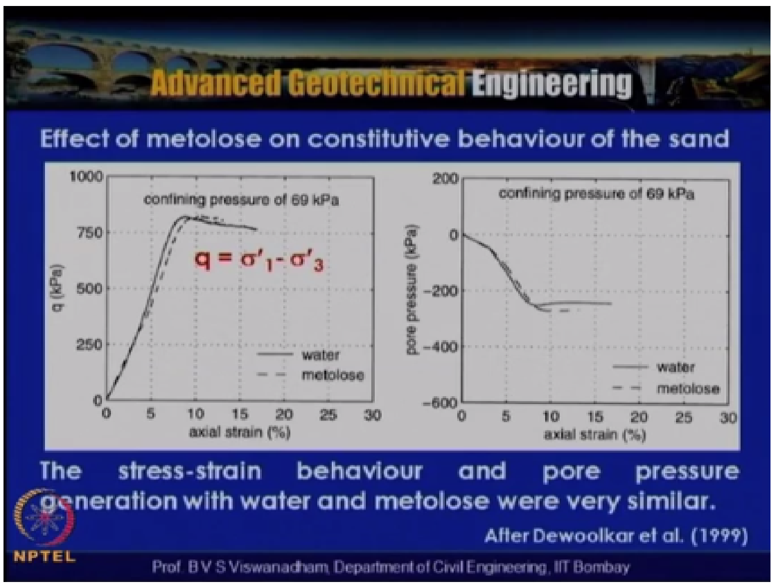

Then here when it is actually plotted with q which is nothing but deviator stress $\sigma1' - \sigma3'$ with the axial strain with this particular curve indicates the water as the pore fluid and this is the 60cSt stroke metolose you know pore fluid. And then here the pore water pressure generation is also shown here for a confining pressure of 69kPa this is a confining pressure of 69lPa. So it indicates that the stress-strain behavior and pore water pressure generation with water and metolose were very, very similar.

So one thing the stress-strain behavior and pore water pressure generations with the water and metolose were very similar, and secondly when we plot the q versus p′ and q is the thing but $\sigma1' - \sigma3'$ and p is nothing but $\sigma1' + 2\sigma3'/3$ then if you look for you know 69kPa and 207kPa with an increase in the confining pressure the agreement is found to be you know in good order.

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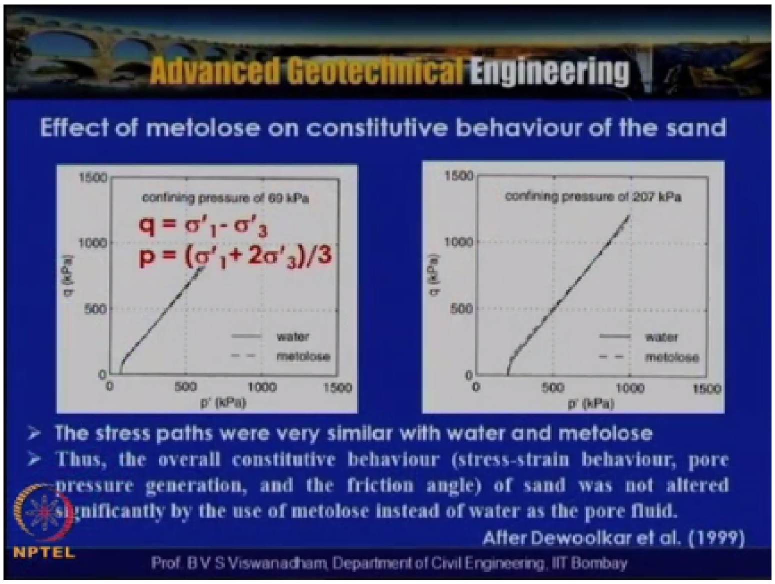

But what it actually indicates that the results indicates that the stress spots are very similar with water and clothes and found to be better with higher confining pressures and thus overall the constitutive behavior that is including the stress-strain behavior pore water pressure generation and the friction angle of sand was not altered significantly by use of the metolose instead of water as the pore fluid.

So if you know a particular new pore fluid is actually being tried then there is a need to verify you know the properties particularly the constitutive behavior of the geometry which is being under consideration and how it is actually you know the considered pore fluid how it is affecting need to be investigated. So from this the example what actually has been given by Doweelker et al, 1999 it says that the stress spots were very similar with the water and metolose pore fluid and the moral constitutive behavior of sand was not altered significantly by the use of metolose instead of water as the pore fluid.

And the further this was actually verified in a centrifuge by using a split container and the splits container actually has got two compartments.

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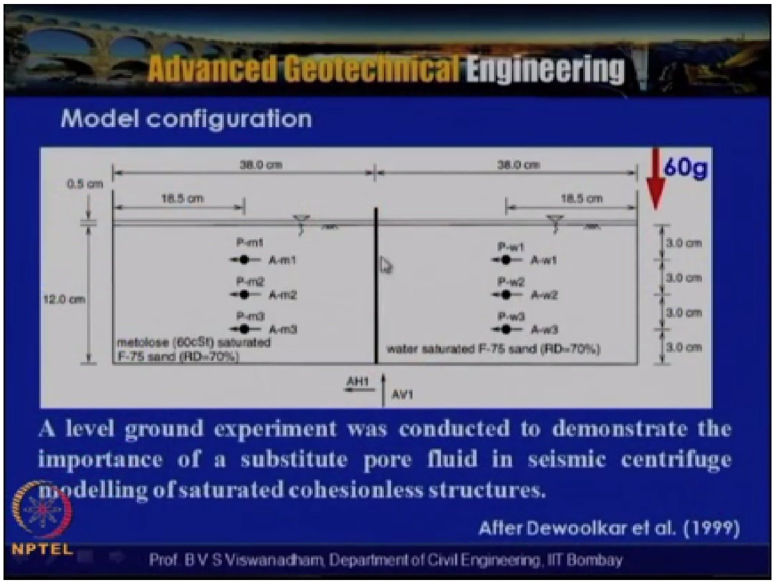

One actually has metolose the pore fluid and other one actually has got water pore fluid and it is separated by a you know a leak-proof separation and these are the horizontal accelerometer in horizontal direction vertical axis accelerometer in vertical direction and these are the accelerometers in horizontal direction and these are the accelerometers in water as the pore fluid these are the accelerometers with you know metolose as the pore fluid and these are the accelerometers these are the pore water pressure transducers.

So here metals of 60cSt you know kinetic viscosity was considered because the model is at a 60 gravities and the relative density of the type of the sand which was adopted is about 70% and here basically to subject identical ground motions this particular type of you know the split container was actually was used and a level ground experiment was conducted to demonstrate the importance of substitute pore fluid in seismic centrifuge modeling or saturated cohesion less structures.

So here the effect of the pore fluid on the model behavior was actually investigated and in this particular figure.

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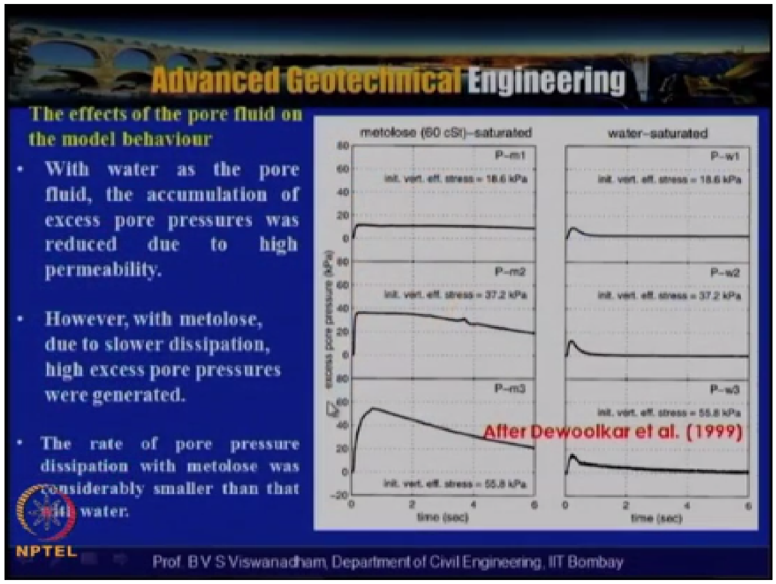

Where this side is the pore water pressure which is actually measured at three different points and this is a Pm1, Pm 2, Pm3 the locations we are shown once again Pm1 which is at the top Pm2 is in the middle of the container and Pm3 is the close to the bottom of the container. Similarly, Pw1, Pw2, Pw3 they are in the water saturated the pore fluid their Pw2 is in the middle of the container Pw1, Pw3 are the top and bottom of the container.

So when they can be seen that this is the initial vertical effective stress is 18.6kPa so you can see that the pore water pressure is actually raising up to that level and you can see here also that you know you have got you know 37.2kPa and the pore water pressure also rising up to this level and this is with the metolose as they pore fluid but the similar for the similar ground motion the pore water pressure measured by using Pw1, Pw2, Pw3are potted and shown here.

And here it can seem that the race was actually very small and dissipation is actually very, very fast so you can see that there is a small raise and the dissipation is fast. so when the water actually has the pore fluid the accumulation of excess pore water pressure was reduced due to high permeability and however with metolose due to slower dissipation higher access provide pressures could be generated and the rate of pore water pressure generation the rate of pore water pressure dissipation with the metolose was considered to be smaller than with water.

So this indicates that you know there were the pore water pressure generations you know the generation as well as the dissipation you know the dissipation particularly was actually slowed down because of the you know the pore fluid which is actually having higher viscosity than that of water. So here the time histories of the acceleration is actually shown here and the accelerometers which is actually placed at the close to the top, middle and bottom shown here.

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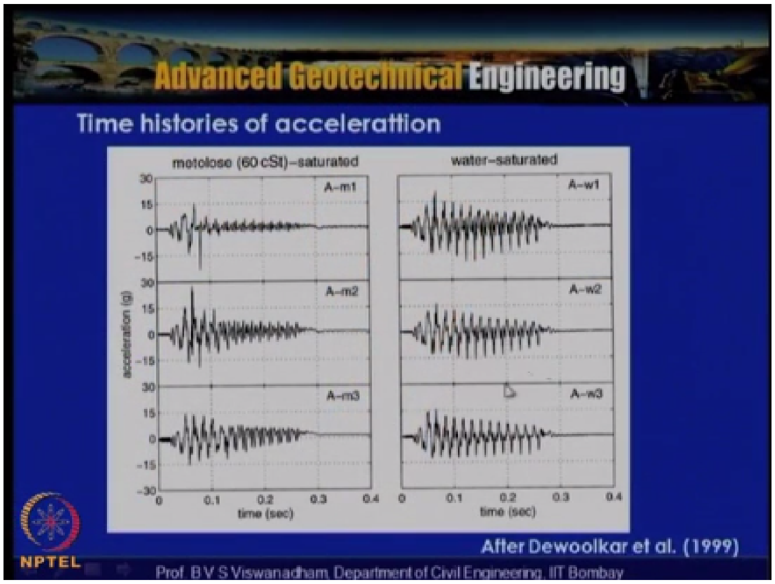

And this is w1, w2, w3 which is in water saturated fluid as shown here they are distinctly different but this is you know the time histories of acceleration which is actually shown.

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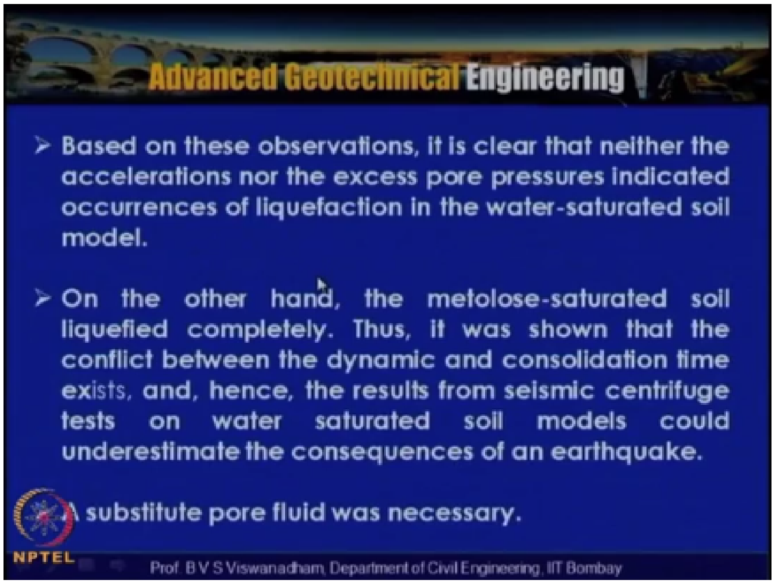

So based on the observations like it is clear that neither the accelerations not the excess pore-water pressures indicated the occurrence of liquefaction in water saturated soil model, because the excess pore water pressure you know as not generated to the level to which actually the liquefaction can be you know attenuated.

But here you know this indicates that if you are actually take a checking a structure which is resting on you know in a certain water saturated model and it is subjected to say tested in a centrifuges then it indicates that you know it may lead to conservative results wherein we actually end up saying that the structure is safe from the liquefaction point of view.

But however in the practice because of you know the difference in you know the pore water pressure generation as well as dissipation there will be you know the settlements and then there will be this lead to you know a different set of results which actually result in the destruction in the structure.

So on the other hand the metolose saturated soil liquefied completely because the pore water pressure raised to the level of that particular stress and thus it was shown that the conflict between the dynamic and you know the diffusion time exists so that there is you know the the conflict exists and this results of the seismic introduced tests and water saturated soil models could underestimate the consequence of an earthquake this is what actually we have been discussing that.

If you are using water as the pore fluid in seismic centrifuge model text then you know the results can indeed to underestimation because of the consequence of an earthquake. So this implies that a substitute pore fluid was actually necessary the substitute pore fluid is necessary for carrying out particularly the seismic centrifuge model tests.

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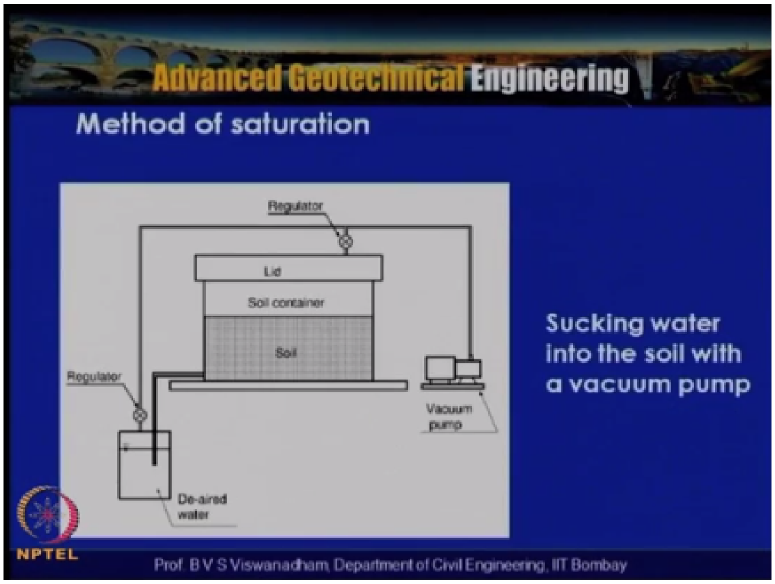

But when we replace you know the water has the pore fluid even to saturate a fine sand a special saturation methods are actually required to be adopted and then they also take long time to for saturate and if we are actually having the layer soil or if you are having clay and silt and you know sand layers you know sometimes is very difficult to saturate with high you know pore fluids, particularly if you are having a sand with the up to say 20. 30% that you know finds there is a possibility that you know the saturation may take longer time and a special methods may be required.

But the general methods which are actually you know adopted schematically shown here one is the sucking water into this soil with a vacuum pump so in this case a model pore fluid you know sucker with the in the help of a vacuum pump to saturate the sample.

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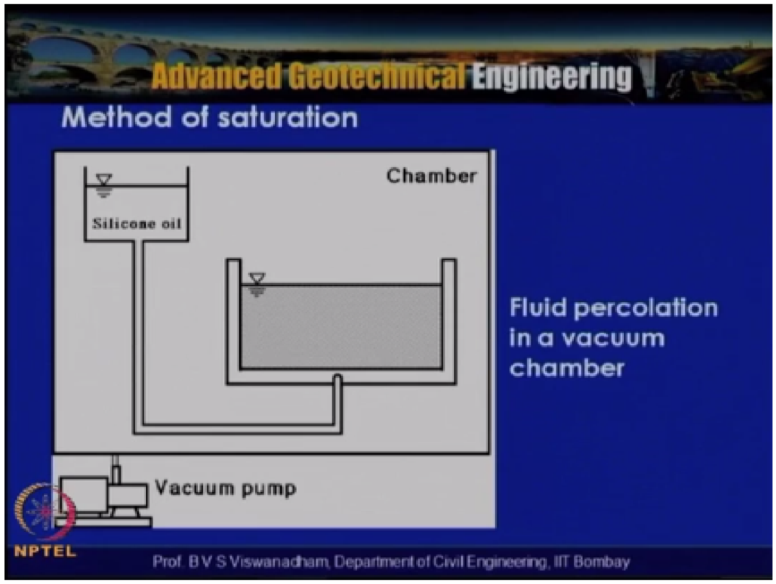

And the second one is that you know in this case a method of saturation with a silicon has actually shown a fluid circulation in a vacuum chamber when actually happens then there is a possibility that you know this can actually get you know the saturation can actually happen.

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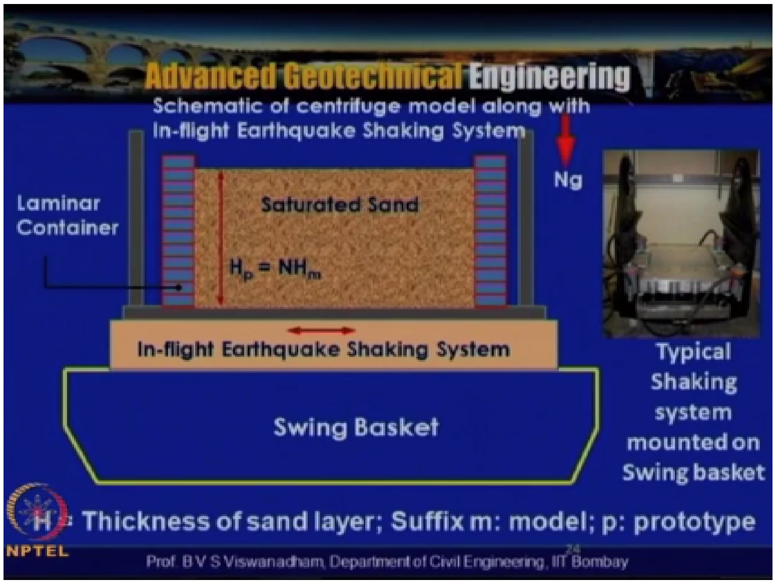

So in order to induce this you know the seismic turbulence to the models the schematic you know the there is a requirement of the in-flight earthquake shaking system so this inflated quake shaking system basically is required to be have high sophistication there because we have said that you know for a model which is reduced with one by times and subjected to n gravities the frequency has to be n times that in the prototype and the duration of the earthquake has to be 1/n times that of the prototype.

So this indicates that you know the in-flight activating system has to be very powerful and should be able to you know use this the earthquake shaking with wide range of frequencies. So in this particular typical saturated sand with an appropriate pore fluid which is actually shown here and the requirement of the one of the other requirements of earthquake shaking system is that the container has to be you know different.

If you are actually using you know it is normal rigid containers so we actually have two types of containers one is for the static tests the other one is for dynamic tests. In case of the dynamic tests with the recent evolution is the laminar containers are actually evolved and these are actually are used and so we are going to discuss about the require by the laminar container is required for the seismic centrifuge experiments.

So here the schematic representation is actually shown here and so this is the basket and this is the you know schematic of a typical shaking system mounted on the swing basket is shown here on this the you know the model which is going to be subjected to shaking is actually place so for large equipments what is actually done is that the shaking will actually happen in this direction that means that if you are having you know in this direction that is perpendicular to the plane of rotation the shaking happens.

So this actually has you know possibility that we can actually have you know large models can be tested in a large centrifuges with an appropriate in flight at way earthquake shaking systems. So here the Hp is nothing but the thickness of the sand layer which is nothing but n times hm if n is say 50g then that it represents about 50 times the NHm of the model which is under consideration.

So please to be noted that this is a laminar container which is actually required and this container is actually fixed here and this depending upon the amplitude model which we are going to do and these are the you know the stoppers wherein you know they actually prevent any detachment of you know the components at the onset of shaking.

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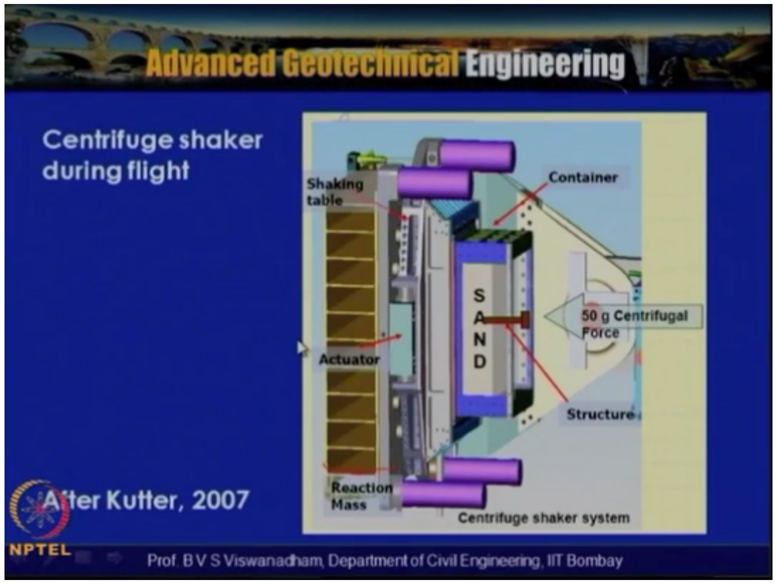

So this is the you know the typical set a few is a shaker during flight when the model is rotating this is this side is the center of the shaft and this is the you know the laminar container and this is the shaking system and these are the accumulators for pumping oil to the actuator and this is the basket so this is actually mounted on the basket were in virtually this is actually shown for a schematically 450 gravities so this implies you know this is a typical the centrifuge shaker during flight.

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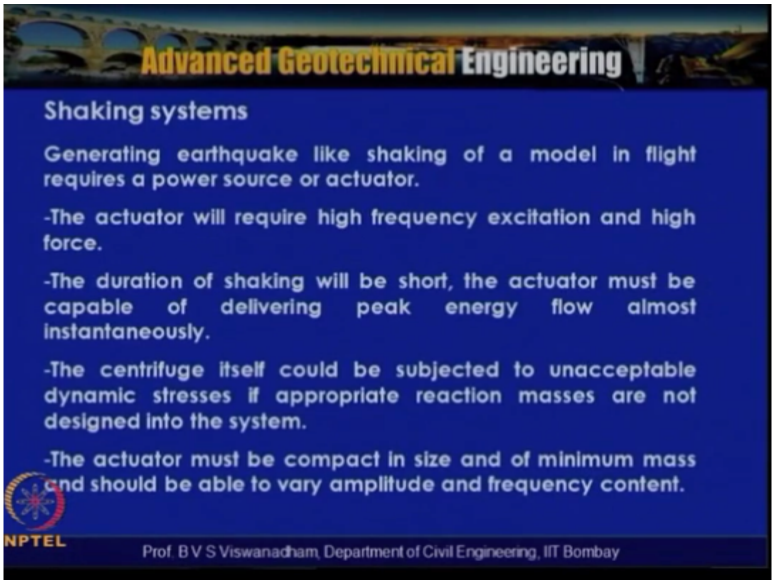

So the first of all let us discuss what are the different shaking systems are required and then we will discuss what are the different you know why a laminar container is required so in order to have you know the earthquake shaking number of ways of by you know have been tried generally the upgrade like shaking your model in the fly it requires a power source or actuator so the actuator requires high frequency excitation and I forces need to be applied and the duration of shaking will be very short.

Because the frequency is intense that in the prototype the duration is short and actuator must be capped with so in this short duration the actuator should be able to deliver peak energy flows almost instantaneously and the center fish itself could be subjected to unacceptable dynamic stresses if appropriate reaction masses are not designed into the system so basically the center piece itself need to be you know safeguarded to prevent any transfer of unacceptable dynamic stresses to the arm and you know the pedestal of the equipment.

The actuator must be compact in size and a minimum mass and should be able to very, very issued we should be able to vary amplitude and frequencies contents say for example we are having a you know amplitudes of about let us say .5 to 1 meter then we will actually model that let us say 500mm something like 10 mm amplitude so the frequency content let us say that the normal range of frequency which are actually possible in the in the field or about one heads to say five heads five head means very high frequency.

Let us say that if we are having a quake of frequency of say one heads or one cycle per second so based on this carrying loss if it indicates that if you are actually modeling at 50 G then the frequency has to be you know 50 hits and it is subjected to say 10 cycles or 50heads are 20 cycles of 50 heads so you know that you know the sinusoidal motion has to be triggered by a suitable shaking system.

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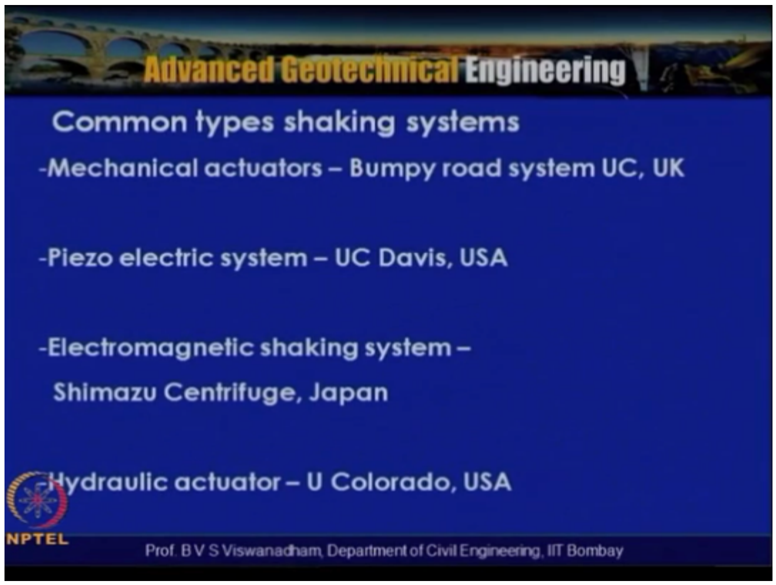

So there are the different types of common shaking systems one of the traditional and world which is now replaced by University of Cambridge that is called mechanical actuators and which was developed by using a simple concept and piezoelectric system which is UC Davis in USA and electromagnetic system shaking system in shiraz centrifuge in Japan and hydraulic actuator in university of Colorado USA.

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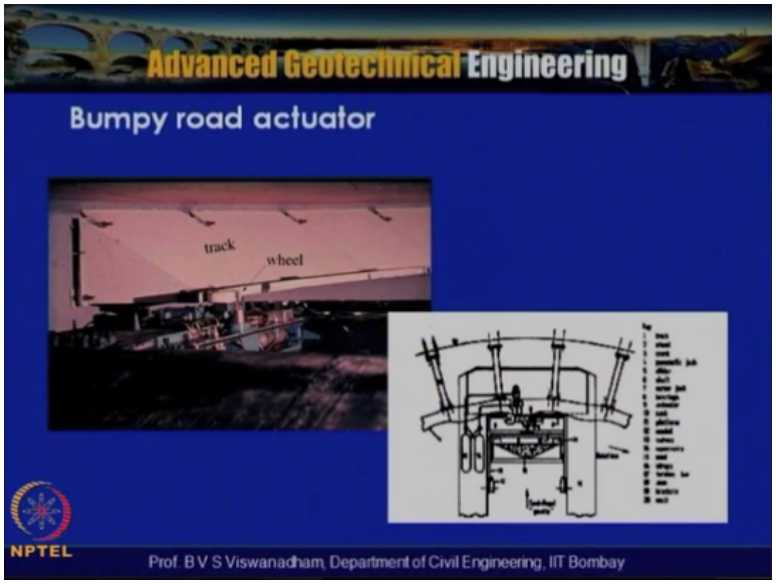

So this is a you know bump in road indicator system wherein the bumpy road in the actuator was actually used so what has been done is that the profile actually has been preset on the periphery of the center fuse and the landing you know is activated and it you know moves along the set profile which is their which is shown here which is sure here in the on the picture onto the you know the center fuse amber vertical wall and the earlier traditionally this was actually used to study the earthquake motions in the, in the university of Cambridge center fuse.

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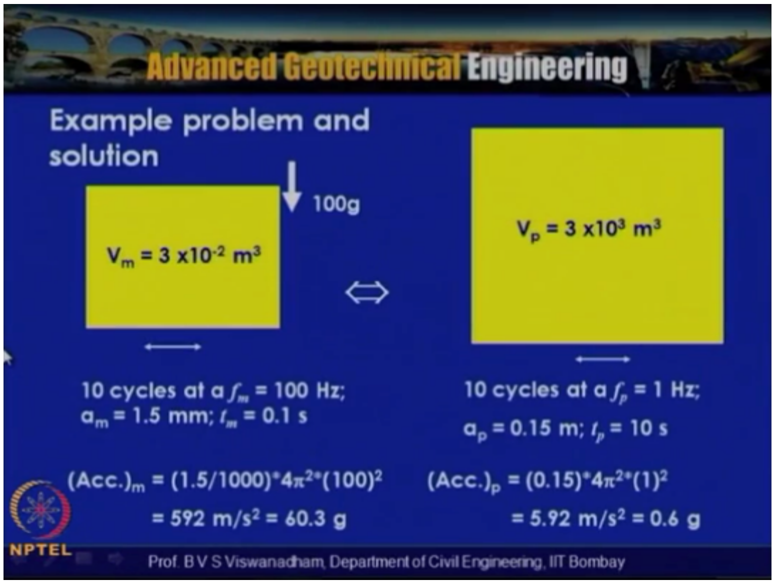

But nowadays this has been replaced with a very powerful actuator now before looking into the different, different types of you know requirement of the containers and then shaking systems let us look into the example problem let consider that we have got a small volume which is which is $3*10^{-2m3}$ is subjected to say hundred gravities and the equivalent volume is nothing but $3*10^{-2m3}$ into 100 cube then let us say that this is actually subjected to 10 cycles at a frequency of100 heads and with an amplitude of 1.5mm so the time in model is about point 1seconds that is 10 x 100 is point one second.

Similarly in the equivalent in the prototype is there 10 cycles at frequency of one head so because of the frequency is one heads is actually model at hundred g so the model frequency is100 hits the same motion but it is actually having 100 its frequency here10 cycles at one heights frequency so the acceleration from the you know the directions we have made that is amplitude into for this is the acceleration term in the equation which we have derived where 1.5 x thousand into 4 π^2 200^2.

So with that what will happen this is the frequency with that what it actually says that if I 92 meter per second square it is 60.3 G similarly the acceleration in the prototype is you know you know point 15 that is amplitude into 4 $\pi^{2}*1^{2}$ is 5.92meter square that is 60 so this is 1 g and so this is lateral acceleration is about point of 6 g so if you know the, the unit weight of the soil then by multiplying 592 meter per second square into the mass of the you know the mass which is actually subjected. We can actually calculate the lateral force that is due to the size del weak force due to this mass into the acceleration.

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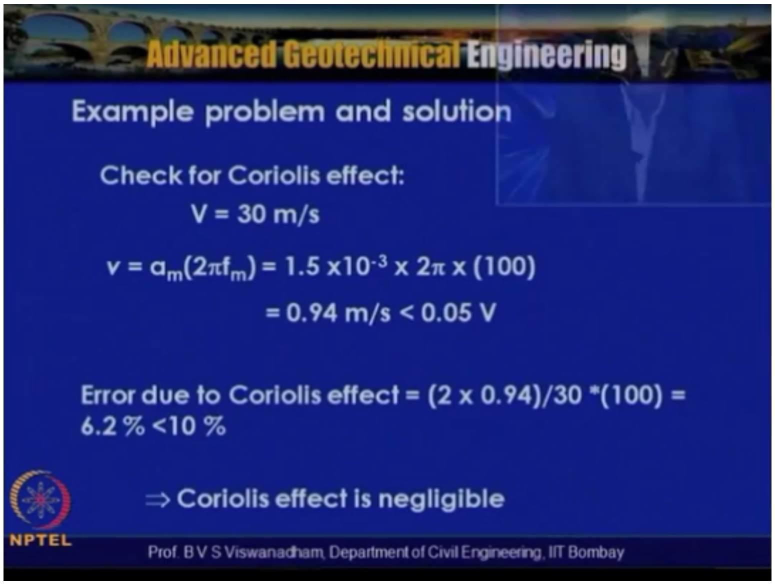

So another thing which what we can try is that we have discussed that if you are having you know the velocity of moving you know particle within the model if it is actually you know let us say that you know say less than 0.05 times the model velocity we said that careless effect can be neglected but if it is in the ratio of 0.05 v-22 v.v said that the Coriolis effect cannot be neglected the models have to be designed to safeguard against a Coriolis effects.

And if the velocity is say more than two times velocity model velocity we said that the correlative because that is very, very fast event example is that you know the you know the throwing of eject due to triggering of a charge so let us check for Coriolis effect for the same dynamic model which you are tested and v is equal to 30 meter per second so with that what we can say we can calculate by u velocity by using velocity magnitude term which is nothing but am is equal to2 pi FM and wherein the amplitude that is 1 .5 $*10^{-3}$m 2 π*100so with that wha twe have got is that .94 meter per second and firstly we let us check whether it is less than 0.05 e so 0.05*30 so about 1.5 meter per second.

So hence this is you know we can say that the for the dynamic model here whatever we have done the error is actually 6.2% which is less than 10% so the dynamic model under consideration where the Coriolis effect is negligible so like this we are actually having any particular model then become out of the Coriolis effect can be you know the presence are can be checked beforehand so this problem what we have done is that we have done a model which is subjected to the shaking and then you know we actually have calculated also whether the Coriolis effect is negligible or what is the error due to Coriolis effect that is actually has been calculated.

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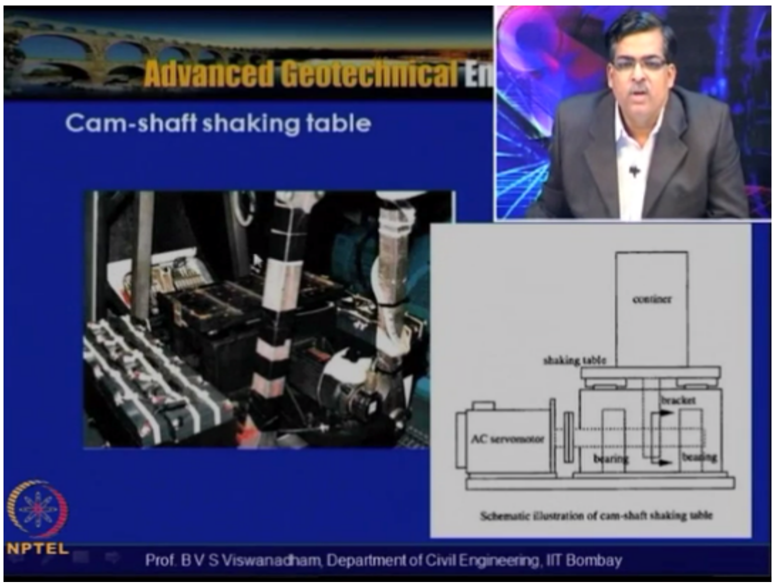

So now let us look into the typical shaking tables which are easily available in different parts of the world and this is a camshaft shaking table which was actually developed for inducing you know the shaking to the models.

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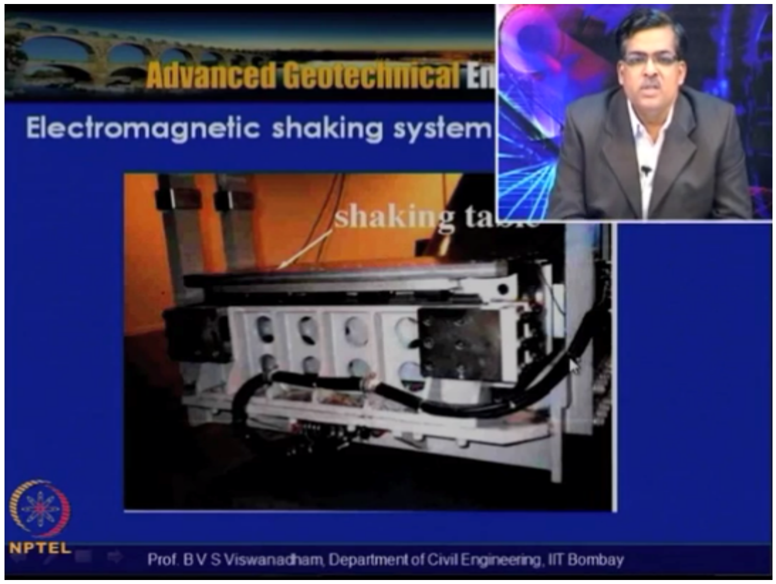

And this is automatic shaking system which is actually you know which Fung works on the principle of you know ac coil and DC coil.

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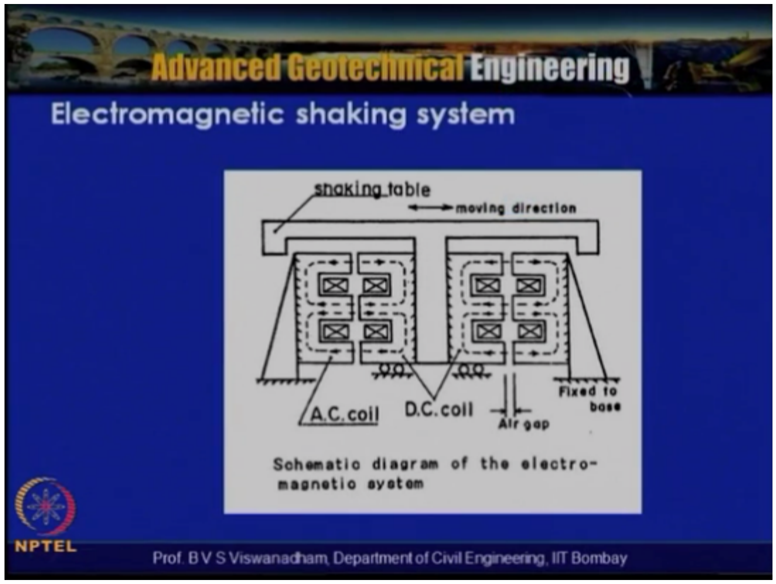

So you can see that this is the you know t-shape put a plate which is fixed here and with the excitation of a sequel and DC coin the shaking table actually is subjected to this is the you know the seismic excitation so but 1d minute of this cell traumatic shaking system is that the system actually, actually is the pay load is very high so that means that you cannot actually take large models subjected to because the electro shaking system it is very the self-weight will be very high.

So because of that you know the payload which can be mounted on the shaking table will be limited and also the you know the broad range of frequencies are also limited this is a another automatic shaking system which was used at shimasu centrifuge in Japan.

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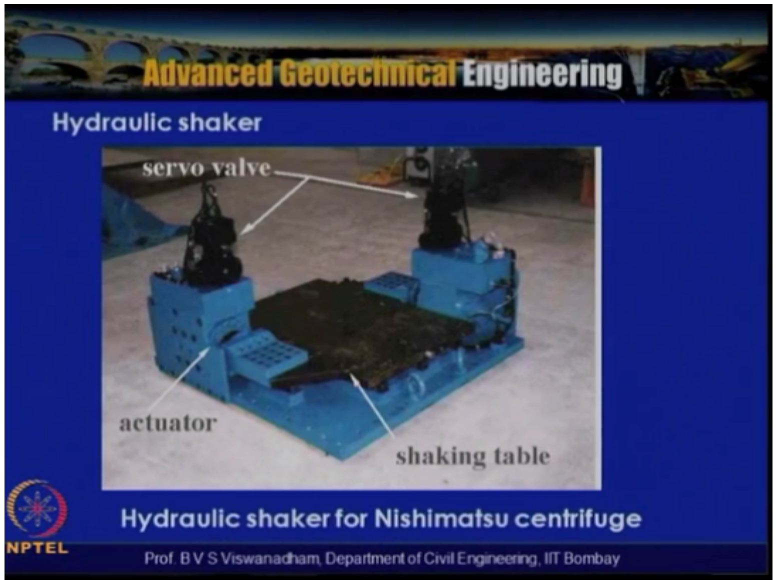

And this is you know typical hydraulic shaking system at Nishimatsu centrifuge where in it has actually has got to server walls and the that is the, the black color one which actually is indicates the shaking table.

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So this is a you know the in-flight shaking table system at Toms University in China where in the this is after Ma et at 2006 where they actually mount the models on this shaking table.

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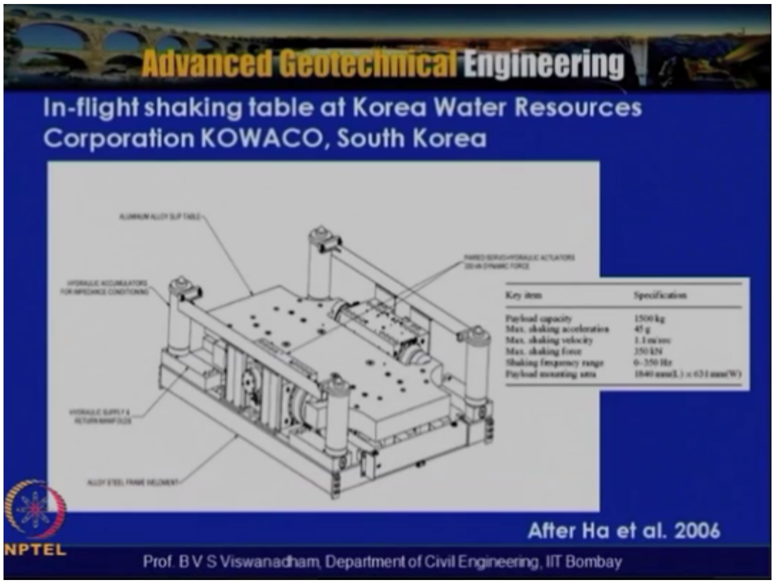

So this is you know in flood shaking table at Korea water resource corporation KOWACO where it actually has the payload of 1.5 tons about 15 kilo Newton and Maxim shaking acceleration is about 45 g and shaking forces about350 kilo Newton's so very high and shaking frequency range is 623 50 heads so it actually has got a wide range of frequency band and so this is a you know a type of shaking table which is actually used in Korea so after having seen the different shaking systems.

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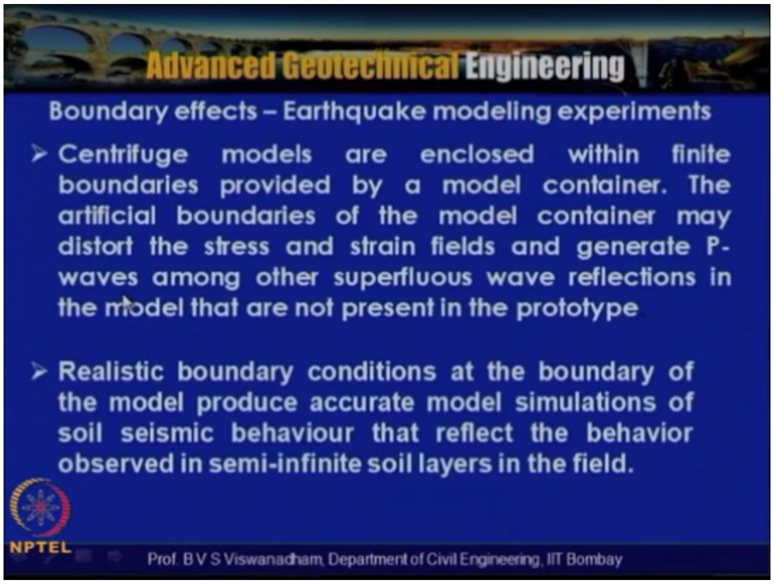

Let us look into the boundary effects particularly when you are actually having earthquake modeling experiment we said that when you are actually having a static container you know that is the container that is rigid container which is used for say, say centrifuge model tests then there can be possibility of multiple reflections of waves at the onset of earthquake motion so the centrifuge models are generally enclosed with the finite boundaries provided by a model container and the artificial boundaries of the model container may distort the stress and strain fields.

And generate P waves among other superfluous wave reflections in the model and that are not present in the prototype so in the prototype you know, you know when the typical typically will not actually have the reflection because of the infinite boundaries but in the model because of the confinement with you know very stiff you know walls in the model container like in the city container there can be you know generations of P waves and also the reflection of the superfluous other superfluous wave reflections.

So the realistic boundary conditions at the boundary of model produce accurate model simulations of soil system behavior basically that reflect the behavior observed in the semi infinite soil layers in the feed so now consider so this is what actually has been discussed when you are actually having in the prototype.

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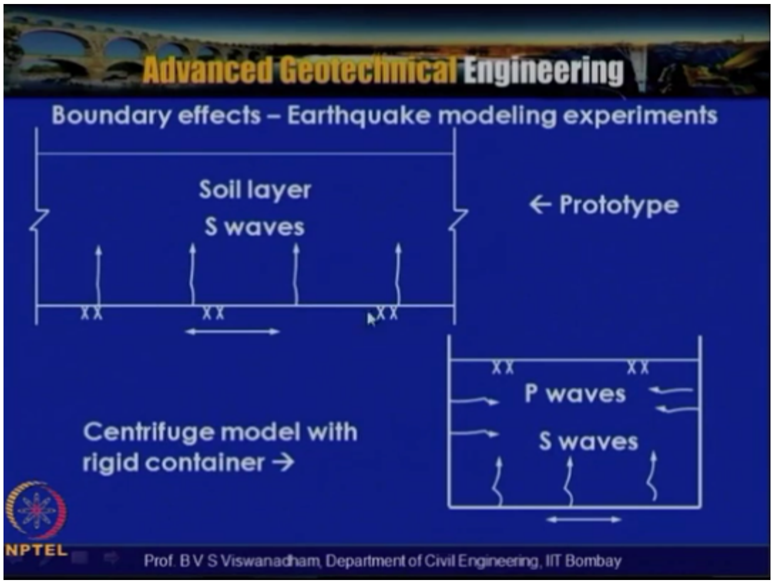

You actually have when it is subjected to say certain ground motion and because of this infinite boundaries there is only the secondary waves are generated but when the centrifuge model with a rigid continue is used because of the seismic excitation there is a you know also the generation of P waves the compression waves and also the other superficial waves which actually cause the multiple reflections so which may affect which is actually going to affect the let us say a particular structure being studied can be a possibility of you know leading to the misinterpretation of results.

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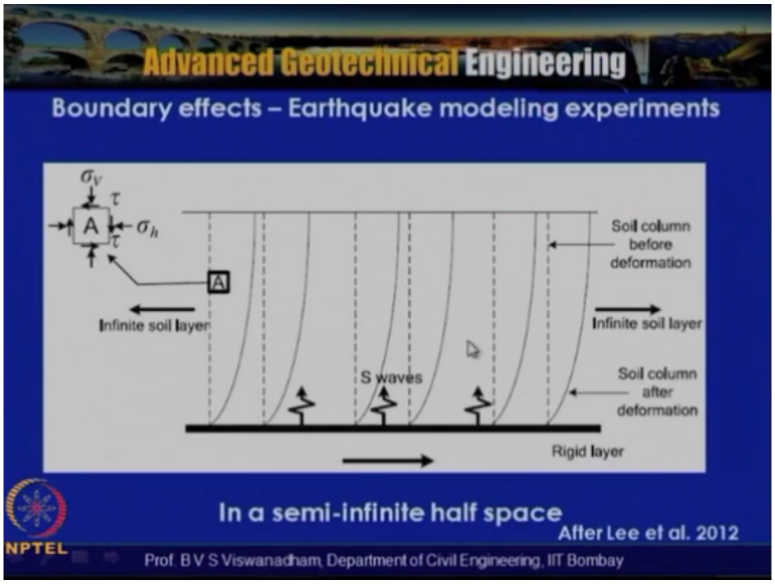

So this is a you know it typically the way how this is there in the prototype so you can say that when it is subjected to a certain type of motion in this direction so there will be a you know deformation in this direction this is the element before deformation this is the element after deformation at the you know you can see that at the center and along the edges you actually have got identical deformations but and then also there is a you know at all points actually the soil stiffness dynamic soil stiffness is identical in you know in this direction.

So and also there exist actually some conjugate shear stresses and the σv this is vertical stress and σh here this is at the element which actually has got the stresses like this σ vertical stress and in original stresses.

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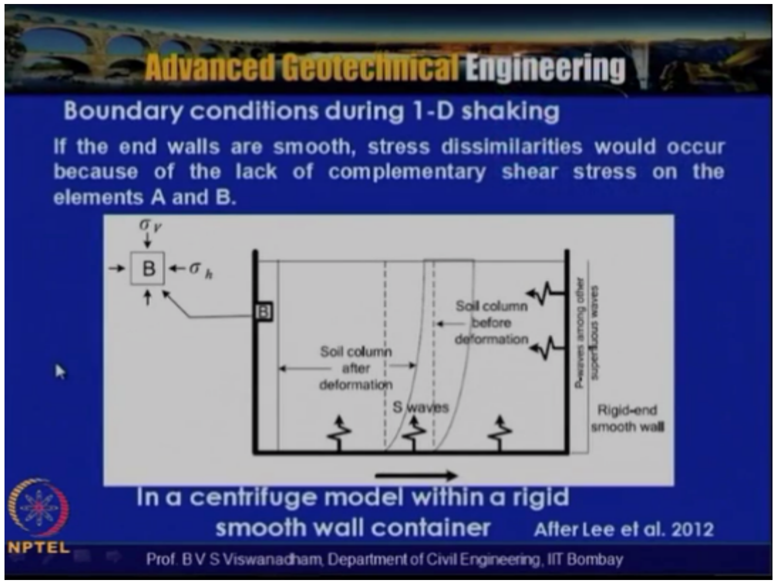

When we are actually having rigid container with a smooth wall so what we have is that the absence of the shear stresses can be noted here and the reflection of you know waves cause you see at the center the deformation may be identical that as that in the in the field but however the edges actually has got when the model is actually you know shaker in this direction subjected to shaking in this direction so the soil column deformation at the edges is actually different.

So this actually can be noted so the deformation see is they are different and also the absence of the conjugate shear stresses are complementary shear stresses so the end walls are smooth and as dissimilarities would occur because of the lack of complementary shear stresses on the elements at a and B so particularly when you are having a rigid container there is a possibility that the rigid container actually having very high stiffness as compared to soil in principle in the prototype the stiffness is actually identical.

So that causes also a problem so this was actually resolved by with the number you know different other options which all right, right like some of the earlier you know containers for like ESP type containers wherein you know the aluminum and rubber alternate you know packing systems are used to induce some flexibility to the side walls of the container but however in the lateral stage the laminar container actually have been developed and this tracking devices originally developed for simple shear tests have been increasingly used to simulate the free boundary conditions in earthquake modeling of soil deposits and this step of container is actually is called as a laminar container.

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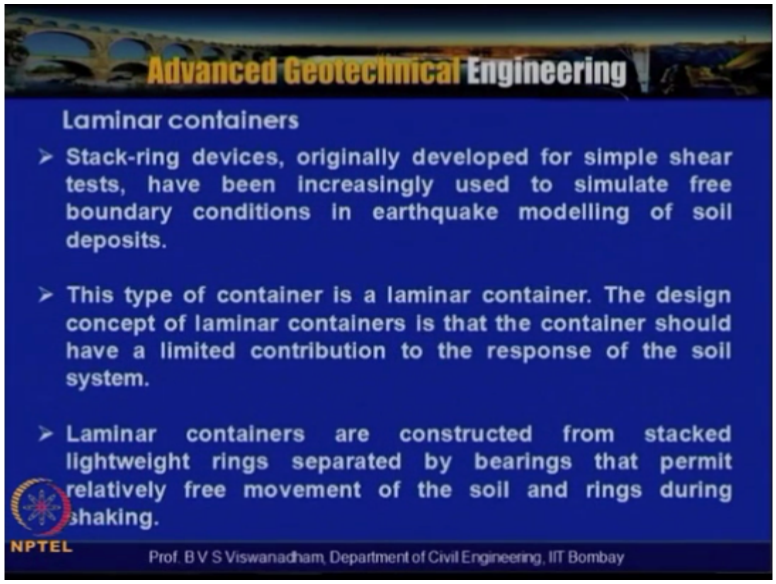

And the design concept of laminar containers is that up is that the container should have a limited contribution to the response of soil system and it should not cause you know the, the reflection of the waves and laminar containers are constructed by stacking light weight rings separated by bearings that perimeter a truly free movement of the soil and the Rings during the shaking and this also this laminar containers are actually found to simulate the actual behavior in the field.

So that it induces the you know the so-called you know the identical deformations at the edges as well as the center.

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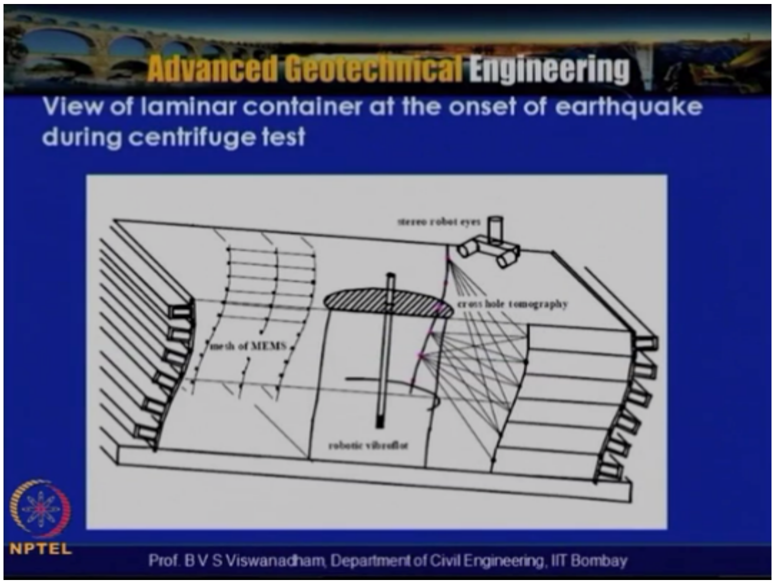

So this is a typical laminar container what you can be seen that when the model is actually subjected to shaking and this is you know a pile which is actually being subjected to some shaking so you can be seen that you know like in the field the deformations are actually identical and then lead to you know the motion which is a log as to that in the field so in this particular lecture.

We try to understand about the, the again the concept of modeling of models and then we also try to see why what is the necessary and how they you know the replacement of the pore fluid can be justified with replacement of conventional waterproof can be justified by using modeling of model segments as well as the, the extra mental evidence which we actually have said that the there is a requirement for dynamics and fluids experiments the replacement of the modeling of the pore fluid is required.

Then finally we have also seen that different types of shaking systems which are actually invoke and then the laminar containers which are actually used for the dynamic equipments so that this actually stimulates the identical, identical behavior of the prototype in the centrifuge models particularly the dynamics centrifuge segments.

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