Geosynthetics and Reinforced Soil Structures
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Lecture - 20
Controlled Yielding to Reduce Lateral Earth Pressures on Rigid Wall

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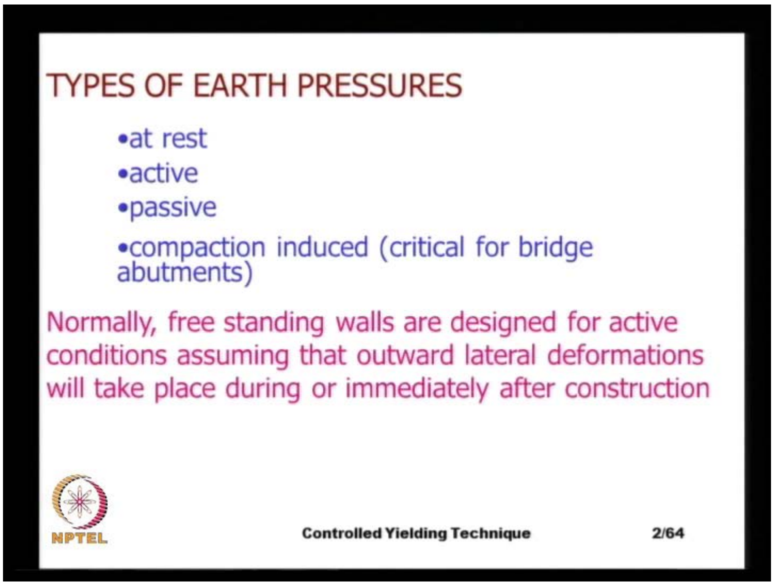

Very good morning students. In this lecture we will look at one of the methods, how we can employ the geo synthetic sphere reducing that pressure. So, just briefly we know that there are different types of earth pressures, the thrust earth pressure, when there is no lateral deformation in the soil, active earth pressures, when the soil moves away from the from the back fill, then passive when we have a compressive type of deformations in the soil. Then of course, apart from all these three classical earth pressures, we have the compaction induced earth pressures, which are particular for different cases especially these compaction induced stresses critical for bridge abutments.

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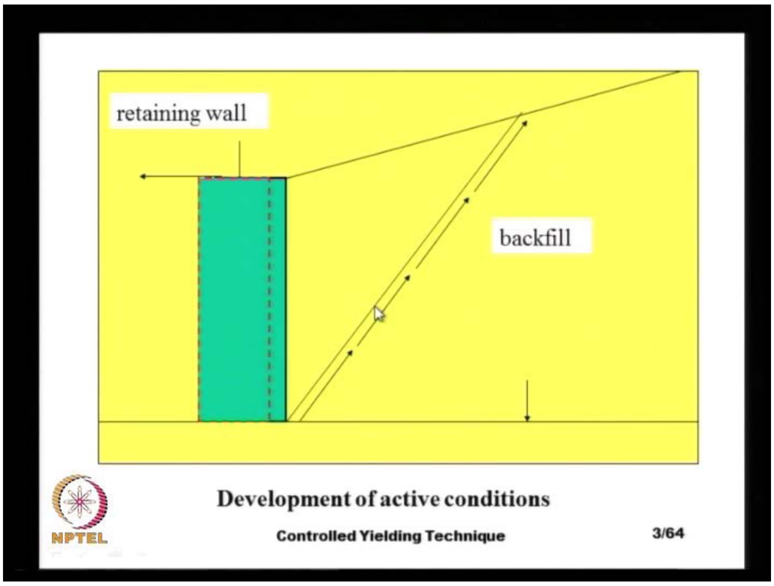

And, this is how the earth pressures are reduced to active earth pressures. Let us say that we have a retaining wall with some backfill, and if it is able to move laterally. Let us say that it has deformed, and it has moved out laterally, and because of this our rankine earth rapture plane develops here along with shear resistance generated on that surface. And because of this shear resistance that is trying to prevent this wedge of soil from moving laterally our forces that are transferred into the retaining wall are reduced, this is the principle of the earth pressure reduction, because the development of active earth pressures.

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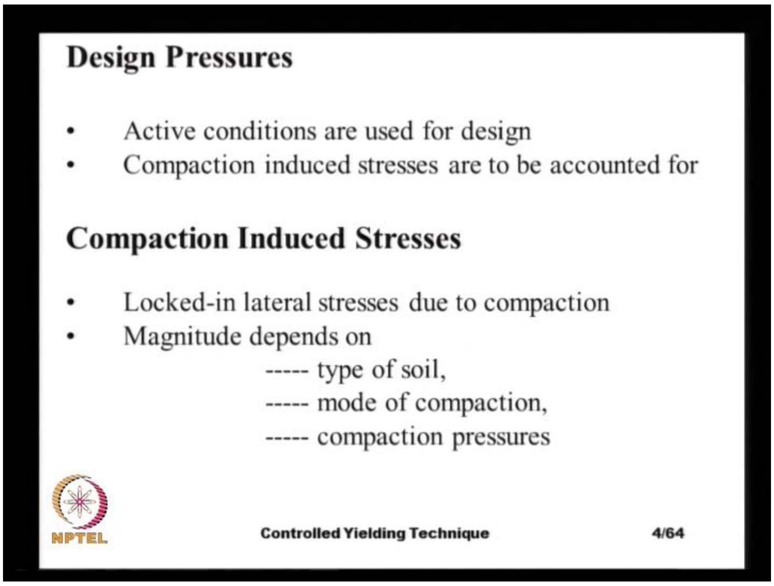

And, for the design purposes we normally use the active earth pressures for most of the free standing retaining walls, because we need only very small amount of deformations of the order of about 0.2 to 0.3 percent of the wall height for achieving active conditions, but then we also have compaction induced stresses, especially against very rigid bridge abutments or basement walls and so on. And, here they locked in lateral stresses because of the compaction could be highly significant especially for some type of soils, and these locked in lateral stresses depend on type of soil that we have, because the soils with higher shear strength like higher friction angle are more sensitive. They have a higher locked in stresses, then the method of compaction whether we are using static rollers or vibro-rollers and so on, then of course, the compaction pressures the energy that we use for compact in the soil also controls the lateral stresses that we generate.

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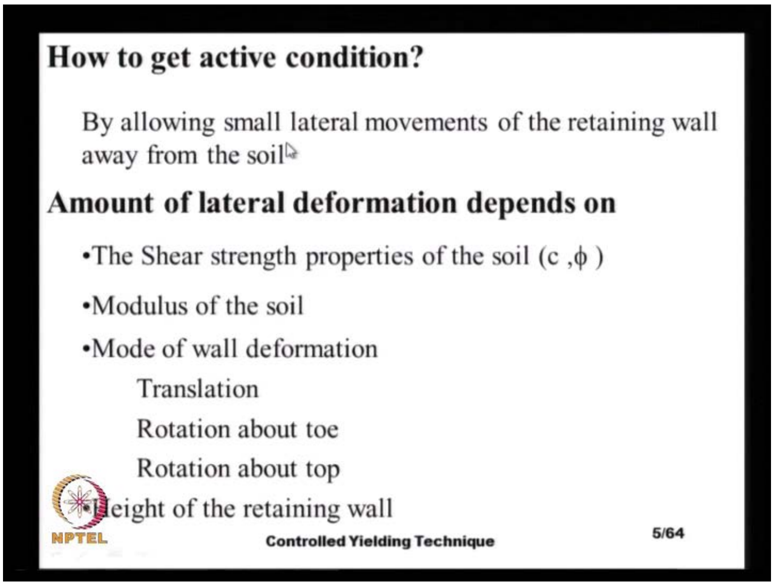

And, how do we achieve the active conditions, we have already seen that the one simple way is allowing lateral deformation of the the retaining wall away from the backfill. And how much of lateral deformation do we require to achieve the active conditions is actually depends on several factors some of them I have listed here, the shear strength properties of the soil. Obviously, the c and phi properties of the soil they control the magnitude of the the pressure that are developed, and then the amount of deformation that we require, then the modulus of the soil.

Because if your soil has very high young's modulus even small deformations will will result in very high stress changes. And then the mode of wall deformation, there are three different identifiable modes of deformation for rigid walls, one is translation; that is the entire wall moves away as a rigid body, rotation about the toe. That is the the retaining wall deforms by rotation about the toe about the bottom point, then rotation about the top this is especially true for very high retaining walls. We assume that the mode of deformation is the top is fixed and then the bottom is moving. And, of course, the amount of deformation also depends on the height of the retaining wall, and the coupled to this we could also say the flexibility of the retaining wall also controls the the deformation that we require.

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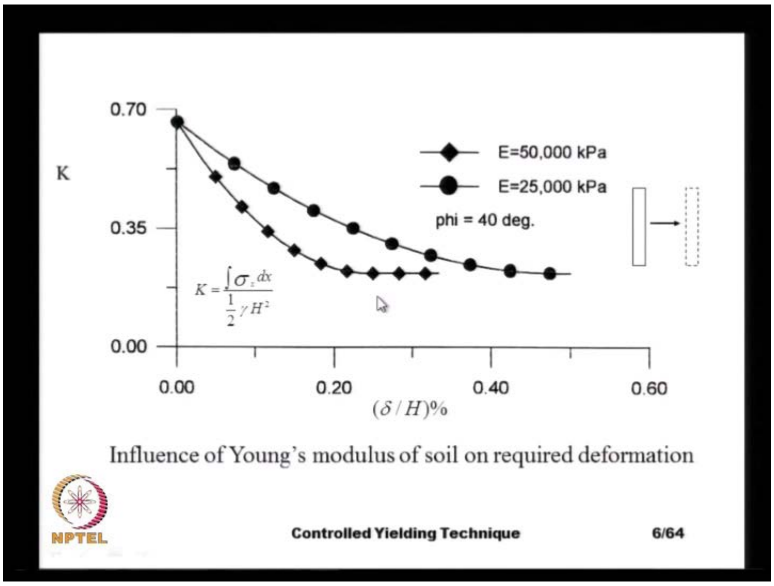

And, just illustrate I am presenting some results from finite element analysis, and how much information do we require, and this particular result is generated for a soil with friction angle of 40 degrees, and c of 0. And for two different soils one with a constant young's modulus of 25000 another with 50000, and we see that the soil with higher modulus it undergoes larger stress changes for the same amount of deformation, and the x axis we have the the percentage of the deformation as a function of the height of the wall. Then, on the y axis we have the lateral earth pressure coefficient that is just simply the the integral of sigma x d x that is the net some of the lateral forces divided by one half gamma h square to define the K.

And, the initial earth pressure constant was fairly high very near to 0.7, and then as the wall is deformed away that pressure comes down to active state, and for 40 degrees its its nearly 0.1 I think nearly 0.19 or something. And, we see that in both the cases the earth pressure comes down at some deformation for soil with young's modulus of 50000. We require about 0.2 percent of the wall deformation, where as for soil with 25000 we may require a wall a wall deformation as much as 0.5 percent of the wall height.

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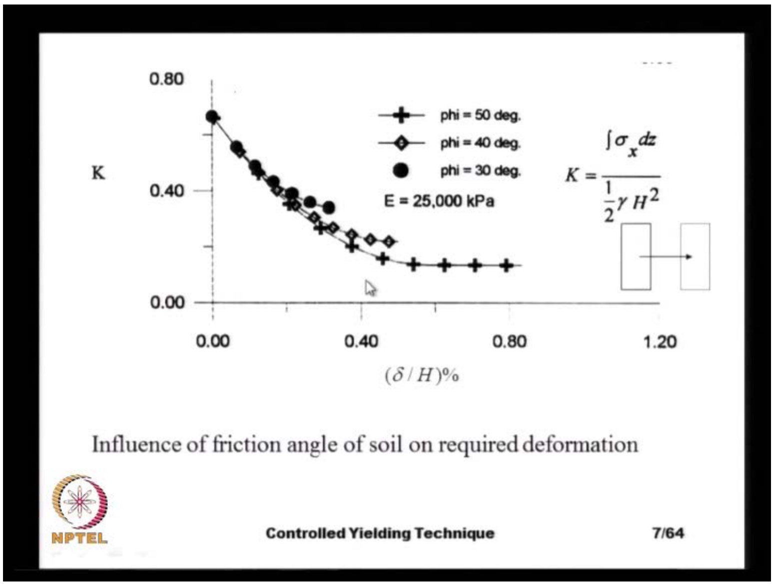

And, this is the data for three different friction angles all with the same young's modulus of 25000. We have the data for 50 degrees, 40 degrees, and 30 degrees. And, we see that the soil with 30 degrees it reaches the active state at at deformation about 0.3 percent of the wall height then the soil with 40 degrees may be at about 0.5 percent wall height, then 50 degrees it requires much larger deformation about 0.6 percent of the of the wall height. So, we see that the amount of deformation that we require depends on the soil property the shear strength then the modulus.

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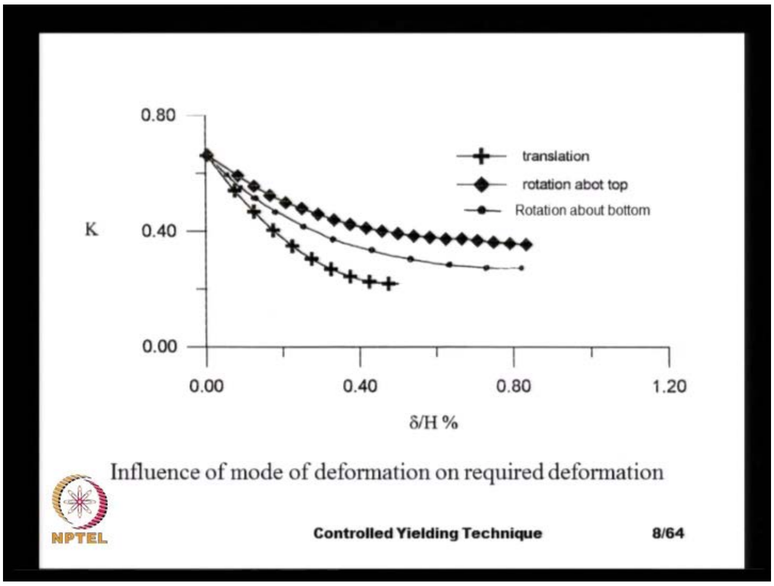

Then, it also depends on the the mode of deformation the usually the translational mode of deformation results in quicker reduction of the pressures, where as the rotation about the bottoms ah Sorry the rotation about the top it requires very large amount of deformation, where as the rotation about the bottom it requires somewhat in intermediate type of deformation. So, the if you want to design a system that will that will allow the soil to deform all to reduce that pressures, we need to somehow design a system that will allow about say about 0.3 percent of the wall height. So that, the earth pressures are reduced. And, now let us look at the rigid walls see in the case of rigid walls there is no possibility for lateral deformation, and because of that we cannot generate active earth pressures the earth pressures are usually very high.

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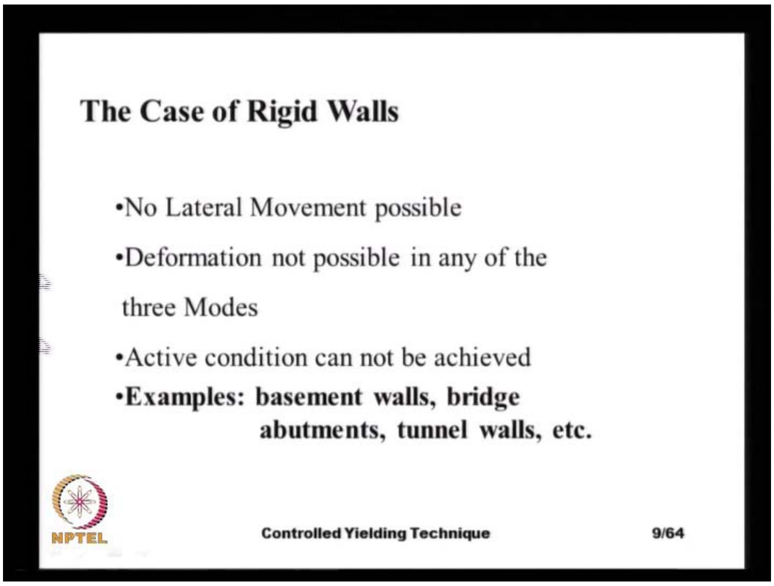

And, some examples of these rigid or the basement walls that we have below the ground level. And then bridge abutments, tunnel walls, and so on.

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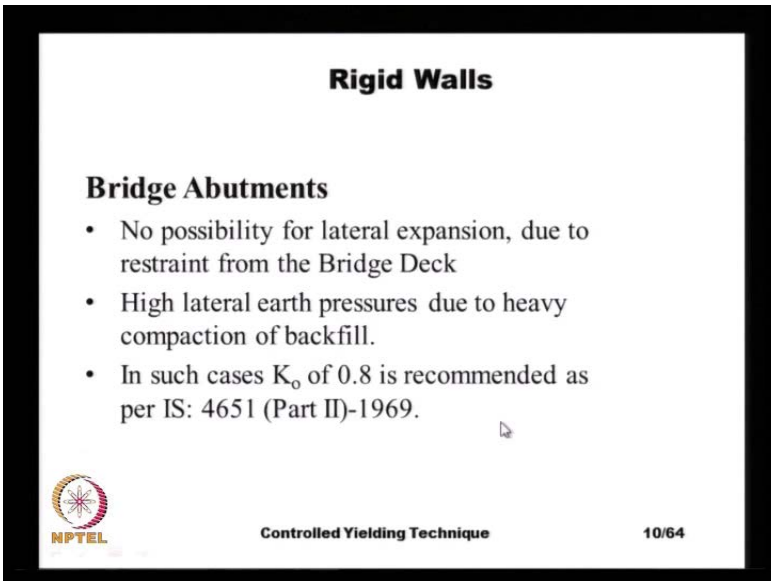

And, in the case of bridge abutment, we usually have very strong foundation at the bottom and at the top the bridge deck prevents the lateral deformation, and we normally use very heavy compaction. And the approach roads leading to the to the bridge slab, and the typically most of the codes they they recommend using very high pressure constants for design of any retaining walls supporting the backfill associated with the bridge abutments. And once in a such cases IS code 4 6 5 1 that recommends k naught of 0.8 for design of bridge abutments; the k naught of 0.8 is very high the normal earth pressure constant that we use are about one third two may be maximum about 0.5 depending on the type of soil that we have.

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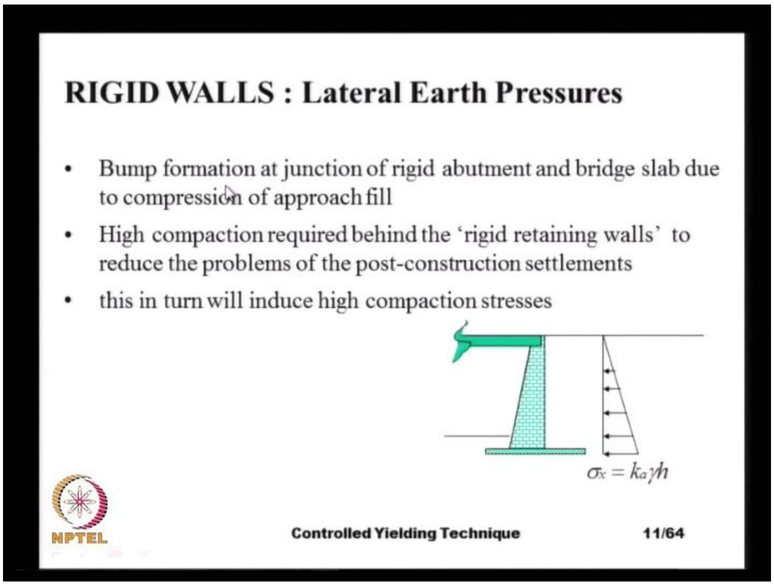

So, why do we need very heavy compaction against bridge abutments the usually the bridge abutments they are very rigid. Because, they have a very strong foundation and sometimes with piles, and then we have the the rigid bridge deck and then we have the we have the the approach road and typically we experience a pump, whenever we reach the bridge on very long approach road that is because soil behind the bridge abutment is compressible, where as the bridge itself is supported on very heavy foundation. So after the construction, there are no settlements within the bridge abutment, but where as in the soil there could be some some compressions.

Because of the the compressibility of the soil, and to prevent these post construction settlements we use very heavy compaction, usually with vibro rollers and this intern leads to very high compaction pressures, and that is the reason why we have a some design codes recommending very high at earth pressure constant for design of bridge abutments and other support structures.

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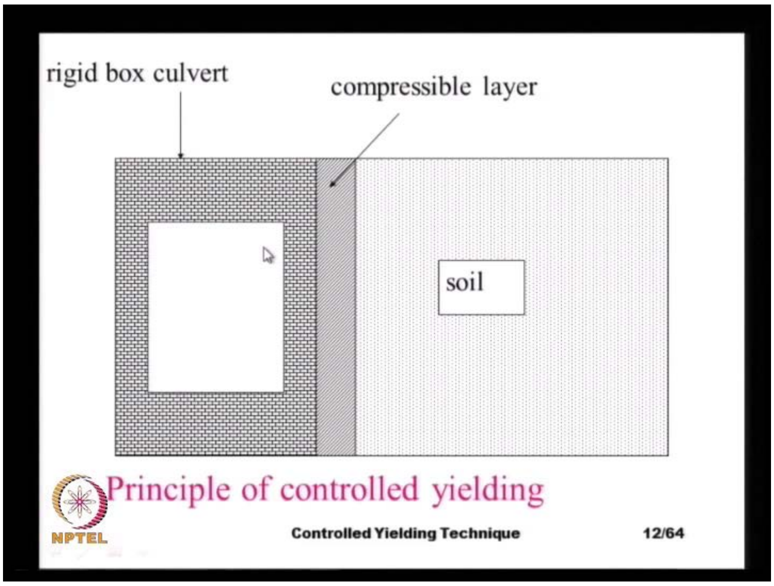

So, in such cases what do we design for high pressures or can we think of some mechanism so that we can reduce that pressures, so as to economize our designs. Let us say that we have a very rigid box culvert like this, which is very rigid, and if you have soil behind it will be under k naught state or under compaction pressure states. But, let us imagine that we have a vertical layer of compressible material like a sponge just imagine that we have a sponge.

And the sponge you know that it compresses and the principle here is that, we as the discompressible layer is compressing the soil expands laterally, and then the process it may reach the the active earth pressure state, so this is called as the controlled yielding. Because, the amount of lateral deformation that we induce in the soil can be controlled by by controlling the properties of this compressible layer the thickness, and then the compressible properties like the modulus and other properties.

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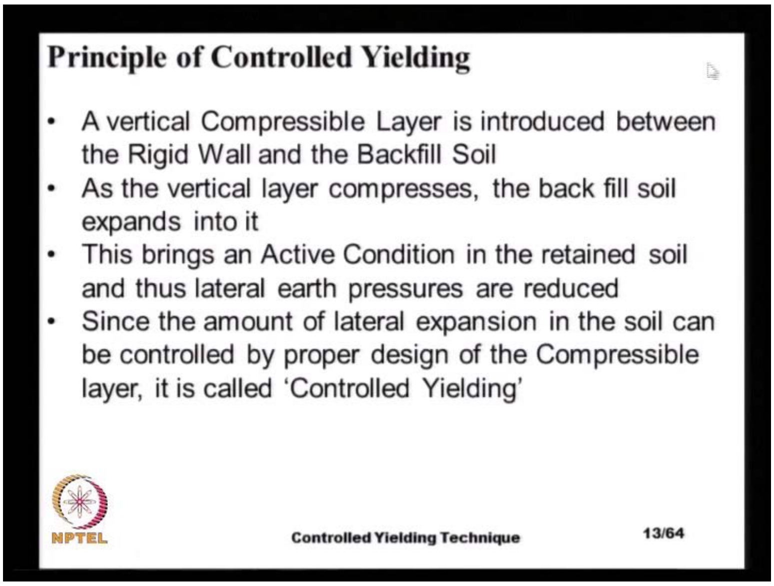

So, because of that we call it as a controlled yielding technique, and as the the compressible layer is compressing it allows the backfill soil to expand into this wide that is created by the compression of the vertical layer, and then this brings in the active condition in the retain the soil, and thus the amount of lateral earth pressures that we need to use for design or reduce, and this intern leads to more economical designs.

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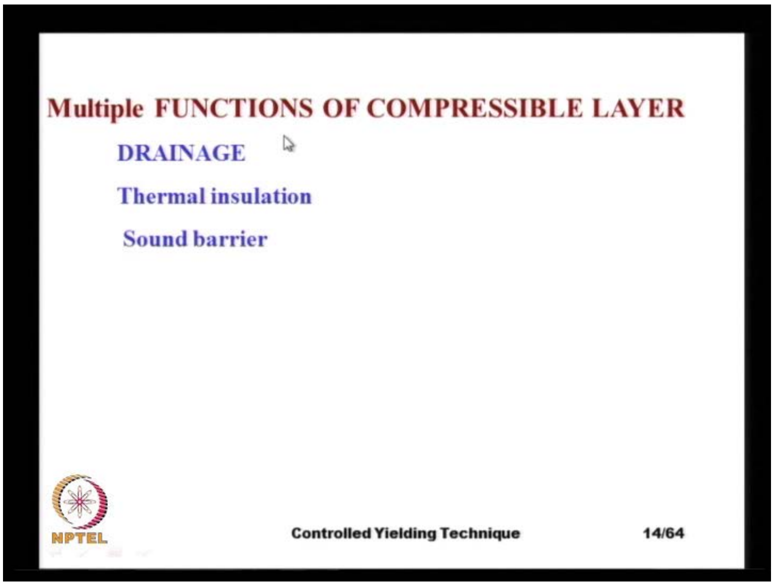

In many cases depending on the choice material that we have for the compressible layer the may function not only to reduce the earth pressures. But in some other ways for as a thermal insulator or as a drainage layer or as a barrier against sound, and heat, and so on.

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And, the some of the distant materials that we have the something like this is actually all these four pictures that we have already seen earlier, under the different types of the geosynthetics. Basically, these are all different types of drainage mediums, and these drainage mediums they have compressibility, and that compressibility we can exploit for inducing the lateral strains with in the soil, and these two are the two pictures these two pictures that we have the drainage mediums, and this is also a drainage medium, but it is made of the rubber tires, and other things they are glued together. And, here we have the expanded polystyrene beans, which are all bonded together loosely.

And this can also act as a drainage medium cum compressible medium, and the different types of compressible materials that we can use they are corrugated cardboard sheets. Just imagine you have very thick cardboard sheet that is placed against the basement wall during the construction, after the construction is over you pore some water into it and the presence of water the cardboard just simply becomes flexible, and then the entire thing compresses removable plywood sheets, we put in the plywood’s which are pulled out after the construction is over the geodrains like this the fiber glass wool, then rock wool, and then the geofoams there are different types of geofoams, one simple example is them is this, then this is also you can think of a foam material that allows for drainage, and also the compression.

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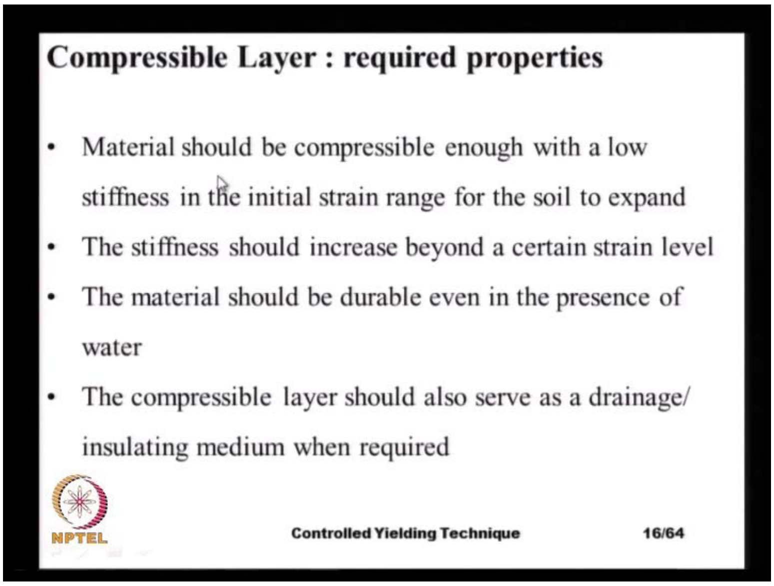

So, some of the requirements for this compressible material are shown here. So, this material it should be the compressible in of initially with a low stiffness, and then once it compresses, once the soil expands this material should not further compress, because if it goes on compressing the soil will yield too much, and then we may have some problems to the surface settlements happening. If, so the stiffness should increase beyond a certain strain level so that the soil will not undergo uncontrolled deformations and the material should be durable in the presence of water. So, whatever material that we provide their it should be able to withstand the effect of water and it is preferable if this compressible layer can also serve as a drainage medium or an insulating medium or for some other things. So, that it serves as for multiple purposes.

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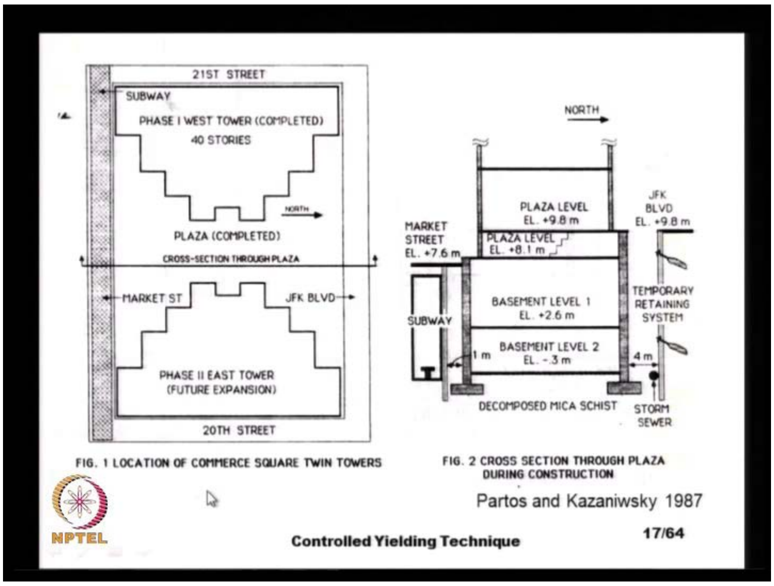

One example applications of this was published by partos and kazaniwsky in 1987. They were dealing with design of a subway tunnel in the city of Philadelphia, and this is actually was a plan view shown here and the sectional view shown here; there is a height difference for the subway from the left side to the right side. And one side we have the market street the top is that road elevation is 7.6 meters and the right side the j f k boulevard is at a height of 9.8 meters. So, there is about 2.2 meters of height difference and that; obviously, generates very large differential earth pressures, and then the overturning moments and in order to achieve the economy in design what they proposed to do is they wanted to reduce the earth pressures on this side by several means.

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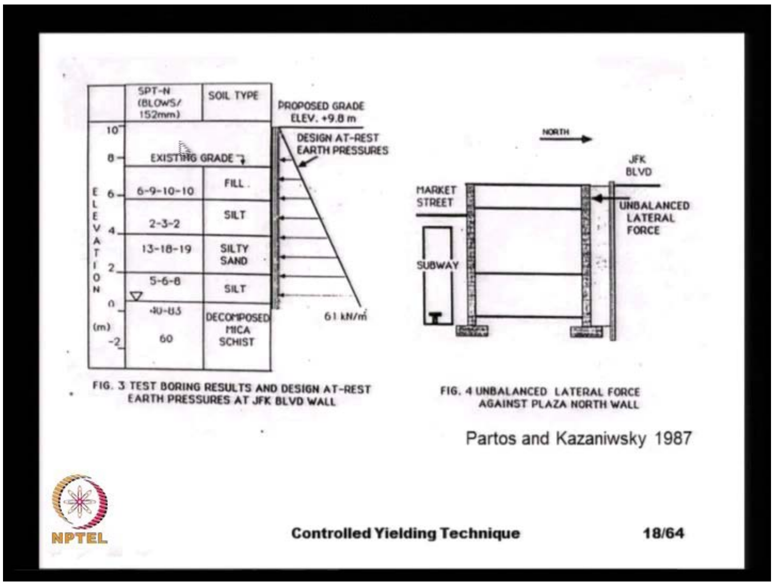

And is actually the soil I will show what are the different methods that they thought about bit later, but this is the typical soil profile that is there at this side.

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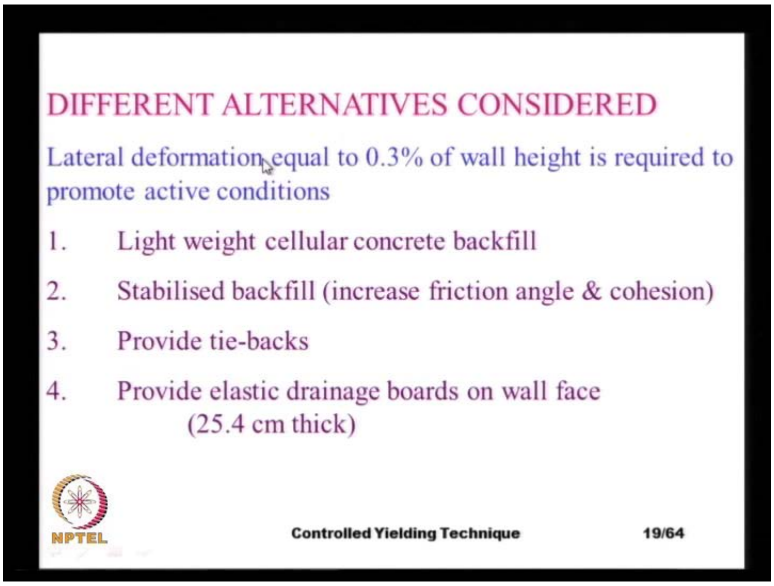

And, the estimated that for the particular soil that is there at the site they require about a deformation equal to 0.3 percent of the wall height. So, that we can achieve active conditions and they thought about different alternatives, if we are not able to achieve lateral deformation. So, we can fill the area with light weight cellular concrete. So, that the lateral earth pressure themselves reduce because of the reduction in the unit weight unit weight of the backfill material or a stabilized backfill.

So, that we increase the friction angle and the cohesion. So, that our earth pressures are reduced or provide tiebacks like this the tieback is something like this or provide the some drainage medium on the wall of thickness 250 millimeters and the cost economics have shown that the fourth option is the most economical one. Because if you want to use the stabilized backfill we need to bring it from far off place and within a city area it is very difficult to operate too many transport trucks and so they went in for the fourth option they provided 250 m thick drainage board on the side with higher. I mean higher elevation. So, that the earth pressures are reduced here.

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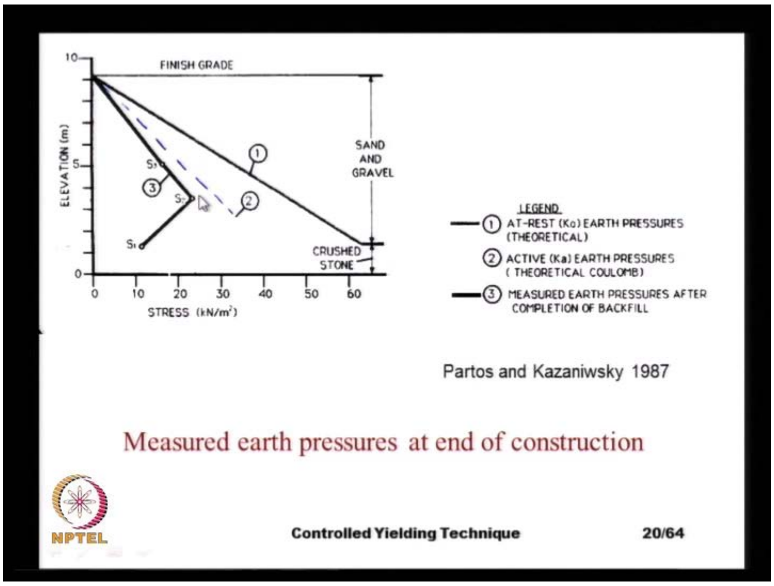

And these are the measured earth pressures see this the first one is the at rest earth pressure that is the theoretical earth pressure. And the second one is the active earth pressures and the third one is the is the measured earth pressures the usually in all these cases the measured earth pressures are smaller than even the active earth pressures, because of the father phenomenon like soil arching. Because the when there is a and when there is a friction; that is acting between two soil layers, because of non-uniform lateral deformations the earth pressures reduce that we call as the soil arching, and because of that phenomenon most of the measured earth pressures are smaller than what we estimate from theoretical analysis.

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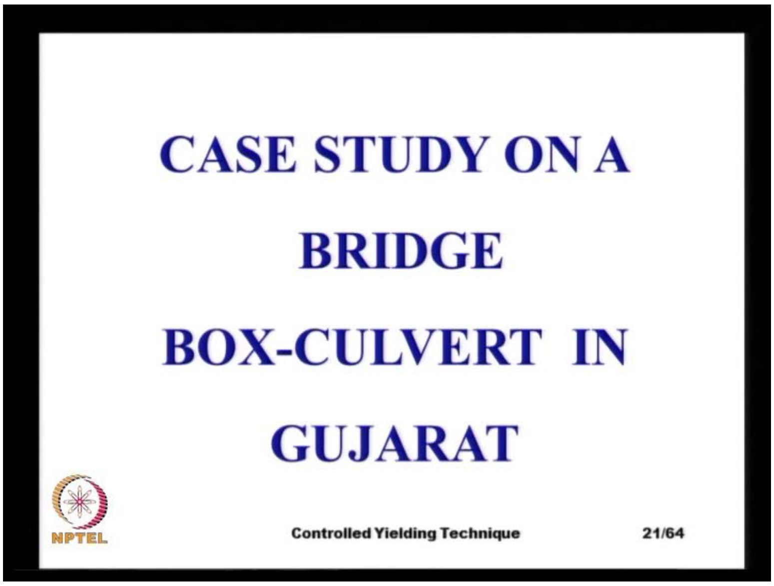

And we have done a similar case study in India on a box-culvert that was built in Gujarat.

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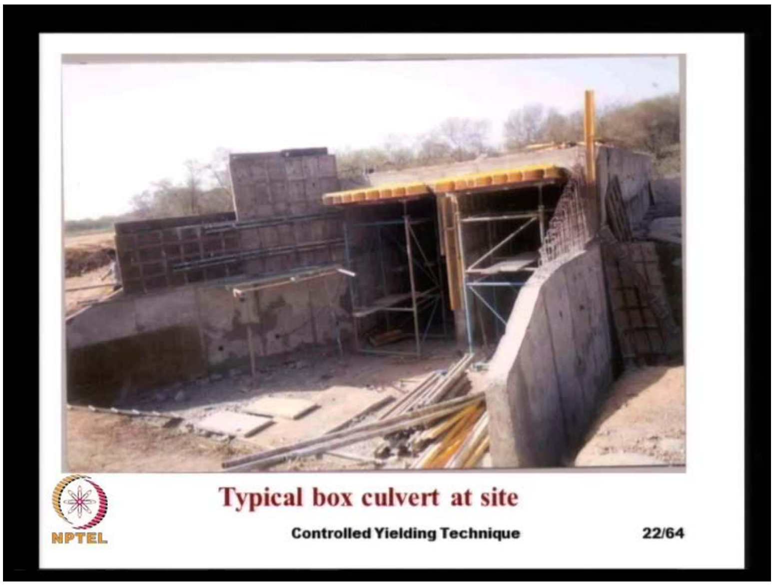

These box culverts are part of a national highway that are running through, and the it is in order to economy is on the thickness of this box culvert walls we thought we can reduce the earth pressures by inducing controlled yielding. And the typical height of this box culverts the maximum height is about 5 meters they vary anywhere from about 2 to 5 meters.

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And this is during the construction you can see the geofoam that was placed there as a compressible medium.

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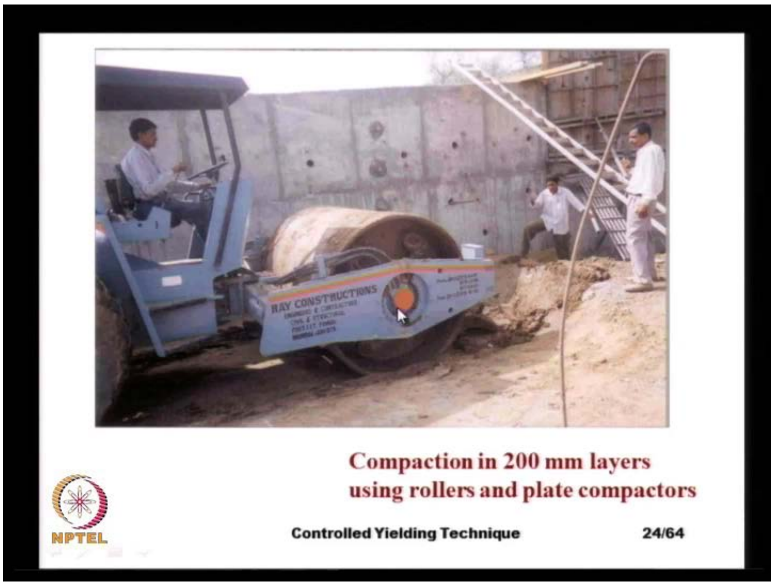

And we can use the main advantage of this method of construction is we do not have to change the method of construction we can use the normal construction procedures in this particular case the soil was compacted in 200 millimeter layers using vibro rollers and plate compactors.

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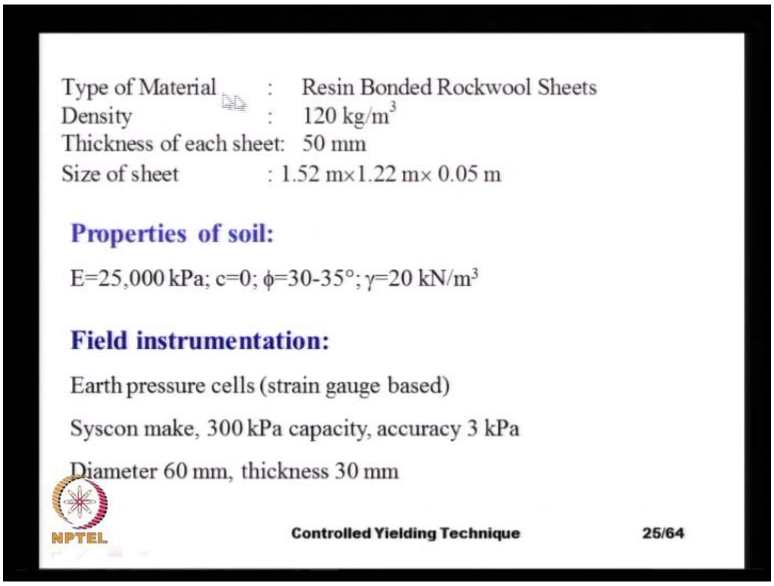

And the particular material the compressible material. That was chosen was resin bonded rockwool sheets these sheets are typically used as ah a the insulators for the air conditioning ducts. And the unit weight or the density is about 120 k g per cubic meters and these are readily available in the market in 50 m m thick sheets with plan size of 1.5 meters by 1.2 meters. And mainly we preferred using this because they readily available in the market and there fair large size which can be taken to the site and then fix to the walls and the assume soil properties only some very rough idea was given to us.

Because because we could not test the soil here at IIT, Madras, but we got the properties from the consultants the the young's modulus was assumed as 25000. And because they have used granular fill we assumed that this is 0 to be on the conservative side and the friction angle varies anywhere from 30 to 35 degrees and the unit weight was assumed as 20 kilo newtons per cubic meter. Because the soil was very highly compacted and we designed the thickness of this compressible material based on some back calculations using finite element analysis.

And the earth pressures that were generated they were measured using earth pressure cells the simple syscon pressure cells were used which have diameter of 60 m m and a thickness of 30 m m and they have a capacity of 300 k p a and accuracy of 3 k p a. They were these earth pressure cells they were fixed along the height of the wall and they were fixed rigidly and then they were the outside surface was flush with the with the retaining walls. So, that we do not have any other phenomenon that affect the earth pressure measurements we make sure that these earth pressure cells are flush with the with the surface.

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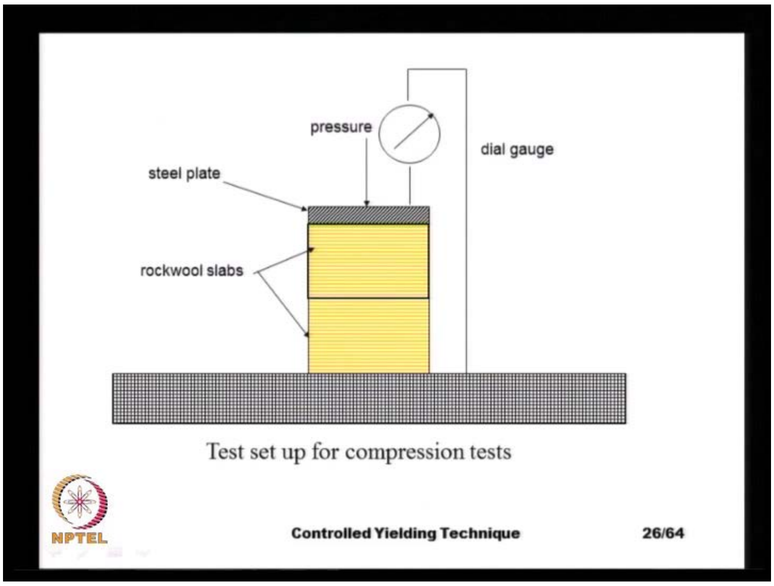

And for estimating the properties of the the compressible material, we have to do the compression test, and the schematic is shown here is actually there is an a s t m standard for doing the compression test and we have followed all these a s t m standards.

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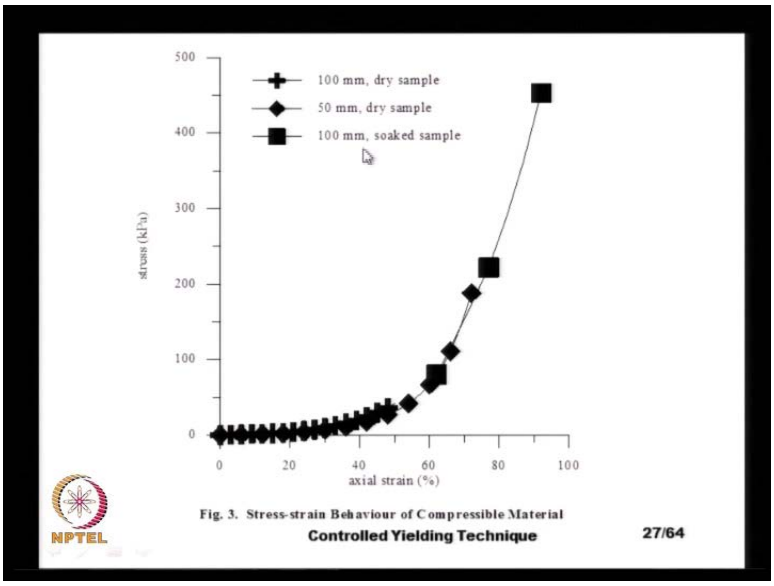

And these this is the data that we have for different types of different thicknesses of this material 50 m m a 50 m m thick, and 100 m m thick, then we also show these rockwool in water because in the worst case during rainy season. If the water enters the backfill it might soak up the the compressible material, and so in order to test the properties even when the the material is wet the tests were done and soaked conditions.

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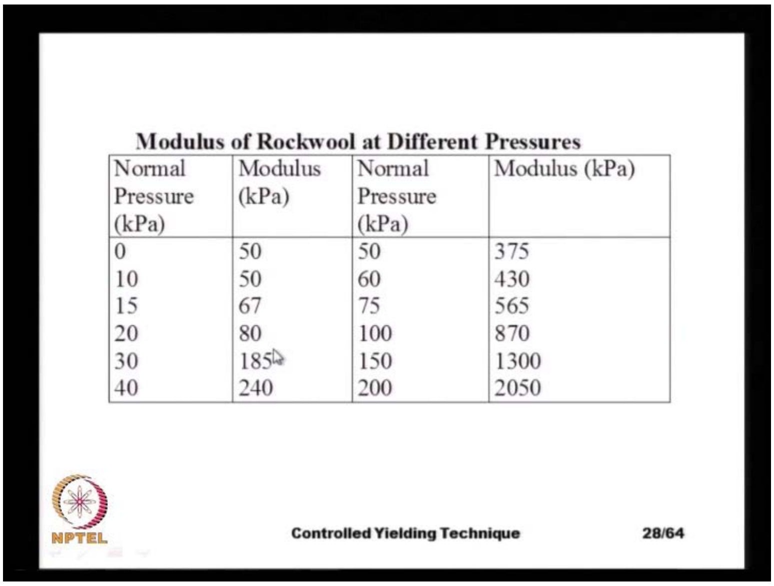
Modulus of Rockwool at Different Pressures

Normal Pressure (kPa)	Modulus (kPa)	Normal Pressure (kPa)	Modulus (kPa)
0	50	50	375
10	50	60	430
15	67	75	565
20	80	100	870
30	185	150	1300
40	240	200	2050

And this is the is this is the data that we have on the modulus, because the modulus is the important parameter, that goes as an input for finite element analysis the at the different normal pressures. The modulus is different it started anywhere at about 50 k P a and then at pressure of 15 k P a to increase to 67 it increases rapidly. And even at a at a normal pressure of 50 k P a the modulus is about 400 k P a, which is high enough to prevent any undu lateral expansions.

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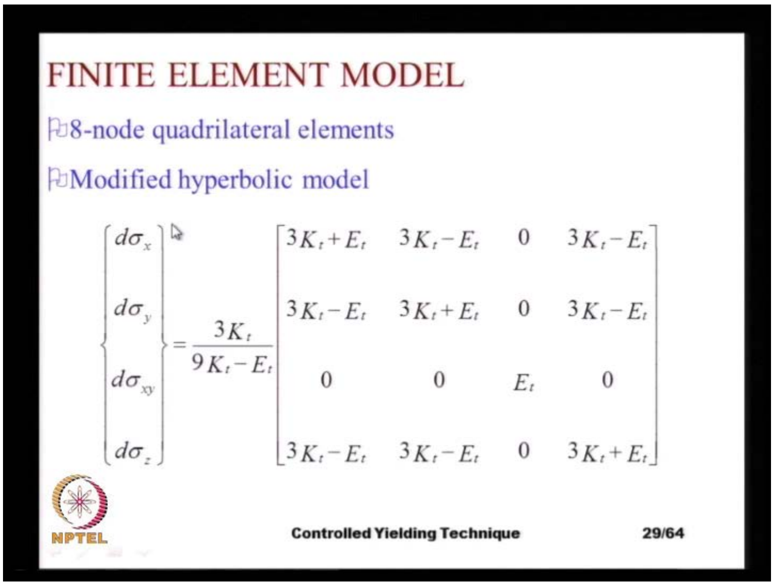

And the finite element analysis was performed by using the modified hyperbolic model with plasticity, and dilation the typical stress strain equation is shown here.

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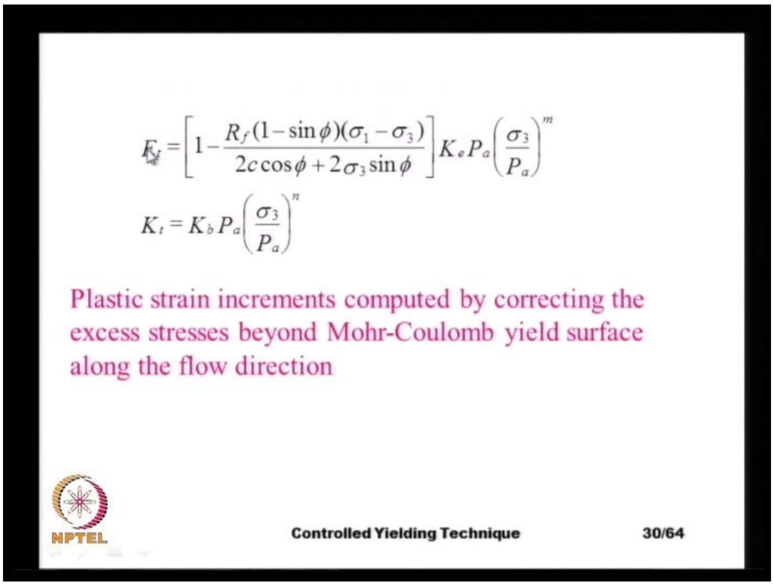

And the the hyperbolic equation the tangent young's modulus is is related to different parameters like this then the tangent young bulk modulus is related to confining pressure like this, and we had implemented a special algorithm for taking care of the plasticity and dilation and other standard features and. So, this is the …

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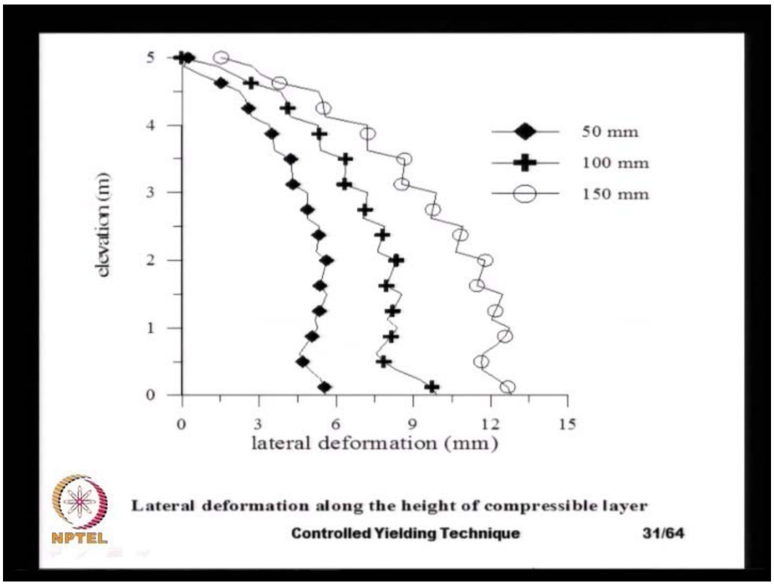

These are the results that we got for this is the analysis were done for maximum height of the wall of 5 meters and once the design works for for this height the similar think. And we adopted the even for other heights and these are the lateral deformations corresponding to different thicknesses of the compressible material the 50 m m 100 m m the 150 m m and 50 m m has the least deformations, where as 150 m m has reasonably high deformations is actually the maximum wall height is 5 meters. And the amount of deformation that we are able to generate with about 150 m m is is about 9 m m on the average.

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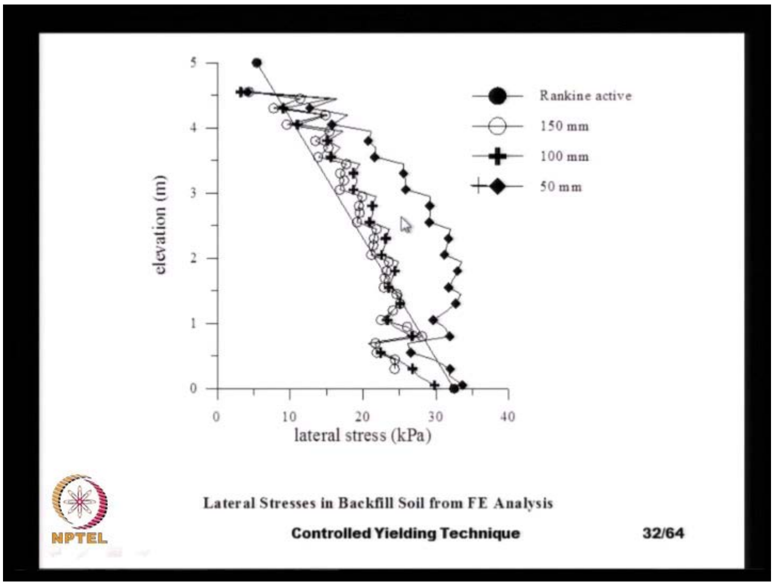

And the result of this deformation is on the lateral earth pressures is like this the 50 m m ah compressible medium could not deform the on the soil sufficiently and because of that the the earth pressures were very high. And the k naught that was used in the finite element simulations was 0.8 that is to account for all the compaction inducing stresses and. So, on and when we used 100 and 150 m m thickness the earth pressures that were generated were very closed to the rankine active state is actually this line corresponds to the rankine active earth pressure, and so we it is clear that with 50 m m thick compressible material. We cannot achieve active state, but with 100 and 150 m m thick thickness we can achieve the active state and to be on the safe side, we recommended 150 m m thick compressible material, and that was adopted at the site.

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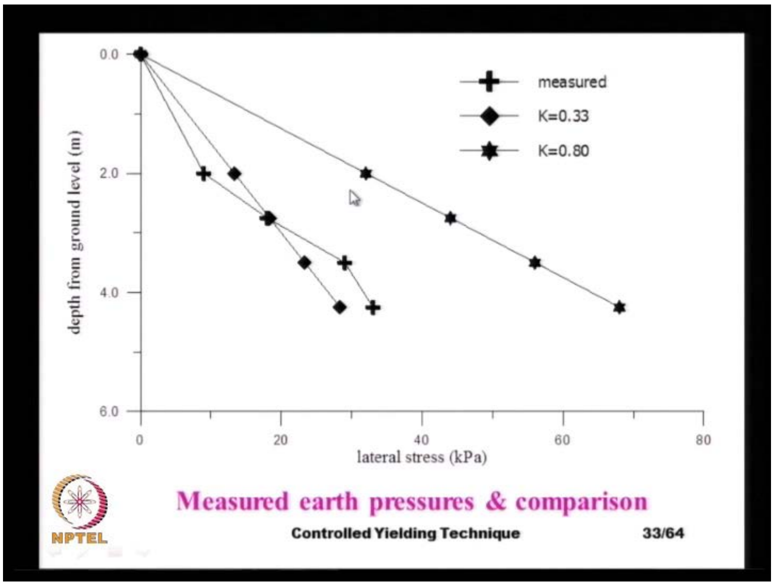

And the measured data is something like this this line corresponds to a net pressure state of K is equal to 0.8. And this line with with diamond shaped symbols corresponds to K of one third and the earth pressure that that were measured are very close to this state this is this plus marks are the measured at earth pressures after about 1 month after the construction was over, once all the construction was over the measurements were taken. And there was not much of a drift even after 1 month the the earth pressures did not increase any further, initially they were low because the soil was being placed. And then later on they increased such some heights the earth pressures are much lower than the K corresponding to one third. And at at bottom heights the earth pressures are slightly higher, but then the you can see the economy that we can achieve by reducing that pressures the actually this is corresponding to K a of 0.8, this is corresponding to a K of nearly 0.33 or 0.35 ah. So, we can reduce the earth pressures by a factor of at least 2 and the moments also we there reduce by factor of 2.

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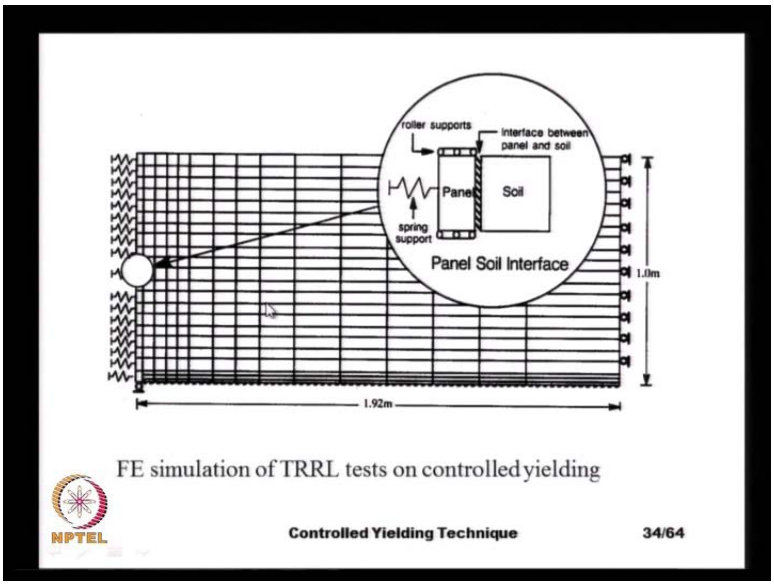

Very large number of laboratory model studies were performed on this topic and here is actually there is some data that was published by professor mcgovern, and others strathclyde universities. And this is a finite element model for simulating their test data what they have done is instead of ah using the compressible material they used a springs that they call as soft medium stiff and hard springs to simulate a different thicknesses of the compressible material, and they had small facing panels which are supported on rollers. So, that they can move only horizontally and they were supported by these a springs and then they placed this backfill, and the height of these walls were 1 meter. Then they measured the the deformation and force that is developed within the springs and correlated that to the to the earth pressures.

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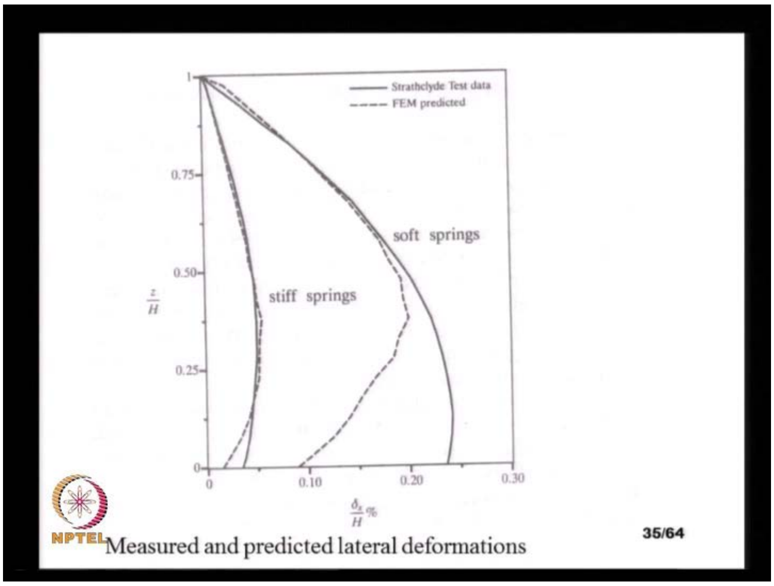

And this is the type of data that is produced and the delta by H on the x axis and z by H on the y axis, and these are deformations with depth for this the stiff springs they have a very small deformation of the order of 0.05 percent. And the soft springs they have very large large deformations and the dashed line is the finite element predicted deformation the solid line is the the experimental data is actually the difference between the experimental. And the finite element one is on the choice of the interface properties at the at the base is actually in the finite element analysis it is assumed that the the ground surface was rough.

And because of that there is a large difference, but otherwise in the top part the deformations of both the measured, and the finite element predicted once are almost same and the similar comparisons were made for earth pressures and so on and reasonable comparisons were obtained.

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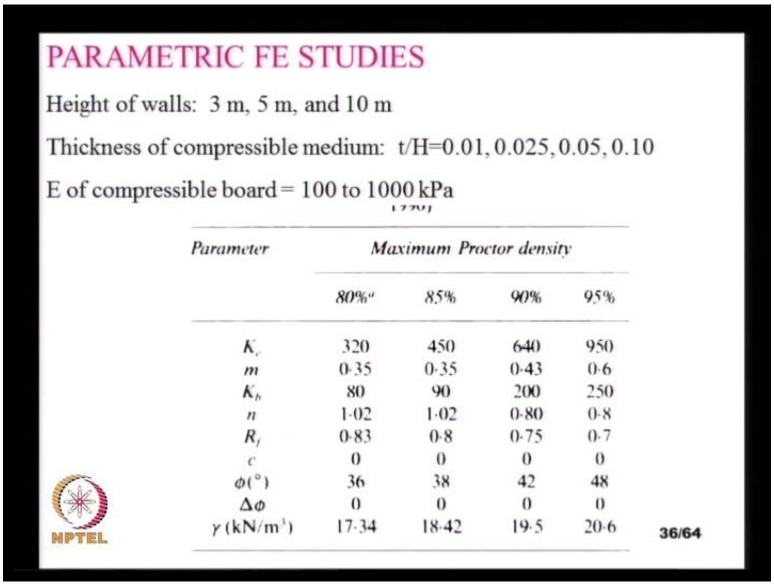

Parameter	Maximum Proctor density			
	80%[a]	85%	90%	95%
K_c	320	450	640	950
m	0·35	0·35	0·43	0·6
K_b	80	90	200	250
n	1·02	1·02	0·80	0·8
R_f	0·83	0·8	0·75	0·7
c	0	0	0	0
$\phi(°)$	36	38	42	48
$\Delta\phi$	0	0	0	0
γ (kN/m³)	17·34	18·42	19·5	20·6

And then at the some parametric finite element analysis were done to determine the to come out with a thickness that will yield that will give us the active conditions for different type of soils; four different types of soils were considered with 36 38 42 48 degrees friction angle. And three different wall heights 3 meters 5 meters 10 meters and then the thickness of the compressible material the t by H of 0.01 0.025 0.5 0.05 0.1 is actually 0.01 corresponds to 1 percent. And then the Young's modulus of this compressible board was varied from 100 k P a to 1000 k P a.

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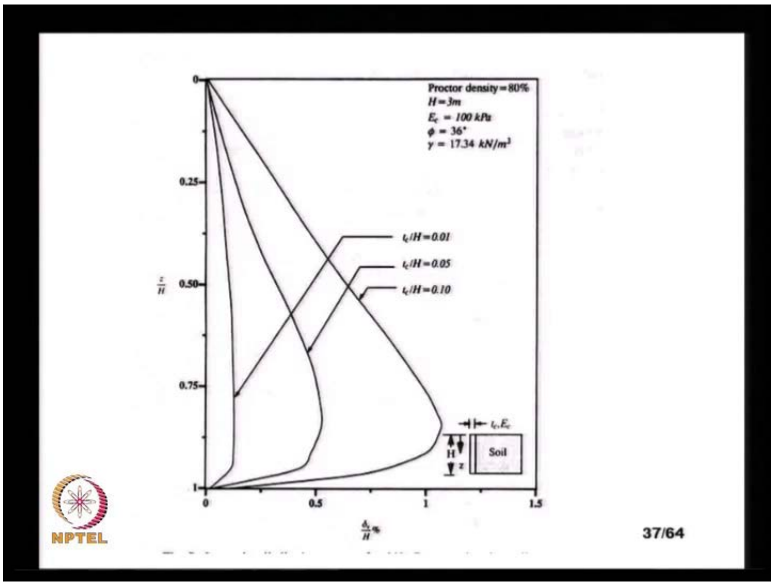

And the typical results they are shown here and the x axis we have the deformation the y axis. We have the the height the elevation for this particular case the proctor density the soil is eighty percent to wall height is 3 meters, and the friction angle of 36 degrees with three different thickness we get three different types of deformations.

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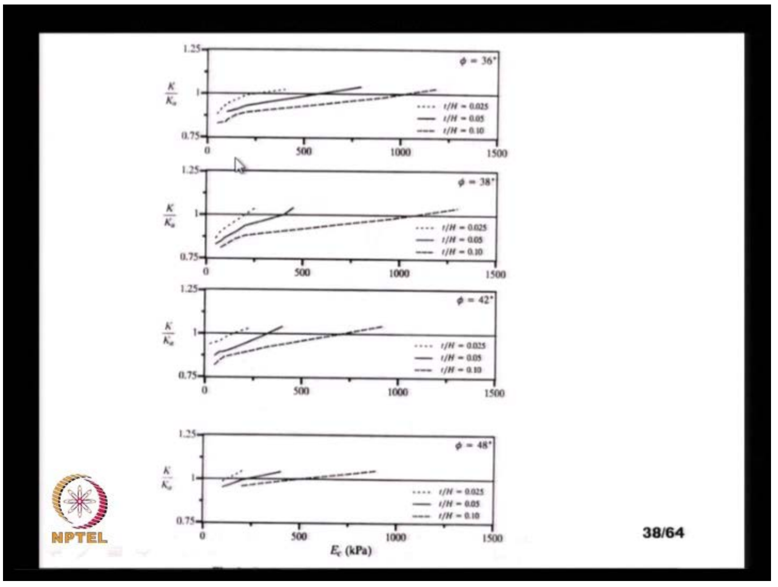

And the resulting earth pressures they are plotted like this and for different thicknesses t by H of 0.025 that is 2.5 percent, 5 percent, 10 percent, and so on. The earth pressures when the modulus is very very small the earth pressures are lower than even the active earth pressures because of the soil arching phenomenon and at some thickness. And modulus the K by K a is equal to 1, and that we called as the critical thickness corresponding to the to the modulus that we have.

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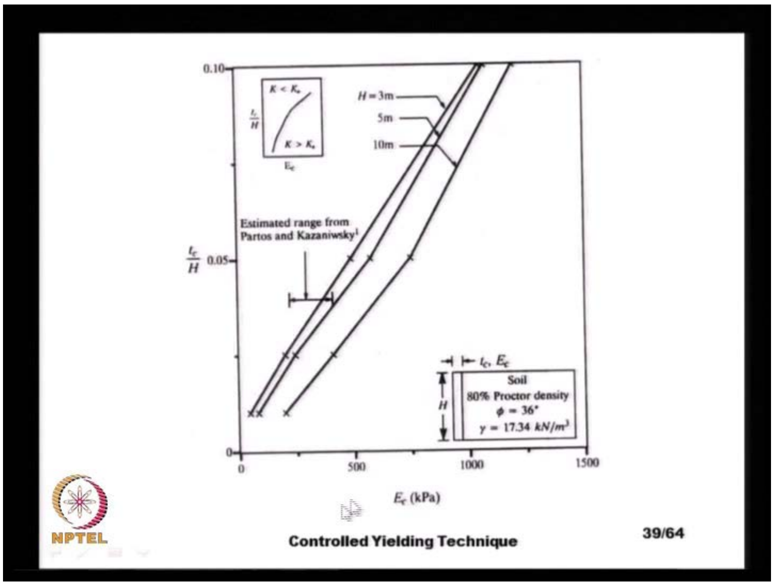

If we plot all this data together in terms of the modulus and the thickness that will give us the active states the data plots like this for different wall heights. So, 3 meter wall height 5 meter and 10 meter wall height, and the particular data that was a proposed by partos and kazaniwsky plots something like this, they data is in this range, which is very closed to the data, that we have for friction angle of 36 degrees and 3 meters wall height which is similar to the the one that they have.

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And IIT Madras, we have done lot of laboratory test quantify the earth pressure reductions and then and then see whether we can further reduce the the earth pressures, and then the resulting deformations.

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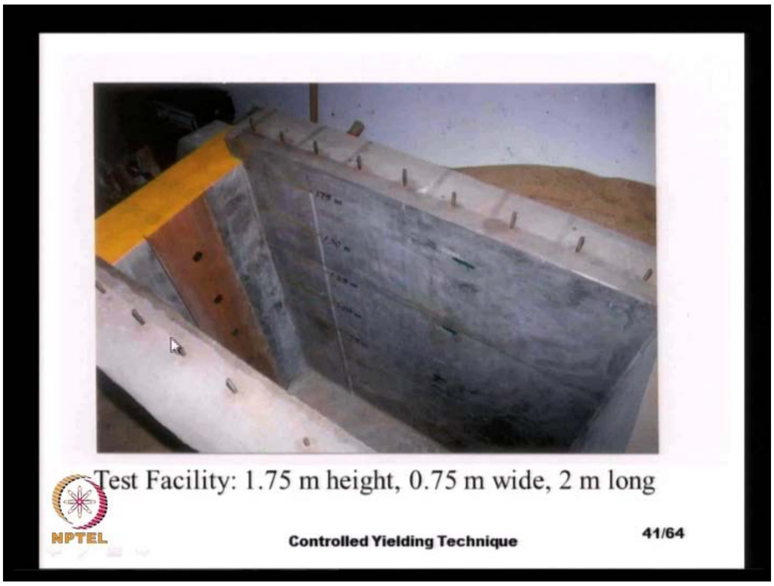

All the tests were performed in a concrete tank these walls were very smooth they were finished with a very smooth finish and then they were coated with double layer plastic sheet and in between a sprayed some oil. So, that there is a very little wall friction that acts the front side of this rigid wall we have fixed a wooden plank with holes in them. So, that we can fix the earth pressure cells which are very which are flush with the, this wooden plank.

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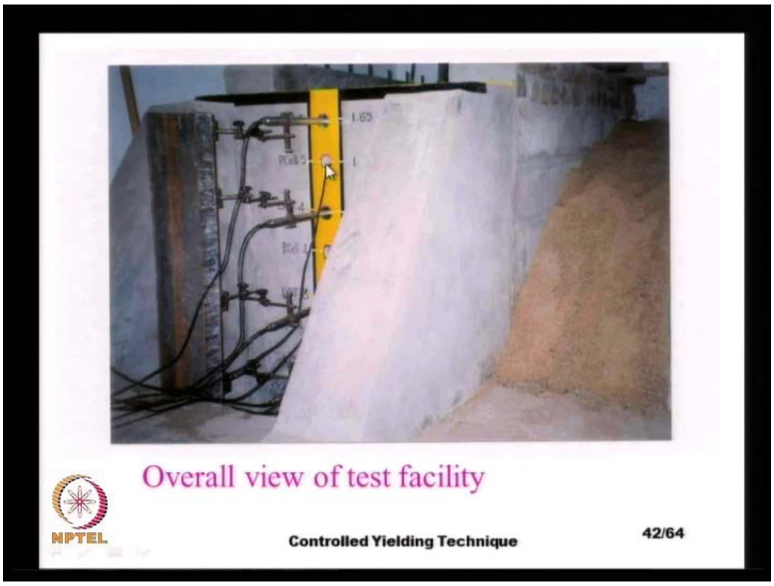

And at different heights the earth pressures were measured and then at the deformations and the tests were all done in a very controlled manner. So, that we can generate.

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The data that we can that we can apply for our design purposes is actually; these are all the electronic hm l v d t’s to measure the the deformations that are taken place in the in the compressible medium and alternately we had the l v d t’s and the pressure cells.

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And the close-up view with styrofoam sheets. So, actually we have used different materials the styrofoam sheets, and then the compressible fiber glass wool as a compressible compressible material and this particular picture shows two layers of a styrofoam sheets.

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And this is the test with Rockwool layer and these are the locations for measuring the the deformations the front of the LVDT's was connected with a a with a plate. So, that the

the earth pressure acts on this plates and then pushes them pushes the LVDT probe to to record the the deformations.

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And this entire height of the tank was filled with soil with a very controlled compaction property. So, that we can achieve the desired unit weight, and then the friction angle of the soil

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And the height of the tank is only 1.75 meters. And in order to simulate higher height walls what we have done is we have applied pressure on the entire soil by inflating

inflating rubber rubber chum to apply the pressure. And once you apply the pressure we can simulate higher height walls. So, actually the additional height that we can simulate is just basically the pressure that we apply divided by the unit weight of the soil.

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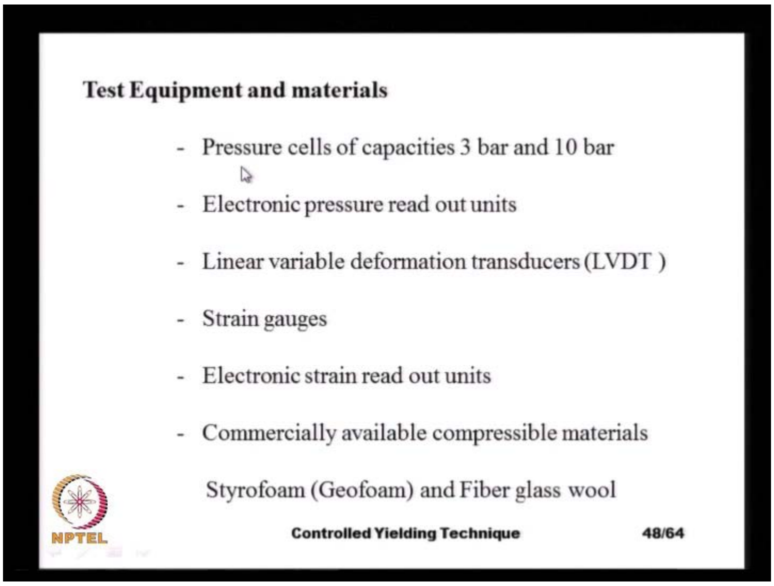

And these are all the different equipments that were used the pressure cells having capacities of 3 bar and 10 bar, because we wanted to measure the pressure along the height of the wall and then along the length of the wall and the electronic pressure readout units then l v d t's. Then the strain gauges to measure the strains that are develop within the reinforcement layers and then the the strain gauge readout units and two different types of compressible materials were used; one is a styrofoam that is typically used for packing the computers and other things and then fiber glass wool.

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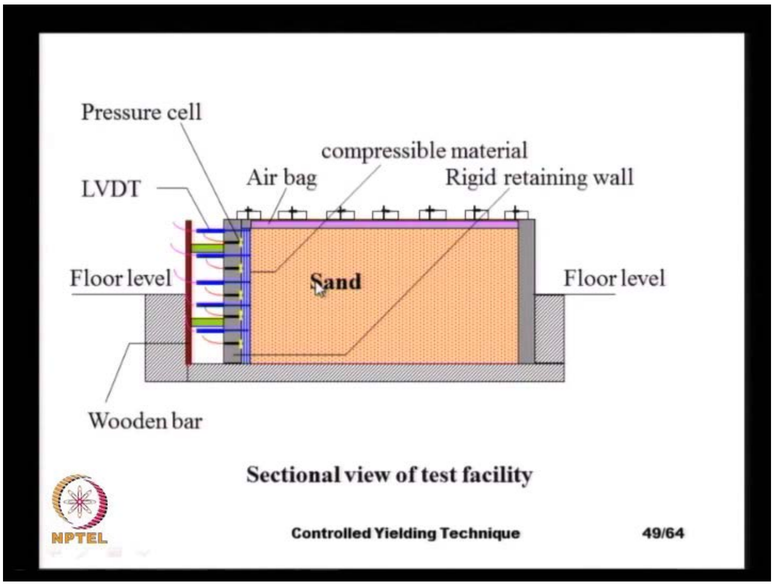

And schematically the sectional view is shown here, we have the backfill soil and then this blue color vertical line is the compressible material, and this is our rigid retaining wall. And we have the l v d t's to measure the the compression that is happening within the within this compressible material and then the the pressures the pressure cells that are fixed on the on the rigid wall to measure the the that pressures.

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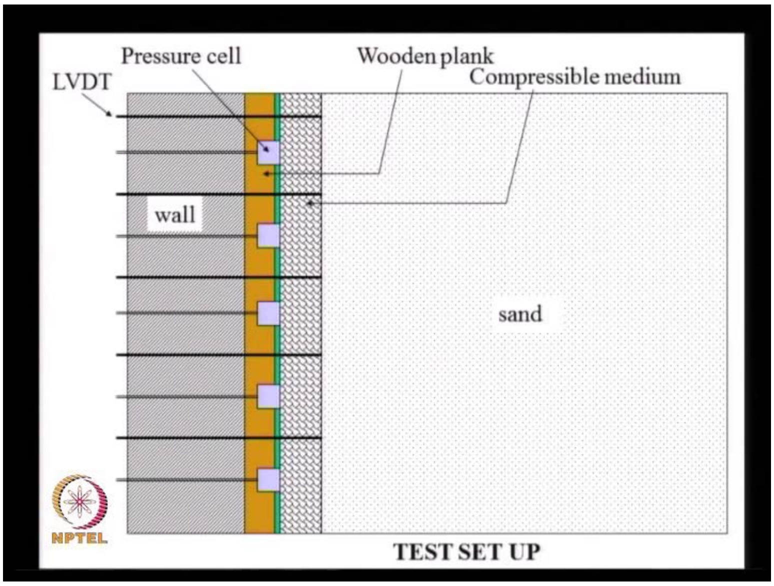

This is another closer these are the earth pressure cells and these are the LVDT clobes and these clobes are connected with a steel plate. So, that they can the LVDT clobe can deform .

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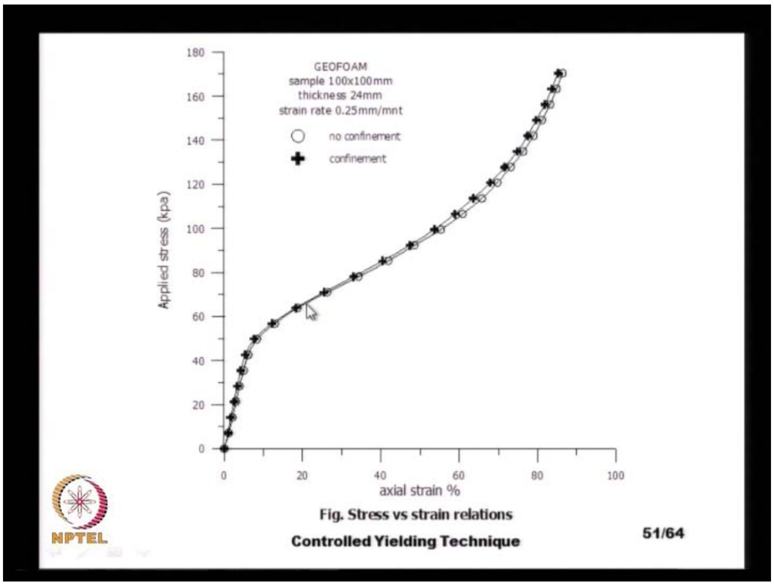

And this is the typical stress strain graph for the geofoam sheets the thickness sheets of this geofoam sheet or the styrofoam sheets is 24 millimeters, and we have done the test with confinement, and without confinement that is within the retaining wall the entire thing is confined. And so we simulate that confined test by putting them within a within a mold having a thickness of 24 millimeters. So, that when we apply the compression the material does not strain in the lateral directions in this case because the material is. So, compressible that and with very low Poisson’s ration it did not deform very much. So, whether we confine this material are do not confine the difference between the stress strain behavior is not very much different.

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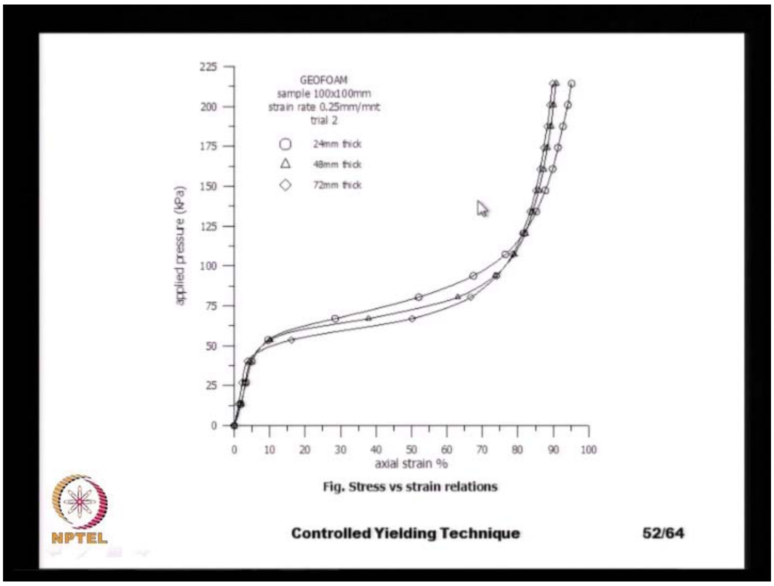

And these are the results for different thicknesses 24 millimeters 48 millimeters and 72 millimeters and more or less they have similar stress strain behavior

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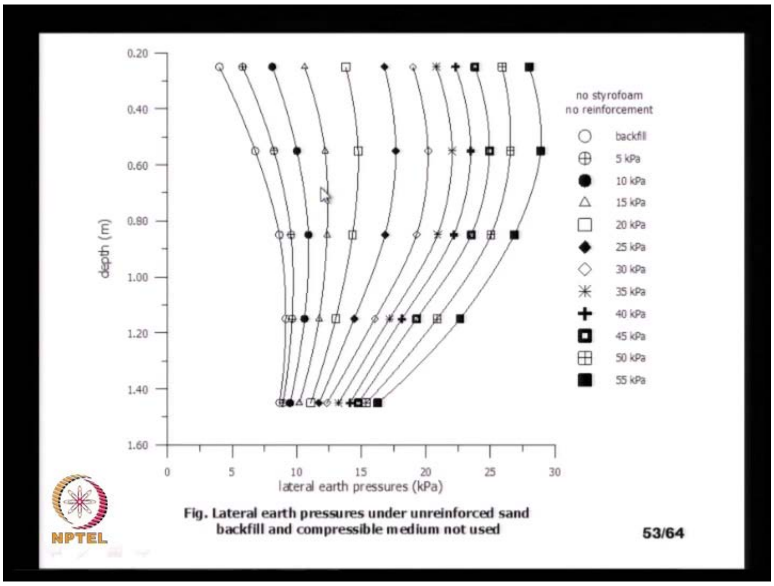

And these are all the different earth pressures that we were able to measure for different cases see, the first one is the earth pressures under self weight condition that is when the backfill was filled up to the full depth and is actually the depth y axis. We have the depth going down from the surface to the to the bottom of the wall and that the maximum pressure that was applied was 55 k P a that is corresponding to to this and the unit weight that we could achieve was 18 kilo newtons per cubic meter. So, 55 k p a corresponds to 3 meters.

So, our actual height of the wall that we were able to simulate is 3 plus 1.75 that is 4.75 meter height of the wall, and as we apply the pressures the the earth pressures increased and this particular data is for a case, where there is no compressible material there is rigid wall and the backfill soil. And then we apply the pressure, and then these are the earth pressures that were generated the maximum earth pressure that is generated was about 27 k P a at 55 k P a pressure

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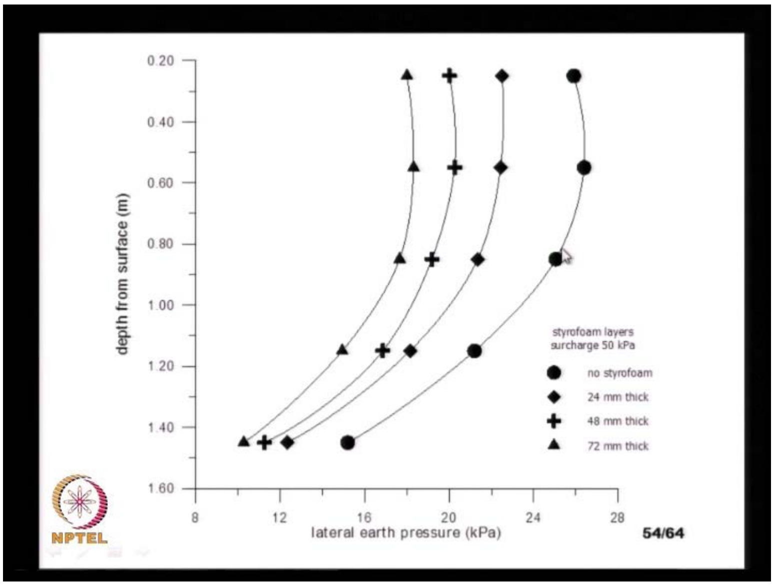

And the these are the the results with different thicknesses of the styrofoam this this one is corresponding to no compressible material this is with 24 millimeters, this is with 48 and this is with 72 millimeters thick. And the earth pressures the maximum earth pressures are reduced from about 27 20k 26 k P a to about 16 k p a by providing the providing this compressible material.

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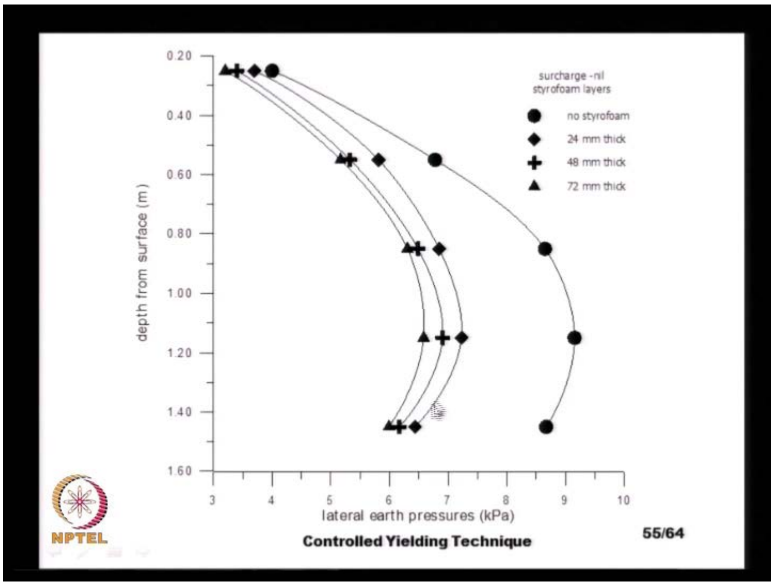

And these are the different earth pressures for the case of self weight is once again without any compressible material with 24 millimeters 48 and 72 millimeters thick layers.

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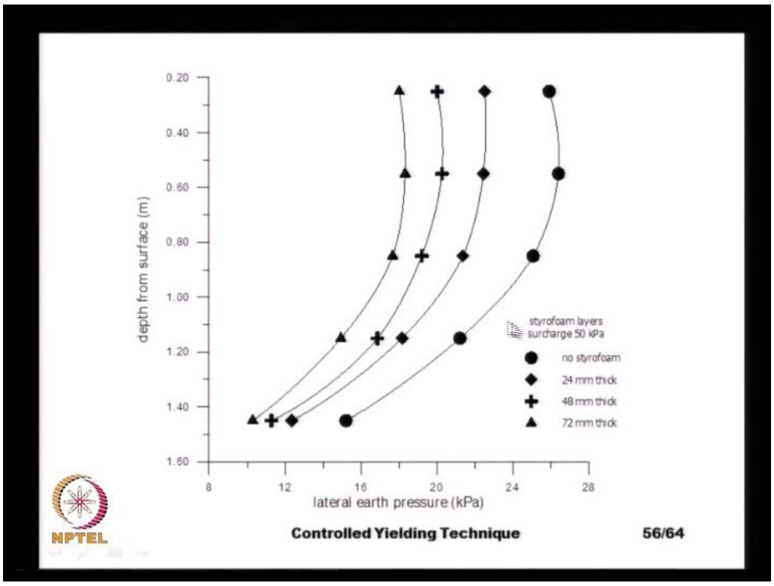

And this is for the case of 50 k P a pressure.

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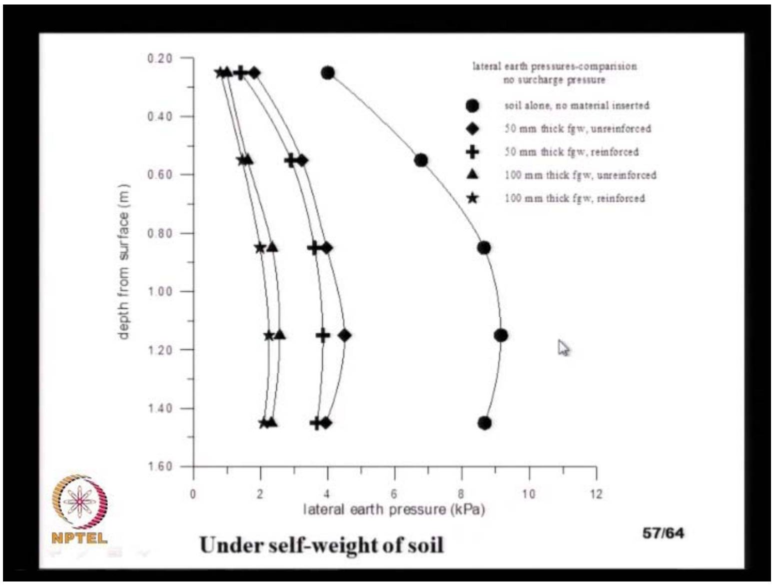

And we have done some test by putting in horizontal layers of reinforcement to see whether the earth pressures can be further reduced and this is the this the data with reinforcement is actually with 50 mm thick glass wool, and when there is no reinforcement these are the earth pressures that were generated. And by putting in three layers of reinforcements the earth pressures have reduced drastically to about this much and with 100 m m glass wool the earth pressures have reduced even further.

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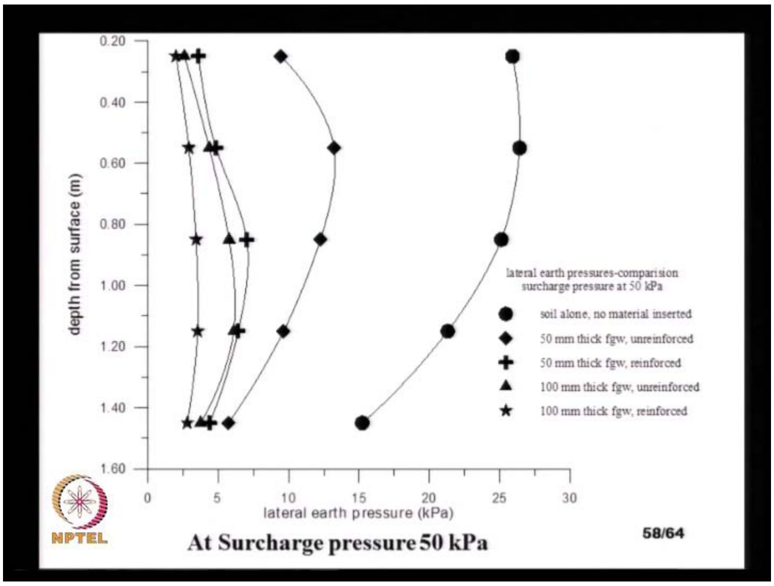

So, this the this data shows that we can use horizontal layers of reinforcement and these reinforcements are not connected to the front face in they are just simply placed within the within the backfill soil. And even then they were able to take the lateral strain that generated in the soil and prevent the the earth pressure from getting transferred into the into the rigid structure and this is the data for 50 k p a surcharge pressure

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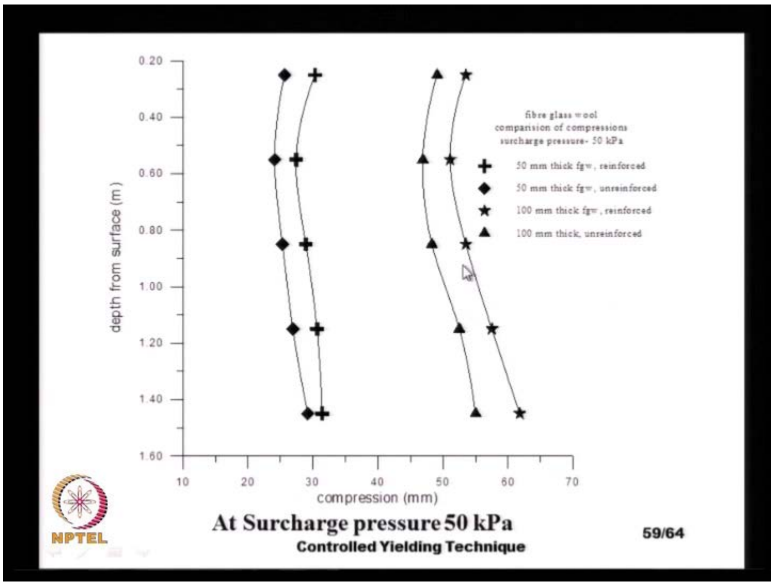

And this is another data for for the same thing for unreinforced unreinforced, this is the the compression data the maximum compression that was generated was about of the order of 60 millimeters for the case of 100 m m, thick unreinforced fiber glass wool and when same thing was reinforced the deformations were slightly lesser.

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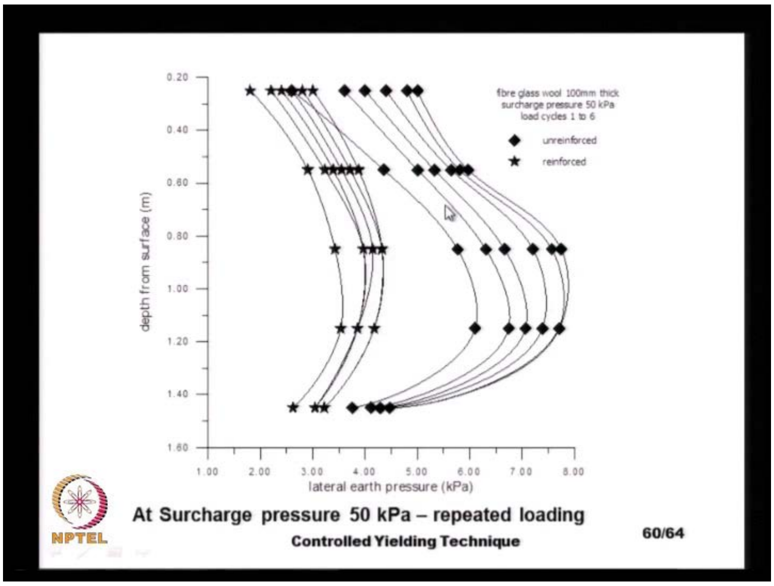

And the some test were performed by repeatedly applying the pressure because the concern is when we apply single load whether it will represent the real life scenario where the the pressure repeatedly applied like. For example, in a in a road the the traffic repeats itself and in order to simulate that case we have done some test by by applying a repeated loads up to 5 cycles this is the first pressure application second third fourth fifth and. So, on the sorry the this is the initial pressure the first repetition second repetition third fourth and fifth repetition and after certain number of cycles the earth pressures have become more or less constant. And the initial maximum earth pressure was about like 6 k P a here, and it has increased about 8 k P a after load repetitions and when the same dearth pressures when three layers of reinforcements were placed they have reduced to almost half 50 percent.

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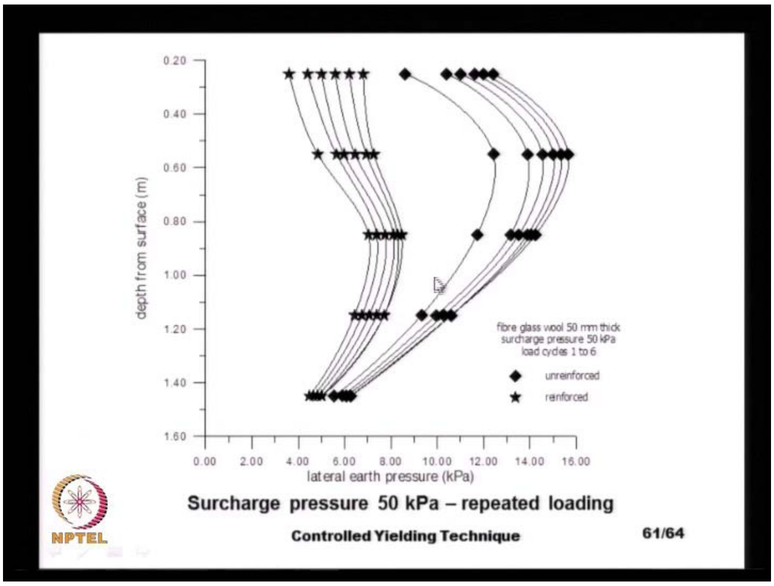

And these are the same data for fiber glass wool.

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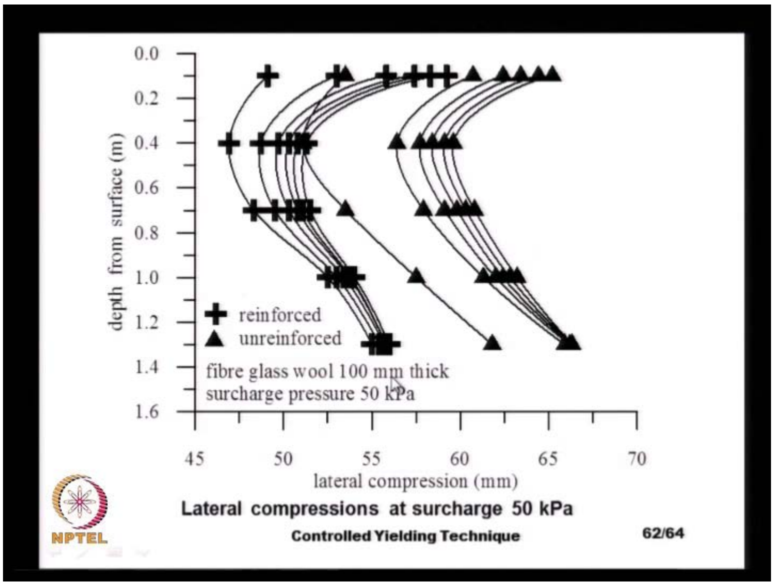

And this I the data with 100 m m thick fiber glass wool.

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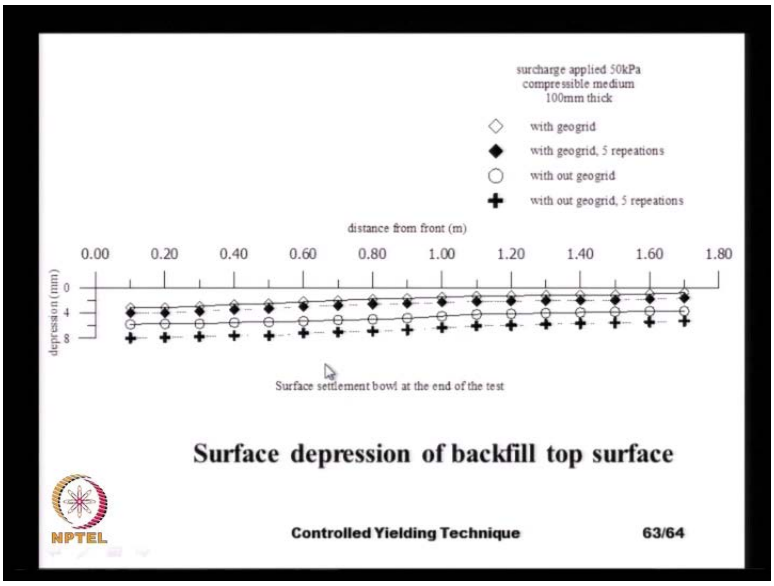

And then what happens to the stiffness of the backfill soil and that we were able to get an estimate by measuring the surface deformations. And we plotted the vertical surface deformations along the length these dashed lines with plus symbols without any reinforcement for five load repetitions and with geogrid reinforcement the then the settlements reduced from about 8 millimeters to 4 millimeters and the similar data for for another case for the first load is is this. So, the under first load application without any reinforcement these are these are settlements and after five load repetitions this is there the settlements.

And the this one is with reinforced one is actually this when the system is reinforced the effect of load repetitions was not very much there was there was not much change in the in the settlements, but when we have unreinforced one there was a significant deformations and that shows that by placing the reinforcement we can not only reduce earth pressures, but also increase the stiffness that is that is very much required for the bridge embankments because we do not want any post construction settlements that take that take place within the backfill soil.

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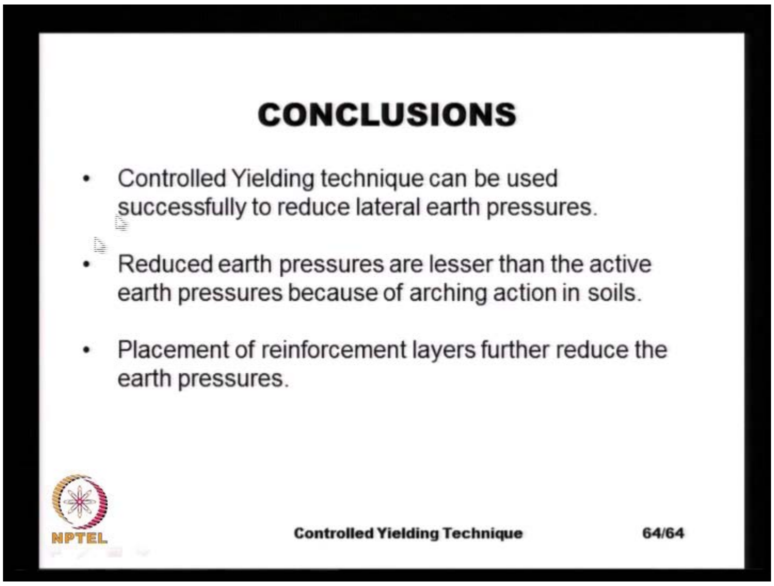

So, just conclude the controlled yielding technique can be used successfully for reducing the earth pressures and the reduced earth pressures are lesser than the active earth pressures. Because of internal arching that takes place within the soil and the placement of reinforcement layers further reduce the earth pressures. So, this the entire concept of controlled yielding is possible because of advanced geosynthetic materials that we have that enable this technique need to be applied, thank you very much.

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So, if you have questions you can contact me at this email address.

Thank you