Geo synthetics and Reinforced Soil Structures

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Lecture - 14
Testing Requirements for Reinforced Soil Retaining Walls

Very good morning students, the previous lectures we have seen the design of reinforced soil retaining walls, then looked at all the parameters that are required. And in today's lecture let us look at the various tests that we need to do, to determine those design parameters.

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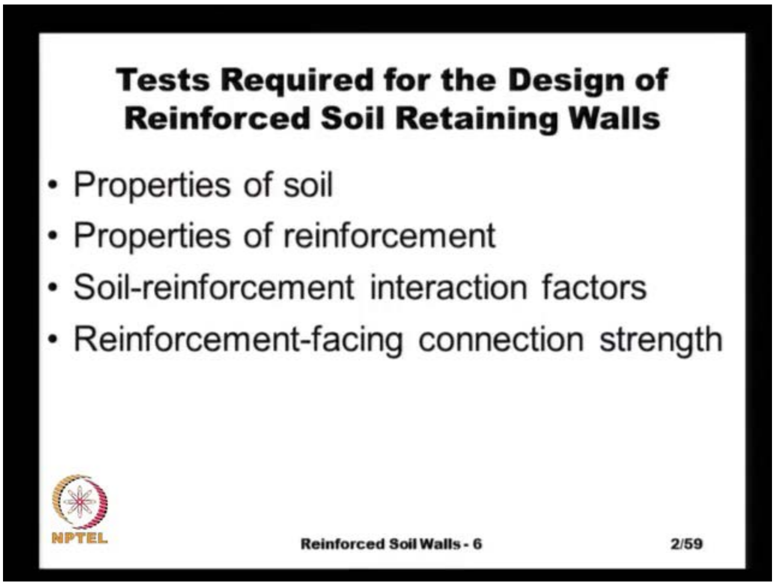

As with all the other type of structures, we need very large number of parameters for the design of the reinforced soil retaining walls. The first property that we require is the properties of the soil, that is the shear strength properties and then the compaction properties and so on. Then the properties of the reinforcement, especially if it is a polymeric type reinforcement, what are the damage factors and what are the three production factors that we could have, we need to determine them.

And then of course, the soil reinforcement interaction parameters, so that we can safely estimate, the pull out capacity of these reinforcement products, and wherever we have modular blocks or the panels, the connection strengths between the reinforcement and the facing is a very important input for our designs. Now, let us look at the different tests that we can perform.

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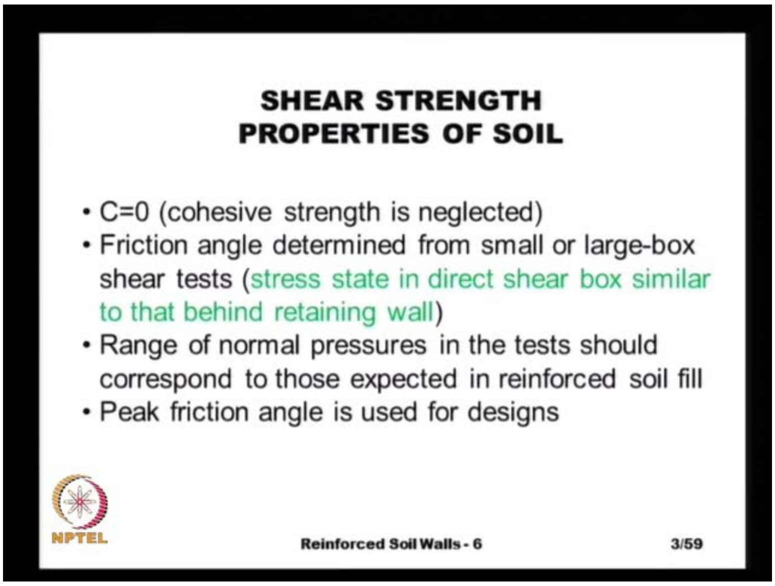

The shear strength properties, they are best determined from small or large scale direct shear box test. And in all these tests, we assume that our cohesive strength is 0, even if the soil is slightly cohesive, we neglect the cohesive strength, so that we have additional fact of safety now a design. And we prefer the direct shear box test because the stress state in the shear box is very similar to that behind the retaining walls. And then it is also very important that, the range of normal pressures that we use in these shear box test, should correspond to the height of the wall, that we have under design. And as we have already studied earlier we need to use the peak friction angle for all our designs.

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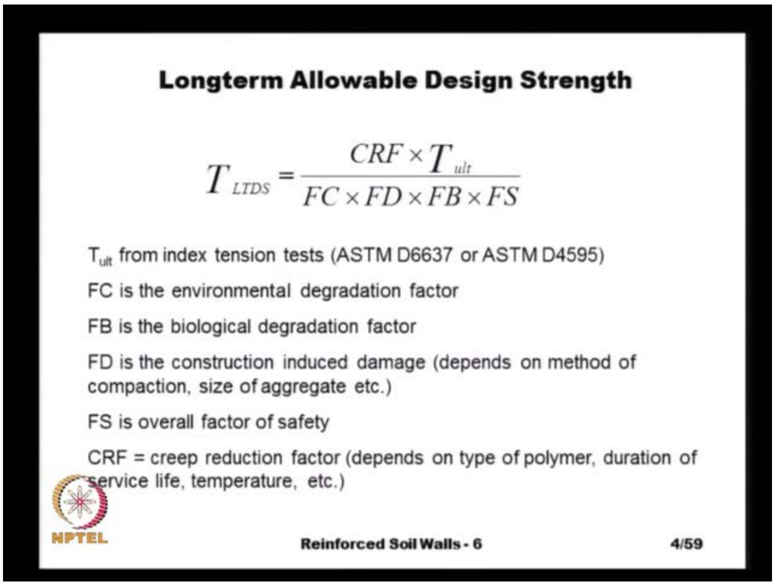

The long term allowable design strength of the reinforcement is obtained from the index tensile strength T ultimate, that we can determine from either ASTM D6637 or ASTM D4595 methods. And that multiplied by some CRF prediction factor which is applicable for polymeric type reinforcements and that, divided by number of factors. FC is the environmental degradation factor, FB is the biological degradation factor, FD is the construction induced damage factor, which depends on the method of compaction the size of the aggregate and so on. Then this the FS is the overall factor of safety and in all these factors the usually the biological degradation factor is equal to 1 and this FC environmental degradation factor variably is 1, unless we work with highly aggressive type of soils.

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And sometimes especially when we work with landfills and so on there may be some lizards that are present in the soil. And in such cases, what we do is we expose our reinforcement products to the contaminate that we could expect in this site. And then after accelerated exposure to this contaminated environment, we perform the tensile strength test to determine the reduction factor because of the exposure to the environmental conditions.

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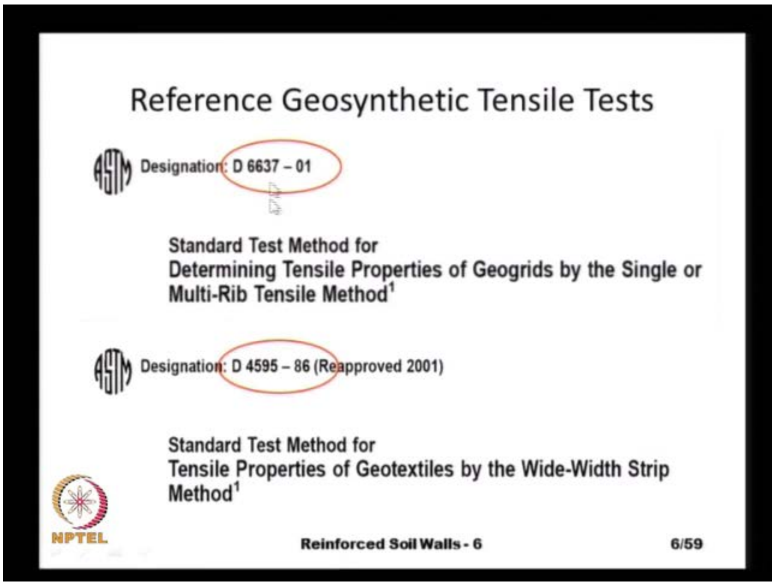

And as we have already seen, there are two methods of tensile test that is the ASTM D 6637 and D4595.

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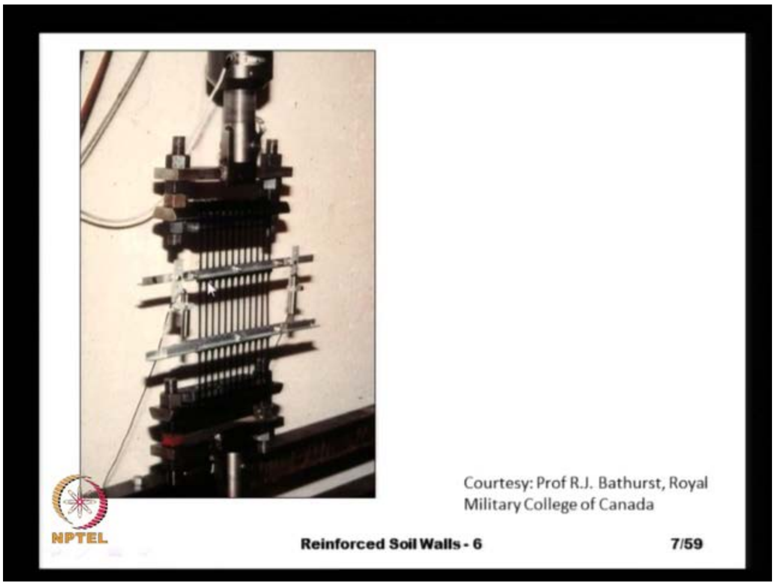

And this is how, we do a any tensile test, we take standard length of the sample. And then during the test we it is very important that we also measure the strain because the load corresponding to our allowable strain is the design load that we consider.

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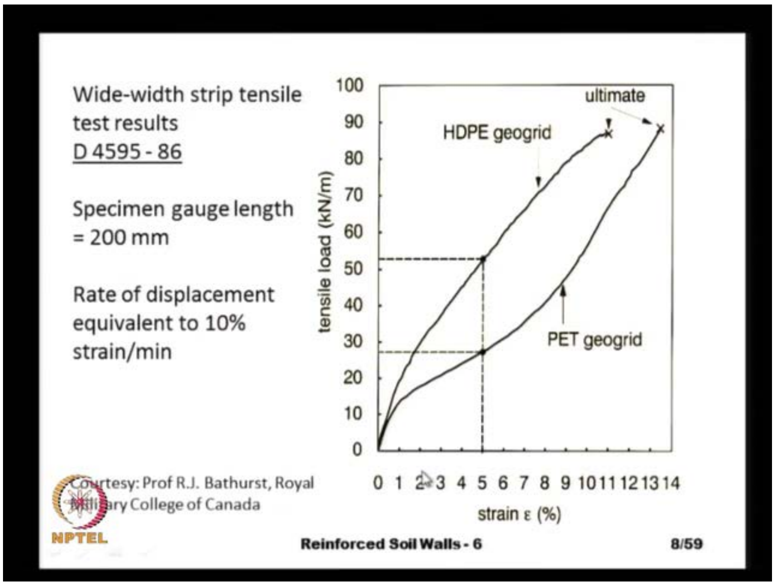

And typical results is something like this, on the x axis we have the strain and the y axis we have the tensile load and this is the ultimate tensile strength that we have. And these could be the working loads corresponding to some 5 percent allowable strain. Then rate of displacement in all our test as per the ASTM standards is about 10 percent strain per minute.

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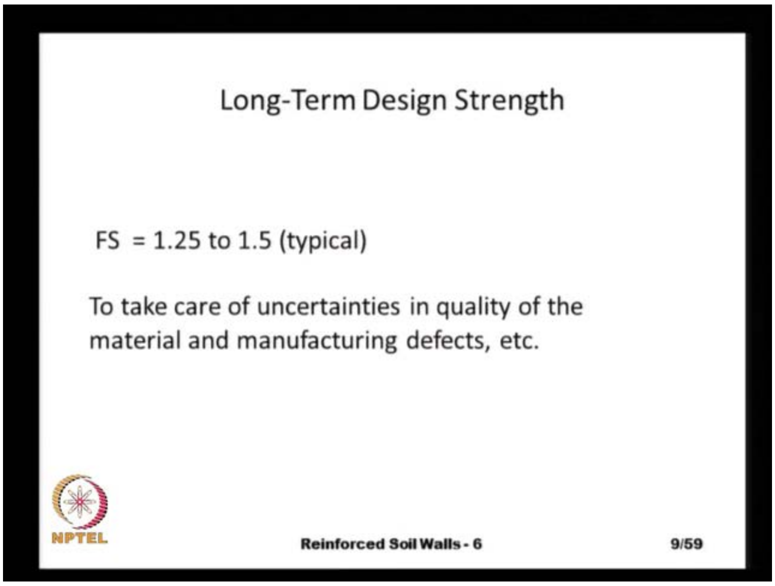

And the from this index strength we can extrapolate the long term design strength, by applying different factors of safety. This FS is the last factor of safety that we have, is typically 1.25 to 1.5 and this is mainly to take care of any uncertainty in the quality control of the material. And then there could be some manufacturing defects, over and above all the factors that we normally consider in our procedures.

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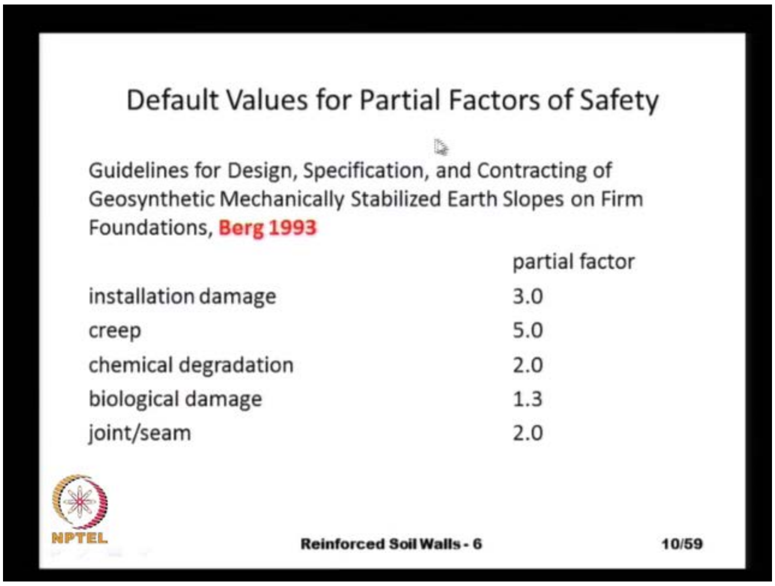

And these are some of the default partial factors of safety that were recommended with way back in 1993 is actually, in those days they used to use higher reduction factors, installation damage of about 3 was recommended. But, the usual installation damage factor is about 1.1 to about 1.3 then creep reduction factor of 5 that is, we consider only 20 percent, that again depends on the type of polymer.

And if you have a polyester type material your creep production factor is very low, maybe of the order of 2 or 1.5 and chemical degradation factor normally, we take it as 1, but in some aggressive environments we will have to do some site specific tests. And then biological degradation factor and then sometimes, the joints and scenes maybe more susceptible to the main parent material, that case we apply additional factor of safety.

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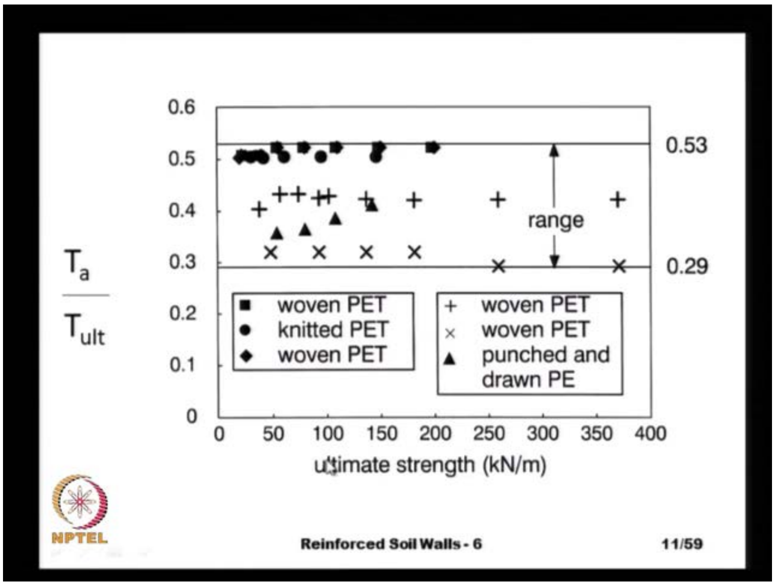

And this graph it shows the relation between the allowable strength as related to the index tensile strength for different type of products and the PET is the, polyester. And there are two types, woven and nonwoven type polyester and then polyethylene, these triangles. And as you can see, we use almost a 0.53 times or 53 percent of the tensile strength in the case of polyesters and we hardly use about 29 percent, in some case of polyethylene's.

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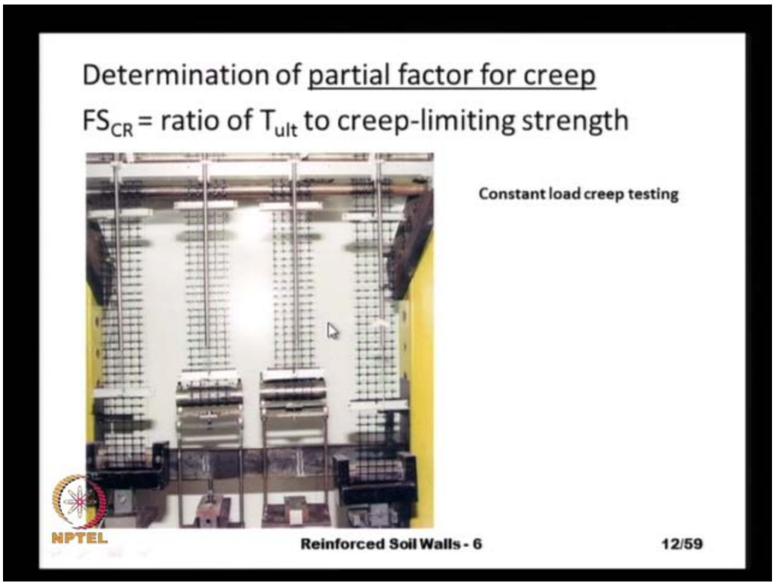

And this is a one picture of creep test, the creep is a constant load applied on the material and subjecting that to continuous elongation.

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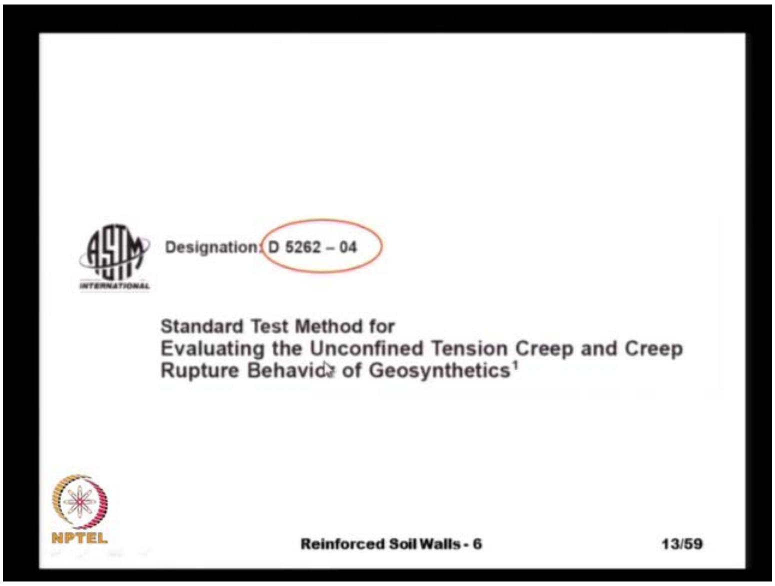

And there are different test that we can perform, as per the ASTM standards the one method is the unconfined tension creep and creep rupture behavior of geo synthetics that is the ASTM D 5262.

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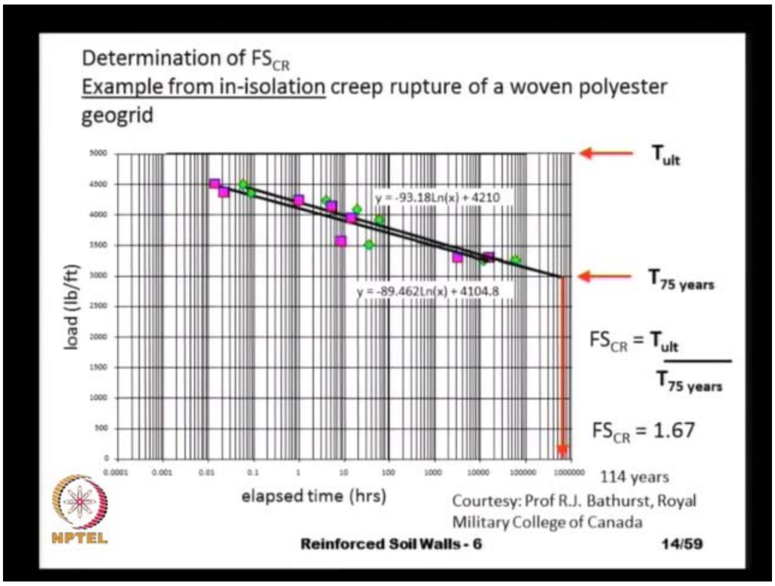

And if you develop the data and plot it versus time a typical data may look something like this on the logarithmic scale. We have the time on the x axis up to about 1 million hours that is equal to 114 years, then on the y axis we have the load. So, many pounds per feet, this is actually this is the data and that was supplied by professor bathurst. So, it is in the f b s units and the ultimate tensile strength for this is about 5000 pounds per foot and at the end of 75 years, it has strength of 3000 per foot and that is the creep limited strength and the FS CR that is the creep reduction factor.

We can now write it as the strength that we can use after 75 years to the ultimate strength under rapid test that is the index tensile strength test and it works out to 5000 by 3000 that is approximately 1.67. And we can do a similar test, but it is takes a very long time to generate this type of data, because we need to continuously subject the samples to continuous load.

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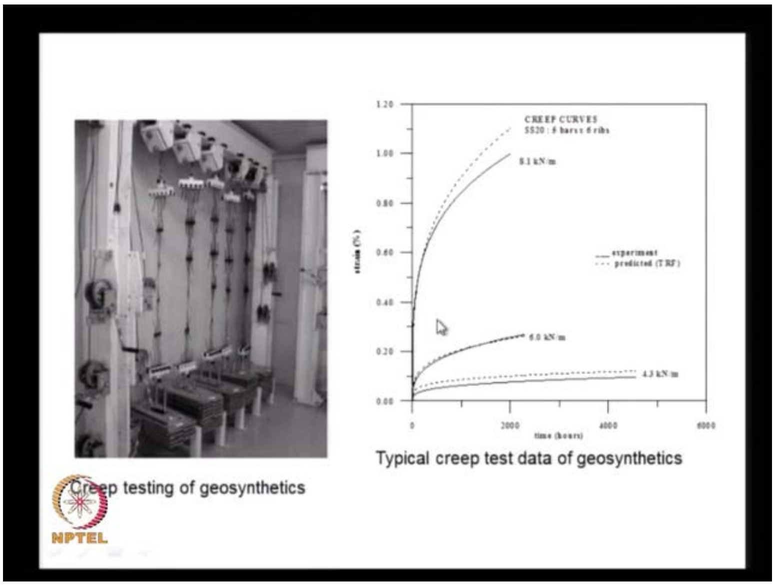

And there are other methods like it is once again the creep data this is from netlon UK and the right hand side, you can see this train that is developed at different load levels. Actually on the x axis we have the time, y axis we have the strain at different load levels this is for s s 20 that is there biaxial geo grid having a tensile strength of 20 kilo Newton's per meter.

When the load is very low at 4.3 kilo Newton's per meter, the study state is creep strain is very low about 0.1. And then at slightly higher load of 6 kilo Newton's is rapidly building up and at even higher load of 8.1 the strain in building up very fast, very rapidly and is actually this particular geo grid, is a polyethylene type geo grid.

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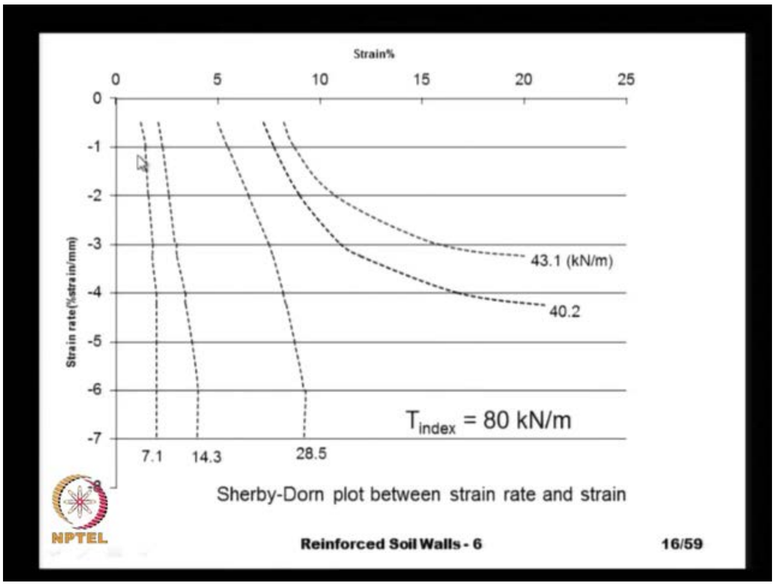

And the same data that we have, we can convert to another plot between the strain on the x axis and the strain rate, on the y axis. And the strain rate is as shown as negative because it goes on reducing with time and this plot is called as the sherby-dorn plot between the strain and the strain rate. And the, beauty of this graph is that as the, material is continuously and the creep at some point it reaches steady state creep; that means, that there are the strain reduces very rapidly.

Whereas in some other at some other load levels, the creep may be accumulating that it maybe failing or it may be rapidly undergoing strains. In such case we see that, the strain is increasing on then the strain rate is also increasing. And this particular data is for a uniaxial geo grid having a tensile strength of 80 kilo Newton's per meter, you see that up to about 28.5 kilo Newton per meter load, the material is fairly stable and the maximum strain is about 9 percent and after this, the strain rate is decreasing rapidly.

Whereas, at higher load levels of 40 kilo Newton's and 43 kilo Newton's the strain rate is increasing and the strain is also increasing. So, we could say that, say if you are interested in long term strain of 5 percent, we can draw a vertical line here and allow only the loads that cause long term strain of less than that much strain. So, this is one way of interpreting.

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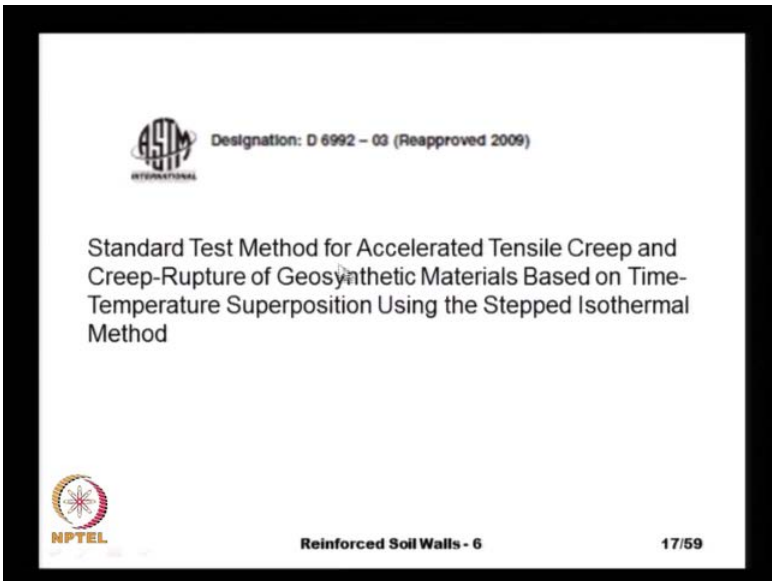

And recently the ASTM has come out with an accelerated drum test method, this is ASTM D 6992 this is the standard test method for accelerated tensile creep and creep rupture of geo synthetics materials based on time temperature superposition using the stepped isothermal method, is actually it is a very simple test.

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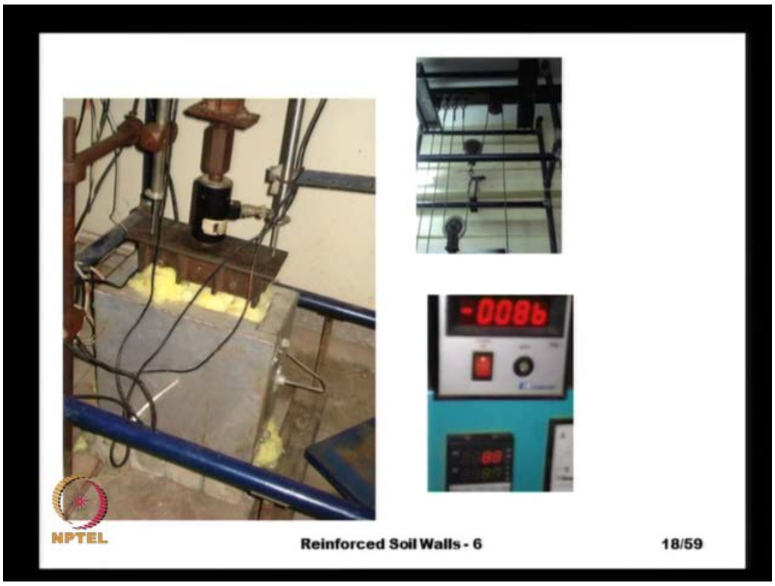

Wherein, we apply a constant tensile load, but then we subject the geo synthetic to some temperature increments, in steps of about 12 degrees to 12 to 15 degree centigrade depending on the type of polymer that we have. And here, we see an apparatus this is the box, the constant temperature box and the geo synthetic is inside and there is a probe to measure the temperature as close to the geo grid as possible and then the load is applied that is a constant load.

In this particular case, the device developed at IIT madras, the load is applied through some levers. So, if you apply small load it gets magnified and the larger load is transferred into the geo synthetic and you can see the applied load of 86 kilo Newton’s and as per the ASTM for geo textiles, we do the test on samples that are 50 mm wide.

And for geo grids, we can either have a single rib or 3 rib test just as in ASTM D 6637 and here, we have the temperature, the temperature as maintained at 88 degree centigrade. You can see this, this is the temperature control to control the temperature and each, we start from 20 degree centigrade then 32 and the 44, 56 and, so on we go in steps.

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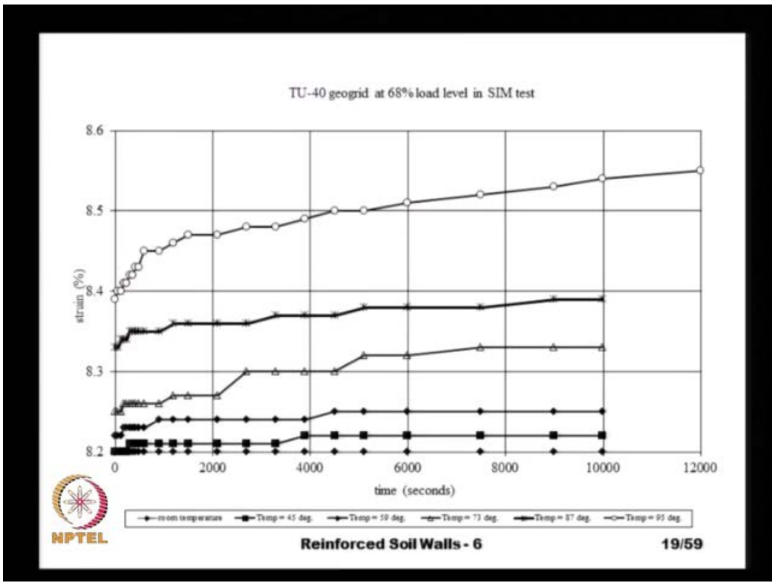

And then plot a graph something like this, is actually the each temperature increment is kept constant for at least 2000 seconds and then we subject it to temperature increments in the, this is the data that we have for one particular type of geo grid. And wherein the applied load was 68 percent and, at a temperature of 95 degrees this is the strain is increasing whereas, at the temperature of 87 degrees the, strains are more or less constant.

The y axis the strains are ranging from 8.2 to 8.6 it had to be elongated otherwise, we cannot see the, increase in the strain and from, these tests and there is a procedure to extrapolate this data this particular.

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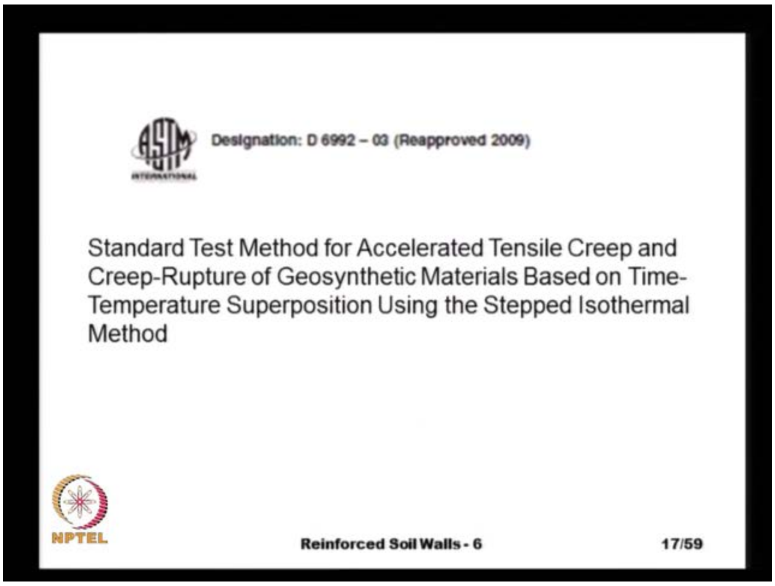

Test is called as superposition in the time scale because each temperature increment, accelerates the creep.

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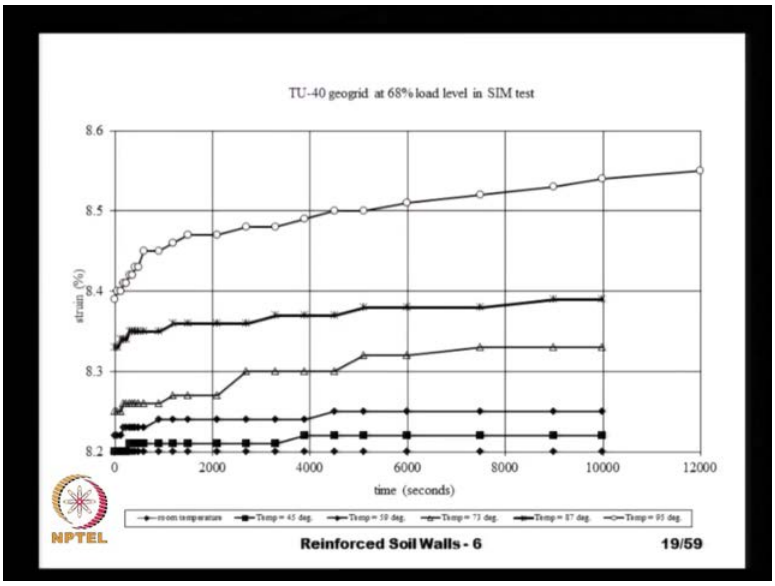

And then we, plot the data on to a log scale on the x axis and extrapolate the time and it is easy to, get the data corresponding to a very long term 75 years or 120 years, by just simply matching the slope, the initial slope that we get at higher at higher temperatures to that of the to the final slope that we get at lower temperatures. And this is actually it is become an acceptable method of for creep testing and many companies are using this scene test or the stepped isothermal method.

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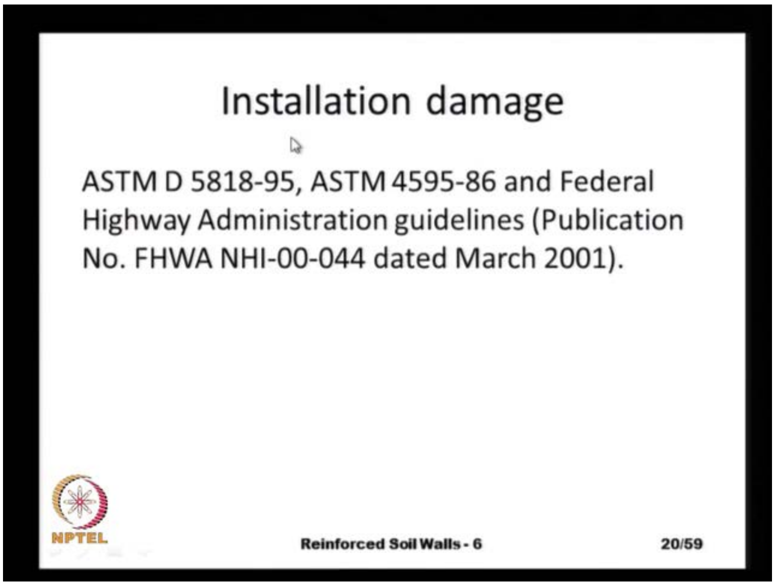

The other factor that we have is the installation damage, the ASTM D 5818 it describes the installation damage test and the federal highway administration guideline NHI 44 also talks about the installation damage test.

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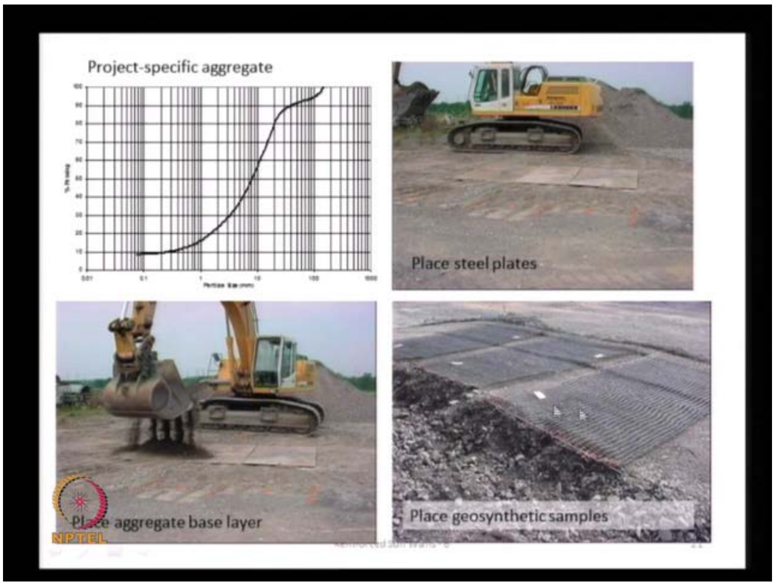

And this particular test is a field test and it should use the project specific aggregate, the aggregate that we are proposing to use in the site should be used. And we, as per the test procedure we place the steel plates and then we place the aggregate and then we place the geo synthetic.

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And then we place the cover aggregate and then we do the compaction as per our requirement to achieve the required proctor density and then after we compact we exhume the sample, here you can see the sample is being exhumed.

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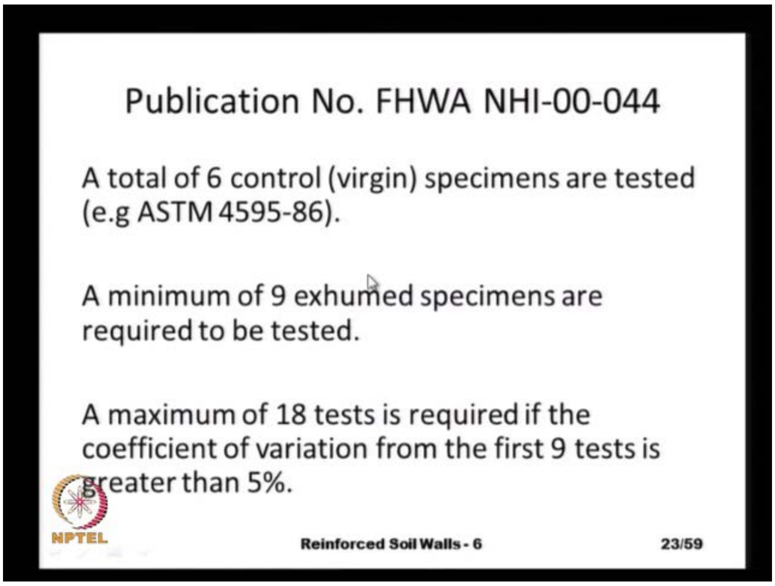

And then the as per the FHWA minimum 6 tests should be done on the virgin samples that is the, sample before we do any field test and at least 9 test should be done on the exhumed specimens. And if there is a large co-efficient of variation, the test method says that at least 18 tests are required.

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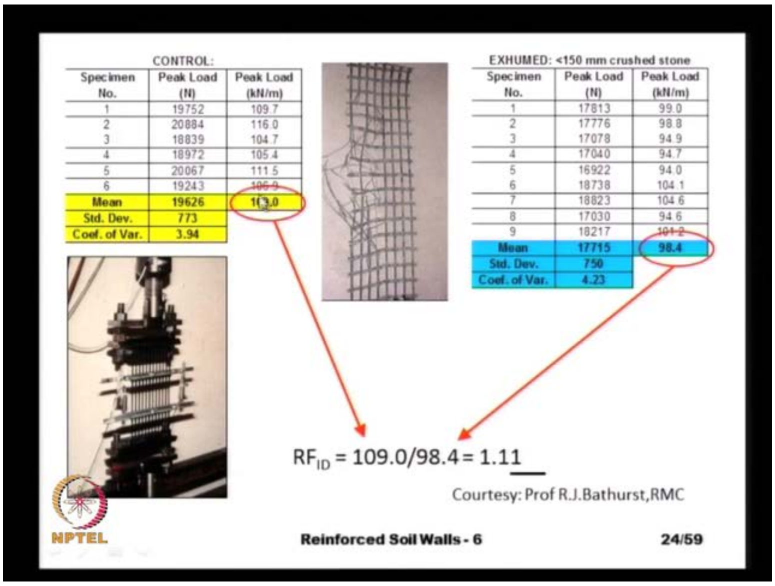

And this is the typical data, this is the test data on the virgin samples, these are all the different specimens the peak loads that we have on the laboratory sample and then the peak load, in terms of kilo Newton's per meter extrapolated to meter length and the average, tensile strength is 109 kilo Newton's per meter and these are all the data, on the test performed on the exhumed samples and the crushed stone is less than 150 mm and there are totally 9 samples.

And then we do the, standard tensile test just as how we do it for any sample and then we get the peak load and then we based on the data from 9 test, we can determine the variation and then of course, the standard deviation and in this case because the co-efficient of variation is less than 5 percent the data from 9 sample is adequate and the tensile strength of these damage samples is 98.4.

So, the reduction factor because of the installation damage is 109 that is the tensile strength of the virgin sample divided by 98.4 that is the tensile strength of the damage sample it is about 1.1 and this particular data all the slides, were applied by professor Bathurst at the royal military college of Canada.

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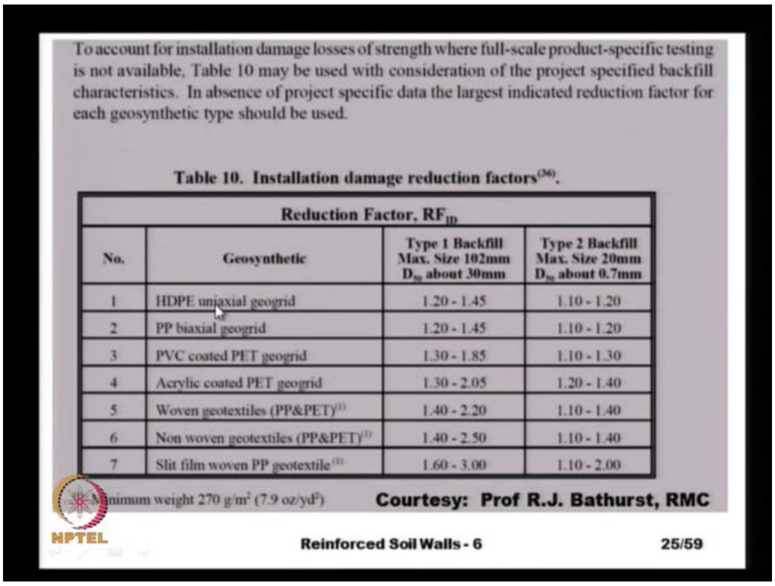

And this is a table, more recent table that recommends different type of installation damages for two types of backfills in this the ash stove, recommendation type 1 and type 2 and HDPE that is the hide and steep polyethylene uniaxial geo grid, type 1 it has slightly larger size aggregate. So, the damage factor is about 1.2 to 1.45 and when we have the polypropylene geo textiles, there are more susceptible to damage and the damage factor could be as high as 3, when we use type 1 in a backfill and then when we use type 2 backfill that is the normal soil, that we have in the reinforced soil backfills, is about two and for polyester type geo grids about 1.4. The absence of any test data, we can use some empherical data like this, but it is best if we do this the site specific test, so that we can, you can get a good idea of the installation damage.

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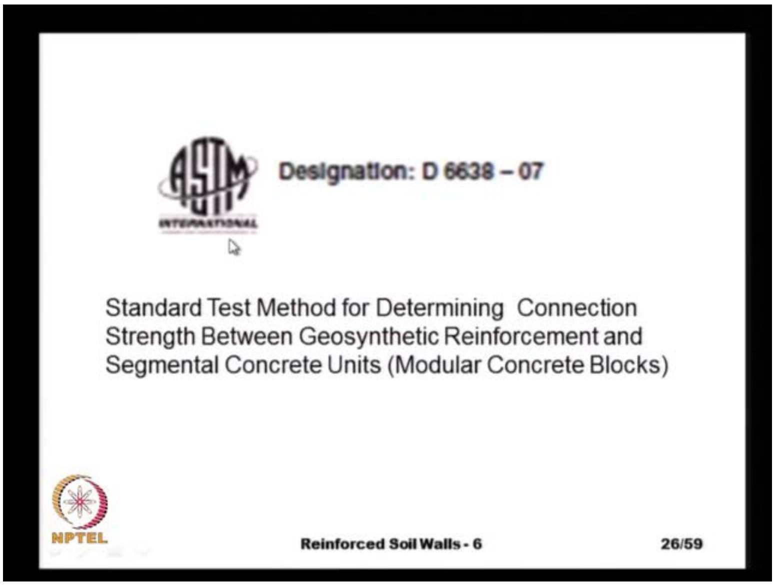

And apart from the tensile test, we perform a very large number of other tests and one test that we do is, the connection strength between the geo grid or the reinforcement and the facing panel and the ASTM D 6638 it, mentions the standards for testing for the connection strength, between modular concrete blocks and then the geo synthetics type reinforcements.

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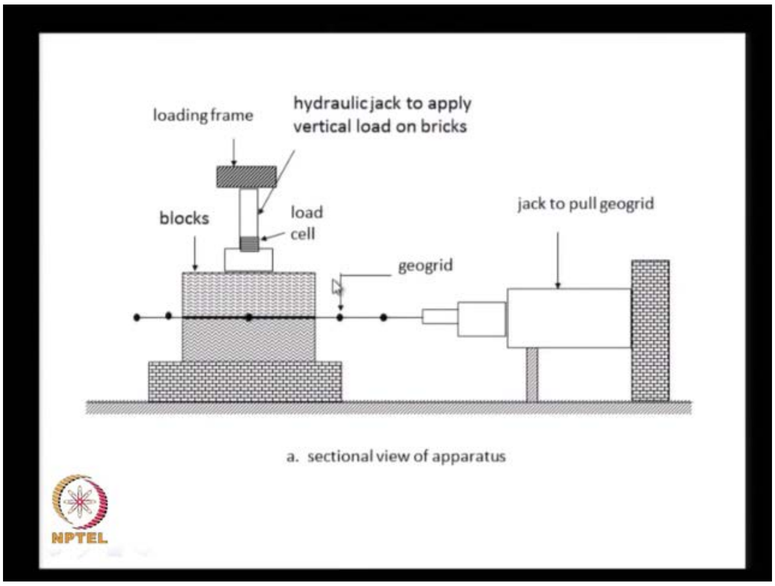

And a typical apparatus, it looks something like this, this is the schematic view we, there should be a facility to, lay the geo grid horizontal in between the two blocks, the facing blocks and then there should be a facility to apply a constant, vertical load that corresponds to a different levels of the vertical load that we can have in the field.

Then there should be a hydraulic jack that, can apply it is actually it is an actuator because we need to apply the pull out load, at a constant rate and then there should be a facility to electronically record the data both, the pull out displacement and then the load that is developed.

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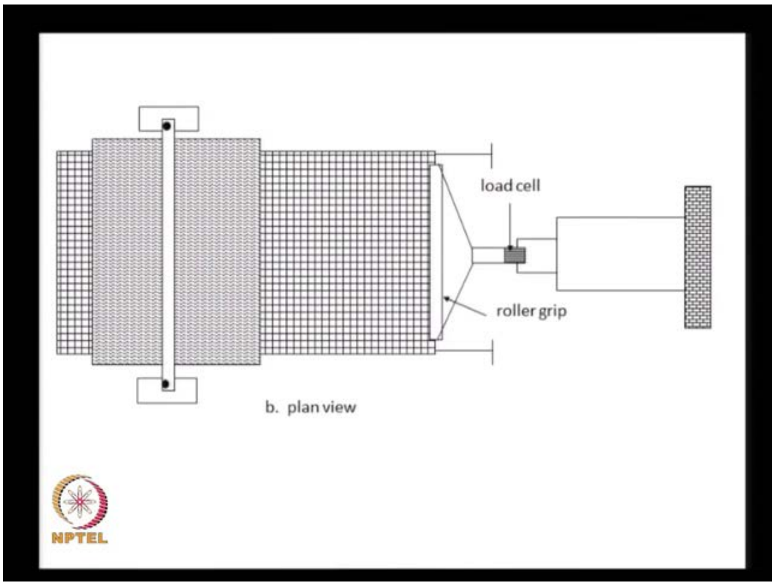

And in plan, it looks something like this, there should be a good gripping at the front. So, that there is no slippage between the grip and the geo grid or the geo textile.

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The apparatus at IIT madras is shown here, is actually this is a test tank, which is nearly 1 meter wide and 1.5 meters long and we have the actuated, the hydraulic actuator that runs on hydraulic pressure and the speed can be controlled anywhere from 1 millimeter per minute to 20 millimeters per minute and these are, all the instrumentation associated with it the load cell and then the LVDT the displacement indicator.

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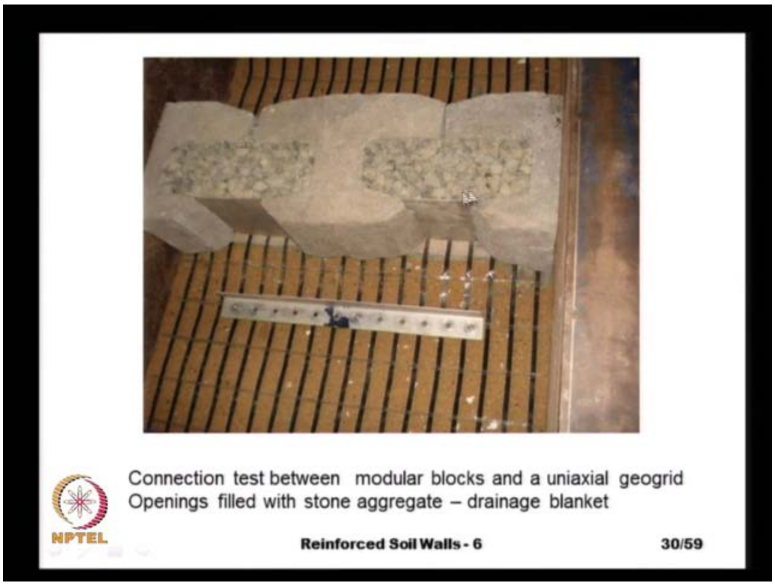

And here, we see a test as specimen being prepared, to determine the junction strength sorry the connection strength between a uniaxial geo grid and then the modular blocks and the in filled material that we use inside these, modular blocks during the test should correspond to the type of aggregate that is used in the site, in this particular case the stone aggregate is the drainage blanket.

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And this is how we need to measure the deformation as close to the phasing block as possible, this is an LVDT to measure the displacement.

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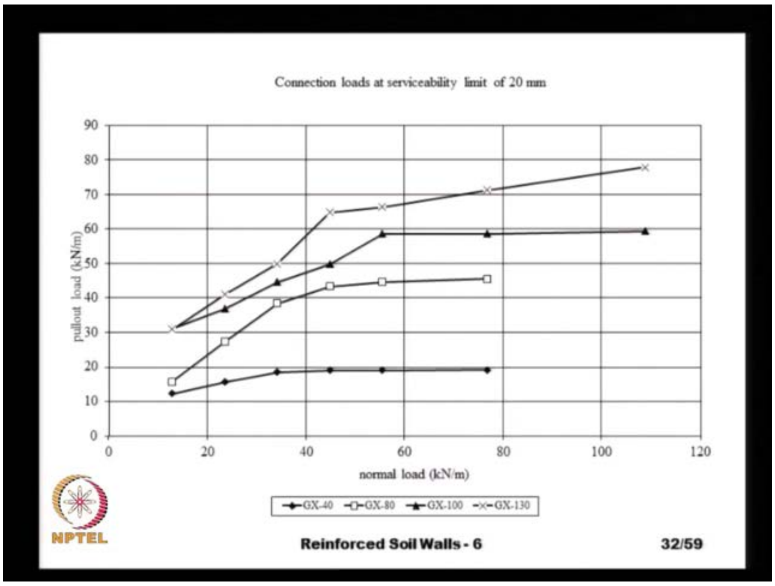

And the typical data, we have is given here and this is for the serviceability limit of 20 millimeter displacement and for different types of geo grids, having tensile strengths of

40 kilo Newton per meter 80, 100 and then 130 at different load levels, the x axis we have the normal load. So, many kilo Newton's per meter, this corresponds to the height of the wall and to different heights of the wall and here, we see that for example, this the lowest strength geo grid, having a tensile strength of 40 kilo Newton's per meter.

Initially at very low normal loads, the connection capacity is about nearly 12 kilo Newton's per meter, but beyond a vertical load of about 35, the connection capacity is constant whereas, the highest strength geo grid that is 130 at very low normal load, the connection strength is about 30 and the connection strength goes on increasing with applied vertical load, goes up to almost 80 kilo Newton's per meter at a vertical loader of 110 kilo Newton's per meter.

And this is for the serviceability limit state, and this is the ultimate load that, is developed that is the maximum rupture load and this for the g h 40 that is the lowest strength geo grid, it is slightly higher than, the serviceability limit state load 20 kilo Newton's whereas, for g x 130 the strength is improved, the ultimate strength increases much beyond the serviceability limit state strength. And in our designs at the maximum load that we, allow inside a geo grid should be corresponding to the into the connection load. Because, if the axial load and the geo grid exceeds, the connection capacity could be there is a possibility for separation between the block and the geo grid.

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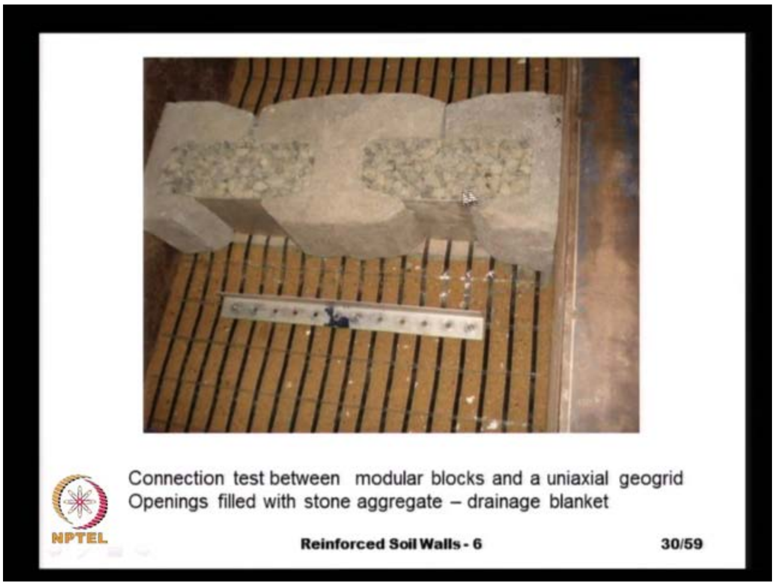

And this is a picture of test done on some other type of connection, some companies prefer to use, what is known as the positive connection. Here, at the time of casting these panels, some hooks are casted inside and usually these hooks are provided at spacing of about 200 millimeters to 300 millimeters depending on the tensile strength of the geo grids. So, that they are planning to use.

And there is a rigid connection, between the geo grid and the panel through this cross rod, usually this cross rod is about 12 millimeters to 60 millimeters and all these are, made of high heal strength steel HYSD. So, that there is a higher strength, and higher ductility and this is the inside of the test tank, that we have. It is this sample is about 850 millimeters wide, and this block is, nearly 1 meter wide.

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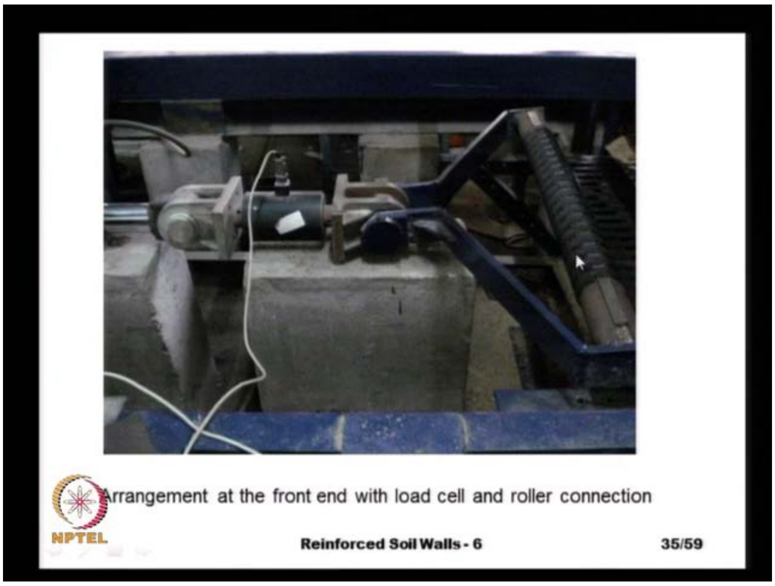

And this is the front connection, can see the roller that is used. So, that we have a good grip and this is the load cell, that we use for measuring the loads.

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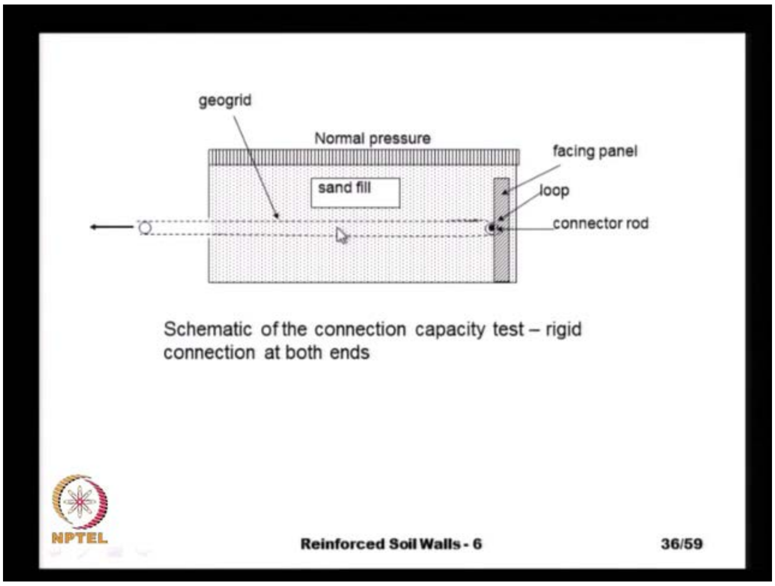

And there are two types of connection that we can test, one is wherein both ends of the geo grid are rigidly connected to the actuator whereas, the backend is connected through a connector rod and the loops, just like here.

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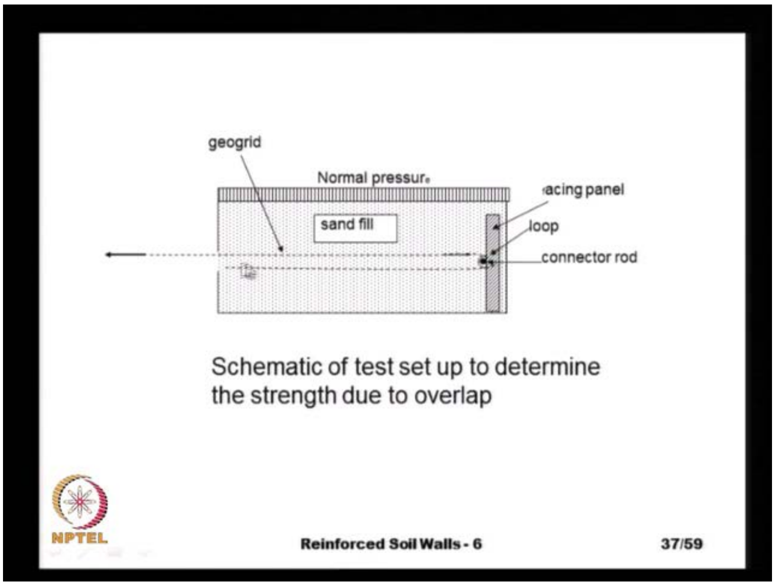

Another possibility is, we have just an lap length. Sometimes, depending on the load level that are developed, we may have just a simple lap whereas, in some cases the reinforcement from one level, goes up and then comes out, into the backfill once again and in that type of for connection is more similar to this test situation whereas, the lap length is more similar to this.

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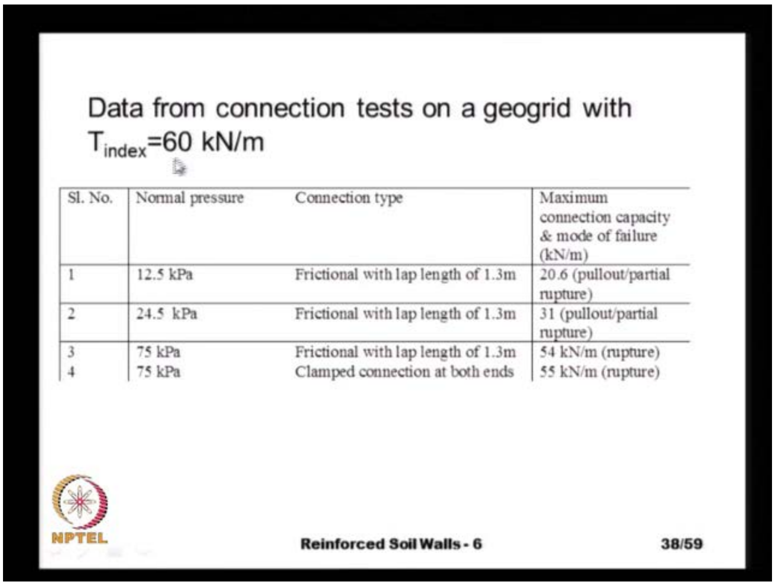

And this is the data on a geo grid having a tensile strength of for 60 kilo Newton's per meter, at a lower normal load of 12.5 and with a lap length of about 1 meter, 1.3 meters the pull out maximum, pull out load is the only about 20. Whereas, if we increase the normal pressure to 75 k P a, is actually this 12.5 k P a corresponds to about a half a meter of soil fill, at that low normal pressures, the pull out capacity is low, but as we increase the normal pressure the, connection strength is almost equal to the tensile strength.

Whether, we have clamped connection or a frictional connection with a lap length of 1.3 meters, and this lap length of 1.3 is given with slightly more than 1 meter as per the federal highway administration guidelines, we require at least 1 meter minimum length beyond the rupture plain; that means, that will have an embedment length of 1 meter. So, because of that, this was taken and at intermediate pressure of about 24 k P a failure is by pull out 31 kilo Newton's per meter that is about half the tensile capacity.

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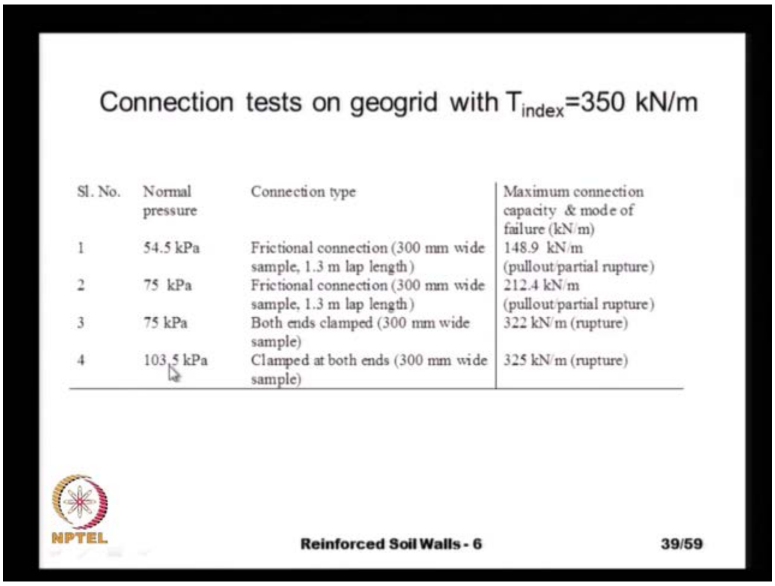

Sl. No.	Normal pressure	Connection type	Maximum connection capacity & mode of failure (kN/m)
1	54.5 kPa	Frictional connection (300 mm wide sample, 1.3 m lap length)	148.9 kN/m (pullout/partial rupture)
2	75 kPa	Frictional connection (300 mm wide sample, 1.3 m lap length)	212.4 kN/m (pullout/partial rupture)
3	75 kPa	Both ends clamped (300 mm wide sample)	322 kN/m (rupture)
4	103.5 kPa	Clamped at both ends (300 mm wide sample)	325 kN/m (rupture)

And this is the data for very high strength geo grid, and at a normal pressure of about 100 k P a the rupture capacity, is almost very close to the tensile strength and, usually the positive connections, like this they give a connection efficiency of almost 85 to 90 percent or even 95 percent. And that connection efficiency is basically, the connection load that we develop, divided by the tensile strength.

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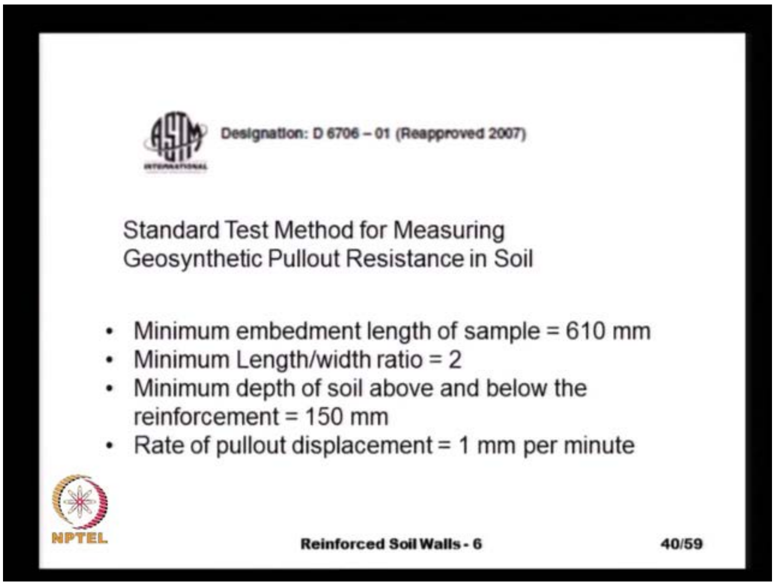

And we also need, some data on the pull out factors and the ASTM standard for determining the pull out resistance between, the geo synthetics and the soil ASTM D

6706 and this, test specifies some minimum dimensions, the minimum embedment length of the sample should be, at least 600 and 10 millimeters and the length to width ratio should be at least 2. So, means that if our length of the sample is 1 meter, the width should be half or less than half a meter and minimum depth of soil, above and below the reinforcement is 150 millimeters. And then the rate of pullout displacement is, approximately 1 millimeter per minute.

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And here, we see a sample of a geo grid of being tested under pull out, from a gravelly type soil this is a picture inside the, inside the soil and the front end.

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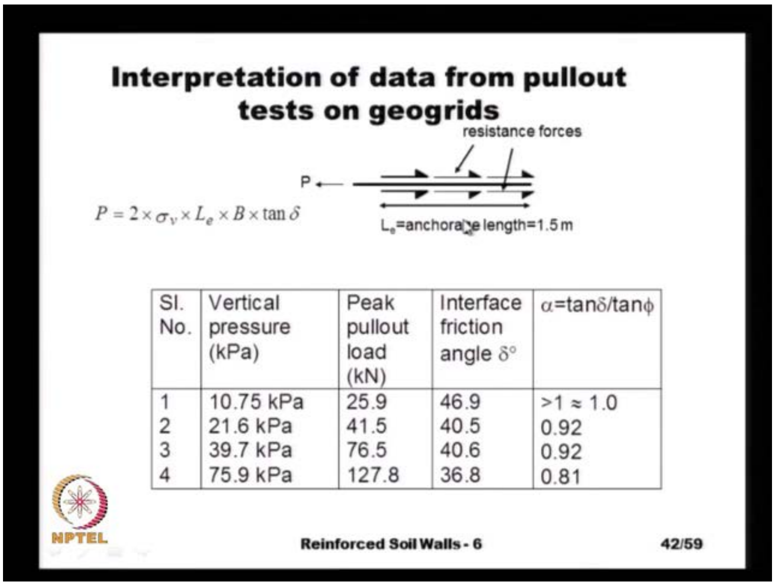

Sl. No.	Vertical pressure (kPa)	Peak pullout load (kN)	Interface friction angle δ°	α=tanδ/tanφ
1	10.75 kPa	25.9	46.9	>1 ≈ 1.0
2	21.6 kPa	41.5	40.5	0.92
3	39.7 kPa	76.5	40.6	0.92
4	75.9 kPa	127.8	36.8	0.81

And this is how we, interpret the data on the pull out test, say if you are l is the embedment length, in this case the length of the tank is 1.5 meters. So, our anchorage length is 1.5 meters because the geo grid was placed for the full length of the tank, the resistance is developed both on the lower surface and the upper surface like this, and the pull out load p can be related to the shear assistance, as two times because we have two surfaces sigma v that is the vertical pressure and L e is the length of the anchorage length B is the width of the geo grid sample times delta.

And at different vertical pressures, we measure the pull out load and then determine our delta and then the, interaction parameter alpha and for example, here at a vertical pressure of 10.75 k P a at the pull out load is nearly 26 kilo Newton’s and if you substitute all the numbers here, the delta comes out as 46.9 and because of this the alpha that is the interaction parameter tan delta by tan phi which is at a low pressure it is greater than 1.

And at slightly higher pressure of 21 kilo Pascal’s, the interaction parameter is almost 0.92 and as we, increase the normal pressure, the interaction parameter usually decreases and then it reaches a steady state. And we see that, at very low normal pressure this interaction value is much more than 1, sometimes it is as high as 1.5 to 1.6 that is because of the dilation that happens is because of cross members that we have in the geo grids. And at very high normal pressures, the dilation is suppressed and only the true strength of the material is developed.

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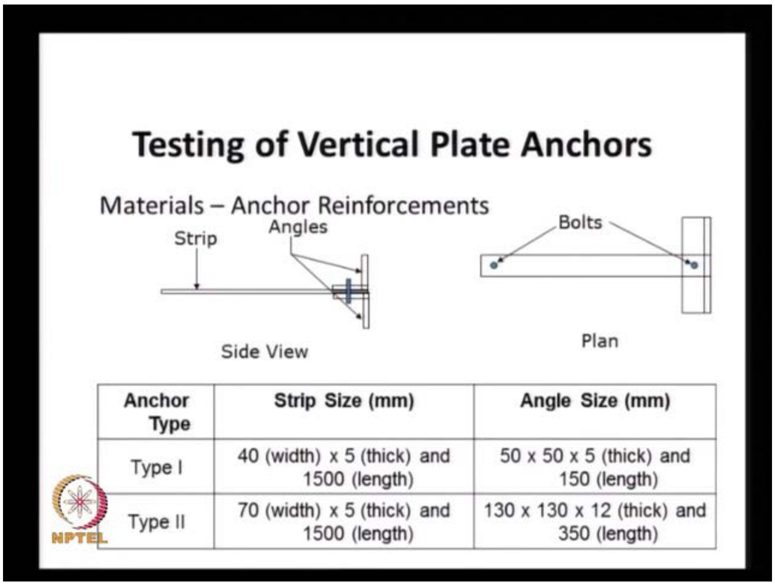

And sometimes when we have a steel strips, we provide some anchors at the end and the BS code, gives the method to estimate the pull out capacity of anchored reinforcement elements whereas, the ash toe and the federal highway administration codes, they do not talk about the anchors. And I will just briefly describe the test that we have done, for developing the, anchors capacities for one particular company.

And when we do this test, is very important that the connection between the steel strip and these anchors, should be strong; that means, the bolt that we use should be strong enough that it does not rupture or it does not shear off and, there are two types of steel strips that are used by this company, one is 40 millimeters wide by 5 mm thick and the other is 70 mm wide by 5 mm thick. And two types of l angles are used 50 by 50 and 130 by 130 and the first one is called as the type one and the second is called as type two in our designation.

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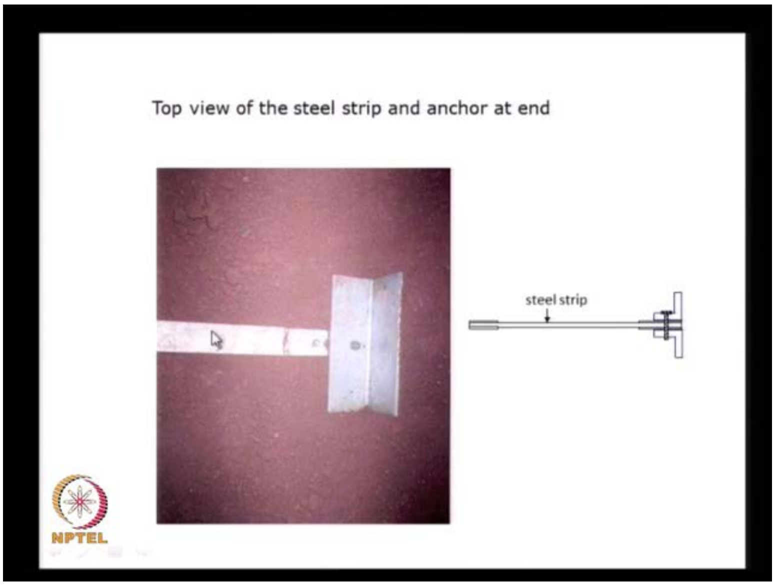

And this is the picture from the test and is actually the initial test, they have shown that when we did the test, the bolt has just simply sheared off and to increase the, anchor capacity what we suggested is they, should wield a another steel plate. So, that the shear load is distributed over a higher thickness and this is what happened, that is the steel strip at both ends, we recommended that they wield at least 3 millimeter thick plates. So, that it the contact area has increased.

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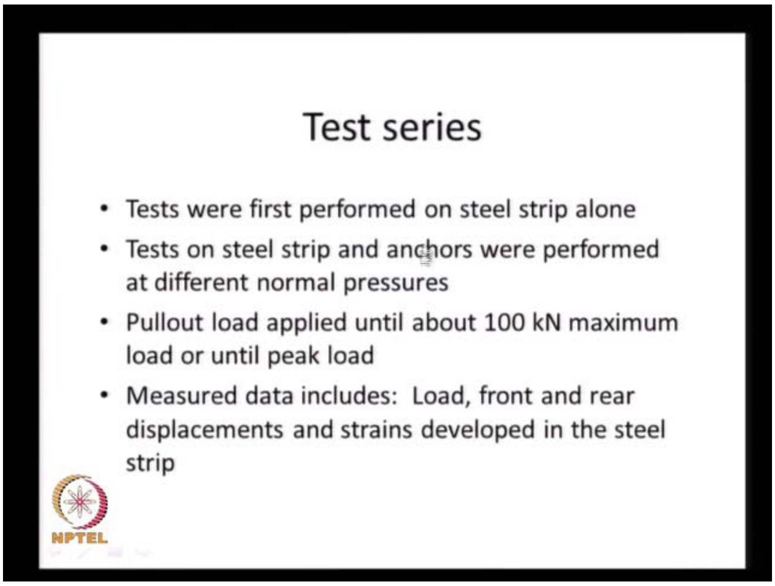

And the different test were performed on the steel on the, some tests on the steel strip alone. So, that we can develop the interaction parameter and then on the steel strip plus the anchors and the measured data includes the load and then the front and the rear displacements and then the strains developed along the length of the steel strip.

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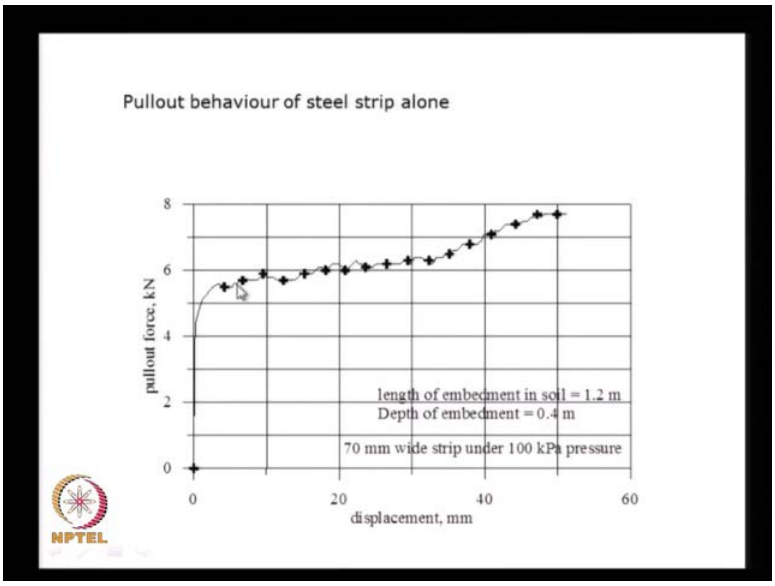

And this is the typical data, and the tests that were done on steel strip alone and the length of the embedment, was 1.2 meters and the depth was 0.4 meters.

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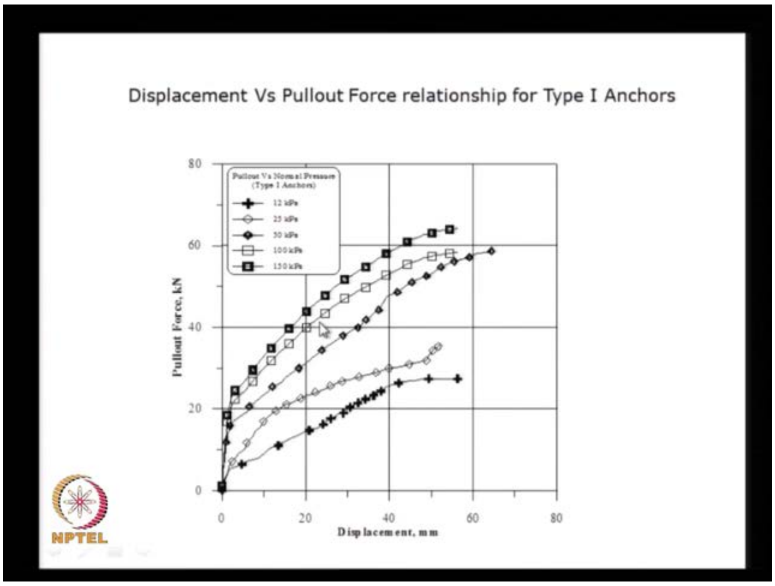

And this can be interpreted for our friction angle or the friction factors, and this is the pullout force, for type one type anchors.

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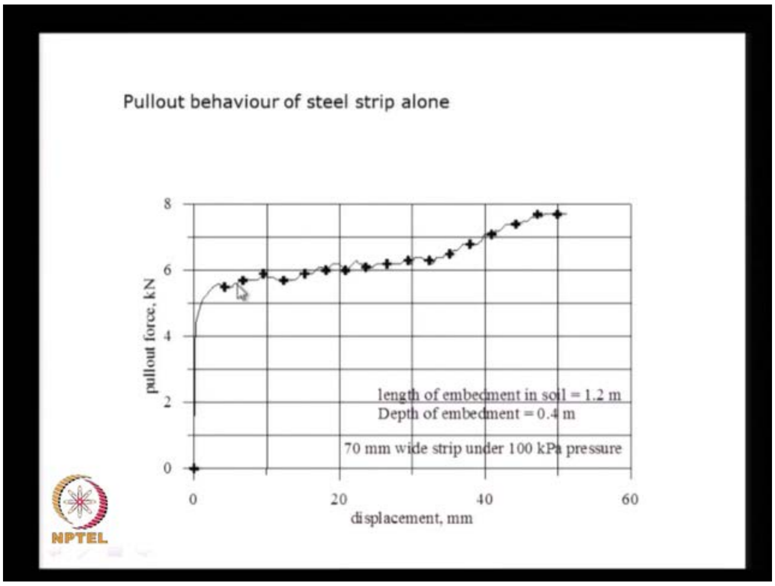

The actually here, when we have a pure steel strip without any anchor, the maximum load that was developed is only about 8 kilo Newton's and this 8 kilo Newton's is very low compared to the tensile strength of the strip.

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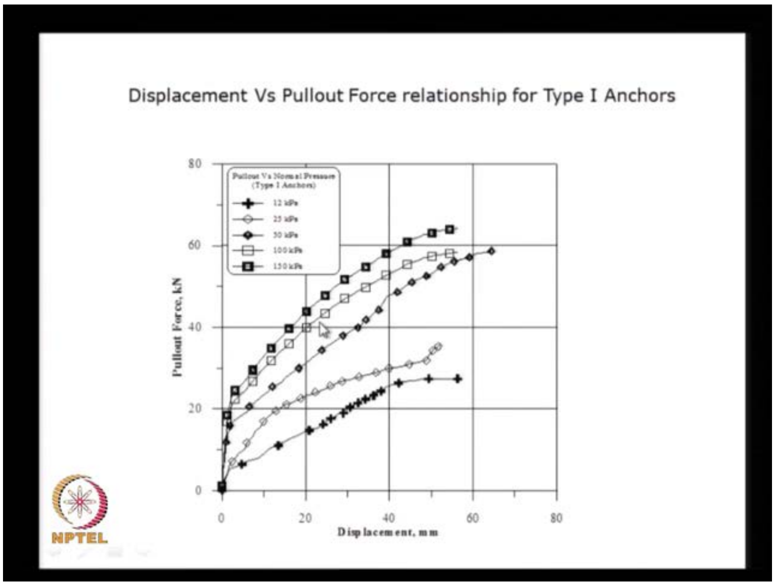

And when we attach an anchor, we can increase the pullout force to much higher values at some high normal pressures this load is as high as 60 kilo Newton's and at very low normal pressures of 12 k P a that is corresponding to half a meter of soil, the pullout force is about nearly 30 slightly less than 30.

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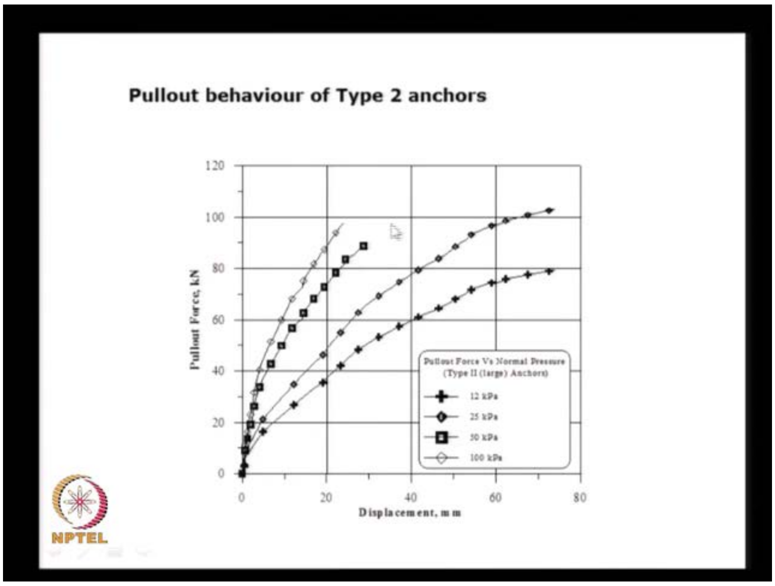

And when, we have the type two anchors, the pullout force is much higher than type one anchor.

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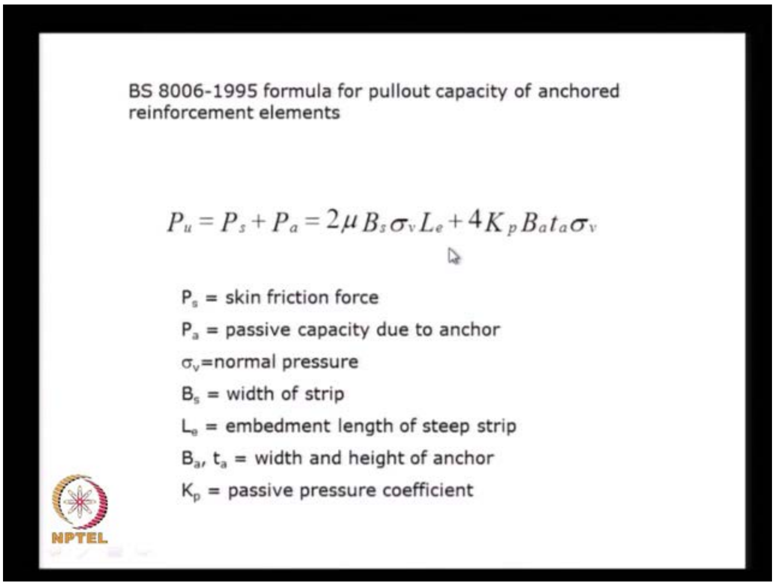

And this data that we have can be interpreted using our the B s code formula that is the pullout capacities because of the surface friction and then the passive resistance developed against the anchor, that is two times new B s that is the width of the strip sigma is the vertical pressure L e is the length of the strip plus 4 times the K p that is the passive pressure co-efficient of the soil and B a is the width of the anchor, t a is the height of the anchor, and then sigma is the vertical pressure.

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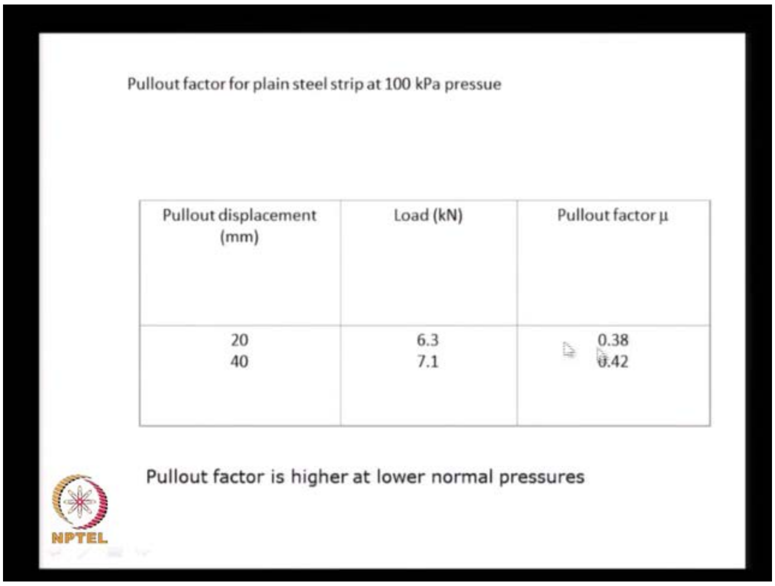

Pullout factor for plain steel strip at 100 kPa pressue

Pullout displacement (mm)	Load (kN)	Pullout factor μ
20 40	6.3 7.1	0.38 0.42

Pullout factor is higher at lower normal pressures

And the pullout factor, for the steel strip is something like this, is very low about 0.4 because the steel strip being a smooth surface and the pullout factor is about we get very low value whereas, for geo grid the pullout factor is nearly equal to 0.9 to 1 very low normal pressures.

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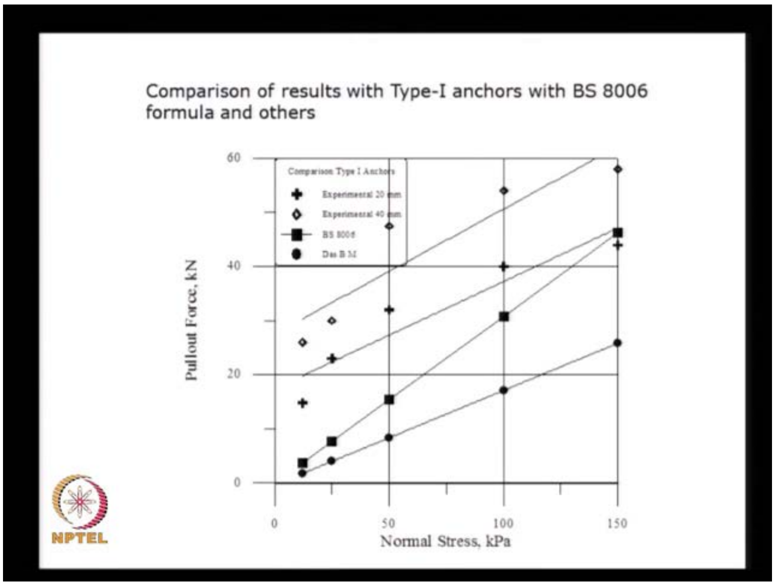

And these are the these are the comparison between the experimental measured pullout capacities and then those estimated from BS 8006 and then the, equations proposed by BM das, is actually this is the experimental data at 20 mm displacement is given, by this plus signs. Whereas, the hollow diamonds is the experimental data slightly higher displacement of 40 mm actually these are all the ones.

And the on the BS code the estimate is given by, solid squares and then the BM das formulas are like this. So, we see that, the measured pullout capacities are much higher than those from the BS code and; that means, that there is lot of conservativeness in the codal formulas.

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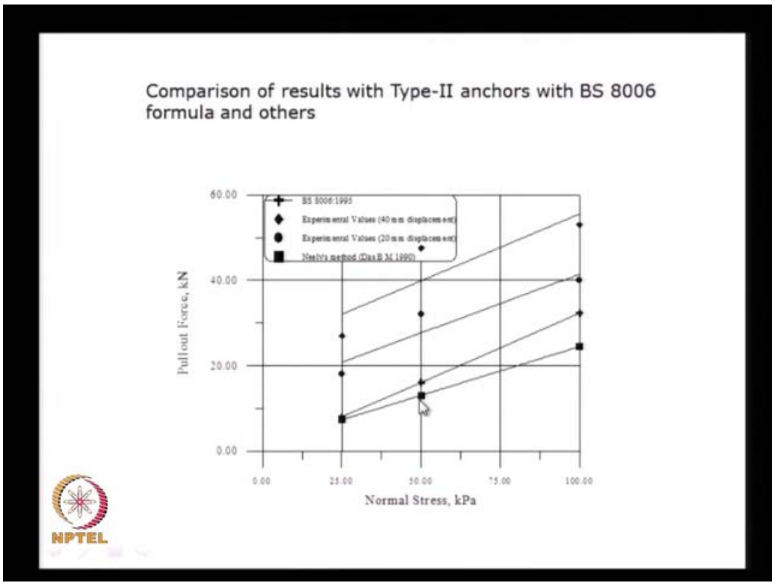

And other theoretical estimates and the same thing for even the type two anchors, is actually the measured strengths are much higher than, those predicted from the BM das formulas.

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And we can do these pullout tests, on different type of reinforcements and one type of reinforcement that is commonly used is the polymer strip, which has a width of about 60 mm and it can be placed for any length because it comes in rolls and here we, see some pictures, is actually when we do some testing on this type of strips.

Which are very hard we need a special grip, for gripping it the front and we have developed a special grip that has a some serrations, these serrations are formed by wielding steel rods to the steel to the steel plates. Then they are connected together and they were bolted like this, to get a good bond.

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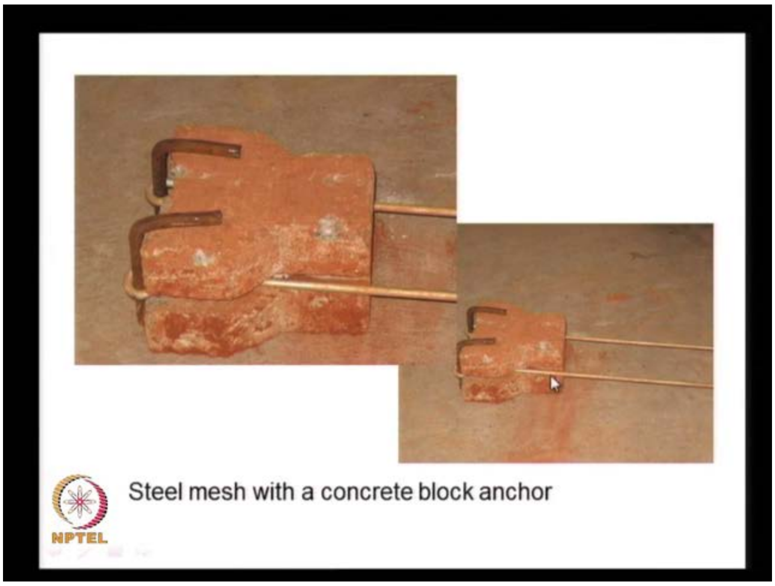

And some companies they use, in place of for steel anchors they use, even the concrete blocks and here, we see one company using concrete blocks as anchor elements to connect their steel measures.

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And when, we have steel measures, we can have different type of connection to the panels and through the hooks, and through the loops and we need to do the test, to make sure that, these connections they develop adequate pullout capacity. Then we also have to make sure that, the steel that is used is strong enough, sometimes if the steel mesh is made up on brittle steel, it will just simply break.

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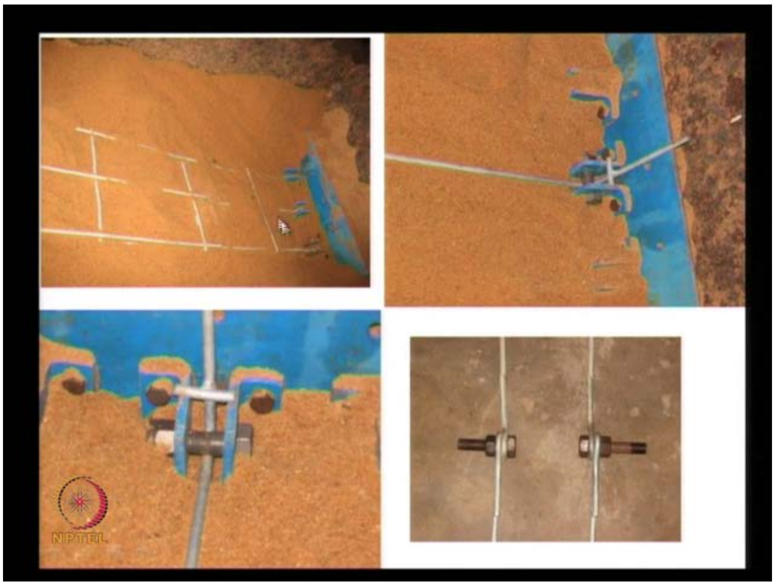

And here, we see number of test configuration. So, this the steel ladder and is connected the backend to stimulate the connection to the facing and here, we have this steel rod and that is connected by means of a crossbar, like this and in some cases we can have bolted connection or we can have a steel rod running across.

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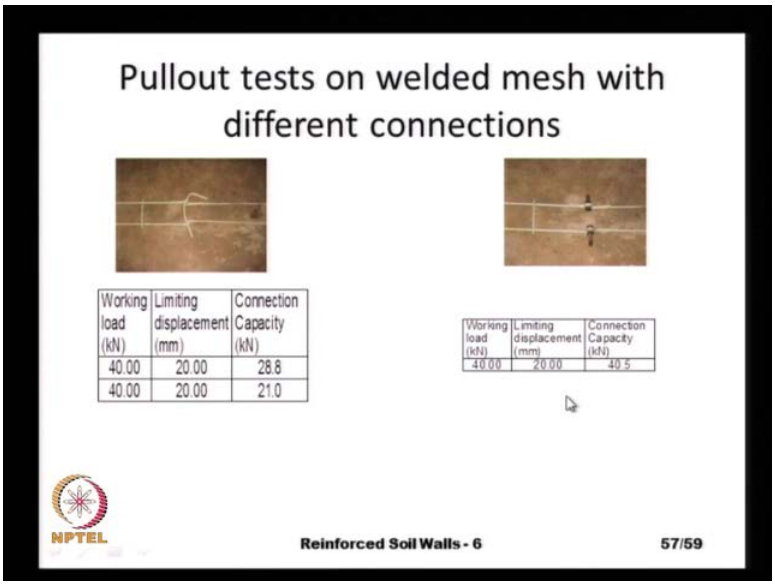

And it is not necessary that all the connections, they give a good strength. And in this case when these steel measures are connected by 12 mm steel rod like this, the steel rod is just simply bent and it was not able to develop the load here we can see, the working load for this particular mesh is 40 kilo Newton's, at a limiting displacement of 20 millimeters, the connection capacity is hardly 28 is actually different test were done and the two data's are reported here in one test, this connection capacity is hardly 21 whereas, in another test it has come to 29 whereas, the working load is about 40.

And that is because this cross rod if it is not of sufficient diameter it will just simply bend and you can see, the bent bar here and if we use, a stiffer connection either a bolted connection or larger size rod, we can increase the connection capacity and the same steel ladders, tested with a more rigid connection it has developed a connection load of about 40.5 at a limiting displacement of 20 millimeters and it is ultimate, capacity is much higher it is about the order of 55.

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And, these are all some of the of the failures that we have and here, in one case the steel hook is provided just simply broke that is because it has become very brittle, in and the process of bending it they have treated it properly and in some, cases these loops they just open out.

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Is actually here we can see, this loop has just simply the toggle that was provided they just simply broke and in one case, the panel itself just simply broke open because it did not have adequate structural reinforcement and in some cases, if our cross rod is not of sufficient diameter it will just simply bend, like this or we have seen another examples of this bent bar.

And in all such cases, the connection capacity will not be high and we have to revise, this particular case this the panel was redesigned, by putting in more structural steel reinforcement. So, that there is no break out at the point where we connect the, in the strip to the facing panel and in this particular case, it was the problem of the steel, it was not properly treated it has become very brittle. And in this case, these polymeric strips they were not cast properly to the concrete. So, it has just come out.

So, this the only through the appropriate laboratory tests we can determine the connection strength, and then the pullout factors and then the tensile strength of the of the reinforcement and, so on. And all this data, they go into the and to the design of the reinforced soil retaining walls.

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So, thank you very much and if you have any questions, you can contact me by this email address.

Thank you.