Geosynthetics And Reinforced Soil Structures
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Lecture - 31
Geosynthetics in Flexible Pavements – I

A very good afternoon students, in today's lecture let us look at the design and construction aspects of the road pavements using the geosynthetics.

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Well, all of us know that we require good pavements, so that we can drive the vehicles comfortably on the roads. And some of the requirements of these roads, the road surface should remain smooth and unyielding that is, when you drive at the vehicle either car or a scooter, the surface should not penetrate into the ground. How it happens when you drive on a wet mud road, it should be unyielding. So, that the free movement of the vehicles is ensured and it should provide a good support in all the seasons.

That is very important, because these roads are open round the year all the time. And so even in the worst of the rainy season, the road surface should provide a good ridable surface. And the thickness of the pavement it should be sufficient to reduce the tyre pressures, that are applied of the road surface to aim less than allowable bearing pressures, when these pressures are transferring into the subgrade and depending on the how we construct, we can categories the pavements into two categories. The first one is the flexible pavement. This consists of multiple layers, which have very low or zero flexural strength. As you may recall, the flexural strength is the bending stiffness or the bending strength that we have, what we studied in the case of simple supported beams and other cases. And then the other type of road pavement could be a rigid, rigid pavement like rain force concrete pavement. This consists of rigid layer, which has excellent flexural strength and stiffness. So, no matter what is below that pavement, the load is as a distributed over a very wide area, thus ensuring that the rider comfort is ensured.

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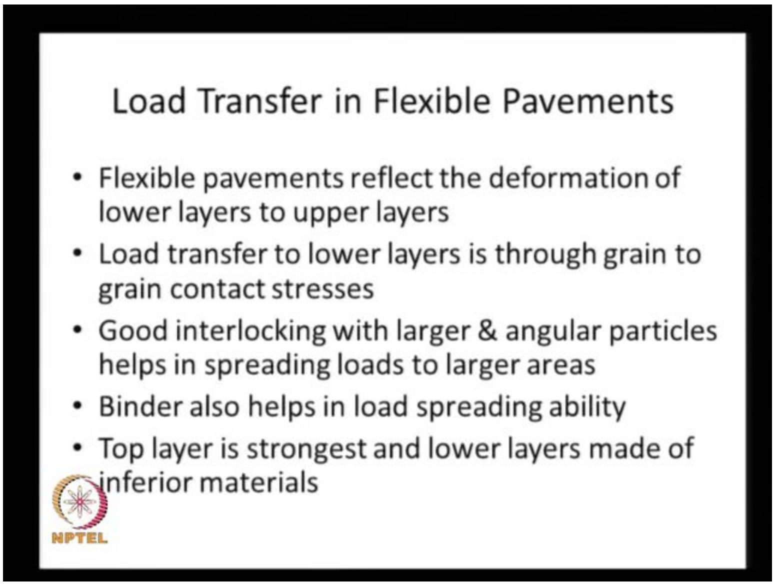

Well let us look at the load transfer in the flexible pavements. And the use of geosynthetics is more or a predominant use of geosynthetics is in the case of flexible pavements, because in the case of rigid pavements like reinforce concrete pavements, we may not require any geosynthetics. So, these flexible pavements, they reflect the deformation of the lower layers to the upper layers. That is because they do not have any flexural stiffness.

Whatever happens in the lower layer, gets immediately reflected up to the upper layers and the load transfer to the lower layers is through grain to grain contact between the particles. So, if there is good contact by way of very coarse grained particles and a good interlocking, we can expect a good load transfer to the layers below. And good interlocking with very large and angular particles helps in spreading the loads to larger areas.

Our object is when the load is transferred to the pavement; it should distribute over as wide an area as possible, so that the pressure that we are a transferring into the subgrade is reduced. And apart from the good interlocking sometimes we may use binders, they could be a bitamin binder or cement binder. Binder also can help in load spreading ability. Once you are able to bind the particles together, they may act as semi rigid layers. And these flexible pavements, the uppermost that is the top layer is the strongest and as we go down, as the pressure is decreasing, we can use more inferior materials that are less strong.

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So, here we see an example of the wave pattern that is a reflected from bottom layers. What we are looking at is a container yard that is built on extremely soft clay and the because of the applied loads, the pressures are transferred into the soft place soil. And because this soft place is extremely soft, it has formed the mud way pattern and that same thing is reflected to the ground surface. And our object of constructing these pavements is, these types of a reflection do not happen, whatever angulations that are there in the layers below, they are not reflected to this top surface. Because once this happens the readability it decreases and we cannot use this surface any more.

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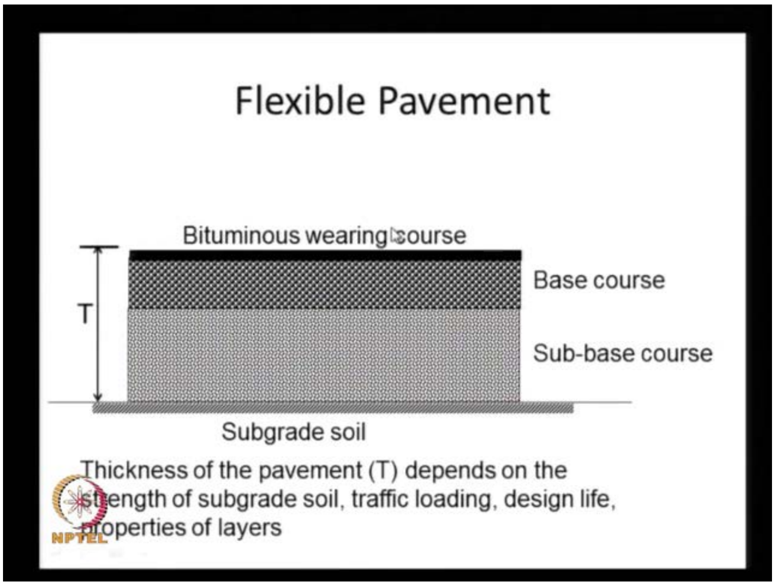

Well, here is a transaction of flexible pavement. What we see at the top is the bitumen wearing course that is made of Bitumen Rashfalt or just simply thar that we use in India and then we have base course and then a sub base course. The base course usually consists of very large stones whereas; the sub base course may consist of a smaller stones. And this thickness of the pavement that is consisting of the sub base course and then the wearing course, this total thickness T depends on the strength of the subgrade and then the traffic loading with the design life, the properties of the individual layers and so on.

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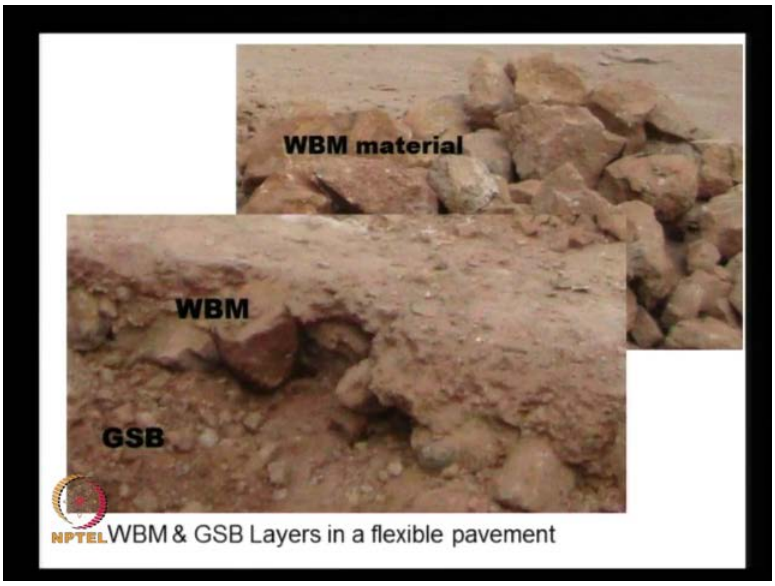

And here we see some examples of these base course materials, this is the WBM water bound macadam. Actually these are very large size stones and here you see the trisection of a flexible pavement with a very large size stone that are bound together by using a some granully soil, morrum soil. And below this we see this GSB that is the granular sub base and both the WBM and the GSB layers, they are usually highly porous so that they also act as drainage layers in our pavements.

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And here you see this, the close up of the granular sub base layer, which is consisting of the smaller sized particles as compared to the base course.

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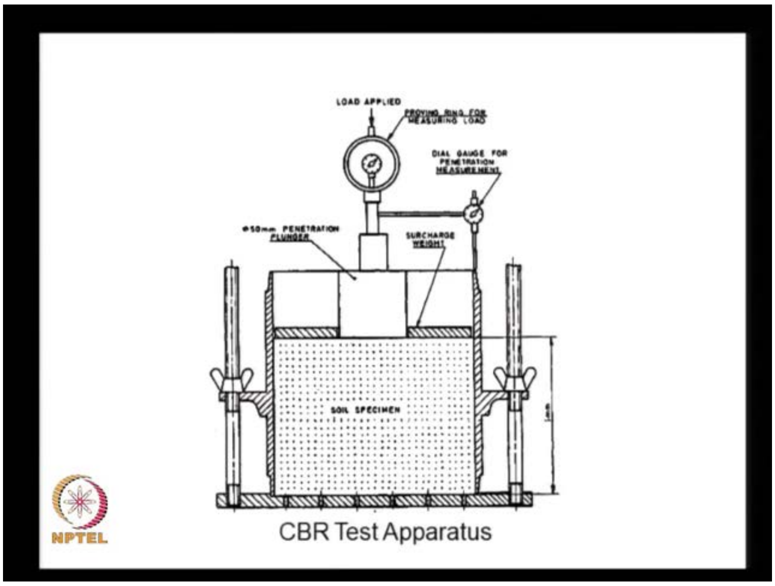

The design of the pavements is based on the CBR value, the California Bared Ratio and what you are looking at is the apparatus to perform the CBR test. We take a soil specimen compactor to the desired density at an optimum moisture contact, as we do it in site and then there is a standard way of applying the loads. And we have put some standard surcharge weight and then we apply the loading at a standard rate of loading.

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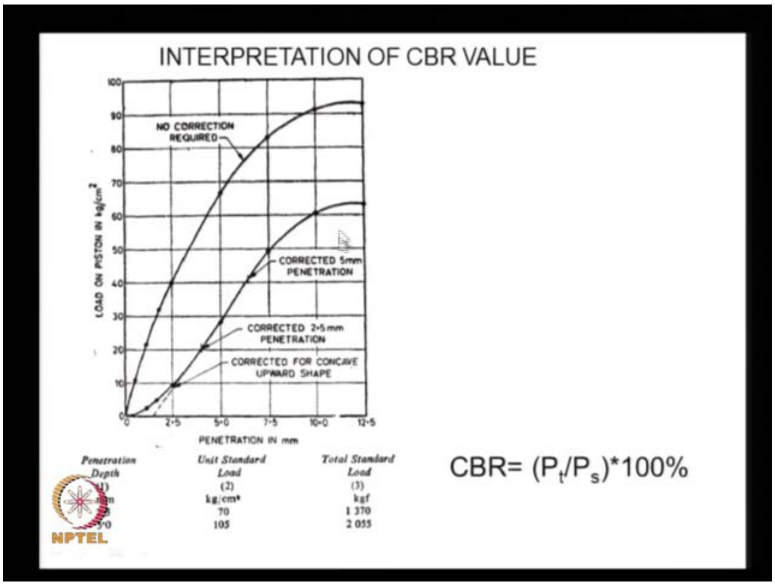

And we get a curve something like this. On the x axis, we have the penetration in millimeters, y axis the load in so many kilograms per centimeter square. And if you get a graph something like this, where the load is linearly increasing with penetration, there is no initial correction that we apply, but sometimes because of a initial imperfections, the compaction or in the loading. Initially the pressure may not be developed, and the pressure is slow to develop. And only after sometime, the pressure goes on increasing in linear proportion to the penetration. In this case what we do is, we do some initial correction like this, and shift the origin here, and we need to look at the load set to different settlements 2.5 millimeters and 5 millimeters settlement; this is as per the standard course of practice.

And we get the load and then the CBR value is the load, that we measure at either 2.5 millimeter or 5 millimeter settlement divided by the standard load multiplied by 100 percent. So, these are the standard load at 2.5 millimeters, the standard load is 1370 kgs and at 5 millimeter settlement it is 2055 kgs. And we can calculate the CBR value which could be even higher than 100 percent depending on the load that we measure.

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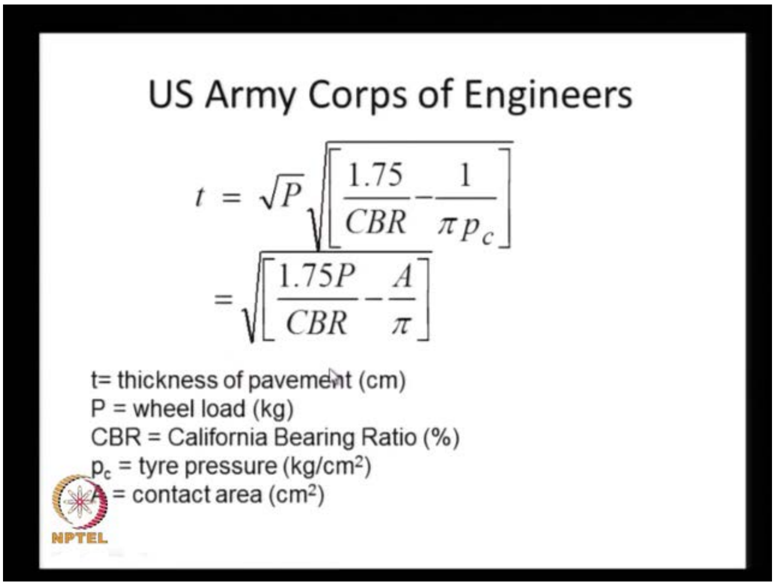

And the US army engineers, they were the first one to suggest the thickness of pavements depending on the type of loading that we have. And here we see some very highly empirical formula, where the t thickness is given in terms of centimeters square root of P multiplied by square root of 1.75 by CBR minus 1 by pi times p c. By taking this P inside this square root, we can write the thickness that is the thickness of the pavements as the square root of 1.75 P divided by CBR minus A divided by pi, where T is the thickness of pavements in centimeters, and the P is the wheel load in kgs, and the CBR is the California bearing ratio in percentage. And the small p c this quantity that is the tyre pressure in so many kgs per centimeter square, and capital A is the contact area which is nothing but the wheel load divided by the tyre pressure that we see here. And we see that the thickness of the pavement is very much dependent on the load that is coming from the wheels and then the CBR value, and then the distribution area the tyre contact area.

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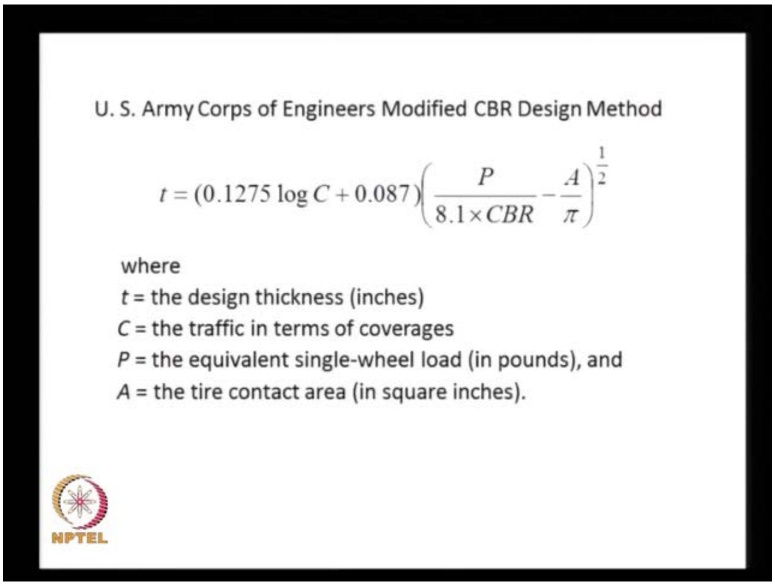

And this is another formula once again proposed by US army core of engineers where they have given the thickness in terms of some more parameters. Actually C is the coverage ratio and P by 8.1 times CBR minus A by P to the whole root. Once again we see that the thickness of the pavement is a function of the wheel load and inversely proportional to the CBR value. The tyre contact area is increasing for the given load and given tyre pressure our thickness of the pavement decreases. And this is another formula is actually, the earlier ones they do not have the number of load passes and then the allowable rate depth, the previous formulas that we saw, they are for standard depth of 75 millimeters.

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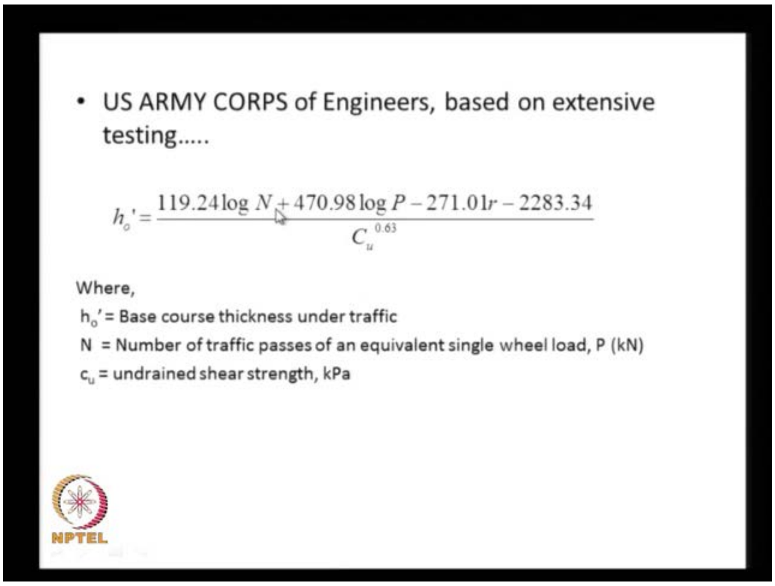

And here we have two more parameters N that is the number of traffic passes of a standard equivalent wheel loads, and then the P is the wheel load, and r is rut depth that is a given in terms of millimeters or centimeters and then the C u is the undrained cohesive strength of the subgrade soil. Either C u or CBR both are linearly related to each other. The C u is approximately 30 times the CBR in so many kilo Pascal units.

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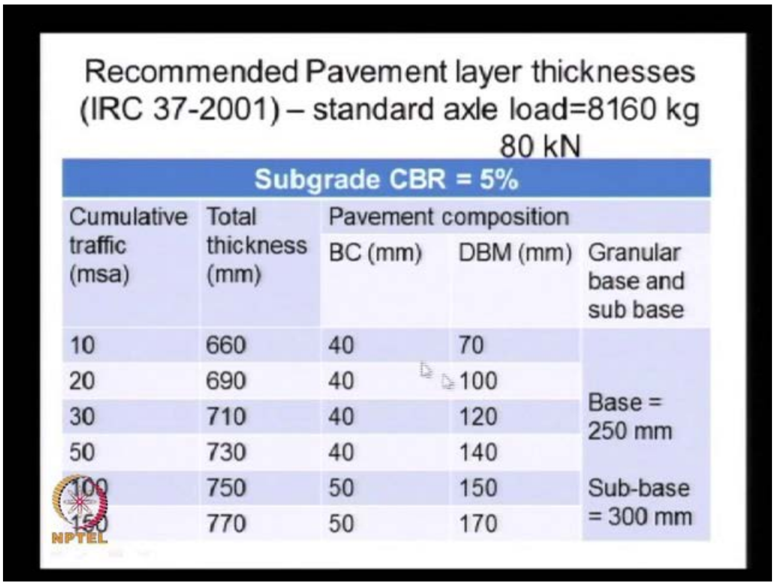

And the Indian roads congress IRC is also given the thickness of pavement in terms of the subgrade CBR value and these are given for standard axle loads of 8160 kgs. That is approximately equal to 80 kilo Newtons and this is given in terms of so many millions of standard axle loads the msa. For 10 msa 20 30 50 100 150 msa and the thickness as you can see, it goes on increasing with the number of axle loads. Actually here also we see that as the number of load passes is increasing, the thickness of the pavement increases.

And this data that is given by IRC 37-2001, that is also highly empirical and the typical pavement composition could be the Bitumen concrete, that is the top most wearing course. If given as 40 mm up to 50 m s a, that is the millions of standard axle loads and beyond that for 100 and 150 mm, the bitumen concrete layer is given as 50 mm. And then the DBM that is the Dense Bitumen Macadam, a thickness is linearly increasing with a higher number of load passes. Then the granular base and sub base thickness is given as base course layer of 250 mm and the sub base layer of 350 mm. And so, if you add up 40 70 250 and 300, you get this total thickness of 660 and these data they are given for different CBR values 5 percent, 7 percent, 10 percent and so on.

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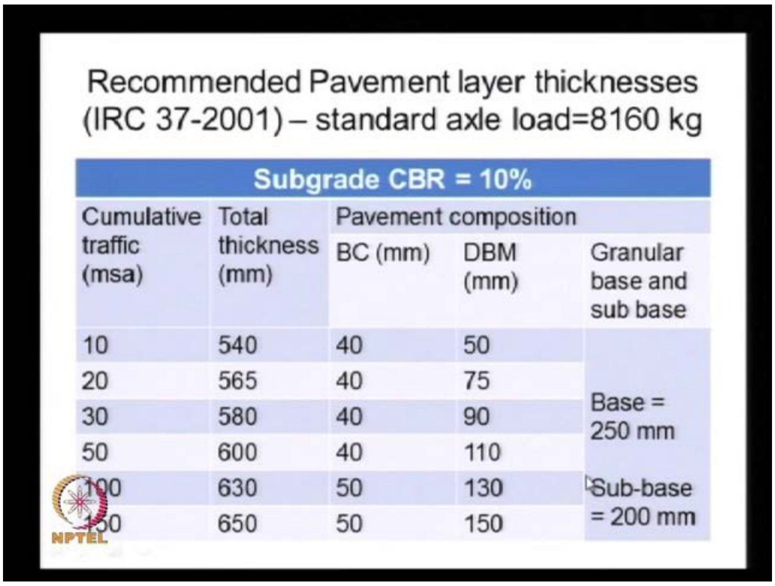
Recommended Pavement layer thicknesses (IRC 37-2001) – standard axle load=8160 kg

Subgrade CBR = 10%				
Cumulative traffic (msa)	Total thickness (mm)	Pavement composition		
		BC (mm)	DBM (mm)	Granular base and sub base
10	540	40	50	Base = 250 mm
20	565	40	75	
30	580	40	90	
50	600	40	110	
100	630	50	130	Sub-base = 200 mm
150	650	50	150	

And here we see the same data given for 10 percent of the CBR value and as the CBR value increases, the requirement of the pavement thickness reduces. So, for example, for 150 million standard axle loads for a CBR of 10 percent, the total pavement thickness is 650 and here for a CBR value of 5 percent it is 770. Once again the standard pavement BC thickness that is Bitumen Concrete thickness is given as 40 mm up to 50 msa and 50 mm for higher number of load passes. And then the DBM thickness and the base course and sub base course thicknesses are given.

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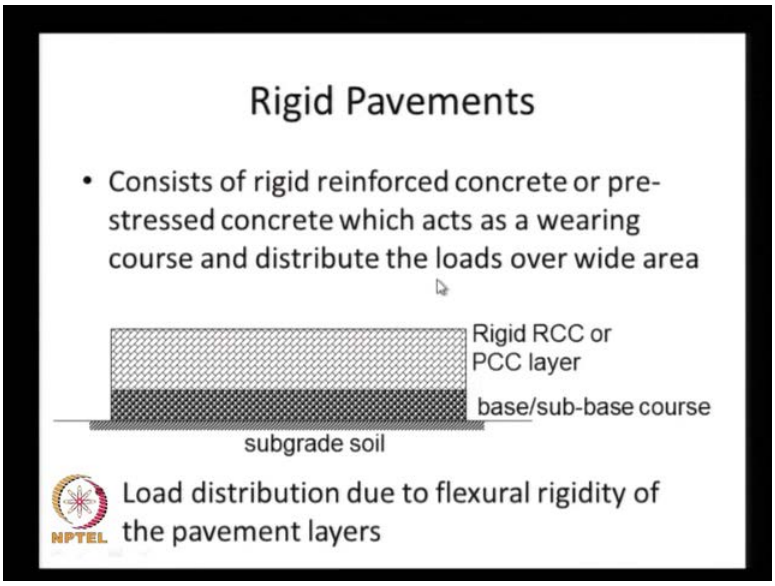

And when it comes to rigid pavement, we do not have too many layers. We have only 2 layers, the one is the top most layers that is the rigid reinforce concrete layer or just simply PCC layer. And because this reinforced concrete surface itself is very hard, it will also act as a wearing course. We do not have additional concrete layer and sometimes this RCC could be the pre-stressed concrete, in order to take care of a heavy loading or in order to take care of extremely weak subgrade. And the purpose of this rigid pavement is to distribute the load to a very wide area and this could be constructed on a prepared sub or base course layer. Basically, the base course is consisting of coarse grind particles that can act as a good drainage layer.

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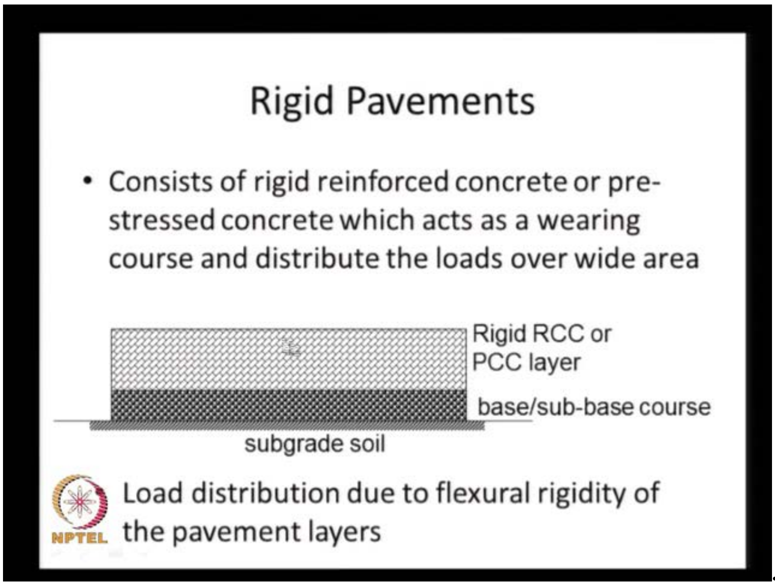

This case, it should also provide a good uniform support to the reinforce concrete slab that is a fabricated at the side. And the load distribution here this in the case of rigid pavements is because of the flexural rigidity of the pavement layers so it has very good stiffness so it can distribute the load over a very wide area. And the design of the thickness is the function of the structural analysis. And in this lecture or in this course we will only look at the flexible pavements and because that is more appropriate, when we are using the geosynthetics.

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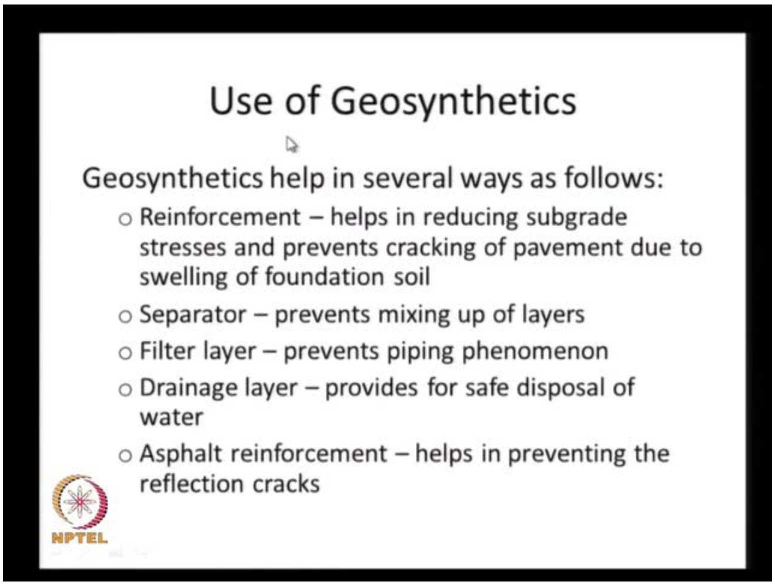

Let us now look at how we can use the geosynthetics in the case of flexible pavements. The geosynthetics we can use them in several ways, one is as a reinforcement layer. If we use as very stiff and strong reinforcement layer, it can help in reducing this subgrade stiffness and prevents the cracking of pavements due to swelling of the foundation soil. In case we have a highly swelling subgrade soil is going to undergo a lot of volume changes either heaving or shrinking.

In that case the provision of very strong and stiff geosynthetics layer can help in evening out these volume changes and the geosynthetics can be used as a separator or along with reinforcement function. This separator helps in preventing the mixing up of different layers and filter layer, it could act as a filter layer. If we use as a woven or a non woven geotextile, they prevent the piping phenomenon.

Then as a drainage layer, we use stick non woven geotextile very near to the top surface tracked as a drainage layer, to lead the surface water that is infiltrating into the pavement section away from the pavement. And within the bitumen or the asphalt layer, we can use the paver fabrics to reduce the intensity of the reflection cracking and that is one main purpose of the geosynthetics. These the application of the geosynthetics we will see in some other lecture.

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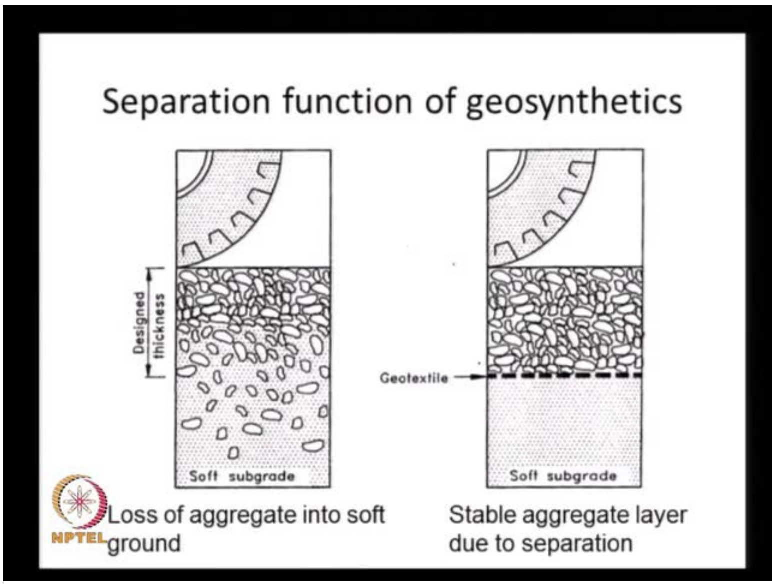

But just to a give you a brief idea, here is the separation function of the geosynthetics. Let us say that, we have provided a designed thickness of the aggregate layer and which is underline by a soft subgrade. As the time passes with the number of traffic loads, gradually, the stone aggregate might just simply get disintegrated and sink into the soft subgrade because there is not much of support given from the subgrade. If you able to provide a good separator either in the form of a textile or as a geogrid, because of the restraint that is provided, this aggregate layer is preserved better and it acts as a good pavement layer because its integrity is preserved.

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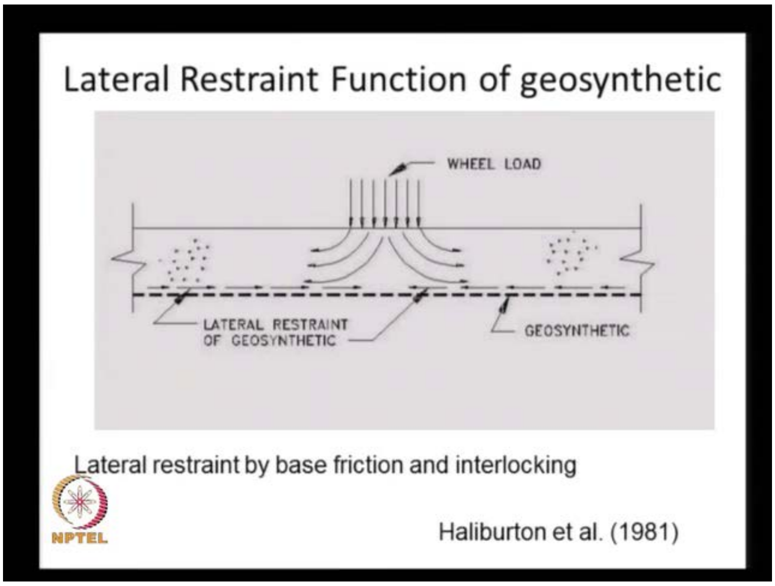

This geosynthetics that we provide because of the friction, that is developed between the geosynthetics and the aggregate layer. It prevents the lateral spreading of this aggregate that is one form of failure. If there is nothing to hold the aggregate, once there is the wheel loads are applied, the aggregates will just simply spread laterally. And because of the good friction and interlocking, that is developed along the geosynthetic surface. Some lateral restraint is provided to the aggregate thus ensuring a better load distribution.

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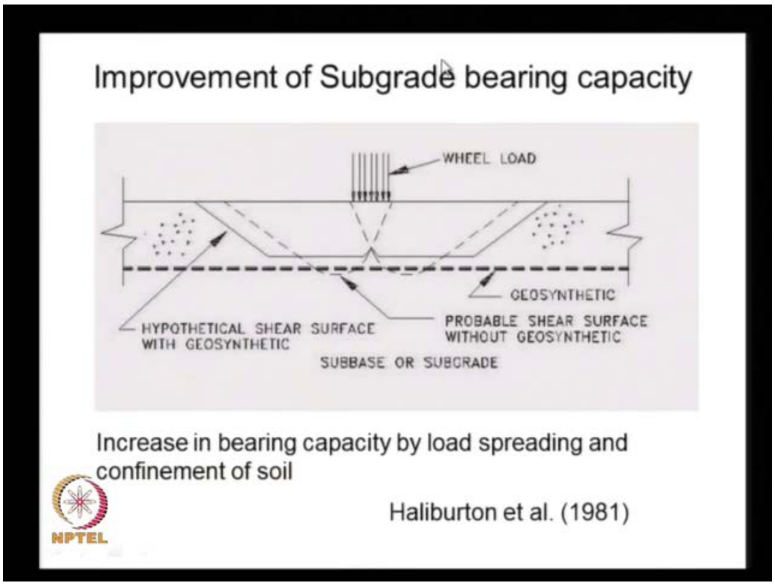

These geosynthetics can also help in improving the bearing capacity. See without the geosynthetic, this could be the bearing capacity failure under wheel load. And if we provide a reinforcement layer, the bearing, the shear surface does not propagate through this reinforcement and the failure is within this top soil. And we have seen that whenever the rapturous surfaces are prevented from formation, the failure is within the top layer. And because of the failure is now in a very shallow or a thin layer of soil, the bearing capacity is much more than what it is for a soil of infinite thickness. So, here in this case the bearing capacity is increased by load spreading and confinement of the soil.

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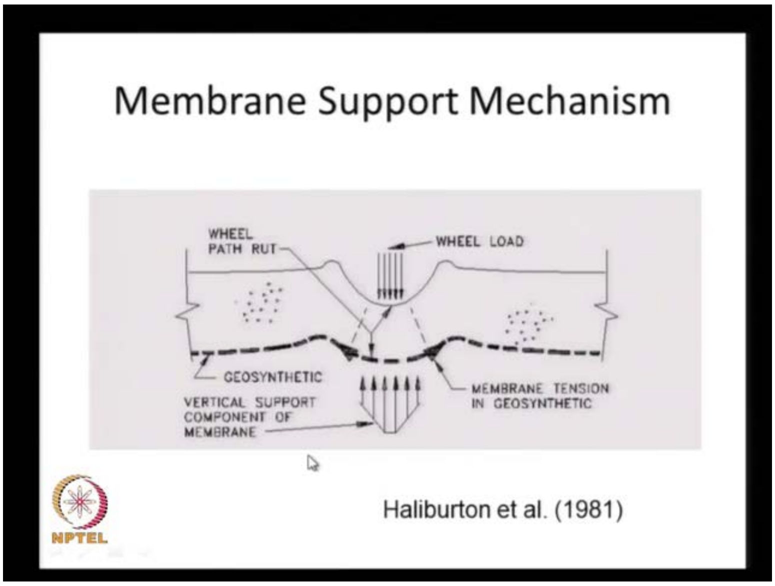

And another mechanism is the membrane support mechanism. When there is good rutting, the geosynthetic is subjected to some tension and vertical component of this tension force directly opposes the wheel load and that reduces the pressures, that are transferred into the subgrade soil; hereby increasing our long term performance.

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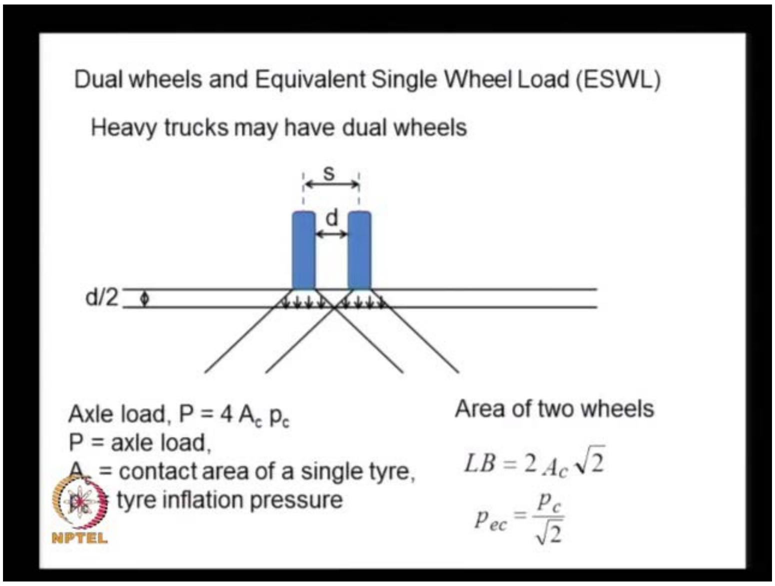

Well let us look how we can design these pavements. And before we design or before we go into the discussion of design, let us look at a dual wheel configuration, because the dual wheel configuration is very typical one in all these transport vehicles, the Lorries that transport heavy goods. And how do we treat the load, that is coming from a dual wheel. Say if there is an axle load of P because there are 4 wheel loads, you have 4 times A c that is the contact area of a single tyre, p c is the tyre inflation pressure.

And in other words, we can calculate the tyre pressure by dividing the axle load with 4 A c and because we have the two wheels close together, we need to do some empirical calculations. And if assume that the load spreading below each wheel is something like this within a shallow depth. Let us say d by 2 below the surface, we can assume that the tyre pressures are independent of each other and the pressure is just simply p c, but below this the affect of the space between the 2 wheels comes into picture.

And because of that the actual pressure that is transferred is lesser and this P e c that is the equivalent pressure is just simply p c by square root of 2 and this is because of the standard wheels. And if you have one single wheel, this is just simply p c is equal to P e c or P e c is equal to p c.

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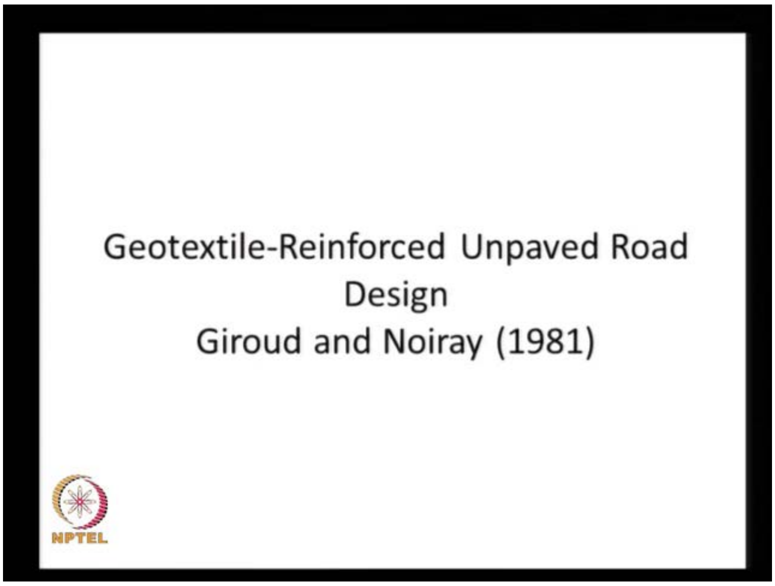

And now, let us look at the design of unpaved roads as given by Giroud and Noiray way back in 1981. They have given semi empirical design method that is based on some mathematical analysis and some empirical correlations.

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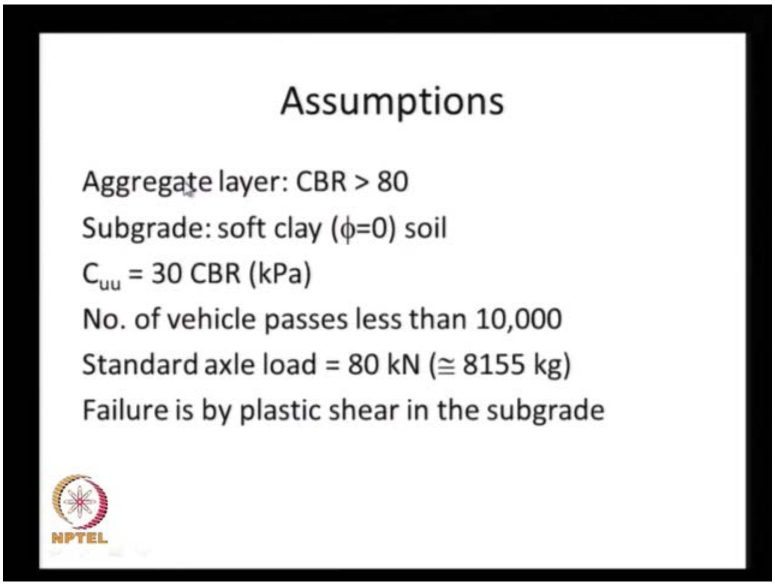

And some of the assumptions, the aggregate layer is assumed to have very high CBR value, that is CBR of more than 80 percent. Usually, the granular sub base material that we use, that will achieve a CBR of much more than 80 usual about 100 to 150. And the subgrade soil is assumed to be soft clay without any friction angle 5 is equal to zero. And C u u can be taken as 30 times the CBR where, CBR is the California bearing ratio of the foundation soil. And the number of vehicle passes is less than 10000 passes and standard axle load of 80 kilo Newtons is considered. 80 kilo Newton's is approximately 8155 kgs that is equivalent to our IRC standard axle load. And the failure is only by plastic shear that is acting within the subgrade soil.

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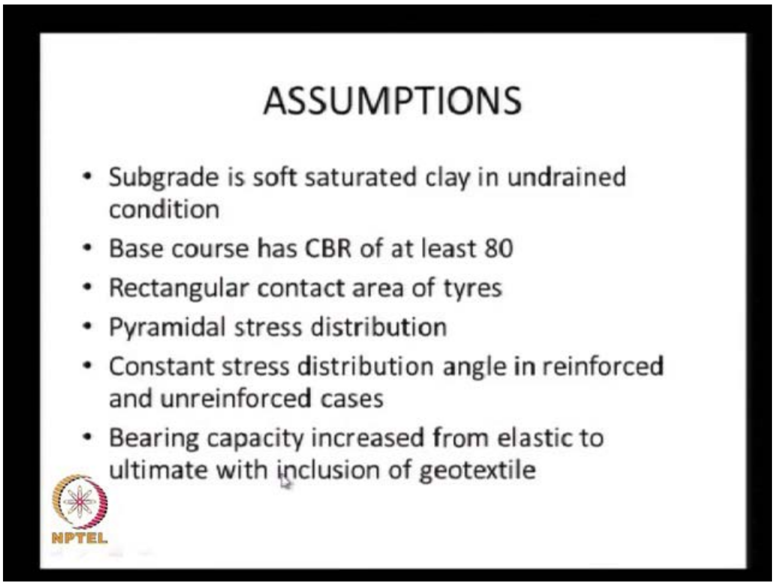

Some of the assumptions are the subgrade soil is saturated in undrained condition, and the base course aggregate has a CBR of at least 80, and rectangular contact area of the tyres, because they have considered the dual wheel configuration. And they assume that this rectangular contact area of l by b, just for simplifying the analysis.

They have assumed that the surface pressure is transferred into the subgrade soil in a pyramidal fashion. And they assume that this load dispersion angle is the same in both reinforced and unreinforced case for simplicity. And the bearing capacity is increased from elastic to ultimate state because of the inclusion of geotextile that we will see a bit later on.

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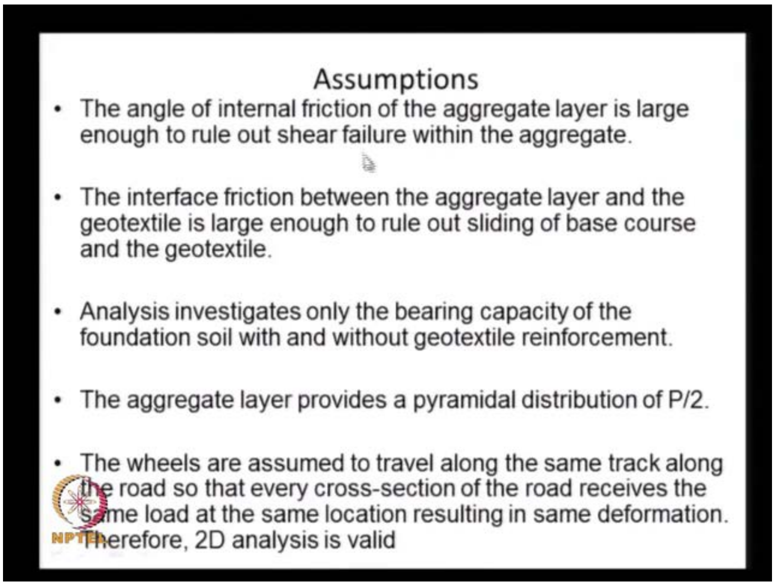

The other assumptions are that the only failure that they have considered is within the subgrade soil. The friction angle of the aggregate layer is assumed to be large enough to rule out any shear failure within the aggregate layer. And the interface friction between the aggregate layer and the geogrid or geotextile is large enough to rule out any sliding failure of the base.

The aggregate layer provides a pyramidical distribution of the load P by 2 that is axle load of P that is divided by 2 in the left side and the right side of the wheels. So, we have P by 2 of the load and the wheels are assumed to travel along the same track along the road so that at every cross section of the road, we have similar load distribution and similar rutting and so that, we can just simply use a 2 dimensional analysis.

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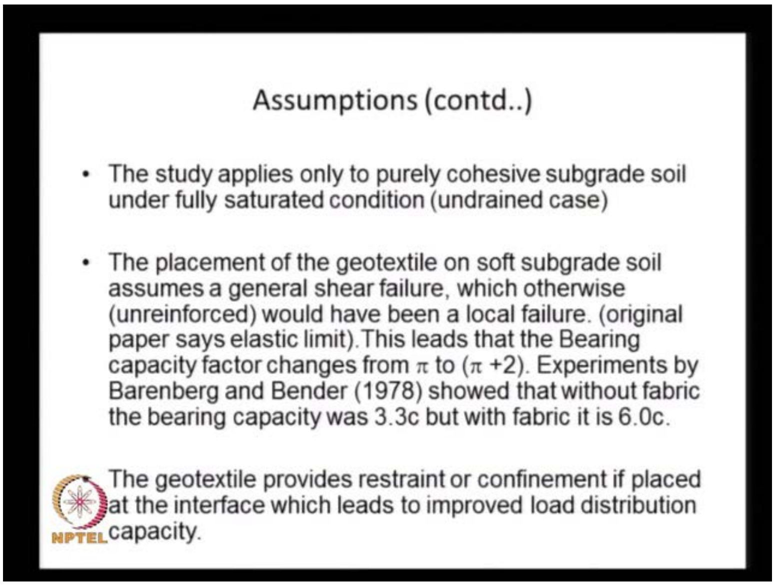

And the main assumption is because of the provision of the reinforcement, we can increase the bearing capacity factored from pi that is 3.1422 plus pi that is 5.14 and that is based on some observations laboratory and field observations by Bahrenberg and Bender, that were published in way back in 1978. And they have shown that, the bearing capacity of undrained clay soil is 3.3 c, when there is no reinforcement. And when there is fabric reinforcement placed above the clay soil, this bearing capacity factor increases almost 6 so this is the observation was given by Barenberg and Bender was used by Giroud and Noiray to develop their method of analysis.

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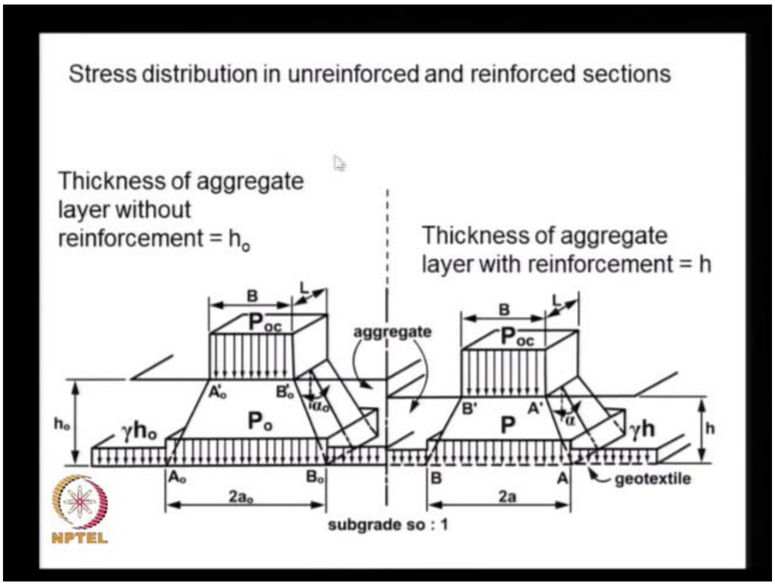

And here they have given their load distribution. Basically, the wheel load is applied over rectangular area of l by b and the thickness of the pavement. The aggregate layer without any reinforcement is taken as its not and the thickness of the same aggregate because of the reinforcement is reduced to small hits. And it is assumed that the load is distributed all around in some angle and this angle is about 31 degrees and it is assumed to be the same for both the unreinforced and the reinforced cases.

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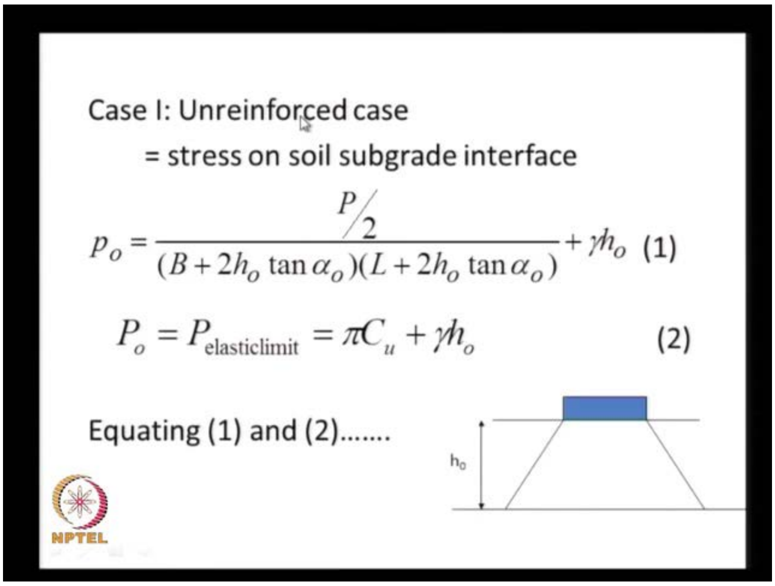

And the case one that is the unreinforced case. The stress on the subgrade soil because of the load dispersion is P by 2 that is the load transferred into each wheel divided by B plus 2 h naught tan alpha times l plus 2 h naught tan alpha. Where, h naught is the thickness of the pavement 2 because the load is dispersed in 2 directions plus gamma h naught is the overburden pressure. And this pressure the P naught and the subgrade level is equated to the elastic limit of the pressures pi C u plus gamma h naught.

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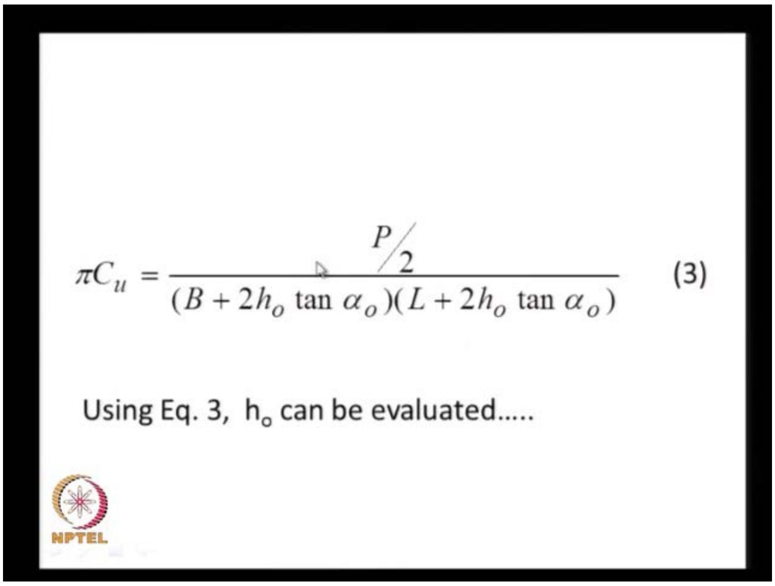

And by equating these two, we can get an equation in terms of the C u and the wheel load and h naught and by solving this h naught, we can get the thickness that we require. So, that the pressure that is transferred into the subgrade is less than the allowable bearing capacity of the soil.

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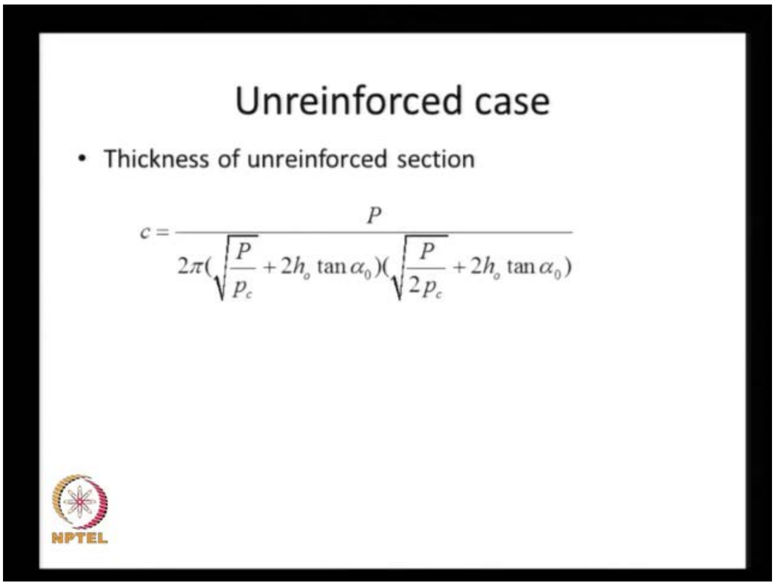

So, this same relation written in a slightly different form and here if we know the c that is the cohesive strength of the subgrade soil and the wheel load P, we can calculate h naught.

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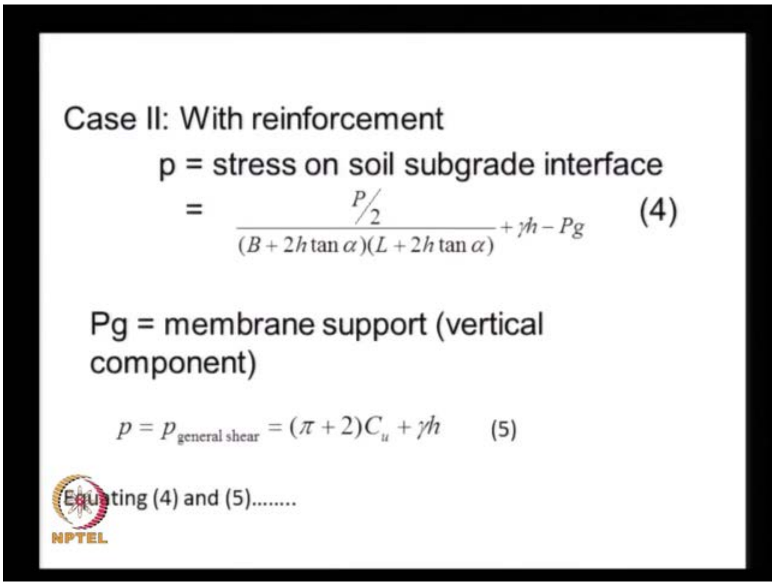

And the case two is with reinforcement. And here the pressure that is transferred into the subgrade soil is P by 2 by B plus 2 h tan alpha times l plus 2 h tan alpha plus gamma hits minus Pg, that is the membrane support that is given by the reinforcement. This is the vertical component and here now we assume general shear failure so that is 2 plus pi times C u that is our bearing capacity.

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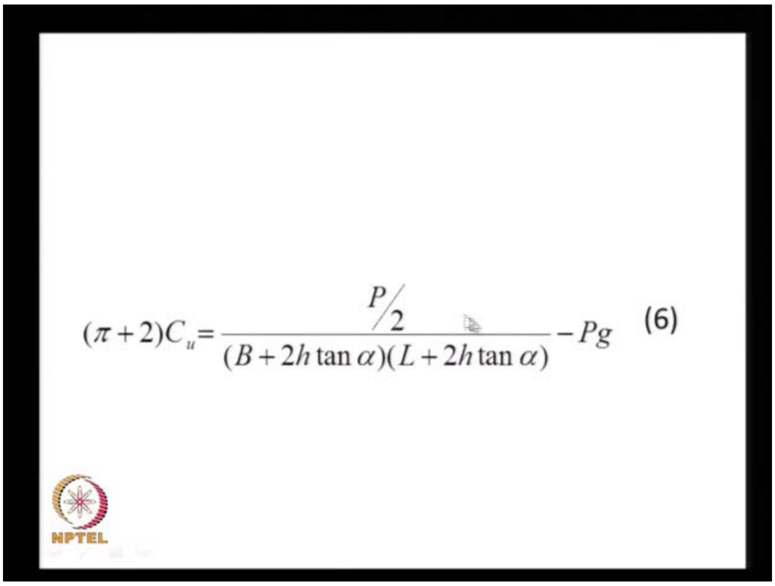

And by equating these two equations 4 and 5, we can get this equation the pi plus 2 C u is p by 2 times this whole quantity minus P g, where P g is the additional support that we get because of the provision of reinforcement.

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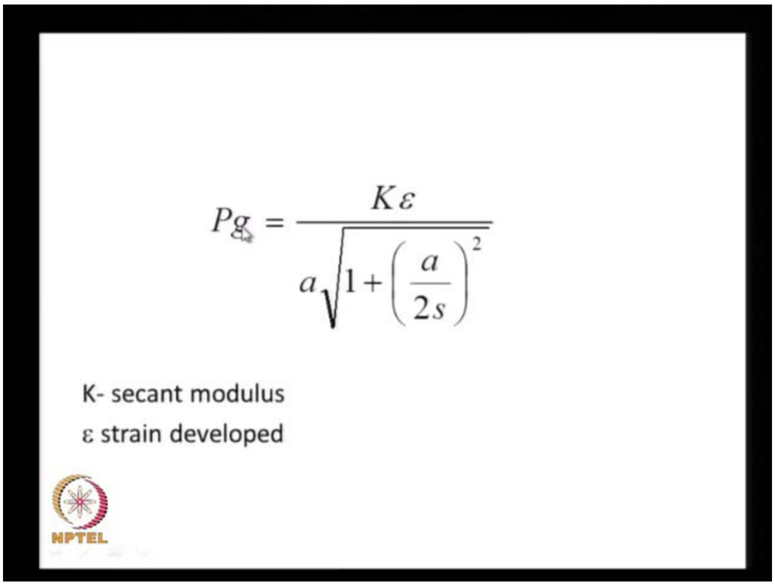

And this P g is the membrane support is related to the strain that is developed and the secant modulus like this. The strain developed is also a function of several other factors that we will see in a minute. The P g is written as k times epsilon by a times Square root of 1 plus a by 2 s times square.

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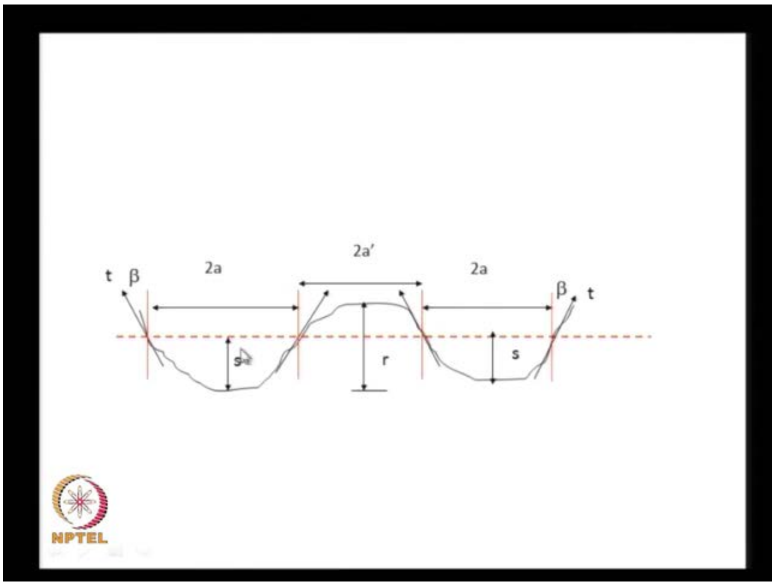

Where the s is the settlement below the wheels, and a and a prime these are just the curved length of the surface rutting.

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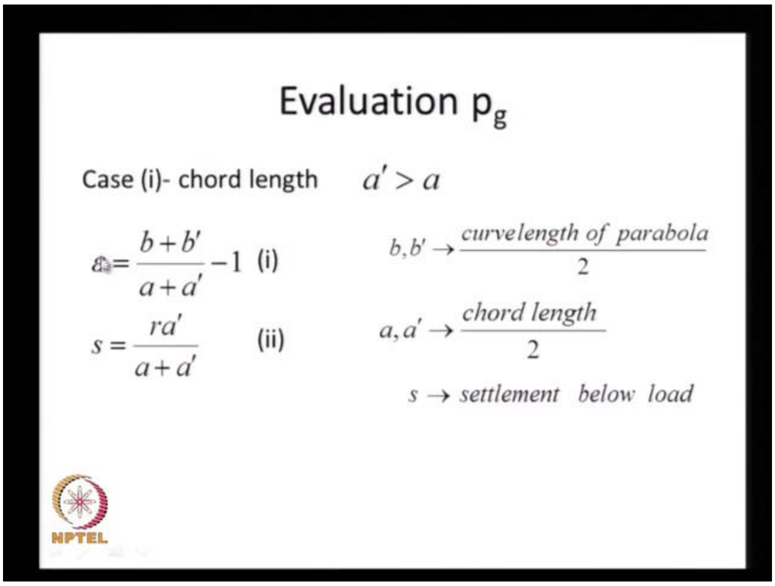

The epsilon that is the strain is written as b plus b prime by a plus a prime minus 1 where, b and the b prime they are the curve length. This is actually the shape is assumed as parabola and this length b and b prime, that is before and after the load application and a and a prime, these are the curved lengths before and after the load application. And once we have these values, we can calculate epsilon and s is the settlement below the load that is related to the rut depth.

Actually, the rut depth is say if there is some soil heaving the vertical distance from the heaved portion up to the bottom depression is the rut depth whereas, the settlement is depression measured from initial road surface. And if we know all these quantities, we can calculate the epsilon. Once we have the epsilon and the other factors, we can calculate the additional support that is given by the geosynthetic.

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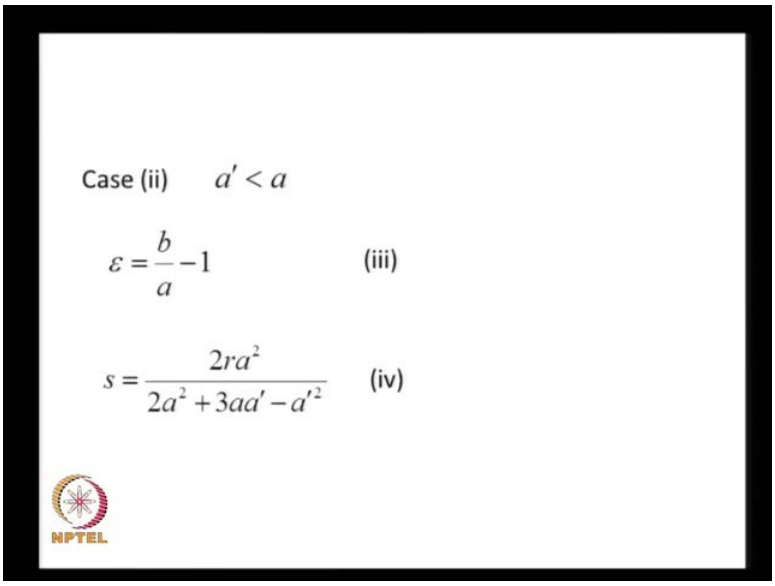

There are different cases that are possible a prime less than a, the epsilon can be written as b by a minus 1 and s is related by this.

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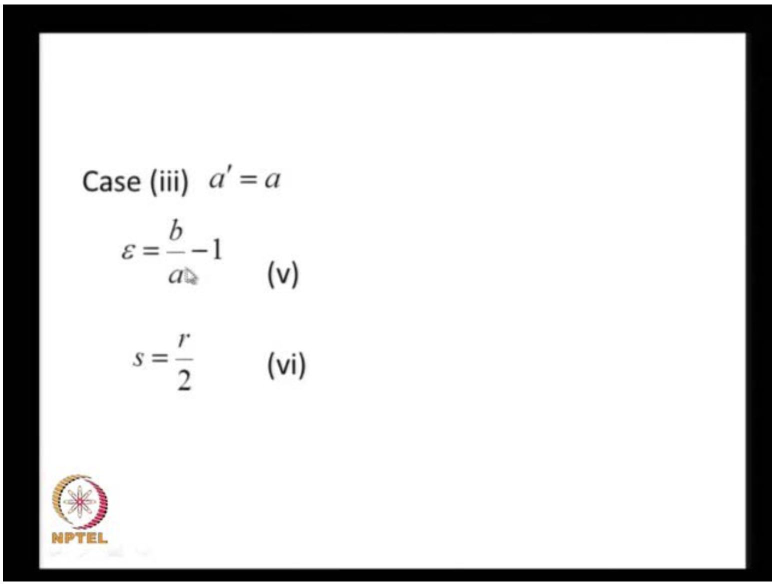

And a prime is a, we can relate the different parameters like this.

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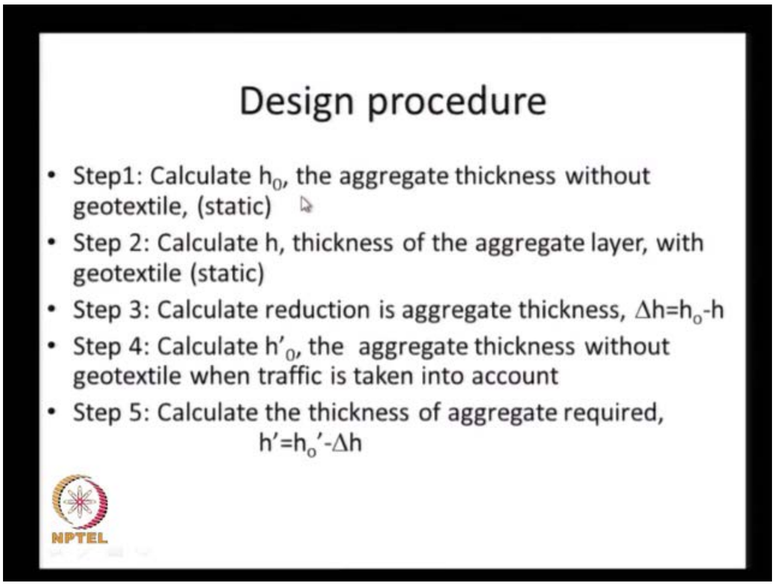

And the design procedure is very simple; we need to calculate h naught that is the aggregate thickness from one of the governing equations relating the stress, that is transferred into the subgrade soil by load dispersion through a height of h naught. And step two is to calculate the thickness of the aggregate layer with geotextile or the geosynthetic.

We can calculate the reduction in the thickness, delta h is h naught minus h. And calculate h naught prime that is the aggregate thickness without geotextile, when the number of load passes is considered. Because the previous equation is only for one single load application or the constant load, and we need to modify the earlier equations by considering the number of load passes. And the final step is calculating the thickness of the aggregate as its prime is h naught prime minus delta h, where h naught prime is the aggregate thickness for the un-reinforced case without any reinforcement.

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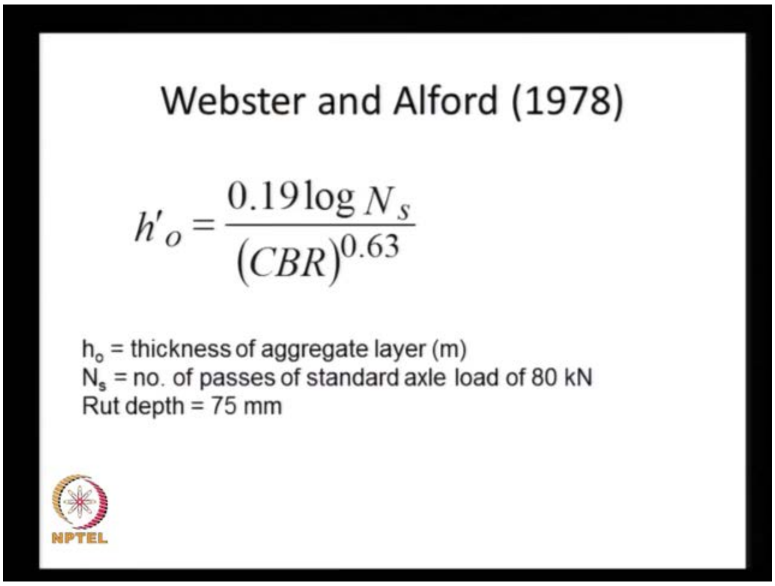

For the purpose of considering the influence of the number of load passes the Giroud and Noiray, they have used this expression that was proposed by Webster and Alfrodis. Actually, this is also from the same group, the US army corps of engineering group who said that h naught prime is 0.19 log N s divided by CBR to the power 0.63 where, N s is the number of passes of the standard axle load of 80 kilo Newtons. This particular relation is given for a rut depth of 75 millimeters; h naught is the thickness of the aggregate layer in meters. And this particular equation is very restrictive because this is only considering a standard axle load of 80 kilo Newtons.

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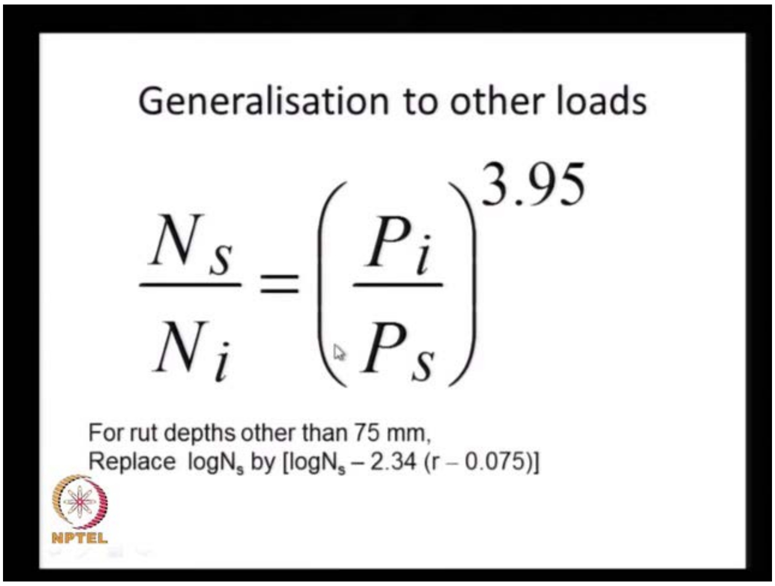

The Webster and his co workers, they have given an extra palation for other wheel loads and for any other load of P i, the number of load passes N i is related like this N s by N i is P i by P s to the power 3.95. Where, P s is the standard axle load of 80 kilo Newtons, P i is any other axle load and N i is the equivalent number of load passes as compared to N s.

And they have also Webster and his co workers they have also, given an extra palation for other rut depths, because the previous equation is for a rut depth of a 75 millimeters. And we can replace log N s in this equation by another empirical equation like this log N s minus 2.34 times r minus 0.075 and this is for a rut depth larger than 75 millimeters. And as we see as our allowable rut depth is increasing, the thickness of the aggregate layer reduces.

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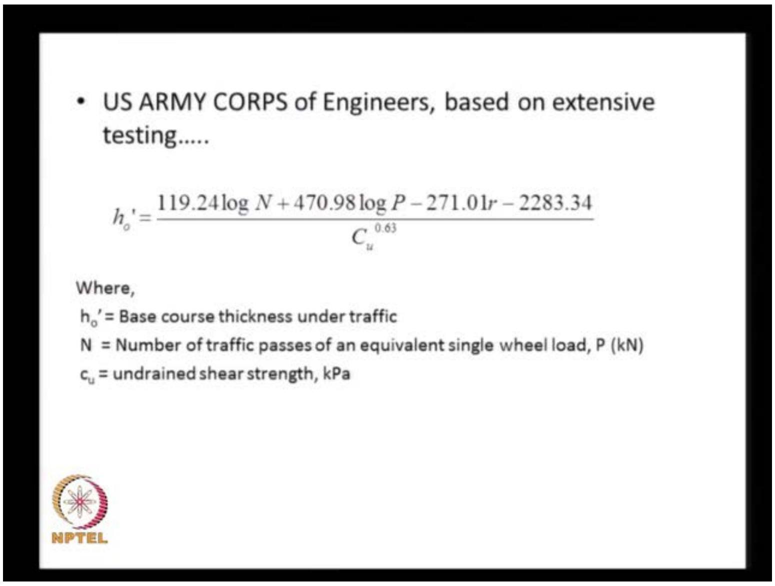

And by combining these equations, we can get a more generalized formula for calculating the thickness of the aggregate layer is h naught prime is equal to 119.24 log of N plus 470.98 log P minus 271.01 r minus 2283.34 divided by C u to the power 0.063 where, h naught prime is the base course thickness for so many numbers of passes and N is the number of traffic passes of axle load and then the C u is the undrained shear strength.

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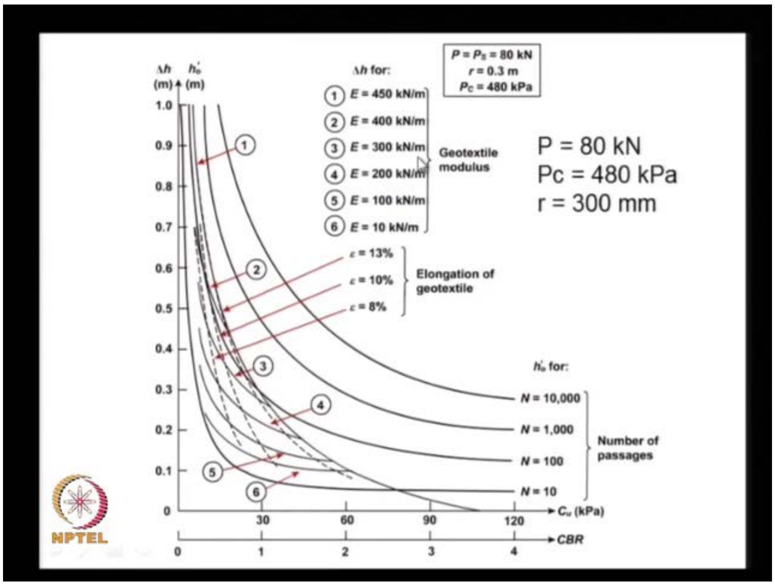

And Giroud and Noiray what they have done is, they have gone through this equation and they have developed a standard design slot, that gives the x axis the CBR value. The y axis the h naught prime, and the delta h for standard axle load of 80 kilo Newtons, and rut depth of 300 millimeters. The tyre pressure of 480 k P a for different modulus values of the reinforcement layers ranging from 10 all the way to 480 kilo Newtons per meter.

This we can utilize for designing the thickness of this the aggregate layer for reinforced pavements and actually it is a very simple way of applying this equation. And here we also have the number of load passes N of 10, 100, 1000, 10,000. And you see that as the number of load passes is increasing the thickness requirement of the aggregate is increasing. Then as our reinforcement modulus is increasing, we need lesser thickness of the pavement material. And we will see how to apply this design slot for design purpose. We will see one example in the next class along with use of geosynthetics in the flexible pavements.

Thank you very much.