Geo synthetics Engineering: In Theory and Practices
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Lecture - 23
Geo synthetics In Pavements

Welcome to Lecture number 23, my name is Professor J. N. Mandal, Department of Civil Engineering, Indian Institute of Technology, Bombay, Mumbai, India. The name of the course Geo synthetics Engineering in Theory and Practice, this is Module 5, Lecture number 23 Geo synthetics in Pavement.

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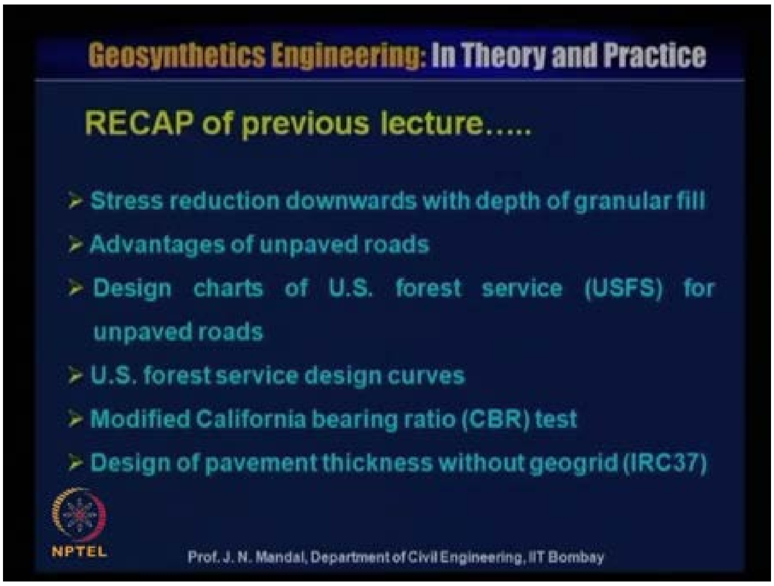

The recap of previous lecture, we have gone through the stress reduction to downwards with the depth of the granular fill. Advantages of unpaved road, design chart of US forest service or USFS for unpaved road, US forest service design curve, modified California bearing ratio that is CBR test or design of the pavement thickness without geo grid that is as per Indian roads congress 37 2001.

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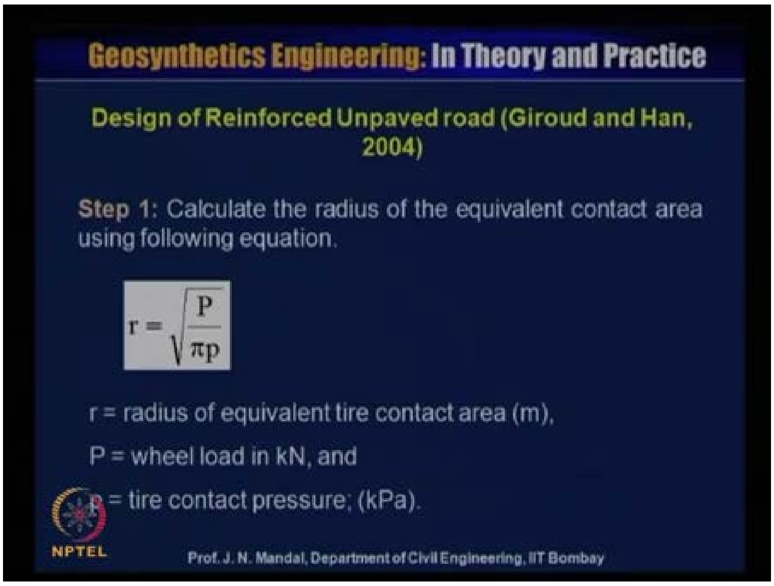

Now, I will focus the design of reinforced unpaved road given by Giroud and Han 2004 step 1, calculate the radius of equivalent contact area using the following equation, and r is equal to root of P divided by pi of small p, where r is the radius of equivalent tire contact area, and P is equal to wheel load kilo Newton and p is the tire contact pressure kilopascal.

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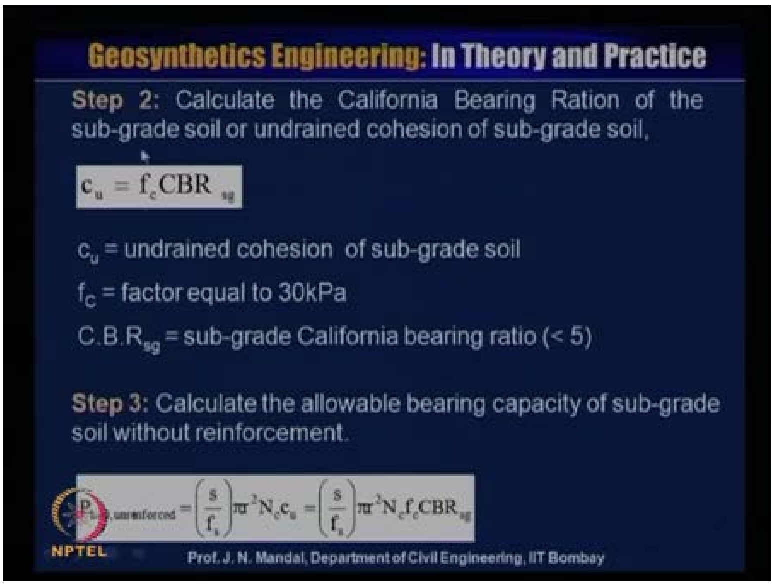

Step 2, calculate the California bearing ratio of the sub grade soil or undrained cohesion of sub grade soil that is C u is equal to f c into CBR s g. So, C u is undrained cohesion of the sub grade soil, f c factor equal to 30 kilopascal and this is CBR s g is the sub grade California bearing ratio that is less than 5. Step 3, calculate the allowable bearing capacity of sub grade soil without reinforcement. So, if you use this equation p of h 0 unreinforced is equal to s by f s pi r square N c into C u is equal to s by f s pi r square N c into f c into CBR s g, you are substituting this value C u is equal to f c CBR. So, C u is equal to you put this substituting this value; that means, f c into CBR f c.

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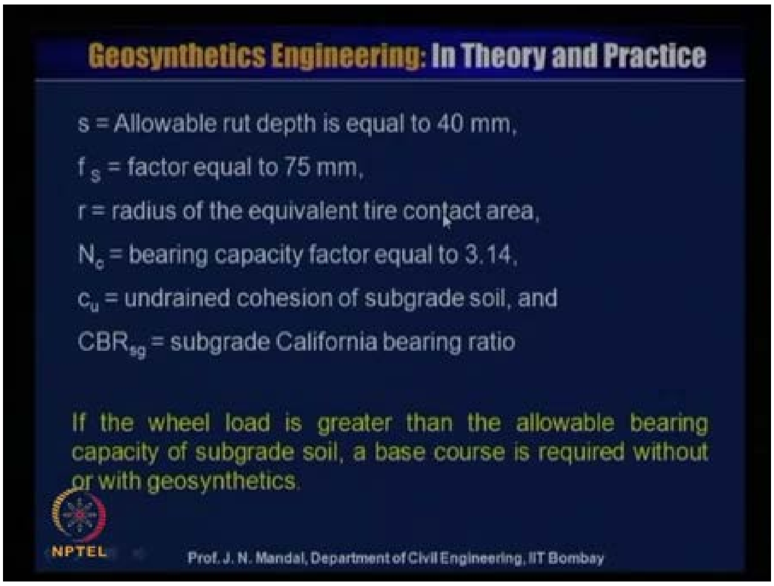

So, where s is equal to allowable rut depth is equal to 40 millimeter, f s is the factor equal to 75 millimeter, r is the radius of equivalent tire contact area, N c bearing capacity factor equal to 3.14, C u undrained cohesion of the sub grade soil and c v or s g sub grade California bearing ratio. If the wheel load is greater than the allowable bearing capacity of the sub grade soil, a base course is required without or with geo synthetics material.

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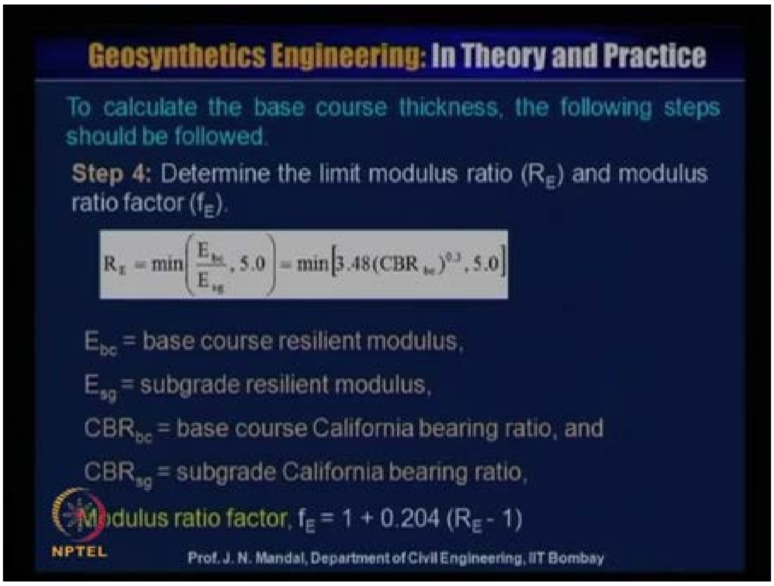

Now, to calculate the base course thickness, the following steps should be followed step 4, determine the limit modulus ratio that is R of E and the modulus ratio factor f E. So, R E is minimum of E b c by E s c comma 5.0 is equal to minimum 3.48 CBR b c one to the power 0.3 or 5.0. So, E b c the base course resilient modulus E s g sub grade resilient modulus, and CBR b c is the base course California bearing ratio. And CBR s g you know that is sub grade California bearing ratio, and the modulus ratio factor f E will be equal to 1 plus 0.204 R E minus 1.

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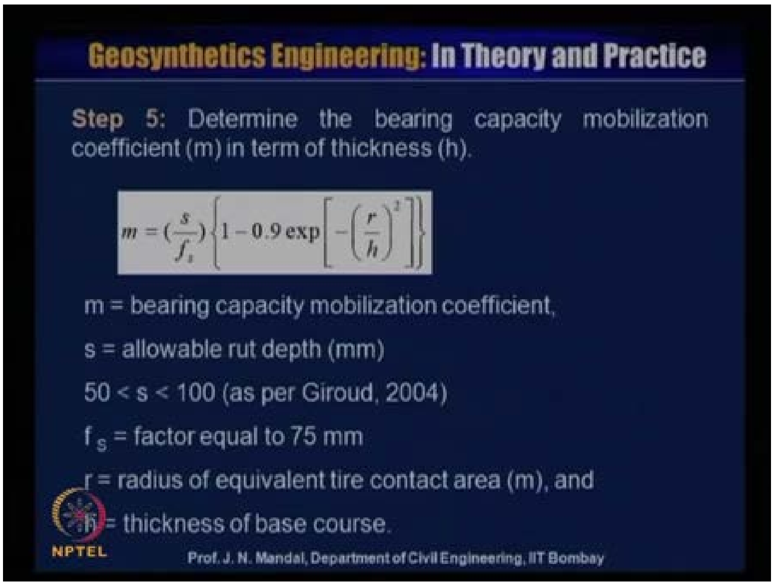

Step 5, determine the bearing capacity mobilization coefficient m in terms of the thickness h. So, m is equal to s by f s 1 minus 0.9 into e x p minus r by h whole square. Where, m is the bearing capacity mobilization coefficient, and s is allowable rut depth in millimeter, and s should be greater than 50 less than 100 as per Giroud 2004, and f s is the factor equal to 75 millimeter, and r is the radius of equivalent tire contact area meter and h is the thickness of the base course.

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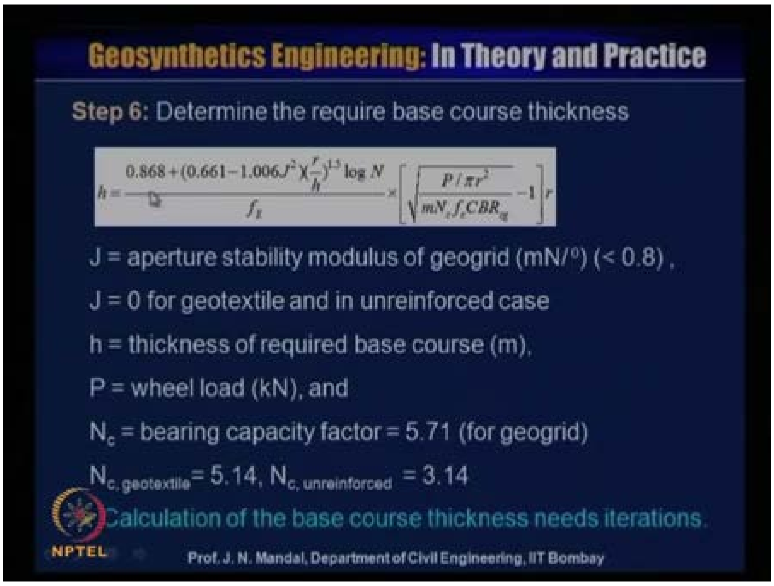

Step 6, determine the required base course thickness, so you have to add up this equation h is equal to 0.868 plus 0.661 minus 1.006 J square into r by h whole to the power 1.5 log N divided by f g into root of P divided by pi r square m into N c into f c into CBR s g minus 1 into r. Where the J is the aperture stability modulus of geo grid that is m n per g that should be less than 0.8 and J is 0 for geo textile and in unreinforced case h is equal to thickness of the required base course in meter.

And P is the wheel load in kilo Newton and N c is the bearing capacity factor that is 5.71 for geo grid and N c if you use geo textile the N c geo textile will be 5.14 or in case of unreinforced N c unreinforced will be 3.14. So, from this equation you have to calculate the what will be the base course thickness required, and this calculation of base course thickness need deterioration.

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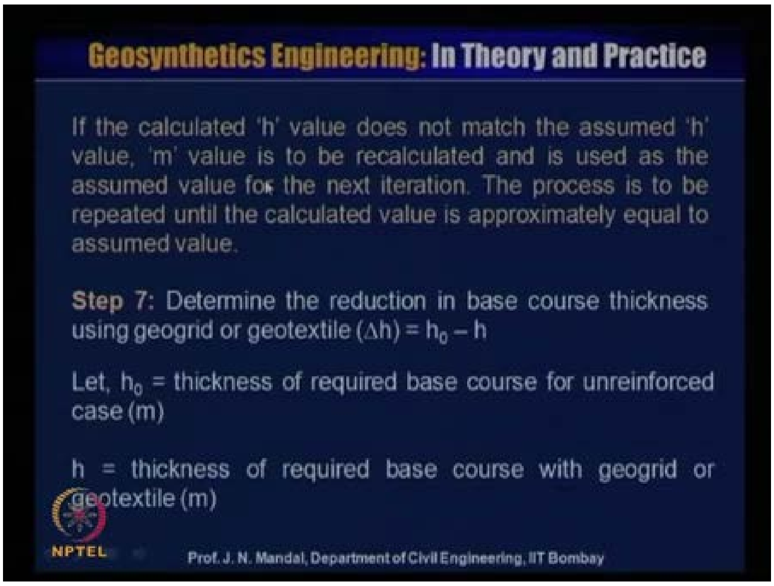

So, what is to be done with this equation, this is important this equation and how you can calculate the thickness. So, if the calculated h value does not match the assumed h value, so you assume some h value, and if it does not match with the you can see here also h here also h. So, you have to calculate h value that does not match the assumed h value, m value is to be recalculated. And is used as the assumed value of the next iteration, the process is to be repeated until the calculated value is approximately equal to assumed value.

So, you have to continue you have to repeat I will show with one of the example step 7, determine the reduced in the base course thickness using geo grid or geo textile; that means, delta h would be equal to h 0 minus, h where h 0 is the thickness of the required base course for unreinforced case in meter, h is equal to thickness of the required base course with geo grid or geo textile in meter.

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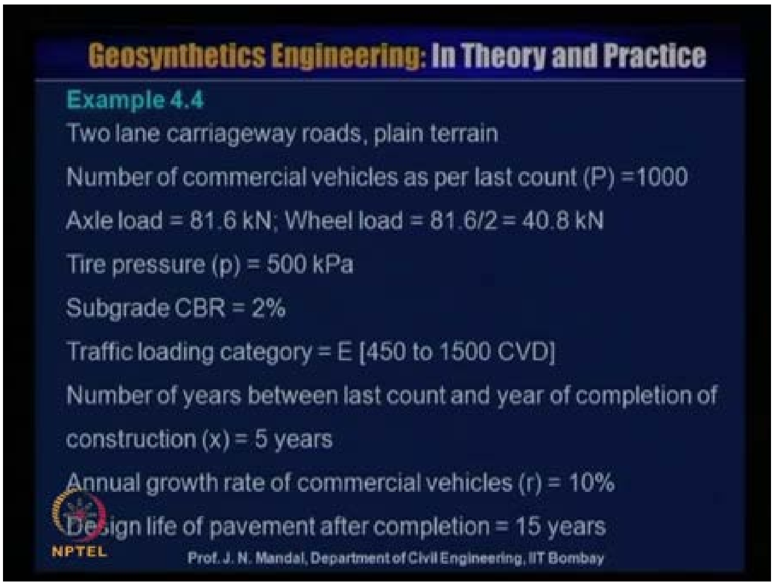

So, this is one example two lane carriageway road, plane terrain and number of commercial vehicle as per the last count P is equal to 1000. Axle load 81.6 kilo Newton, so wheel load will be half of the axle load; that means, 81.6 by 2 is about 40.8 kilo Newton, tire pressure p is 500 kilopascal, sub grade CBR is equal to 2 percent. Traffic loading category E is 450 to 1500 that is CVD commercial vehicle per day. And number of the years between the last count and the year of the completion of the construction x is equal to 5 years, annual growth rate of commercial vehicle r is equal to 10 percent and design life of the pavement after completion is equal to 15 years.

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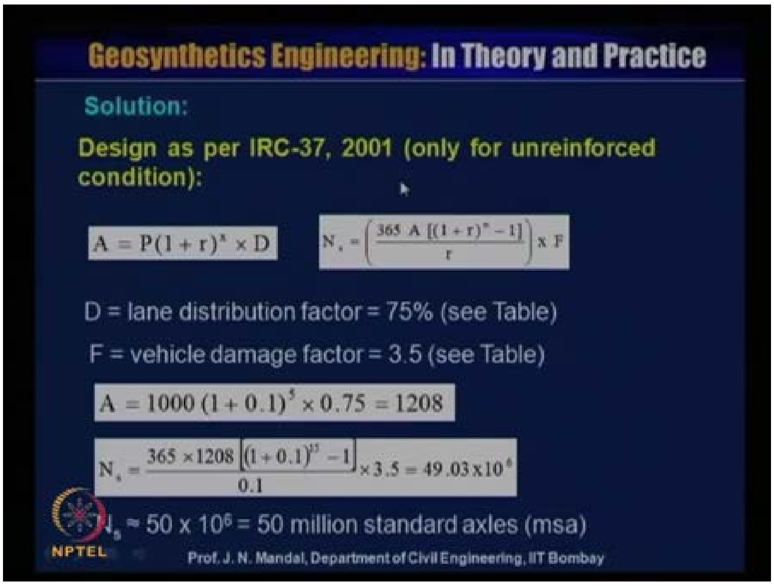

Now, the solution, so we adopt initially that design as per IRC 37 2001 only for the unreinforced condition. We have earlier shown you this equation for IRC A is equal to P into 1 plus r to the power x into D and also we have shown that what is N h value 365 A into 1 plus r into the power n minus 1 by r into F. So, where D is the length distribution factor that is 75 percentage, you can see the lane distribution factor this you can have the lane distribution factor that you can have from the table that is 75 percentage. And then also the F that is the vehicle damage factor that is 5.5, actually we have shown it earlier that vehicle damage factors here.

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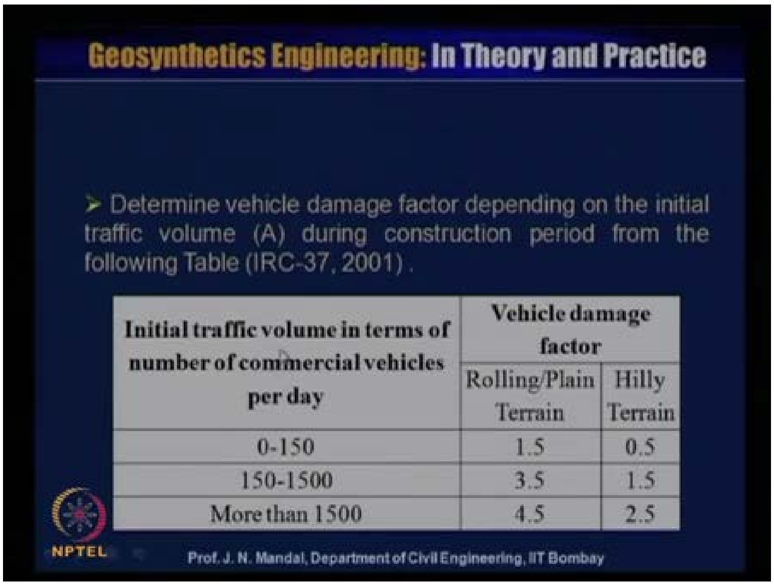

That vehicle that is what you call vehicle damage factor, so damage factor is three point we say that terrain plain terrain we consider, and the CVD is between this 150 to 200 that is why it is the 3.5. So, from here we have taken this value that what should be the vehicle damage factor this is 3.5.

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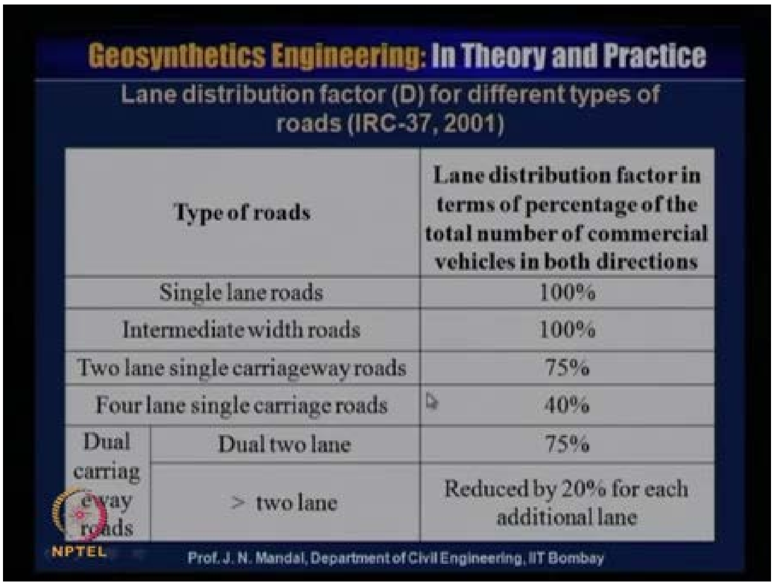

And also this is D we have calculated, and also if the two lane single carriageway road and that is why the lane distribution factor we have taken about 75 percentage. So, you have taken this is 75 percentage.

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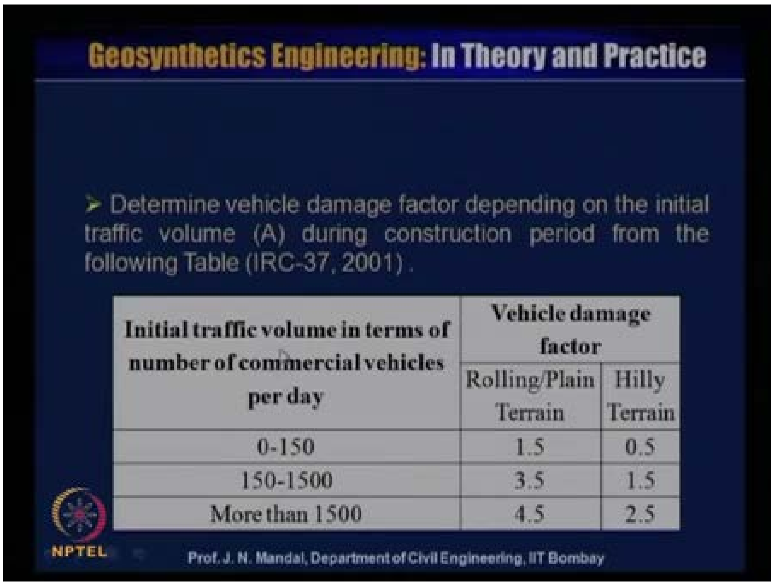

And we have taken this is vehicle damage factor is 3.5, so this way we have calculate that what will be the D as well as what should be the F factor value.

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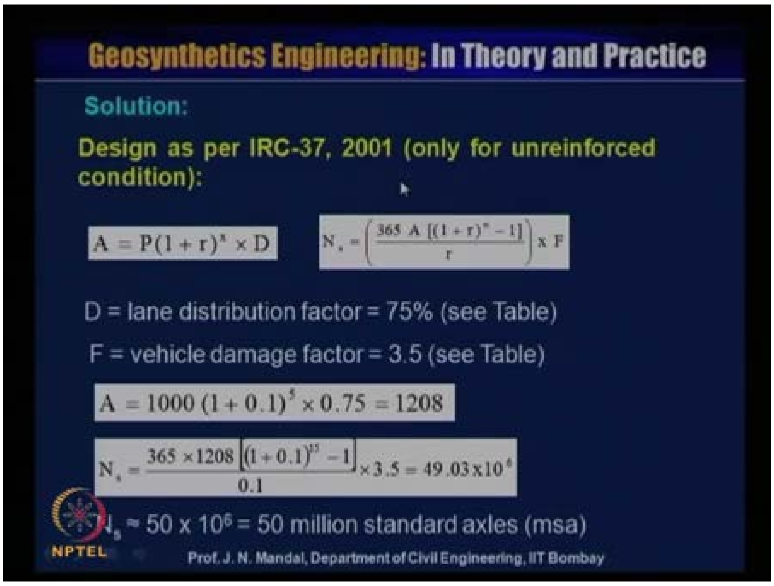

So, here is the D; that means, D lane distribution factor that is 75 percent as I showed you in the table. Similarly, F is the vehicle damage factor that is 3.5 that is as I show you in the table, so you know the D you know the F, so you can calculate what is A A P is given 1000 1 plus r is also given in our problem R also it is given it is 10 percentage. So, this is 0.1 P also it is given we have that 1000 here, so P is 1000 1 plus r is I told you it is given that r is 10 percent; that means, 0.1 this is 0.1 whole to the power x x is given 5.

You can see that x, this is x, this is x the number of year between last count and the year of completion of the construction x is 5 year. So, this is x 5 into D, D is this 75 percentage 0.75, so you can calculate this A is equal to 1208, similarly you can calculate N s, N s is equal to 365 into A, A we obtain 1208. So, this is 1208 into 1 plus again r r is equal to 0.1 here you can have the r 10 percent as I show annual growth rate of the commercial vehicle is 10 percent, r is equal to 0.1 whole to the power n, n is how many years.

That means, 15 years you have considered the design life of the payment completion year is 15 years. So, we have taken this is 15 minus 1 divided by r again r is equal to 0.1, this into F, F is equal to vehicle damage factor, this vehicle damage factor we have calculated from the table that is 3.5 this is 3.5. So, if you calculate you will obtain N s value is equal to 49.03 into 10 to the power 6. So; that means, you can take approximately N s value is equal to 50 into 10 to the power 6. That means, 50 million standard axle which is called m s a; that means, 50 m s a most of the time we will use this term, so you could remember this m s a, so N s is equal to 50 m s a.

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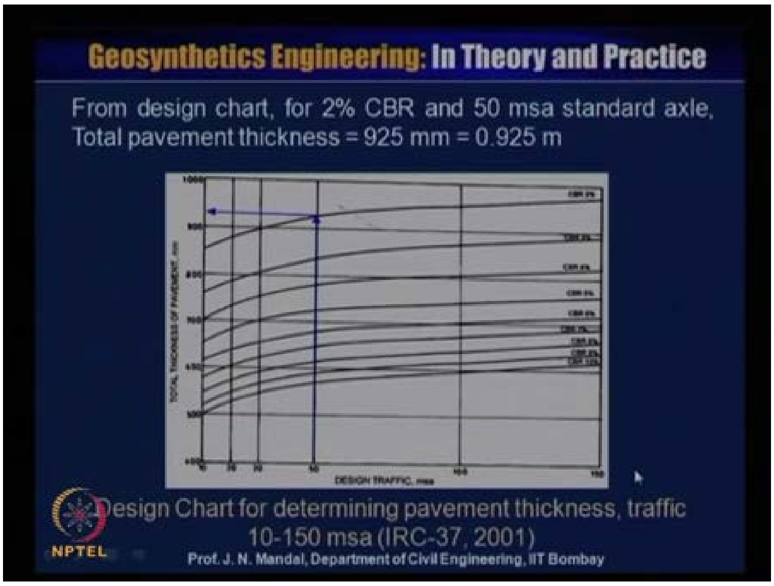

So, now you know that this is the design chart for the determination of the pavement thickness, traffic lies between 10 to 150 m s a I say that m s a remember million standard axle this is million standard as per IRC 700. So, you know now what will be the design traffic, so your N s value is note is 50 million, so this is you know 50, now you know that what will be the CBR value, CBR value is 2 percentage. So, you move up you can see that here that we require sub grade CBR is 2 percentage.

So, from this design chart knowing the value of traffic that is 50 you move up this is for CBR 2 curve. So, it touches this curve when the CBR is 2 and then you move horizontally, and which will give you that what will be the thickness of the unreinforced pavement in terms of the millimeter. So, it may be lies between 900 to 1000 and this value will be approximately 925 millimeter, so from this design chart for 2 percent CBR and 50 m s a standard axle then total pavement thickness will be 925 millimeter or 0.925 meter. So, when you will design for unreinforced case you know that what will be the thickness of the pavement.

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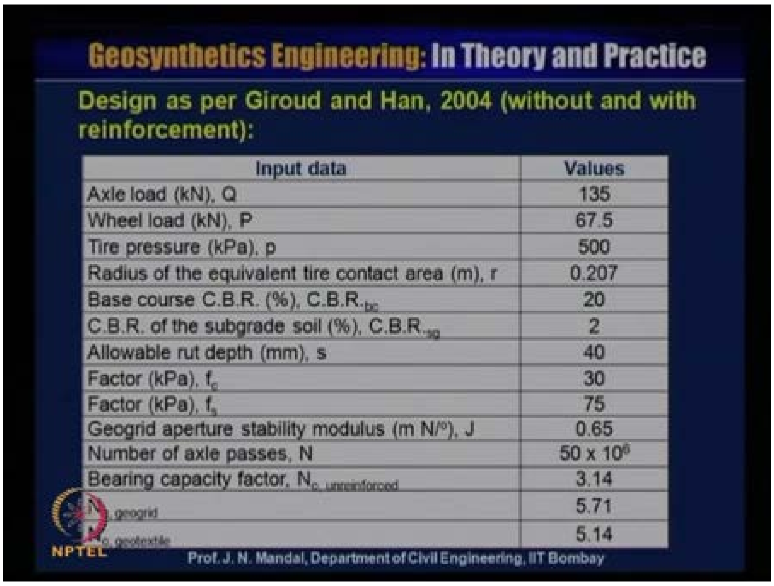

So, as per IRC quote specification, so this total thickness of the pavement is 92.5 this is centimeter. So, this is the cross section of the pavement, this is the soil sub grade whose CBR value is 2 percent, and traffic is 50 m s a that is you know that million standard axle and axle load is 81.6 kilo Newton. So, this thickness of the pavement we calculated 92.5, now as far as IRC course specification you have to provide with the bituminous surfacing.

Course you can have in the IRC course that how you can distribute this between a surface course is about 1.5 millimeter, 46 millimeter is the sub base, and this is about 25 millimeter is the base course, and 17.5 meter dense bituminous macadam, and 4 centimeter bituminous concrete. So, this way you are to, so the cross section of the pavement, so what bituminous surface is about 21.5 centimeter, bituminous concrete BC is 4 centimeter and bituminous macadam is 17.5 centimeter.

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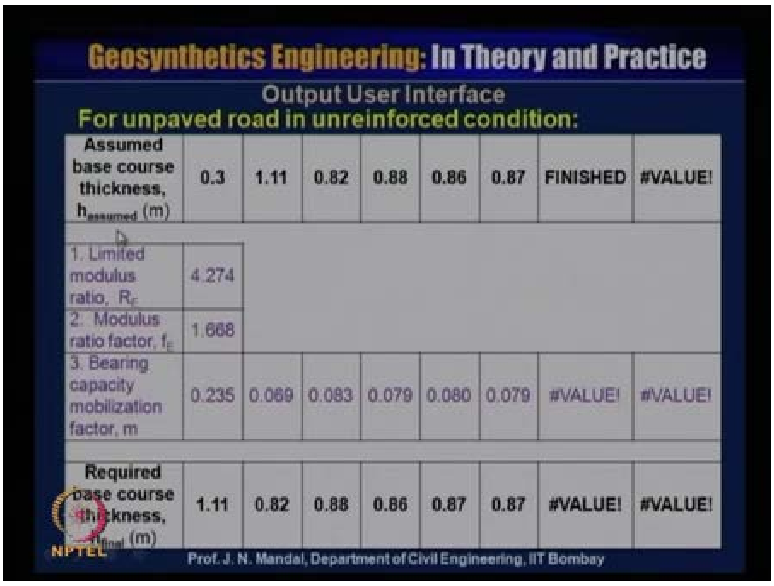

So, you can design that now that design as per Giroud and Han 2004 without and with reinforcement. So, we can see here that what will be input data and what should be the value, so axle load Q kilo Newton 135, so wheel load P will be the half of this, this is 67.5 tire pressure kilopascal p is 500, radius of equivalent contact area meter r is 0.207. Base course CBR percentage and CBR b c is 20 CBR of the sub grade soil percentage CBR r s g is 2.

Allowable rut depth millimeter small s is equal to 40, this factor k P a f c is equal to 30, factor f s k P a is 75, geo grid aperture stability modulus this is important J m N particle this is 0.65. Number of axle passes N is equal to 50 into 10 to the power 6 and bearing capacity factor N c unreinforced is 3.14 N c geo grid is 5.71 and N c for geo textile is 5.14. So, we have used both type of the material geo grid and as well as geo textile material, we will see that what will be the thickness of the pavement with geo grid and as well as with geo textile, what will be the deduction of the thickness that we will check.

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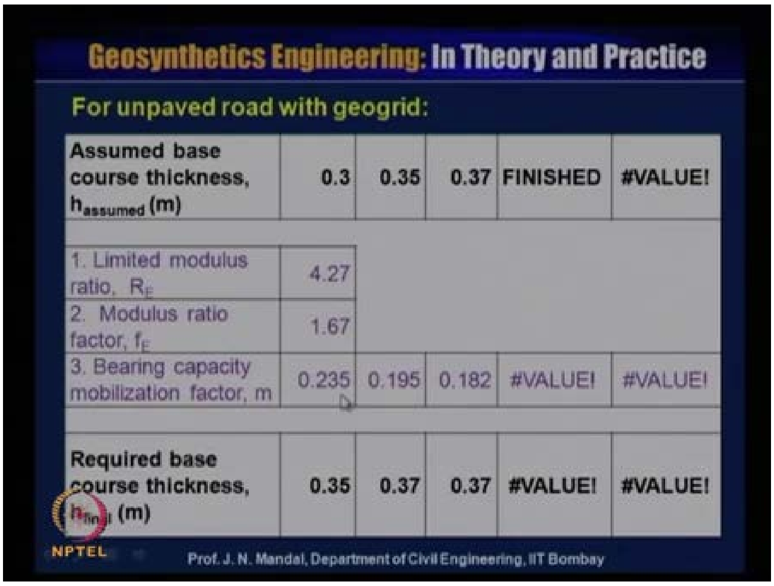

Assumed base course thickness, $h_{assumed}$ (m)	0.3	0.35	0.37	FINISHED	#VALUE!
1. Limited modulus ratio, R_E	4.27				
2. Modulus ratio factor, f_E	1.67				
3. Bearing capacity mobilization factor, m	0.235	0.195	0.182	#VALUE!	#VALUE!
Required base course thickness, h_{final} (m)	0.35	0.37	0.37	#VALUE!	#VALUE!

Now, this is output user interface for unpaved road in the unreinforced condition, so unreinforced condition assume the base course thickness as I told you that earlier equation, we assume something value h assume in meter, you assume 0.3 whatever it may be you can assume. And limited modulus ratio R E is 4.274 to modulus ratio factor f E 1.668, bearing capacity mobilization factor m 0.235, this how it all the changing what about to do with the iteration.

And then you can have what will be the required base course thickness, this is h final, so this is by the iteration you can see if you do the iteration, and then you can have this value for unreinforced grain, this is as per Giroud. So, this is 0.87 meter you can see this is gradually it is increasing, then it is stabilized when this is matching with 0.87 and 0.87, you can gradually you can see that this is the end then it is finished. So, this is by iteration you have to check that what value it should match with the left with the right. So, you can see for unreinforced case this value will be 0.87, so therefore, we can say that the thickness of the unpaved road in unreinforced case will be 0.87 meter.

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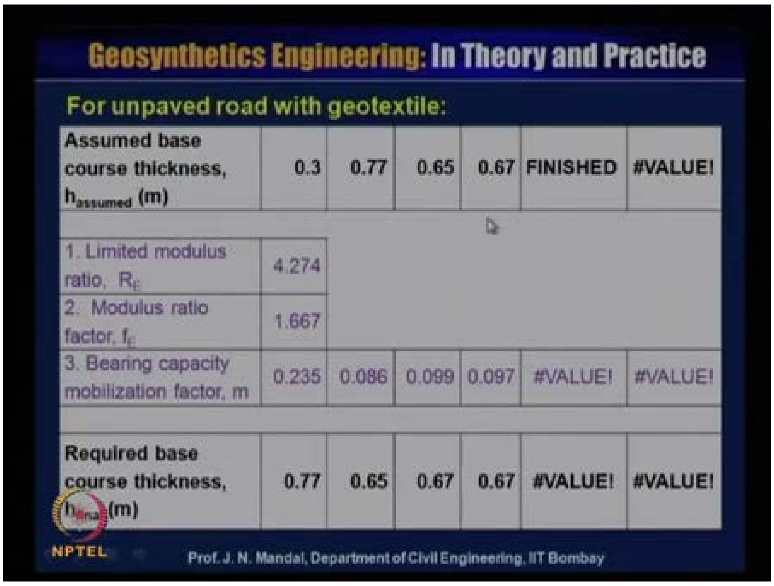

Assumed base course thickness, $h_{assumed}$ (m)	0.3	0.77	0.65	0.67	FINISHED	#VALUE!
1. Limited modulus ratio, R_E	4.274					
2. Modulus ratio factor, f_E	1.667					
3. Bearing capacity mobilization factor, m	0.235	0.086	0.099	0.097	#VALUE!	#VALUE!
Required base course thickness, h_{final} (m)	0.77	0.65	0.67	0.67	#VALUE!	#VALUE!

Now, for unpaved road with geo grid, so assume the base course thickness again h assumed. So, like this limit modulus all are it is there, modulus ratio is there, bearing capacity mobilization is there, and the required base course thickness is final, you can see by the iteration left to the right and you can have you can see 0.37, you can see 0.37 it is matching here then it is finished here.

So, with the geo grid material you can say the thickness of the pavement with geo grid in unpaved road is 0.37 meter or else you have seen the earlier in case of the unreinforced 0.87 meter. In case of the geo grid it is 0.37 meter, now if we use the geo textile material, and you can see here that in case of geo textile material it is thickness is 0.67 you can see it is matching here 0.67 this is by all iteration, so with geo textile is 0.67 meter.

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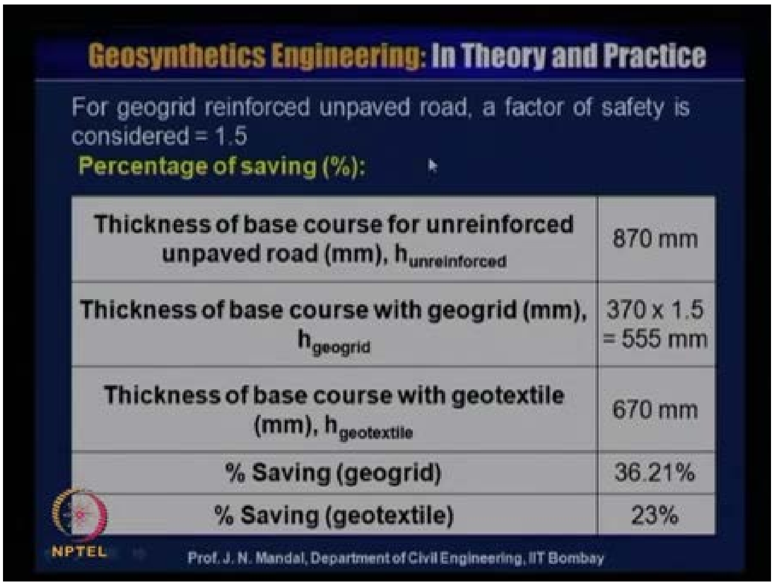

So, for the geo grid unreinforced unpaved road a factor of safety is considered as 1.5, so you can check what will be the percentage of saving in percentage. Now, thickness of the base course of unreinforced unpaved road that is h unreinforced is 870 millimeter, which we calculated from the table. Now, thickness of the base course with geo grid that is h geo grid is 370 we have shown that here that is 370 this is unreinforced 87.87 meter and 870 then geo grid is 0.37; that means, here is 370 millimeter and with a factor of safety 1.5 we consider, so this will be the 555 millimeter.

Now, thickness of the base course with the geo textile that is millimeter h geo textile is 670 millimeter this is here 670 millimeter, this is 0.67 meter 67 meter. So, percentage of saving with the geo grid will be 36.21 percentage, and percentage of saving with geo textile will be 23 percentage. So, geo grid and the geo composite layer are to be provided in between the sub grade and the sub base layer.

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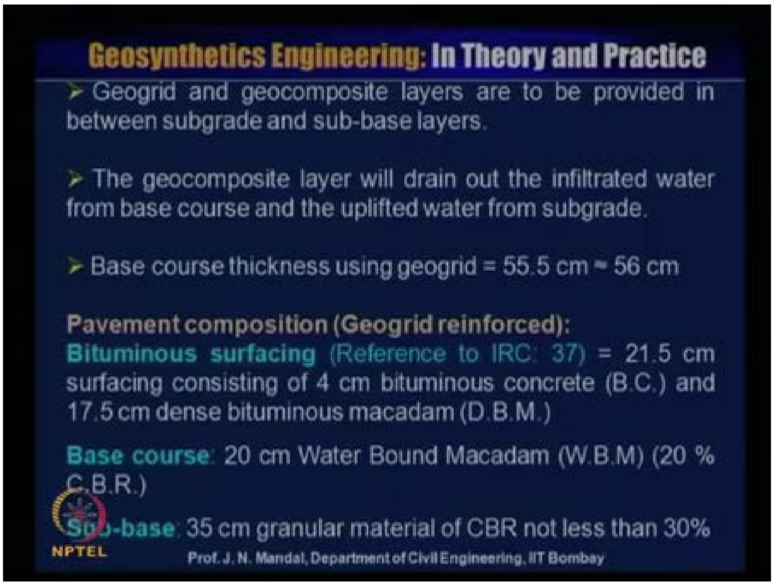

Geo composite layer will drain out the infiltrated water from base course and the uplifted water from the sub grade, base course thickness using geo grid is 55.5 centimeter you can take approximately 56 centimeter. Pavement composition geo grid reinforce bituminous surface reference to IRC code 37 it will be 21.5 centimeter surfacing consisting of 4 centimeter bituminous concrete that is BC and 17.5 centimeter dense bitumen macadam that is DBM. In the base course, we provide 20 centimeter water bound macadam, WBM that is 20 percentage of CBR in sub base course 35 centimeter granular material of CBR not less than 30 percent.

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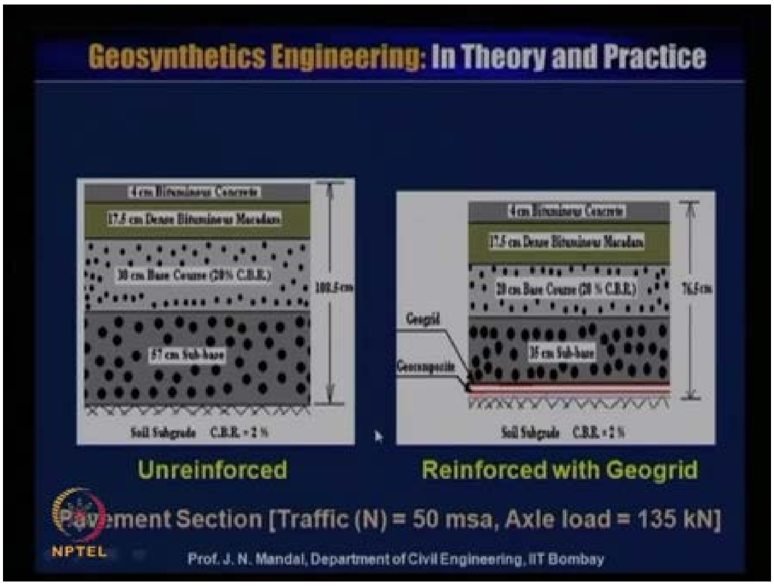

These are all according to IRC code specification, so ultimately we are showing this pavement section what traffic N is equal to 50 m s a and axle load is 135 kilo Newton, you can see that unreinforced case, this is the soil sub grade this is CBR value is 2 percent. So, this is the thickness of the pavement that is 108.5 centimeter and this is 60 centimeter for the sub grade, 30 centimeter for the base course; that means, 20 percent of the CBR and 17.5 centimeter dense bitumen macadam, and 4 centimeter bituminous concrete.

But, in case of the reinforced with the geo grid for soil sub grade CBR is equal to 2 percent the thickness of the pavement is 76.5 centimeter, and this is 35 centimeter sub base, 20 centimeter base course that is 20 percentage CBR. And 17.5 centimeter dense bituminous macadam or d b m and 4 centimeter bituminous concrete. So, here is the geo grid is placed between the aggregate and the sub grade course this grey line, apart from this geo grid you have to provide with one geo composite material, which will act as a drainage and the filtration this is essential.

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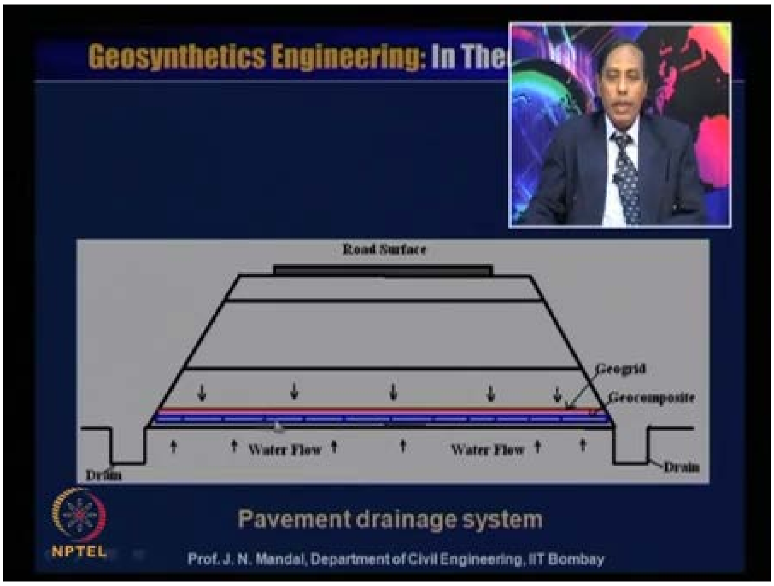

Because, you are proving this geo grid material it will act as reinforcement whereas, geo composite material if we put with along with the geo grid material, either it is a woven or non woven geo textile material. And laminated also with the geo grid this whole will be as a geo composite material will act as a very good drainage and the filtration material. So, it will solve all the problem here you can see how the thickness of the pavement has drastically reduced due to the introduction of the geo grid or the geo textile material.

This is the some section you can see that as I say the why geo composite material there is water may flow up and down, and then there is a possibility for water should be drained it out to the drain. So, if we provide with the some geo composite material then it will act as a very good drain because, drainage is very important most of the time water is stagnant and load is deteriorated because, you do not provide proper kind of the drainage system.

So, if we provide with the some geo composite as a drainage along with the geo grid material then it will act as a very good drainage. Because, there is a possibility for excess poor water pressure development, some water may move in the upper direction or due to the rain then water can percolate through this geo composite material. So, which will act as a separation, as well as it will act as a drainage and the filtration.

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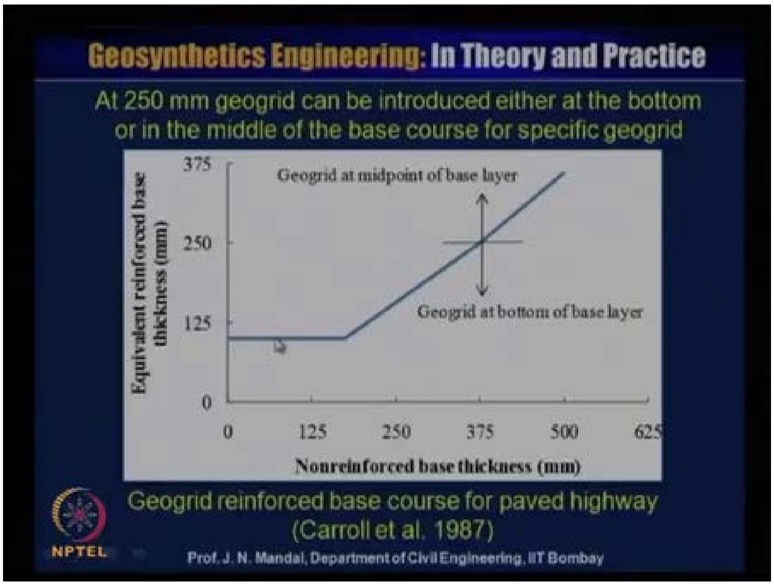

So, this is the pavement design system which have to be this figure show the relationship between equivalent reinforced base thickness versus non reinforced base thickness. Now, here geo grid reinforced base course for paved highway given by Carroll et al 1987 based on the experiment, and it can be observed from this experimental result that a 250 millimeter geo grid can be introduced either at the bottom or at the top of this level. That means, geo grid at the bottom of the base layer or geo grid at the midpoint of the base layer. So, this under the equivalent reinforced base thickness of 250 millimeter, so this is based on huge experimental result.

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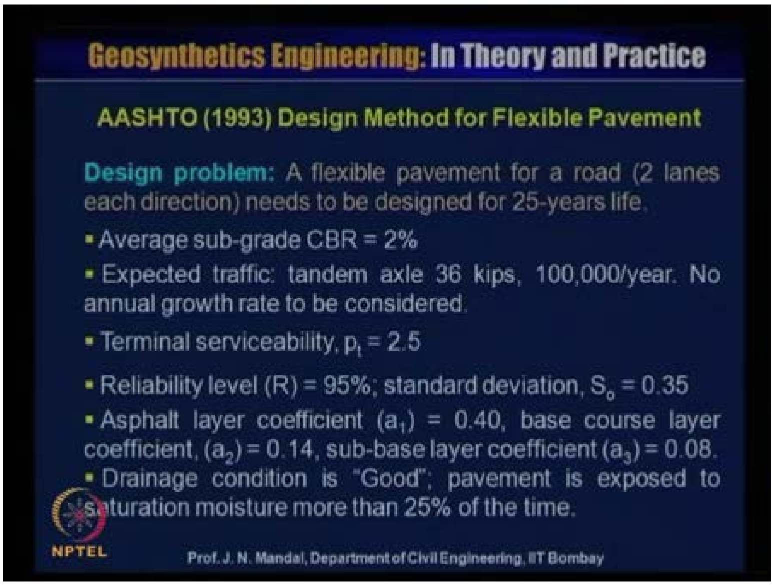

Now, I will explain the AASHTO 1993 design method for flexible pavement, now design problem a flexible pavement for a road 2 lane each direction need to be designed for 25 years life. Average sub grade CBR is equal to 2 percentage expected traffic that is tandem axle 36 kips 1,00,000's per year number annual growth rate to be considered, terminal serviceability p t is equal to 2.5 reliability level capital R is equal to 95 percentage.

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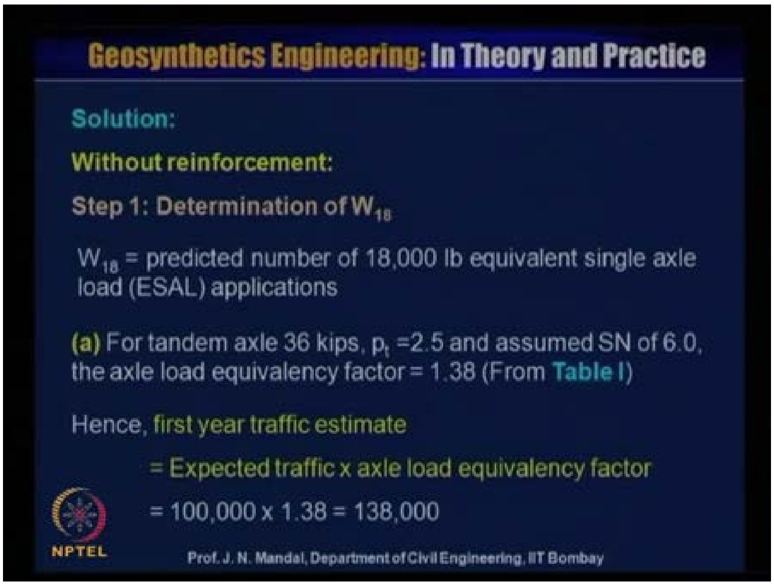

So, standard deviation S 0 is equal to 0.35, asphalt layer coefficient a i is equal to 0.40, base course layer coefficient a 2 is equal to 0.14, sub base layer coefficient a 3 is equal to 0.08. Drainage condition is good, pavement is exposed to saturation moisture more than 25 percentage of the time.

Now, we will solve this problem this is solution without reinforcement step 1, determination of W 18 that is W 18 is predicted number of 18,000 pound equivalent single axle load or that is ESAL application, a for tandem axle 36 kips p t is equal to 2.5. That means, terminal serviceability is 2.5 and I assume SN Structural Number of 6.0 the axle load equivalency factor is equal to 1.38 which we can determine from the table 1.

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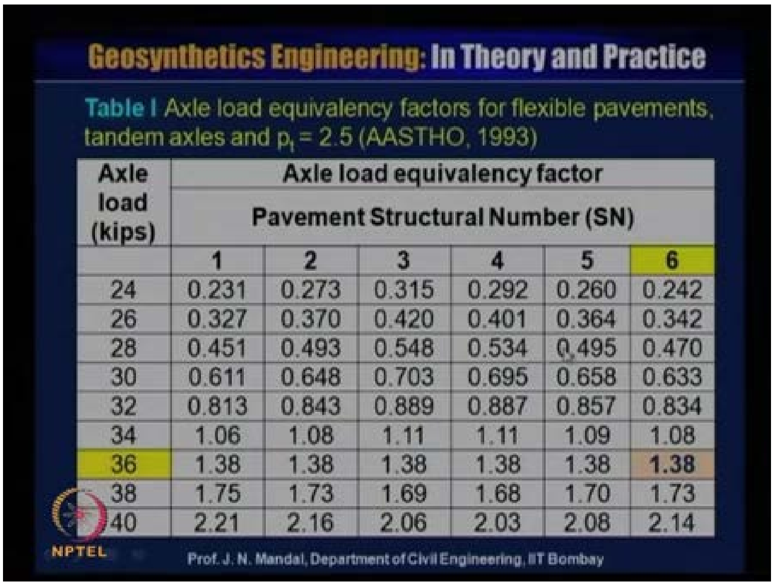

Axle load (kips)	Axle load equivalency factor					
	Pavement Structural Number (SN)					
	1	2	3	4	5	6
24	0.231	0.273	0.315	0.292	0.260	0.242
26	0.327	0.370	0.420	0.401	0.364	0.342
28	0.451	0.493	0.548	0.534	0.495	0.470
30	0.611	0.648	0.703	0.695	0.658	0.633
32	0.813	0.843	0.889	0.887	0.857	0.834
34	1.06	1.08	1.11	1.11	1.09	1.08
36	1.38	1.38	1.38	1.38	1.38	1.38
38	1.75	1.73	1.69	1.68	1.70	1.73
40	2.21	2.16	2.06	2.03	2.08	2.14

So, for tandem axle of 36 kips we can calculate this standard axle kips is 36 kips, and this is the structural number pavement structural number SN. So, this table is the axle load equivalency factor for flexible payment for tandem axle load and the p t is 2.5 as far as AASHTO 1993, so for the axle load of 36 kips this standard SN value is equal to 6.

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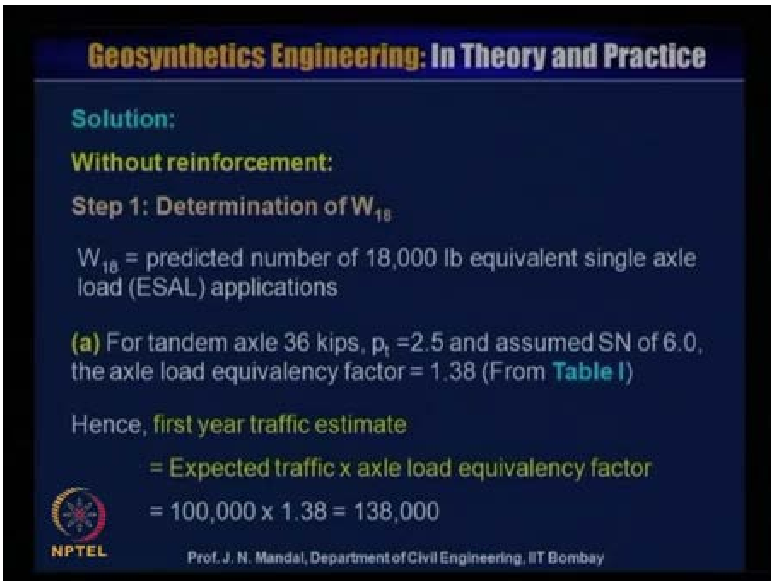

So, here that is why SN value 6 has been considered and axle load equivalent factor is 1.38.

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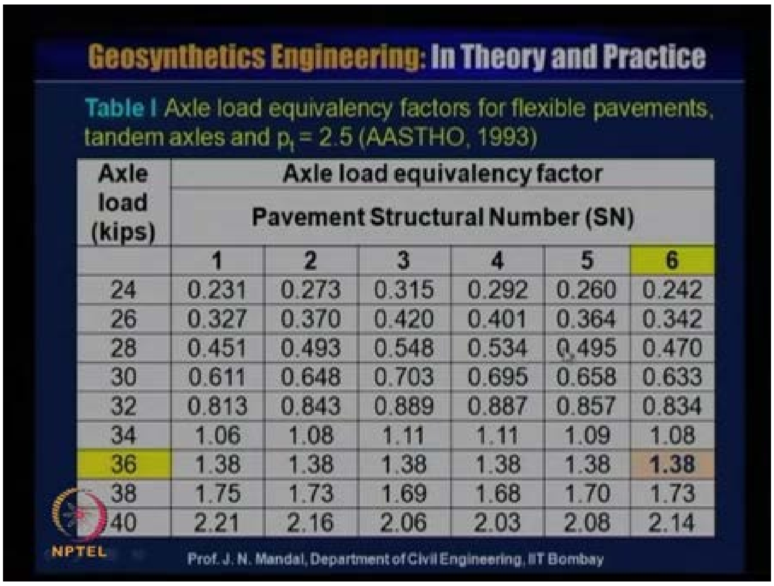

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38	1.75	1.73	1.69	1.68	1.70	1.73
40	2.21	2.16	2.06	2.03	2.08	2.14

So, for this axle load 36 and assumed value of 6 this axle load equivalent factor is 1.38.

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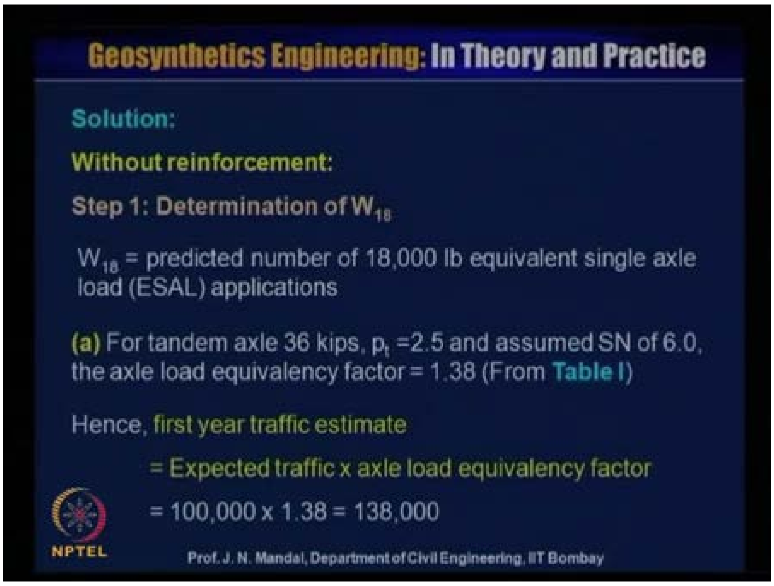

So, here axle load equivalent factor is equal to 1.38, which we have obtained from table 1, hence first year traffic estimate is equal to expected traffic into axle load equivalency factor. The expected traffic is 1,00,000 into axle load equivalency factor is 1.38, so 1,00,000 into 1.38 is equal to 1,38,000, so this is the first year traffic estimate.

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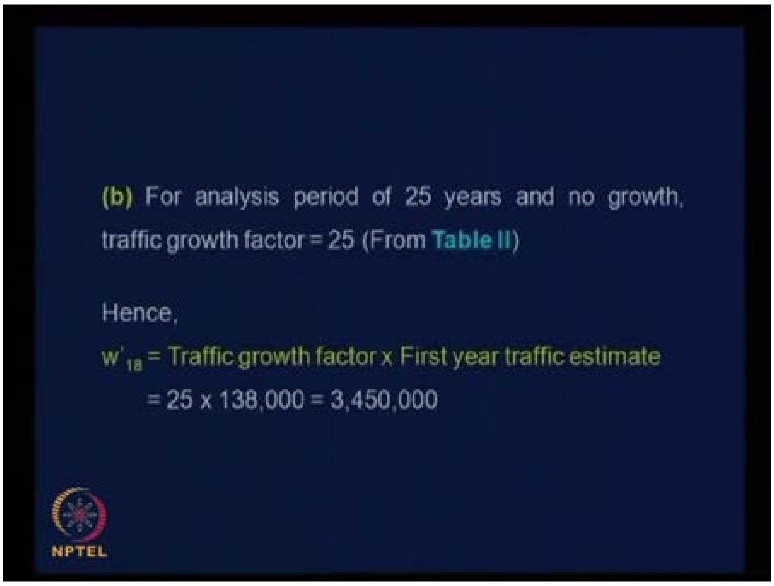
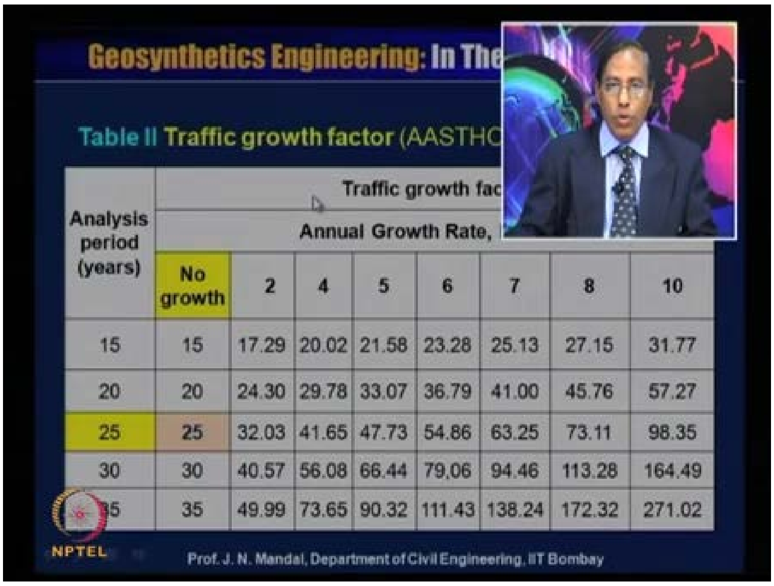


Now, b for analysis prior of 25 years and no growth traffic growth factor is equal to 25, this we have calculated from table 2.



So, no growth factor for 25 years this is from table 2 this is the traffic growth factor as per AASHTO 1993, and analysis for the period year is 25 and no growth that is why this number will be traffic growth factor will be equal to 25.

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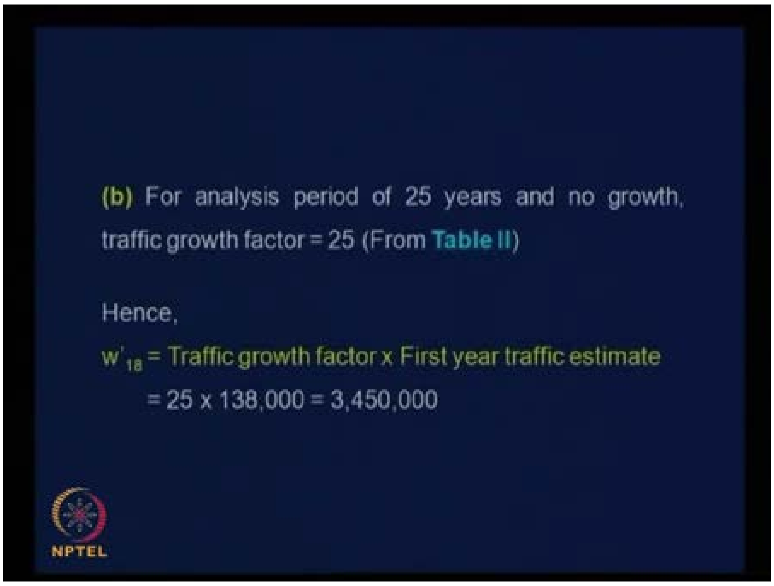

So, this is traffic growth factor is equal to 25 there is no growth, but for the analysis period of 25 years, hence double dash 18 will be equal to traffic growth factor into first year traffic estimate. So, growth factor is 25 into 1,38,000; that means, 3,450,000, so this is W s 18.

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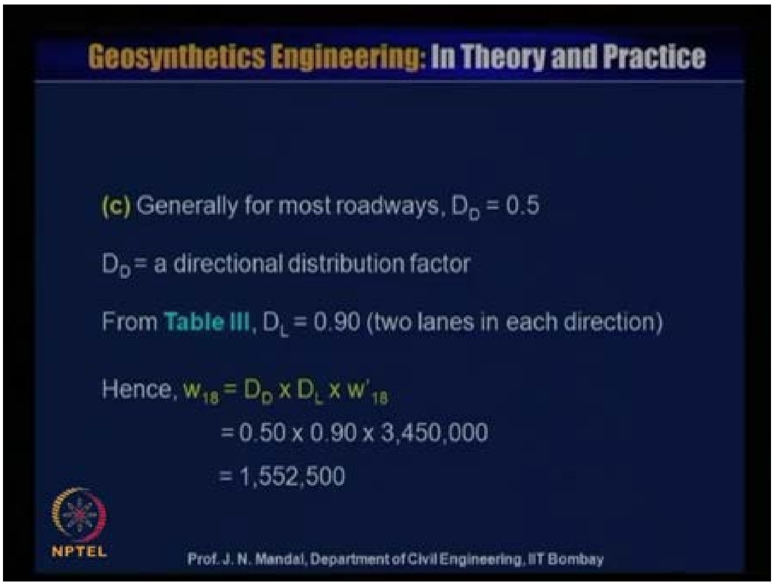

Now, see generally for most roadway D D is equal to 0.5, where D D is equal to a directional distribution factor, so from the table 3 D L is equal to 0.90 the 2 lane in each direction.

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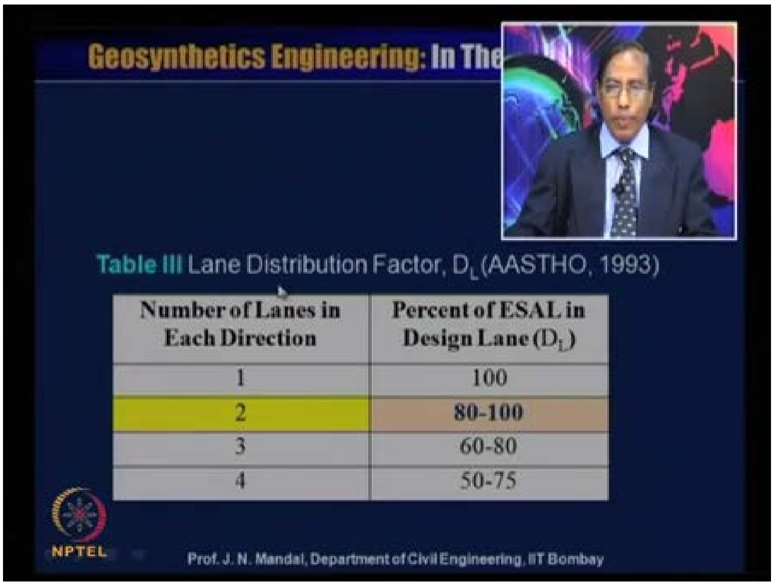

Number of Lanes in Each Direction	Percent of ESAL in Design Lane (D_L)
1	100
2	80-100
3	60-80
4	50-75

So, from this table 3 which give length distribution factor D L as per as AASHTO 1993, this is number of lane in each direction it may be 1, 2, 3, 4 and this is percentage of ESAL in design lane D L. That means, 100, 80 to 100, 60 to 80, 50 to 75 here we have consider a number of lane in each direction is 2, and percentage ESAL in design lane D L

80 to 100.

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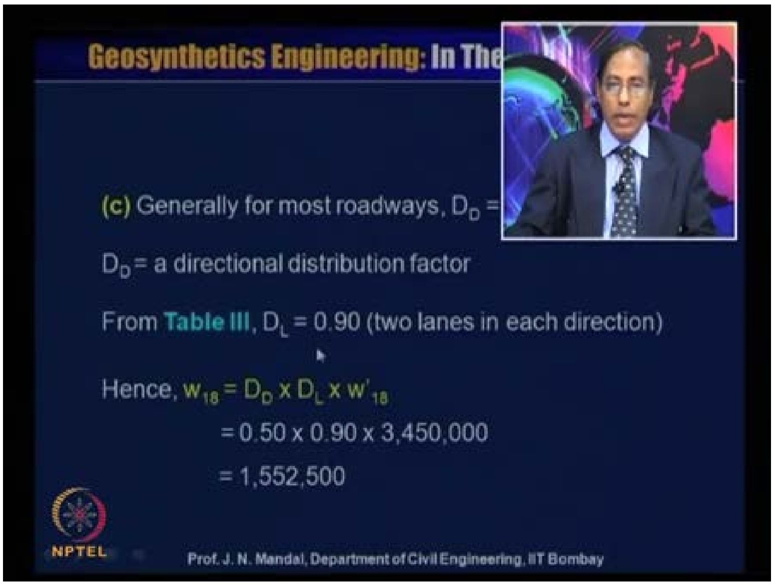

That we have considered here that D L is approximately 0.90 that is 2 lane in each direction. Hence w 18 will be equal to D D into D L into w dash 18, and D D we have calculated that is 0.5 year D L we have obtained from table that is 0.90, and w dash 18 we have calculated earlier 3,450,000. So, this will give this w 18 is equal to 1,552,500.

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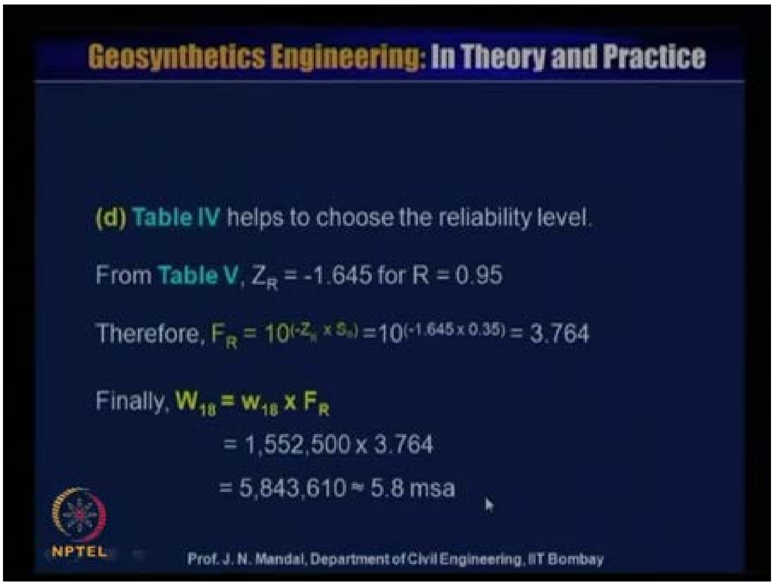

Now, d table 4 helps to choose the reliability level and from table 5 Z R is equal to minus 1.645 from R is equal to 0.95.

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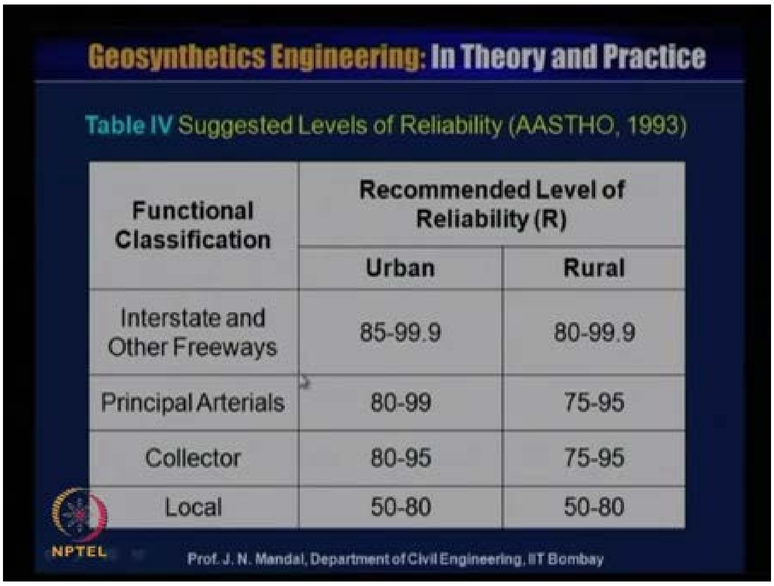

Functional Classification	Recommended Level of Reliability (R)	
	Urban	Rural
Interstate and Other Freeways	85-99.9	80-99.9
Principal Arterials	80-99	75-95
Collector	80-95	75-95
Local	50-80	50-80

So, we have chosen that this is the reliability this table 4 suggested level of reliability as per AASHTO 1993, and this is functional classification, interstate and other freeway, principle arterials, collector, local and this recommended level of reliability capital R whether it is a urban or rural. So, depend upon this urban and rural, so you can be able to obtain the reliability factor from this table, so let us say this is interstate and other freeway and this is the urban, so you are considering some reliability factor which will lie between 85 to 99.9.

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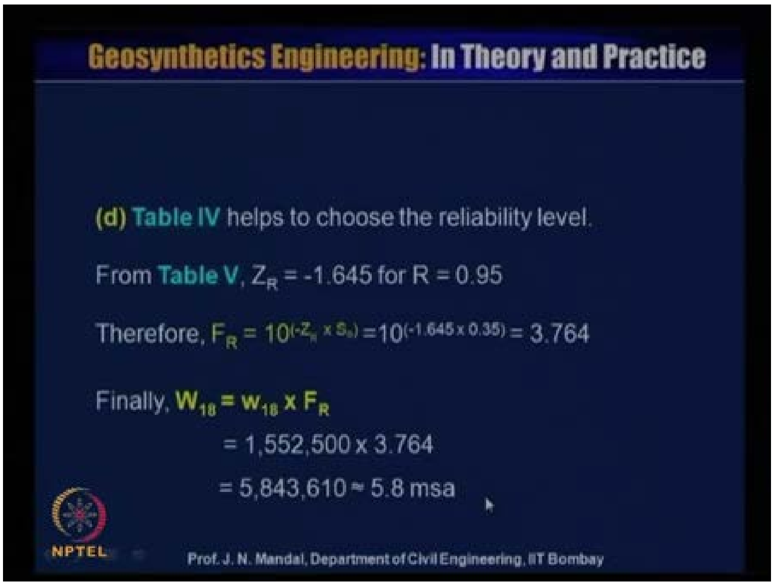

So, here considering that reliability factor is equal to 0.95, so for this 0.95 we have to calculate Z R value from table 5.

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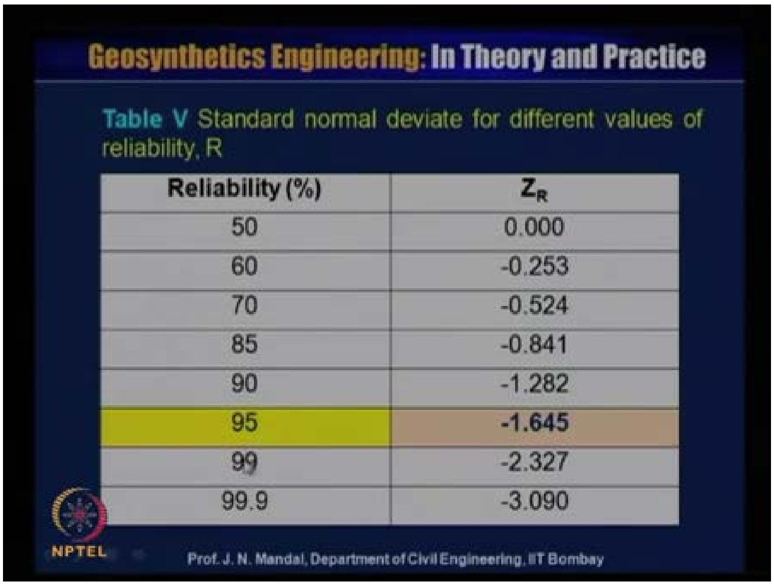

So, Z R value you can calculate from table 5 this table shows the standard of normal deviation for different values of reliability, you can see reliability percentage starting from 50, 60, 70, 85, 90, 95, 99, 99.9. And correspondingly Z R value is given on the right hand side, here as we have considered it the reliability is 95 percent, so Z R value is minus 1.645.

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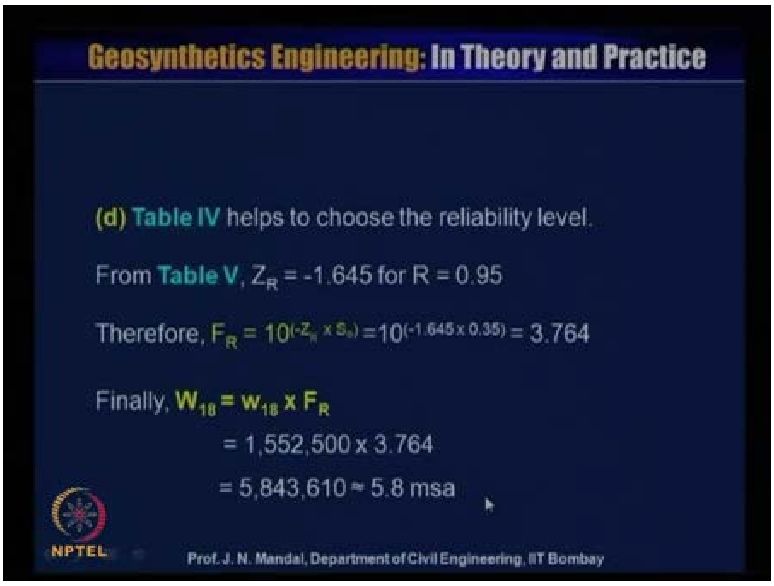

So, for the 95 percent reliability, so Z R value we obtain from table 5 is equal to minus 1.645. Therefore, you can write F R is equal to 10 into minus Z R into S 0 for S 0 is the standard deviation; that means, 10 into minus Z R value is minus 1645 and the S 0 which we call the standard deviating that is 0.35. So, if you calculate you can have F R value will be equal to 3.764. Finally, W 18 will be equal to W 18 into F R; that means, 1,552,500 into this F R; that means, 3.764. So, this will give about 5.8 MSA that is Million Standard Axle, so you obtain this finally, W 18 is 5.8 m s a that you should remember.

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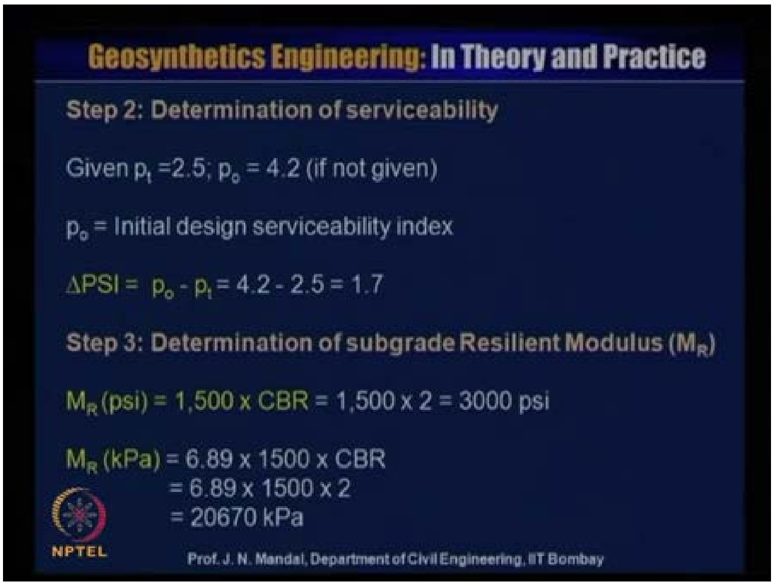

Now, step 2, determination of serviceability now given p t that mean terminal serviceability is equal to 2.5. And p 0 assume is 4.2 if not given, so p 0 where is initial design serviceability index, so delta PSI will be equal to p 0 minus p t; that means, p 0 is 4.2 minus p t is 2.5 is equal to 1.7. Now, step 3 determination of sub grade resilient modulus that is M R, so M R in PSI is 1500 into CBR as CBR value is 2. So, 1500 into 2 is equal to 3000 PSI or M R in terms of k P a it will be in terms of 6.89 into 1500 into CBR; that means, 6.89 into 1500 CBR value is 2, so it will give M R in kilopascal 20670 kilopascal.

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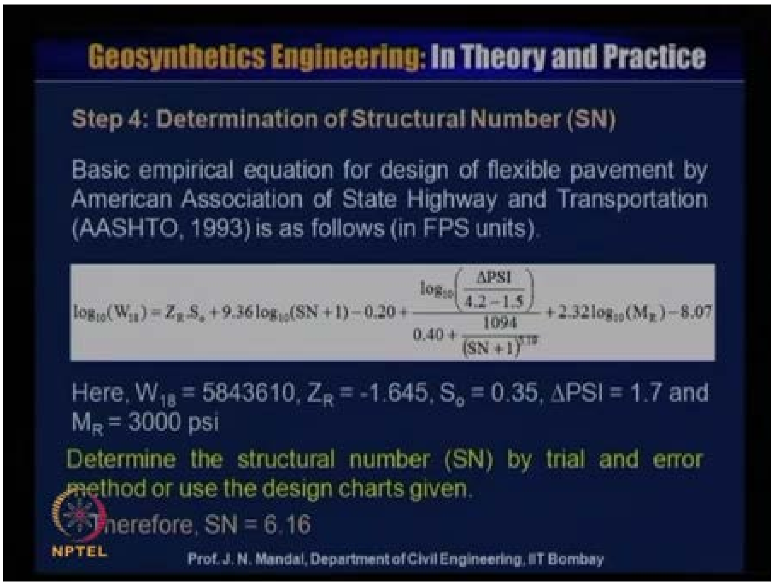

Step 4, determination of structural number that is S N, the basic empirical equation for design of the flexible pavement by American association for state highway and transportation AASHTO 1993 is as follow in FPS unit, this is W log 10 W 18 is equal to Z R into S 0 plus 9.36 into log 10 S N plus 1 minus 0.20 plus log 10 of delta PSI divided by 4.2 minus 1.5, this divided by 0.40 plus 1094 divided by S N plus 1 whole to the power 5.19 plus 2.32 into log of 10 into M R minus 8.07.

Now, we will use this equation here we know what is W 18 is 5843610 Z R we have calculated we have obtained Z R value is minus 1.645. And then we know that what is the value of S 0 that is this S 0, S 0 is 0.35; that means, standard deviation is 0.35 S 0 and then delta PSI, delta PSI we calculated 1.7 and this M R value M R value is equal to 3000 PSI. So, we can determine the structural number that is S of N by trial and error method or you can use the design chart which is also given. So, from the trial and error method you calculate that what will be the S N value and S N value is here about 6.16 this is approximately 6.16, so you assume 6 and we obtain about 6.16.

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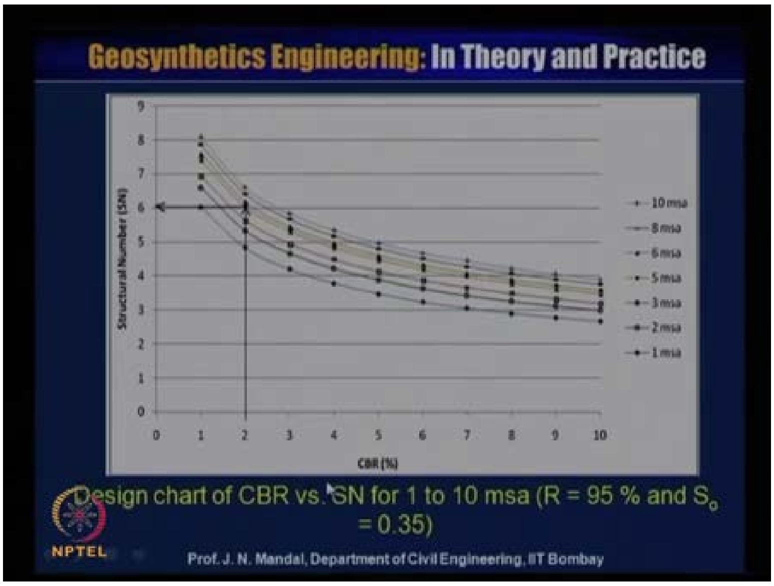

So, this is the design chart for the CBR versus S N for 1 to 10 m s a, and reliability factor R is equal to 95 percent, and S 0 is equal to 0.35, this is structural number versus CBR for different m s a, this may be m s a 1, m s a 2, m s a 3, m s a 5, m s a 6, m s a 8, m s a 9 and 10 m s a. So, if we know that what will be the CBR value, and if you know that what should be the millions of standard axle, so you can determine what will be the structural number.

In this problem our CBR value is 2, so you know in the x axis CBR 2 then we move up, and we know that what will be this value; that means, we know the m s a value what will be the million standard axle and here m s a value is about 5.8, this W 18 this is 5.8 that is million standard axle. So, this is 5.8, so you can have the 5.8 this is the 5 in between 5 and 6, so this is 5.8 and then you move horizontally and then you can obtain what will be the standard structural number that is S N. So, this structural number S N will be about 6.16, so you can calculate that will be the structural number, which we obtained here 6.16, so this is 6.16.

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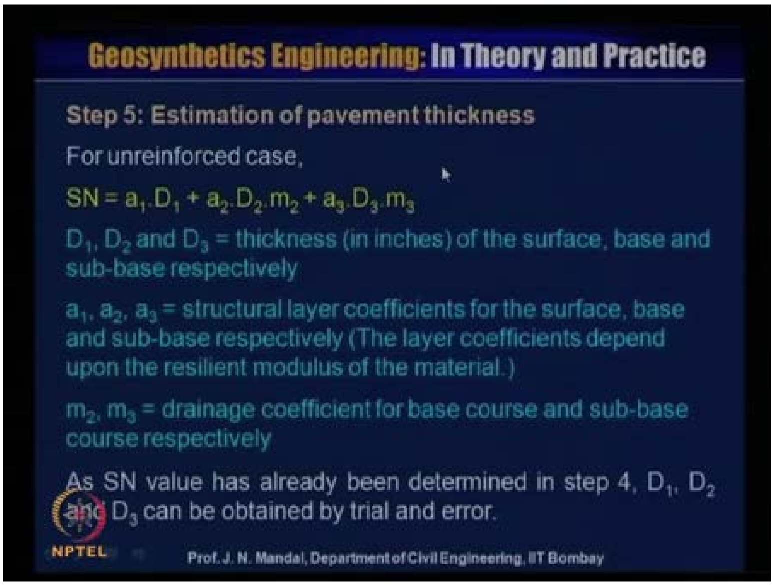

Now, step 5 estimation of pavement thickness for unreinforced case S N is equal to a 1 D 1 plus a 2 D 2 m 2 plus a 3 D 3 m 3 for D 1, D 2 and D 3 are the thickness in inches of the surface, base and sub base respectively a 1, a 2, a 3 is structural layer coefficient for surface, base and sub base respectively. The layer coefficient depend upon the resilient modulus of the material m 2, m 3 drainage coefficient for base course and sub base course respectively as S N value has already been determined in step 4, so D 1, D 2, D 3 can be obtained by the trial and error method.

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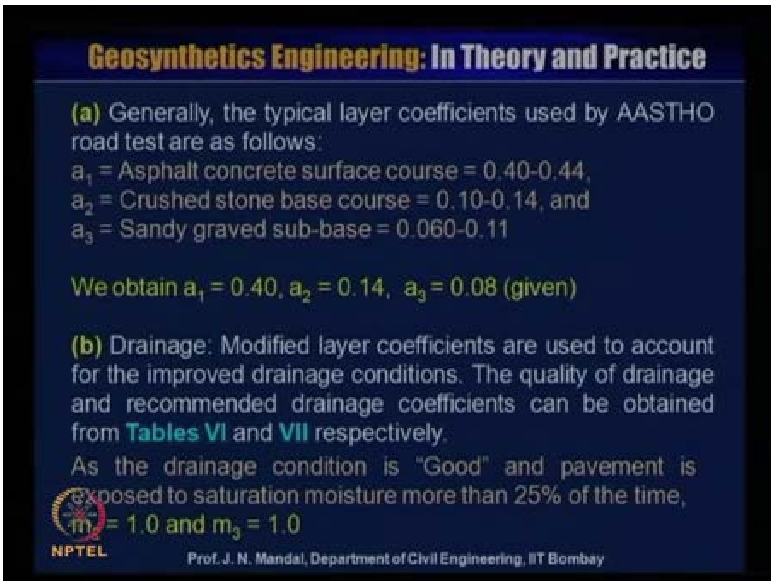

Say generally the typical layer of coefficient used by the AASHTO road test are as follow, a 1 is equal to asphalt concrete surface course that is equal to 0.40 to 0.44, a 2 crushed stone base course that is 0.10 to 0.14 and a 3 sandy gravel sub base that is 0.060 to 0.11. We obtain in our problem a 1 is equal to 0.40, a 2 is equal to 0.14, a 3 is equal to 0.08 this is given.

Now, drainage modified layer coefficient are used to account for the improved drainage condition is very important, most of the time we do not consider the drainage condition. But, we should consider the drainage condition the quality of the drainage and the recommended drainage coefficient can be obtained from the table 6 and 7 respectively, as the drainage condition is good and pavement is exposed to saturation moisture more than 25 percent of the time, then we can obtain the m 2 value is equal to 1.0 and m 3 value is equal to 1.0.

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So, this is the drainage condition as per AASHTO 1997 this is quality of drainage whether excellent, good, fair, poor, very poor and duration of the water removal 2 hours, 1 day, 1 week, 1 month or water will not drain, we are considering that quality of the drainage is the good and it is for the 1 day.

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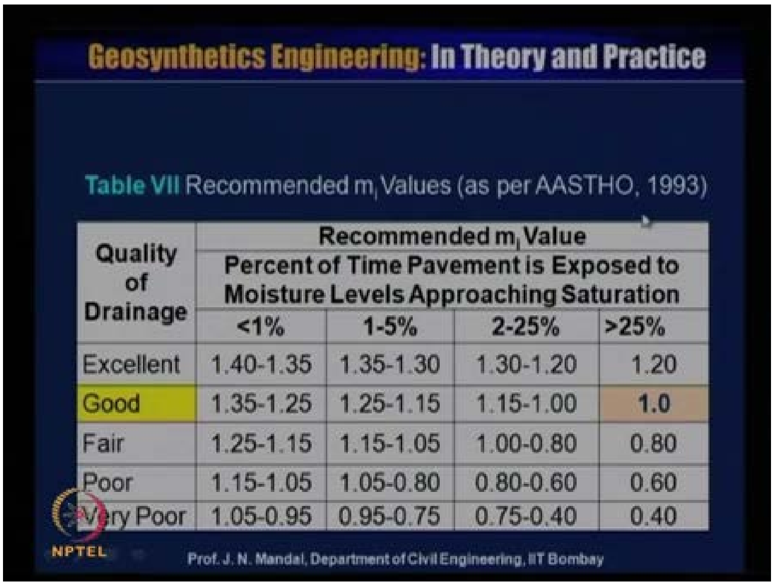

Quality of Drainage	Recommended m_i Value Percent of Time Pavement is Exposed to Moisture Levels Approaching Saturation			
	<1%	1-5%	2-25%	>25%
Excellent	1.40-1.35	1.35-1.30	1.30-1.20	1.20
Good	1.35-1.25	1.25-1.15	1.15-1.00	1.0
Fair	1.25-1.15	1.15-1.05	1.00-0.80	0.80
Poor	1.15-1.05	1.05-0.80	0.80-0.60	0.60
Very Poor	1.05-0.95	0.95-0.75	0.75-0.40	0.40

And this is the table recommendation for m value as per AASHTO 1993 this is quality of the drainage say excellent, good, fair, poor or very poor. And this is the percentage of time pavement is exposed to moisture level approaching saturation, so we have considered it that moisture content should be greater than equal to 25 percentage. Therefore, recommended value for m is equal to 1 because, quality of drainage is good, so this is the 1. So, we are considering that sub base course and the base course is the same moisture content, so this m 2 and m 3 value we are considering 1.

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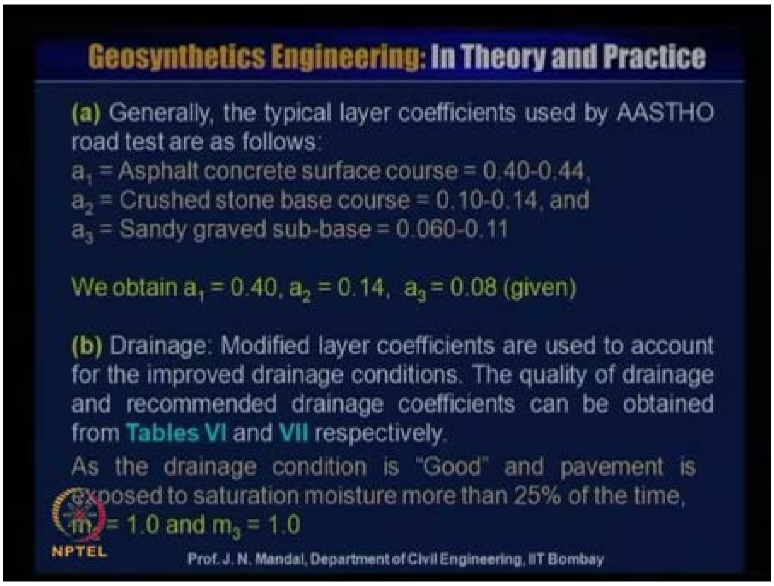

Here you can see the moisture content is more than 25 percent of the time, so m 2 value is equal to 1.0, m 3 value is equal to 1.0 because, we have considered the sub base and base course is the same moisture content.

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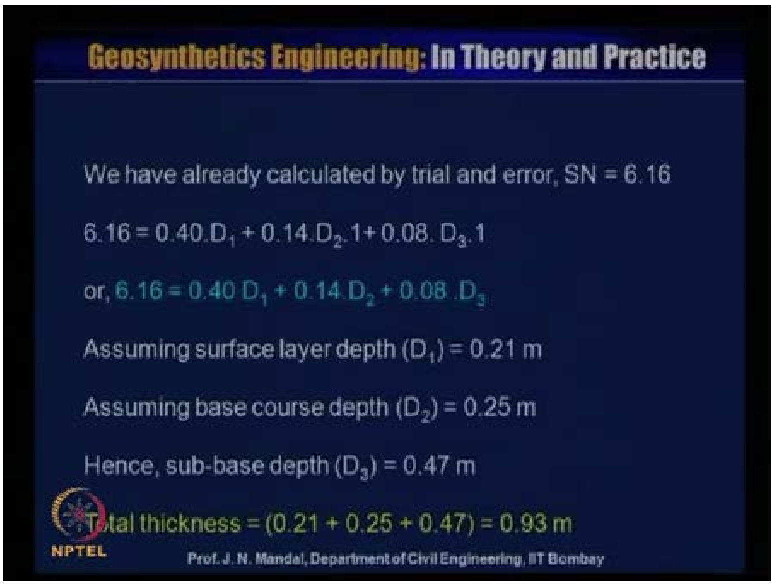

So, you can obtain this moisture content, so we have already calculated by trial and error that S N value is 6.16. So, we can write 6.16 is equal to a 1 D 1; that means, 0.40 into D 1 plus 0.14 into D 2 into 1, 1 is the moisture content m 2 and plus 0.08 plus D 3 into 1 this is m 3 is equal to D 3. So, if we calculate by the trial and error assuming that different value, and check up whether the left hand side will be on the right hand side. So, from this you can calculate what will be the thickness of the pavement, assuming surface layer depth D 1 is equal to 0.12 meter, assume the base course depth D 2 is equal to 0.25 meter, hence you can determine the sub base depth D 3 is equal to 0.47 meter. So, total thickness will be 0.21 meter plus 0.25 meter plus 0.47 meter is 0.93 meter.

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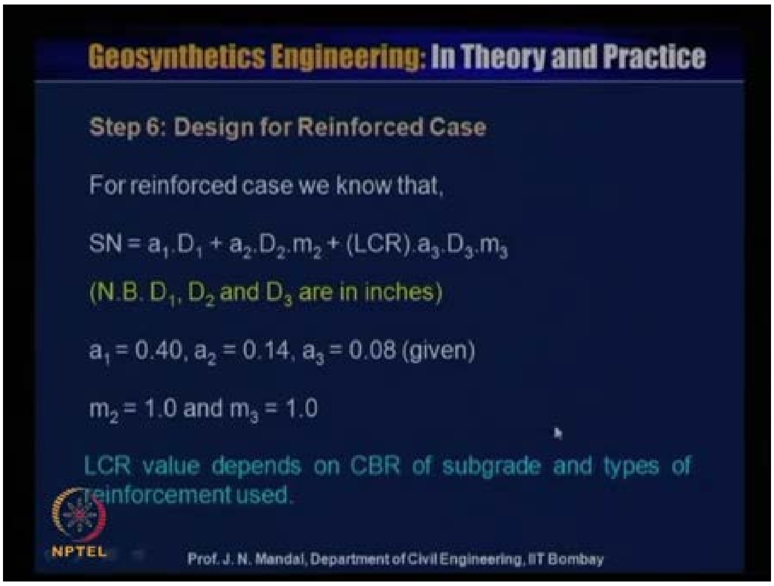

Now, step 6 design for reinforced case, for reinforced case we know that S N is equal to a 1 D 1 plus a 2 D 2 m 2 plus LCR into a 3 D 3 m 3, where LCR is equal to linear coefficient Ratio. So, these are all are in inches, so a 1 we know, a 2 know, a 3 know is given m 2 know 1 m 3 1, so LCR value is dependent on the California bearing ratio of sub grade, and the type of the reinforcement used.

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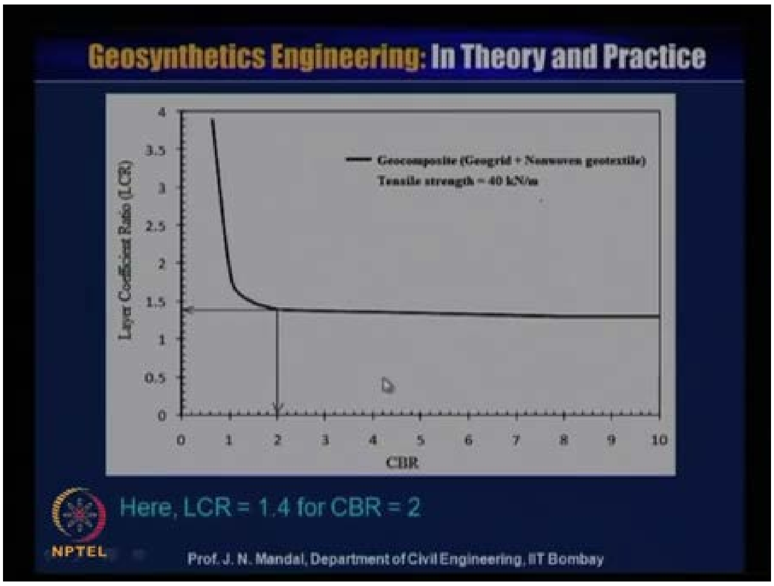

So, we can obtain the linear coefficient value from this figure, this figure shows that we have used the geo composite that is geo grid and non woven geo textile, whose tensile strength is 40 kilo Newton per meter. So, for the defined value of CBR, CBR you can obtain the linear coefficient ratio LCR, here CBR value is 2, so correspondingly the LCR value will be near about 1 to 1.5 it may be 1.4.

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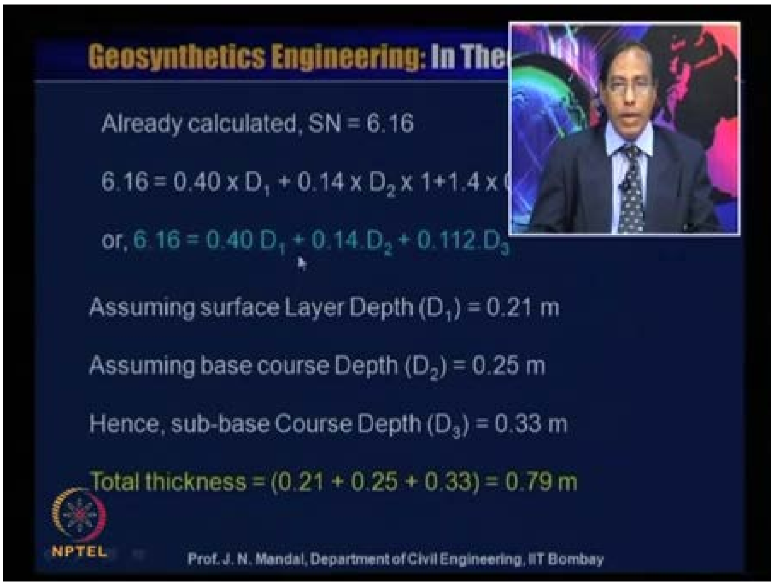

So, LCR value we are considering that 1.4, so if substitute this LCR value is equal to here 1.4. So, you know that LCR value, so again you can calculate that assuming the surface layer depth D 1 0.21 meter, and base course depth D 2 0.25 meter, and sub base course depth D 3 0.33. So, total thickness will be 0.21, 0.25, 0.33; that means, 0.79 meter you can see that thickness has reduced due to the deployment of the geo synthetics material.

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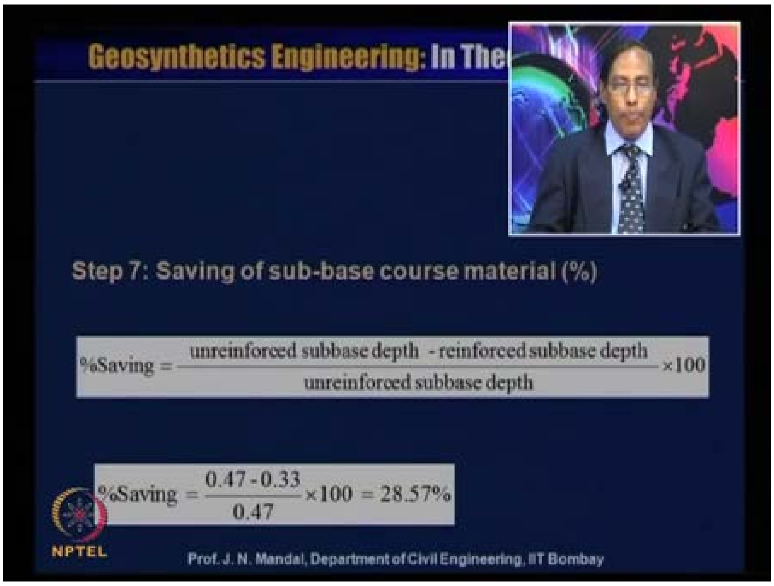

Step 7, saving of the sub base course material, so percentage of saving is unreinforced sub base depth minus reinforced sub base depth divided by unreinforced sub base depth into 100 that is percentage of saving is 0.47 minus 0.33 divided by 0.47 into 100, you can see saving about 28.57 percentage.

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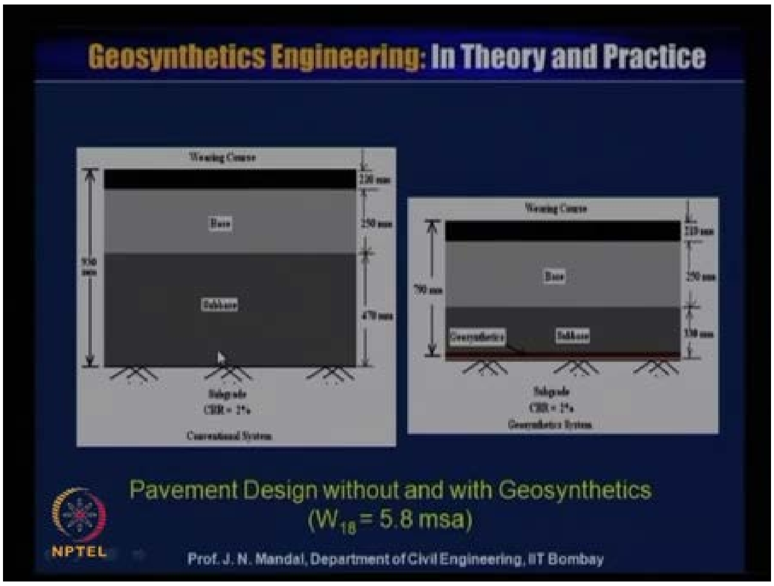

This is the pavement design without and with geo synthetics material for W 8 is equal to 5.8 s m a for in case of the conventional system where CBR is equal to 2 percentage. So, thickness of the pavement is 930 millimeter, and then you can divide it into sub base

base and the wearing course that is sub base course is 470 millimeter, base course is 250 millimeter, and the wearing course is 210 millimeter. And the right hand side we are showing that with the geo synthetics reinforcement system, whose CBR value is 2 percent.

And here is the geo synthetics material lies between the sub base and the sub grade material, and over the sub base is equal to 330 millimeter, and the base course is about 250 millimeter, and wearing course about 210 millimeter. So, you can see that how much we are saving of this good quality of aggregate with the deployment of geo synthetics as a reinforcement material in unpaved road, with this I ended up this lecture today please let us hear from you any question.

Thanks for listening.