Geosynthetics Engineering: In Theory and Practices
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Lecture - 29
Geosynthetics for Reinforced Soil Retaining Walls

Dear student warm welcome to NPTEL phase 2 video program on Geosynthetics Engineering in Theory and Practice. Lecture number 29, the name of the course Geosynthetics Engineering in Theory and Practice, this module 6 lecture 29 Geosynthetics for Reinforced Soil Retaining Walls.

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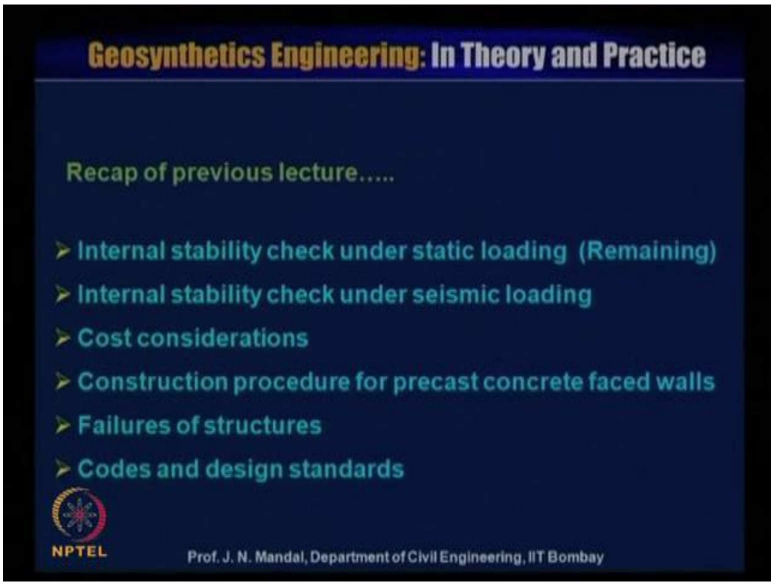

I will now focus the recap of the previous lecture. This internal stability check under the static loading remaining, internal stability check under seismic loading, cost consideration, construction procedure for precast concrete faced wall, failure structure, code and design standard.

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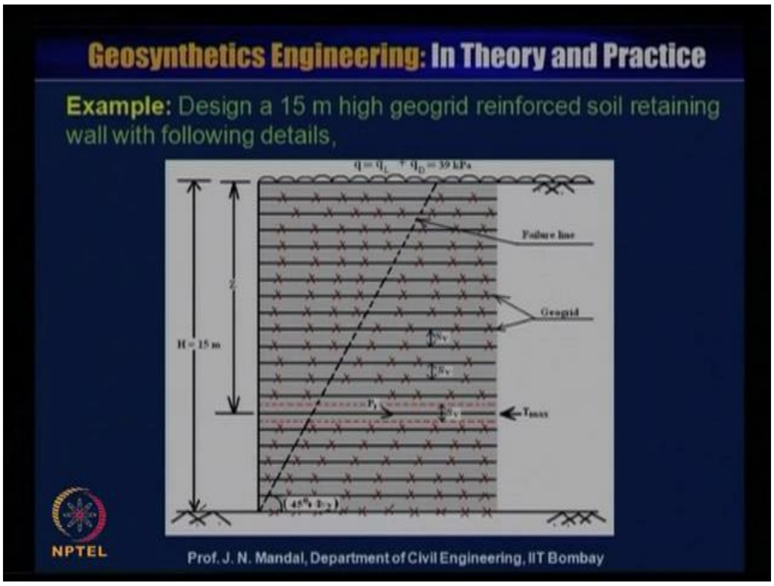

Now, I will present a example, design a 15 meter high geogrid reinforced soil retaining wall, whose following is given details. This is height of the wall, this is 15 meter and this is the failure surface, which is making at an angle of 45 degree plus pi by 2. And there is a live load and dead load, so total load is about 39 kiloPascal.

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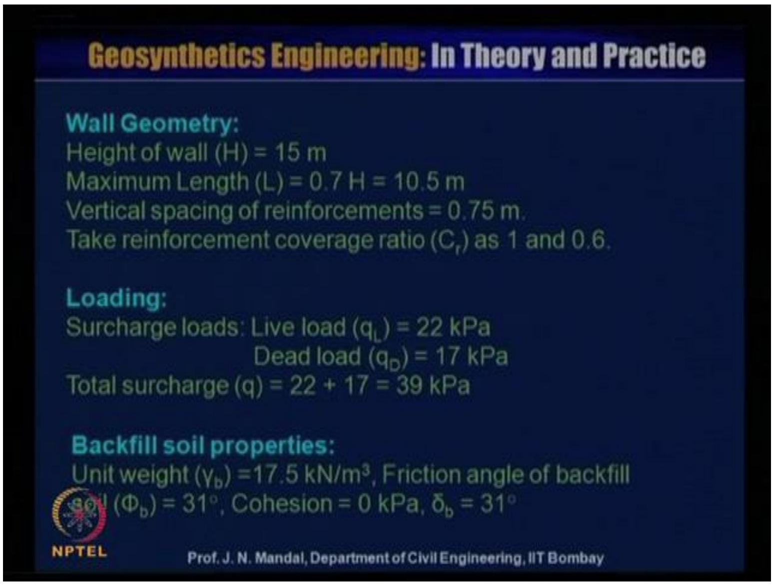

The problem is like this wall geometry, I say height of the wall is 15 meter, maximum length is 0.7 times the height of the wall, that mean 10.5. Vertical spacing of reinforcement is 0.75 meter, take the reinforcement coverage ratio C r as 1 and 0.6. So, you are taking the coverage ratio 1 and 0.6 so loading is surcharge load, live load q L is equal to 22 kiloPascal, dead load q D is 17 kiloPascal so total surcharge q is equal to 22 plus 17 is 39 kiloPascal.

Now, in backfill soil properties, unit weight of backfill soil gamma b is equal to 17.5 kiloNewton per meter cube, friction angle of backfill soil pi b is 31 degree, cohesion is equal to 0 kiloPascal and delta b is equal to friction angle between the reinforced soil zone and backfill soil zone. We are considering the same 31 degree generally, it should be less than the 31 degree but in our problem, we have considered the same angle.

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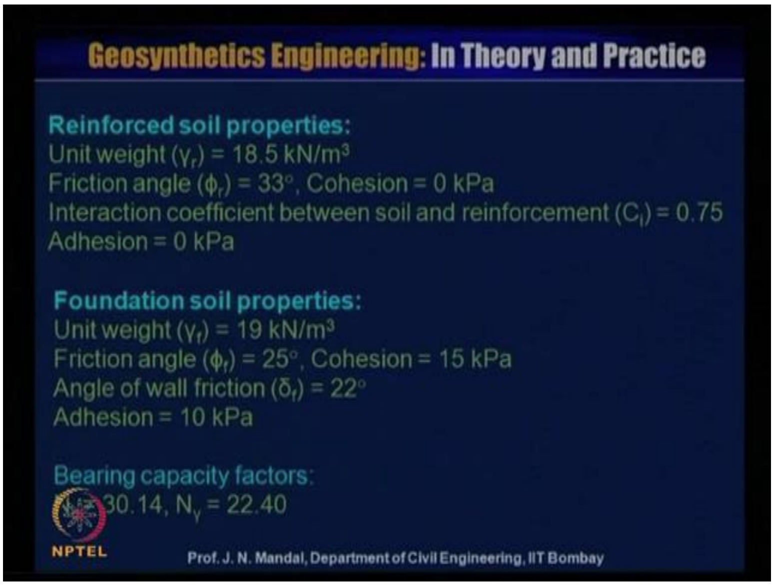

Now, reinforced soil properties unit weight gamma r 18.5 kiloNewton per meter cube, friction angle pi r 33 degree, cohesion 0 kiloPascal, interaction coefficient between soil and the reinforcement that is, C i is equal to 0.75 and adhesion is 0 kiloPascal. So, do not confuse with the interaction coefficient between soil and reinforcement C i and C of r. C r is the coverage ratio that is, the width of the geogrid strip divided by center to center horizontal spacing.

Then, foundation soil properties, unit weight of foundation soil is 19 kiloNewton per meter cube, friction angle pi r is 25 degree, cohesion value 15 kiloPascal, angle of wall friction delta r is 22 degree, adhesion 10 kiloPascal. Next, bearing capacity factor is given, N c is equal to 30.14, N gamma is equal to 22.40.

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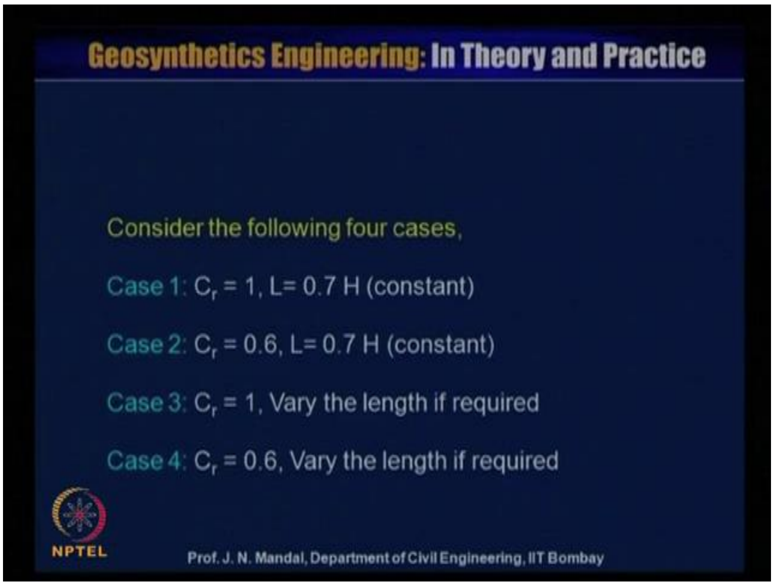

So, these are the properties of the reinforced soil retaining wall is given, now you have to design. We have considered here the four cases, case 1 when the coverage ratio is 1, when the length of the reinforcement is 0.7 times the height of the wall, that is constant. Case 2, when the coverage ratio is 0.6 and length is equal to 0.7 H that is constant, case 3 that is, coverage ratio C r is equal to 1, varying the length if required and case 4, C r is equal to 0.6, vary the length if required. Now, I am trying to say, what do mean by the coverage ratio.

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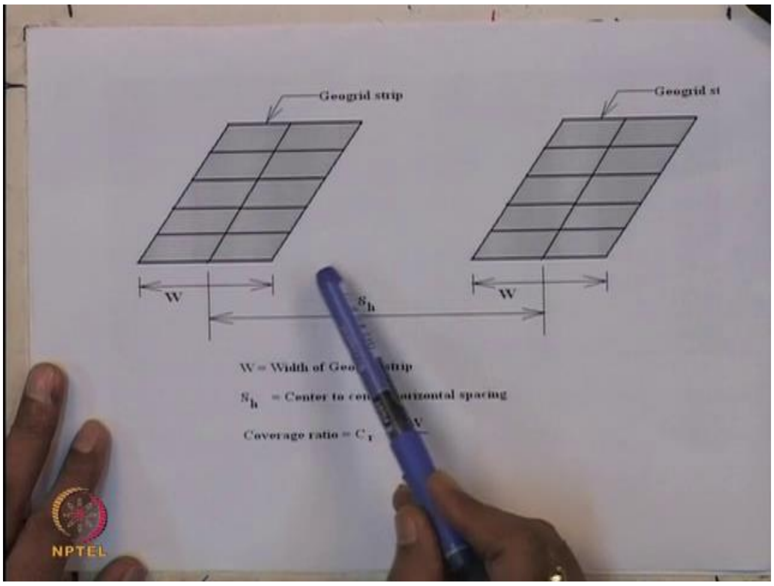

Coverage ratio we have already explained earlier, if this is the geogrid strip and this is the width of the geogrid strip and this is the center to center horizontal spacing of the geogrid strip that is, S h. So, coverage ratio C r is defined as this W divided by S h so that means, if C r value may be 0.6, may be you have to provide the geogrid strip like that at a certain interval. But, when the C r value is 1 that mean, W is equal to S h that means, the entire portion will be geogrid that is, 100 percent with the geogrid. So, we can minimize the geogrid sample by considering the coverage ratio either 0.6 or 0.5, 0.4 or 0.7 or 0.8. But, in this problem, we have considered that C r value is equal to the 0.6.

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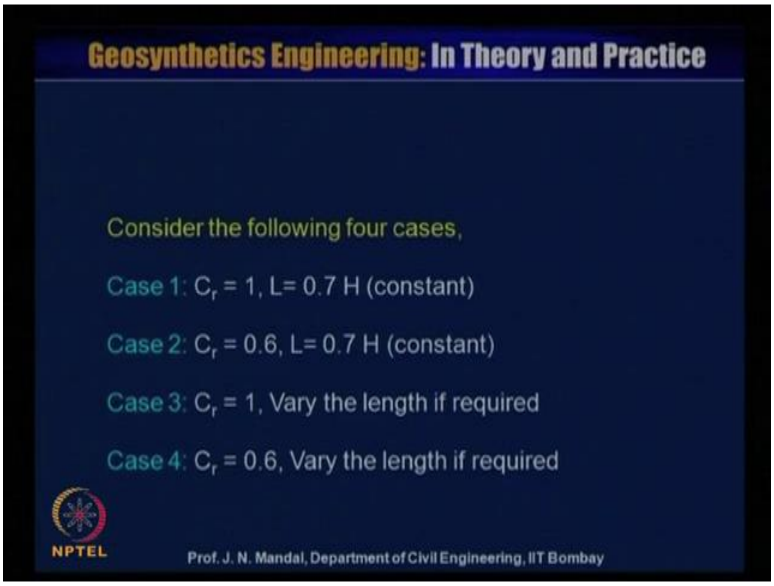

And C r value is equal to 1 so we will consider the one by one for the solution, now when I have to design this geosynthetics reinforced soil retaining wall. So, you have to check, what will be the internal stability, what should be the external stability. So, for the internal stability, we have to determine what will be the ultimate tensile strength of the geogrid from rupture criteria.

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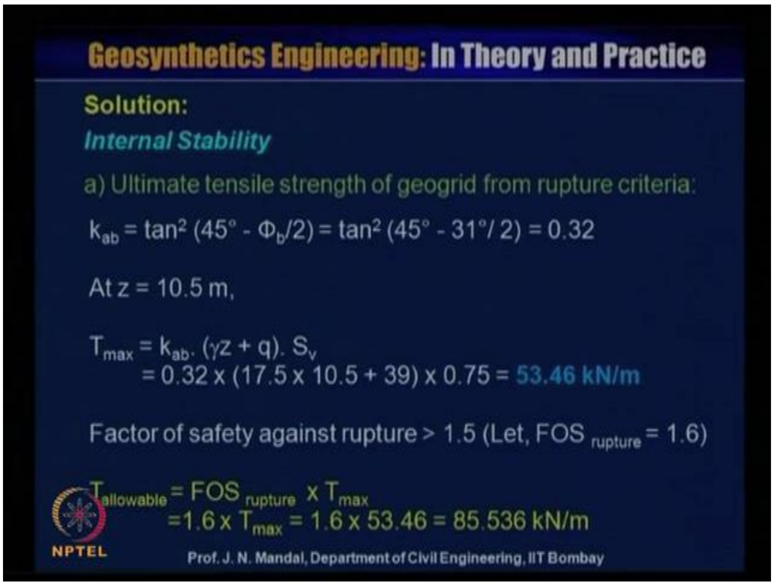

So, to determine the ultimate tensile strength, you have to check what will be the k of a b that means, coefficient of active earth pressure at the backfill soil, that is equal to tan square 45 degree minus phi b by 2. Phi b value is given 31 degree so tan square 45 degree minus 31 degree by 2 is equal to 0.32. So, you know k b is equal to 0.32 now, we are considering that, at a depth z is equal to 10.5.

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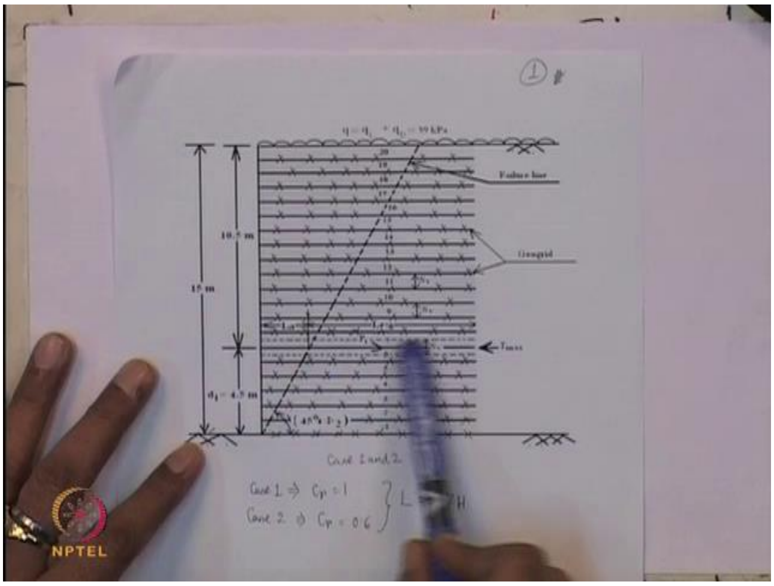

For example, that this is the wall whose height is about 15 meter, we are calculating what should be the T maximum at a depth of 10.5 meter because spacing is given. That means, spacing is S v that is what will be the spacing between the two reinforcement, that is 0.75 meter. So, we wanted to check that, what will be the maximum tensile strength value at a depth of 10.5 meter. So, at depth z is equal to 10.5, what should be the T maximum. So, T maximum will be equal to k into a b into gamma into z plus surcharge load q into the spacing S b.

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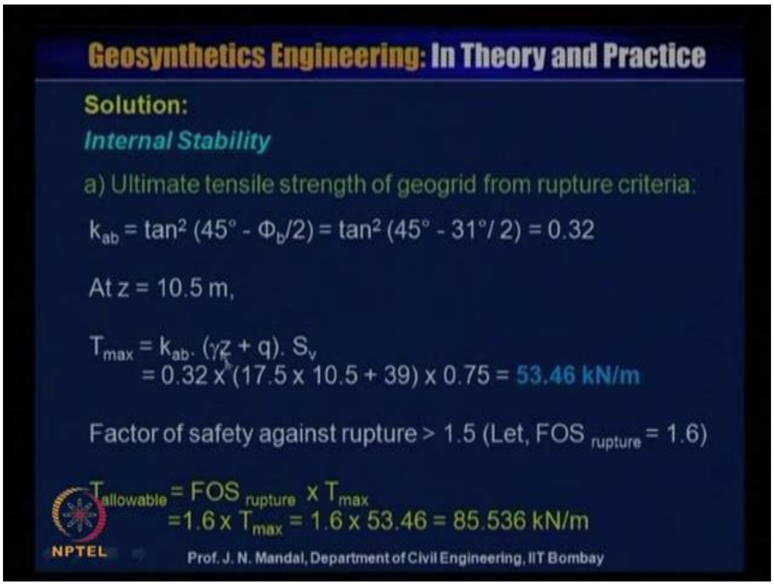

So, we can show you that, k b is given 0.32, gamma is 17.5, z is 10.5 because at a depth of 10.5 meter and q is the dead load plus live load, this is 39 into S v, the spacing between two reinforcement 0.75. So, T maximum will come 53.46 kiloNewton per meter now, you have to check, what will be the factor of safety against rupture and it should be greater than equal to 1.5. Let us consider factor of safety against the rupture is 1.6 so T allowable will be equal to factor of safety rupture into T maximum.

So, we have consider factor of safety for rupture 1.6 into T maximum, T maximum we calculated 53.46 kiloNewton per meter. So, 1.6 into 53.46 is 85.536 kiloNewton per meter.

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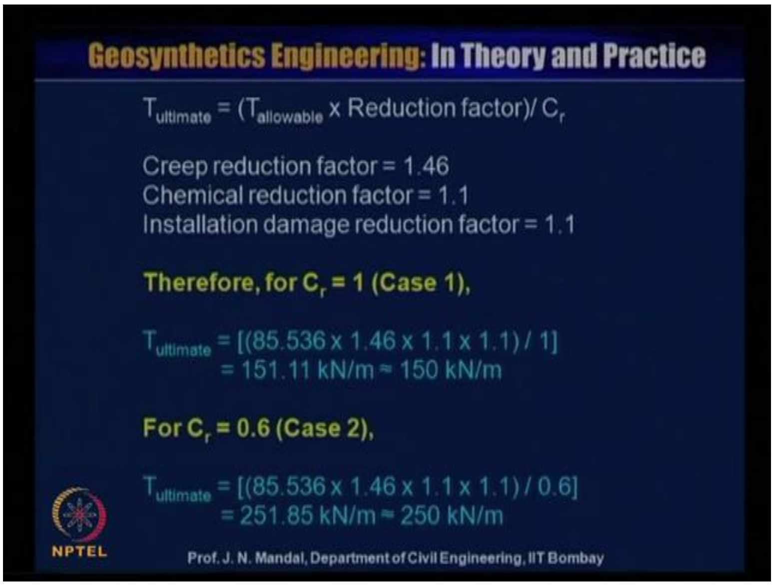

Now, what will be the T ultimate value, that will be T allowable into reduction factor divided by C of r. Now, this reduction factor that we can consider, that creep reduction factor is 1.46, chemical reduction factor is equal to 1.1 and installation damage reduction factor is equal to 1.1. So, all these reduction factor you have to take into consideration and then you have to calculate what will be the ultimate tensile strength of the geotextile geosynthetics material.

Now, we have considered the two case, first of all we are calculating what will be the ultimate tensile strength for the geogrid, when the C r value is equal to 1 that means, case 1. So, T ultimate will be equal to 85.536 into that reduction factor value that is. 1.46 into 1.1 into 1.1 and this divided by C r, that is the coverage ratio and here, we have consider coverage ratio is equal to 1. So, ultimate tensile strength of the geogrid material will be 151.11 kiloNewton per meter, we consider approximately 150 kiloNewton per meter.

Now case 2, when the C r value will be the 0.6 that means, the coverage ratio will be 0.6 so you have to calculate what will be the T ultimate value. So, T ultimate will be equal to 85.536 into 1.46 into 1.1 into 1.1 divided by 0.6 because the coverage ratio is C r is 0.6. So, we calculate 251.85 kiloNewton per meter or approximately 250 kiloNewton per meter. So, we can observe here that, due to the coverage ratio, there is change of the tensile strength of the geogrid material.

When the coverage ratio value is 1 then the strength of the geogrid material is 150 kiloNewton per meter but when the coverage ratio is 0.6 then the tensile strength of the geogrid material is about 250 kiloNewton per meter, this is hard side.

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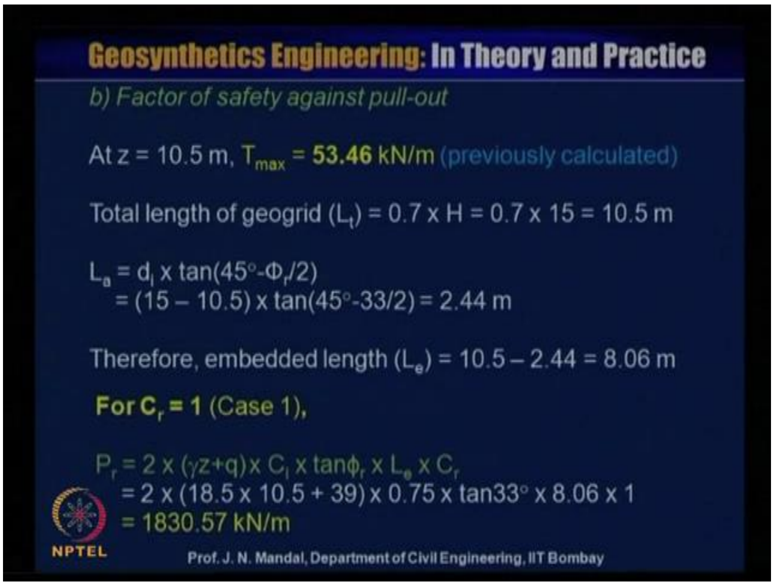

Next, b that, you have to check factor of safety against pullout at depth z is equal to 10.5 so we know that, T maximum is equal to 53.46 kiloNewton per meter. We have already previously calculated now, what will be the total length of the geogrid. We know total length of the geogrid is equal to 0.7 into H, H is the height of the geogrid wall. So, 0.7 into 15 is equal to 10.5 meter, now we have to calculate the L of a.

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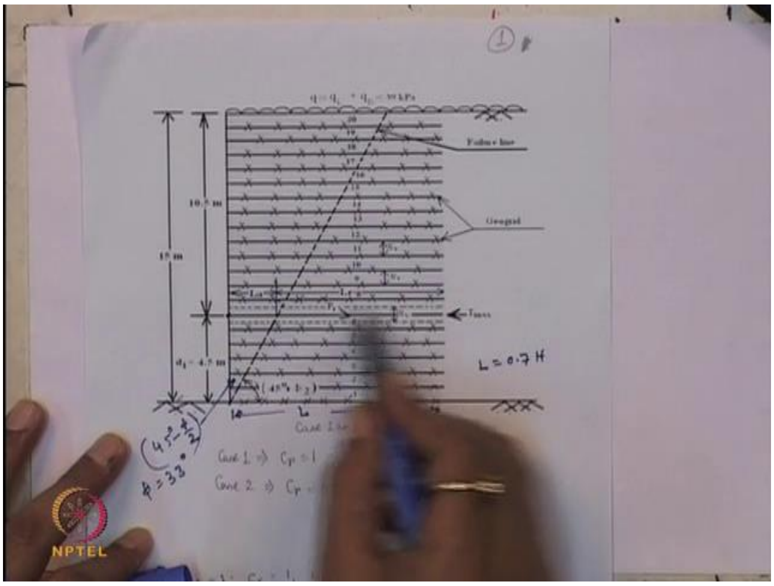

So, for example, to calculate the L of a, we know this is the height of the wall and this is the failure line, which is making at an angle of 45 degree plus phi by 2. So, here this angle will be 45 degree minus phi by 2 so this will be 45 degree minus phi by 2. So, this is the L a so this is the total length L, if this is the total length, total length is equal to L and this is the L of a because we are considering at a depth of 10.5 meter. So, the remaining depth will be from here to here will be 15 minus 10.0, this is 15 minus 10.5 so this will give 4.5 so 4.5.

So, this length L a will be equal to this is 4.5 into tan of 45 degree minus phi by 2 so phi value is given so phi value is equal to 30 of 3 degree. So, we can calculate, what is the L of a so we can calculate what is L of a. So, L a will be equal to 4.5 into tan 45 degree minus phi by 2 and phi value is given 33. So, if you know the L a, you know what will be the total length that is, L is equal to 0.7 times the height of the wall and H is given 15. So, we know, what will be the total length L so we know the total length L, we know this L a. So, we can also calculate what is L of e, this is embedment length so we can calculate this embedment length like this.

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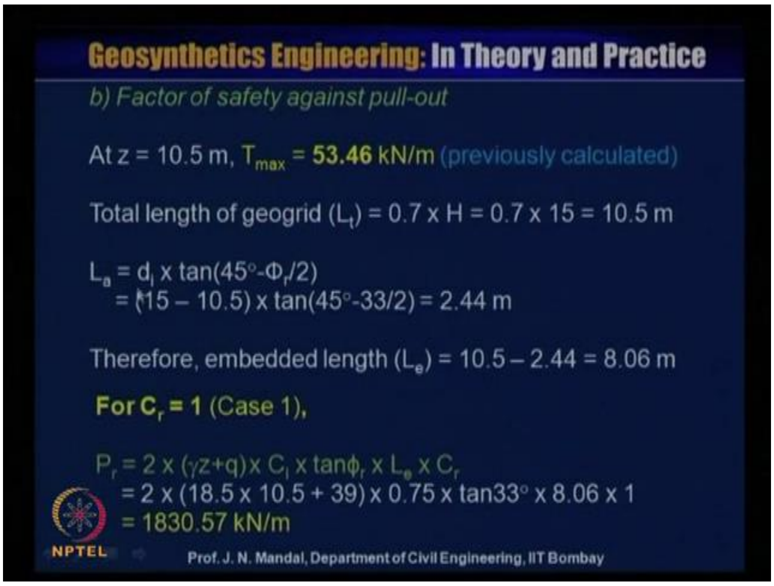

So here, we are just showing that L a, how you have calculated so this is d i means, that is 15 minus 10.5 into tan 45 degree minus phi r value is 33 divided by 2, this is 2.44 meter and embedded length L e, that is total. We know L t, we know that 10.5 so this minus this L of e so this is 2.44. So, this L e will be 8.06 now, for C r is equal to 1, case 1 we are considering and we have to calculate, what will be the P of r that means, what will be the pullout force.

So, pullout is equal to we know the equation 2 into gamma z plus q into C of i into tan phi r into L of e into C i. So, we know 2 gamma is 18.5 into z is at a depth of 10.5 meter, q is 39, this is total dead load and live load, C i interaction coefficient, it is given this is 0.75, tan phi r is phi r is equal to 33 degree. L e we calculated 8.06 into C r that is, coverage ratio here coverage ratio is 1. So, that is why it is one. So, if you calculate then you can calculate what will be the P r value, P r value is 1830.57 kiloNewton per meter.

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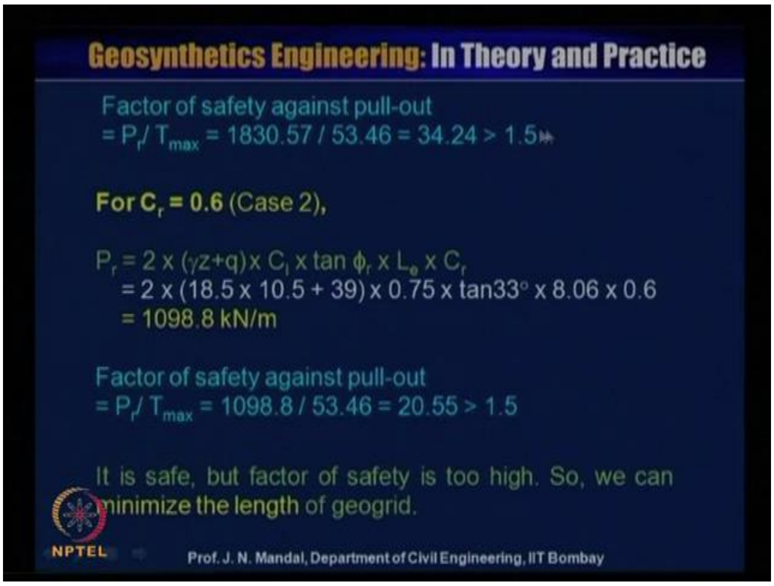

Now, factor of safety against pullout that means, that is the ratio of P r divided by T of maximum. So, you calculated now, P r value 1830.57 divided by T maximum, we know 53.46 that means, is equal to 34.24, which is greater than 1.5 that means, it is ok. So, factor of safety against the pullout when C r is equal to 1, it satisfying the criteria that means, it is ok in terms of the pullout for case 1 when C r is equal to 1. Now, we will deal for C r is equal to 0.6, case 2 so what will be the P r value.

So, P r value also can be determined again the same equation so we can have this only change in C of r, other remain as it is. So, here C r value is equal to 0.6 so you can have this P r value is equal to 1098.8 kiloNewton per meter then you check factor of safety against this pullout. That means, P r divided by T maximum so P r is 1098.8 divided by T maximum is 53.46, that will give 20.55. So, it is greater than 1.5 that means, it is safe but you see the factor of safety in all the cases, it is too high. So, what we can do, we can minimize the length of the geogrid material.

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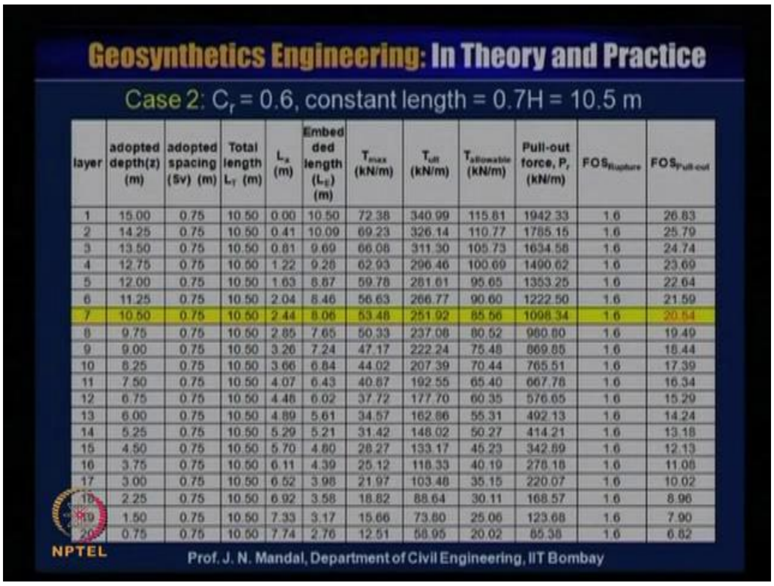

layer	adopted depth(z) (m)	adopted spacing (Sv) (m)	Total length L_T (m)	L_a (m)	Embedded length (L_E) (m)	T_{max} (kN/m)	T_{ult} (kN/m)	$T_{allowable}$ (kN/m)	Pull-out force, P_r (kN/m)	$FOS_{Rupture}$	$FOS_{Pull-out}$
1	15.00	0.75	10.50	0.00	10.50	72.38	340.99	115.81	1942.33	1.6	26.83
2	14.25	0.75	10.50	0.41	10.09	69.23	326.14	110.77	1785.15	1.6	25.79
3	13.50	0.75	10.50	0.81	9.69	66.08	311.30	105.73	1634.58	1.6	24.74
4	12.75	0.75	10.50	1.22	9.28	62.93	296.46	100.69	1490.62	1.6	23.69
5	12.00	0.75	10.50	1.63	8.87	59.78	281.61	95.65	1353.25	1.6	22.64
6	11.25	0.75	10.50	2.04	8.46	56.63	266.77	90.60	1222.50	1.6	21.59
7	10.50	0.75	10.50	2.44	8.06	53.48	251.92	85.56	1098.34	1.6	20.54
8	9.75	0.75	10.50	2.85	7.65	50.33	237.08	80.52	980.80	1.6	19.49
9	9.00	0.75	10.50	3.26	7.24	47.17	222.24	75.48	869.85	1.6	18.44
10	8.25	0.75	10.50	3.66	6.84	44.02	207.39	70.44	765.51	1.6	17.39
11	7.50	0.75	10.50	4.07	6.43	40.87	192.55	65.40	667.78	1.6	16.34
12	6.75	0.75	10.50	4.48	6.02	37.72	177.70	60.35	576.65	1.6	15.29
13	6.00	0.75	10.50	4.89	5.61	34.57	162.86	55.31	492.13	1.6	14.24
14	5.25	0.75	10.50	5.29	5.21	31.42	148.02	50.27	414.21	1.6	13.18
15	4.50	0.75	10.50	5.70	4.80	28.27	133.17	45.23	342.89	1.6	12.13
16	3.75	0.75	10.50	6.11	4.39	25.12	118.33	40.19	278.18	1.6	11.08
17	3.00	0.75	10.50	6.52	3.98	21.97	103.48	35.15	220.07	1.6	10.02
18	2.25	0.75	10.50	6.92	3.58	18.82	88.64	30.11	168.57	1.6	8.96
19	1.50	0.75	10.50	7.33	3.17	15.66	73.80	25.06	123.68	1.6	7.90
20	0.75	0.75	10.50	7.74	2.76	12.51	58.95	20.02	85.38	1.6	6.82

So, we can check that, if we reduce the length of the geogrid material then what will happen. Here, we have case 1 when C r is equal to 1 or constant length 0.7 H into 10.5 meter, we have calculated this is the wall layer of number of the form from bottom. But, we have calculated only at a depth of 10.50 and spacing is constant 0.75, this is the total length L is equal to 0.7 times the height of the wall, 10.05. We calculated what is L a, 2.44, we have calculated embedment length 8.06, we also calculated T maximum that is, 53.48.

And also, what will be the T of allowable is 85.56 and also pullout 1830.57, pullout force P r and then this is the factor of safety against the rupture is required 1.6 and factor of safety against pullout are then 34.23, that is why this value is on the higher side. So, this is for case when C r is equal to 1 so similarly, you can calculate for other depth so at any depth, you can calculate like this and you can form this table. So, you can check all this factor of safety against rupture and factor of safety against this pullout and also, you will be knowing, what will be the ultimate tensile strength of the geogrid material at the different layer.

So, there are you can see, this is about 1920, layer of the number of the from the bottom and with a spacing of 0.75. So, our aim to, how to calculate, how you will obtain this spacing and also what will be the ultimate tensile strength of the geogrid material. And also you have to check, whether it is safe in terms of the factor of safety in rupture and also in terms of the pullout so if it is safe then it is ok. Now, case 2 when the coverage ratio 0.6 but constant length that is, 0.78 and we calculated for the depth 10.50 meter. This is spacing 0.75 and this is the total length you can see that, L a 2.44 embedment 8.06 and this is the T maximum, 53.48 and this is T ultimate is 251.92 and this is the T of allowable is 85.56.

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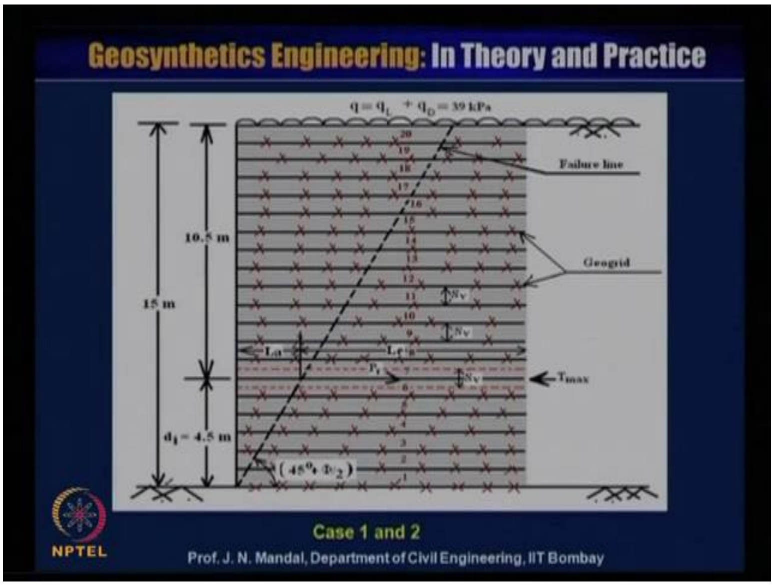

And this is the pullout force 1098.34 and this is the factor of safety against the rupture is 1.6 and this is the factor of safety against this pullout 20.54. So, in all cases, whether it is the case a or case 2, this C r value, whether it is a 1 or 0.6, we find that factor of safety against pullout is on the higher side. Now, we will see that, ultimately what we are obtaining and if you can place the geogrid material and this is the figure, what it has been shown that, in case of 1 and the 2.

And because this is the height is 15 and this is every 0.75 interval has been placed because we cannot show this like this diagram, this is diagram it may be entirely from the planar form, one case and also you can give in the strip form also. Strip form that means, when the coverage ratio only 60 percent of geogrid material also allowed so you can make this design chart like this due to the live load and the dead load of 39 kiloPascal and you can design this geogrid reinforced soil wall. Now, we find that factor of safety is on the higher side so we just wanted to check that, if we minimize the reinforcement length.

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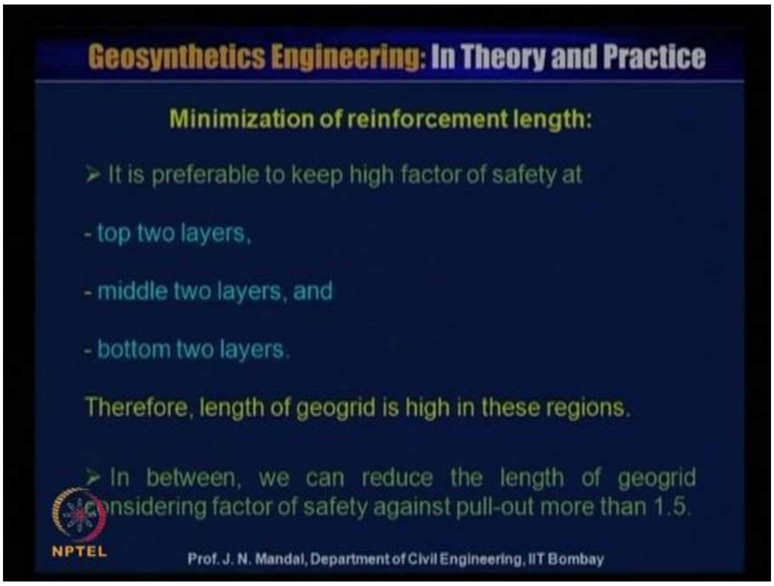

So, it is preferable to keep the high factor of safety and then if we can provide the top two layer of the reinforcement then middle two layer of the reinforcement and bottom two layer of the reinforcement. Therefore, length of the geogrid is high in this region in between, we can reduce the length of the geogrid considering the factor of safety against the pullout is more than 1.5.

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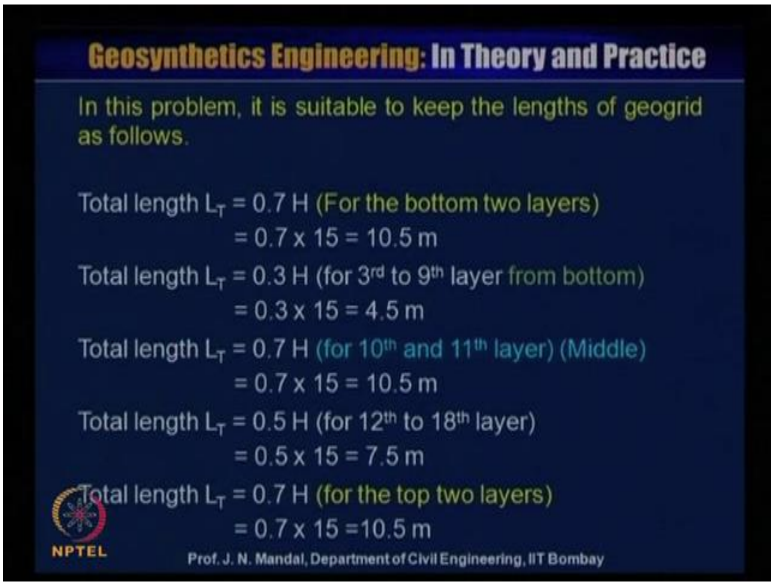

So, if we minimize then what will happen and how we can minimize, in this problem it is suitable to keep the length of the geogrid.

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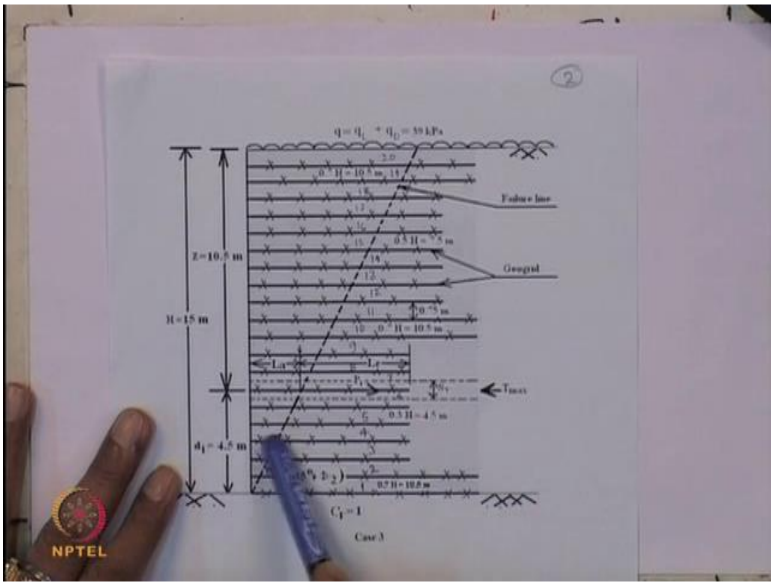

So, what we are doing here that, you can see this in this problem, when the coverage ratio is 1 and this is the case 3 that we are assuming, assuming that in this problem, that we are keeping here. That mean, total length that means, 0.7 times of H that is from the bottom two layer, one and two layer we are giving 0.7 of H, height is 15 meter. So, 0.78 is equal to 10.5 meter so total length L t that is, 10.5 meter from the bottom two layer.

Now, total length here that is, L t for 3 rd, 4 th, 5 th, 6, 7, 8 and 9 that means, for 3 to 9 layer from the bottom and we are minimizing the length is 0.3 times of height that means, 0.3 times over a 4.5 meter. So, at the bottom, 10.5 meter two layer then from 3 to 9 layer, we are providing 0.3 times of H that means, this length is equal to 4.5 meter. And then again for the layer 10 and the 11 layer that is, middle layer for the length is 0.7 times the height of the wall that means, 0.7 to height is that is, 15 that means, 10.5 meter.

So, in the middle, that our 10 th or 11 level, the total length of the geogrid is 10.5 meter then again from 12, 13, 14, 15, 16, 17, 18 so that means, from 10 to 18 layer so this length 12 to 18 layer this is, 0.5 times of H. That means, it is height is 15 so 0.5 times to height is equal to 7.5 meter then again top 19 and the twenty, this layer top two layer here, we are providing the 0.7 times the height of the wall that means, it is about 10.5 meter.

Now, you can see here that, bottom two layer 10.5 meter, middle layer that means, your 10 and the 11 layer is 10.5 meter and here, top this is also the 10.5 meter. Whereas, in between from 3 to the 9 layer is 0.3 times of H and from 12 to 18 layer is 0.5 times of H. So, we have minimized the length of the reinforcement, the reason for the selection of the reinforcement, more length on the top and the bottom and the middle. The most of the cases it has been observed that, this failure of the reinforcement may it will bit like a bulging form or also it has been shown a kind of the trapezoidal form.

So, it may fail due to, there are many case history it has been observed that, it may fail due to the bulging at the middle of the reinforcement. So, that was one of the reason that, we have kept the longer length at the middle of the reinforcement. Secondly, this is bottom two layer also, we have kept the longer length, the reason is that because it is on the foundation soil. If foundation soil is poor then it is preferable you can provide with the longer length.

But, you have to be taken care if the bearing capacity is to be improved or any ground modification have to be done, that also we can take care. Because, sometimes that, if it is a relatively soft soil, if you keep the longer length of the geogrid material, it may also satisfy the criteria. That means, factor of safety against this bearing capacity and top layer also, we have kept the longer length. The reason is that, if there is any seismic effect and there will be the shear stress development here, and which the longer length of the geogrid can prevent this. So, that was the basic logic for the selection of the geogrid material at the different location at the different length.

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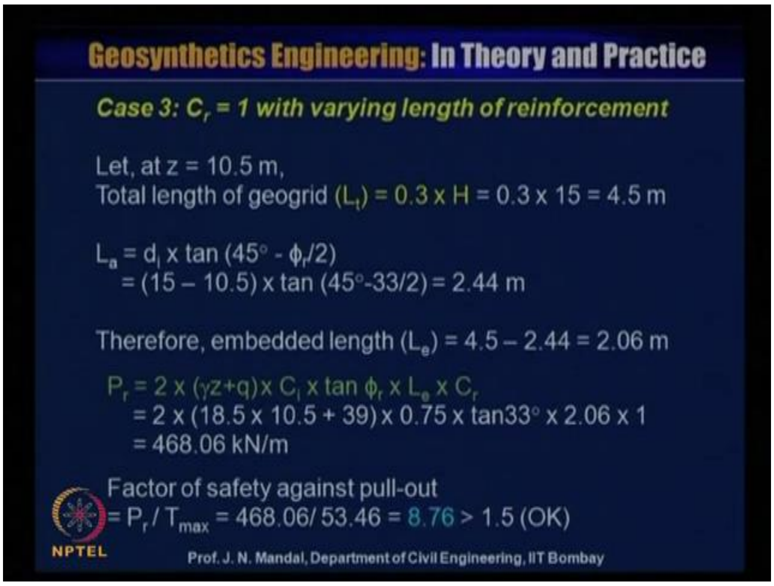

So now, this case 3 we are this varying length, we are considering case 3 that, when coverage ratio is equal to 1 that means, whose varying length of the reinforcement. So, we have shown you that, at a depth of 10.5 meter let us say that, total length of the geogrid L t is equal to 0.3 times H that means, 0.3 into 15, 4.5meter. And at that point, you have to calculate what will be the L of a that means, L a is equal to d i into tan 45 degree minus phi r by 2.

That means, 15 minus 10.5 into tan 45 degree minus 33 divided by 2, that equal to 2.44 meter therefore, embedment length L of e will be equal to 4.5 minus 2.44 that means, 2.06 meter. Now, P r that is pullout will be equal to 2 into gamma z plus q into C i into tan phi r into L e into C of r. Here, C r is equal to 1 and L e, you calculated 2.06 and other value is also is known to you.

So, you can calculate P r is equal to 468.06 kiloNewton per meter now, factor of safety against pullout that is, P r by T maximum is equal to 468.06 divided by 53.46. You can see here, this for the varying length, this factor of safety pullout is coming about 8.76, which is greater than 1.5 that means, it is ok.

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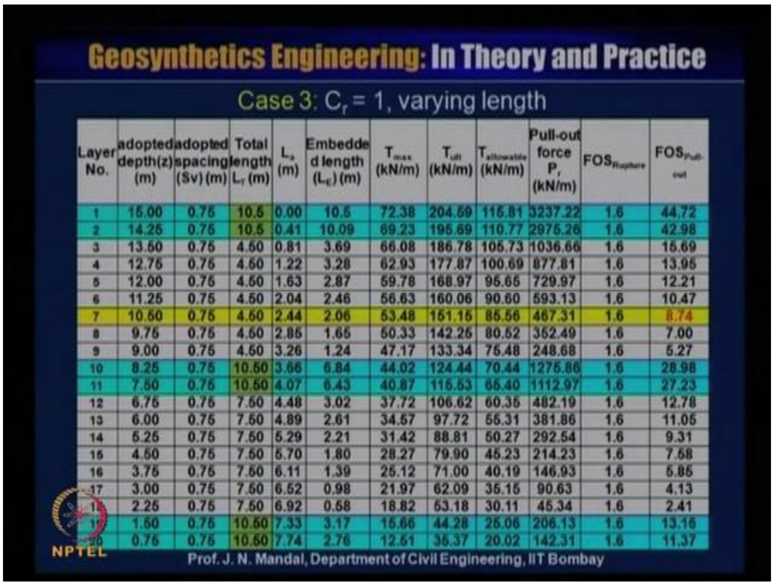

Layer No.	adopted depth(z) (m)	adopted spacing (Sv) (m)	Total length L_T (m)	L_a (m)	Embedded length (L_E) (m)	T_{max} (kN/m)	T_{ult} (kN/m)	$T_{allowable}$ (kN/m)	Pull-out force P_r (kN/m)	$FOS_{Rupture}$	$FOS_{Pull-out}$
1	15.00	0.75	10.5	0.00	10.5	72.38	204.69	115.81	3237.22	1.6	44.72
2	14.25	0.75	10.5	0.41	10.09	69.23	195.69	110.77	2975.26	1.6	42.98
3	13.50	0.75	4.50	0.81	3.69	66.08	186.78	105.73	1036.66	1.6	15.69
4	12.75	0.75	4.50	1.22	3.28	62.93	177.87	100.69	877.81	1.6	13.95
5	12.00	0.75	4.50	1.63	2.87	59.78	168.97	95.65	729.97	1.6	12.21
6	11.25	0.75	4.50	2.04	2.46	56.63	160.06	90.60	593.13	1.6	10.47
7	10.50	0.75	4.50	2.44	2.06	53.48	151.16	85.56	467.31	1.6	8.74
8	9.75	0.75	4.50	2.85	1.65	50.33	142.25	80.52	352.49	1.6	7.00
9	9.00	0.75	4.50	3.26	1.24	47.17	133.34	75.48	248.68	1.6	5.27
10	8.25	0.75	10.50	3.66	6.84	44.02	124.44	70.44	1275.86	1.6	28.98
11	7.50	0.75	10.50	4.07	6.43	40.87	115.53	65.40	1112.97	1.6	27.23
12	6.75	0.75	7.50	4.48	3.02	37.72	106.62	60.35	482.19	1.6	12.78
13	6.00	0.75	7.50	4.89	2.61	34.57	97.72	55.31	381.86	1.6	11.05
14	5.25	0.75	7.50	5.29	2.21	31.42	88.81	50.27	292.54	1.6	9.31
15	4.50	0.75	7.50	5.70	1.80	28.27	79.90	45.23	214.23	1.6	7.58
16	3.75	0.75	7.50	6.11	1.39	25.12	71.00	40.19	146.93	1.6	5.85
17	3.00	0.75	7.50	6.52	0.98	21.97	62.09	35.15	90.63	1.6	4.13
18	2.25	0.75	7.50	6.92	0.58	18.82	53.18	30.11	45.34	1.6	2.41
19	1.50	0.75	10.50	7.33	3.17	15.66	44.28	25.06	206.13	1.6	13.16
20	0.75	0.75	10.50	7.74	2.76	12.51	35.37	20.02	142.31	1.6	11.37

Now, here is the table case 3, when the coverage ratio is 1, but varying the length, we have shown the different varying the length. Now, here you can see for the top layer, this is 1 and 2, it is a longer length. We have consider 10.5 and because we have shown only that 10.5, that what should be the result and it is 10.5. So, you can calculate, what will be the L of a embedment length and what will be the T maximum and what should be the T allowable, what will be the P pullout force, P kiloNewton per meter and factor of safety against rupture and factor of safety against pullout.

But, you see that, we have only shown this layer that means, at a depth of 10.50 for spacing is 0.75 and the total length is 4.60. And this L e is equal to 2.44 and L a is equal to 2.06 and this is T maximum is equal to 53.48 and T ultimate 161.15 and T allowable is 85.56 and P pullout force, P r kiloNewton per meter square, 467.31. And factor of safety against rupture 1.6 and factor of safety against this pullout 8.74. You can see that, how the pullout force has been reduced when you are varying the length and keeping the coverage ratio 1.

Similarly, this is middle layer, also has been calculated and the bottom two layer also is been calculated. The middle layer, we have change it, it is the same length we have considered and the bottom layer also, the same layer we have considered but in between here, the length has been changed, length has been minimized. So, when C r is 1 and you are varying the length so also, it can satisfy this criteria. So, this is the case 3, when C r is equal to 1 with the varying length.

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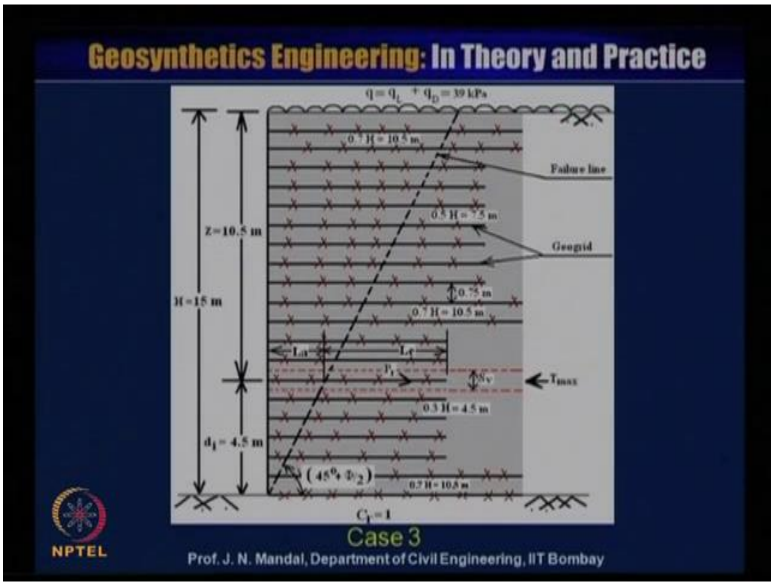

Now, this we can have, like this we can place the geogrid material like this, this is the top two layer. Here, longer length, then you are reducing the length then again in the middle, this is 0.7 times of H. And again, they are giving 0.3 times of the H and then again at the bottom two line is 0.7 times of H. So, this is the arrangement of the reinforcement I have shown for case 3, when C r is equal to 1 but varying the length at different location.

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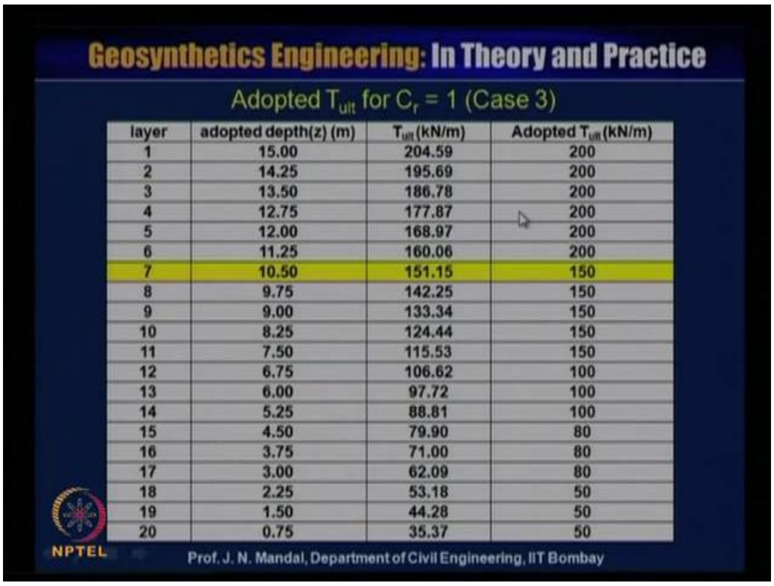

layer	adopted depth(z) (m)	T_{ult} (kN/m)	Adopted T_{ult} (kN/m)
1	15.00	204.59	200
2	14.25	195.69	200
3	13.50	186.78	200
4	12.75	177.87	200
5	12.00	168.97	200
6	11.25	160.06	200
7	10.50	151.15	150
8	9.75	142.25	150
9	9.00	133.34	150
10	8.25	124.44	150
11	7.50	115.53	150
12	6.75	106.62	100
13	6.00	97.72	100
14	5.25	88.81	100
15	4.50	79.90	80
16	3.75	71.00	80
17	3.00	62.09	80
18	2.25	53.18	50
19	1.50	44.28	50
20	0.75	35.37	50

Now, whatever the result you will obtain that ultimate value, ultimately we check that what will be the ultimate value. Here, only we have shown one calculation for this at a depth of 10.5 meter and T ultimate value is 115.15 kiloNewton per meter but adopted ultimate value you can consider 150 kiloNewton per meter. So, in this case 3 1, when C r is equal to 1 for you can see that, how the ultimate value is… from here, you can see 204 that means, you consider 200 so 200 to 200 then 150 and then 100 and then 80 then 50.

So, some layer you are providing with the lower strength then you are increasing then gradually increasing 100, 150 and then 200. So, because you can see from the manufacturer side, that they are sometimes produce the kind of the geogrid material. It may be have a kind of the round figure like this kilonewton, either this geogrid material may be available on the 200 kiloNewton per meter or the 100 kiloNewton per meter or 250 kiloNewton per meter or 300 kiloNewton per meter or 350 kiloNewton per meter, 80 kiloNewton per meter, 40 kiloNewton per meter, 60 kiloNewton per meter. So, therefore, that we have to adopted certain kind of the ultimate tensile strength of the geogrid material. So, this is case 3, when the coverage ratio value is equal to 1.

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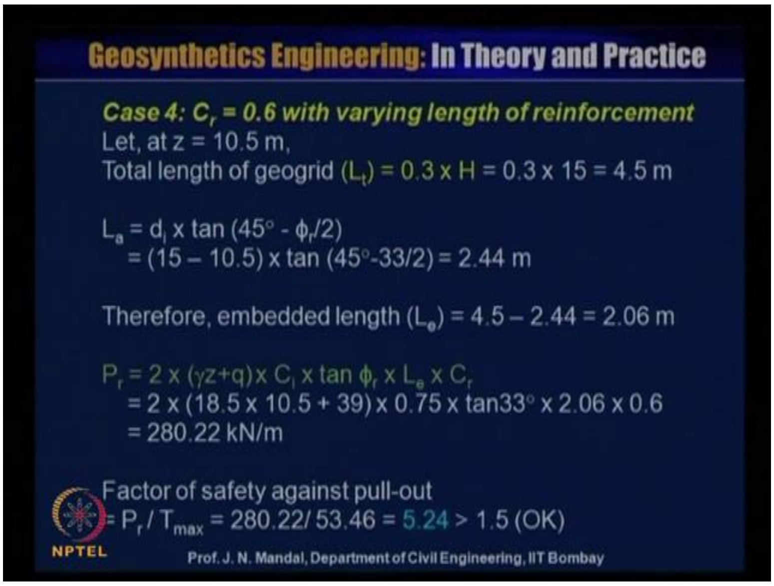

Now, case 4 that, when the coverage ratio is 0.6 with varying length of the reinforcement. So, let at depth z is equal to 10.5 meter so total length of the geogrid L t will be 0.38 that means, 0.3 into 15 that is, 4.5 meter. L a will be equal to d i into tan 45 degree minus phi r by 2 that means, 15 minus 10.5 into tan 45 degree minus 33 by 2 by 2 is equal to 2.44 meter. Therefore, embedment length L e will be equal to 4.5 minus 2.44 is equal to 2.06 meter.

So, pullout P r is equal to 2 into gamma z plus q into C i into tan phi r into L e into C r here, everything is constant, only C r value will change because C r is equal to 0.6. So, P r value we can calculate is equal to 2.28 T into 0.22 kiloNewton per meter. So, factor of safety against pullout is P r by T maximum is equal to 280.22 divided by 53.46, that equal to 5.24, which is greater than 1.5, so it is ok.

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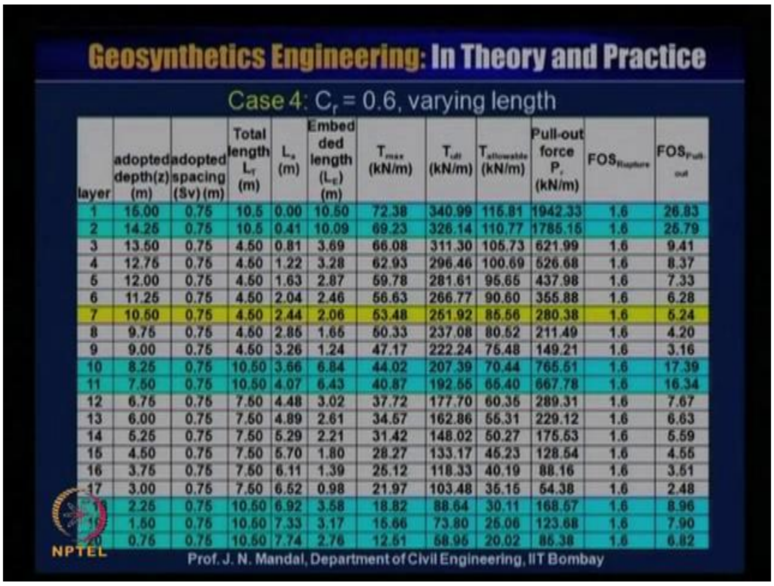

layer	adopted depth(z) (m)	adopted spacing (Sv) (m)	Total length L_T (m)	L_a (m)	Embedded length (L_E) (m)	T_{max} (kN/m)	T_{ult} (kN/m)	$T_{allowable}$ (kN/m)	Pull-out force P_r (kN/m)	$FOS_{Rupture}$	$FOS_{Pull-out}$
1	15.00	0.75	10.5	0.00	10.50	72.38	340.99	115.81	1942.33	1.6	26.83
2	14.25	0.75	10.5	0.41	10.09	69.23	326.14	110.77	1785.15	1.6	25.79
3	13.50	0.75	4.50	0.81	3.69	66.08	311.30	105.73	621.99	1.6	9.41
4	12.75	0.75	4.50	1.22	3.28	62.93	296.46	100.69	526.68	1.6	8.37
5	12.00	0.75	4.50	1.63	2.87	59.78	281.61	95.65	437.98	1.6	7.33
6	11.25	0.75	4.50	2.04	2.46	56.63	266.77	90.60	355.88	1.6	6.28
7	10.50	0.75	4.50	2.44	2.06	53.48	251.92	85.56	280.38	1.6	5.24
8	9.75	0.75	4.50	2.85	1.65	50.33	237.08	80.52	211.49	1.6	4.20
9	9.00	0.75	4.50	3.26	1.24	47.17	222.24	75.48	149.21	1.6	3.16
10	8.25	0.75	10.50	3.66	6.84	44.02	207.39	70.44	765.51	1.6	17.39
11	7.50	0.75	10.50	4.07	6.43	40.87	192.55	65.40	667.78	1.6	16.34
12	6.75	0.75	7.50	4.48	3.02	37.72	177.70	60.35	289.31	1.6	7.67
13	6.00	0.75	7.50	4.89	2.61	34.57	162.86	55.31	229.12	1.6	6.63
14	5.25	0.75	7.50	5.29	2.21	31.42	148.02	50.27	175.53	1.6	5.59
15	4.50	0.75	7.50	5.70	1.80	28.27	133.17	45.23	128.54	1.6	4.55
16	3.75	0.75	7.50	6.11	1.39	25.12	118.33	40.19	88.16	1.6	3.51
17	3.00	0.75	7.50	6.52	0.98	21.97	103.48	35.15	54.38	1.6	2.48
[illegible]	2.25	0.75	10.50	6.92	3.58	18.82	88.64	30.11	168.57	1.6	8.96
[illegible]	1.50	0.75	10.50	7.33	3.17	15.66	73.80	25.06	123.68	1.6	7.90
[illegible]	0.75	0.75	10.50	7.74	2.76	12.51	58.96	20.02	86.38	1.6	6.82

So here, case 4 we are showing that, when the C r value is equal to 0.6 but varying the length. So, you can see that, we have only shown the calculation at a depth of 10.50, this spacing is constant 0.75 and this is the total length 4.50. This is, that L of a, we have shown 2.44 and this is the L of e, which is embedded length that is, 2.06 or bond length and this is the T of maximum 63.48 kiloNewton per meter. And then the T of ultimate value 251.92 and then the T of allowable is equal to 85.66.

And total pullout force is 280.38 and factor of safety against the rupture 1.6 and this factor of safety against this pullout is 5.24. So, you can see that, how the factor of safety against the pullout have drastically reduced. So here, that one point is to be observed that, when we are considering the case 4 and we find that, in the bottom layer here, you can see that length is 10.50, there are three layer whose total length is 10.50.

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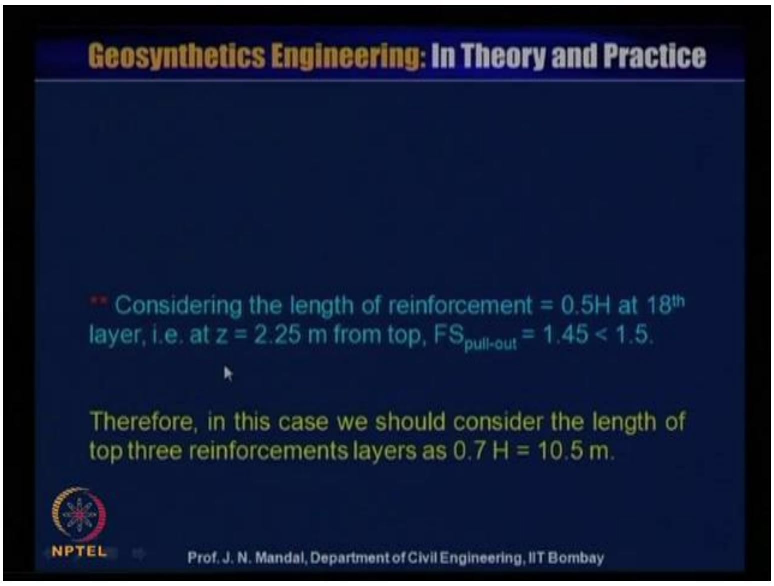

Now, I want to say that, you can see that considering the length of the reinforcement for example, that here, we earlier consider that 0.5 times the height of the wall. So, if you consider the 0.5 times the height of the wall then at the 18 th layer that means, at z is equal to 2.25 mater here. This is 18 th layer at a depth of 2.25 meter, at this depth from the top, the factor of safety against this pullout, if you determine you can have the value 1.45, which is less than 1.5 so it will not satisfy the criteria.

Therefore, in this case, we should consider the length of the top three reinforcement layer is 0.7 times the height of the wall and that was the reason that, it has been considered this layer 0.7 times the height of the layer. So, this is important, you can check that, what the criteria has not been fulfilled even then if you consider point… When the C r value is equal to 1 and varying the length, this satisfy the criteria. That means, when the length of the reinforcement is 0.5 times the height of the wall, it satisfy the criteria there.

But, in case of 4, when the coverage ratio is equal to 0.6 but varying the length, this layer when we consider 18 layer, when we considered the length of the geogrid is 0.5 times the height of the wall. So, this criteria that, pullout factor criteria does not satisfy so that is the reason that, we can provide with the length of the reinforcement 0.7 times the height of the wall.

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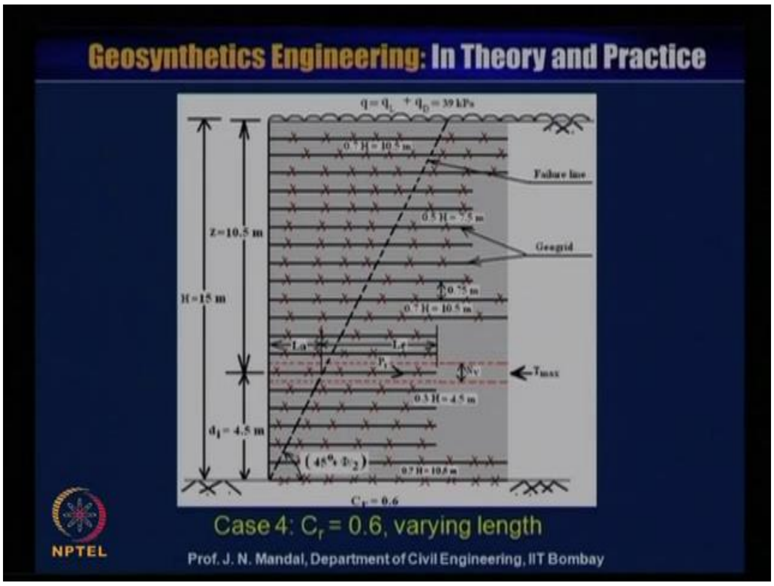

Now, case 4 that, when the coverage ratio is 0.6 and varying the length, it has been shown, it is the layout of the reinforcement. You can see that tough layer, we are providing the three layer here, it is a three layer so it was like this.

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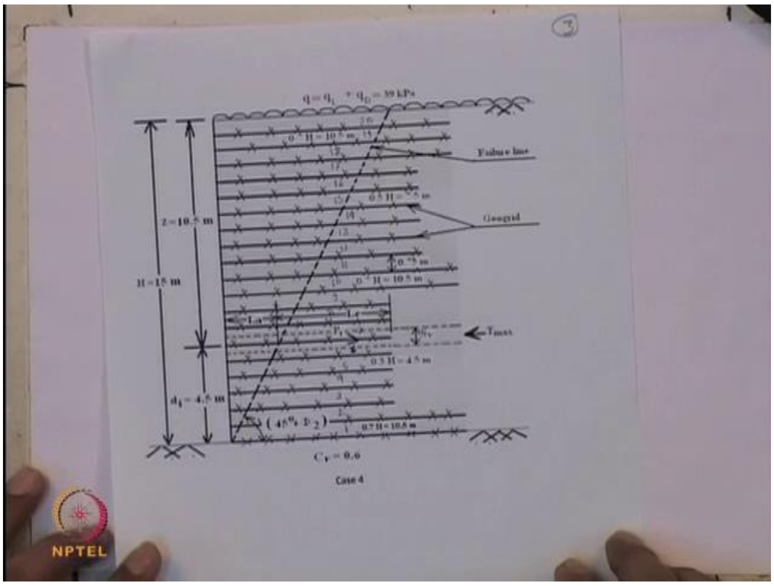

Case 4 you can see that, top 1 2 3, this is 0.7 times the height of the wall and here, bottom the two layer 0.7 times the height of the layer and in between and also middle here, 0.7 times the height of the layer. And whereas, from 11 to 18, this length of the reinforcement 0.5 times the height of the wall that means, 7.5 meter. And this between 2 to your 9 layer is 0.3 times the height of the wall that means, 4.5 meter. So, this is the layout for the coverage ratio is 0.6 for fourth cases.

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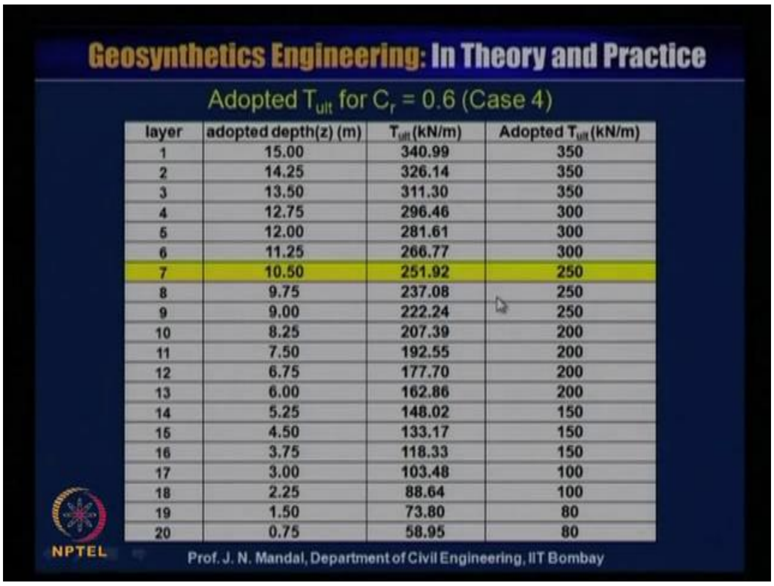

layer	adopted depth(z) (m)	T_{ult} (kN/m)	Adopted T_{ult} (kN/m)
1	15.00	340.99	350
2	14.25	326.14	350
3	13.50	311.30	350
4	12.75	296.46	300
5	12.00	281.61	300
6	11.25	266.77	300
7	10.50	251.92	250
8	9.75	237.08	250
9	9.00	222.24	250
10	8.25	207.39	200
11	7.50	192.55	200
12	6.75	177.70	200
13	6.00	162.86	200
14	5.25	148.02	150
15	4.50	133.17	150
16	3.75	118.33	150
17	3.00	103.48	100
18	2.25	88.64	100
19	1.50	73.80	80
20	0.75	58.95	80

Now again, that what will be the adopted T ultimate value for C r is equal to 0.6 for case 4 so we have shown here, only for 10.50 meter depth and you are having the T ultimate value 251.92. So, we are considering 250 kiloNewton per meter here, you can see that, for other layer also, it is 350, 300, 250, 200, 150, 100 and 80. So, you take a round figure as per the availability from the manufacturer site.

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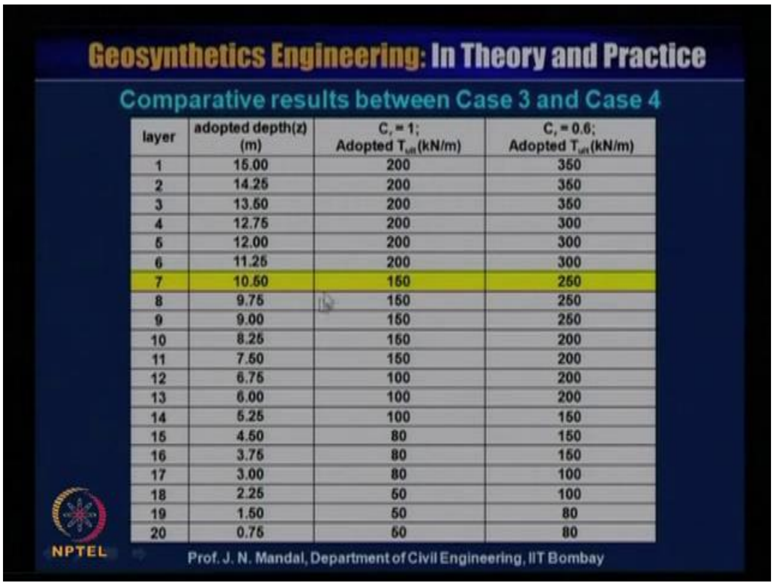

layer	adopted depth(z) (m)	C_r = 1; Adopted T_{ult} (kN/m)	C_r = 0.6; Adopted T_{ult} (kN/m)
1	15.00	200	350
2	14.25	200	350
3	13.50	200	350
4	12.75	200	300
5	12.00	200	300
6	11.25	200	300
7	10.50	150	250
8	9.75	150	250
9	9.00	150	250
10	8.25	150	200
11	7.50	150	200
12	6.75	100	200
13	6.00	100	200
14	5.25	100	150
15	4.50	80	150
16	3.75	80	150
17	3.00	80	100
18	2.25	50	100
19	1.50	50	80
20	0.75	50	80

And now, if you compare the result between the case 3 and case 4 so all are 20 layer and this is the adopted that, depth this is the 15 meter height of the wall and we have shown only calculation for at a depth of 10.50. In this example, you see that, when the coverage ratio 1 so adopted ultimate tensile strength value 150 kiloNewton per meter. But, when you are considering C r value is equal to 0.6 or coverage ratio 0.6, adopted ultimate tensile strength value 250 kiloNewton per meter.

Similarly, that all other layer or depth, you can see how the variation so in case of the coverage ratio 0.6, the ultimate tensile strength of the geogrid material is on the higher side. But, you can reduce the reinforcement about 60 percentage with respect to that coverage ratio, when it is the 100 percentage. When you put the 100 percentage, you are having the tensile strength is 200 to 50 but when you are providing the geogrid only the 60 percentage then your ultimate tensile strength value is from 350 to 80.

So, you can compare the quantity of the geogrid material and also the cost of the geogrid material accordingly and can check that, which one can give you the most economical result by using this innovative system for the design of mechanically stabilized reinforced soil wall.

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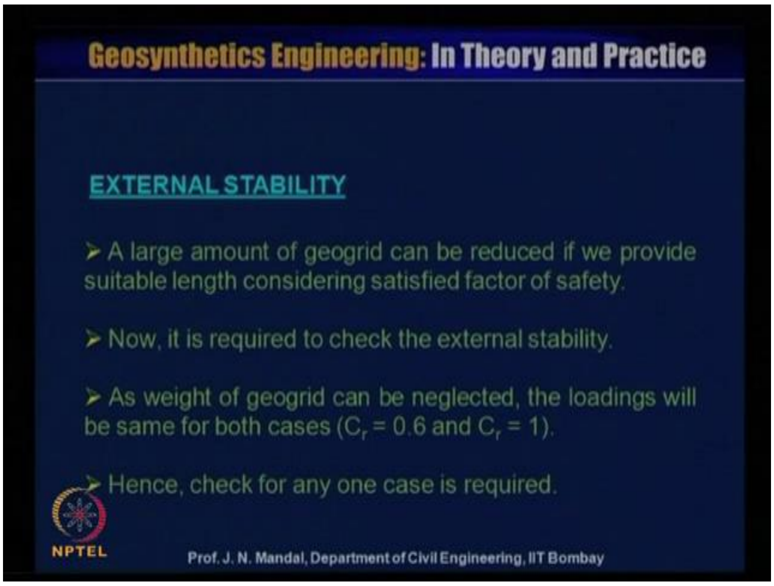

Now, external stability, a large amount of geogrid can be reduced if we provide the suitable length, considering satisfy the factor of safety. Now, it is required to check the external stability, as weight of the geogrid can be neglected, the loading will be the same for both cases. That means, when the coverage ratio is 0.6 and when the coverage ratio is equal to 1 hence, check for any one case is required.

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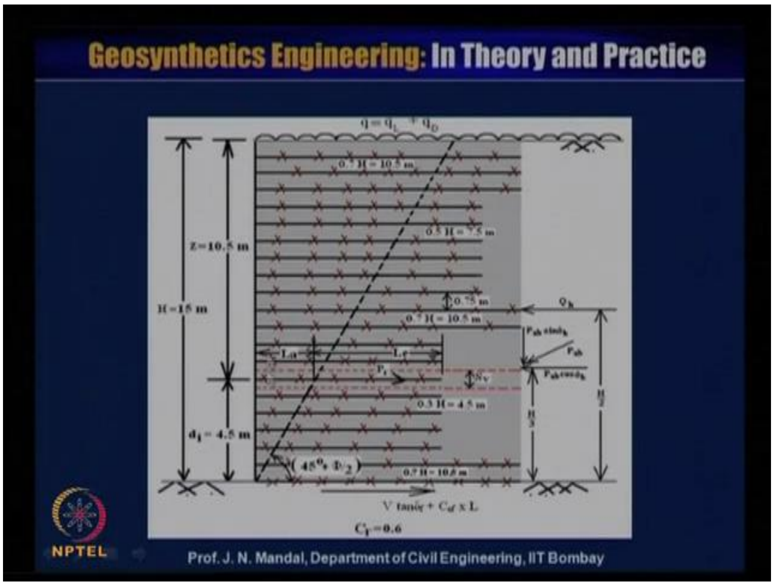

So, let us say here, that coverage ratio is 0.6, when the coverage ratio is 0.6 and you can see, this is the wall whose height is about 15 meter and this is the failure line.

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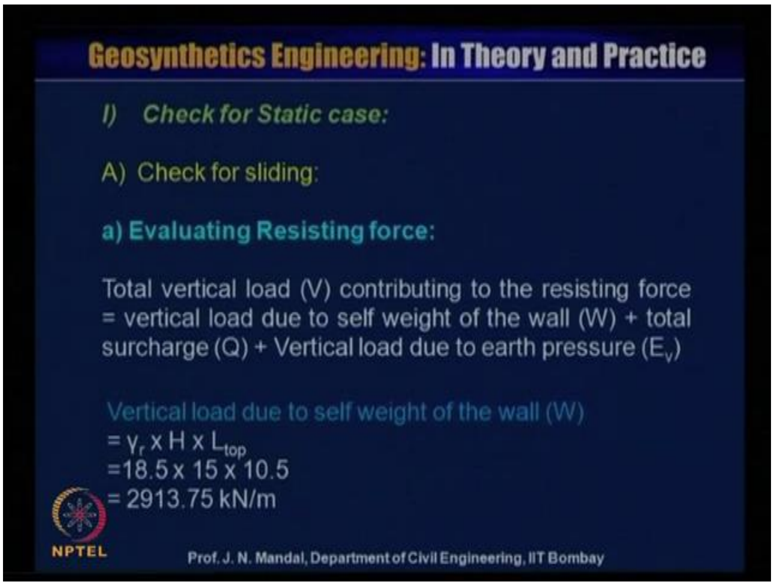

And you have to check for the static case so let us consider for this external stability of the wall.

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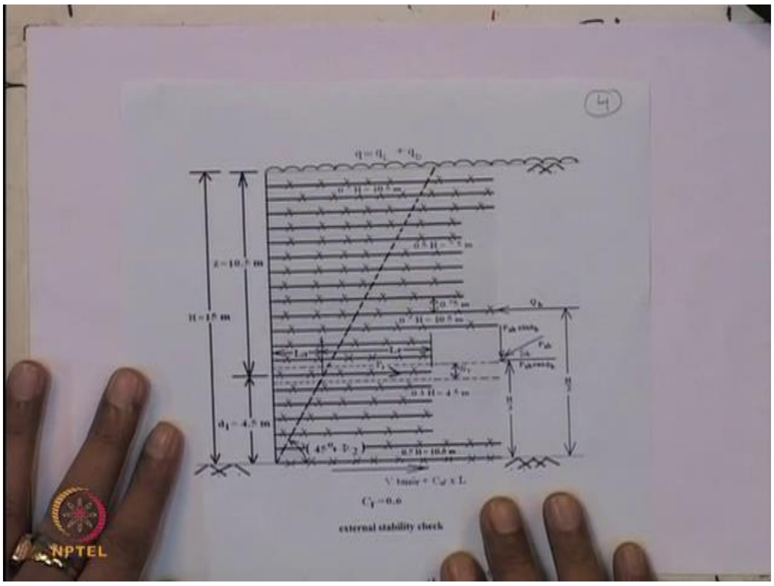

So, when C r is equal to 0.6 so first of all, you have to check for the sliding, the wall may slide. So, here to evaluate what should be the resisting force so it is required to determine the resisting force. So, what will be the total vertical load so total vertical load is, if it is a v which is contributing to the resisting force that is, the vertical load due to the self weight of the wall. If the self weight of wall is W plus, what will be the surcharge load that is, q plus vertical load due to the earth pressure that is, q of b.

So, these forces you have to take into consideration as a total vertical load so vertical load due to the self weight of the wall. That is, W will be equal to the unit weight of the reinforced soil zone, gamma r h is the what you call, height of the reinforcement and the L top. That means, length of the reinforcement at the top so that gamma r is given 18.5 H is equal to 15 meter and L top is 10.5 meter. So, 18.5 into 15 into 10.5, which will give you the vertical load due to the self weight of the wall that is, W is equal to 2913.75 kiloPascal, kiloNewton per meter, which will give this value.

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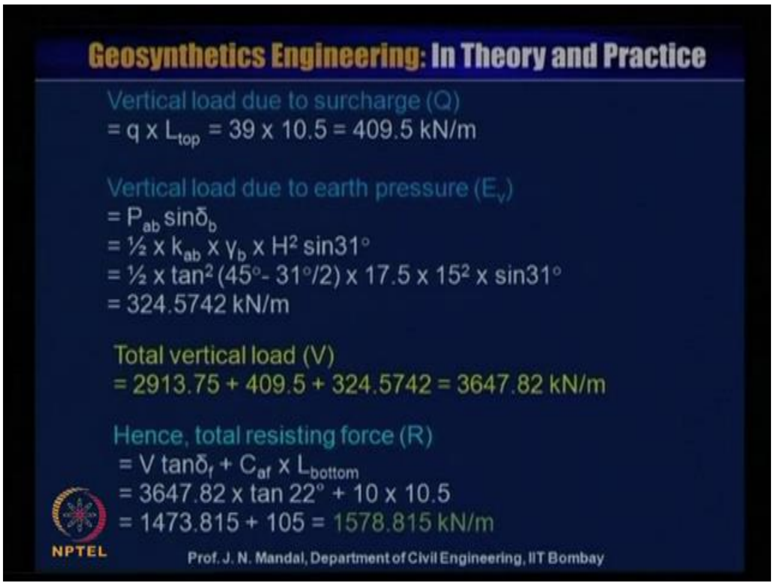

Now, this vertical load due to the surcharge so that is q into L of top, length of the top reinforcement and you know that, q is equal to 39 that is, dead load plus live load and length of the top layer is 10.5. So, this will be equal to 409.5 kiloNewton per meter, what is vertical load due to the earth pressure E v.

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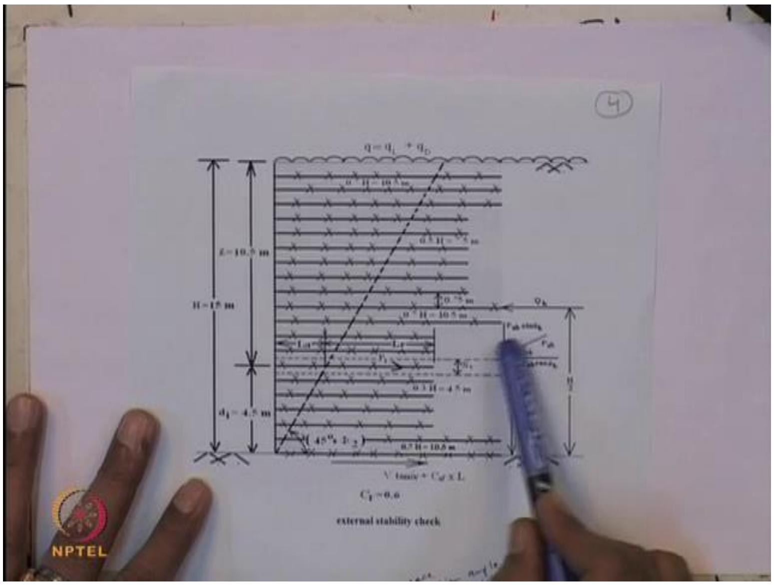

So, this will be again you can see, what will be the vertical earth pressure also is acting, if this is the P a b, which is making at an angle of delta b here. So, here will be the P a b cos delta b and this vertical will be P a b sin delta b. So, vertical load due to the earth pressure if we designated E of b, E b will be equal to P a b into sin delta b.

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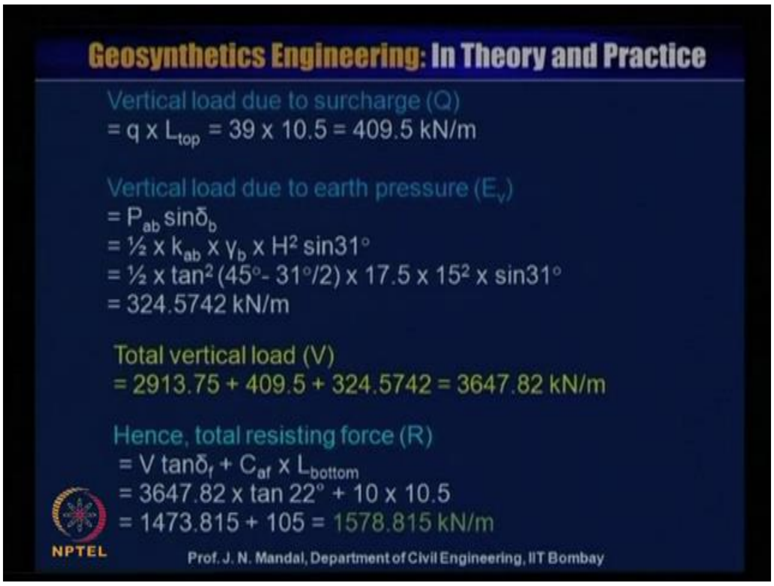

So, we are showing here that, vertical load is equal to P a b into sin delta b and again P a b you know, half into k a b into gamma b into H square into sin delta b, delta b is 31 degree. So, you know half tan square 45 minus 31 by 2 into H, that is gamma b is 17.5 into H is equal to 15 square into sin 31 degree. So, if you calculate, you can have the vertical load due to the earth pressure, E b is 324.572 kiloNewton per meter. What will be the total vertical load then V.

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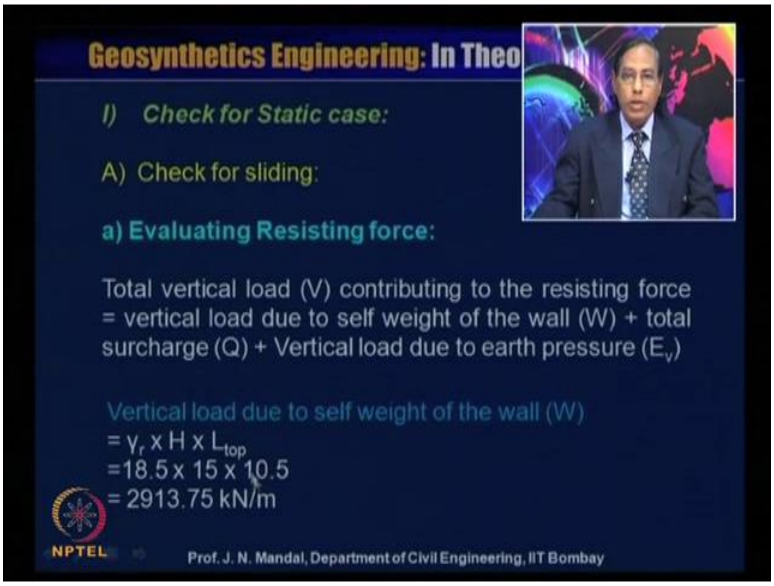

That V will be equal to 2913.75, we have to calculate here 2913.75 that is, vertical load due to the self weight.

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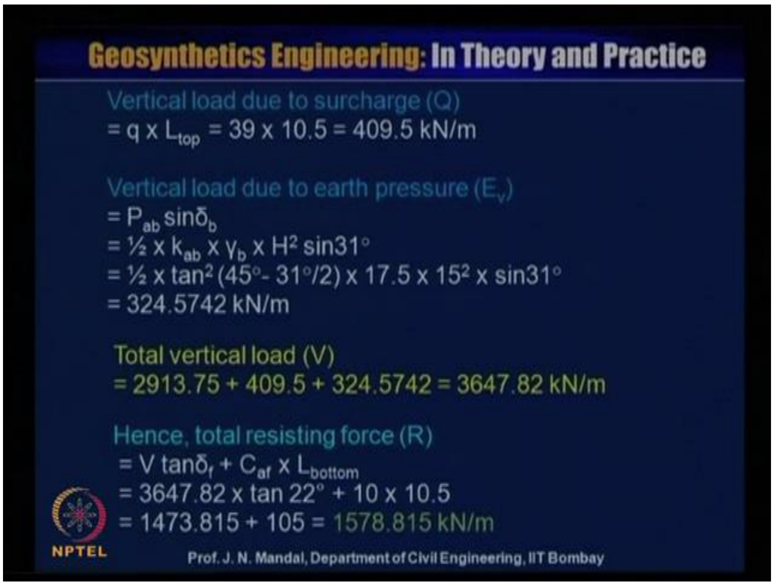

That is, W plus this the load that is, vertical load due to surcharge that is,409.5 plus vertical load due to the earth pressure that is, 324.5742. This will give 3647.82 kiloNewton per meter so you know what will be the total vertical load V. Hence, total resisting force R.

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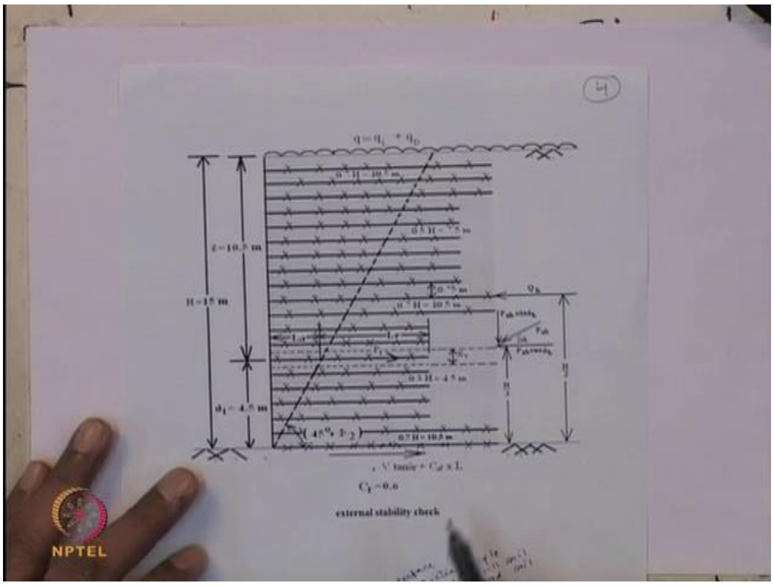

Now here, we calculated that, what will be the total vertical force for this component due to this load and also due to the surcharge. Now, this force, what should be the total resisting force, it should be resist so resist this, if the total is the b. So, b into tan of delta f because there is a foundation soil and there is a reinforcement so there will be interaction between the soil and the reinforcement and that we consider here. So, the total resisting force if it is R so R will be equal to b into tan of delta f plus, if there is a cohesion value then C into f, foundation into this length, this length in the bottom it is about 10.5 meter. And C f value is given that is, 10 and V value we have calculated, that is 3647.82 and this delta value is given is 22 degree, so we can calculate.

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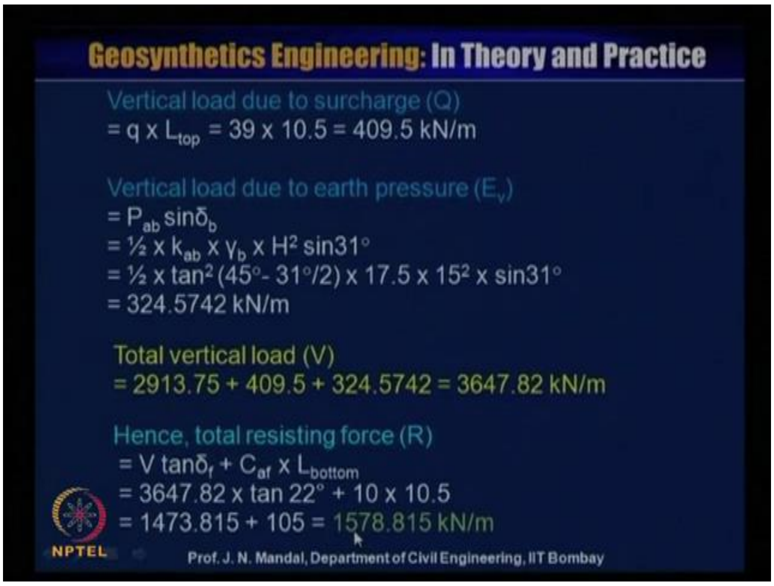

So, we are showing here that, how you have calculated hence, the total resisting force R V tan delta f C a f into L of the bottom. So, this will be 3647.82, this value plus into tan of 22 degree plus 10 into that is, C a f 10 and this into L bottom, 10.5. So, this will give you the total resisting force R is equal to 1578.815 kiloNewton per meter. So, you know that, what should be the total resisting force now, you have to check, what should be the driving force.

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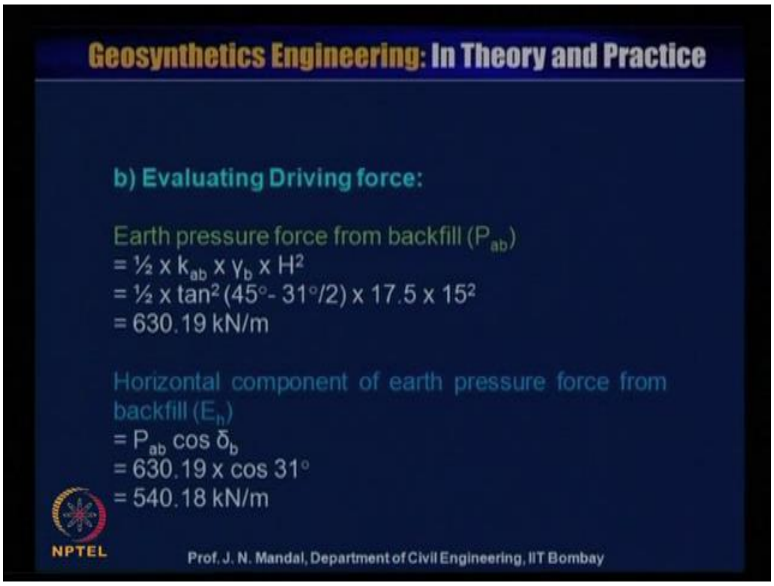

So, this is earth pressure from the backfill that is, P a b. So, you can see here that (Refer Slide Time: 56:27) earth pressure due to the P a b. So, earth pressure force from the backfill is P a b, you can calculate that half into k b into gamma b into H square so this will give you this value.

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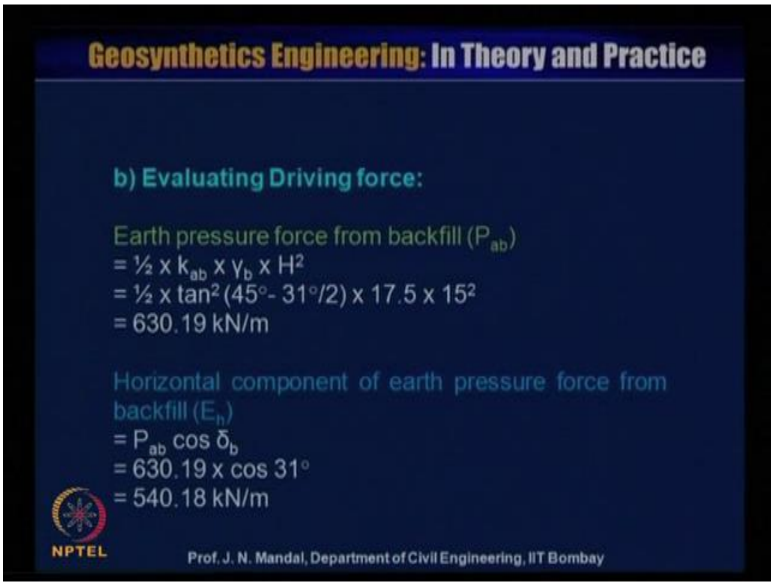

You can see here that, this half into tan square 45 minus 31 by 2 into 17.5 into 15 square so this is 630.19 kiloNewton per meter, that is the driving forces earth pressure from the backfill. Now, horizontal component of the earth pressure force from the backfill that is, E h that will be equal to P a b into cos delta b, that is 630.19 into cos 31 that means, 540.18 kiloNewton per meter.

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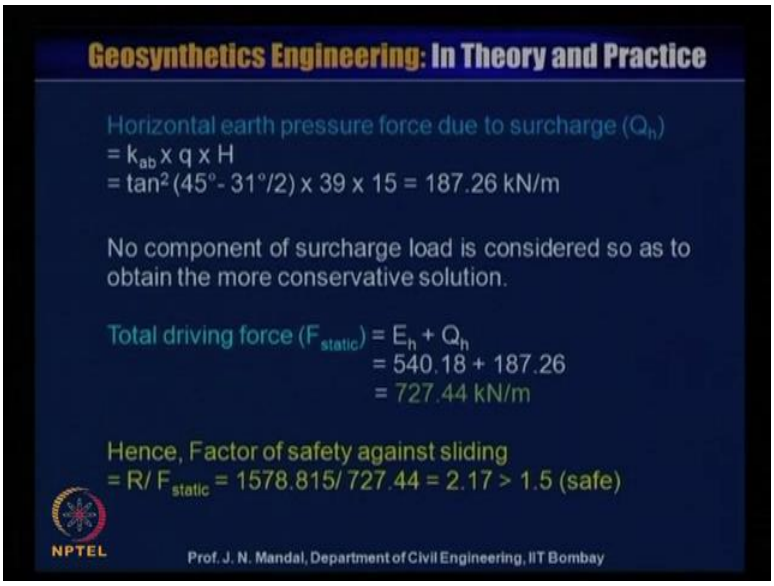

So, if you calculate this then you have to calculate what will be the horizontal earth pressure force due to the surcharge Q h that is, k a b into q into H that is, tan square 45 minus 31 by 2 into 39 q into H is equal to 15 then 187.26 kiloNewton per meter. So, no component of surcharge load is considered so as to, obtain the more conservative solution. So, total driving force F static will be equal to what is, E h plus Q h. So, we have calculated earlier, what is H, that is 540.18 plus 187.26.

So, total driving force F static is equal to 727.44 kiloNewton per meter so you have to check that, what will be the factor of safety against the sliding will be equal to R divided by, what will be the F static. That means, we have calculated the earlier R is equal to 1578.815, this divided by the total driving forces that is, 727.44 kiloNewton per meter is equal to 2.17 so it is greater than 1.5, so it is the safety.

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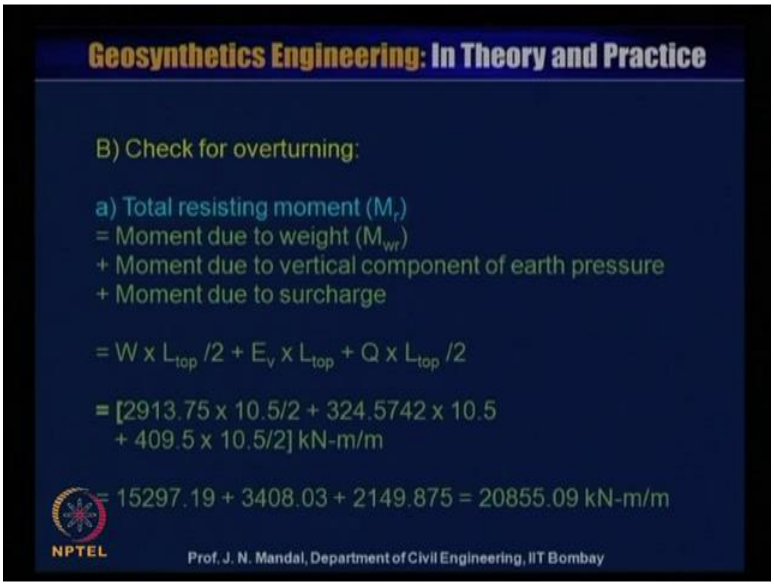

Next, we have check for the overturning so total resisting moment M r is equal to moment due to the weight M w r plus moment due to the vertical component of the earth pressure plus moment due to the surcharge. So that means, you know what is weight, weight into L top divided by 2 E v that mean, moment due to the vertical component of the earth pressure that is, E v into the L top and plus due to the surcharge that is, Q into L top by 2.

So, if you can calculate W, you know that is, 2913.75 into L top by 2 mean, 10.5 by 2 plus your E b. We have calculated 324.5742 into the 10.5 plus the Q into L top divided by 2 that is, 409.5 into 10.5 divided by 2 that is, kiloNewton meter per meter. So, total resisting force M r will be 15297.19 plus 3408.03 plus 2149.875 is equal to 20855.09 kiloNewton meter per meter.

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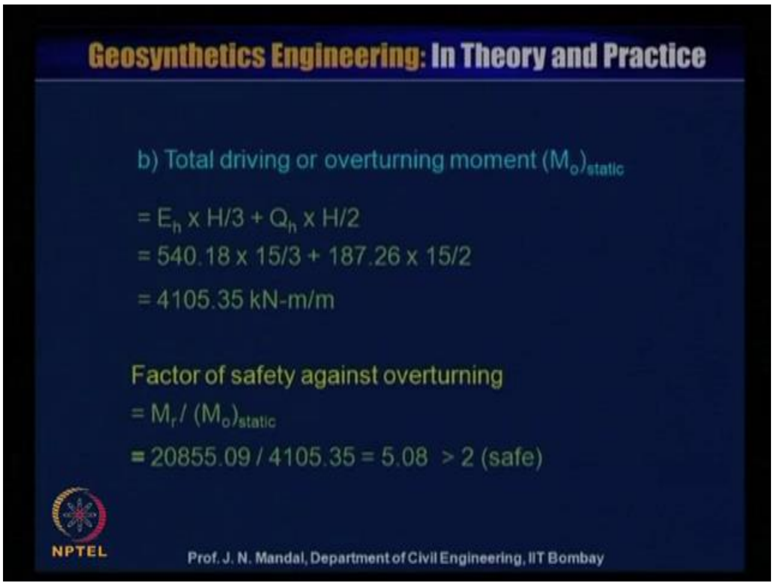

So, total driving, overturning moment M o at the static is equal to E h into you know that, what at a depth of one third of the height of the wall. So, H by 3 plus Q h, which is acting at the middle so this is H by 2. So, this will give 540.18 into 15 by 3 plus 187.26 into 15 by 2 so total driving force or overturning moment is 4105.35 kiloNewton meter per meter. So, factor of safety against overturning M r divided by M 0 static that means, is equal to 208555.09 divided by 4105.35 is equal to 5.08, which is greater than 2 so it is the ok.

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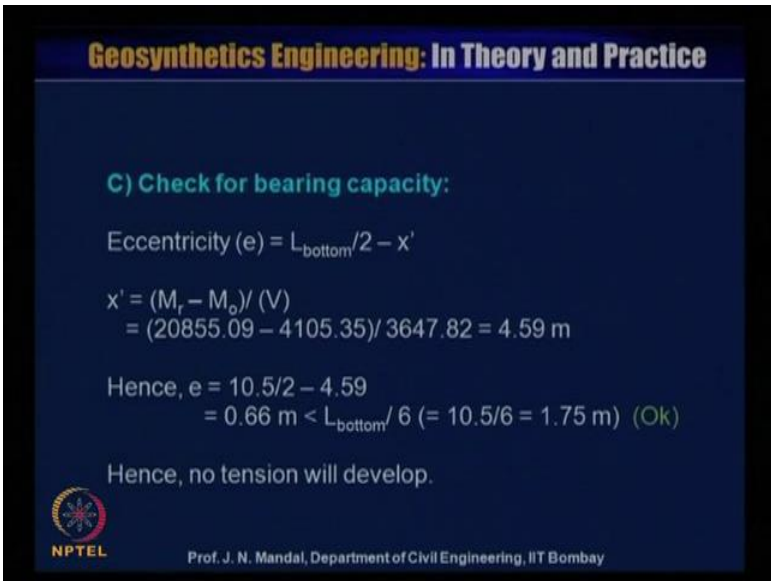

You have to check for the bearing capacity so eccentricity you know, e is equal to L bottom divided by 2 into x bar where, x bar is equal to M r minus M 0 divided by V. You know M r, 20855.09 minus M 0 you know, 4105.35, this divided by V that is, 3647.82 so this will give 4.59 meter. So, you can calculate the eccentricity e is equal to L bottom by 2, 10.5 by 2 minus x bar, x bar is equal to 4.59. So, this is 0.66, which is less than the L bottom divided by 6 that mean, 10.5 by 6 is equal to 1.75 meter that is ok hence, no tension will develop.

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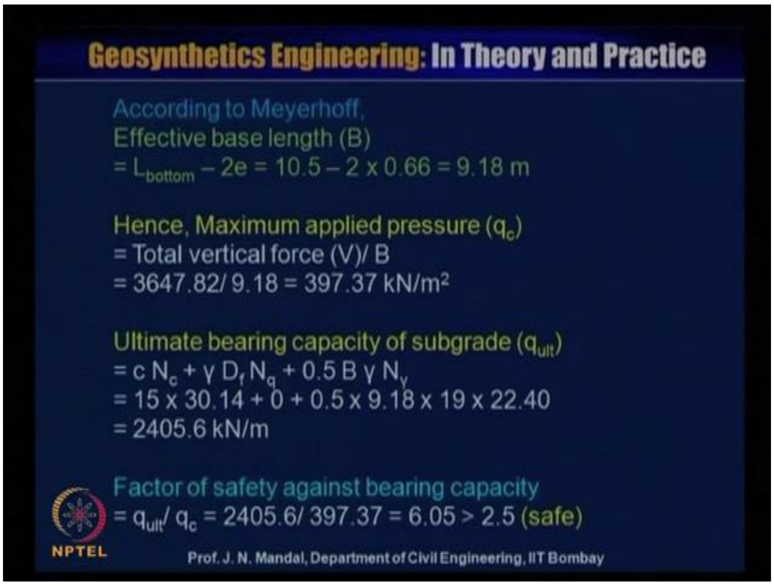

So now, adding M to the Meyerhoff distribution, what will be the effective base width B so effective base width is important, that is equal to L of bottom minus 2 e, L bottom also 10.5 minus 2 e, you calculated 0.66. So, 10.5 minus 2 into 0.66 is 9.18 hence, maximum applied pressure q c is equal to total vertical force V divided by B. So, that is 3647.82 divided by, this is the acting length 9.18 so this is the 9.18 so this is 397.37 kiloNewton per meter.

Ultimate bearing capacity of sub grade, q ultimate is equal to c into N c, gamma D f N q 0.5, B gamma N gamma, this is known to you. So, you just put these value c 15, N c value is given 30.14, this is 0 and plus 0.5 into B is 9.18, we calculated B 9.18 that is, the acting length that is, L bottom minus 2 e that is, 9.18 into the gamma 19 and into N gamma given 22.40. So, you can have the ultimate bearing capacity of subgrade, q ultimate is equal to 2405.6 kiloNewton per meter.

So then you check what will be the factor of safety against the bearing capacity q ultimate by q c that is, 2405.6 divided by 397.37 that is, 6.05 and this is greater than equal to 2.5 so it is safe.

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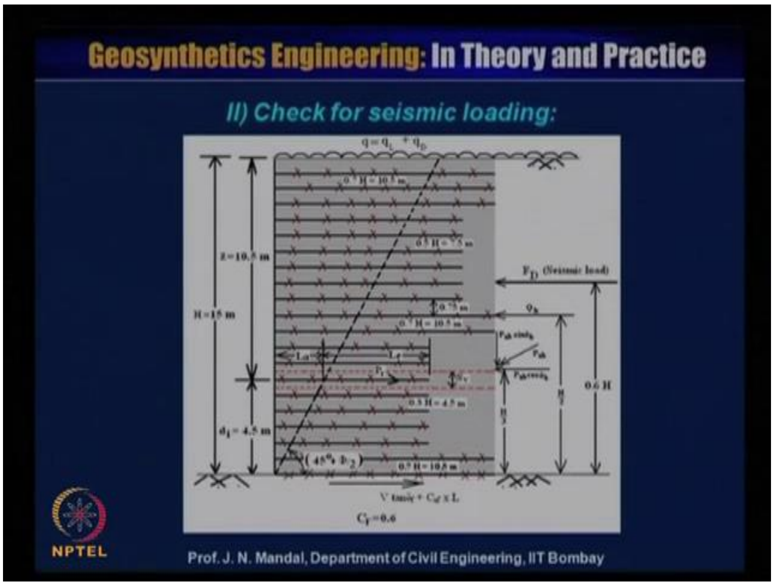

So, you have to check all this factor of safety and then it satisfy all this criteria, when it satisfy all this criteria, whether it is a sliding, whether it is a overturning and also you check the pullout also in the rupture. And then also, you check up with the bearing capacity of the soil, so when it satisfy all this criteria then it is designed with safe. So, most economical design can be made with this system, let us hear from you, I ended up this lecture now, if you have any question.

Thanks for listening.