Geosynthetics Engineering: In Theory and Practices
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Lecture - 30
Geosynthetics for Reinforced Soil Retaining Walls

Dear student warm welcome to NPTEL phase 2 video course on Geosynthetics Engineering in Theory and Practice. This lecture number 30, my name is Professor J.N Mandal, Department of Civil Engineering, Indian Institute of Technology Bombay Mumbai, India. This is module number 6 lecture number 30 Geosynthetics for Reinforced Soil Retaining Wall.

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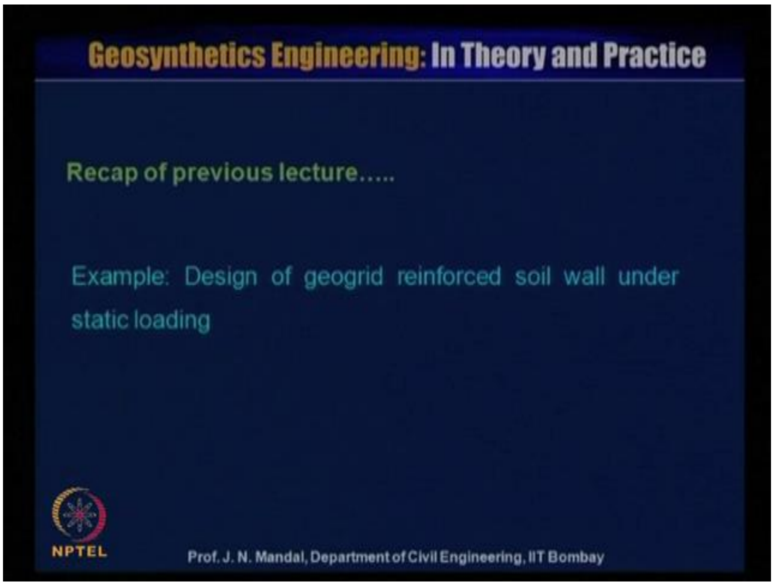

Now, I will show the recap of the previous lecture, that is we covered the example design of geogrid reinforced soil wall under static loading, we have also covered the different coverage ratio. And 4 cases have been considered, where the C R value is equal to the one with the length remain the constant and C R value is equal 0.6, the length remain constant and C R value is equal to 0.6 with varying the length of the reinforcement and C R is equal to 1 with varying the length of the reinforcement. And we have optimized and most economical and stable design, I have already been covered with the different example.

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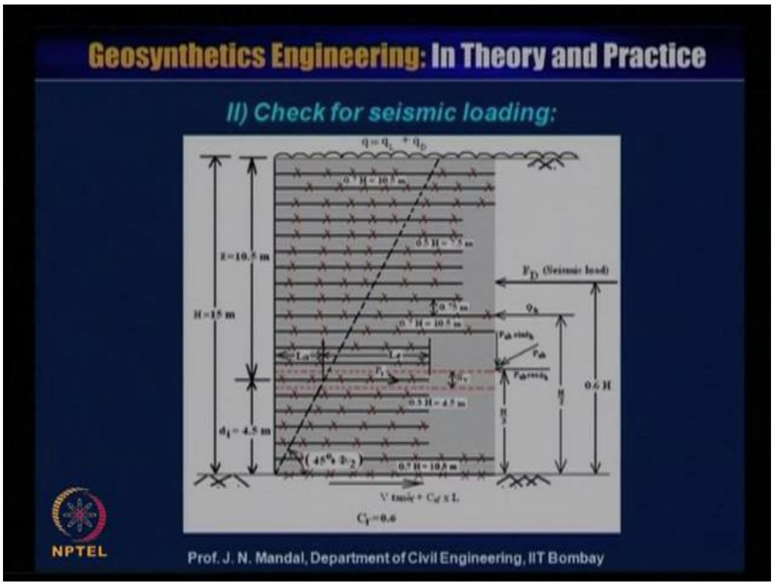

Now, I will focus that stability problem, for the check for the seismic stability, seismic loading condition, what will happen this reinforced soil wall.

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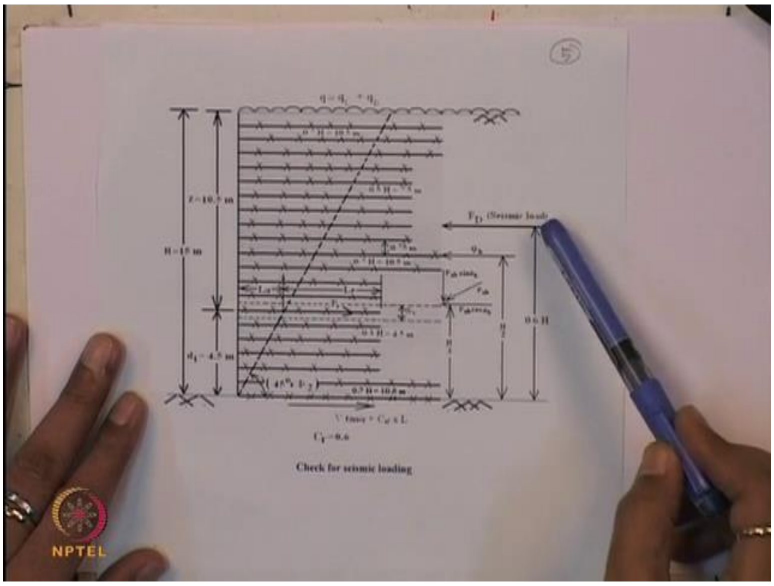

You can see here, this is the same wall, this is 15 meter height and it is the varying length of the reinforcement and in case of the seismic and this force will be acting the 2 3rd or 0.6 time the height of the wall. So, we have to be considered into this design.

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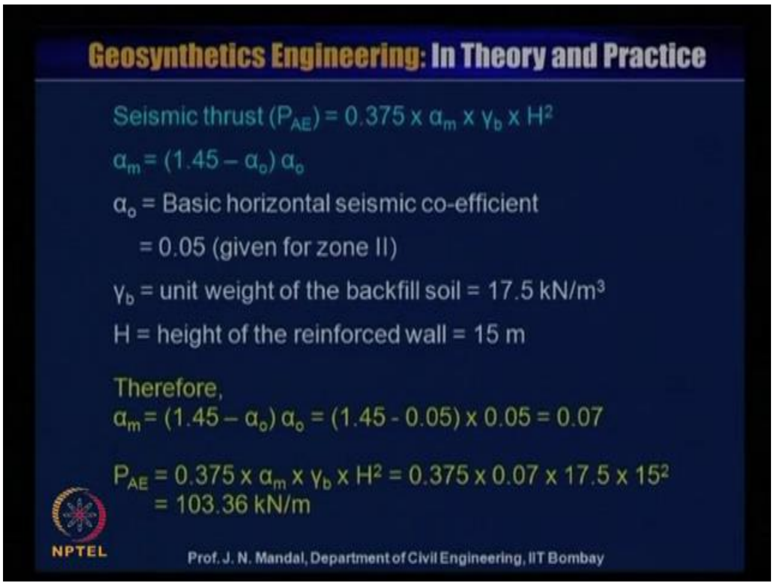

Now, for seismic thrust P A E is equal to 0.375, alpha m into gamma b into H Square, we know this equation, what will be the seismic thrust, where alpha m is equal to 1.45 minus alpha 0 into alpha 0, where alpha of 0 is the basic horizontal seismic coefficient that is 0.05 given for the zone 2.

So, India has the different zone; zone 1, zone 2, zone 3, zone 4 and you have to be careful for the selection of the basic horizontal seismic coefficient that is alpha 0. Let us say for the zone 2, where basic horizontal seismic coefficient is 0.05 and gamma b unit weight of the backfill soil is 17.5 kilo Newton per meter cube and H is equal to height of the reinforced wall that is 15 meter. So, from the equation that alpha of m is equal to 1.45 minus alpha 0 into alpha 0, we know now from the zone that alpha 0 value is equal to 0.05. So, you are substituting this value of alpha 0 that will be 1.45 minus 0.05 into 0.05 is equal to 0.07.

So, ultimately we have to calculate, what will be the seismic thrust, that is P A E, that is P A E will be equal to 0.375 into alpha m, we calculated 0.07. And gamma b, we know that unit weight of the backfill soil, that is 17 point kilo Newton per meter cube into H is equal to height of the reinforced wall, that is 15 here, H square will be the 15 square. So, we can write 0.375 into 0.07 into 17.5 into 15 square, that is 103.36 kilo Newton per meter, that what is the seismic thrust. So, we know that what is seismic thrust P AE?

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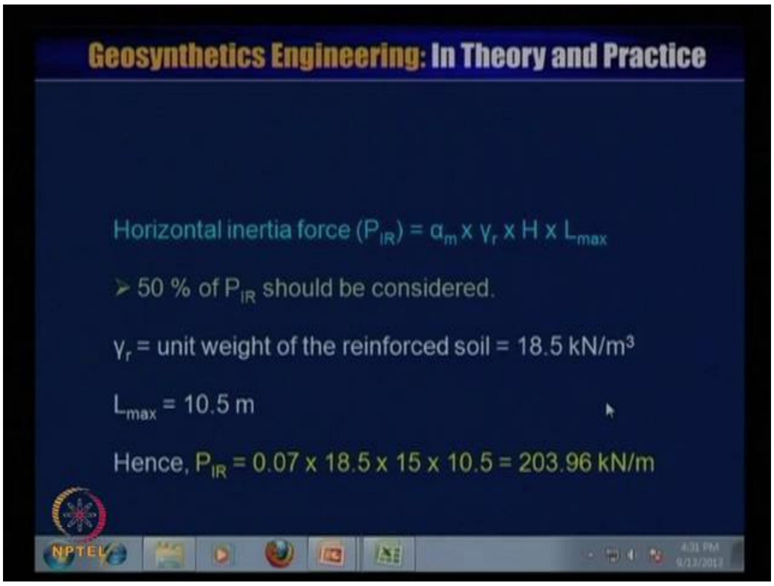

Now, what will be the horizontal inertia force, that is P I R. So, P I R is equal to alpha m into gamma r into H into L maximum here, L maximum is the length of the reinforcement, that is 10.5 meter and gamma r is the unit weight of the reinforced soil, that is 18.5 kilo Newton per meter cube, but horizontal inertia force, you have to keep 50 percentage of P I R should be considered. So, what is P I R, so P I R from the equation alpha m gamma r H into L max, we substitute the value alpha m, you know 0.07, gamma r is equal to 18.5 and H is equal to 15 and L maximum is 10.5. So, P I R value will be 203.96 kilo Newton per meter, so this is horizontal inertia force.

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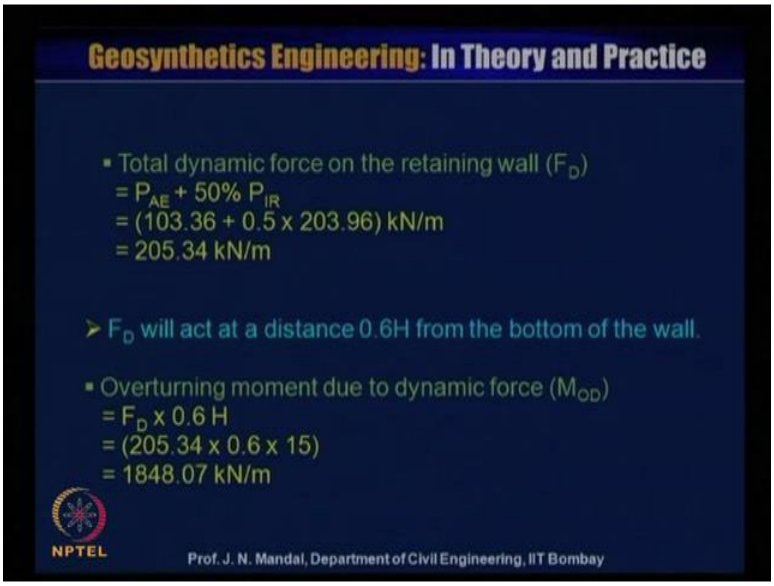

Here in case of horizontal inertia force, you have to consider 50 percentage of the P I R. So, total dynamic force on the retaining wall F D will be equal to we have calculated what is P A E plus 50 percentage of P I R. So, that means, 103.36 plus 0.5 into 203.96 kilo Newton meter that means, 205.34 kilo Newton per meter. Now this F D will act at a distance of 0.16 H from the bottom of the wall as I shown you earlier, that this force will act 0.6 times the height of the wall from the bottom of the wall. Now, what is overturning moment due to the dynamic force, that is M O D, M O D will be equal to that total dynamic force F D into 0.6 H that means, 205.34 into 0.6 into 15 that means, 1848.07 kilo Newton per meter, this is overturning moment due to dynamic load.

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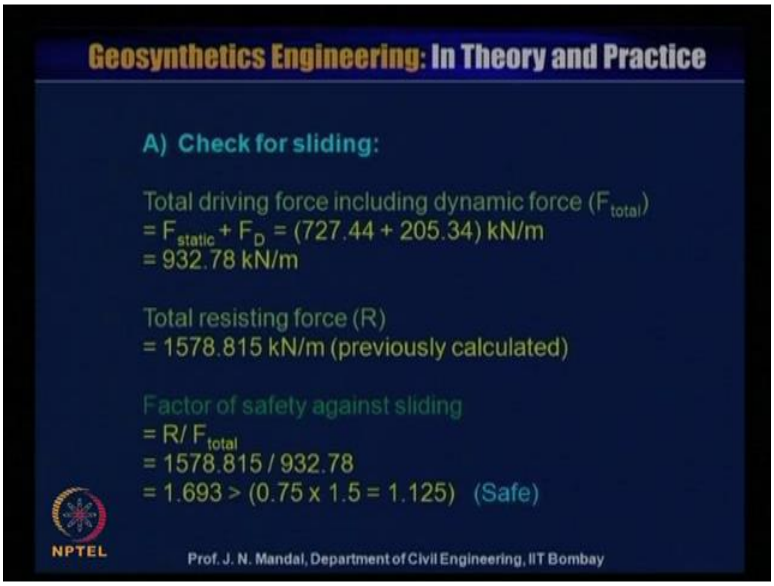

Now, we have to check for the sliding total driving force including the dynamic force F total will be equal to F of static plus F of dynamic F static, it is 727.44 F dynamic 205.34 kilo Newton per meter that will give 932.78 kilo Newton per meter. You check what will be the total resisting force R, which we have calculated earlier, it is 1578.815 kilo Newton per meter. So, factor of safety against sliding is equal to R divided by F of total that means, 1578.815 divided by 932.78 that means, 1.693, that is greater than 0.75 into 1.5 that means, 1.125 that means, safe. So, it is 75 percentage of the what will be the factor of safety for the static case. So, it is satisfying the criteria, so you have check for the sliding, so it is ok.

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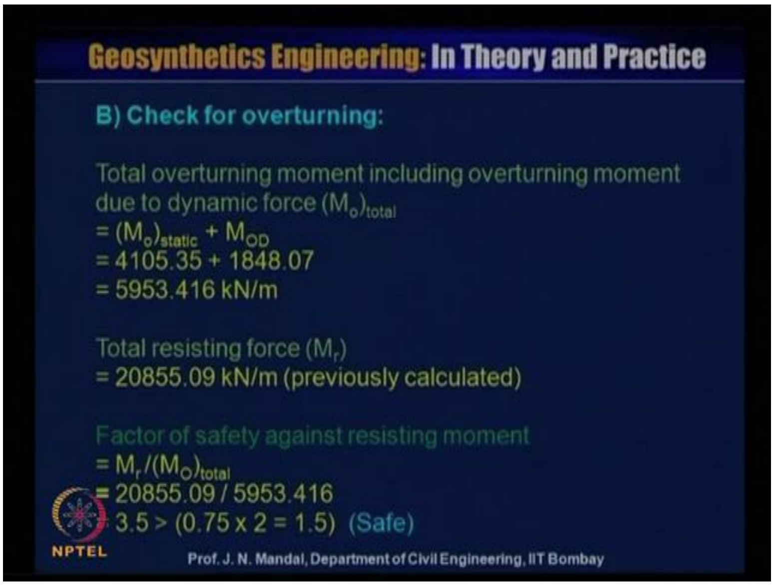

Now, check for the overturning total overturning moment including the overturning moment with due to the dynamic force M o total will be equal to M o static plus M O D for dynamic. So, that is 4105.35 plus 1848.07 is equal to 5953.416 kilo Newton per meter, similarly total resisting force M r, which we have calculated earlier, that is 20855.09 kilo Newton per meter. So, factor of safety against the resisting moment will be equal to M r divided by M 0, total that means, 20855.09 divided by 5953.416 is equal to 3.5, that is greater than 0.75 into 2 is equal to 1.5. So, we check against the overturning and it satisfy this criteria.

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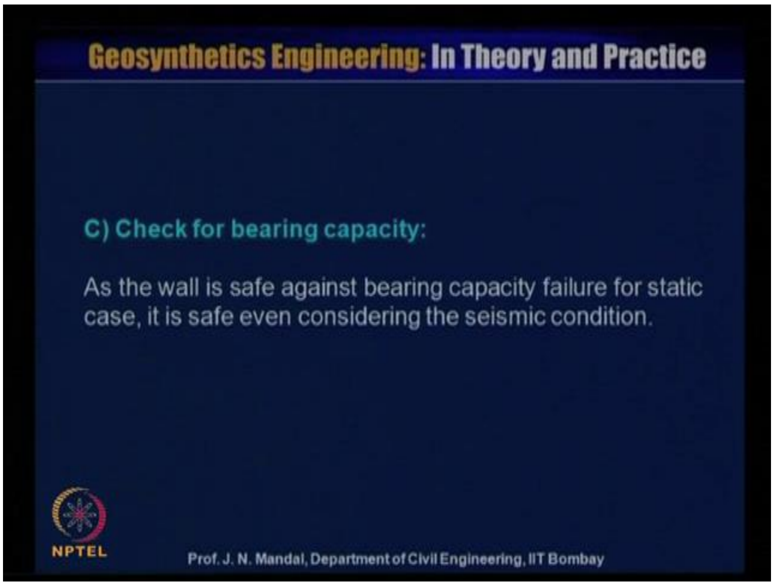

Due to seismic loading, similarly you can also check for the bearing capacity as the wall is safe against the bearing capacity failure for the static case, it is the safe even considering the seismic condition.

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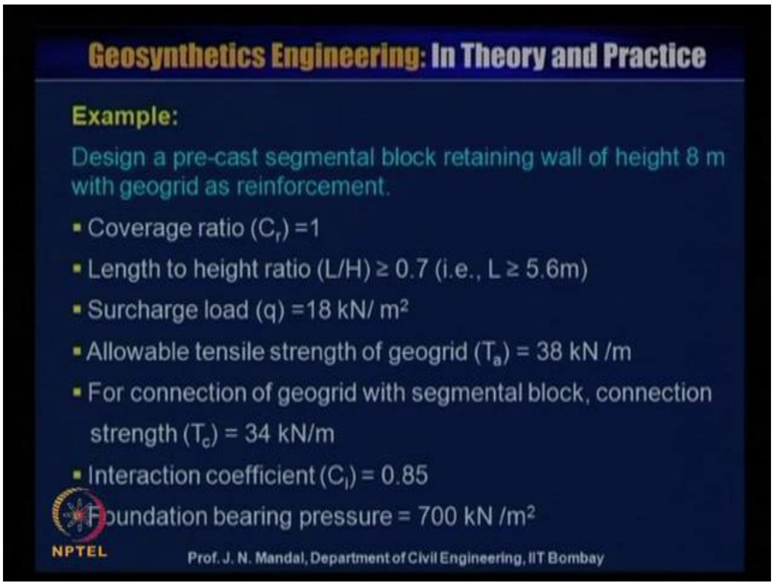

Now, we will give one example that is design for precast segmented block retaining wall height of 8 meter with geogrid as reinforcement. In this problem it is given that coverage ratio, that is C r is equal to 1 length to height ratio L by H greater than or equal to 0.7, that is L should be greater than is equal to 5.6 meter, surcharge load q is equal to 18 kilo Newton per meter square allowable tensile strength of the geogrid T allowable 38 kilo Newton per meter. For connection of the geogrid with segmental block connection strength T c is equal to 34 kilo Newton per meter interaction coefficient C i is equal to 0.85 and foundation bearing pressure is equal to 700 kilo Newton per meter.

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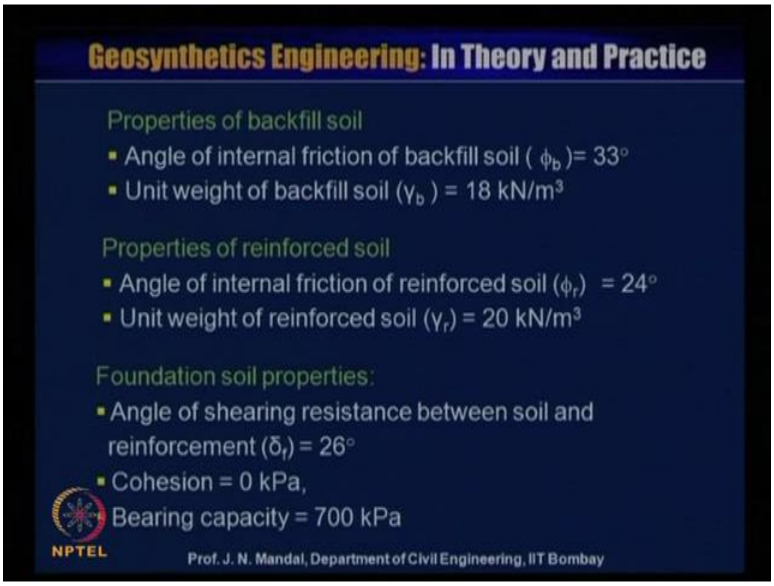

So, these are the some parameter is given apart from that, here properties of the backfill soil is given, that is angle of friction of the backfill soil pi b is 33 degree, unit weight of the backfill soil gamma b is equal to 18 kilo Newton per meter cube. And properties of the reinforced soil angle of internal friction of reinforced soil pi r is equal to 24 degree unit weight of the reinforced soil gamma r is equal to 20 kilo Newton per meter cube. And foundation soil properties angle of shearing resistance between soil and the reinforcement that is delta r is equal to 26 degree cohesion is equal to 0 kilo Pascal and also bearing capacity of the soil is equal to 700 kilo Pascal.

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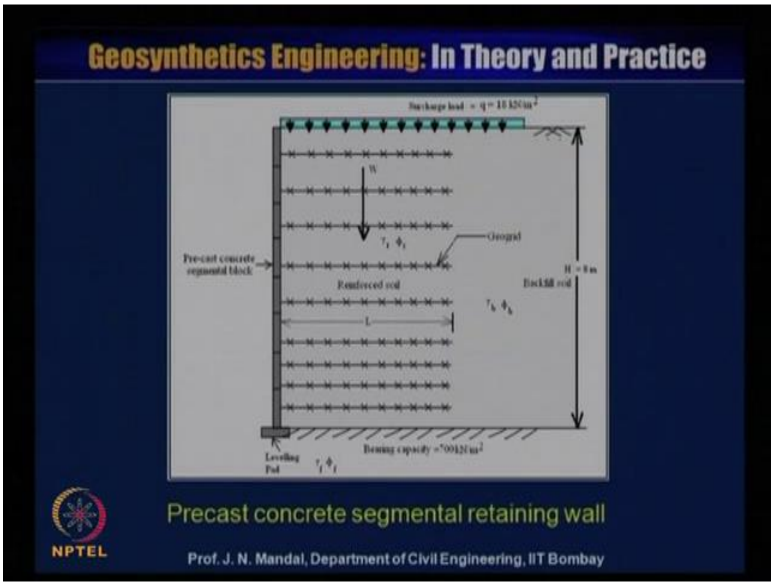

So, this is the wall, you have to design and this height of the wall is equal to 8 meter and here is the surcharge load 18 kilo Newton per meter cube and this the bearing capacity, which is given about 700 kilo Newton per meter. And this is the properties of the foundation soil, this is the properties of the backfill soil and this is the properties of the reinforced soil zone and this is the precast concrete segmented block. And this is number of the layer of the geogrid.

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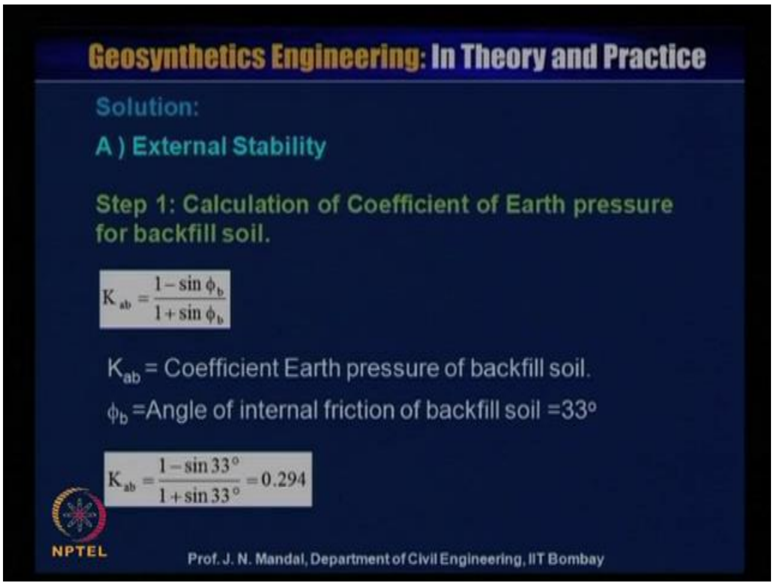

So, now we have to work for solution a external stability step one calculation of coefficient of earth pressure for backfill soil. So, first of all you have to calculate, what will be the coefficient of...

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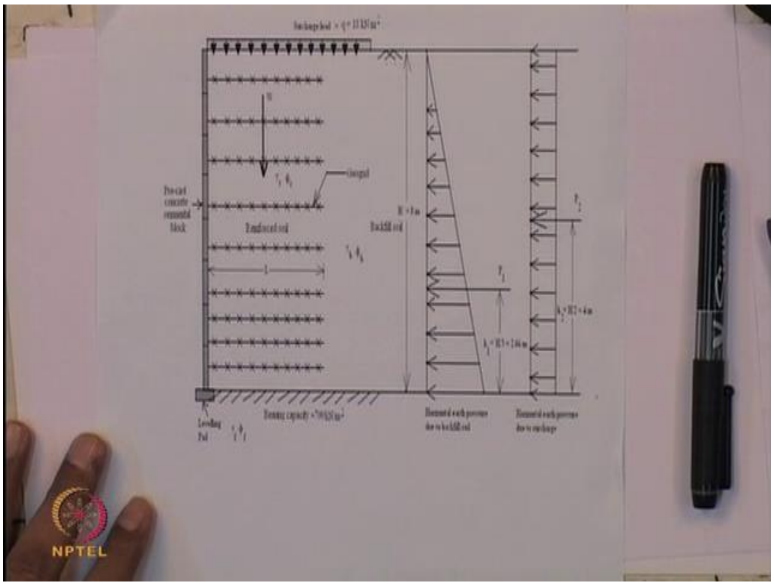

So, if this is the wall, this is the backfill soil, so here you have to find out, what is the K of a b where pi of b is given pi b is equal to angle of internal friction of the backfill soil, which is given 33 degree. So, you can calculate that K a b from this equation that is K a b is equal to 1 minus sin b by 1 plus sin b.

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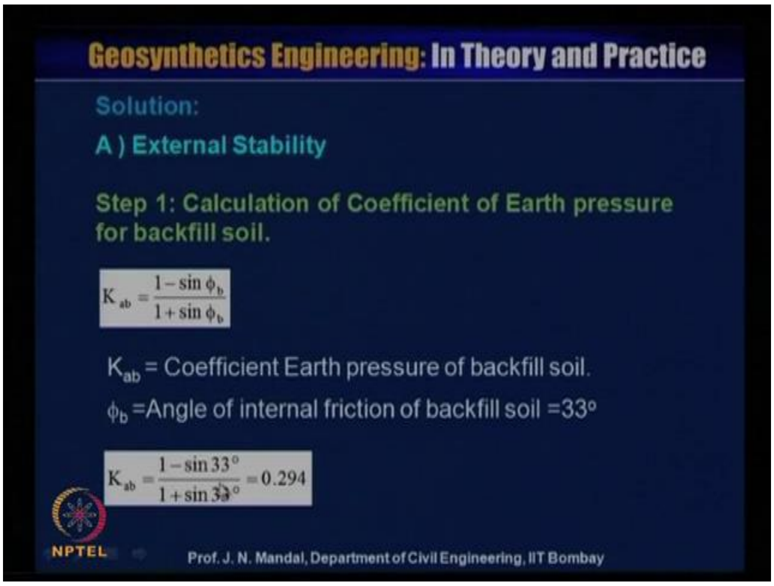

So, sin pi b value is give 33 degree, so K a b is equal to 1 minus sin 33 divided by 1 plus sin 33, that is 0.294. So, we know K a b that coefficient of earth pressure of backfill soil 0.294.

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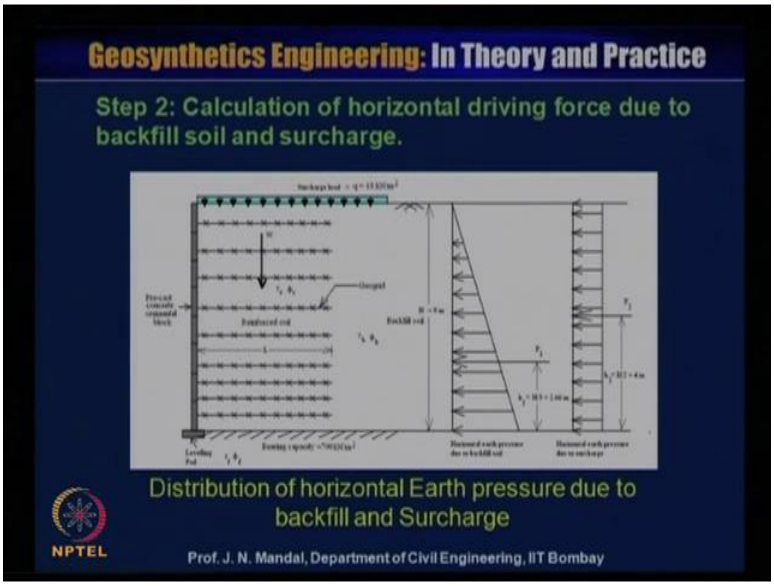

Now, you calculate the horizontal driving force, due to the backfill soil and the surcharge, here you can see that, this is the horizontal earth pressure due to backfill soil and this is the horizontal earth pressure due to the surcharge load. So, this load, it is force is acting is P 1 at a distance of H 1 from the base of the wall.

So, H 1 is equal to H by 3, if the height of the wall is H, if height of the wall is 8 meter, so this small H 1 will be equal to H by 3 is equal to 2.66 meter, when the horizontal earth pressure due to the backfill, that is P 1, what will be the horizontal earth pressure due to surcharge is P 2. And which is acting in the middle of the wall that means, H by 2 that means, small h 2 is equal to H by 2 is equal to 8 by 2is equal to 4 meter. So, you know that, what is H 1 and what is H 2, we know what is P 1 and what is P 2 and where, it is the acting.

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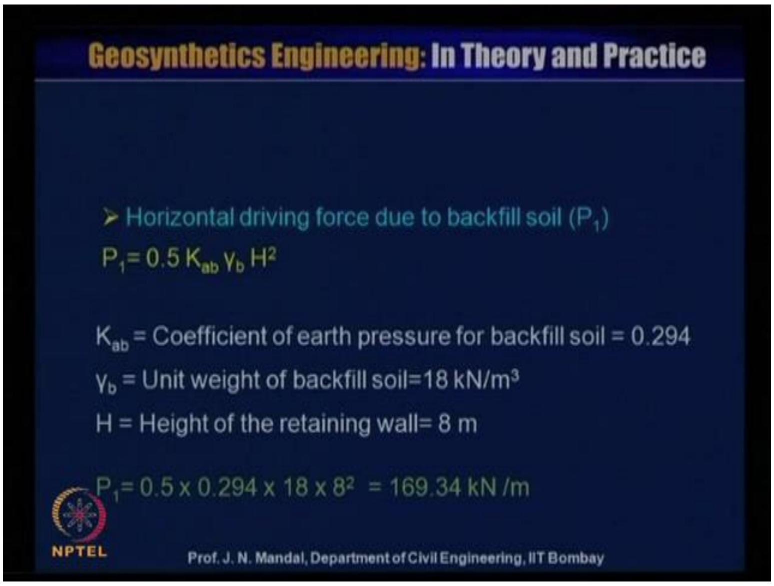

So, horizontal, we have to calculate what will be the horizontal driving force due to the backfill soil that is P 1. So, P 1 is equal to 0.5 K a b into gamma b into H square, this is P 1, we know K a b coefficient of earth pressure of backfill soil, we calculated 0.294 gamma b unit weight of backfill soil is given 18 kilo Newton per meter cube, height of the retaining wall is 8 meter. So, you calculate P 1 is equal to 0.5 into K a b is 0.294 into gamma b is equal to 18 kilo Newton per meter cube into height is equal to 18 then h square. So, it will given P 1 value is 169.34 kilo Newton per meter, that is the horizontal, driving force due to backfill soil.

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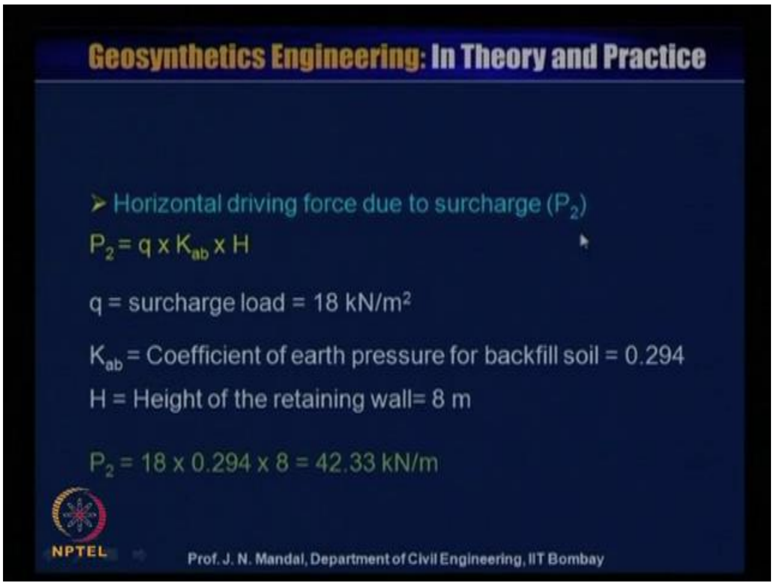

Now, similarly what will be the horizontal driving force, due to surcharge that is P 2, so P 2 is equal to q into K a b into H. So, q is equal to surcharge load, which is given 18 kilo Newton per meter square, K a b is known 0.294 height is known 8 meter. So, P 2 we can calculate is equal to q is equal to 18 into 0.294 into 8 is 42.33 kilo Newton per meter.

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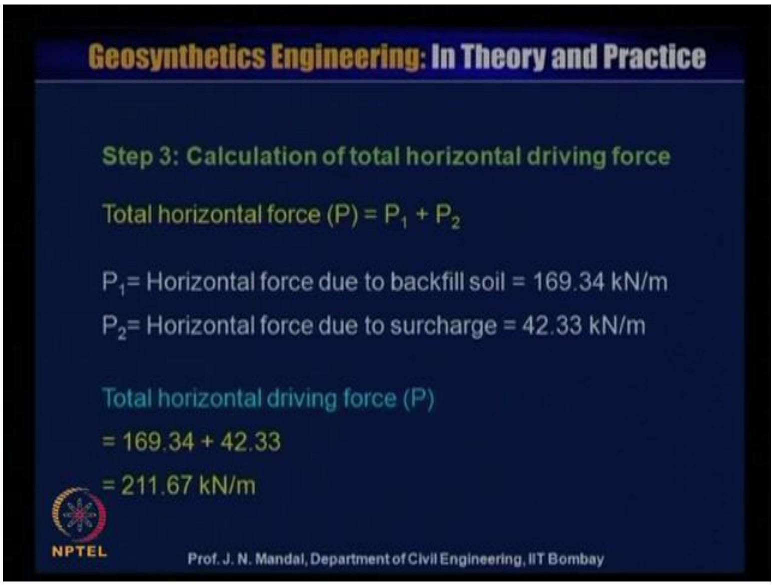

So, we know, that what is P 1 and what is P 2, so we can calculates step 3, what is the total horizontal driving force. So, total horizontal force P will be equal to P 1 plus P 2. So, P 1 I say horizontal force due to backfill soil is calculated 169.34 kilo Newton per meter and P 2 horizontal force due to surcharge is 42.33 kilo Newton per meter. So, total horizontal driving force P is equal to 169.34 plus 42.33 is equal to 2 1 1.67 kilo Newton per meter.

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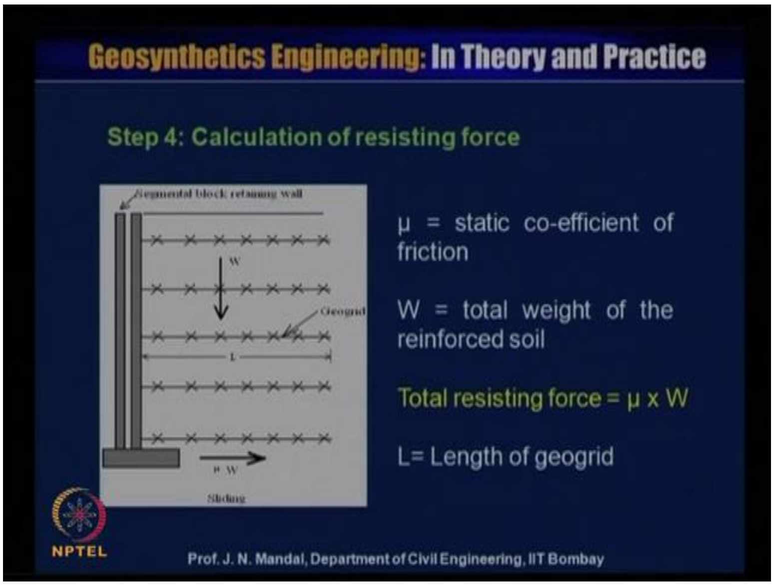

Step 4 calculations of resisting force, so here we can see here, this is the W what will be the total weight of the reinforced soil. And here the wall moves, this is the segmented block retaining wall, wall wants to move and it should be resisted, this is due to the sliding and if weight of the reinforced soil is W and it will be resisted by mu of W. So, this is mu of W, W is equal to total weight of the reinforced soil and total resisting force will be mu of W. So, mu is equal to the static coefficient of friction and for the W, you know, what will be the length, what will be the height of the reinforced soil and you know, what will be the gamma of r unit weight of the reinforced zone. So, you can calculate what will be the W value.

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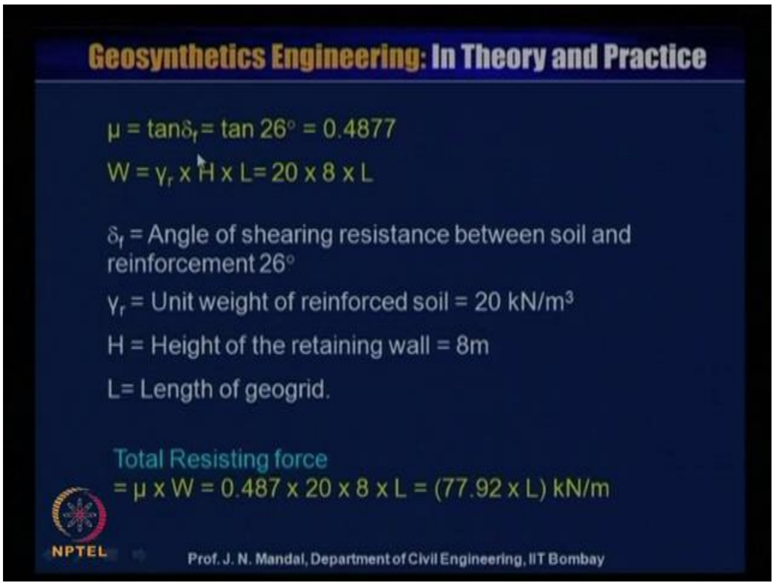

So, we can calculate the resisting force, you can see mu is equal to tan of delta f, delta f value is given 26, so tan 26 is equal to 0.4877 and weight is equal to I say gamma r into H into L 20 into 8 into L. So, where delta r is equal to angle of shearing resistance between soil and the reinforcement, that is 26 degree and gamma of r is the unit weight of the reinforced soil, that is 20 kilo Newton per meter cube, H is equal to height of the retaining wall is equal to 8 meter, L is equal to length of the geogrid. So, total resisting force is equal to mu into W, that means, mu value is 0.487 into that w is equal to the 20 into 8 into L, 20 is the unit weight of the reinforced soil, 8 is the height let us say it is the L. So, you are keeping the total resisting force in terms of the length, so that will be 77.92 into L kilonewton per meter.

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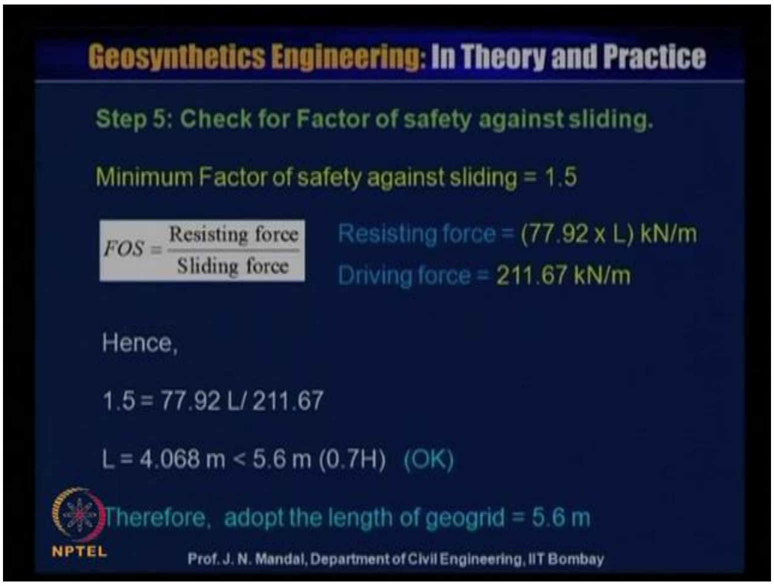

Now, step 5, you have to check for the factor of safety against the sliding and you consider minimum factor of safety against the sliding is 1.5. So, we know the factor of safety is the ratio of resisting force and the sliding force. So, what is resisting force resisting force we calculated, that is 77.92 into L kilo Newton per meter and driving force is 211.67 kilo Newton per meter. So, hence we can write, that 1.5 is equal to 77.92 into L divided by 211.67, so from there you can calculate the L, L value is equal to 4.068 meter, which is less than 5.6 meter, that means, 5.6 meter mean, that is 0.7 times the height of the wall is 8 meter. So, it is less than 5.6 meter mean ok, so therefore, adopt length of the geogrid should be 5.6 meter.

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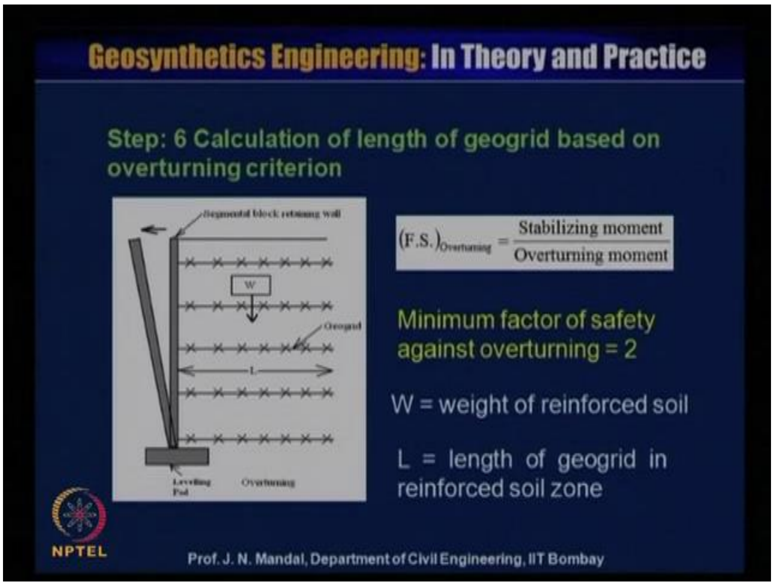

Now step 6, you have to calculate the length of the geogrid based on the overturning, now there is a possibility for the overturning, so you have to check up, what will be the factor of safety against this overturning. So, factor of safety overturning is the ratio or the stabilizing moment and the overturning moment. So, you have to calculate what will be the minimum factor of safety the against the overturning, let us consider the minimum factor of safety against the overturning is 2. And this is the weight of the reinforced soil and L is the length of geogrid in the reinforced soil zone and there is a leveling pad and you have to take a moment at the tau of the wall.

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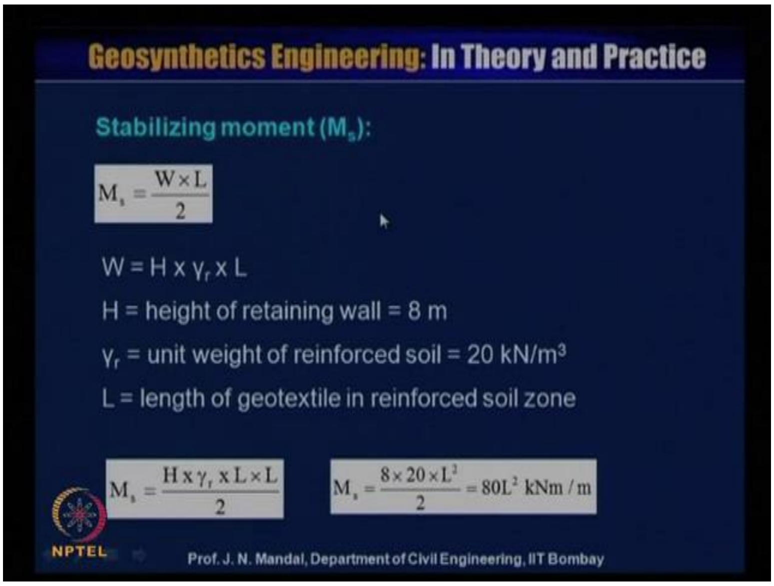

So, we need the stabilizing moment, which is designated as M s, M s is equal to W into L divided by 2, because this resisting moment, which is acting at the middle of this wall middle, this is W and this is length L. So, this you take a moment at the tau the W into L by 2, so this is W into L by 2, that is stabilizing moment. So, W is again is equal to H into gamma r into L and H value is 8 meter gamma r value is 20 kilo Newton per meter cube and L is equal to length of the geotextile. So, you can calculate the M s in terms of the length, so M s is equal to 8 into 20 into L square divided by 2. This will give the stabilizing moment M s is equal to 80 into L square kilo Newton per meter.

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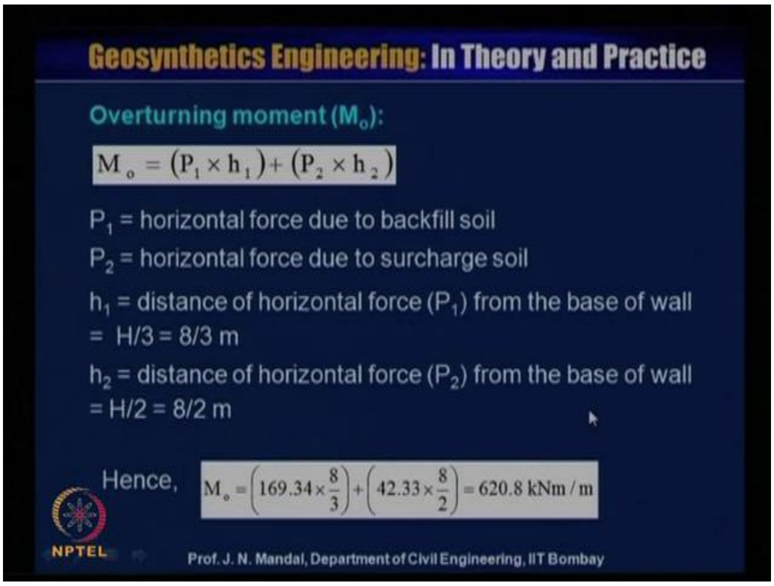

So, then overturning moment, you have to calculate the overturning moment, that is M 0, so overturning moment, if you can calculate.

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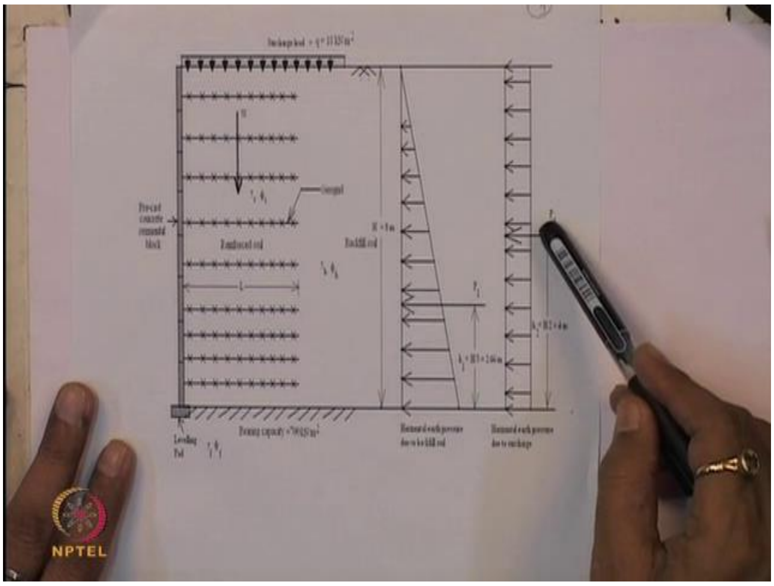

Suppose, this is the P 1 force, that is horizontal force due to the backfill. So, this P 1 and this distance H 1 is known, so P 1 into H 1 horizontal earth pressure due to the backfill soil, similarly this is the P 2, so P 2 into H 2 that is horizontal pressure due to the surcharge. So, you take a moment at the tau that is P 1 into H 1 plus P 2 into H 2, so where P 1 is equal to horizontal force due to the backfill soil and P 2 is equal to horizontal force due to the surcharge soil. And you know that, H 1 that is the distance of the horizontal force P 1 from the base of the wall that means, H by 3 that means, height of the wall is 8, so 8 by 3. And H 2 is the distance from the horizontal force P 2 from the base of the wall and height of the wall is equal to 8, so small h 2 will be equal to H by 2 is equal to 8 by 2 is 4 meter.

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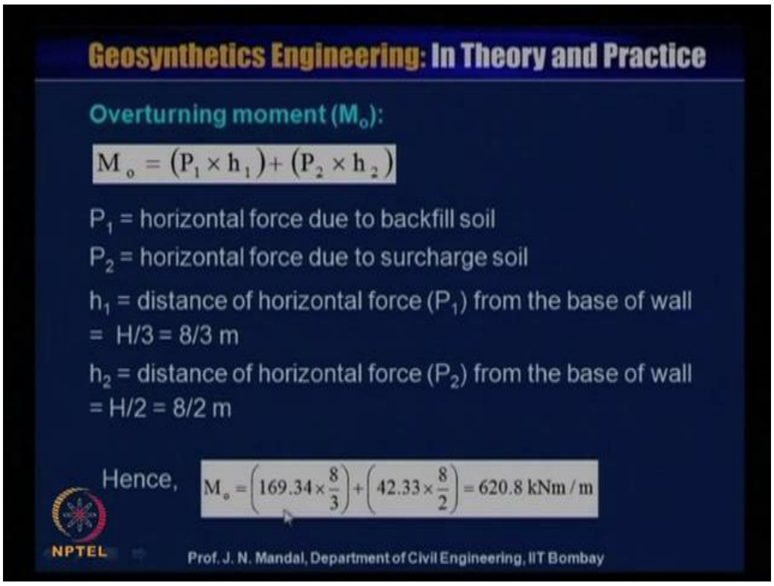

So, hence you can calculate, what will be the overturning moment, then overturning moment will be equal to P 1, you have calculated earlier 169.34 into 8 by 3 plus 42.33 into 8 by 2, which will give the overturning moment is equal to 620.8 kilo Newton meter per meter.

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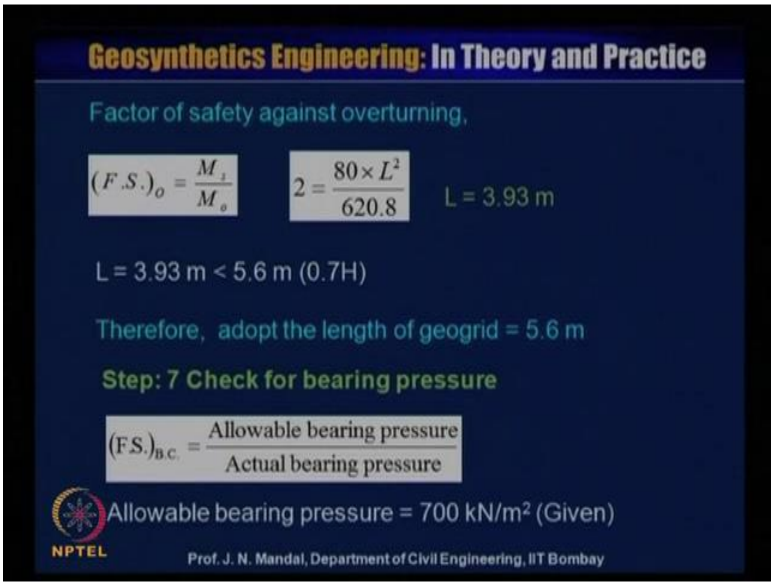

So, you know the overturning moment, so you have to calculate, what will be the factor of safety against this overturning. So, factor of safety against overturning will be equal to M s by M 0, so you know the factor of safety, we consider 2, you know factor of safety against that, M s is value is 80 into L square, these divided by M o is 620.8. So, L you can calculate and that L value is equal to 3.93, so L is equal to 3.93 meter, which is less than 5.6 meter or 0.78 therefore, you adopt the length of the geogrid is 5.6 meter. Now, step 7, you have to check for the bearing pressure, them factor of safety against bearing capacity, that is the ratio of allowable bearing pressure by actual bearing pressure. Now, allowable bearing pressure is given in the problem, that is 700 kilo Newton per meter square.

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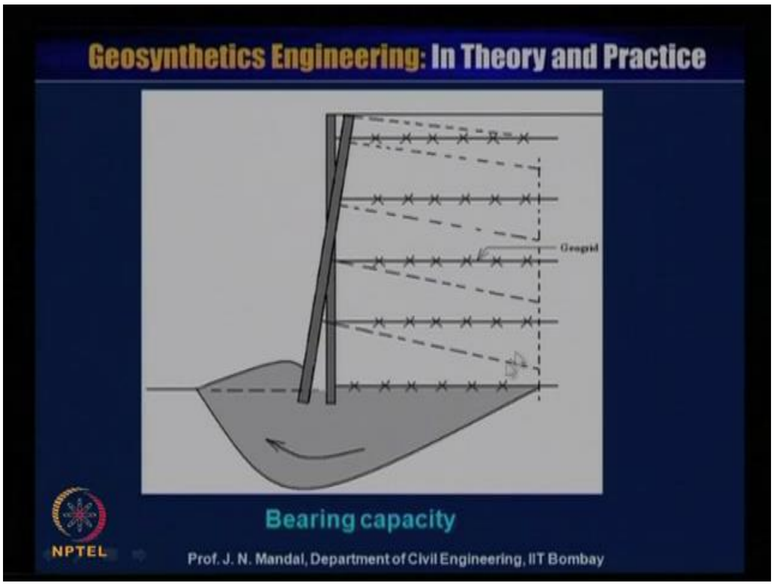

Now, we can see this is the wall, this is reinforcement and there is a possibility for the failure, due to the bearing capacity, so it is necessary to check the bearing capacity at this zone.

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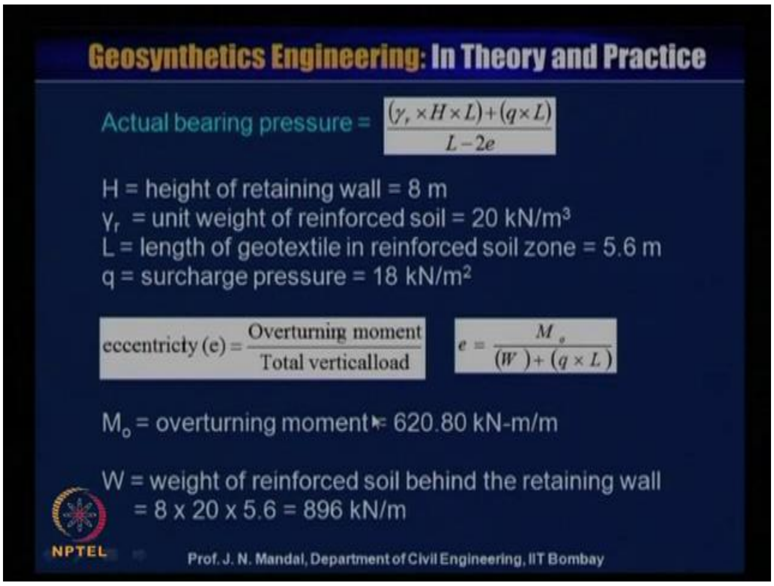

So, if you want to check, that bearing capacity then what will be the actual bearing pressure, that is due to the load of the reinforced soil wall and due to the surcharge load by the acting length as per meyerhoff pressure distribution, that is L minus 2 e, I have shown you also the earlier. So, where h is equal to height of the wall 8 meter given L is equal to length of the geotextile reinforced soil, that is 5.6 meter and q is equal to surcharge pressure is 18 kilo Newton per meter square.

So, you can substitute, this all this value gamma r also unit weight of reinforced soil is 20 kilo Newton per meter. So, you can substitute this value and check that eccentricity, eccentricity is equal to overturning moment by total vertical load, that is e is equal to M 0 by W plus q into L where, M 0 overturning moment given 620.80 kilo Newton meter per meter and W is the weight of the reinforced soil behind the retaining wall, that is 8 into 20 into 5.6, that is 896 kilo Newton per meter.

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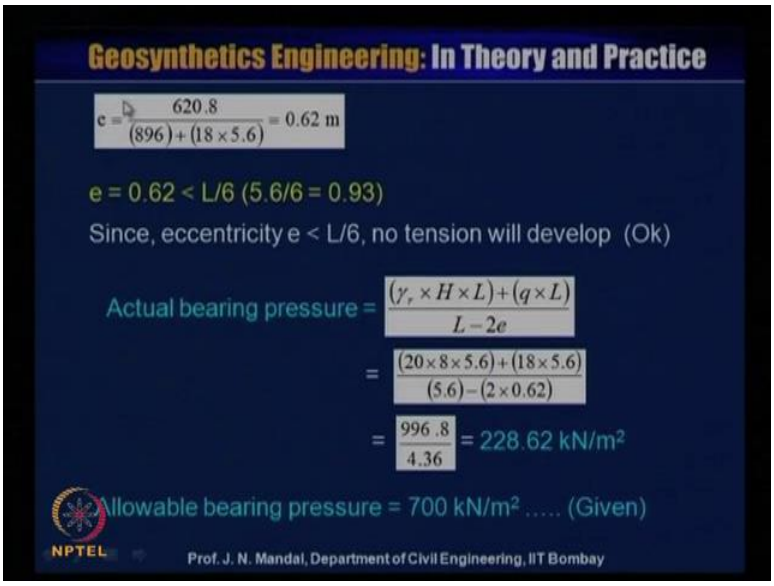

Now, eccentricity e, if you substitute this value, this value M 0 by W plus q into L that means, M 0 value is given 620.8 divided by this is calculated q value, that also it has been calculated is about 896 plus that is that q into L, q is equal to surcharge load 18 and length of the reinforcement 5.6. So, eccentricity is 0.62 meter, here e is equal to 0.62 meter, that mean less than L by 6, that is 5.6 by 6 is equal to 0.9.

Since the eccentricity value e less than L by 6, so no tensile will develop that means, it is so actual bearing capacity, which we have shown you earlier that gamma r into H into L plus q L divided by L minus 2 e, this is active zone, now you know what will be the value e is 0.62. So, you substitute this value 0.62 here and gamma r is 20 H value is 8 meter height L of the length of reinforcement 5.6 plus q surcharge load 18 L again 5.6 L 5.6 minus 2 into e, e is 0.62. So, if you calculate, you will have actual bearing pressure 996.8 divided by 4.36, that is equal to 228.62 kilo Newton per meter. But, in the problem, it is given that allowable bearing pressure is 700 kilo Newton per meter square.

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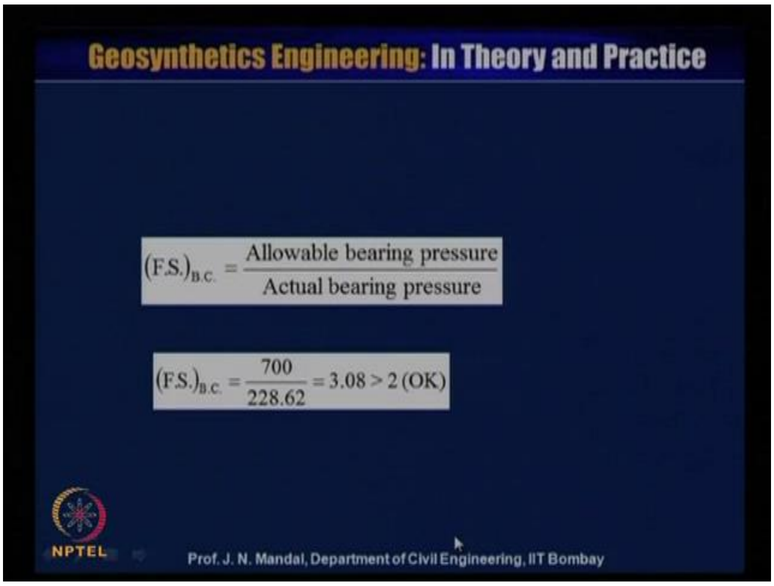

So, you can check that factor of safety against bearing capacity, that is allowable bearing pressure by actual bearing pressure that is factor of safety against bearing capacity is 700 divided by 228.62, that is 3.08 and this is greater than 2 means it is ok.

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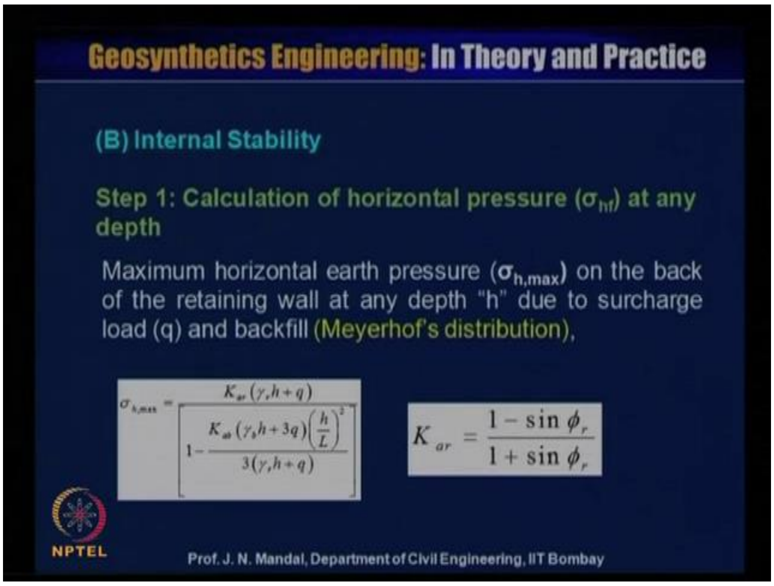

So, now B is the internal stability step one, calculation of the horizontal pressure sigma h f at any depth, maximum horizontal earth pressure sigma h maximum, on the back of the retaining wall at any depth h, due to the surcharge load q and the backfill also considering that Meyerhof pressure distribution.

So, we can obtain this equation that is sigma h maximum is equal to K a r into gamma r into h plus q divided by 1 minus K a b gamma b into h plus 3 q h by L whole square, this divided by 3 into gamma r into h plus q where, K a r is equal to 1 minus sin phi r divided by 1 plus sin phi r. So, we will use this equation, for the calculation of the horizontal pressure at any depth.

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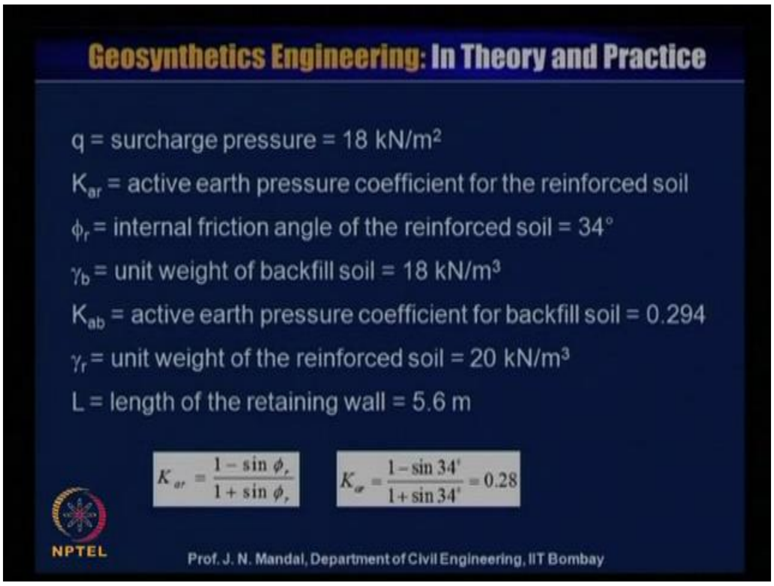

Now, here that you know, K a r is 1 minus sin pi r value is given, that is internal friction angle of the reinforced soil, that is 34 degree, so you can calculate K r 1 minus sin 34 1 plus 340.28, so K a r is equal to 0.28. Now, q although surcharge pressure is give 18 kilo Newton per meter, K a r is equal to active earth pressure coefficient of the reinforced soil, gamma b unit weight of the backfill soil given 18 kilo Newton per meter cube. And K a b active earth pressure coefficient for backfill soil is 0.294 gamma r unit weight of the reinforced soil 20 kilo Newton per meter cube and L is the length of the retaining wall, that is 5.6 meter.

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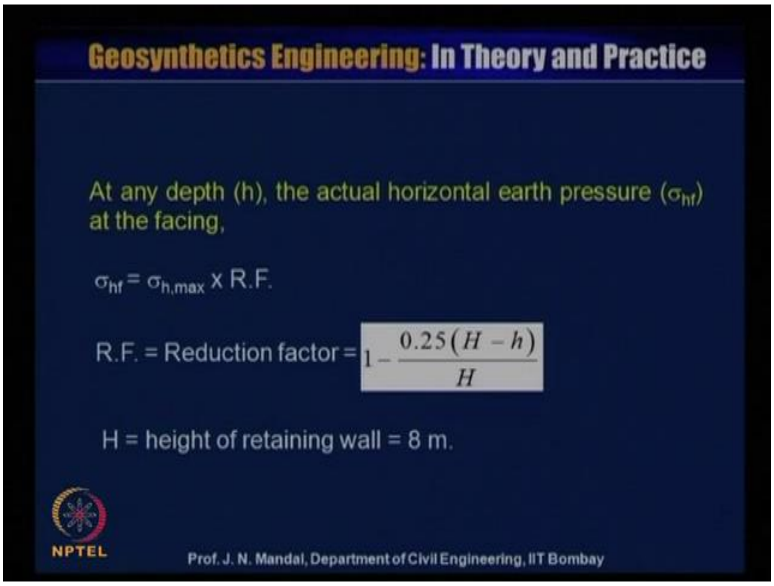

Now, at any depth, you have to calculate the actual earth pressure that is P h f at the facing, so at the facing sigma h f will be equal to, what will be the maximum earth pressure sigma H maximum into R F. For R F is called the reduction factor and this reduction factor can be determined with this equation 1 minus 0.25 into capital H minus small h divided by capital H where, H is equal to height of the reinforced soil wall at any depth, you can calculate that, H value. Suppose, H value is 5 meter height then you can calculate what will be the reduction factor.

So, if you know the reduction factor at any depth then you can calculate, what will be the actual horizontal earth pressure at the facing. So, horizontal earth pressure at the facing, you know what will be the sigma h maximum and then you know at depth, what will be the reduction factor. If you know the reduction factor then you can calculate what will be the actual horizontal earth pressure at the facing, which is called the sigma of H f and you know height of the wall, H is equal to 8 meter.

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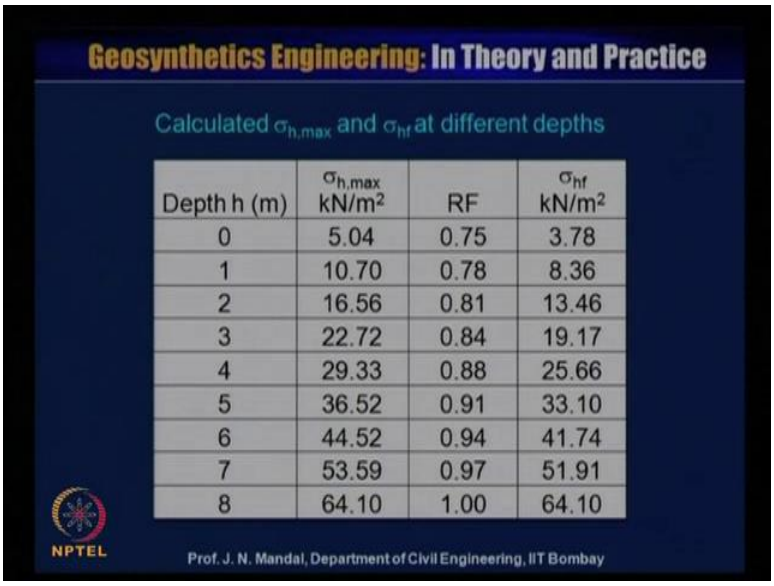

Depth h (m)	$\sigma_{h,max}$ kN/m²	RF	σ_{hf} kN/m²
0	5.04	0.75	3.78
1	10.70	0.78	8.36
2	16.56	0.81	13.46
3	22.72	0.84	19.17
4	29.33	0.88	25.66
5	36.52	0.91	33.10
6	44.52	0.94	41.74
7	53.59	0.97	51.91
8	64.10	1.00	64.10

So, with this equation for this wall, this is about 8 meter at any depth, you can calculate what will be the sigma of maximum from this equation, you know what is the maximum.

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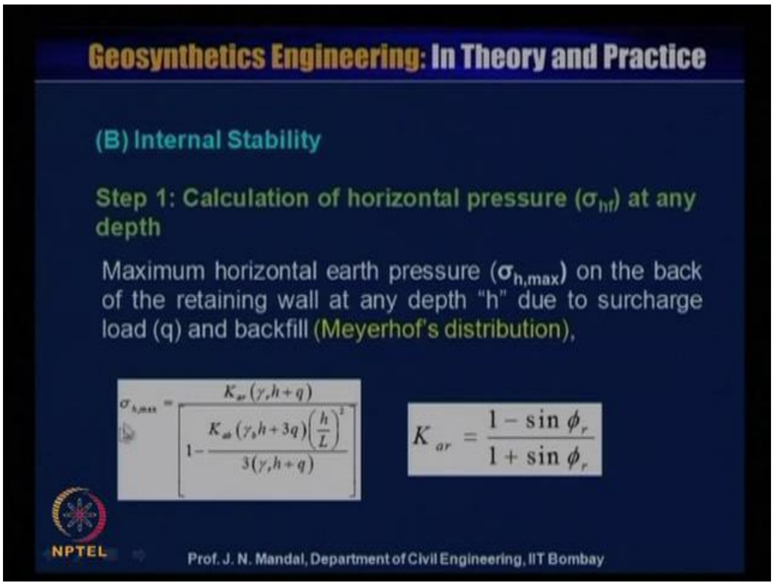

This equation all, these values are known to you. So, you have calculated, what sigma of h maximum.

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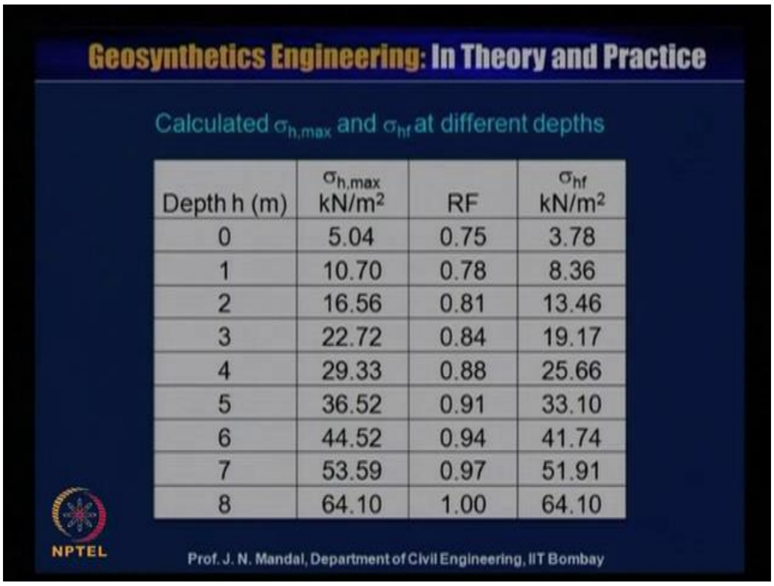

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7	53.59	0.97	51.91
8	64.10	1.00	64.10

And you are bring those values here, so what is sigma h maximum and then you are calculating the reduction factor at any depth, if you take h small h value is 3 meter. And if you know that small h value 3 meter and capital value is 8 meter, so you can calculate, what will be the reduction factor.

So, with this equation, you can calculate reduction factor, here the reduction factor at various depth. So, if you know reduction factor, then what will be the pressure at the facing, that is sigma h f, you are using this equation, that is sigma h f is equal to sigma h maximum into reduction factor. So, you know sigma h maximum into reduction factor 0.75 will give you that what will be the pressure at the facing, that is 3.78. So, on all depth you can calculate the sigma h maximum, you can calculate the reduction factor and equally, you can calculate, what will be the pressure at the facing. Now, I can show you that, what will be the relationship between the depth and the maximum pressure, what will be the depth between the, what will be the pressure at the facing.

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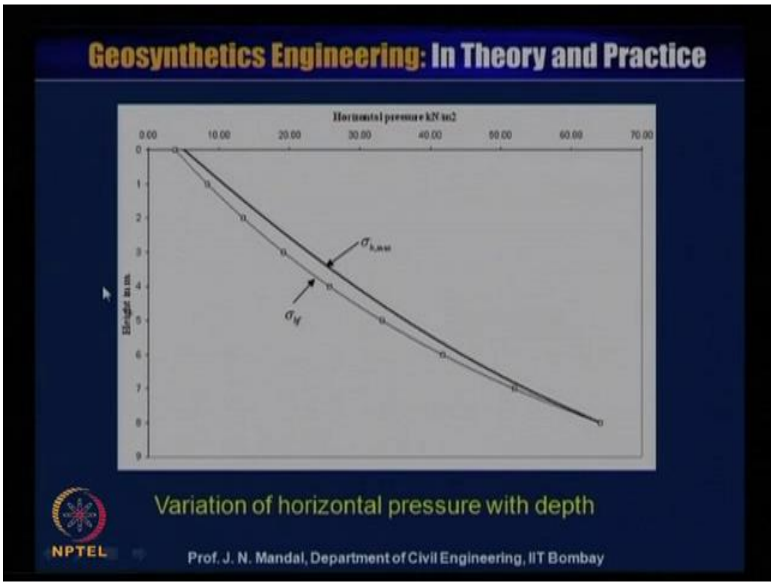

So, this the figure shows the variation of horizontal pressure with the depth, so this is 8 meter depth and this is the horizontal pressure, you can see, this is the nature of the curve when sigma h is the maximum and this is the relationship between the horizontal pressure, with the height when it is at the facing. So, sigma h f at the facing, so sigma h f facing is less than the sigma h of maximum.

So, you can you can determine, that what should be the maximum pressure and what should be the pressure acting at the facing. So, this figure shows the variation of the horizontal pressure with the depth how it is that increasing with this depth. Now, step 2 calculation for the vertical spacing.

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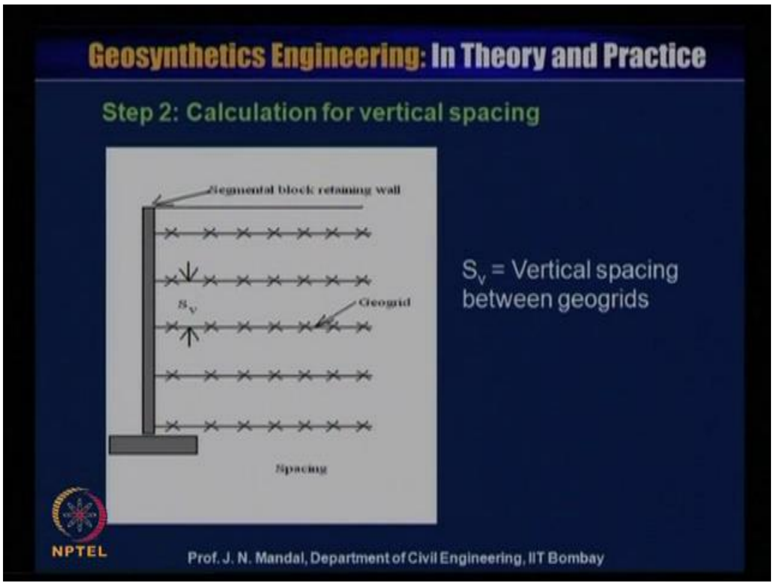

So, if this is the retaining wall and you have to calculate, what will be the S v that means, what will be the spacing between the 2 reinforcement and which is designated as S of v.

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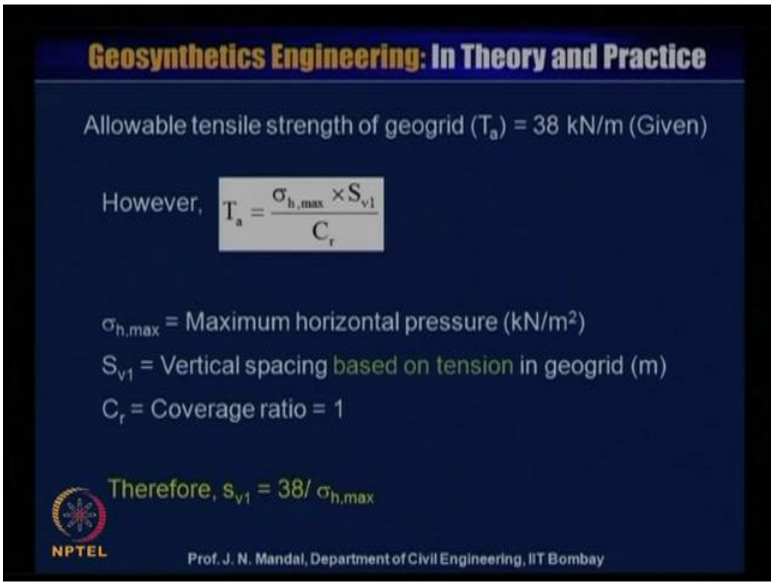

Now, if require allowable tensile strength of the geogrid, so allowable tensile strength of the geogrid is 38 kilo Newton per meter is given, however T a is equal to sigma h maximum into S v 1 by C of r. Now, sigma h maximum is equal to maximum horizontal pressure kilo Newton per meter square S v 1 is the vertical spacing based on the tension in geogrid meter and C r is the coverage ratio here, coverage ratio is equal to 1. Therefore S v 1 will be equal to 38 divided by sigma h maximum.

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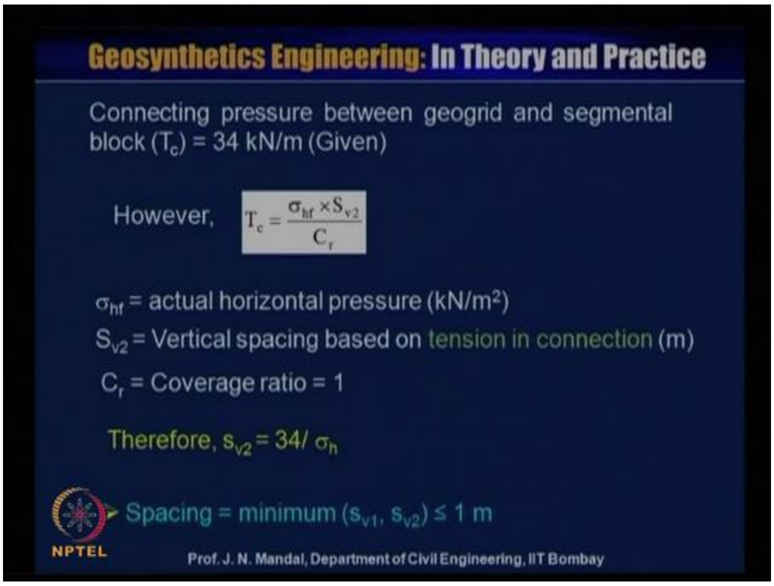

Next connecting pressure between the geogrid and the segmental block, that T c is given 34 kilo Newton per meter, however, T c is equal to sigma h f into S v 2 divided by C of r. So, sigma S is equal to actual horizontal pressure kilo Newton per meter square, here S v 2 vertical spacing based on tension in connection in meter and C r is the coverage ratio is equal to 1, so therefore, S v 2 will be equal to 34 by sigma h.

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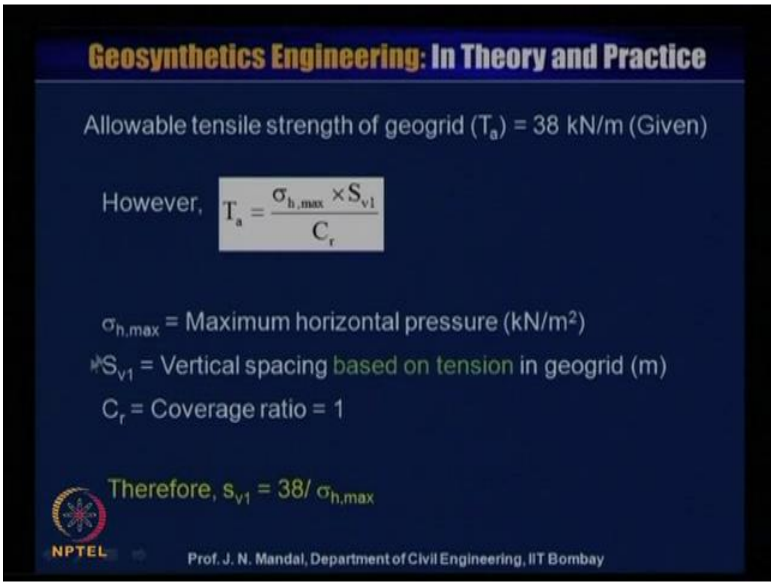

Now, here it is point to be noted that, we are considering vertical spacing S v 1 when based on the tension in the geogrid, that is a failure for the tension in the geogrid.

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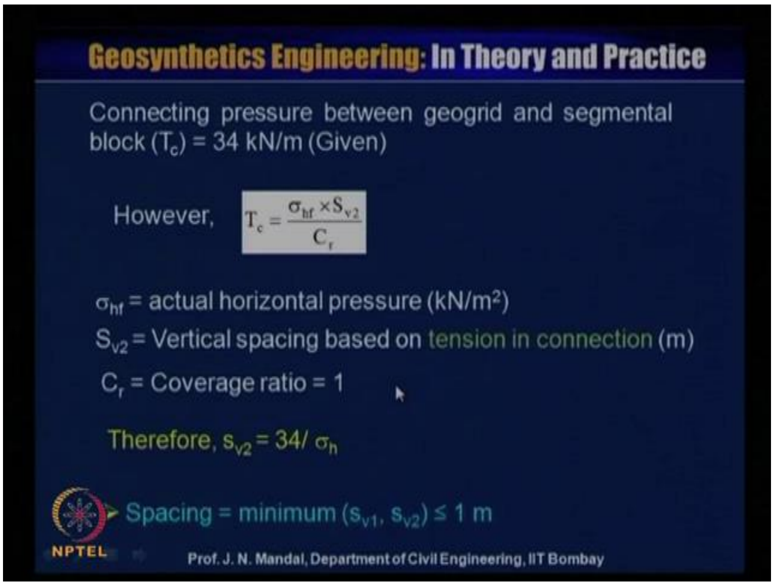

So, what spacing you should consider or here S v 2 vertical spacing based on the tension in connection, the failure may due to the connection or failure may due to the tension in the reinforcement. So, if the spacing is S v 2, that is the vertical spacing based on the tension in connection then S v 2 will be 34 by sigma of h. Now, spacing you have to select minimum of S v 1 or S v 2, that is tension in connection or the tension in the geogrid itself. So, based on that you have to select the spacing and whichever will be the minimum either the S v 1 or the S v 2, but it should be less than or equal to the 1 meter.

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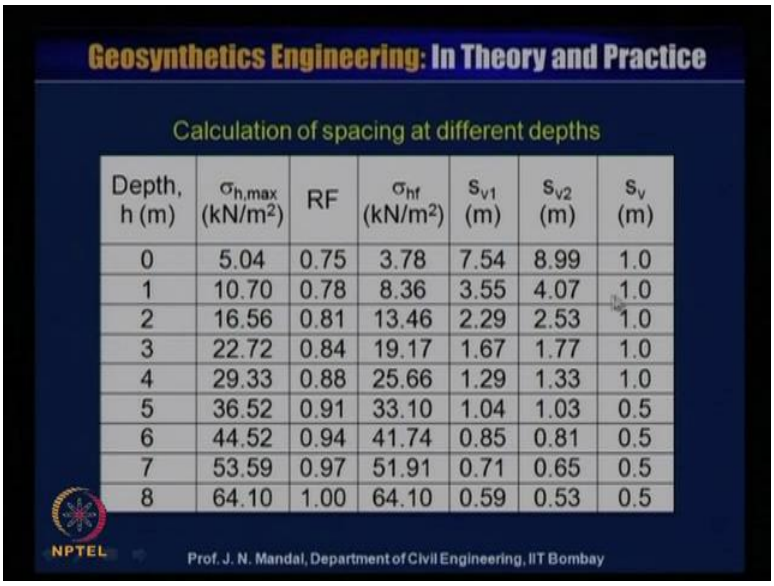

Depth, h (m)	$\sigma_{h,max}$ (kN/m^2)	RF	σ_{hf} (kN/m^2)	S_{v1} (m)	S_{v2} (m)	S_v (m)
0	5.04	0.75	3.78	7.54	8.99	1.0
1	10.70	0.78	8.36	3.55	4.07	1.0
2	16.56	0.81	13.46	2.29	2.53	1.0
3	22.72	0.84	19.17	1.67	1.77	1.0
4	29.33	0.88	25.66	1.29	1.33	1.0
5	36.52	0.91	33.10	1.04	1.03	0.5
6	44.52	0.94	41.74	0.85	0.81	0.5
7	53.59	0.97	51.91	0.71	0.65	0.5
8	64.10	1.00	64.10	0.59	0.53	0.5

Now, here this table calculation of spacing at different depth, this is 8 meter height wall sigma h maximum, you know reduction factor already calculated, this is the pressure for the spacing element, you can see that, this is the S v 1 and S v 2. So, geogrid may fail due to tension or geogrid may fail due to the connection with the spacing element, so these are the facing, these are the spacing for S v 1 and S v 2.

So, you have to select, I mention that, it should be less than equal to 1 meter. So, you cannot adopt this, you can adopt this spacing between the reinforcement 1 meter 1 meter 1 meter and 1 meter, this is also 1 meter and this also, we can appropriately less than 1 meter 0.5 meter, you can consider.

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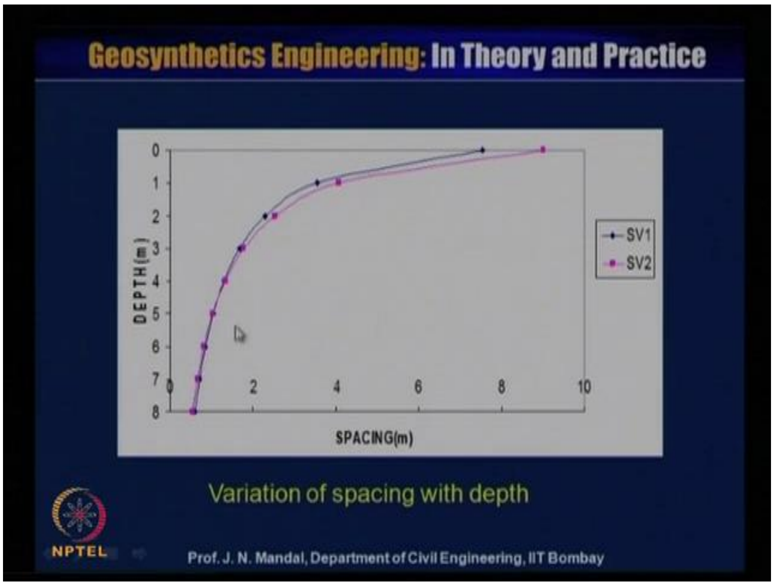

So, here also between the spacing and the depth, for the different value of S v 1 and S v 2 and with the depth, I have shown the curve, you can see this is increasing, the depth is increasing also spacing and after certain times it is like this. So, whatever it may be, you have to be consider the spacing about the 1 meter or less.

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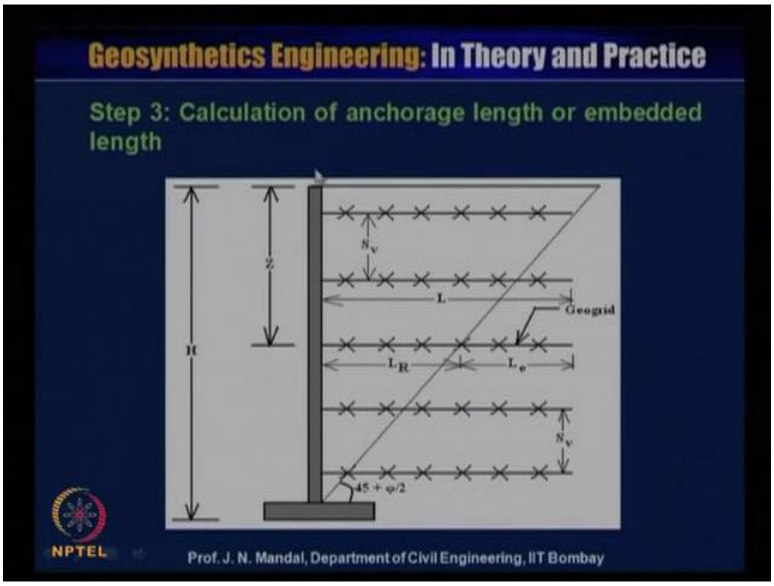

Step 3 calculation of anchorage length of the embedded length, now here this is the geogrid reinforced soil wall and this is the length of the geogrid and this is the embedded length, what is called L e. And this is the failure surface, which is making at an angle of

45 degree plus pi by 2, so at any depth z, you can calculate what will be the embedded length L and this spacing between the 2 geogrid is S v.

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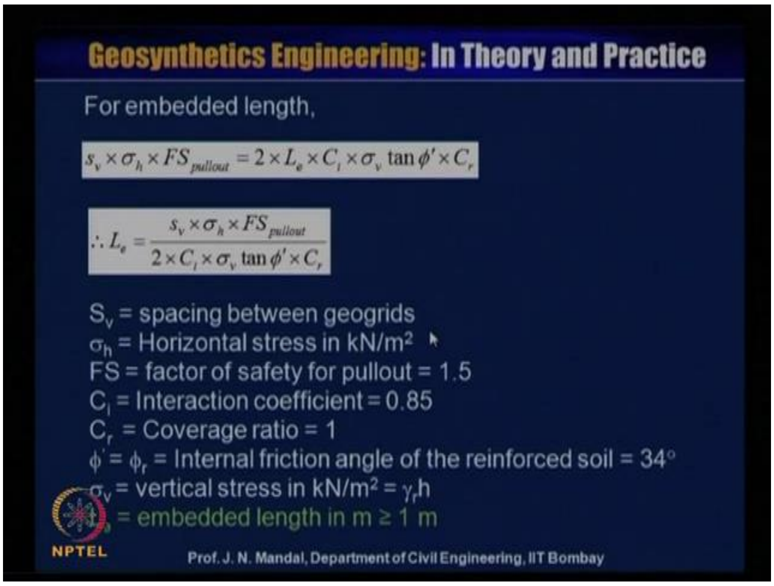

So, from the embedded length, we know that S v into sigma h F S pullout, that is 2 into L e into C i sigma v tan phi dash into C r. So, from this equation, you can calculate L e is equal to S v into sigma h, factor of safety due to pullout divided by 2 into C i into sigma v tan phi dash into C i. You know what is spacing, that is the spacing between the geogrid, you know sigma h horizontal stress kilo Newton per meter and this is factor of safety due to pullout and that, we assume that is 1.5.

And this is the C i which is called interaction coefficient and this value also given 0.85 and sigma v is the vertical stress and this sigma v is vertical stress is equal to gamma r into h. So, you know that gamma r at any depth h is known, so you can calculate the what is sigma v and tan phi dash, which is phi r, that is internal friction angle of the reinforced soil, that is 34 degree and C r is the coverage ratio that is 1.

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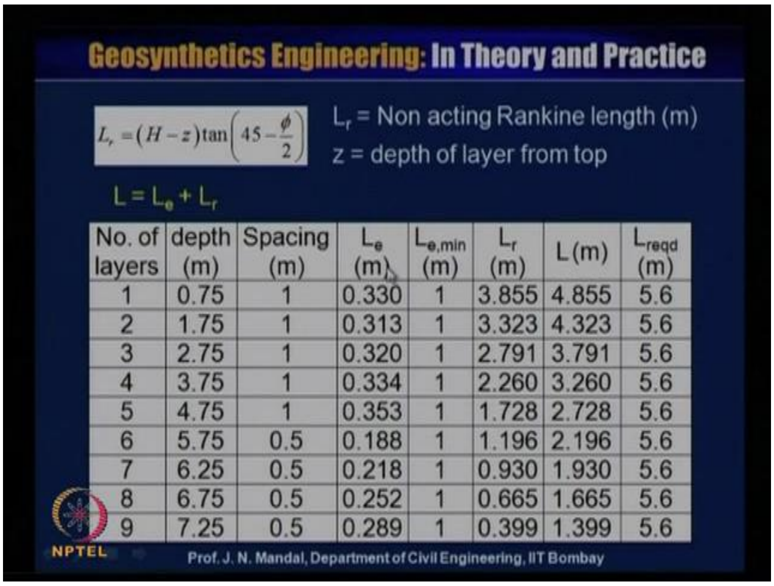

No. of layers	depth (m)	Spacing (m)	L_e (m)	$L_{e,min}$ (m)	L_r (m)	L (m)	L_{reqd} (m)
1	0.75	1	0.330	1	3.855	4.855	5.6
2	1.75	1	0.313	1	3.323	4.323	5.6
3	2.75	1	0.320	1	2.791	3.791	5.6
4	3.75	1	0.334	1	2.260	3.260	5.6
5	4.75	1	0.353	1	1.728	2.728	5.6
6	5.75	0.5	0.188	1	1.196	2.196	5.6
7	6.25	0.5	0.218	1	0.930	1.930	5.6
8	6.75	0.5	0.252	1	0.665	1.665	5.6
9	7.25	0.5	0.289	1	0.399	1.399	5.6

So, now if you substitute all this value then you can calculate the L of e, what is called the embedded length. So, you know the embedded length, then you can calculate the what is the L r, that mean non active or ranking length, so this L r, I am just showing, you that.

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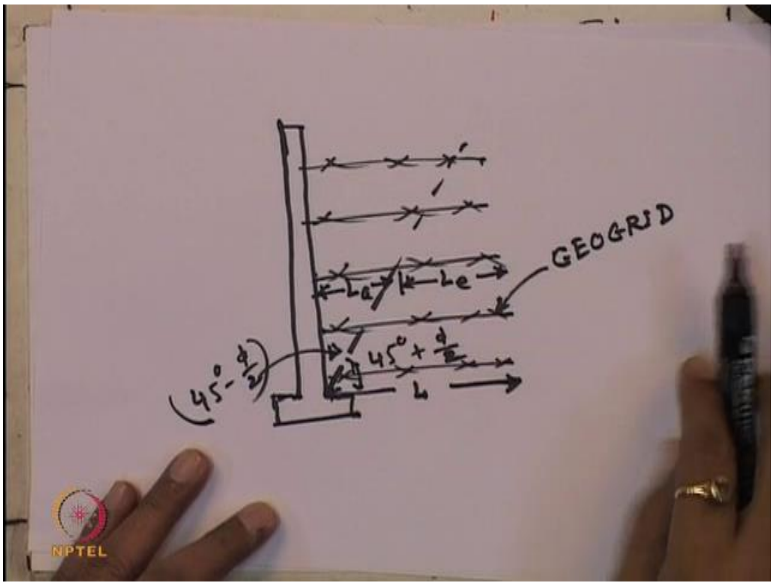

So, if this is the total length of the reinforcement is that L and this is the let us say geogrid. So, this length is equal to L of e and this length is equal to L of a, now this angle is 45 degree plus phi by 2. So, this angle will be 45 degree minus phi by 2.

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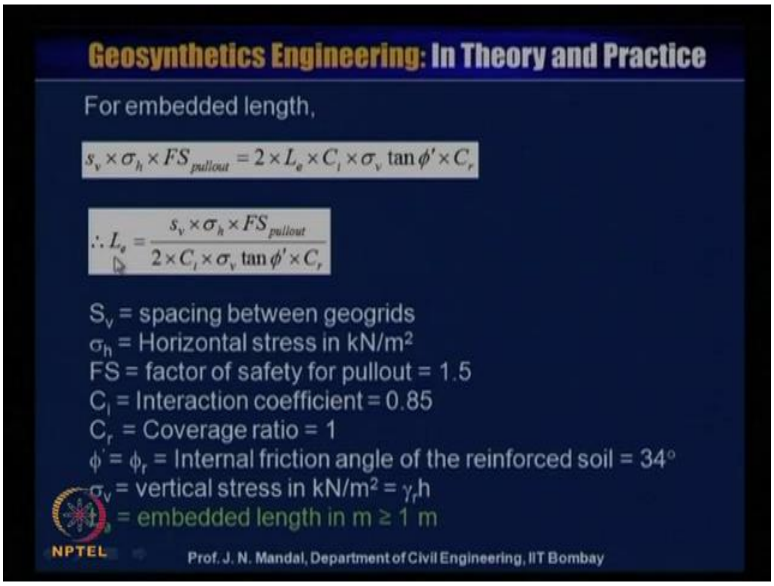

So, what we have done, that we have calculated, what is L of e, here with this equation from pullout, we can calculate that L of e. So, L e value is known, because you know all these parameters.

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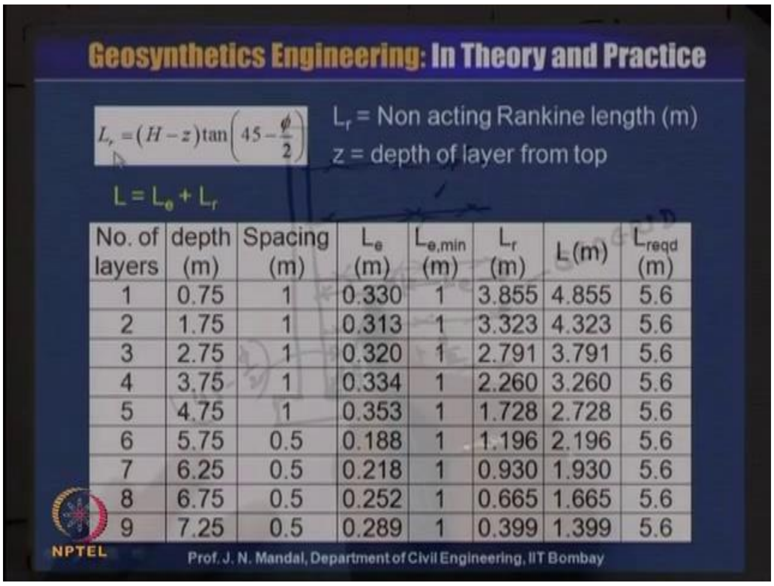

So, you have to calculate L of r ok.

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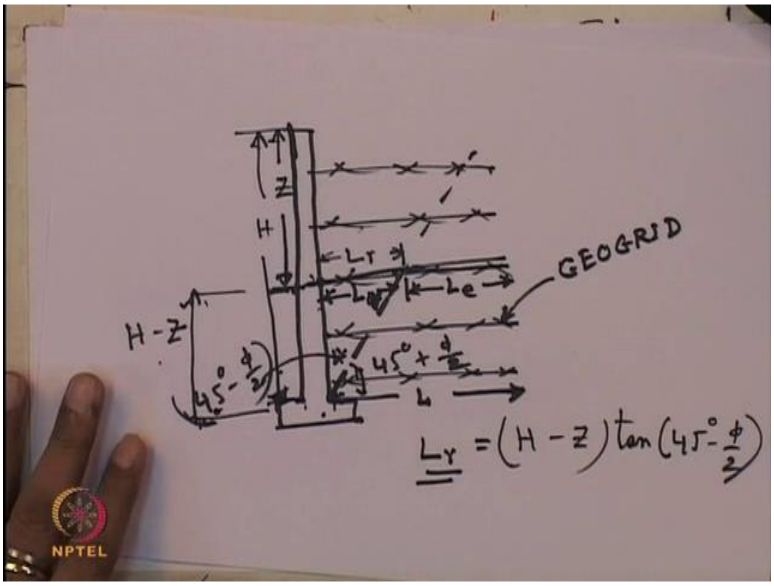

This is L r, so this L r, you have to calculate that means, if the height of the wall is equal to h. So, you are calculating at any depth, let us say this depth is equal to z, so this height will be h minus z, this is from here to here h, here to here z from where, you want to calculate this L of r, you want to calculate that means, this distance, you want to calculate.

So, this will be h minus z, so L of r will be equal to h minus z into this angle tan of 45 degree minus phi by 2. So, you can write L of r, this is equal to h minus z, this is h minus z into tan of 45 minus phi by 2, this is tan of 45 degree minus phi by 2. So, from this equation, you can calculate L r value, that is non acting ranking length at any depth, so from this equation, you can calculate.

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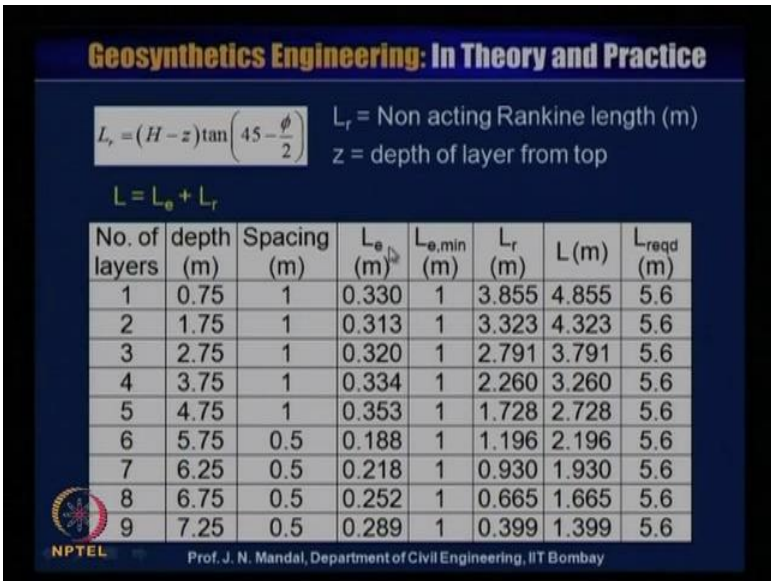

No. of layers	depth (m)	Spacing (m)	L_e (m)	$L_{e,min}$ (m)	L_r (m)	L (m)	L_{reqd} (m)
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2	1.75	1	0.313	1	3.323	4.323	5.6
3	2.75	1	0.320	1	2.791	3.791	5.6
4	3.75	1	0.334	1	2.260	3.260	5.6
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8	6.75	0.5	0.252	1	0.665	1.665	5.6
9	7.25	0.5	0.289	1	0.399	1.399	5.6

So, from this then you can calculate, the total length, that is you know L e, you know L r. So, total length can be calculated. So, here in this table showing the number of layer and this is the depth 0.75 spacing and mean vertical spacing and here may be spacing is given 1 1 1 1 and 0.5 0.5 0.5 as I shown you earlier. And then you have calculated, what is L e that is embedded length, but embedded length, you require 1 meter minimum, so L e that is why I put 1 meter and then you have calculated L r L r from this equation.

So, L r you have calculated this equation, so total length will be L e plus L r, so L e is known 1 meter L r, you know 3.85, so this plus this will give you the total length L, so you know this is the total length. But, you see that, because the height of the wall is about the 8 meter, so this 0.7 times of the height of the wall, it will be the 5.6, so therefore, L required is 5.6 is keeping constant for all the layer.

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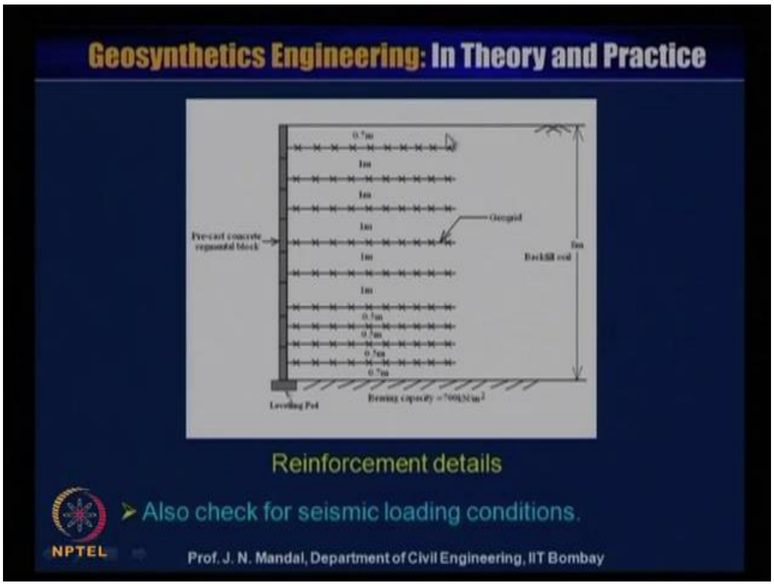

Now, here is the reinforcement detail has been shown, so this is the precast concrete segmented block and this is length of the reinforcement, that is constant and initially, you know that, how many spacing 0.5 meter up to this and then again 1 meter like this, so geogrid has been placed accordingly. Here also check for the seismic loading condition, I have already mentioned, that how to check the seismic loading condition, so you can check the seismic loading condition from this.

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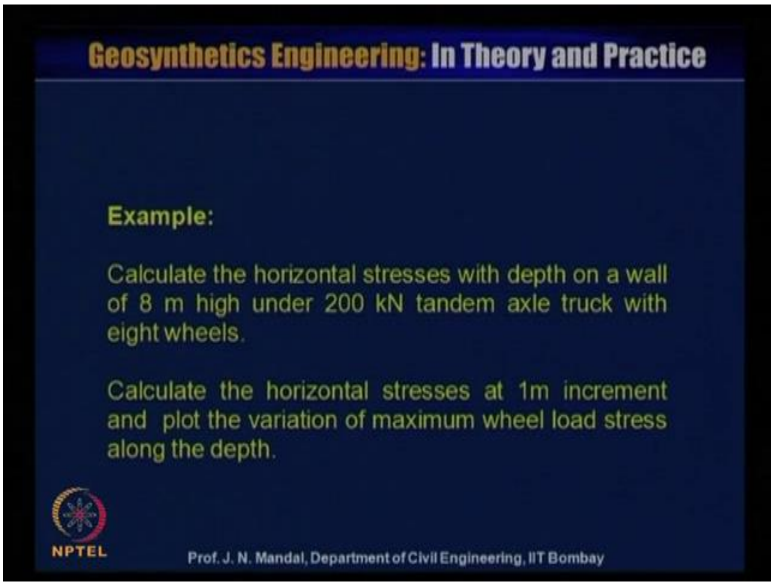

This another example that, calculate the horizontal stresses with depth on a wall, of 8 meter high under the 200 kilo Newton tandem axle truck with 8 wheels, you have to calculate horizontal stresses at 1 meter increment. And plot the variation of maximum wheel load stress along the depth, most of the time, we do not consider, that wheel load into the design for the wheel load what will be the pressure acting on the wall. Here, with this example, we will show you, how and what kind of the pressure is acting on the wall.

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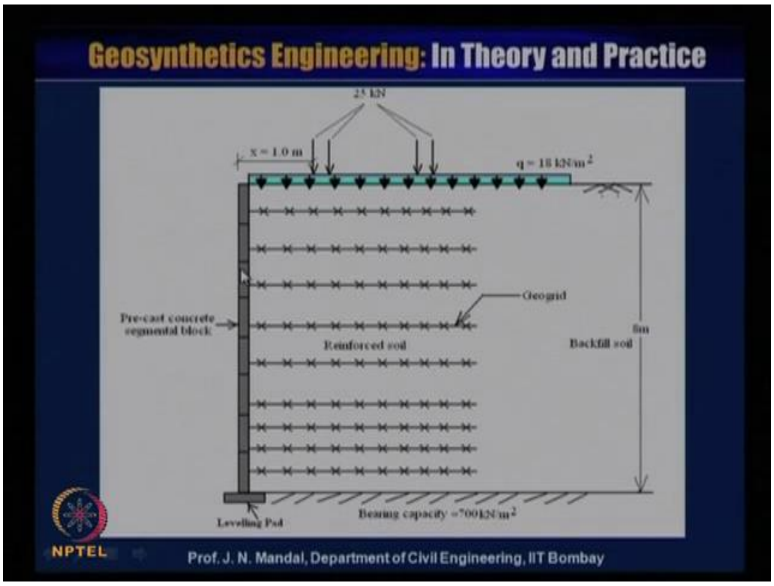

So, this is the wall, this has precast concrete segmented block, this is the layer of the reinforcement, this is the leveling pad and this is the 8 meter height wall and there is also surcharge load, this is the wheel load, you can see here wheel load and which is located at a distance of 1 meter from the spacing of this element.

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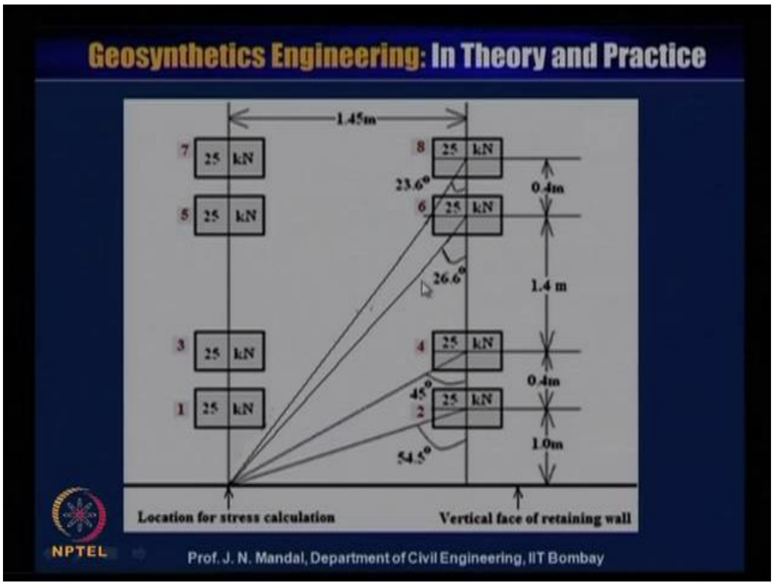

Now, what is the wheel load here, it has been shown, now this is the 200, so there are 8 wheel 1 2 3 4 5 6 7 and 8 and this is the location for stress calculation that means, this is the vertical face of the retaining wall, which is located at a 1 meter from this wheel. And because there are 200 kilo Newton, so each wheel will carry 25 kilo Newton or 25 kilo Newton and this is the configuration of the wheel from this to this distance 1.45 meter and here this distance between the wheel is 0.4 meter, this is 1.4 meter, again here there is a 0.4 meter.

And you have to calculate, that what will be the stress is here and this is located at a 1 meter from this face from the vertical face of the retaining wall. And this angle is 54, the wheel load 2, this angle is 54.5 degree, this is 45 degree, this is 26.6 degree and this is 23.6 degree.

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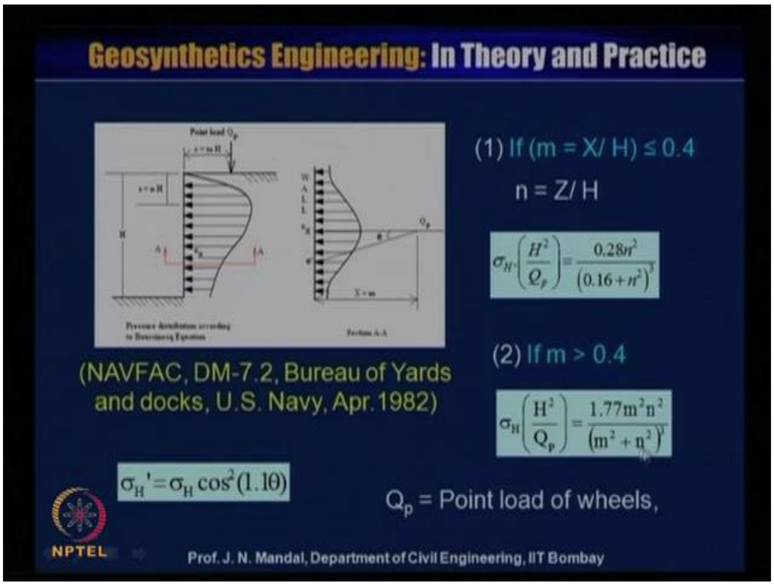

So, these are all given, so to calculate this stresses, we have to adopt some equation, that is NAVFAC DM 7.2 bureau of yard and dock US navy april 1982. So, here is the pressure distribution according to bossiness q equation and here Q p is the point load and this distance x is equal to m H and here that is z is equal to m H, this you have to remember. What x is equal to m H where z is equal to m H and point load is Q p and this is the pressure, that is sigma of H, if you take a section, you can have of section a and here Q p is the point load of the wheel at any angle theta here.

So, this is the wall sigma H, so where this is equal to x and if you want to calculate, what is the sigma of H dash sigma of H dash will be equal to sigma H into cos square into 1.1 theta. And now, it depend upon the value of m first that, you know that m is equal to x by H, it should be less than equal to 0.4, if it is a less than equal to 0.4, you calculate the n value, the n value is equal to z by H. If it is a m value x by H is less than or equal to 0.4 then you adopt, this equation, that is sigma h is equal to h square by Q p is equal to 0.28 n square divided by 0.16 plus n square, whole to the power cube.

Case 2, if the m value greater than 0.4 then sigma H into H square by Q p is equal to 1.77 m square n square divided by m square n square, whole to the power cube. So, first of all you have to calculate that, what is n is equal to z by H, also you have to calculate m, m is equal to x by H, you know at what location, the wheel is located from the face of the element.

So, you can calculate that, what will be the m value, so m value is equal to x by H, H is equal to height of the wall, similarly you can calculate the n. So, you know at what depth, you are considering z and you know H is equal to height of the wall. So, first of all you should calculate, what is m and n and then you check whether you check m value is less than equal to 0.4 or m value is equal to greater than 0.4. So, depending on that then you can select that, what will be the sigma H value that you can calculate.

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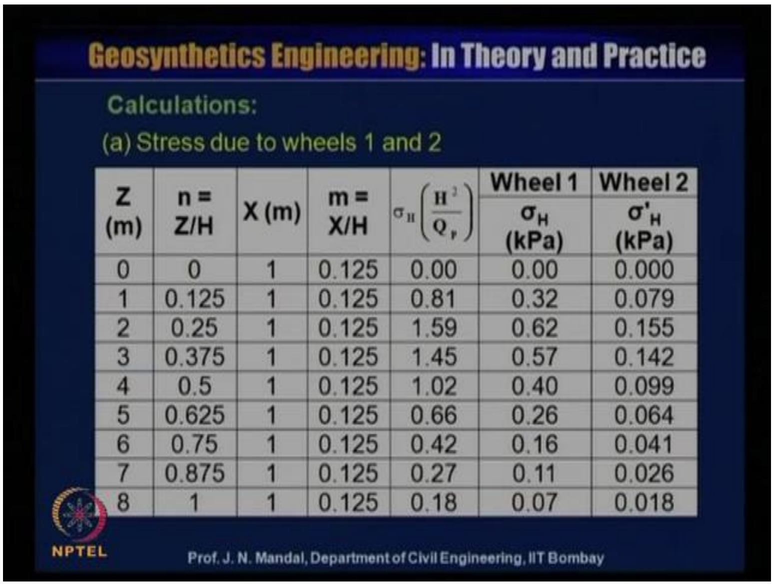

Z (m)	n = Z/H	X (m)	m = X/H	$\sigma_H \left(\frac{H^2}{Q_p}\right)$	Wheel 1 σ_H (kPa)	Wheel 2 σ'_H (kPa)
0	0	1	0.125	0.00	0.00	0.000
1	0.125	1	0.125	0.81	0.32	0.079
2	0.25	1	0.125	1.59	0.62	0.155
3	0.375	1	0.125	1.45	0.57	0.142
4	0.5	1	0.125	1.02	0.40	0.099
5	0.625	1	0.125	0.66	0.26	0.064
6	0.75	1	0.125	0.42	0.16	0.041
7	0.875	1	0.125	0.27	0.11	0.026
8	1	1	0.125	0.18	0.07	0.018

So, this you should know, now, here is showing some calculation, that is stress due to the wheel 1 and 2. So, we have considering the stress due to wheel 1 and 2.

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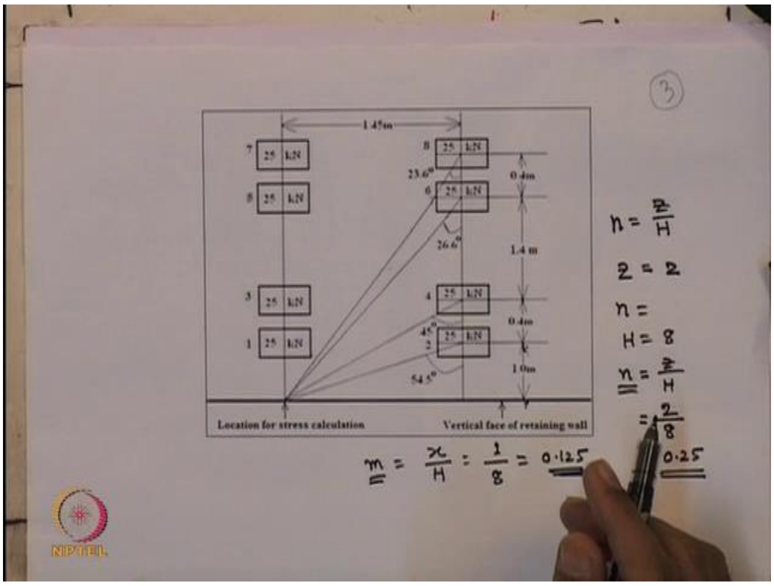

Let us say that, you want to calculate that, what will be the location for stress, this is wheel number 1, this is wheel number 2 and we know that, what will be the z, that is height of the wall this start from 1 to 8 meter height. So, you have to calculate, what will be the n value, we know that n value is equal to z divided by h, so you consider the z at different depth that means, 0 1 2 3 4 5 6 7 8 up to 8 meter, for example, that z value is equal to you are assume that, z value is equal to 2.

So, what will be the n value, because height is known is equal to 8 meter, so n value will be equal to z divided H that means, what is z is 2 meter, so this is 2, this divided by 8, so this n value will give you is equal to 0.25. So, for any depth, you can calculate that, what should be the n value and x is given 1 meter from here to here, this is x is 1 meter and you know that m is equal to x by H. So, if x is equal to 1 and H is equal to 8, so m value will be equal to 0.1250.125, so this m value is 0.125, now you check the equation.

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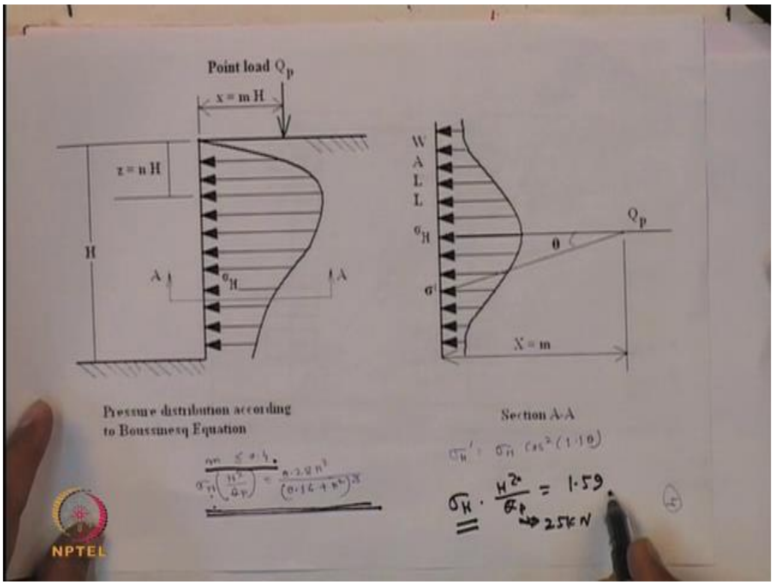

So, you check this equation, that whether m value is less than 0.4, if it is a less than 0.4 in our case m value is less than 0.4. So, you adopt this equation that means, sigma H into H square Q p is equal to 0.28 n square by 0.16 plus n square, whole to the power cube.

Now, you know what is the n value, n value is known 0.25, you can substitute n value 0.25 then you can have sigma H by H square by Q p. So, if you know sigma H into H square by Q p is equal to some value, let us say for 2, it is a 1.59. So, H is known H 8 square and Q p, you know for that wheel is 25 that is 25 kilo Newton. So, you can calculate the sigma H for the wheel.

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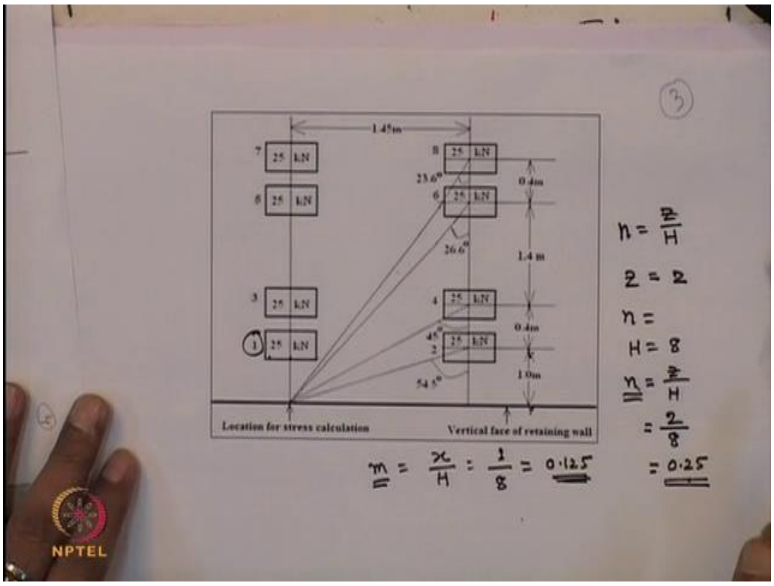

Let us say, we want to calculate for this wheel number 1, so you can calculate that, what will be sigma of H for the wheel number 1, so I am showing, you this here the chart.

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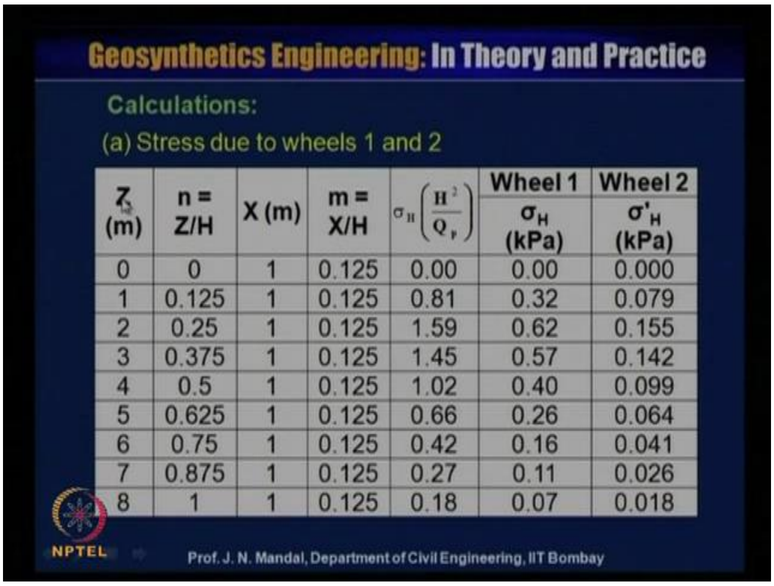

That this is the z, this is you are calculating stress due to wheel 1 and 2, so this is the z, this 8 meter height wall, so 1 2 3 4 5 6 7 8, so n as I said that z by H. So, at any depth z when, it is 2 meter I said and H is 8 meter, so z you can calculate 0.25 like this, you can calculate, what is n value at different depth and x i say this is 1 meter and then m is equal to x by H x is known height is known 8 meter. So, this is 1.25 is constant at all depth, now you know that, because this m value is less than is 0.4, so you adopt this equation.

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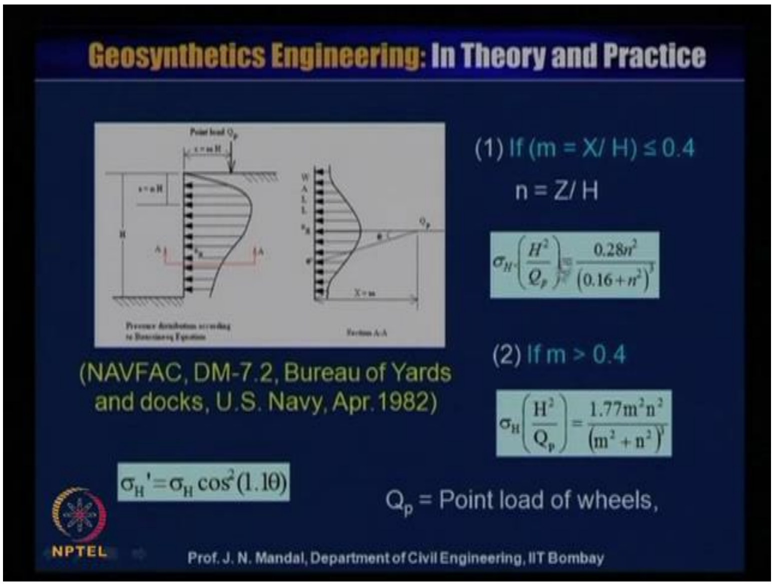

I say this equation, we have adopted that means, sigma H by H square Q p is equal to this n value is known. So, you can calculate this.

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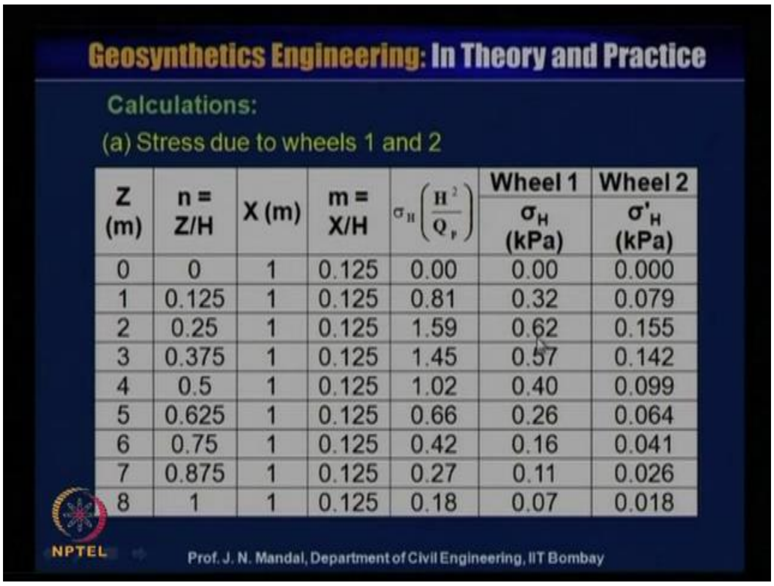

So, this you have calculated for let say 2, you have calculated 1.59, now for the wheel 1, so sigma H you have to calculate that means, sigma H will be equal to 0.62, because H is 8 and Q p is 25, this is for wheel load it is given 25, this is 25 kilo Newton Q p for wheel

1. So, when you calculate for wheel 1, this is 25, so you can calculate sigma H by H square Q p from this equation, this equation you will have some value, so you can calculate, what is sigma of h for wheel load 1, suppose 0.62.

When you calculate for what will be the wheel load 2, so wheel load 2, you can see that, this is wheel load, wheel load 2 and which is making at an angle of 54.5 degree, this is wheel load 2. Here also Q p is 25 kilo Newton and it also located at a 1 meter here. So, for this angle, you can adopt this equation, that sigma H dash is equal to sigma H into cos square 1.1 theta, so you know that what will be the theta value, this is 54.5 degree, so you know 54.5 degree, this is theta.

Sigma H is known to you have calculated from here that sigma H, so sigma H dash will be sigma H into cos square into 1.1 theta and theta is known, that is 54.5 degree. So, you can calculate, what is sigma of H dash. So, knowing this value knowing the theta value, so you can calculate this, what is sigma H dash kilo Pascal for the wheel load 2. So, I think that, you have some idea how to calculate the stress for the wheel load 1 and corresponding the wheel load 2.

So, later on we will also discuss for the other wheel load 3 4 5 6 7 and the 8 and we check up what will be the pressure and we will also check up, what would be the relationship between the depth and pressure. How it is increasing and it reach to the maximum value and then it is decreasing and what depth, it can give that maximum lateral pressure, that we will check up with this example.

So, I think that, you have some idea about, the reinforced soil retaining wall and also, we have some idea, if there is a wheel load, that also we have to be take into consideration into the design apart from the static load, dynamic load, seismic load also wheel load, we have take into consideration with this. I ended up this lecture, today let me hear from you any question.

Thank you for listening.