Ground Improvement

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Lecture 55
Geosynthetics in Ground Improvement (Contd.)

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Hi everyone. Let us continue on ground improvement class. We are almost towards the end of this lecture and today I will start 55 Module, that means your module 11 but it is 5th class, but this is 55 modules will be continuing remaining 5 classes because this is a big chapter that is geosynthetics in ground improvement.

There are various applications on which I have discussed 2-3 lectures and then as I have mentioned that I will try to go in detail, a few applications and for example MSE wall that means mechanically stabilized earth wall and about mechanically stabilized earth wall how it behaves and what is different parameters etcetera; something we have discussed and for the design purpose some more details are essential. And I will try to take up this one first in two lectures and then in the third lecture I will try to give you the design example.

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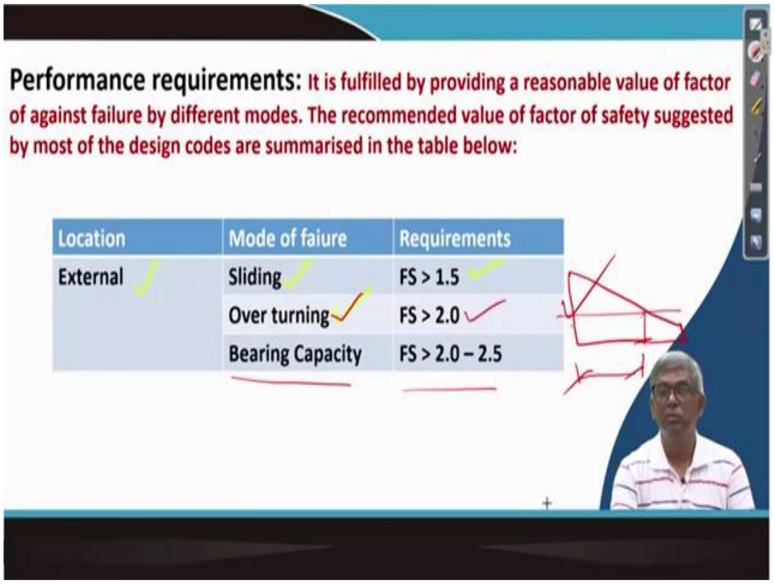

So let me start with this first slide that when we want to design something and that has to perform for a particular purpose actually for activity and for that the performance required, to perform well and while designing we have to provide a suitable factor of safety. And you can see here there are different modes of failures we have discussed before and there are external failures, there are internal failures and there are if it is external failures again there are different modes of failure there is, failure can be based on sliding or by over-turning or by bearing capacity.

If it feels external failure by sliding that means entire wall moves laterally that means the base resistance is insufficient compared to the lateral pressure developed in that case actually you have to find out factor of safety; ratio of the resisting force divided by the disturbing or sliding force that means active pressure, lateral active pressure and how to find out the resisting force; the resisting lateral force?

Actually, you have to find out the total vertical force multiplied by $\tan\delta$ will become the resisting lateral force and that resisting force divided by the lateral active earth pressure that will give you factor safety against sliding and that there actually you need at least you have to keep factor of safety 1.5 to have better performance.

So that is what it is given here; that external, the failure it can be sliding in that case FS has to be greater than 1.5, similarly, it can be overturning and this overturning can be because of that driving moment sorry that resisting mode divided by driving moment and how to calculate that we have discussed also; one second, we will discuss, and that actually if you discuss that overturning fact of safety against overturning that factor of safety desired to be greater than 2.

Similarly bearing capacity, so after the, on the wall there are several types of force will be applied and finally resultant force will act some, at some point and then because of that there may be moment or there may be either you can consider that it is eccentric force, vertical force at the base and because of that there will be moment and vertical force you can consider.

And because of that you can get the difference in pressure in two sides; both the two edges and one side will be more, one side will be less at that pressure where actually it is getting more pressure like distribution of pressure can be something like this; this pressure should not be greater than you know, the allowable bearing pressure.

Because of that you have to compare that developed pressure divided by the allowable pressure or allowable pressure divided by developed pressure that will be factor of safety against bearing capacity and to have better performance that factor of safety should be between 2 and 2.5, and ofcourse while solving this problem we can assume that the, there is an equivalent equal force of with lesser width that can be considered.

We have discussed that, one second will discuss, how to calculate that reduced weight, based on reduced weight, how to find out the pressure acting on the base that will calculate and the ultimate pressure we can calculate from the ultimate pressure, we get some factor of safety and from there we can find out allowable pressure divided by developed pressure that will give you factor of safety against bearing capacity.

So, these things actually required greater than 2 to 2.5, so that means if the designer can pick up or choose any value between 2 and 2.5, it can be more sometime. Let us take some value suppose 2.5 for our calculation we will see later on.

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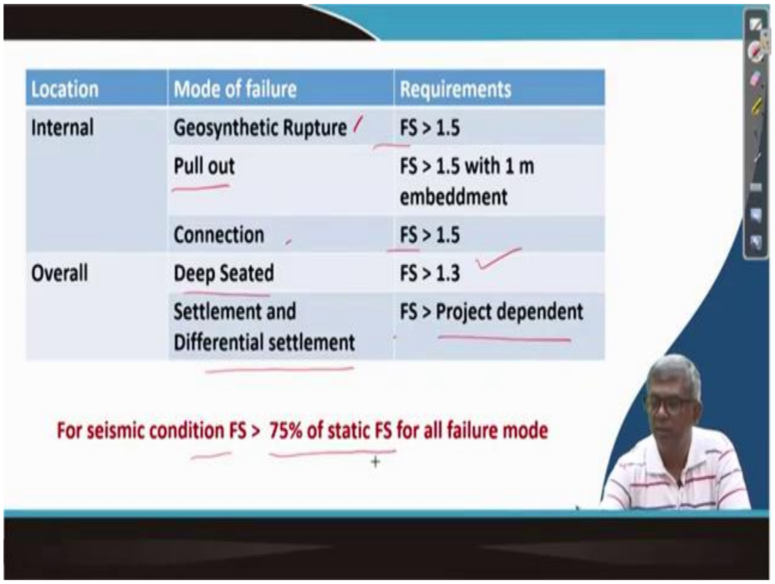

This is actually external failure, now next actually, let us see that if the failure is internal and when it is in internal failure that failure can be because of rupture, whatever reinforcement we use it can a tear actually. That is actually, so if that is the rupture, that factor of safety should be greater than again 1.5 then pull out that means rupture means because of the excessive tension this can break okay, and pull out means when the inside the soil the reinforcement the hole because of the friction.

But if the force is too much and developed friction is not that much then it will come out like this, so that is pull out. So, that factor of safety should be again greater than, greater than 1.5 with at least one meter embedment and there is again internal failure can be because of the failure because of connection and connection failure means the reinforcement finally connected the facing element by some arrangement.

And if the tension is too much that connection may fail, so there actually again factor of safety should be greater than 1.5. Now again, overall failure can be sometimes, overall deep seated then factor of safety greater than 1.3 and settlement and differential settlement again factor of safety should be greater than some value which is again dependent on project it can be 1.5; 1.2; 1.4 whatever the project recommend that value to be satisfied.

So, these are all different performance requirement but that means you have when you are design something you have to design in such a way that it gives you a factor of safety greater than some value. If there it is mentioned accordingly and if you consider the seismic loading again those values factor of safety should be greater than 75 percent of F S for static condition, double, if it is a 1.5 then point 0.75 into 1.5 that should be taken.

That is sometime question may arise, why it is less? Because we are taking earthquake load and because of earthquake since the wall is flexible, it can resist some amount of earthquake load because of that factor of safety anyway we are taking the load, so because of that factor of safety can be reduced little, so that is the logic.

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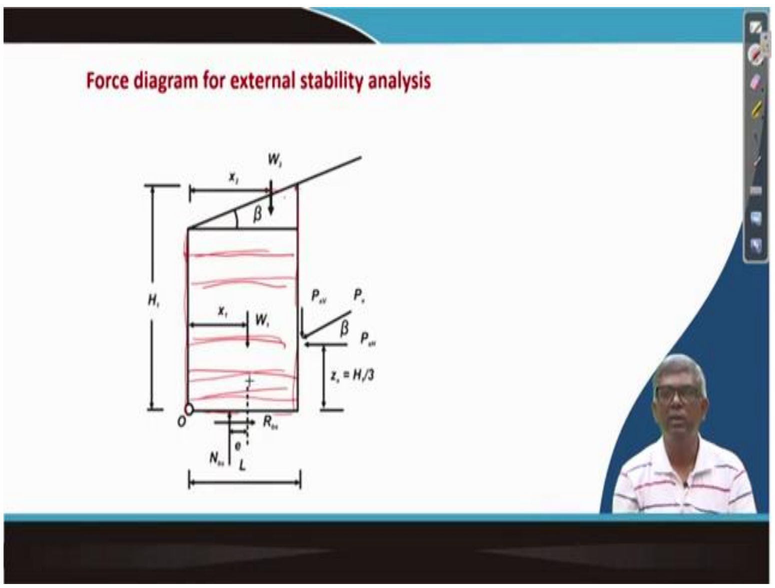

You can see here force diagram when you have a reinforced add and then that the force diagram will be like so this is the facing element actually and wall you can say and reinforcement are provided up to this is actually reinforced zone it is called and these two, this entire area can be considered as a wall and when you consider the external stability then I will calculate this as a wall.

And then the active earth pressure will act here only and for stability analysis I will consider the weight of this also, we will consider for the stability analysis and will and if you want to find out over turning then I will consider over-turning with respect to this. Then your driving moment will be because of this horizontal force multiplied by this distance and resisting moment will be because of this weight multiplied by the CG distance will be the resisting moment.

Similarly, this but this active earth pressure will be parallel to this line, we can make two components; one is vertical and one is horizontal, so this vertical force multiplied by this distance also will be the resisting moment. This is the force diagram and for the external stability analysis and I will consider the reinforcement will be from here to all through, so this is actually called reinforced zone.

And when I consider the stability, external stability I will consider this entire thing as wall active pressure I will show, though height of the wall is this but I have to consider now because of this slope at this point what is the height? That become the height of the wall. Accordingly, I have to find out point of application then I have to take Sine component and Cos component to show the horizontal and vertical component.

And this force will be considered for stability analysis like if I want to do factor of shifting and sliding then this horizontal force actually is the driving force and resisting force will be this entire vertical load multiplied by $\tan\delta$. And similarly, if you want to find out overturning then actually because of this weight, this is the resisting moment with respect to this and because of the horizontal moment this is the driving moment.

This ratio of these two will be factor of safety. And similarly bearing capacity actually I can consider now this is the foundation base and I can find out the point of application and based on that I can find out E; that is eccentricity and from there I can find out what is the effective width and from there I can find out what is the pressure on the base.

And that pressure I can compare with the allowable pressure available for this foundation and then that ratio of the two will become the factor of safety against bearing capacity. This is the force diagram we have to do for external stability analysis.

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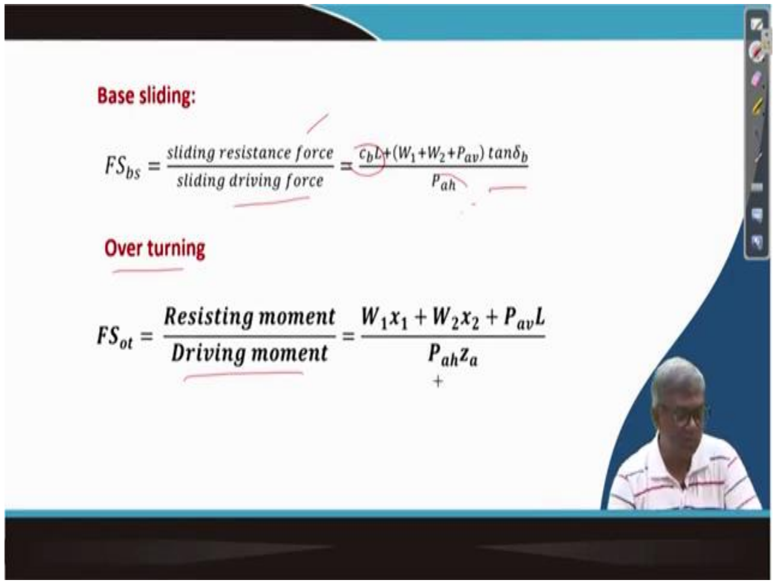

And you can see here, now, whatever I have told is written again, factor of safety again base sliding actually sliding the resisting force, sliding driving force, so sliding registration for actually will be this W_1 plus W_2 plus P_{av} $\tan\delta_b$ plus C_b into L if the base of the soil, the cohesive soil then cohesion multiplied by l will be there.

$$FS_{bs} = \frac{sliding\ resisting\ force}{sliding\ driving\ force} = \frac{c_b L + (W_1 + W_2 + p_{av}) \tan\delta_b}{p_{ah}}$$

So, if there is no question only this will be there and sliding driving force will be that horizontal force only; that active pressure which is parallel to the sloping surface but when I will take for a component that will horizontal, that will become the driving, sliding driving force. Base sliding Similarly overturning is resisting moment by driving moment, resisting moment will be W1 X1 whatever we have shown previous figure W2 X2, there are 3 forces; P a v into l and P a h into Za.

$$FS_{ot} = \frac{Resisting\ moment}{Driving\ moment} = \frac{W_1 x_1 + W_2 x_2 + p_{av} L}{p_{ah} z_a}$$

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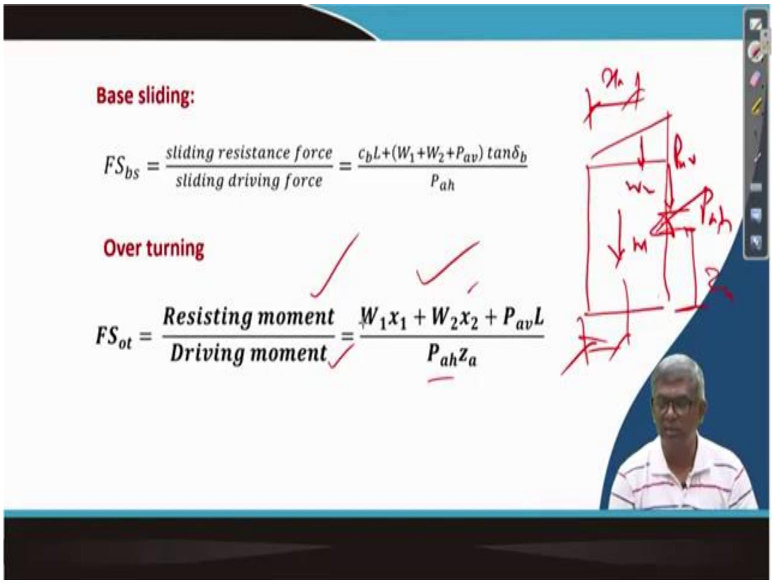

So, I can go back to the previous figure I can draw here, this is W_1, this is W_2 and this is P_{av} and this is P_{ah} and P_{ah} actually acts somewhere here which will be at some height that is p h into Za this is suppose Za. And so W_1 X_1, so this is X_1 and W_2 X_2 this distance is X_2 and this distance is Za, so then that is actually this force will be in this direction, this moment will be this direction, this moment also is this direction. Only this horizontal force multiplied by this distance moment is this direction, so this is resisting moment and this is driving moment. So, ratio of these two will be factor of safety against overturning.

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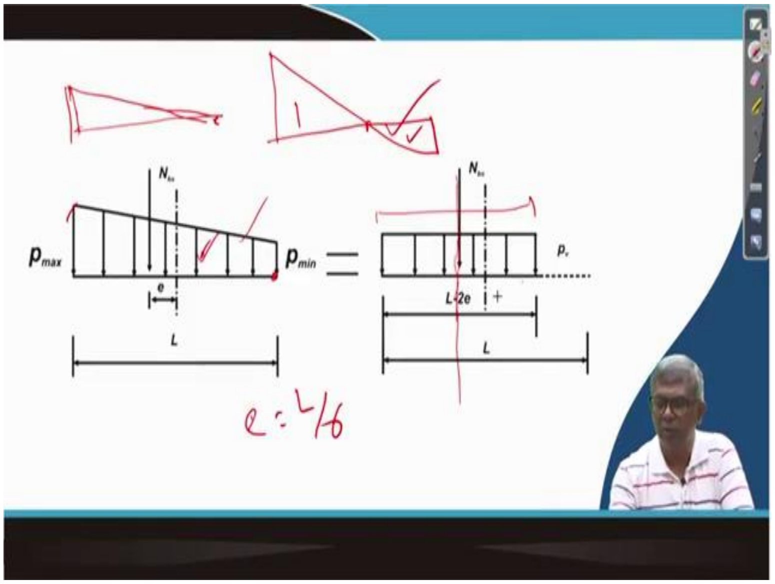

And for bearing capacity you can see as I have told you that if the force is act, force acts at some sensitivity here, then typical pressure diagram will be like this, it can have three different pressure diagrams. If you have too much of eccentricity other than that you can have another pressure diagram something like this, sorry this is zero and this is maximum and then there can be another pressure diagram something like this.

The eccentricity is too high then it can become negative that means we cannot have, no contact less also sometimes, so it is tension this is a compression. If the eccentric value, eccentricity value is too large then pressure diagram can be like this, otherwise the expected pressure diagram like this should be throughout constant, sorry compressive. And limiting value is actually; when E will be such that it this point will become zero, this will be maximum and this point will be.

That limit value actually can be obtained at E equal to l by 6, if this l by 6, if the eccentricity is l by 6 it become exactly 0. Now, that, this is the pressure diagram but this pressure diagram if I want to do little complication will be there, so very simplified way we can do it actually what we can do; if the eccentricity is E, then I can assume, so this is the eccentricity, so with respect to these I consider this as a center.

And then I want to make a symmetric, then this distance, this distance will become l minus 2E, this distance, so this (minus) this distance will become l minus 2E, so that is called effective foundation width. So, l minus 2E, so total force is acting through this if I assume and over this much area then I can find out some average compressive pressure and that is suppose pressure acting.

And then what is the allowable pressure? Based on the phi value I can find out q equal to CNC plus Qa plus half gamma b n gamma and then applying factor of C2 I can that, allowable bearing pressure, that allowable pressure bearing pressure divided by the developed pressure will give you the factor of safety against bearing capacity. So that is what we have to do. We will discuss again while seeing, while solving problem this this part, how to do it.

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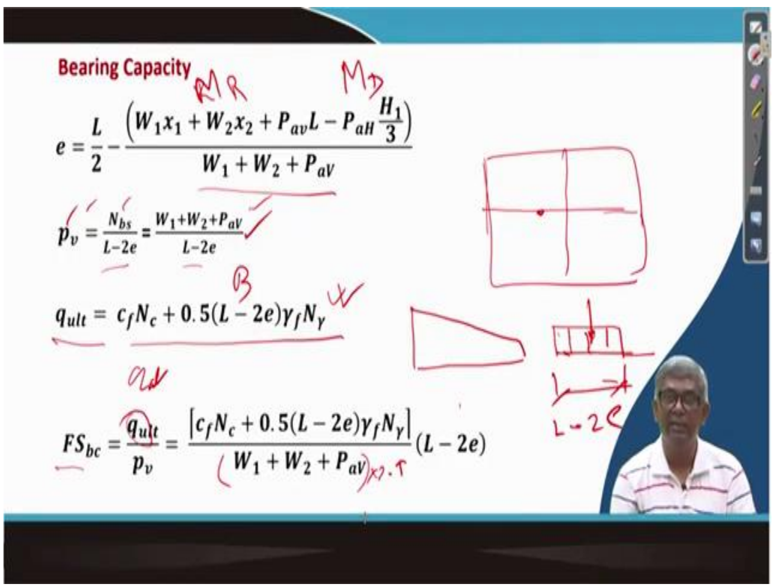

And you can see the calculation of eccentricity; how to find out eccentricity? This is our l by 2 that means this is the l and this is eccentricity, so this is the foundation suppose, this eccentricity will be and then different forces; W_1 X_1, so this is actually resisting moment MR and this is actually MD, MR minus MD divided by total vertical force, so l by 2 minus this will be actually eccentricity.

$$e=\frac{L}{2}-\frac{\left(W_1x_1+W_2x_2+p_{av}L-p_{aH}\frac{H_1}{3}\right)}{W_1+W_2+p_{av}}$$

$$p_v=\frac{N_{bs}}{L-2e}=\frac{W_1+W_2+p_{av}}{L-2e}$$

$$q_{ult} = c_f N_c + 0.5(L-2e)\gamma_f N_\gamma$$

$$F_{sbc} = \frac{q_{ult}}{p_v} = \frac{\left[c_f N_c + 0.5(L-2e)\gamma_f N_\gamma\right]}{(W_1 + W_2 + p_{av}) \times 0.5}(L-2e)$$

And then pv that means whatever average pressure you can prefer, so that is what actual pressure will be like this but I want to find out the actual width is this, I want to find out an effective width, so that is actually l by, l minus 2E which is shown in the previous diagram, so that means I want to find out the P_{av} that is nbs the total normal force divided by l minus 2E.

And of course, other direction is 1, unit weight, unit width is taken, so nbs is how much; is summation of the vertical forces W_1 plus W_2 plus P_{av}, so whatever I have shown pressure the force diagram from there actually total vertical force will be W_1 plus W_2 P_{av} and it is acting over l minus 2E from there I can get p v and q ultimate I can get from this equation.

Again, here that supposed to be b of width of the footing but since it is reduced to it, so I can take as l minus 2E whatever I have taken here and accordingly I will find out ultimate pressure and then applying factor of safety I can find out allowable pressure. Then allowable pressure also should have some factor of safety that is what, so let me see actually, it is not q ultimate better you can have q allowable divided by p v.

And, this and divided by multiplied by 2.5 actually I can do because this should be allowable by 2.5. This is the way, so this problem it can be understood quite clearly when I will take the problem, okay.

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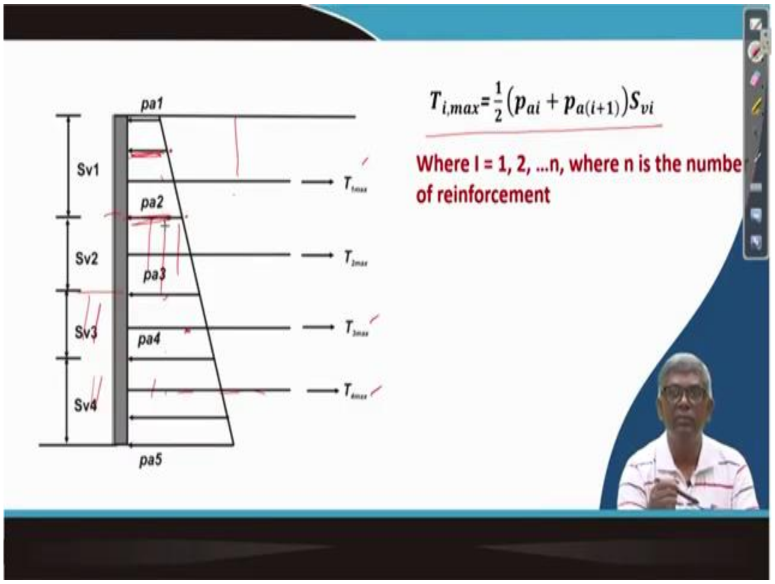

Here actually I have to find out internal failure, so you can see here, if this is the reinforcement 1, these are reinforcement 2, this reinforcement 3, this is the reinforcement 4, then you can see that tributary area of this enforcement will be this distance sorry this distance plus half of this, so this is SV1.

$$T_{i\max} = \frac{1}{2}\left(p_{ai} + p_{a(i+1)}\right)s_{vi}$$

where I=1,2,.......n, where n is the number of reinforcement

And then again from here to here, this will be SV2 that means this portion whatever force is coming it is resisted by this enforcement. Similarly, this portion whatever force the lateral force is coming resisted by this reinforcement these reinforcements. Similarly, the SV 4 that means within this zone whatever force is coming resisted by this reinforcement. So T1 max, T2 max, T3 max, T4 max, so Ti max can be will be, so we can find out actually.

We can find out at this point what is the pressure at this point, what is the pressure then average of that value actually will be the pressure here. So that way we can find out. This is pa2; pa,1 pa2, pa 3, pa 4, pa 5 so like that we are doing and typically this equation if you want to find out then how to find out t1 max? You find out before and after and then half of that.

So before, before this reinforcement you find out the pressure, after this reinforcement you find out the pressure, so the average of these two will be the tension on this, on the reinforcement or okay, this is not, so since is a bottom, you can take here itself. This average of this, oh-no; actually average of this and this has to be taken, that is okay.

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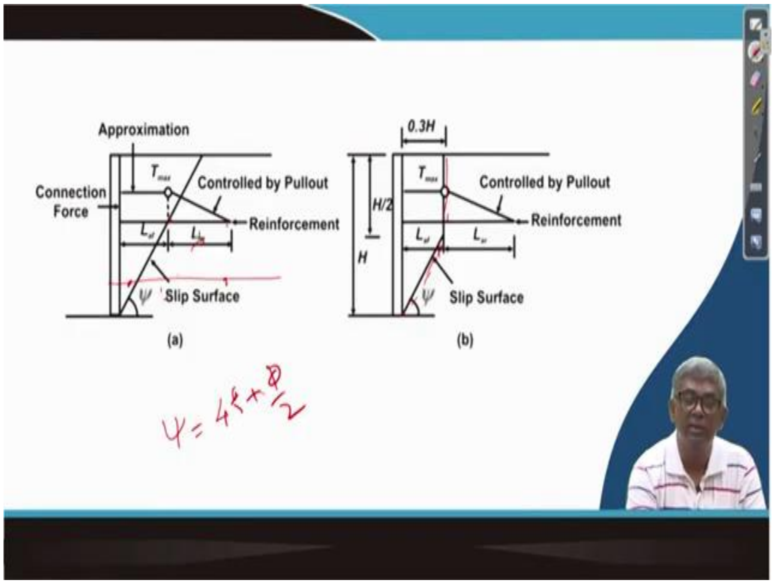

And then I think I have discussed that the failure surface typically in regular retaining wall we have taken that the linear sliding surface and that and has having angle phi psi equal to 45 degrees plus phi by 2 but when it is a geosynthetics reinforcement, same assumption can be made, whereas in when the strip then it is actually up to some distance you can take this then it will be constant over some depth actually.

It is not linear actually, it will be curved, actually it is a curve but it can be approximated in linear with psi here up to this and then constant. This is the way you can consider and then if I know this, this is the failure surface and then if I provide how much length has to be provided beyond failure surface, this is the resisting zone only, resistance developed from there only so how much distance; so that is called La R, that is resisting length.

And this is actually AF that is actually another within failure surface that length, so total length required would be this length plus this length. Similarly, here if I know this length plus this length, so like that I have to find out and accordingly we can find out how much; if I put this much length how much resistance is developed that we can calculate by applying some formula, so we will discuss that again.

So, first of all if it is geosynthetics, you assume a failure surface and that value surface angle will be 45 degrees plus phi by 2, phi is the friction angle of the soil. And then I have based on the position of the reinforcement, how much length is required; you can find out or you provide the length initially and calculate resistant force and then find out what is the factor of safety available.

And if the factor of safety is reasonable then that can be the design. So, 2-3 trial that can be done like this. Generally, design is done, we assume initially the length of the reinforcement and so that the factor of safety is satisfied. And when it is a metallic strip or reinforcement is used then we can have the pressure diagram like this, accordingly if I put a reinforcement something like this then this will be the within failure zone and this will be within resisting zone. This length will be considered to find out the resisting force.

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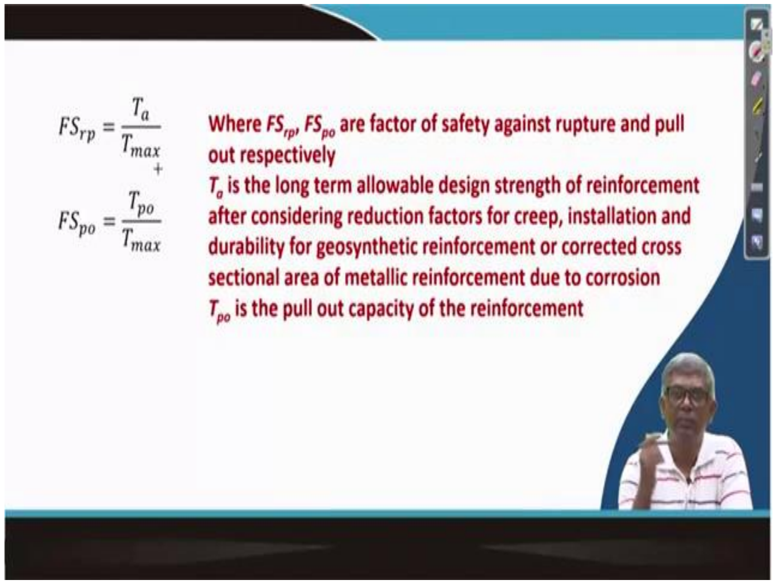

And then factor of safety against rupture and you can see here that Ta divided by T max, so t allowable tension along for a particular material if you use how much level strength you know T max what is developed and f s factor of safety against pull out; so Tpo divided by T max, so how much is the pull out force and divided by how much is the T max; so here actually you can see where is FS rp, FS po are factor of safety against rapture as pull out, t is the long term available design strength of reinforcement and Tpo is the pull out capacity of the reinforcement. This can be calculated.

$$FS_{rp} = \frac{T_a}{T_{\max}}$$

$$FS_{po} = \frac{T_{po}}{T_{\max}}$$

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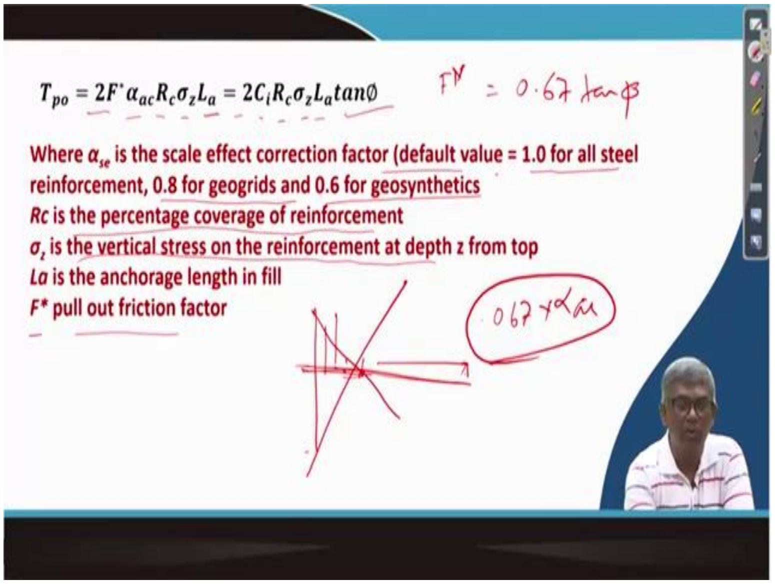

And, so Tpo, how to calculate? There is a formula given here, tpo actually 2 f star alpha ac Rc sigma Z la and f star actually I will show you one figure there actually approximately 0.67 tan phi r or something is taken, so if I substitute this one then this can be written and rewritten as 2Ci Rc sigma Z la tan phi, so Ci actually is nothing but 0.67 multiplied by alpha, alpha ac, so these two together actually Ci.

$$T_{po} = 2F^* \alpha_{ac} R_c \sigma_z L_a = 2c_i R_c \sigma_Z L_a \tan\phi$$
$$F^* = 0.67 \tan\phi$$

So, here actually you can see the scale effect correction factor default value 1 for steel reinforcement, 0.8 for geogrid, 0.6 for geosynthetics, Rc is the percentage coverage of reinforcement, generally 100%, if it is 1; sigma j is the vertical stress on the reinforcement. If I have a wall and if I want to find out pull out at this level, so that means I have to find out what is the vertical stress at this level.

And then La is the anchorage length, so this is maybe this is the length of the reinforcement but the anchorage length is this which is beyond the sorry failures are, beyond the failure surface that length to be considered and f star is a pullout friction factor.

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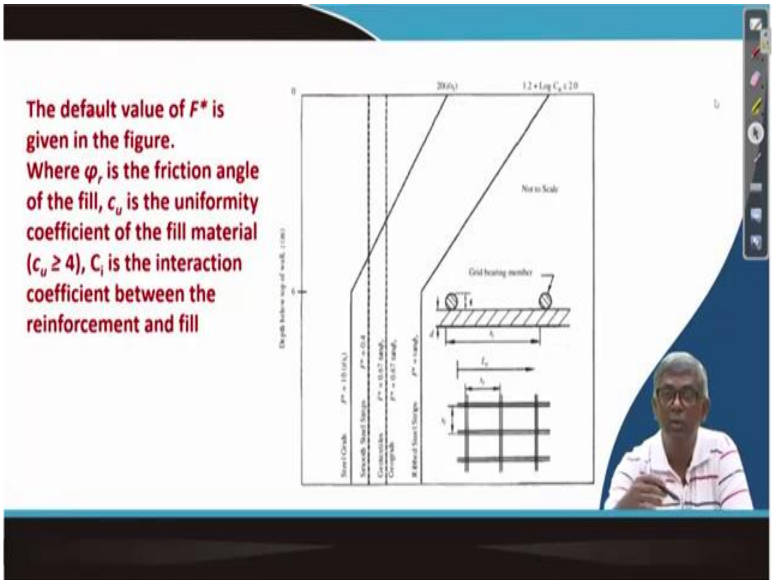

Here actually, the f star whatever we have shown some friction factor that is actually given, so some recommendation is there a you can use, you can see here that when it is a (geosynthetic) geogrid f star actually 0.67 tan phi r, f star 0.67 tan phi r.

Whereas a smooth steel strip then again this is f star actually 0.4, constant and what is the steel grid actually; f star equal to 10 T by St so here T St what is shown in this figure and when the rib steel strips then again f star equal to t tan phi r, so here actually what it is actually given here, so based on that one can decide otherwise it will be given actually, designer, it will be given to the designer what are those and something this can be used.

Somewhere it is available, but now most of the text it is not available, it is available in only in the hand book actually which I am referring right from beginning, I will again give you the details in the may be next class and so this is the one can be used for the for calculation of tpo whatever different parameters I have already explained, f star is explained through this diagram.

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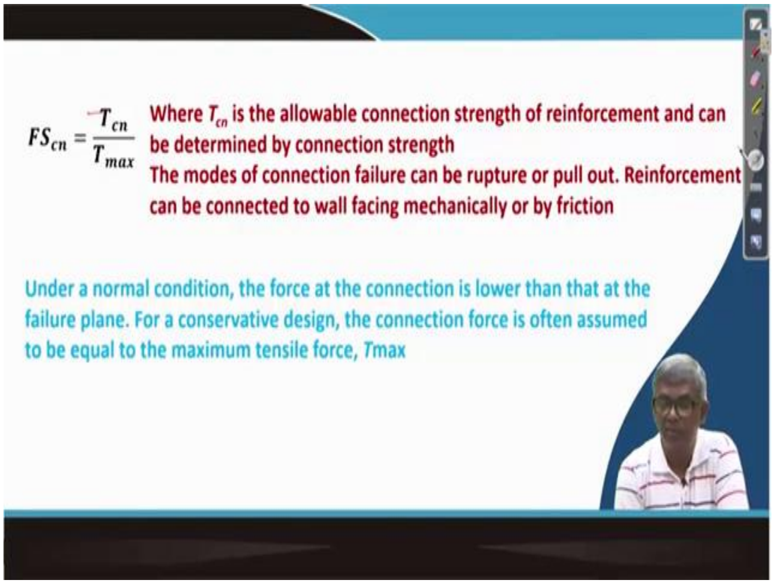

And then FS and the connection failure Tcn by Tmax so this is a connection force and t max, this will be the connection fails then this is there also. Under a normal condition the force at the connection is lower than that at the failure plane for a conservative design, the connection force is often assumed to be equal to the maximum tensile force, Tmax and with this actually there are different design aspect I have discussed on the under this module.

$$FS_{cn} = \frac{T_{cn}}{T_{\max i}}$$

And again, some more discussion, some more things are there, so I will take another lecture on it and then I will give you the design example. I will close here. Thank you.