Ground Improvement
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Lecture 56
Geosynthetics in Ground Improvement (Contd.)

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Hi, everyone. Once again let us continue on Ground Improvement lecture. We are discussed about geosynthetics in ground improvement. We are also discussing about the in-detail design of MSE wall using geosynthetics. Geosynthetics or strip, anything, both metallic or geosynthetics geogrid, anything it can be, it is a general design. And there is little deviation while designing. You have to appropriately pick up, choose the appropriate values and complete the design.

In the previous lecture I have given so many performance requirements, that means different types of factors of safety, what it is, how to calculate, what is the meaning of different aspects. We have discussed now. Some more aspects, actually, there are we have discussed failure, about external failure, internal failure.

And that external failure, actually, that we have shown that factor of safety against sliding, wall turning and bearing capacity. Internal, actually, rupture, pullout and connection failure. And other than we have also discussed in the beginning that there are local failure and there can be overall failure. So those things actually we will try to discuss.

We will not do much. Only, I will make some remarks and maybe global failure analysis if you want to do, that is like slope stability analysis, which we are not doing right now. I will just make some remarks there. And then we will proceed, for something else.

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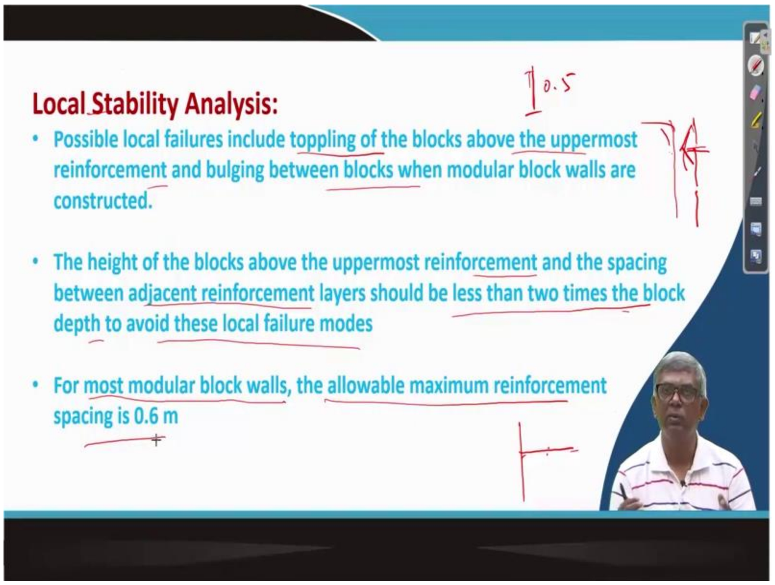

So let me go to the first slide. You can see we have mentioned external stability and internal stability, now, there are local stability analysis. Local stability analysis means exactly what? what is a local failure? Local failure is, one is toppling of blocks above the uppermost reinforcement that means, if you have the wall and there maybe one or two things are topple there.

And the bulging bit in the blocks when modular blocks, so there maybe, the blocks are connected, one block again connected to another block, then another block, and because of some problem there may be some bulging here. That means this comes like this and this comes like this. And when this bulging occurs then it may fail here.

That is actually, possible, local failure actual one is toppling, one is bulging. So how to avoid that actually? The height of the blocks above the uppermost reinforcement and the spacing between the adjacent reinforcement layer should be less than two times the block depth. The block depth means there is a, suppose there is a unit, or particular block, the number of units we connect and make the wall. So, this is the box, so this is the depth of the block.

The uppermost reinforcement, the height of the blocks above the uppermost reinforcement, that means this is the uppermost reinforcement, and height of the block above this reinforcement should not be, reinforcement and the spacing between the adjacent reinforcement, that means this is the wall perpendicular, this is perpendicular to this and this is the one layer of reinforcement.

Similarly, there, on some distance there will be one more, then some distance some, one more, then some distance, there is one more. So that is called spacing, horizontal spacing. The height of the block above the uppermost reinforcement and the spacing between the adjacent reinforcement layer, these two, these, so this is one and this is one, so spacing between these two should be less than two times the block depth.

So, if it is supposed 0.5 meter, it should be less than 1 meter. Then spacing should be less than 1 meter. And also, above the last layer it should be less than 1 meter to avoid this local failure. This is the requirements. If you follow this, this may be avoided.

And for most modular, modular blocks the allowable maximum reinforcement spacing is 0.6 meters. So that is what, so because of that, the modular blocks, what is the depth is known and accordingly the spacing is fixed. Most of the cases it is 0.6 approximately. So that way if I do then the bulging and local failure can be avoided.

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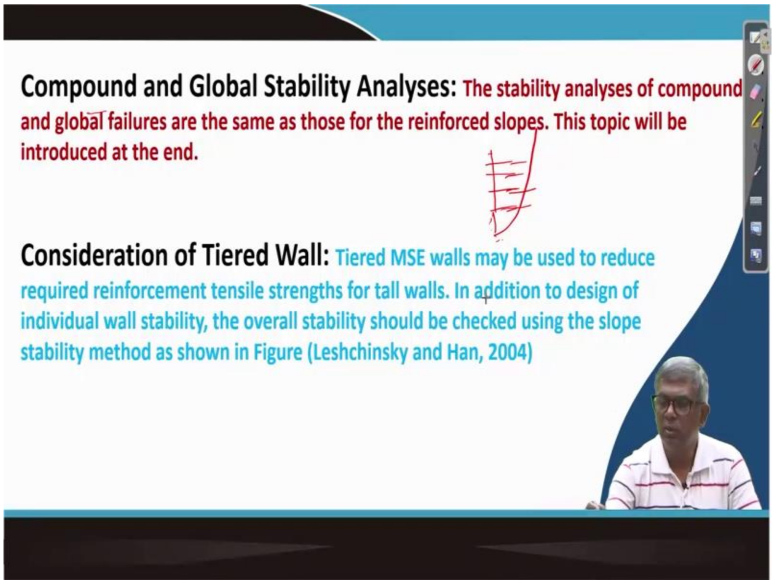

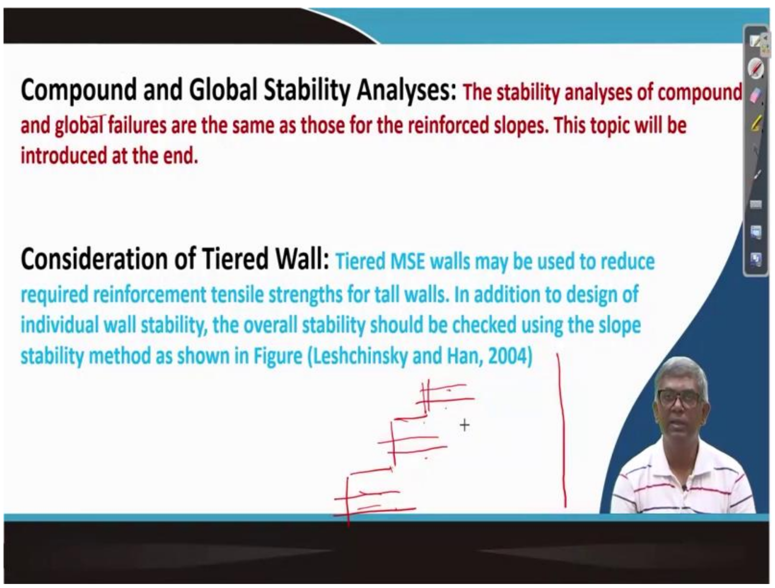

The compound and global stability analysis, compound means there may be, I have mentioned perhaps sometimes, there is a wall and reinforcements are like this and, or maybe like this, and maybe like this, like this, and failure may occur sometime, something like this, some more, some are there some are not here, actually, not, reinforcement is not in the resisting zone. So that can be there.

So, this type of different combination of all those things. We have to consider the failure surface and then accordingly you have to do some analysis like almost like a slope stability analysis, that is what we have mentioned here, stability analysis of compound and global failures is the same as those for the reinforced slope, which actually we have not discussed yet. We will, if I get time, I will give us some introduction to that.

So of course, we are not doing that. It is quite in rigorous, this analysis. We are, in a classroom, it is difficult. Then we are avoiding that. Otherwise, this has to be done to make the overall safety of the structure.

Next is consideration of tiered wall. So, this is actually, tiered wall means actually step, stepping. Instead of making a very high wall like this, and in that if I design the reinforcement, on the reinforcement, tension will be quite high, and the reinforcement length also will be quite long, so to avoid that this wall can be designed something like this. I can have something like this, one wall, then I can go like this, I can go like this there.

So, like this I can do. I can have reinforced wall here. So here, if I do this, then for on this reinforcement, this is the wall height, for this reinforcement, this is the wall height, for this reinforcement, this is the wall height. This way, tension on the wall will be reduced. And also, length of reinforcement also reduced.

Of course, if you have this much space, otherwise this is difficult to do. If you have space to make more stable MSE wall, this tiered well can be designed. So that is what we have mentioned here.

You can see here the tiered MSE walls may be used to reduce required reinforcements tensile strength, that means, the required tensile strength of the, but then we have too thick and too wide strip, or too strong geogrid you have to use. To reduce that, actually you can do these tiered walls.

And in addition to design of individual wall stability the overall stability should be checked using the slope stability, that means when I have this stepping, then again, I have to consider a slope stability type of thing. I will just show you in the next slide.

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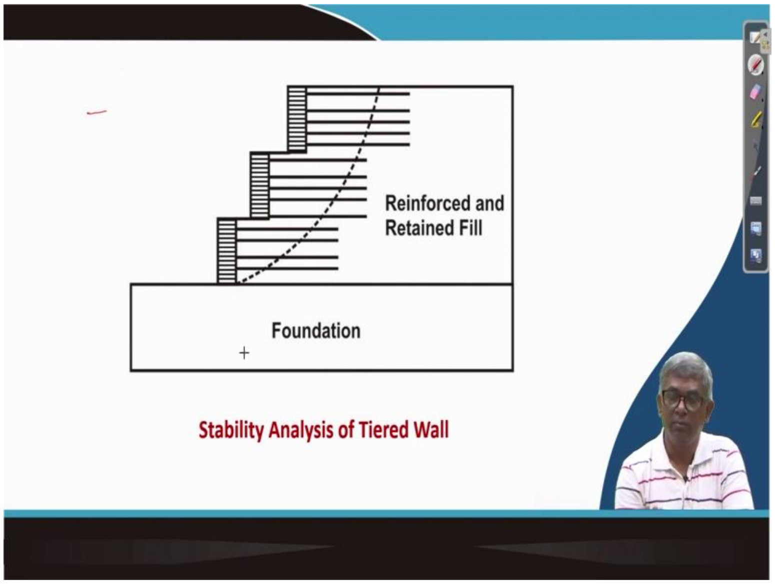

You can see here this is the exactly, or the typical tiered wall. This is the foundation, then we will go up to this with reinforced wall, then I will be, again make another reinforcement wall little away, and then this will be the reinforcement detail, then this is the reinforcement, this is another wall, again, or starting from here this is the reinforcement.

So now if this is the wall there is a likely that, the possibility of failure somewhere here or somewhere here. The way we do slope stability analysis, this is, this also has to be checked. This is the typical stability analysis of tiered wall. This is the way actually to be done. We assume failures surface and then consider different forces and then find your resisting force, finding out the driving force and then finding out the factor of safety of, of the slope failure.

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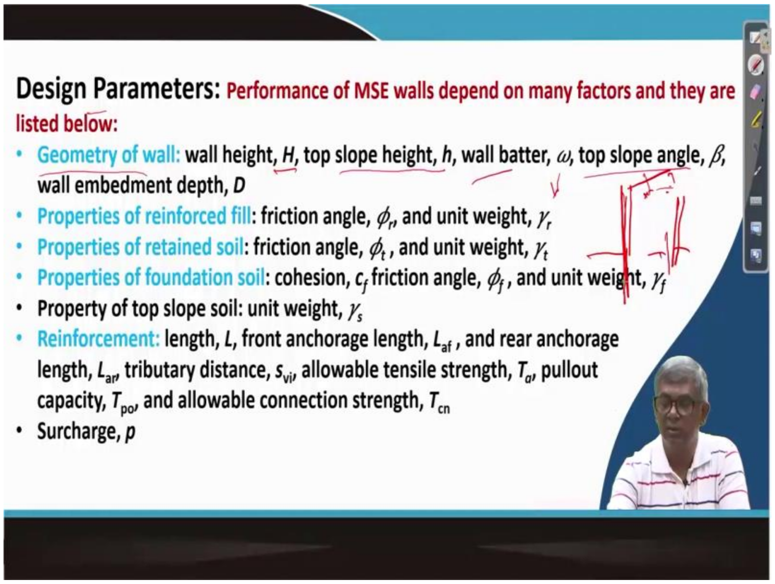

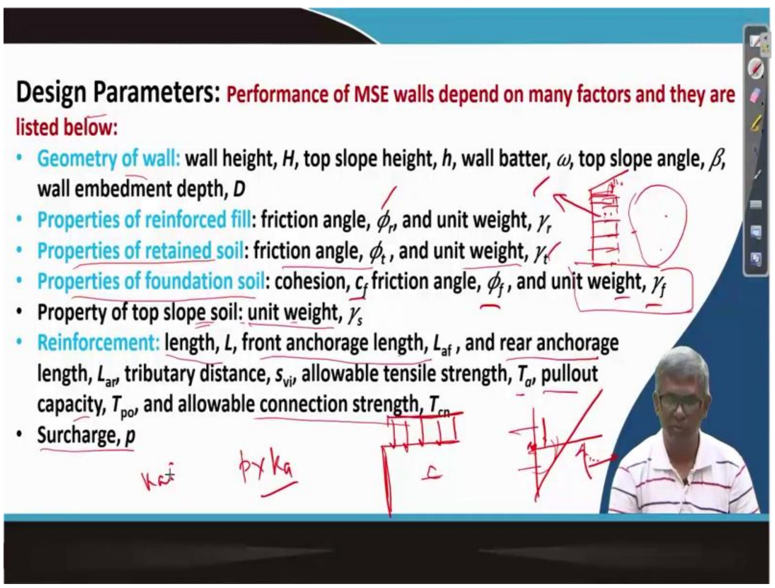

Design parameters. we have discussed so many things, now how to design the reinforced earth, MSE, mechanically stabilized earth wall, and here actually, performance of MSE walls depend on many factors, and, and they will be, they are listed here.

And you can see here that some properties are related to geometry of the wall. Geometry means what is the height of the wall, that is required, what is the top slope height, that means if the wall is something and then this slope, and what is the height of top slope height, actually, maximum, that is, h. Then wall batter, that means this is vertical, but most of the time MSE wall will be little inclined towards backfill, like, like typically something like, this something like this. This angle moved to vertical will be 15, 20°.

And then, that is denoted as omega (ω). Top slope angle that means, this angle, this is denoted as beta (β) and wall embedment depth, that means this all, in the, how much, from where, from started, it should not be started, started from the ground level. Then, only then sliding et cetera will happen very easily. It has to be embedded. Foundation should be start from some depth. So that, what is the depth of embedment, that is also required for the design.

Next is related to properties of reinforced fill. There are two, there are two fills. One is reinforced fill, and there is a retained soil. So that means, if this is a reinforced wall and suppose like this, the reinforcement will be like this, like this, like this. Then reinforcement has got, extended up to this. So, within this reinforcement, this portion, the soil, is called reinforced, properties of reinforced fill, this is a reinforced fill.

So, this is a reinforced fill. That, this fill actually reinforced, whatever material is there, sand or silt or, generally sand and silt, clay cannot be used in the MSE wall, so that, this material will be, how can we characterize? It should be of Φ_r and gamma (γ). So, cohesion (c) shall never be used. If there is a cohesion also, it has to be ignored. Φ_r and γ_t is essential.

Another is properties of retained soil, that means, as you have mentioned that when you do the external stability analysis then this becomes the wall, and then this soil will become the backfill. This is actually retained soil. There properties required. What is those property of retain soil be? Again, Φ_t (phi t), and unit weight, gamma t (γ_t). And c can be there of course, foundation soil sometime can be, c can be there.

And properties of foundations soil. If this is the wall then this, below this, this is the foundation, and this foundation soil can have also, can be characterized by c, cohesion, phi (Φ) foundation, then (γ) gamma foundation. So then three-character properties actually, cohesion, friction and unit weight.

Then property of the topsoil. This is the topsoil. Again, this may not be same as foundation soil, may not be as same as retained soil, may not be the same as the reinforced soil. It may be something else. If it is same then, same value can be taken. If it is different, their property has to, so property of topsoil, that means unit weight (γ_s) gamma s only is required because only, you have seen that for external stability analysis, this weight of this portion weight we are concerning. Otherwise, it is not required.

Then reinforcement, that properties of reinforcement, means what are the reinforcement properties required, what is the length, that is required, front anchorage length, then rear anchorage length, L_{ar}, front, anchor, that means, this is the wall, and this is the failure surface, and this is anchorage, then this is L_{af}, and this is L_{ar}. This is anchorage zone, and this is anchorage length, front anchorage length it is called, and this is rear anchorage length, and so L_{ar}.

And tributary distance, that is S_{vi}, that means if this is the reinforcement, up to what distance the, it will be taking the responsibility, actually. So, if there are number of them, so the, if I, if the level of reinforcement is here, so there is another here, there is another here, so between these two 50% has to be taken by this, 50 percent taken by this. Half of this, half of this, that is S_{vi}, that means vertical spacing.

And then allowable tensile strength T_a. What is the tensile strength of the reinforcement? Pullout capacity T_{po} that has to be actually, that is actually depend on soil and reinforcement, and the allowable connection strength, T_{cn} that means it is connected here, what is the connection strength.

And then finally, surcharge P. So sometime the wall maybe something like this, and because of this equipment movement and etc. so sometimes you have to consider some amount of surcharge here so that actually values, is this is wall, and over that there is a surcharge ‘p’ can act. So that has to be considered in the analysis.

When this ‘p’ is acting, then what will be the lateral stress? That will be p multiplied by K_a. And K_a, when we do analysis for external analysis, that is K_a, and when we do internal analysis, that is K_{ai}. Two types of artificial coefficient we have discussed, and we have given equation K_{ai} and K_{ae}. And that can be used. So, and based on that you can find out what is the lateral pressure. Whether, when it is K_{ai} internal, into p, when external K_e into, K_{ae} to p.

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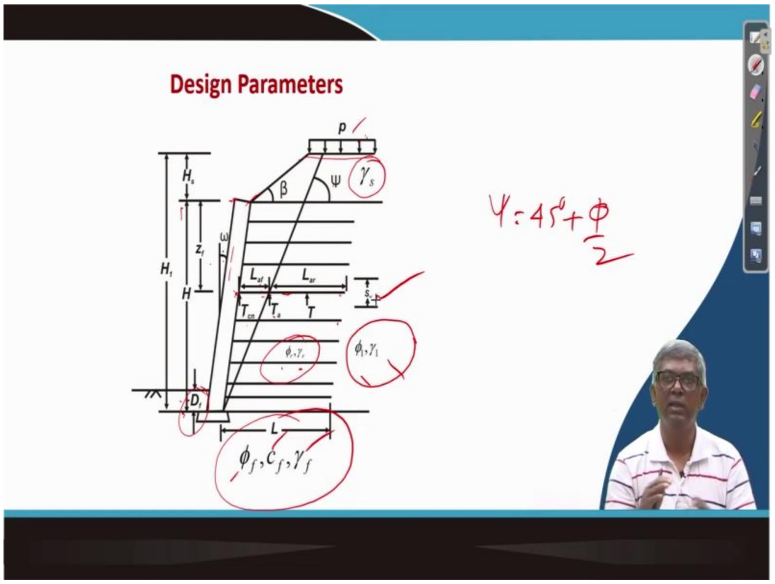

Next let us go to the next slide. And you can see the design parameters, whatever I have tried to bring by a small, small case. Everything is here, actually, you can see. This is the sub wall. This wall actually, instead of vertical, there is a little batter. This batter angle is (ω) omega.

And you can see here this is the top surface, and this is the base of the foundation of the wall. This is the height of the wall. And if this is the, the slope surface of the top surface, this is beta (β). And this is the surcharge, I was talking. This may be like this, and then horizontal, and then surcharge. This is surcharge.

And you can see for this soil characterized by gamma s, and, and you can see that if this is the failure plane, and so this angle is p_{si}, where p_{si} equal to 45° plus ϕ by 2, most of the cases. And you can see, if this is a failure plane then with respect to that then, and this is the reinforcement, then this portion is called L_{af}, and this portion is called L_{ar}.

$$\Psi = 45^0 + \frac{\phi}{2}$$

And you can see this connection, this strength, this T_{cn}, and this reinforcement is having allowable strength T_a, and you can see that, that at any depth, at any reinforcement if you want to find out the force etc. So, you have to find out what depth actually, that we will denote by z. And this foundation soil, it is characterized by Φ_f, c_f and γ_f. And depth of foundation is D_f.

And you can see here, reinforced soil Φ_r or γ_r, and if it is a retained soil, it is a Φ_1 phi 1, γ_1 gamma 1. And you can see that tributary area, S_{vi} for this reinforcement is shown here, in this. So, like that, these are the information is required for the analysis.

So, if, before doing any analysis we have to, either from the designer, someone will give you that these are the requirements. These are the requirement, based on that we will get some information, and then based on material, available material etc., you have to pick up some of them. And then you have to design length, etc., or you have to assume some length and finally show that their factor of safety is adequate.

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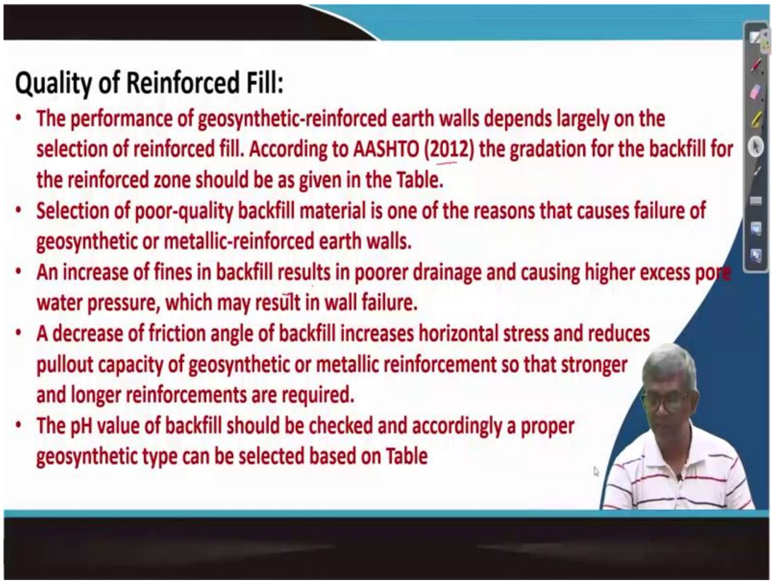

Now, quality of the reinforced fill. That, actually the performance of geosynthetic reinforced earth wall depends largely on the selection of reinforced fill. The reinforced fill actually, that is what I have mentioned already, that the soil should be granular, free draining, and it should have sufficient value of friction, phi Φ.

And so, that is one thing, and according to AASHTO 2012, the gradation for the backfill for the reinforced zones should be given to the table. I will show the table in the next page. Let me show you first, and then.

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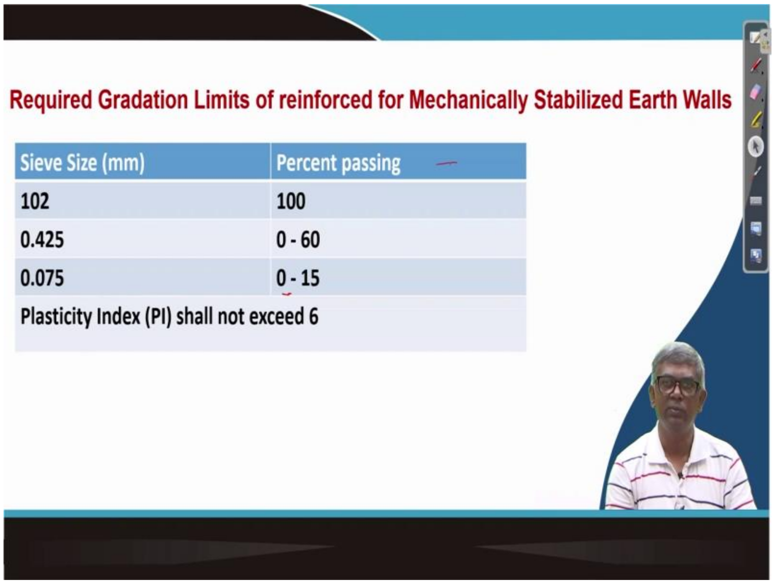

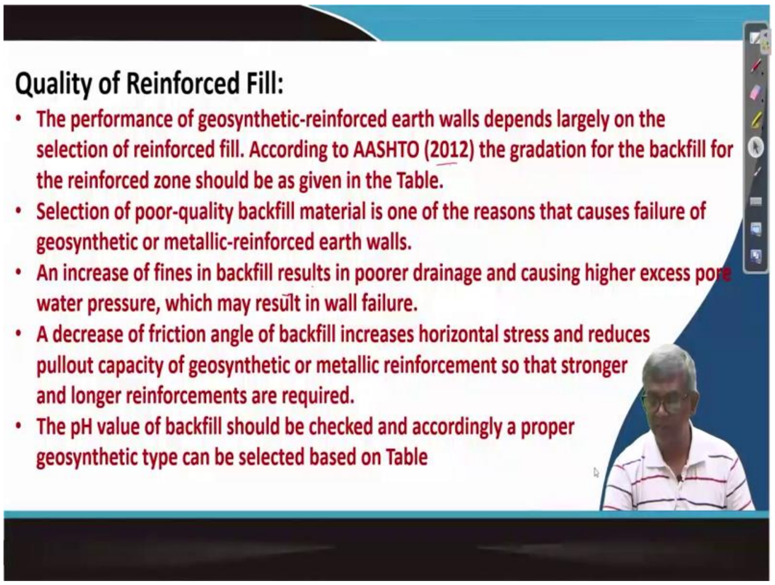

So, this is the one. You can see that sieve size 102 or 100millimeter, it is, 100percent should pass. It should not be, any particles should not be bigger than 100millimeter, that is require, first requirement. Then 425 sieve, around, between 0 to 60 percent should be passed. And 75micron actually passed should be less than 15 percent. It should we be doing 0 to 15 percent.

If it is more than 15 percent passing 75micron, then that soil will not be used, as suitable for the reinforced fill. And if there is some amount of silt etc., is there, then that soil may have some plasticity and then the, if, you have to check, and if the plasticity is greater than 6, actually, that will also not be suitable for the reinforced fill.

It should be less than 6. Plasticity should be, plasticity index, plasticity index P I should be, should not exceed the 6. This is the requirement as per AASHTO. It is given P_I, so, for the reinforced fill.

Selection of poor quality backfill material is one of the reasons that causes of failure geosynthetic or metallic-reinforced wall. If you have poor reinforced material, retain material where between the two-material sufficient friction will lot develop then automatically it will cause failure.

And particularly, of course, as we have mentioned that generally granular material has to be used as a backfill or reinforced fill, but there are some research that actually granular soil is required to develop friction. So, there are some technology is used nowadays that sometimes you can use soft soil, but soft soil, then you put a layer of granular soil then lay the reinforcement then put the layer of granular soil, then you can use some amount of soft soil. Like that also it can be done.

But again, of course, the subsoil will not be free graining, it is good, acceptable as, as far as fiction is concerned, but the free getting capability will be less. So that way actually, to be avoided, better.

And then, an increase in fines in backfill results in poor drainage and causing higher excess pore water pressure which may result in wall failure. So, if you have, we have given that limit is 15percent. If we fine content is more than that, then it will cause poor drainage and if there is poor drainage then it will cause development of excess pore water and that development of excess pore water can cause the failure of the wall.

And then again decreasing friction angle of backfill, increased horizontal stress and reduce the pullout capacity of geosynthetics, the pullout cover sheet which we can calculate, that is again $\tan\Phi$ tan phi, you have to multiply. if phi Φ is less automatically that will be reduced and a stronger and longer, so if the Φ phi is less to develop certain amount of tension or resistance you have to give, make a longer reinforcement or you have to give wider reinforcement. So that is the requirement.

And then pH value, again, of the backfill should be checked. And accordingly, a proper geosynthetic type can be selected based on some table, is given, I will show again. That, that means if you know the pH value of the soil then accordingly all geosynthetics or all metallic metals will not be, metal strip will not be, cannot be used as reinforcement. There should be some guidance. So that guidance is there. I will just come to that now.

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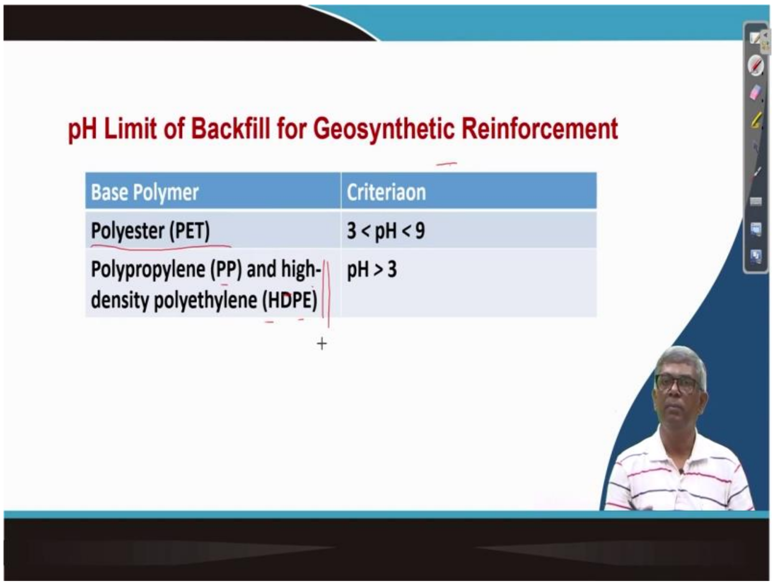

You can see this is already explained, and this is the one, you can see, that if the polyester, PET, polyester reinforcement, then actually pH value should be between 3 and 9. And polypropylene and high-density polyethylene, HDPE and PP, this material is, is there, then pH should be greater than 3. So, these are the requirements.

For metallic, nothing is mentioned. Of course, but of course, if there are some chemicals and et etcetera, then there can be some effect on the reinforcement. So that also has to be, to be taken care of. But when you are using geosynthetics, these two guidelines have to be kept in mind.

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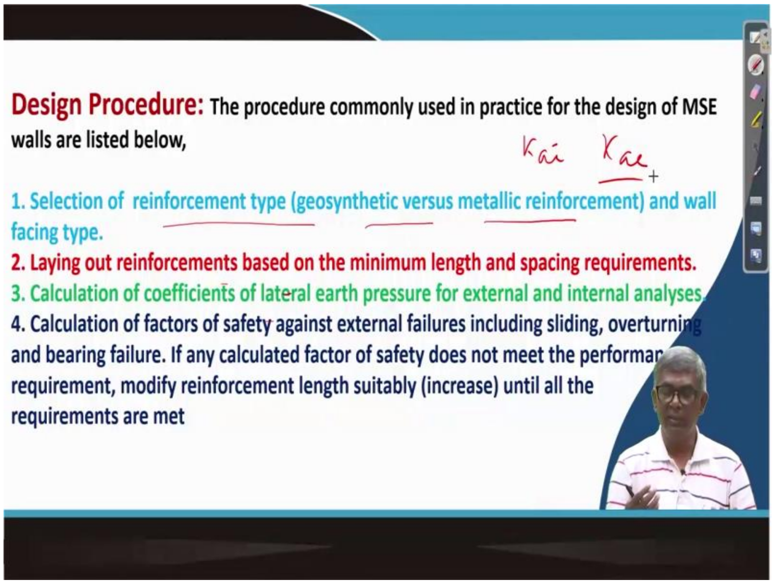

And design procedure, how will you design, actually? So first of all, actually selection of reinforcement type. So, either geosynthetic or metallic, and wall facing type. Three things have to be selected, wall facing, whether it is block or something else, that to be decided and whether it is geosynthetic or strip, that has to be selected.

And layout, laying out of reinforcement based on the minimum length and spacing requirements. A minimum length and resequencing, because there are requirements. Based on that you have to decide some layout and then you have to show that it is adequate. If it is not adequate then you have to modify it.

Calculation of coefficient or lateral earth pressure for external and internal analysis. What we have mentioned as k_{ai}, that is internal analysis and k_{ae}, external analysis that has to be calculated.

Then calculation of factor of safety against external failures including sliding, overturning and bearing capacity, and so, that already, we have mentioned. If any calculated factor of safety does not meet the performance requirement, modify the reinforcement suitably until the requirements are made. Modify suitably means, you have to increase the length, that is what is the requirement.

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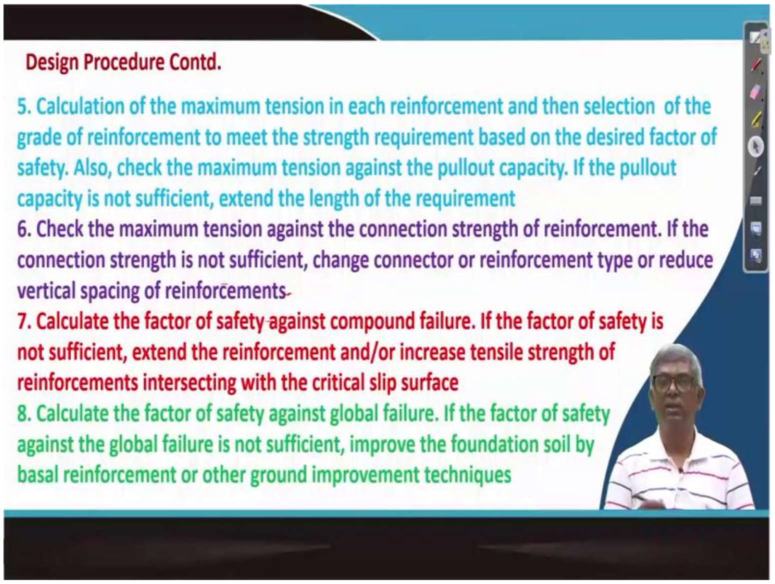

And sorry, next is the calculation of the maximum tension in each reinforcement. Level of reinforcement actually, you have to consider, and then whatever we have $T_{max}, T_{1max}, T_{2max}, T_{3max}$, like that we have shown the formula, that to be considered. And then tension in each, and then selection of the grade of reinforcement to meet the strength requirement.

So, T_{max}, T_{1max}, T_{2max} etc., we were calculating, and then what type of material to be used, so that that can be available. So that to be selected then. Check the maximum tension against the connection strength of the reinforcement, if the connection strength is not sufficient, change connector or reinforcement type to reduce, or reduce the vertical spacing of the reinforcement. So that is another, connection strength to be taken.

Calculate the factor of safety against compound failure, which we, of course, we have not done, but it has to be done when you do actual design and calculate the factor of safety against global failure. That also, we have not done, but actual design you have to do that. What we have done, actually, we have tried to discuss the factor of safety, internal external.

And internal means, rupture, pullout and connection failure, and external means, these are the basic failure actually, most of the time happens, so other one is rarely required, but it has to be checked sometime. So, these are the, calculate the factor of safety against global fitness. If the factor of safety against the global failure is not sufficient, improve the foundation soil by basal reinforcement or other ground improvement techniques.

So, bearing of, global failure, then, analysis, if you, if it fails, then there may be, foundation strengthening may be required so you can use the enforcement, reinforced foundation or you can use some ground improvement technique to improve the foundation. So that is the design step.

Sorry, let us go to the next slide. I think these are actually, I wanted to mention, actually, these are all regarding the design steps of MSE wall. Various aspects, we have, we have initially discussed different types of factors of safety, then how to calculate, what are the requirements for actually performance, then factor of safety, I know, then what should be the value, that we have discussed.

And then what are the design parameter, how to select, and how, what are the steps actually, how we will follow, while designing the MSE wall. So, we have discussed by two lectures on MSE wall. Now, I can take one problem to illustrate the design steps. With this, I will close here. And maybe I will start the next one, the next lecture. Thank you.