Ground Improvement

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Lecture No. # 30

Reinforced Soil Slopes

Slope Stability Improvement

We will be continuing this slope stability improvement using geosynthetics on or any other suitable form of reinforcement in this lecture.

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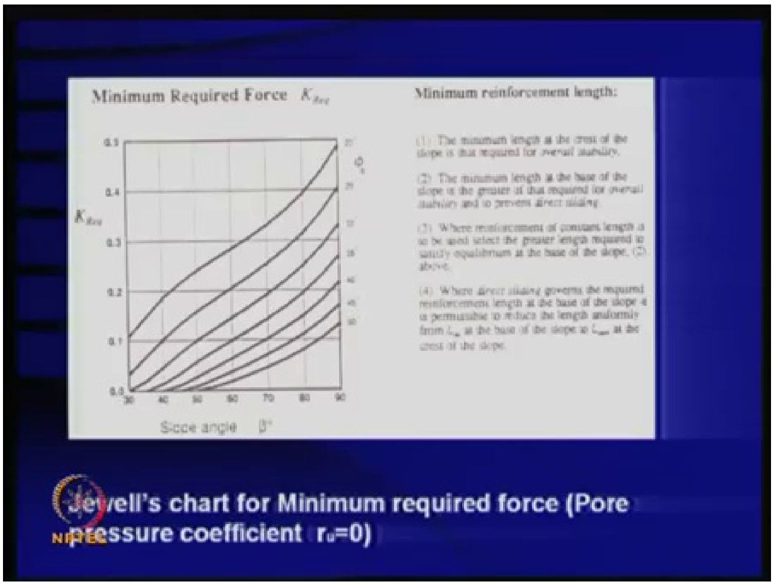

And as I just mentioned, we have a simple method in which if, you know, the required reinforcement force in terms of the coefficient K. As I just mentioned, we, we say, in the case of a retaining wall, which is vertical K a gamma H square by 2 will be the, the force and K a can be calculated in terms of this, you know, like 1 minus sin phi by 1 plus sin phi something that and if you know the inclination, it can be found out. And if you know, there is some, if there is an earthquake that comes, one can even calculate, what is the earth pressure increment, dynamic earth pressure increment also one can calculate.

So, this concept is very important in terms of understanding what is earth, required earthquake, earthquake. I mean, what is the resistance required to really see that it can sustain some horizontal force, either it is in the form of lateral pressure from its own weight or because of, it is the earthquake or it is because of the seepage forces and all that.

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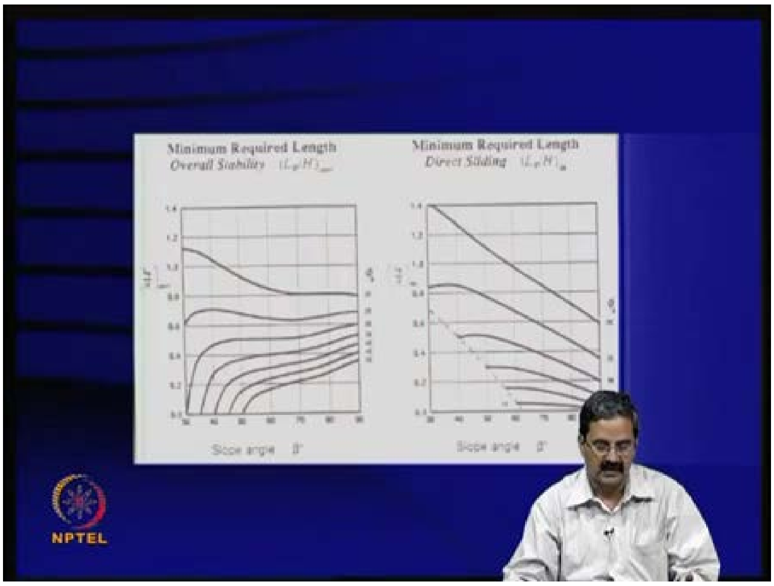

So, this design charts, that are developed; of course, there are many design charts developed in this lines, but I find, that the jewel charts are much elegant to use and simple to understand. And as I just mentioned, we try to calculate the required force and also, what is the length now.

Length is something, that like, so it is very important to understand, that as I just mentioned in the previous class, that if you know, that length of the reinforced, the height is say 10 meters, 0.7 times will be the length of the reinforcement. So, that is about vertical and that is a just a preliminary guideline. And say, for, for example, you can see, that same thing also comes here, like if the wall is vertical, and if the friction angle is say for example, if it is 20 degrees, it is 0.8 times the length of reinforcement; if the friction angle is 20 degrees, this is 0.8 times.

Similarly, if it is 25, it just, it is like this and it is about point, maybe 0.63 or something like that. So, these, these things will give you some idea of what should be the length of the reinforcement required for overall stability. This is the length required for overall stability and this is the minimum length required from direct sliding considerations.

You can see here, that if the slope angle is about 90 degrees and if it is 5 equal to point 20 degrees, it is about 0.6 here, like if it is 25, it is 0.38 here or something, but you have to take whichever is higher.

So, they have assumed some sort of failure mechanism, you know, the basis of this is, that they have assumed some sort of failure mechanism, it can be in the form of a log spiral or it can be a, you know, to calculate earth pressure coefficients you have to make some assumptions. One can use a log spiral failure mechanism, one can use wedge mechanism or one can make a two part wedge like, you know, it will have two wedges because it is much more close to what people have observed in the field, like why this failure mechanisms are assumed is, that some of this failure mechanisms are noted when you see, that there is a failure. Say, when the retaining, retaining wall failure is there, there is a sort of a logarithmic parabola or whatever, you know, it can be a logarithmic spiral.

You know, some sort of failure mechanism is there and that is the reason to calculate, that forces, that are acting on the retaining walls or you know, even in slopes we try to calculate this earth pressures. So, you can see, that based on the combination of these three diagrams, one can calculate the length of the reinforcement and also the, you know, the required force, that we will see with an example, that will be much clear.

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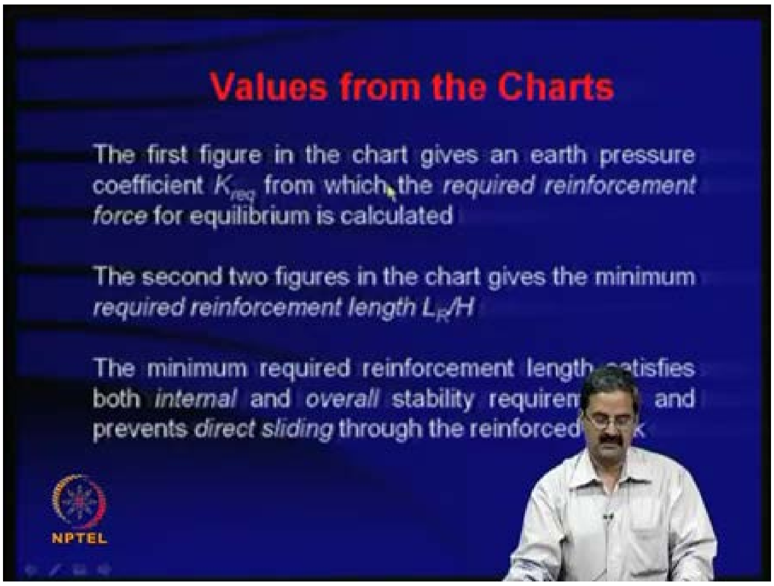

So, the 1st figure in the chart that I just presented gives earth pressure coefficient K required, which is the required reinforcement force for equilibrium to be calculated. The 2nd two figures in the chart give the minimum required length L R by H. The minimum required reinforcement to satisfy both internal and overall stability requirements and prevents direct sliding through the reinforcement block.

So, what we do actually? We will have to assume number of failure surfaces and finally, try to come out with this number and already it is internally done in this particular method. And how do you use this charts is something that I would like to illustrate.

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In, in the form of the simple example you have for us, to help values from the charts. You need to construct what is the maximum required stress in the soil, like you know, what is the, say for example, you know, the thing is K, K a gamma H will, will be the stress at any point, is it not? You, if you, you can, as that, that is called the line envelope or line of maximum required stress of the soil.

Then, locus of minimum available stress from the reinforcement; what is that the reinforcement is giving? See, you, you know, something is required like, you know, the earth pressure at any point is calculated in terms of K a gamma H, but what is it, that the reinforcement can give? If it is very stiff reinforcement, it can give invert shear stresses and it can be little stiffer.

So, it will, what is available is that and there is also a surcharge and all other things are also there, you know. Even if one can consider some of these things in some design, you know, suppose the vertical, the slope, we have some traffic load at the top, how do you consider that in the design, that also should be addressed, we will see that.

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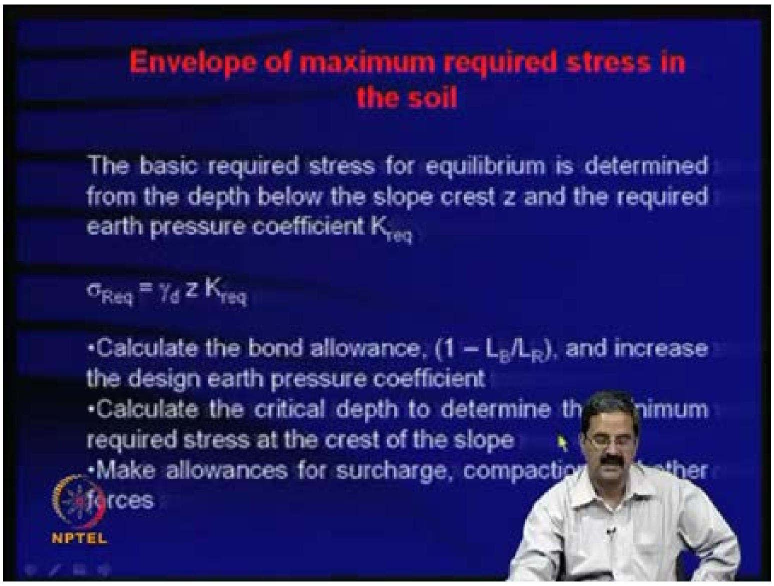

So, first thing is the construction of envelope of maximum required stress in the soil. The basic required stress for equilibrium is determined from the depth below the z, you know, and we know, that it is K a gamma H type of thing, where sigma required equal to gamma d is nothing, but gamma b is in terms of the design, d is the term, that denotes design, like what happens, as I just mentioned, you may have a number of density values, like you know, from backfill and you should choose some number, which is the basis for design. So, that we say is gamma d.

Then, z, z is any depth and K is the required coefficient. So, at any z, the required stress is nothing, but gamma d into z into K required and as I just mentioned, if you remember, that calculate the bond resistance and, and increase in the earth, earth pressure coefficient. If you remember, I just mentioned, that there are two things, which will decide the effect of reinforcement.

Actually, I just mentioned, that if this is the failure surface and you try to provide a reinforcement like this and you know, I was mentioning, that if you place the reinforcement in the direction of principals, the tensile strains, if there are some tensile strains in this direction, if you place the reinforcement, the tensile strains will be very, you know, the effect the reinforcement will be very effective.

If there are no, if there is a compression, you know, you put a reinforcement it is not useful, it is as simple as that. And if there is a some, you know, what happens when I just said, there, there is a sliding, that is occurring in the reinforced soil, take one element, we discussed this in the class, take one element on the failure surface and when it is subjected to shear, some part of it is subjected to, you know, a tension and the other part is subjected to compression, you know, in the direction of shear. It is, there is a tendency for elongation and assuming, you know, shear and tension is there, they are all together.

So, you try to put the reinforcement in this same direction, what is it we have seen? The reinforced soil principle, where if you place the reinforcement in the direction of tensile, stress is maximum; that is one consideration.

And we also discussed, that the, for the, to get the maximum effect in the reinforcement, the 45 minus 5 by 2, you know, that we discussed, you know, 45 plus 5 by 2 will be the angle at which it will be very appropriate, you know, I have, we have plotted a diagram in which the orientation effect is there and then, you try to calculate the delta shear force, that comes from reinforcement. We saw, that at a particular angle they are all optimum or maximum. So, that is one thing we have seen.

And the in terms of the two important things, for reinforced soil to be effective, one is called tensile force mobilization, the other one is bond resistance, the bond resistance point of view. The orientation of reinforcement should be like, if there is a vertical load applied and if the reinforcement is like this, you cannot pull out. So, the direction of bond stress is like that and the direction of reinforcement is like that. So, the angle is 90 degrees. So, to get the maximum benefit due to bond, you have to place the reinforcement at 90 degrees to normal stress; that is one thing. Whereas, in the case of tensile force mobilization, you should put the reinforcement in the direction of tensile strains, you will get the maximum effect.

So, the direction of the placement of reinforcement, you know, in one case, it is 90 degrees from bond; in the other case, it is 90 degrees, in terms, the 0 degrees in the case of tensile reinforcement. And most of the time what happens is, that as I just mentioned, it will be at an angle, so, so that small correction has to be applied, you know. See, that is what I was trying to mention here, like all these earth pressures we assume, that it is total force acting and you are calculating the K required based on this, but the K required will be little higher, you know, it should be little higher, why? Because the, the reinforcement, you know, this is not the force in which it is acting and you know, the reinforcement is at some inclination with reference to the failure surface. So, to make that correction, we have to use the factor called 1 minus L B by L R and increase the design earth pressure coefficient.

Then, calculate the critical depth to determine the minimum required stress at the crest of the slope; make allowances for surcharge compaction other forces; that we will see. Like you know, surcharge is nothing, but 1, you know, like traffic loading. Then, compaction, you know, because you will be, do, doing the road rolling, road, I mean, rolling you know, using equipment and there will be earthquake forces, seepage forces and all that.

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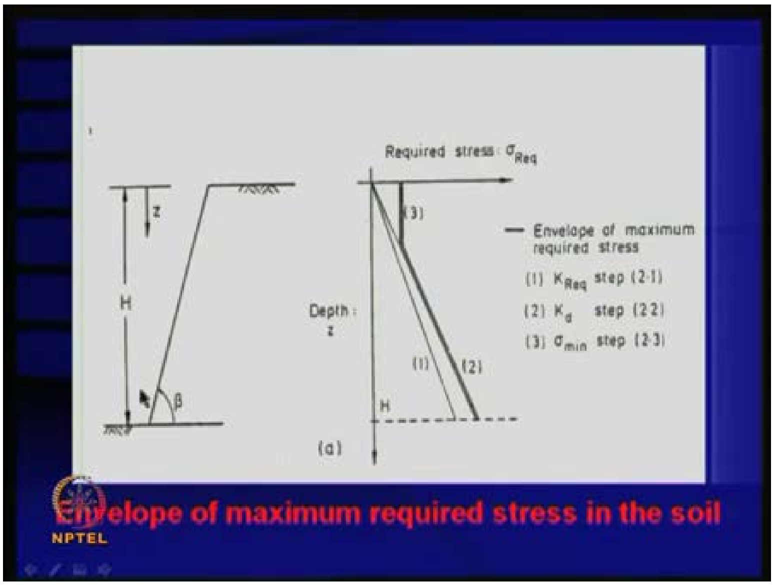

What I want to show you is that this is what I have meant. This is the force, this is actually the reinforcement slope at an angle beta and this one is, that if I just take it as K a gamma H, it will be like this K required, you know, this is, it will be like this, is it not?

But so, if you just calculate the reinforcement based on this, actually how do you calculate reinforcement force? It is nothing, but K required into gamma H into S V into S H, as simple as that, you know. You have some space, vertical spacing and horizontal spacing in the case of some reinforcement elements, so that much, that is the tensile force, that mobilized or that, that is likely to mobilize.

So, what you should do is, that, that is, we assume, that its whole force is acting, but there are some small changes here, that you know, there is a 2nd one, which is nothing, but there is some from bond and reinforcement angle consideration; there is a small correction factor you have to put in. So, because of which the required reinforcement force will be little higher.

Then, at the top, actually you are trying to do the compaction. Actually, you know every layer we do, we do the compaction, but what happens is that the compaction stresses will be much. See, the (( )) is very high compact. See, what happens during the process of compaction? We will have some sort of pre-stress induced into the system, so that compaction could be, say for example, I am just mentioning it here, like gamma B into say, depth is something, say for example, it is 18 into 1 meter is one value and 18 into 2 meters is something like, it follows like this, you know, 18 into 2 meters, 18 into 3 meters or something like that it follows this line, but at the top it is 0.

But practically, it is not 0, why? Because you have compacted it and there is always some sort of earth pressure for which it is to be designed because the earth pressure is never 0 at the top and you have allowed compaction static. Actually, we do not really compact, you know, we use some sort of simple compaction equipment, like handheld equipments are there, we do, just do some compaction here, whatever.

There is some compaction stress induced and to resist that compaction stress, you should have reinforcement. So, up to this point it is just, that it is K a into s, K a into gamma H into S V into S H will be that force and as you come up, as the depth is less here and it, it should not go here because that you will have some stress because of the compaction, that you should take here. And then, you should design, that this is what is called required stress in the reinforcement. So, this is that minimum value actually, minimum value because of compaction and other things, that we have and after that it is like this.

So, see, you may have a general impression, that if you put a, there is no pressure here, there is no need for reinforcement, it is not correct, why? Because there is a pressure because of the earthquake, sorry, the earth compaction, so that is very important. And not only that, suppose you have a surcharge here, we have some (( )). Now, this is just a slope, which does not have any surcharge, there will be some lateral pressures also here.

So, to keep that in the stable condition we need to have some sort of reinforcement here as well. So, that is what I want to say.

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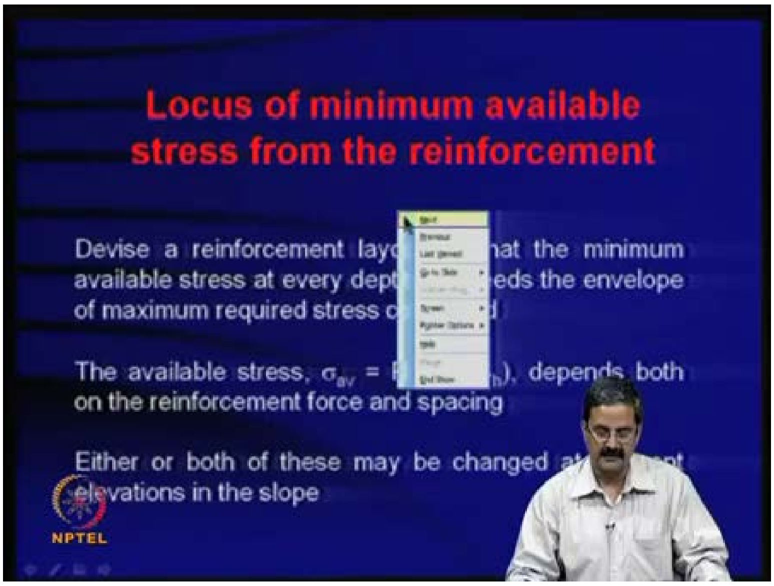

So, we normally try to come out with some sort of reinforcement at the locus of minimum available stress. From the reinforcement we try to device the reinforcement layout, so that the minimum available stress at every depth exceeds the envelope of maximum required stress.

Actually, what we did in the previous case was that, this is that required stress and you come out with a reinforcement diagram, which is like this, you know, where the stress in the reinforcement is always more than the required stress. That way, you are ensured, that it is stable at all levels, we will see that anyhow.

And available stress P aV is nothing, but this is S V into S H, they depend on both, the reinforcement force and spacing and you can always meddle with spacing and length and all that. Of course, if you are using a geogrid or a geotextile, its horizontal spacing is per meter length. Actually, there is nothing like you can change any spacing, but if you are doing some nailing and other things, one can have some suitable horizontal spacing of half meter, 1 meter and whatever, 0.75, you can change it. So, you try to see, that the available stress in the reinforcement.

See, the allowable, this is what you are going to get from the company; the available stress should be more than the required stress, that is what we do. Suppose, you are, you take some reinforcement bar in nailing, you can always say, that allowable force into S V into S H should be more than the required stress, if you are able to do that, it is fine, job is done.

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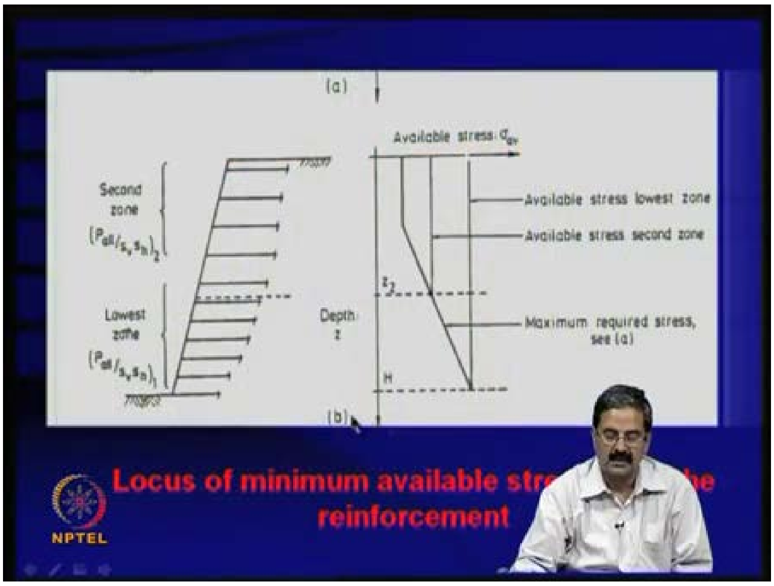

That is what I am trying to show here. This is the available stress in the reinforcement, this is what I showed you just now and sometimes our objective is to place now reinforcement. So, you place the reinforcement like this and you try to calculate. See, there are two zones here. In fact, what you are trying to do is, that one way is, that you calculate and put one, one single type of reinforcement, which is like, this is the lowest zone because sometimes what happens, if the depth is shallow, say for example, 5 to 6 meters is ok, but if the depth is say 10 meters or something it is or 7 meters, it is better to choose two types of reinforcement, so that you do not really waste the material.

What happens is, that this is the lower, lower zone, lowest zone stress, where P allowable divided by S v into S H is nothing, but this one type and here you select in such a manner, that this is one and then the 2nd one also you try to choose in such a manner, this available stress in the two zones.

So, actually, suppose you are using the same reinforcement everywhere, what happens is that you will have a vertical line here and this is the required, this is available, extra available, so you are not utilizing it properly. Say, for example, this is, say for example, this could be some number here and the available force in the reinforcement is so much, which means, that you have taken a very good grade of geogrid or something. So, this is underutilized.

So, what we do is, at, at some point, depending on availability of the material, we will try to choose some material, which is something better, better, but then it can be cheaper cost, cheaper and less strong compared to the previous one. So, this way you can really understand this whole concept and see, that at any stress level you try to keep the reinforcement satisfactory and you know, in the sense, that limit like, always the available stress in the reinforcement should be more than the required stress.

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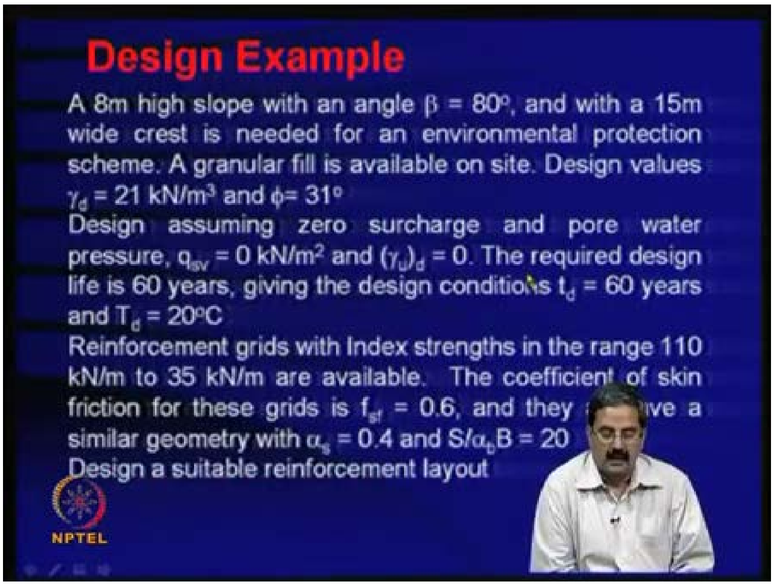

Now, it is an example; you are trying to design a 8 meter slope with an angle of, you know, 80 degrees, you know, it is nearly vertical, you can say that with a, you know, 15 meters wide, you know, maybe you are trying to have a car parking or something, road widening work, like you know, say for example, you have a narrow area here, you would like to increase the road width. So, you, 15 meters this side and 80 meter slope you can make. In fact, that is what we people have been doing elsewhere.

And now, you have a granular fill you are taking and design values, you know, you may have lot of values for the same material, but you take 21 as the design value, friction angle as 31 degrees. Now, design assuming 0 surcharge and pore pressure, pore pressure. So, surcharge is not there and pore pressure coefficient is also 0, these two things are very important actually, you know. The, you know, you have a simple equation to, say for example, if there is some surcharge applied you can convert into an equivalent height actually.

So, if there is some 8 meters is what you have, suppose somebody says that I have 20, 20 kpa as load, then the way, that we get the equivalent height is, that you can, you know, the thing is that, that you, you have to get the equivalent height by considering that extra 20 kpa was load and also its unit weight of that soil.

So, once you do that, that you, you will get that equivalent height like nothing, but it is like q is 20 kpa, q divided by then, that bulk density. Say, for example, 18, 20 by 18 will give you the extra height, say 1.1 or whatever. So, when you have a surcharge, you assume, that it is only 8 meter slope, but design it for 8 plus 1.1, that surcharge effect is considered and like that. So, design in this case, example, I am just only illustrating, but you know, suppose you have a problem with surcharge, you know, particularly when you are trying to design using IRC and other guidelines, you need to know, how do you handle surcharge.

The required design life is 60 years, then the design conditions are t d equal to 60 years and the design temper is 20 degrees. These are all some, you know, these are all, that you get from geosynthetic company and the reinforcement gets and index properties in the range of 110 to 135 are available. Like you have number of companies nowadays in India and abroad, where you get index strengths varying from, you know, quite big, you know, if you are going for geosynthetic, the slope applications there is so much range, they will come and give you, even geosynthetics can be there.

Then, as I just mentioned, the coefficient of skin friction for this geogrids is point, 0.6 and they will have a similar geometry with alpha s equal to 0.4 and s alpha B equal to 20. In fact, I was just, I, actually I need to mention, that these are all required in the case of calculation of bond resistance and objective is to design a suitable reinforcement layout, right suitable reinforcement layout and you try to come out with you know, you have some geogrids and all that materials and there is some loading and everything is given. How do you come out with suitable reinforcement force is a question?

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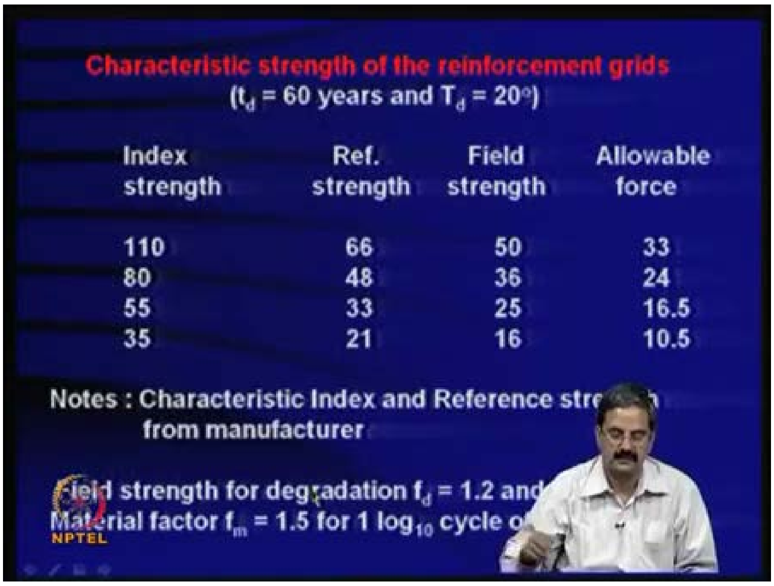

What is available here is that now you are designing it, say for example, 50 years or 60 years and room temperature is also given. The companies know they will give in this form; index strength is say, 110, 80, 55, 35. They are all called reference strength; it is called characteristic strength and reference strength from the manufacturer.

Then, they have, as I just mentioned, there are some, you know, the finally, the you need to apply this character, the you know, partial factors, such as f d, you know, damage factor 1.2, 1.1 and 1.5 for one log cycle of extrapolation. So, once you do that, you have, it comes to 66. Then, if you want to correct it for damage and other (( )) 50, then finally, it comes to 33. What it means is that it, all 110 divided by some of these factors will lead to this number 33.

Though this is reference strength, you have a factor of safety of 110 divided by 33. All these partial factors, whatever you choose, will be having common depth number and so, what you are allowing is only 33 because I said, it is for 60 years, 60. At the end of 60 years also it should, you know, it should work for 60 years; that is assumption. So, we, at the end of 60 years, we expect, that this is the force that it comes down, so we assume, that we design for this. Actually, you know, we assume that this is the design force, design allowable force.

And for 80 grid 24; 55, it becomes 16.5. You have 4 varieties actually, because why we have 4 varieties is, that you can optimize, as I just showed you, that one can optimize the length of the, not length, at least the spacing and also the, the, the, you know, each could be, you know, expensive, which say, this may be very expensive compared to this last one, like that. So, once you have all these factors, these are all the important numbers. Now, once you know this, normally this will be given by manufacturers and all the, all these of things you should get from the manufacturer literature.

And even, in fact, one should do tests also, like say for example, if somebody says, there is, 110 is index strength, you have to measure in the lab using a tensile, we showed you, we discussed various types of tests one should do. And we have seen, that the, this is, these things are very important and quality control and we also should check out with the, some of this, you know the, the factors.

In fact, as I just mentioned, the tensile strength reduces with time, I showed you the diagram. So, tensile strength reduces with time and if it is, see, if you test for 1 hour, there is a test actually where you test immediately and test for a few, like you know, 10000, I mean, like you know, it is at least 5 at the end of 42 days. Also, it can be, if people can, you know, continue the test and then take the samples and then measure them, you know, measure the test, get that values and one should understand that and then they extrapolate actually. If you have, say for 1 day and 10 days, it can be extrapolated to 100 days, like 1 and 10 and 100, they constitute a log cycle. 100 days, 1000 days, like that, you know, one can extrapolate because it is simply, extend that horizontal line, the line in the log, log sheet actually.

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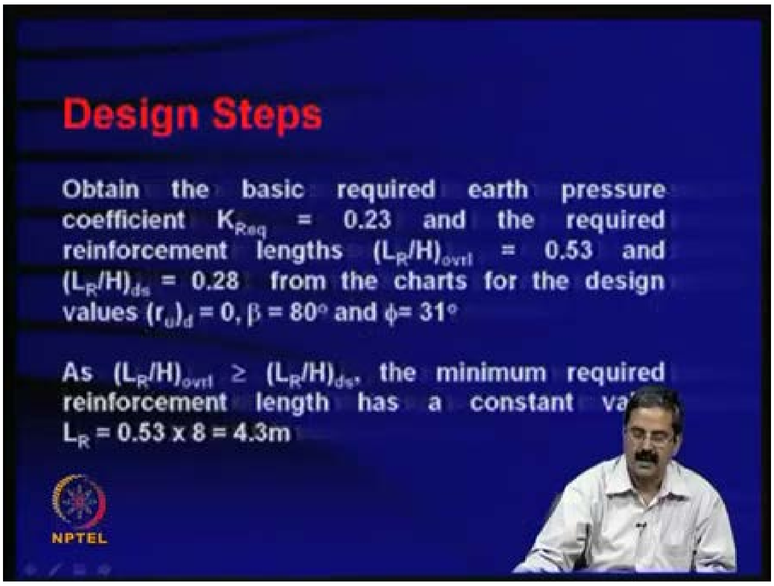

So, what are you trying to do is that. So, I will show you how do you go about this design. Obtain the basic required earth pressure coefficient 0.23 and the required reinforcement length, you know, I just showed you the previous diagram, like you know, that chart. Based on the 80 degrees inclination and friction angle of the, this thing, you will get this required.

If you remember, I just mentioned that if it is vertical and phi is 30 degrees, it is 0.3 or something like that, it is little less here now, like maybe, its slope angle is 80 degree, 80 degrees, so K required is 0.23. And we also see the charts for the same thing and 0.53 and 0.28 for the design charts for r u equal to 0, beta equal to 80, phi equal to 31, slope angle is little higher. So, what it means is, that whichever is higher, like you know, 0.53 and 0.28, we should take the lean the reinforcement length. So, the reinforcement length will be 0.53 into 8, 8 meter is the height is 4.3. So, the length of the reinforcement is 4.3.

So, suppose you do for a surcharge, you know, surcharge is there, about 20 kpa, what you should do is, that here you should just, you know, everything is, you know, because these are all in terms of L R by H, there is no problem here, but then here you have to make it as 9.1 or something, depends whatever extra height you will get here. So, that length you have to provide.

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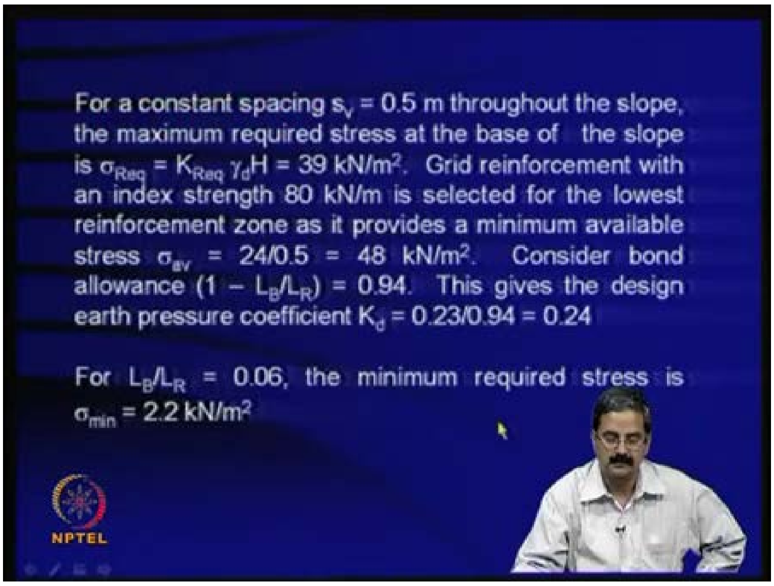

So, now, what we do is that we provide some spacing of those materials for a constant spacing of S v equal to 0.5 meters. Throughout the slope the maximum required stress at the base of the slope is like, you know, k required is what? Point, you have already got the number, K required is some 0.23 and H and all that you get 0.39 you get at the bottom.

The grid reinforcement, if index strength is 80 selected for the lowest reinforcement zone as it provides a minimum available stress, say for example, I have given you those diagrams and 24 is allowable, one for one of the materials, it has 24; 24 divided by 0.5 will give you 48. So, consider one more thing, as I was just mentioning, this is 24 is nothing, but the material property. 80 has been reduced to allowable force, you know, 24 divided by… Now, this 0.5 is spacing, so 48 is a allowable force required.

So, considering bond resistance 1 minus L B by L R, this is another one the L deal. The, the other one is, that there is a calculation required for L B also and L R, we have already got that length has point, say 5.3. In the previous, previous diagram L R is point, you know, 4.3 meters and L B is we have another expression. Finally, you know, it will be always less than the 1.

So, you get this term called 0.94 and this gives, now as I just mentioned this reinforcement coefficient, like 0.23, which was there, which we obtained in the previous step, should be little corrected and this will become 0.24. Essentially, as I just mentioned, that this is because of the orientation effects.

Orientation, you know, as I just mentioned tension, the reinforcement should be placed in the direction of tensile strains for the maximum benefit and for the bond it should be placed in the, at 90 degrees to the vertical stress. But in the field condition there is an intermediate angle and because of which the k required will be has to be corrected, you know, it has to be increased actually.

And for L B by L R equal to point naught 6, the minimum required there is another computation, that we have and we have another step, that actually, this given in my book and L B by L R is point naught 6. The minimum required stress is sigma, minimum is 2.2.

Like as I said, at the top also you have some minimum stress, like as I said, it cannot be 0. You have to have, you know, if you are simply placing with hand and other things minimum stress, but if I have compacting, it can be much higher, like it can be 100 kpa. Now, what you have is about 2.2 kpa, which is very small number.

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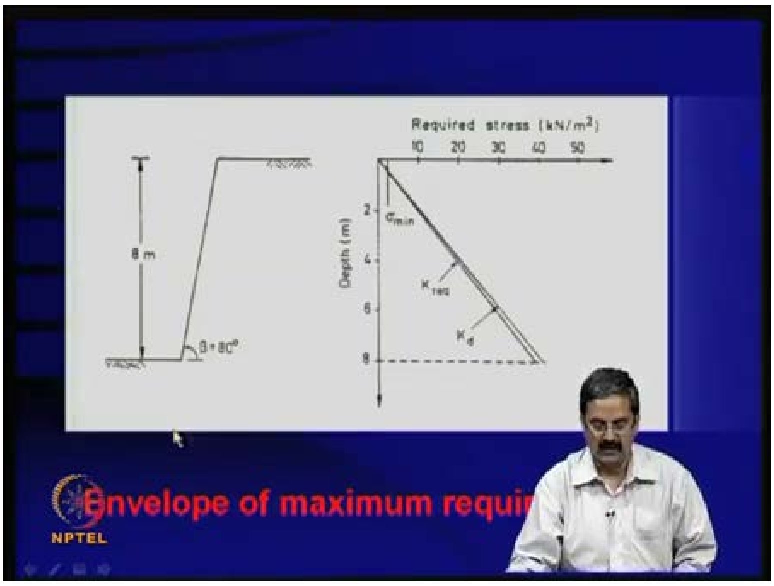

So, what we did was that we just have this correction, which we have the required stress and like minimum value, this is about 2.2 and this is the slope angle. And assume, that you are using some compaction and all that, so it may have, the required stress could be little here, like you know, how do you get that thing, one can also do. What you do is, that is a sandy material only and you do a sort of a consolidation, you know, e log p curve for that. And then, there is you know, the, the you can draw the tangents from, on either sides and then there is an intersect, that you get, intercept you get and then it could maybe, correspond to 100 kpa.

If you remember, I showed in the case of compaction chapter the amount of pre-stress that the materials have. For example, in the case of clays, there is lot of pre-stress in the clays, but in the case of sands it could be lower, so that pre-stress value one can get from here and maybe, make it with some correction and then use it here. And to get you know, if you are using compaction, if you are not compacting, it is fine, you know, you need some minimum stress because of the bond considerations. So, this is k required and k design and then minimum stress values.

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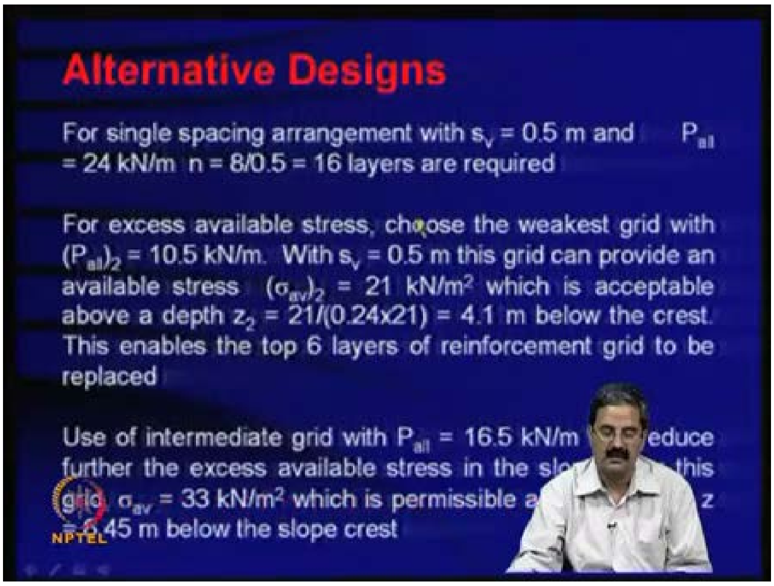

Now, suppose, you are going for a single reinforcement layer throughout that 8 meters level, the allowable 24 by 24 is that and then 0.5, you have 16 layers right at every 0.5 meters. Actually, the thickness, why is it 0.5? In fact, as I just mentioned in the compaction class, that the density within this 0.5 should be same and constant and it should be very good strength and also, it could, it should give very good resistance between the soil and reinforcement, this is very important.

And so, when you take P allowable as 40, 24 and spacing as 0.5, the number of layers will be 16. In some case, you know, as I said, you have other two materials also. I said just 10.5 is one thing and you can also use, you know, where at the top because you may have, you may not have lot of stress at the top, you may have a weaker material, that one can use with the same spacing and also intermediate one, 16.5, one can see, that it can also be used.

I will just show you the diagram.

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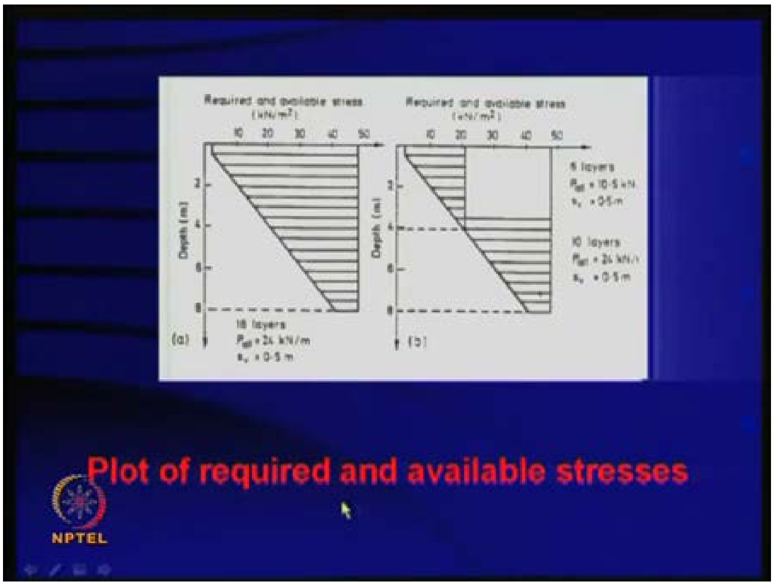

What it means is that this if you are using, you know, this depth versus the required available, stress required and available stress, this is what is required and this is what is available, you can see that 48 kilonewtons is available. Maybe, you just find here up to some level, up to some level, but you can see, that it is all wasted here. The, if you use very good material, like you know, with 24 kilonewtons, it is not worth, you know, having 16 layers, it is underutilized.

So, what we do is that one common, one way is that you take 10.5 kilonewton in one and then have spacing and you can put up to some layers, wherever it comes in, you know. See, that the important point is, that the available stress should be more than the required stress, you know, up to this point you can go and you kept, you, you know, at the top you can only keep this 10.51 and then this, at this, all this points, it is fine, but once you come here, you try to go for higher one.

So, you are able to effectively use your material in some sense with just replacing, you know, the good material with a somewhat weaker one at the top.

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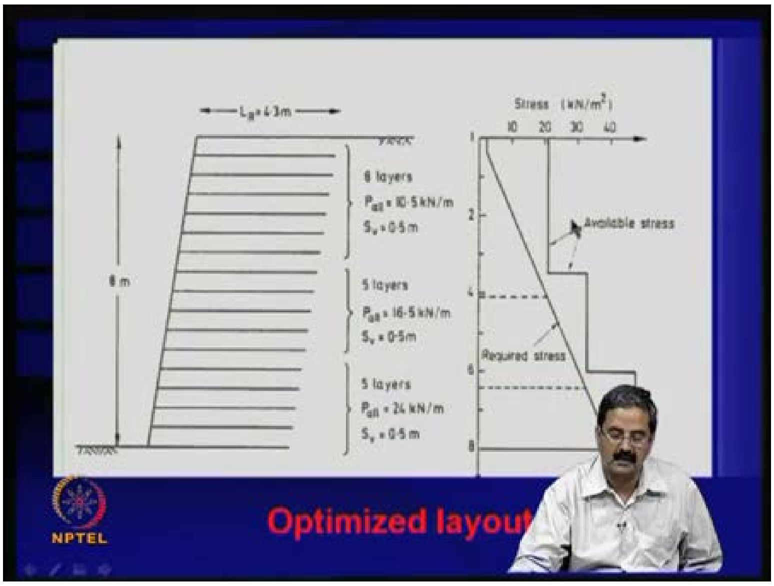

But here, you have much more better configuration here. 8 meters is there and say, you can, you do not need, you also have one more geogrid material, which is in between. Also, like you know, you have 3 materials, one is 24, one is 16.5, one is 10.5 and try to maintain the spacing. Actually, you know, we do not meddle with spacing too much unless it is required or when it is very useful because you know, it is, sometimes from construction point of view it is much better. And particularly in small slopes, you know, like, so you can see, that all at 0.5, 0.5, 0.5 provide, and this is the required stress and allowable stress. You can see, that at this point little extra, you know, it is fine, this thing, it is little extra, it is fine. At every point, you see that all available stresses are more than the required stresses.

So, it is very useful to say, that yeah, the design is also like, you know, the way, that we calculated was, that we also had directly the factors of safety because we got this numbers based on that time and other extrapolation numbers, you know, damage effects and all that.

What was some number, you know, it became? You know, the, they have, we have considerably reduced those numbers and got the design. So, this is the length of the reinforcement required, this is the spacing required and this is the type of geogrid required. This is what the answer is, answer for the question is, that if you want to say, that if I want to say, that this is the suitable reinforcement configuration, yes this is that.

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What you got in the process was that, like you had three materials, like 80 kilonewtons, 55 and 35 and assume, that relative unit cost may be 5, 4, 3, like you know, this could be, maybe 5, you know, say in Indian currency I can say 500 rupees, this could be 400 rupees, it can be 300 rupees. So, like some units, like 5 units, like it could be, say 10 dollars, it could be 8 dollars, it could be 6 dollars or whatever.

So, when you say that and in the design 1 you have 16 layers and you know, the relative cost is 80 because 16 into 5, 16 into 5 is 80 in the two configuration, that we discussed. 10 into 6, it is 68 and you are going for the 3, one where you know, you have all the three things, like you know. So, you have 5, 6, 6, it is 63.

Even within that geosynthetic material, you know, normally, see what you did, 80 meters is definitely unstable, you do not get, any factor of safety is definitely is less than 1 and usage reinforcement, geogrid reinforcement and actually this reinforcement charts, that I just showed you, are based on some, you know, the design coefficient of 0.8, you know.

So, even using that you are able to get with wiser choice of reinforcement, you are able to get 20 percent, about 21 percent savings over the design 1. What I want to say is that one can do a very systematic analysis. In fact, this is, the design charts are simple tools, but one can do rigorous analysis and come out with wonderful this thing.

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And this is a typical slope actually, you know. See, in fact, the 8 meters is one, but you know, but have, suppose you want to go for, say 40 meters. In fact, the highest, the recent, about sometime back I have listed a two reinforced earth slopes, one is 22 meters high, which is very good, which is doing very well and, but then the, I have listed another one, which is supposed to be 42 meter high, which is supposed to be very high, one of the highest walls and, but it had lot, some problems because the field engineers have not understood the behavior of reinforced soil well, soil, soil walls or soil slopes very well.

And you can see, that when it can be even tiered construction, we call it, you know, it can be you know, see you can just put in terms of tiers and then construct. This is the highway and one can do a sort of, instead of a regular detaining wall, one can construct this.

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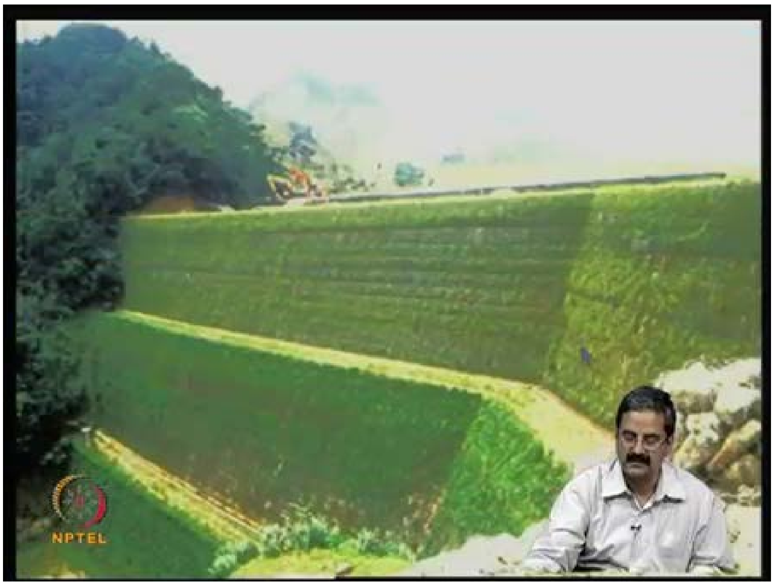

So, this is the, another one, that you know, one can have in any type of diagrams and the, this is what type of initials one can have. This is another interesting example and you have, see all, all could be pathways and it can be blended into our ascetic design very well.

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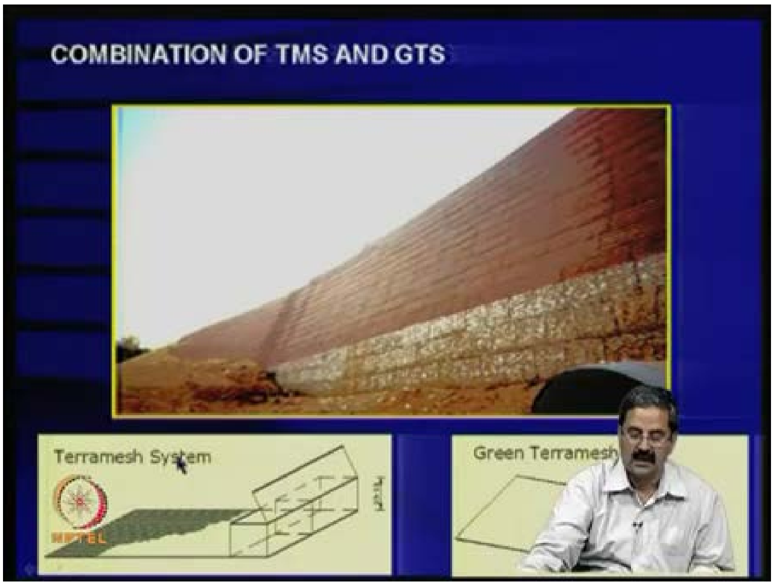

This is another example of course. Actually, we have so many companies in India and abroad, that if we just visit their home pages, you know there are so many companies. Now, this is one case with one company called Maccafferi in which they supply this sort of reinforcement and you put some gabions like this and all that and you can construct, this is the reinforcement system, you know, reinforcement system and you say, that whatever is the, you can design this, you know, you can specify and then the company may have standard designs.

What happens is, that when the companies may have standard designs, it is objective, our objective as designer is to cross check the design because the designs are sometimes not full, full-proof and you know, there could be some unusual situations where the designs can go wrong.

So, in fact, what I saw in the particular RE wall, RE slope, in the other place called Vijayawada, where the, they could not estimate the deformations of the slopes properly, that was a big issue. Now, it is somewhat stable, but there are, it, it, it, it has really been a bit problem in reinforced soil slopes because height is 42 meters, which is one of the, it is not a small height and it is also in the curvature.

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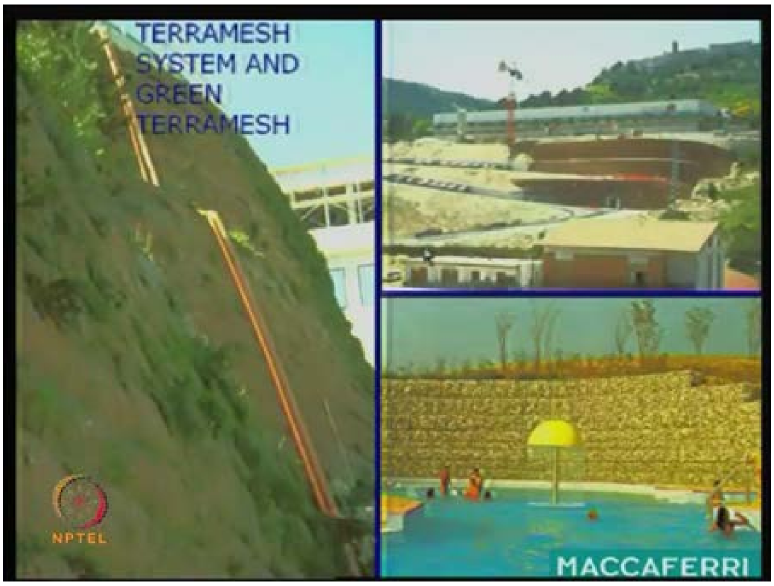

There were many design issues and this is another example that one can have here. See, this is the reinforced soil slope; it could be about 70 degrees. It could, this you can see, that this is also about very high slope, it is not easy.

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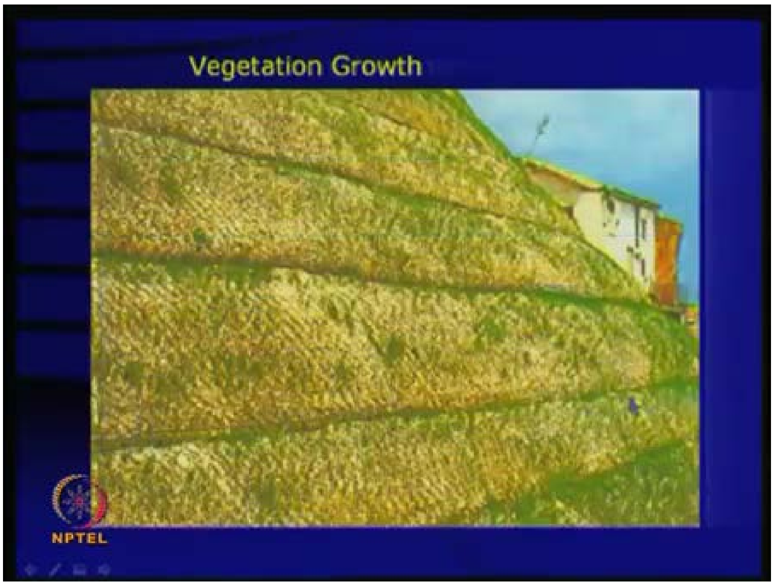

So, one can, the beauty with the some of the systems is that you can also allow the vegetation to grow up, you know, in nice terraced slopes.

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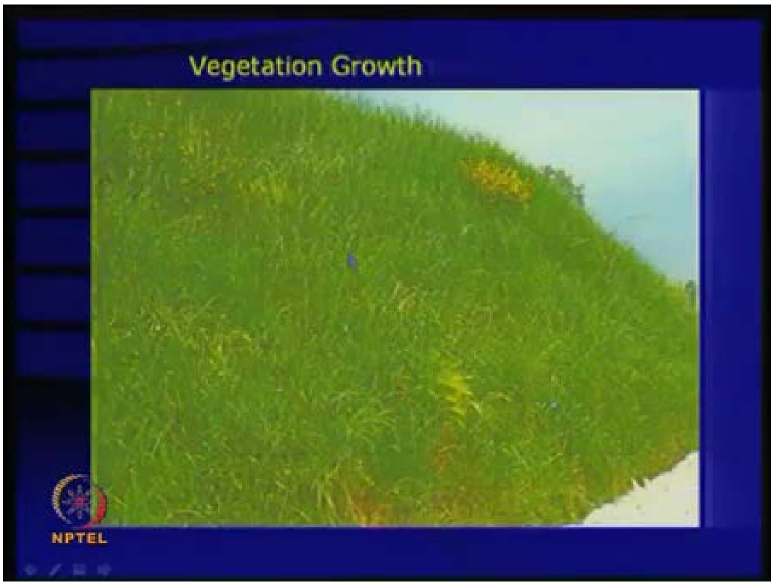

It can be very nice and it can be like this, as good as this, you know. If you, just in the beginning itself you construct and then put some sort of nice plans, that can come and you know, it can be as rich, rich green like this and it is very useful.

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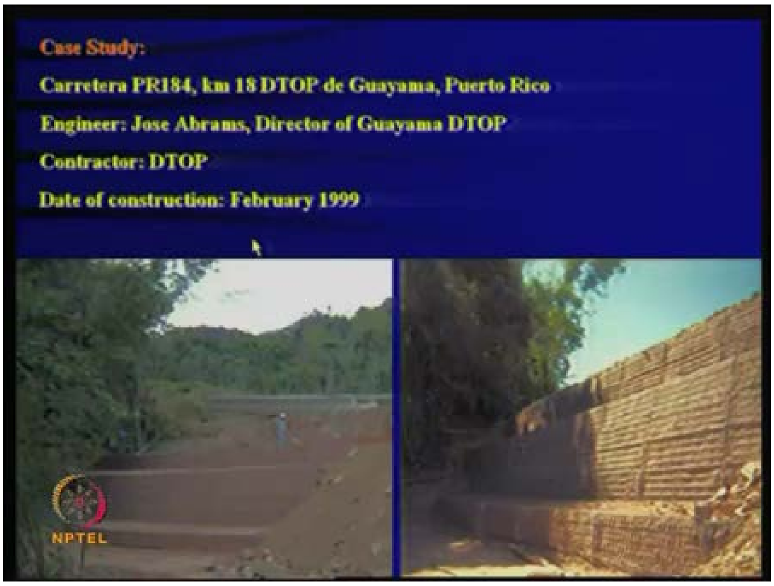

This is another case study, of course, in, from some other company. There are many case studies, that one can do and like, this is another type of construction, that people have and this is again, you know, it is simple.

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You can see even the construction that they are doing here, like you know, normally like you have reinforcement and then, on the reinforcement you have a backfill being spread and you know, then it should be rolled and compacted. As I just mentioned, you should have good densities, it should have good density because see, the, the objective is, that it should have very good friction between the soil and reinforcement and there should be a very good drainage actually, because what I just showed you was that the, you know, the drainage is very important.

You have, I, I have gave you the slope design for RE equal to 0, where the pore pressure coefficient is 0, but if there are seepage pressures or some horizontal force, what happens is, that earthquake force or even the length of the reinforcement will be high. Length of the reinforcement required, as I said, it could be, say 0.7 times height or some, you saw, you know. Depending on the length of the reinforcement, what should be the depending on the slope angle and the friction angle of the soil? What should be the angle you can get, but it also should account for the seepage conditions?

Like, you know, if there is a saturated condition or you know, if there are some pore pressures you should have, say for example, in a hilly area if there is some water always coming, then it is not. So, you should possibly put proper drainage and see that the water is removed and also the length should be adequate, you know. In such case what happens if the length is not adequate? Then it fails.

In fact, in many places, in abroad, like you know, in Vietnam and other places, the, because of not providing adequate length, the reinforced slopes and walls have failed. And even in India there are many cases, where if they do not understand the principles of reinforced soil wall well or reinforced slope well, then they are in for trouble.

But then, it is a very efficient technique where you can see, that you cannot construct a 70 degree slope, but because of this technique it is possible to construct. So, so this is a typical backfilling operation.

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This is about phasing elements and all that, one can do all these things, you know, many things are possible. Then, so this way they construct and you know…

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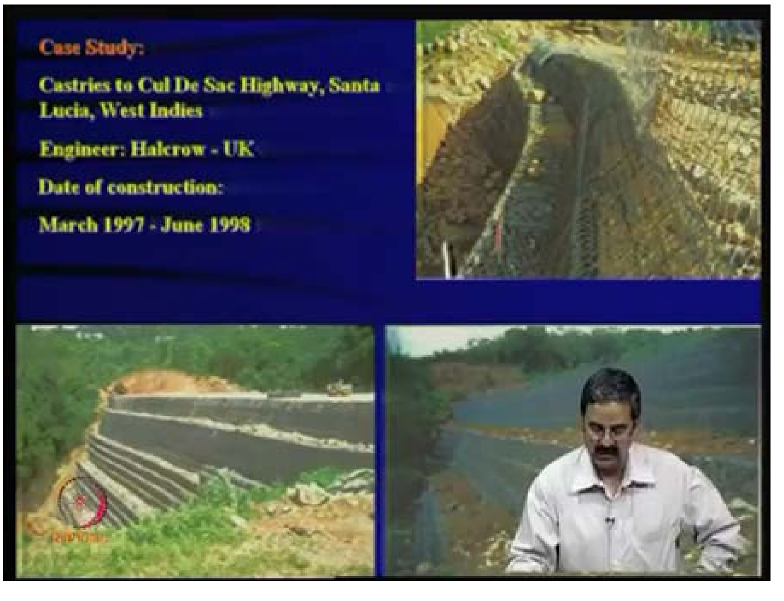

This is also some case studies we have and in fact, if we just go to, actually as I just mentioned, if you remember, in the 1st class Henri Vidal was the discoverer of the reinforced soil technique and the one applications of reinforced soil technique are in slopes, particularly in France, and they have been very effective.

And people have, even in Himalayas, you see, you have lot of slopes like this and then, many places people have been doing it very effectively because the thing is, that particularly in hilly areas you want to extra widen the road and, but so you have to start from bottom and have some… Say, suppose you want to increase to say 10 meters, you can, you know, you know, identify the area and see, that it is ok and you know, try to find out the backfill material, try to give a design and it is possible, you know, that is very important and this can be done, you know, this type of phasing, any type of materials can be used.

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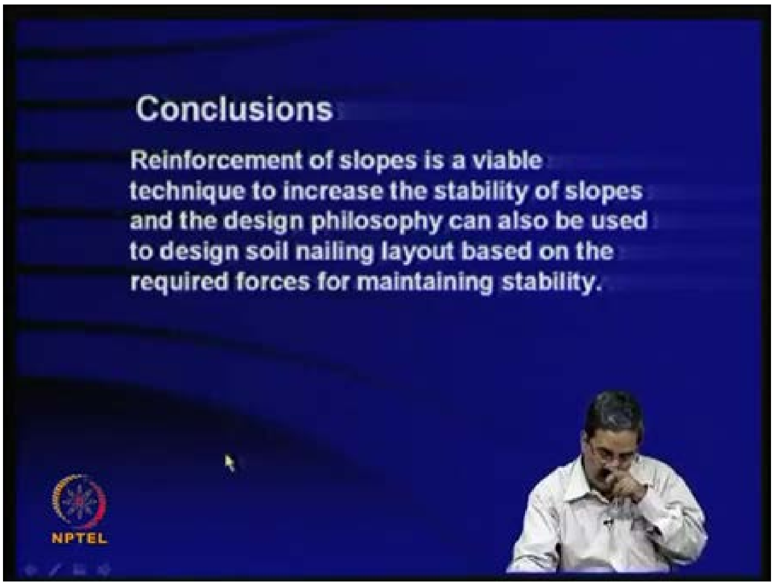

What I want to just say is that, this reinforcement of slopes is a viable technique, particularly in, you know, as I just mentioned, the design of slopes, it is very important and the design philosophy has been very simple, right, design philosophy. In fact, I must tell you, there are so many guidelines on this, so many software are there, online software and commercial software and company software also.

Say for example, if you are using a particular company, they have their own, you know, the thing is, that they will only make geogrids of certain grades, like see, they may use one material only, like you know, say for example, as I just mentioned, you have different types of geogrids, you have different types of geotextiles. So, you also saw in the same example, like it has a tensile strength of 80 and something like that.

So, some of this people, what they do is that to make it all the process easy, they just make it customized to their own needs to, you know, they, they would have had their own labs, each company will have their own labs and all that you know, to find out the tensile properties, drainage properties, friction properties and all that.

You know, whatever is required in design, like as I said, even you know, many things, they are just even damage factor, you know. If I was just mentioning about the damage factors and environmental factor, all should be calculated. The companies will have all that information and once you have that information, then it is very easy, in the sense that you have to use the appropriate software and do that. And actually, see, the method is also quite simple. You have seen, that you are trying to calculate what is the driving force and what should be the resistance, that is, to be is available and if the resistance is not available, you are trying to increase that by a suitable factor, of one suitable factor.

In fact, this factor of safety is another big problem; I want to tell you that, you know, see this in slopes. If you have less factor of safety, say for example, 1.3 and 1.4 or whatever, it means, that there will be some deformation. In fact, many people have not even be able to appreciate, that there is a friction between the soil and reinforcement because of which there will be some deformations and if there will be, if you, if you do not understand, that there will be deformations. Then, and say for example, in some wall, you know, where, which I saw, say for example, some, you say Vizag or someplace, it is, say 10 meters high wall, there will be some point naught 1 percent will be the deformations. So, if there is some deformation of say 5 mm or 10 mm are expected, it will happen and if you, if you, if you think, that because it is a structure, compacted soil structure, there will be some deformations. So, like literature says, about 0.1 percent.

In one case what happened was, that the height of the retaining wall was about, it is a slope, it is about 42 meters and if you take about 0.1 percent, it is about 420 mm. Actually, say 420 mm is a big number, you know, this much; so, 40 mm, 40 mm. So, if you construct that wall, it is bound to settle by that much amount and these people, what they did was, that they have just placed everything. They constructed RE wall and started pouring the concrete on the top, you know, they want to construct the road, you know.

But then the road cracked, you know, in the sense, that you know, 420 mm is the, it's total settlement expected and there will be some changes also, you know. The PCC cannot take tensile strains, pre-stressed like, you know, that plain concrete cannot take. It is not reinforced concrete also, like you know, they started some simple pavement wall block or something, they started putting. And what happened was, that you know, you just settling and they kept on adding, you know, they are trying to put layer by layer cement and all that, which was not necessary. And finally, they were very alarmed, that it was, there are lot of cracks, but the fact was, that they did not, it is a, the deformations of the reinforced soil have to be expected, you know.

Because it is a, as I said, the compatibly between reinforcement and soil is there and to sure make sure, that the compatibility works, there will be small deformations and that lead to that much thing and if the wall height is going to be higher, it is definitely have this thing. So, that is very important.

And see, many of the, see this techniques could be used for repair of failed slopes also. As I just showed you in the beginning, like there, there is a slope failure and how do you repair it. So, in that point what happened? Maybe everything was fine, but only at that point there is some problem, where you know, because the driving forces are more than the resisting forces, so you can do nailing there only.

Say for example, nailing you know, some places you do not need everywhere. You know, the thing is, wherever it is weak, you have to strengthen that place. So, one can really even use the same design philosophy. Of course, we will discuss this much more in detail, but essentially, one can evaluate some of these factors very well using this reinforced soil technique very usefully. And drainage is very important because you have to, I have seen where, you know, particularly these techniques are useful in slopes, and slopes, there will be lot of water coming up.

So, you have to provide drainage layers, be, even before constructing and the other important point was, that there is some native soil will be there and you are putting up a backfill. And between the backfill and the native soil you have to have some sort of connections because what happens, this is a new material somewhat, you know, it will be, the stiffness will be different from the stiffness of the native soil.

Native soil has some stiffness, say for example, there will be a fractured rock and you are trying to put a backfill here. So, the stiffness of the fractured rock is different and the, this thing, the, the backfill is different. So, you need to have some sort of interface connections between the native soil and the, native soil and the, native rock and the soil.

In fact, if you just see, in Vizag, they have, Vijayawada, they have, you know, shear connectors, you know, just transfer the, if there is some, there is some integrity somewhat maintained. Otherwise, at the interface should not be a cause for failure, it should not; just whole thing should not come out at the interface. Shear resistance, you know, between two interfaces, like native rock and soil, there should be some intersect and then, if it tends to fail that length, that you know, area of cross-section should be sufficient, you have, see that, that shear will not occur.

So, this is a very important and I am sure, that this needs much more, you know, lot of research is being done on these lines, both on experimental side, numerical side and in the field studies, like people have been doing this, you know. There are so many issues in this.

So, thank you.