Ground Improvement

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Lecture No. # 31

Reinforced Soil Walls – I

This is lecture number 31, in this lecture would be talking about reinforced soil retaining walls. In fact, this is one of the biggest contributions of reinforced soil, because of which you are able to construct many retaining walls made of this reinforced soil. This is a significantly contributed to infrastructure construction.

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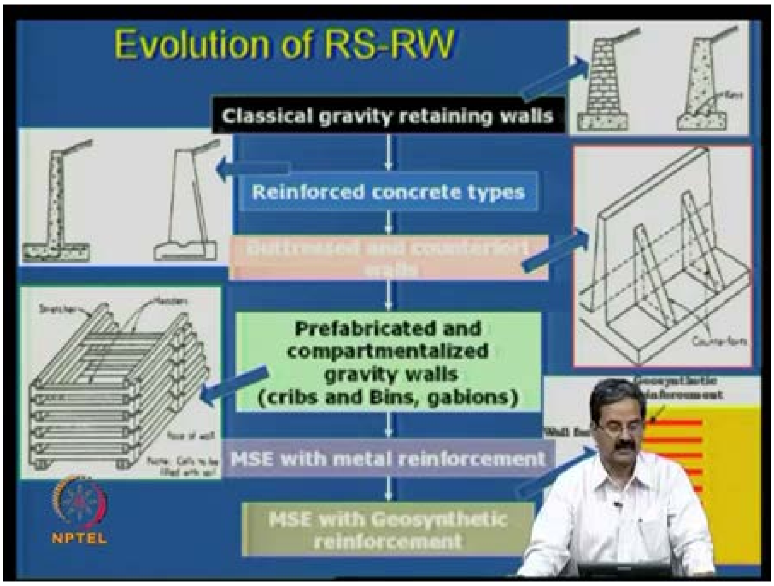

The way that the reinforced soil, we have already seen and its applications to reinforced soil walls or the retaining walls is something that is very unique. And in fact, this is the one that we had in a classical retaining walls in which has, say for example, you call the gravity retaining walls in which the weight of the soil, exerts some sort of a lateral pressure component and if by the weight of this soil alone the the retaining structure you try to resist the horizontal force. So, that is a concept of gravity wall in which the weight of the soil the retaining system, and it is, you try to have some geometrical propositions;

in such a way that the it it will have, it will withstand all the pressures both lateral pressures and the vertical components of pressures.

So, we design this, and in fact, sometimes when this is required we try to provide shear keys also to increase the shear resistance, because when there is a lateral force acting the there should be some sort of resistance that needs to be provided, either it can be a shear resist keys here and it can be even at the bottom sometimes like, so, that is one concept for gravity retaining walls.

Next thing is a reinforced concrete types in which you have you know when bending and bending develops you know. So, you try to put some sort of you this is a reinforced concrete wall in which because of the, you try to understand the bending moments developed and try to provide the steel to withstand the bending and all that and try to have a suitable design methodology for that which is well established.

So, you have essentially by the you try to resist the earth pressures by this cantilever action here and we also have what you call the buttress and counter fort retaining wall in which you try to provide you know when you want to reduce the thickness you know the thing is that what happens is that the base width of this wall and there are certain propositions in our retaining wall literature in which you may you must have sort of dimensions here some dimensions here, some dimensions here and then when the height is beyond seven meters or eight meters the possibility is that this widths become little bigger.

So, we try to provide some short of counter forts here which will see that the concrete areas are reduced the quantities of concrete are reduced in this system .The other one that we have in the retaining walls is that you try to compartmentalize the systems like you know in in the form of a bin or a you try to, this is a system in which you can place all this materials and it is like it acts as like a confined material. In a confined material that though there is a pressure from all the sides this confinement that we have it takes care of the pressures developed.

So, that way it is a simple system that we have. In fact, this has been used effectively in some of the flyovers in Bangalore which is very cost effective.

And the final one was that what we would be talking today is the reinforced that walls in which you have facing element, you have a geosynthetic reinforcement and you have a back fill.

So, this we call it see in in there are two types here, One is actually mechanically stabilized earth walls. We call it m s e with metal reinforcement, one can have metal reinforcement otherwise you can also have a geo-grid reinforcement or a geosynthetic reinforcement or whatever.

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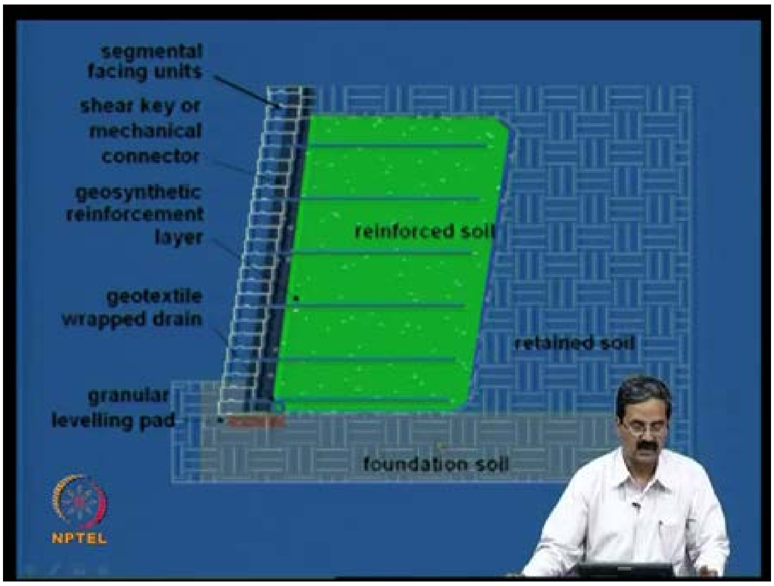

So, these are the categories and this is the way that it looks like that you have a reinforced soil and then you have retaining wall and foundation soil.

And you have different elements here you have a segment these are all called actually this type of wall is called segmental retaining wall, in which you have a you know this called segmental facing. We will see that what is the difference, you can have a full there are different types of facing.

One one can have as I just mention earlier these retaining the reinforced elements are designed to take care of the lateral pressures.

Once you know, what should be the length and the spacing of that? We have seen this idea in the reinforced soil slopes and once you know this design comfortably then, whatever you get here, the pressures are somewhat going to be [minimals/minimum] minimum and we try to provide some short of segmental facing types,it can be full facing or it can be even concrete panel that is what we see in most of the flyover projects in India and we also have; what you call a shear key or a mechanical connector between the two facing elements.

And then do a geosynthetic reinforcement and geo you have a geo-textile drain here and you have a granular leveling pad and all that.

So, this is a simple way of [re/reinforced] reinforced earth retaining wall system. We will see its design and how it can be constructed in field and all that in this lecture and the coming lectures also.

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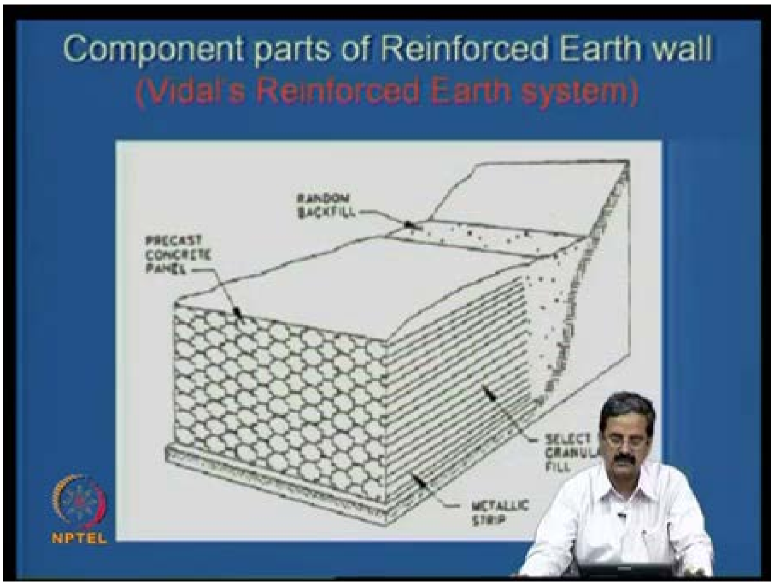

As I just mentioned vidal is one person, who developed this technique and when he developed this technique he had this precast concrete panels then this is a back fill this is actually back fill this we call it a wall fill wall fill means this is a reinforced soil wall. So, whatever you are trying to use it as a wall fill, because it should have good friction right good friction should be there and that is what we call it the reinforced earth. In fact, the same company has been continuing and then construct a lot of reinforced earth walls in abroad and india and it has been quite very useful technique.

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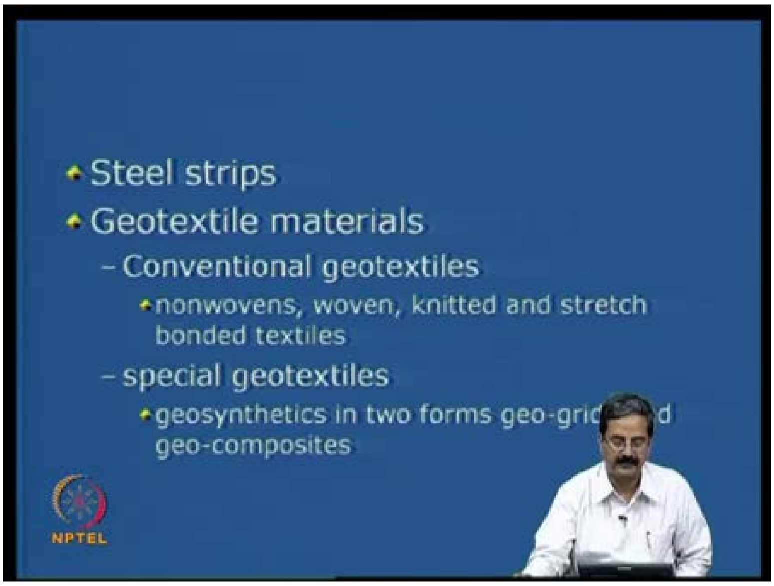

And you can have steel strips as a reinforcement then have geo-textile materials you can have you know the conventional geotextiles can be you know, it can be nonwovens woven’s knitted stretch bonded many types of materials that we saw earlier can be used as a reinforcement material.

Sometimes ,even geo-textile special geotextiles like say for example, geo-composites like as I said, when the pore pressures are going to be higher or if the clay is somewhat poor quality, we can use a geo-composite in which you have a reinforcement as well as a drainage material attached to it.

So, the reinforcement is good enough to take care of the lateral pressures and the drainage action of the geo-composite helps in draining the back fill.

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What are the principal requirements of the reinforcement?We have seen that strength of the reinforcement. In fact, we did calculations on slope stability and other things strength of the geo-textile or the geo-grid is important and its stability like it should not creep to much of course, the polymeric materials do creep and this strength and stability are important then durability like how long you know, because you are trying to design for 100 years or 50 years or whatever.

Then ease of handling reinforcement should be able to, you should be able to handle in a very easy manner like you know, you can bring them to a in a lorry or you know in some short of containers and put them on the field very importantly high coefficient of friction or the [adhe/adherence] adherence with the soil like, you know we need good friction between the soil and reinforcement that is very important, because that is a whole concept of reinforced soil.

Now, it should have low cost also like you know why are you using this?You need to have you know apart from technical advantages like we say that, we can increase the width of this reinforced concrete you know the thickness of the stem and all that in the case of reinforced concrete it involves you can say that.

But we essential want low cost readily available, readily availability. You know ready availability is something very important why because, it should be done faster; it should be comfortably in the way that it can influence the whole system.

So, the whole construction should be faster you know the, so we we saw that advantages of the reinforced soil earlier. It should be able to should have this some of this principle requirements and see that it is also intended function. So, it should have among them the important properties as I just mentioned tensile strength.

Like say for example, there is so much earth pressure that is developed with some spacing and length of the reinforcement we get this tensile strength like that is one thing we will see that.

Tensile modulus is very important, because if there is a deformation, you know movement is very important and reinforced soil walls also deform and tensile the modulus of deformation like the tensile when you get what you get from tensile strength is very important.

And the third one is interface shear strength is also very important these 3 components are very important in the design.

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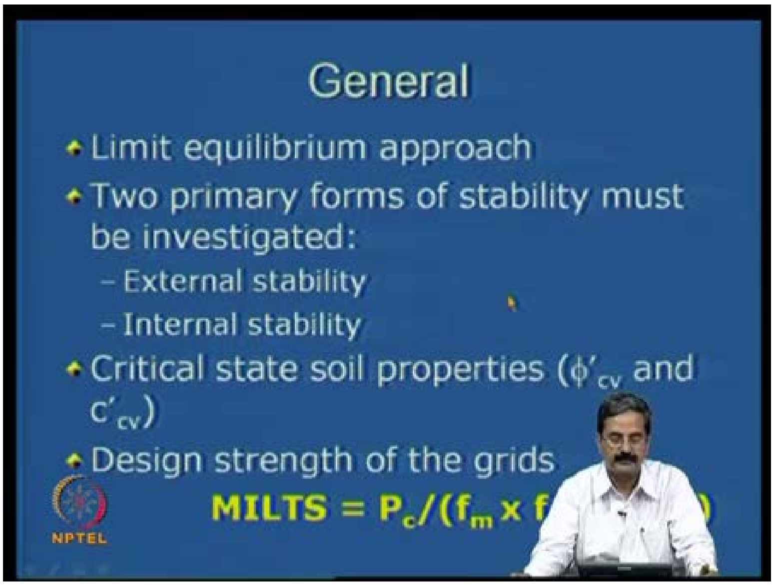

So, how do you go about design particularly when you are trying to use the the the reinforced soil technique in this is something that we use a limit equilibrium approach.

We need to look for stability, external stability, internal stability and the properties of the back fill will be the friction angle at constant volumes phi and c.

You know this shear strength parameters should be obtained corresponding to law sates. This what we saw in reinforced slopes also that we try to conduct say direct shear test or triaxil test say for example, better to do triaxial test in which you get c and phi parameters for effective stress parameters and for say for example, 3 or 4 normal stresses and then you get CV from this large strain.

So, essentially CV means Constant Volume strains and design strength of the geo grids is what we have seen that the company gives some property say for example, we are seen one example, where you can say its 50 kilo newton per meter.

And then you have various factors like the partial factors like f m the manufacturing constant environmental factor, damage factor and all that all this factors are there one can use and then finally, you should just use this as a design strength ok.

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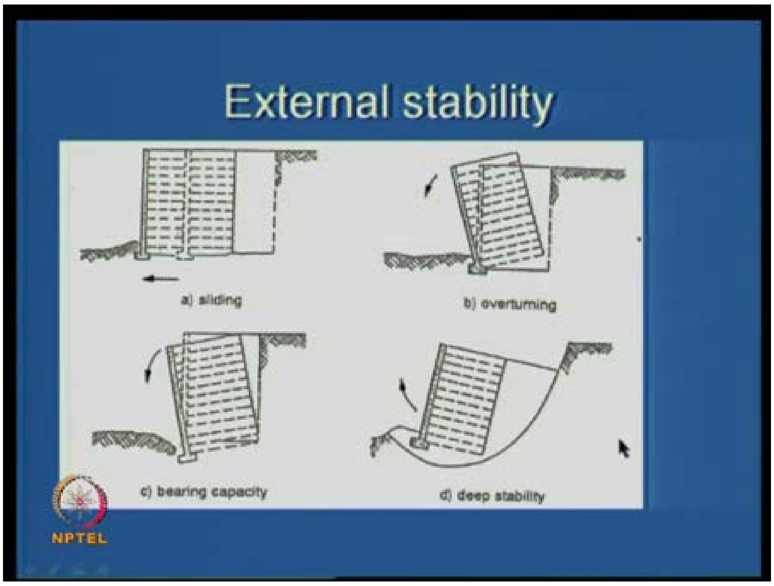

So, what are the external stability conservations?These are all you know standard even for regular retaining walls. We know that, we design the retaining walls for bearing overturning and sliding and deep deep stability like the retaining wall whether it is a reinforced earth wall or a any other like conventional retaining wall it should not slide right.

That is one thing so sliding resistance is important overturning is also important, then bearing capacity failure should not occur say for example, it has some it will once you construct a [str/structure] structure like this, since there is nothing here there is some sort of pressures and moments that get developed.

And the pressure bearing pressure should satisfactory here deep seated stability like you may construct a retaining wall.

But it should not it should not be in a slip circle you know if this is a you try you should construct, you know you should really do a some sort of analysis in which wherever you are going to place a reinforced earth wall the area should not lead to some stability like issue like this [globa/global] global stability we call it. So, all this things have to be satisfied.

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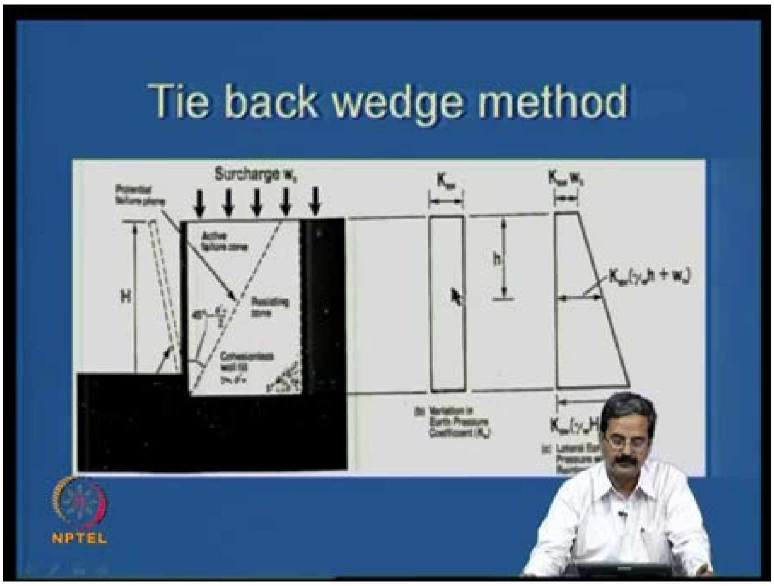

In fact, to to design the reinforced earth walls we have two methods, one is called Tie Back Wedge method I will just explain what it is and see we what tie is a tension member and then this is a wedge that is forming right.

So, you try to put reinforcement like a tie member and then keep the wedge back in position.

So, that is why we call it Tie Back Wedge method and the assumptions some of the things are that like, you have a rotation is above this thing and the earth pressure distributions like this.

It is like 44 minus phi by 2 is a act failure zone like, this is a failure zone at which the failure surface and this essentially we assume that the wall is cohesion less and it rotates above this and the earth pressure variation know we assume that, it is same everywhere like we assume [ac/active] active earth pressure conditions ok.

Activate earth pressure conditions we assume and, because the there are two conditions state of in the beginning I said the state of soil is it a K Naught condition or a K A condition like is it the coefficient of earth pressure thrust is there or is it for the active earth pressure we should design is something very important.

So, this material like you know, you put a geo-textile say for example, what you are trying to do is that we later will put some geotextiles here and then there will be some deformation. So, because of which there will be an active condition.

So, we assume that the variation earth pressure is constant and the earth pressure lateral ea[rth]- pressure diagram will be like this you know.

Earth pressure diagram in terms of this thing this is just a k a constant this is K A gamma h right K A gamma h is the pressure and now you have a surcharge also W S so, plus you add you know. So, this is a actually the earth pressure at any point due to it is a with a its variation with depth as well as due to the surcharge charge as well.This is called Tie Back Wedge method.

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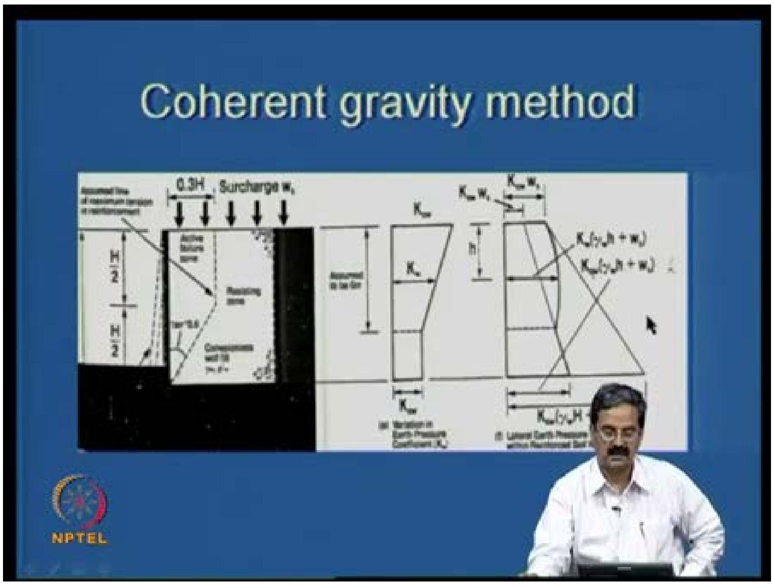

We have another method which is something which people have you know based on observations of many of the RE walls you know they have observed that you can in the earth pressure, if you really –[ob]serve it will not be you know an active condition.

It will be in a K Naught condition for some about at least 5 to 6 and based on that. In fact, see they they say that, In fact, K Naught they just put here.

You can see K Naught into that is one thing K Naught will be its about 6 meters up to say for example, if you are trying to measure small high retaining walls like 3 meters or 4 meters if you measure earth pressure it will be K Naught like I have measured.

In fact, in one of the cases in Delhi, it is about 7 or 8 meters, but I was [ma/measuring] measuring with depth at some points the earth pressure was K Naught. You know we have we have a measurement of by using some diaphragm and all that there is a method of measuring earth pressures [we/i] I used it and found that the earth pressure is corresponding to K Naught condition.

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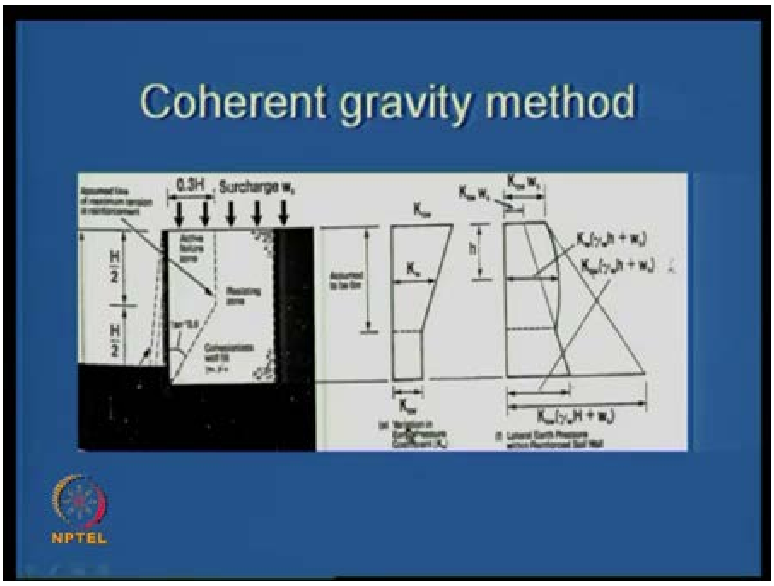

Like which means that soil has not moved like there is no lateral strain is 0 that is what the point is.

So, when you have that. So, then. So, K Naught is always 1 minus sine phi and K A is 1 minus sine phi by 1 plus sine phi. So, as the height is increased it will become K Naught to K A.

It will decrease actually ok. Say for example, if the wall height is 8 meters. So, it will be this. So, you have to assume a distribution diagram like this ok. Earth pressure distribution diagram like this and same thing also here. Like, there the the difference is only that you have the other one superimposed on this.

So, this is a the coherent gravity method is what it means is that, people have observed that many of the retaining walls of particularly smaller heights or having a state of rest and then the even the failure diagram. In fact, people have measured.

You know how do you measure the earth pressure diagram in fact, you can monitor the tensile strengths in the reinforcement instead of the 45 minus phi by 2 that what we have seen this is the earth pressure the failure zone that they have taken. In fact, even if you just do a finite element analysis it comes like this. It is this point you know like in the previous case.

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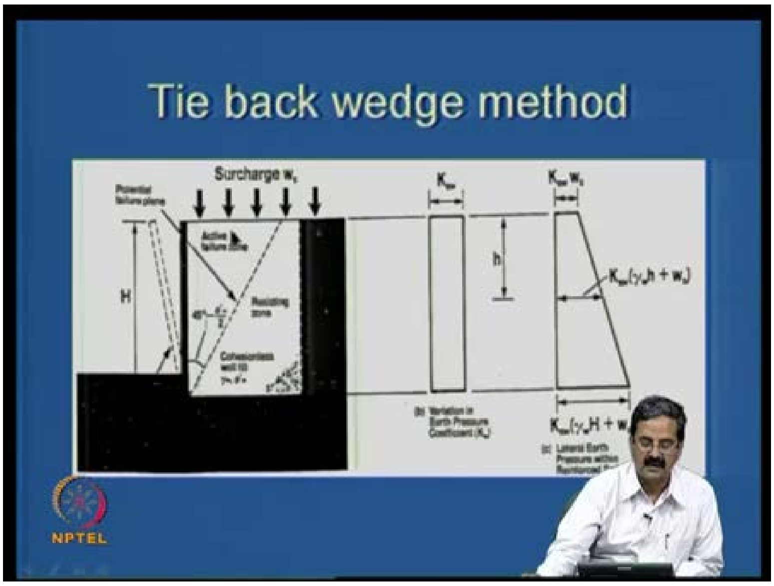

It is like this you know. So, whereas, you are just cutting it here only what it means is that now the advantage is that, earth pressure that you have to coincident design is much less in the in the next in the coherent gravity method compared to this case.

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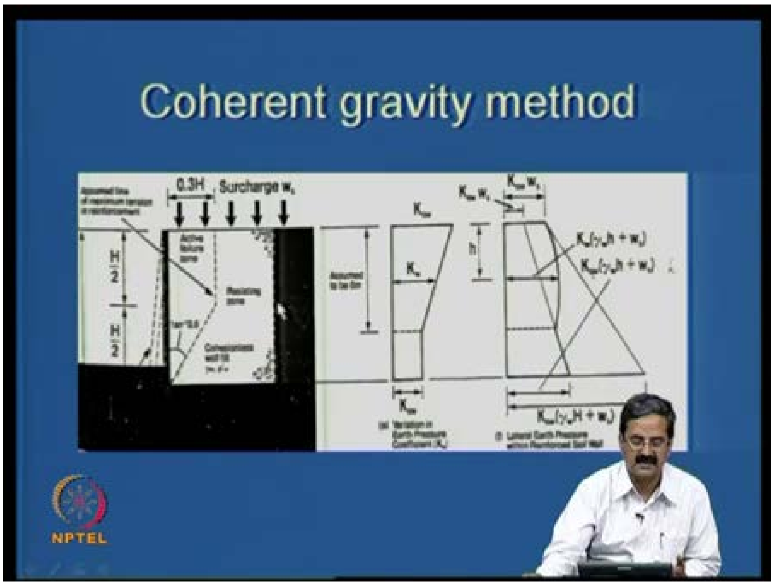

Here you are trying to consider all this pressure whereas, in the next this case the earth pressure is only like this which is which means that this method is somewhat economical is it not, we are trying to make this if you make based on the observations this is a method that was used developed by you know some group of people in France and particularly it is valid for steel reinforcement. You know, because they are initial working for steel reinforcement and steel reinforcement is stiffer we have seen that.

And, whereas, a geo-textile is a flexible reinforcement at it needs some strain. So, I cannot assume this sort of a distribution I should only go for the previous distribution.

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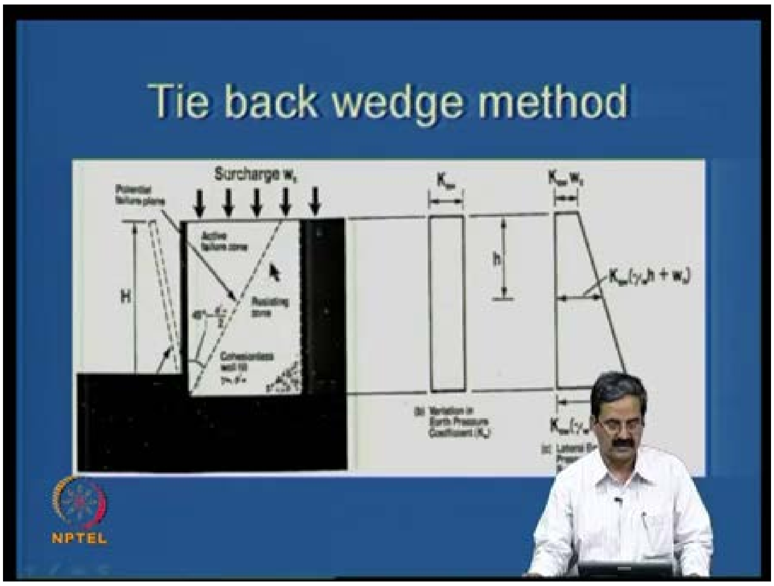

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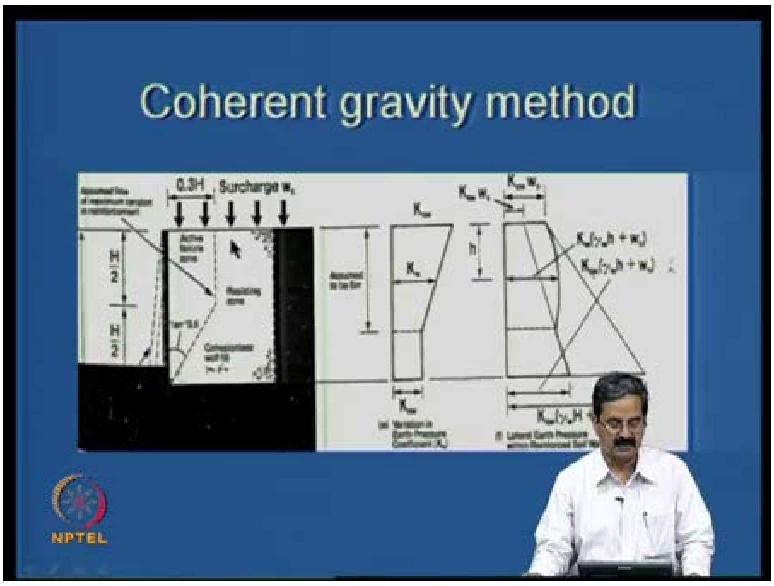

In this distribution, what people have observed is that this is just a. So, it also rotates about this point not in other case it was somewhat reverse like you can see in the previous case.

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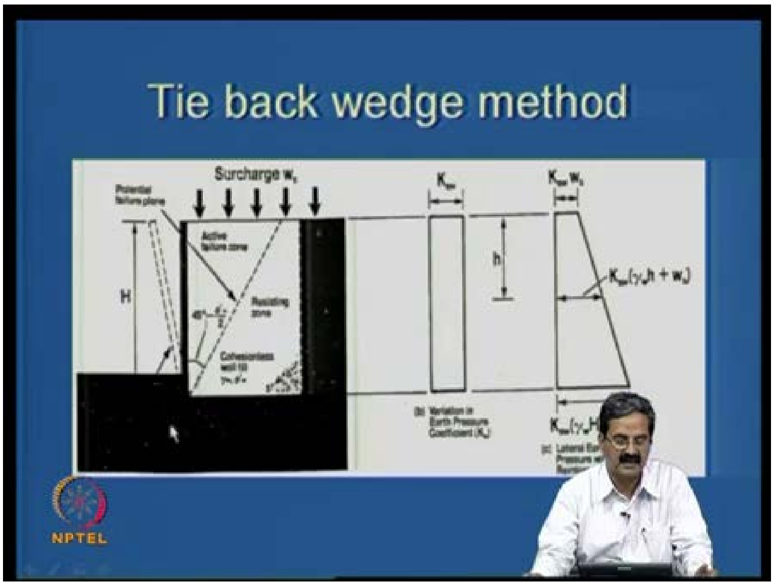

It is the rotation is about the toe whereas here the rotation is at the top. So, that is what the assumption that they have and this is they have measured actually they have measured the earth pressures and even measured the strains.

Like you know you can place you know you can measure the strain along the reinforcement entire length of the reinforcement. And in this zone what happens is that the if this is the lateral force acting the tensile strains direction will be in the opposite direction ok.

The strain measurements they will be like this and beyond a failure point the they try to hold it ok.

They direction of strain should be different on both sides. So, direction based on that actually shear stress distribution along this reinforcement you know, because this is a shear stress mobilization right.

Shear stress mobilization along the reinforcement based on that, you can locate this actual failure surface, because at this point you know the beyond you know this point will constitute one location where the shear strain that distribution will be different on either side you know. So, that is what you know the thing is that what it means is that.

You can construct this like you know you what people have done is using finite element analysis also or using experiments also people have measured using you can put reinforcement and measured its tensile strengths.

So, at this point actually the point at which it is maximum you know we have seen one even in the Binquit Lee method , also they assume some maximum strain distribution and we we made some assumptions there similar to that we have the location of strains here. So, it will be like that right. So, if you construct this particular line and based on the observations they found they observed that for a h by 2distance it is about 10 inverse 0.6, 0.6 and another h by 2 the height of that it will be straight line and this particular things is 0.3 h. So, actually this is the line of maximum tension reinforcement.

So, if you observe for all the reinforcement elements where is the maximum tension and then locate them and join them you know the that actually, you know that there is a you can find out the distribution of tension on the reinforcement. So, as friction develops along this there will be a strain mobilization and then all this points you can join even in flack and flack's analysis you can get that. So, this is one important method that one should understand.

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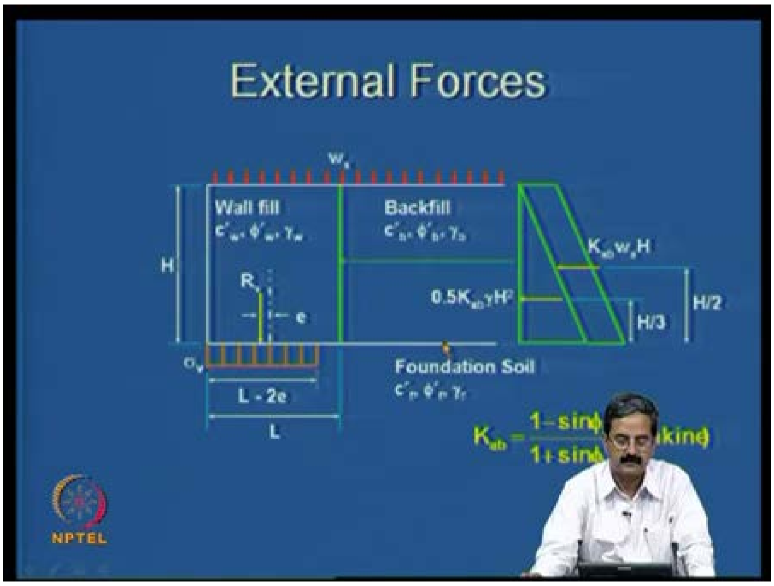

So, these two are some design philosophies that people have and another important thing that is that ok.- You have seen that the there are three different ways of assessing the external stability.

We just saw the pictorially the diagram and how do you really calculate that.We will see that say for example, this is earth pressure diagram that we have to consider like half K A b gamma h square half K A b like point 5 gamma k a active, because this is for a geo-textile I am what I am telling is a geo-textile.

Say, half K A gamma h square and then this is h by 3 we assume and then this is the sub the other one is W S is what other one. So, you have to, like the other important thing is that.

The bearing for the bearing pressure we assume that, there are two types of earth pressure distribute[on]- the distributions of pressure contact pressure actually.

You know that we have a trapezoidal putting Trapezoidal distribution you know where you have a maximum tension developed and the minimum tension developed and we have that b by 6 rule right b by 6 rule we have. So, that b by 6 rule is very important and here also similar thing we measure and that is called trapezoidal distribution that is valid for stiff footings I mean rigid footings like concrete footings and all that and whereas, this is since reinforced soil is a flexible structure and you will not have the development of maximum pressure and minimum pressure .It gets adjusted in such a manner that, if l is the length of the foundation like in R E wall length is about l over a distance l minus 2 it gets adjusted sigma v is what you get.

And. So, instead of a trapezoidal you can have trapezoidal is one type of distribution we can assume and this is called Meyerhof distribution ok.

In Trapezoidal distribution we assume that, you have a maximum value you have a minimum value and the distribution varies is in the form of A the the trapezoid.

But then that is valid in the case of rigid foundations, but reinforced soil being a flexible structure what happens is that any pressure gets redistributed and you will have only constant value.

So, that is a maximum value sigma v you get and this is ok. This is a usual thing. So, this one another important thing it is called Meyerhoff distribution.

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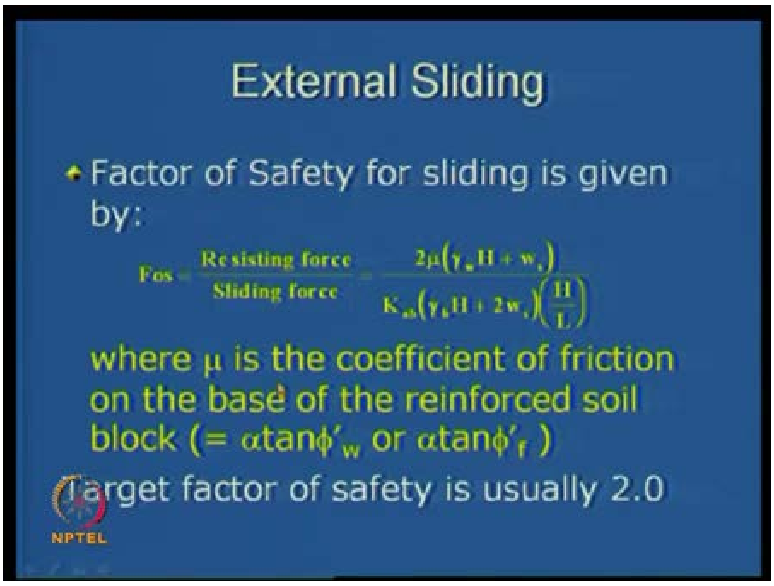

So, how do you get this factors of safety like we have seen that.

For sliding, there is a sliding force which is, because of K A b gamma h square by 2 and surcharge and all that that you just put here resisting force is nothing, but the weight of the that 2 at bottom comes here.

So, 2 into mu is nothing but, the mu is nothing but, the coefficient of friction on the base soil of the reinforced soil and it is the total resisting force you know gamma w into height plus W S is a total resisting force right.

So, the fact of, So, you try to calculate this and the fact of safety has to be two right this is one thing.

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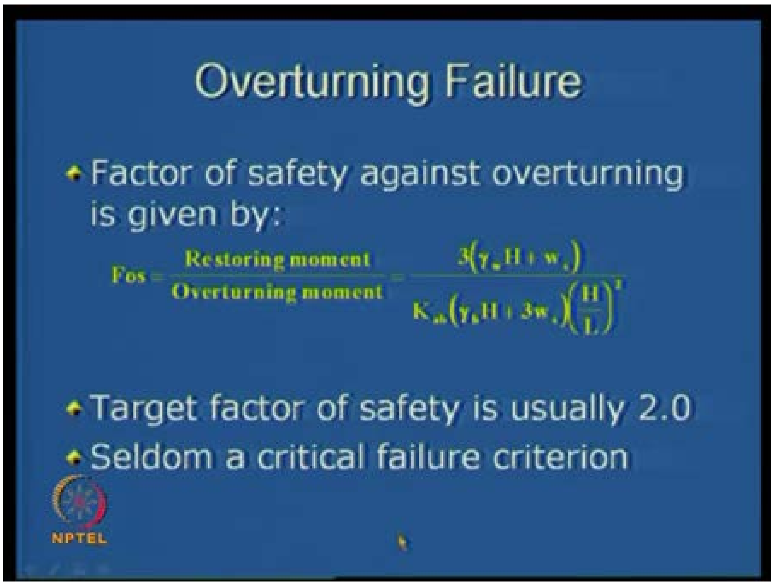

Now, even the for the overturning you have to calculate resisting moment and also the [overtu/overturning] overturning moments.

So, this is actually you should know the base of that like one third where it acts and all that and then you these are all expressions actually details are you can simply derive this equations which are straight forward ,considering the equilibrium of forces and the factor of safety should be somewhat say two or something and most of the cases it is the sliding that governs the design. So, in this case overturning is not a serious issue if you are able to satisfy the stability issue, the sliding stability issue automatically this gets shorted out.

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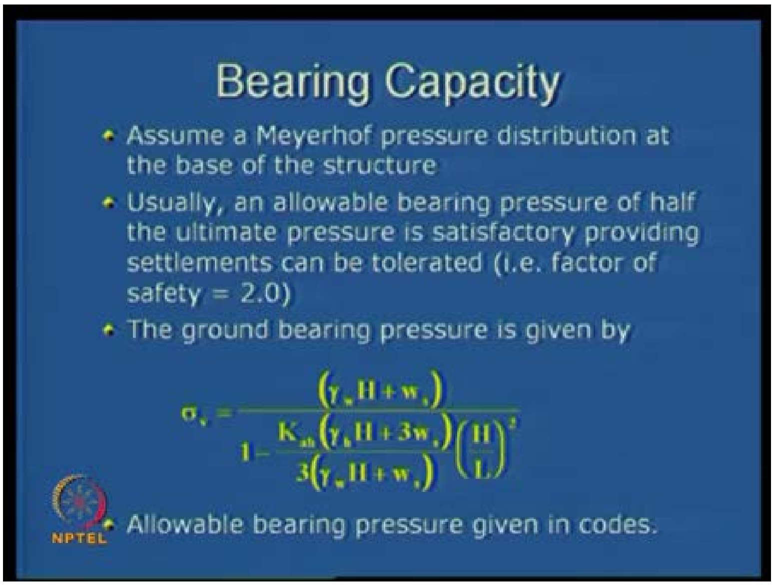

Then bearing pressure bearing pressure is that you know I just showed you about I told, you about the two types of distribution. One is called Trapezoidal distribution you can do that also.

And also you can do Meyerhoff distribution which is nothing but, like there is simple expression that one can get based on the moments and the forces acting on the at the you know at that below the foundation you will get a simple expression one can derive this [con/considering] considering the weights and all that.

And earth pressure coefficients, the maximum pressure will be this and from meyerhoff distribution even you can get from trapezoidal distribution also we know how to get maximum pressure and minimum pressure.

So, actually that this pressure whatever pressure should be the less than the bearing pressure of the soil that is what is very important.

Whatever is the pressure that is created because of the this pressure should be less than the bearing capacity of the soil.

So, usually an allowable bearing pressure of half the ultimate is taken ultimate pressure is taken.

So, we [na/normally] normally have a factor of safety of 2 ,normally you can see that bearing bearing capacity calculations we know and we calculate say for example, 200 k p a is a bearing pressure of the soil and if this pressure is say, 150 it is alright like that right.

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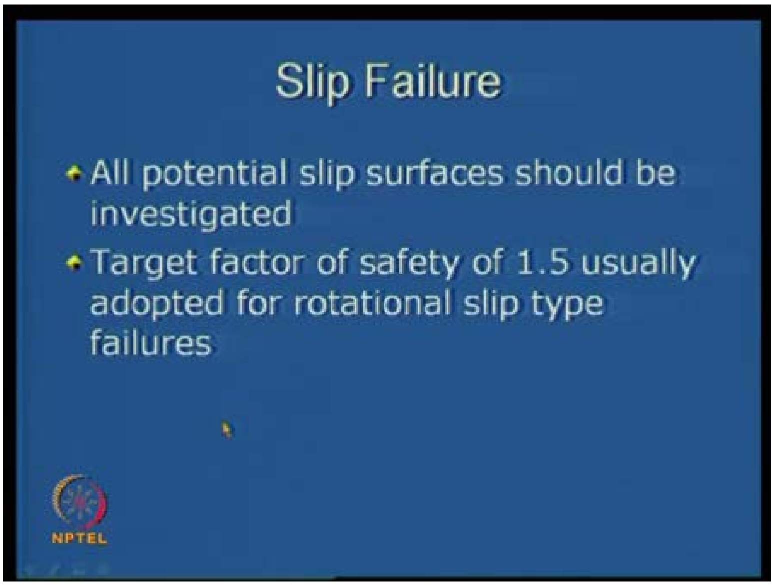

Then we have to say as I said, we are looking at all this global stability issues we should look for you may construct a retaining wall, but is should not be located in a slip surface.

So, all potential slip surfaces should be investigated and the target factor of safety 1.5 is used.

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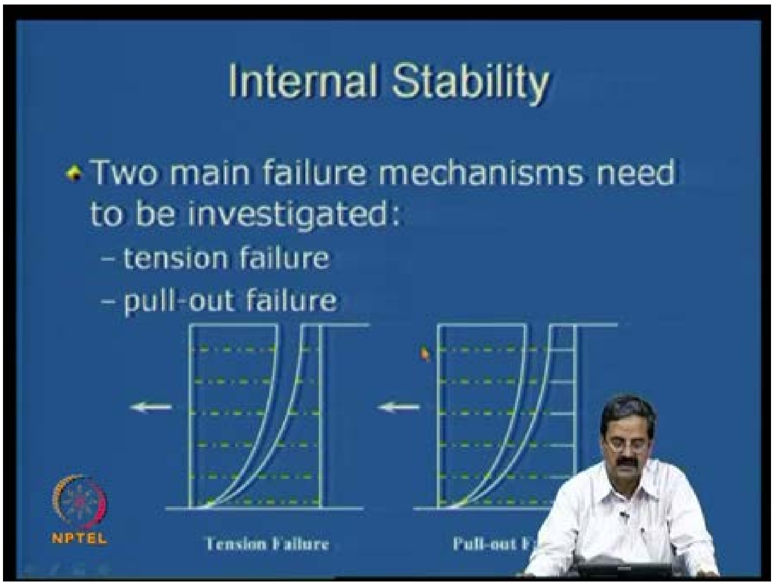

In this case that is what is ours External Stability.

Then, what is Internal Stability, like now, you have introduced a reinforcement. So, it should not fail by tension or it should not come by pull out. It should not just come out like a pull out or it should not fail by tension like this is a tension failure where there is a clear breakage where this pull out you know reinforcement just comes out this pull out.

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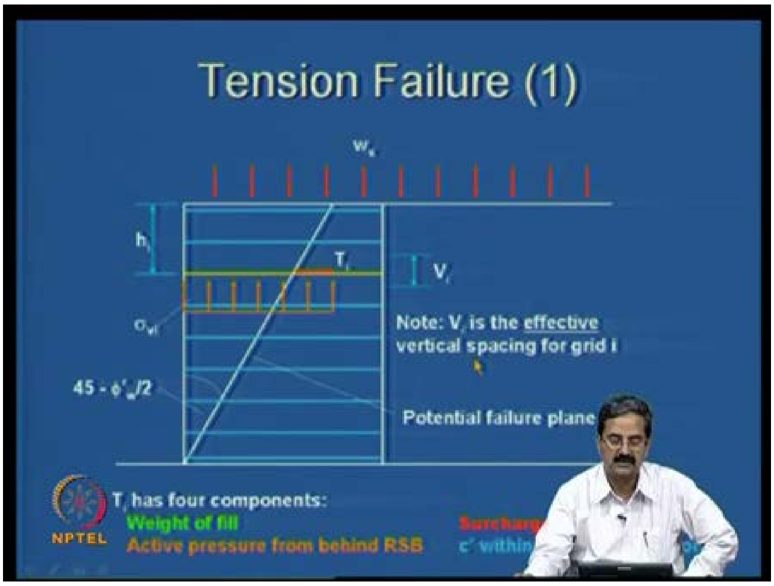

For that we have a method, how do you calculate this tension failure and all that you will see that this is a diagram. You know there is a surcharge acting and you take a a particular reinforcement that is located at a distance h i and this is what I said, is a actually the Meyerhoff distribution type you know the pressure actually, the foundation pressure acts here right.

You can assume that the same pressure acts this is for the maximum height. If the height of the wall is h and this is the maximum pressure that acts here and then as you go up the pressure comes down.

So, the at any level h i you can always calculate the vertical pressure acting total vertical pressure and for that you you are actually calculating horizontal force you put k a times vertical pressure you will get the lateral pressure and.

And then design for T i. what we say is that at this V i you know V i is a horizontal.

We assume that at this I th level which is at at a distance for the top H i and V i is a spacing you know the reinforcement is effective, it can take care of the you know it can provide force within that spacing right.

So, how do you calculate that reinforcement force, it is actually sigma V i you calculate and sigma then K A times sigma v we will get that that we will see there ok.

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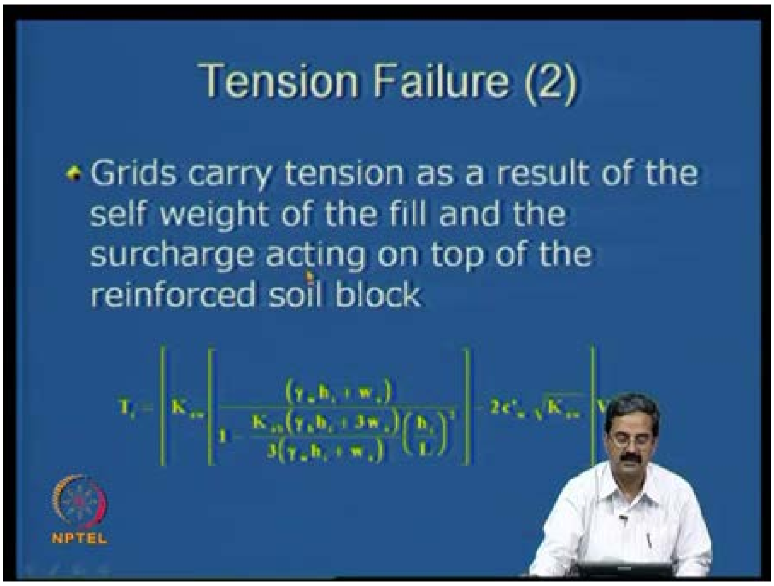

So, the grids carry tension as a result of the self weight of the fill and the surcharge acting on the top of the block, that is what why that is what we did like this is what I said, you know this is actually if we have seen the previous figure, we have seen the expression for you know this is nothing but, the vertical pressure into k a times ok.

And actually we if the soil has cohesion we introduced cohesion term also otherwise it is not required and this acts over a distance V i ok.

T is nothing but, it is like K A times into this vertical pressure minus this actually whatever is this thing and then into V i.

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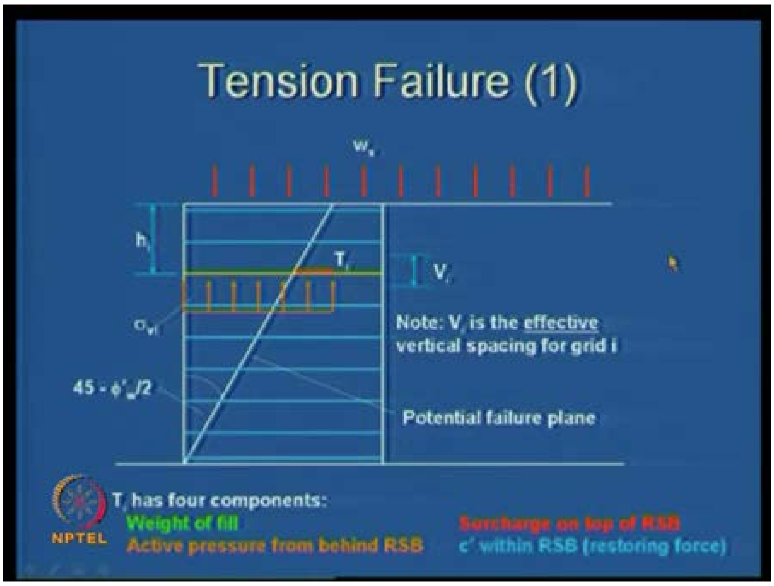

You know as I said, it acts over a distance V i, the T i is nothing but, it acts over this distance you know in this area which is with a spacing V i ok.

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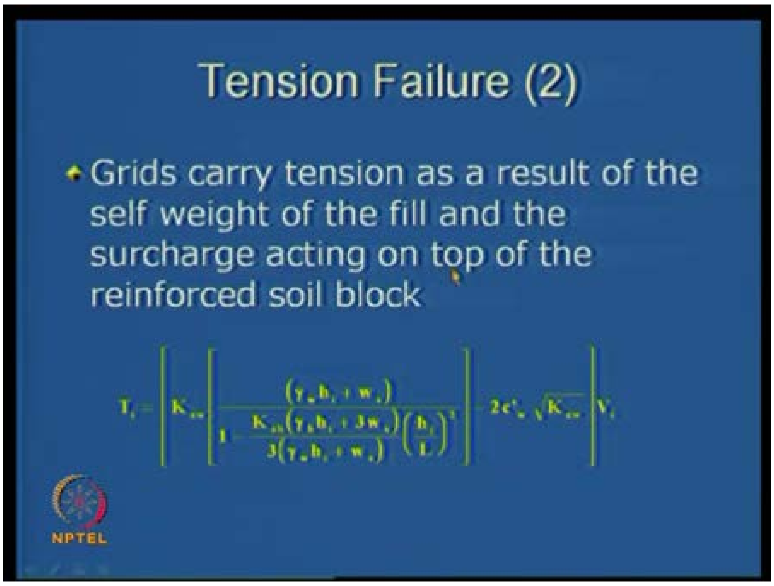

This is how we have this equation.

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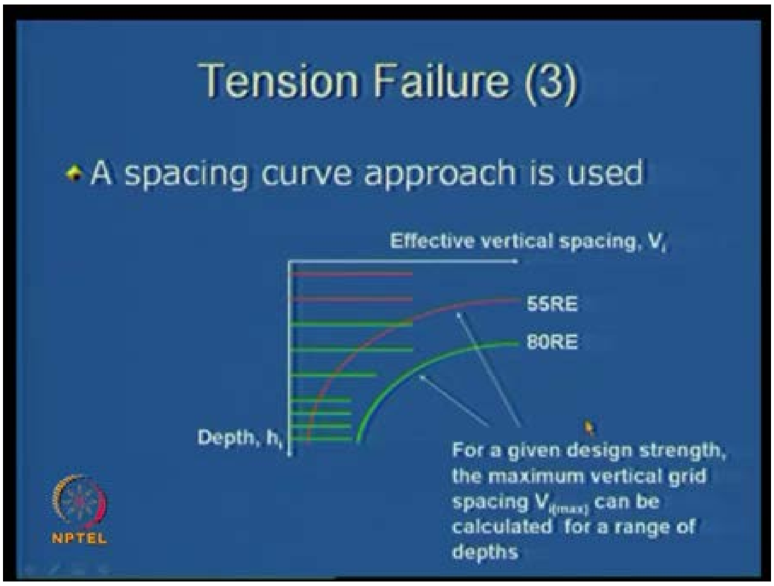

So what we do is that, we calculate for different reinforcement types you know like I will just show you that.

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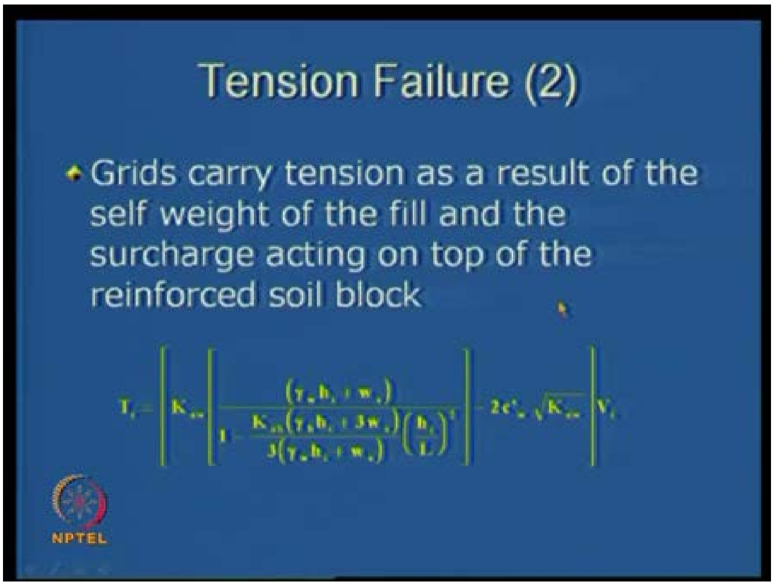

This is an expression and we will see

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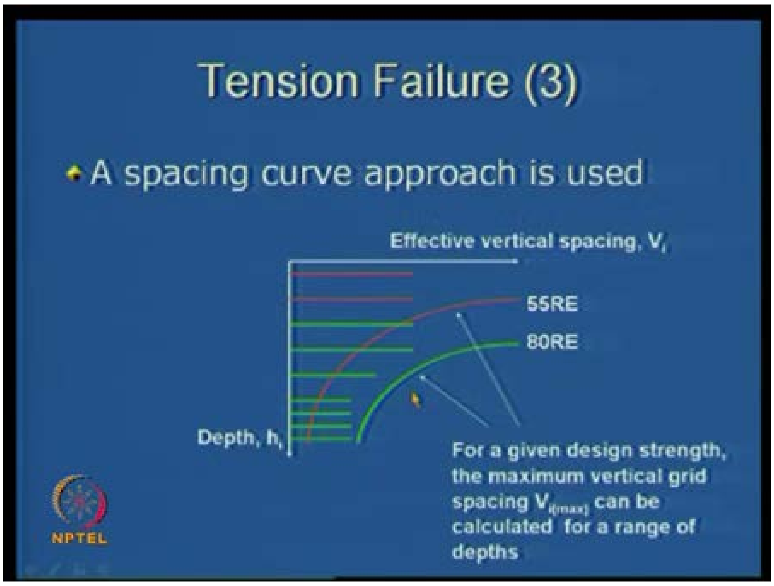

the different you will have as a higher as you you can calculate this as we go down this spacing has to be little higher.

And depending on the type of reinforcement you can develop the short of curves like as I said, see this is the V i spacing . you can have different V i's and also their depth actually h i is here ok.

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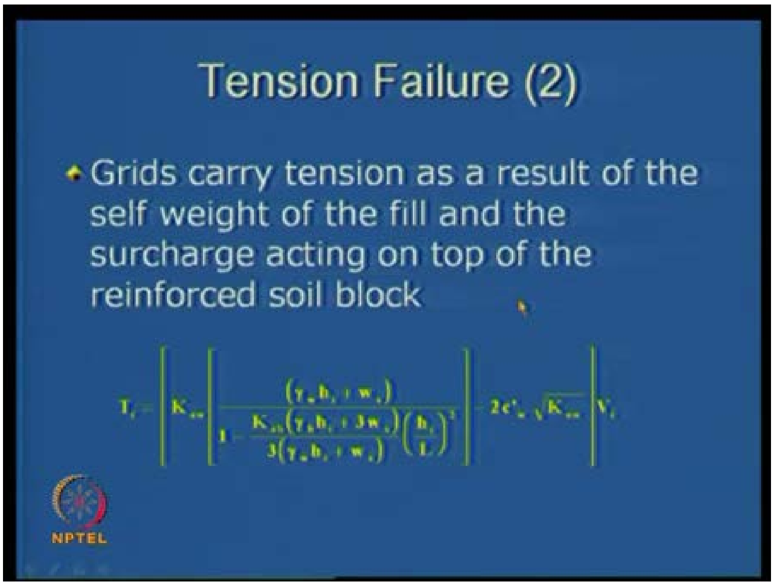

h i is a everything is known here and once based on this you can calculate the T i required [o/otherwise] otherwise we know what type of reinforcement materials I have. You know I have say for example,

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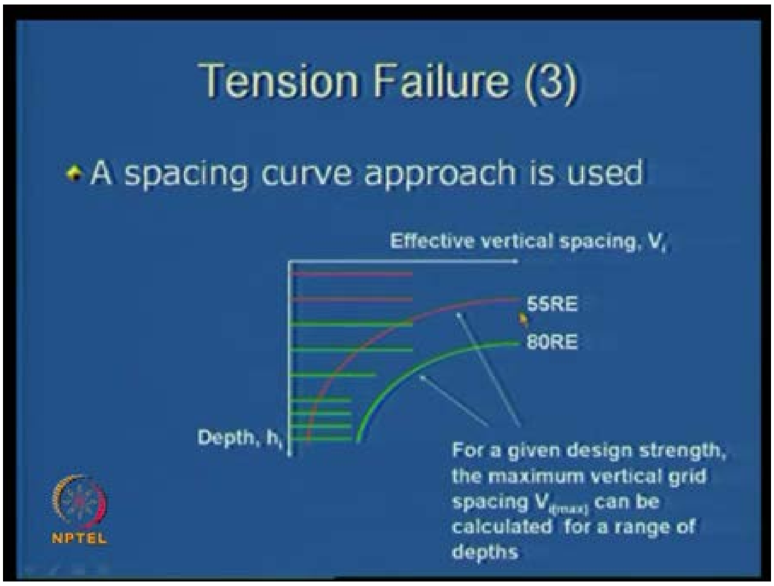

in this case 55 grade and 80 grade.

I can construct back what should be the spacing , if I have this short of reinforcement at different depths is what is given by this equation.

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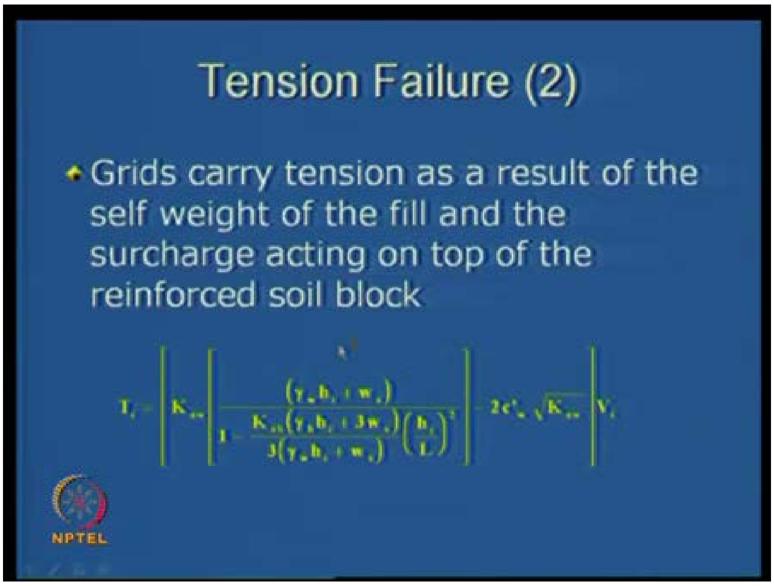

So, this is that say for example, 40 grade 40 grade I do not want to use, but I can say that forty divided by all the partial factors right.

So, maybe you will get some 20 number or 15 number here 15 15 is equal to this and then you have the only variable you assume this as c equal to 0.

So, this term vanishes and all the terms are known and only unknown is so you put different values of V i right. It can be from 1 meter to 0.5 meters to 0.3 meters and all that.

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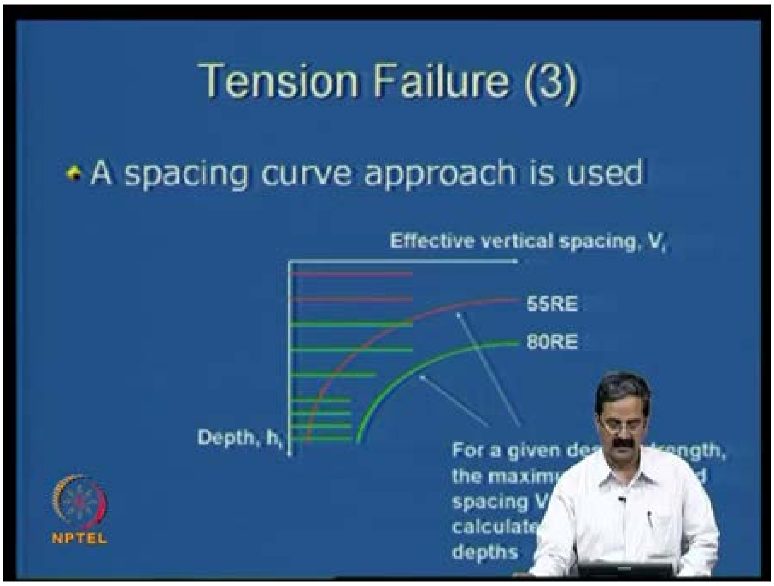

You will get a diagram like this 0.3, 0.4, 0.5 like this and then you can get a diagram like this. So, it is called spacing versus depth diagram and, this will help us to we will see, how it helps us in calculating a spacing ok.

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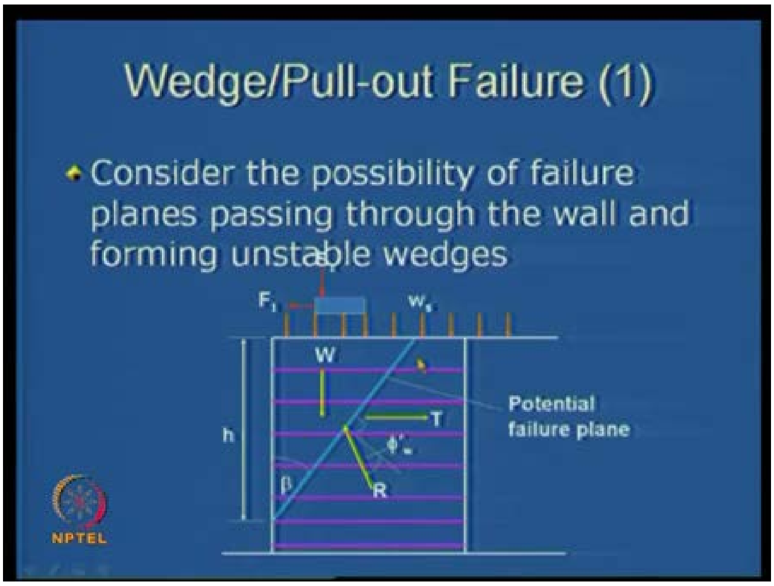

That is one thing we know how to calculate now, some you know you know the reinforcement and [pa/particularly] particularly in the case of geo grades say for example, some grade of geo grid is available you know how to work back what should be the spacing, that needs to be provided so, that that spacing in that spacing ,the lateral pressure is really handled properly or taken care of. then once you provide this reinforcement we have some more considerations like, it should not fail so, we have to calculate tension using the wedge pull out failure also consider the possibility of failure planes passing through the wall and forming unstable wedges.

We try to have number of wedges like this and what we do is that say for example, in this case , you have in this wedge of this particular thing you have 1, 2, 3, 4, 5, 6 layers of reinforcement here like 1 1. So, you have six layers of reinforcement and that.

They have to be in the position that wedge should be stable which means that the sum of all this tension forces reinforcement should be such that it is stable like the t, should be equal to the you know it is a component of this weight ok.

Which you can get from. In fact, I will show you that it can be you know from graphics element. We know the basics of graphics, engineering graphics, one can get that you know from, what is called polygon force polygon, you can get that ok.

I will see like you know, if you know the weight acting you know the horizontal they actually this is the horizontal force acting you know imagine that there is a curvature and there is a vehicle goes like this there is a [com/component] component of f 1 that is acting there is a vertical load acting.

So, it is like a retaining wall and a flyover imagine that ok. So, what we should do we are trying to take a wedge here at an angle beta and then there is a because of the weights acting W and all that, there is a resultant is a force resultant, you have a resultant which has a an angle phi w with this and then you have a theta tension force t which will be required to keep all these things in equilibrium that is what we try to find out.

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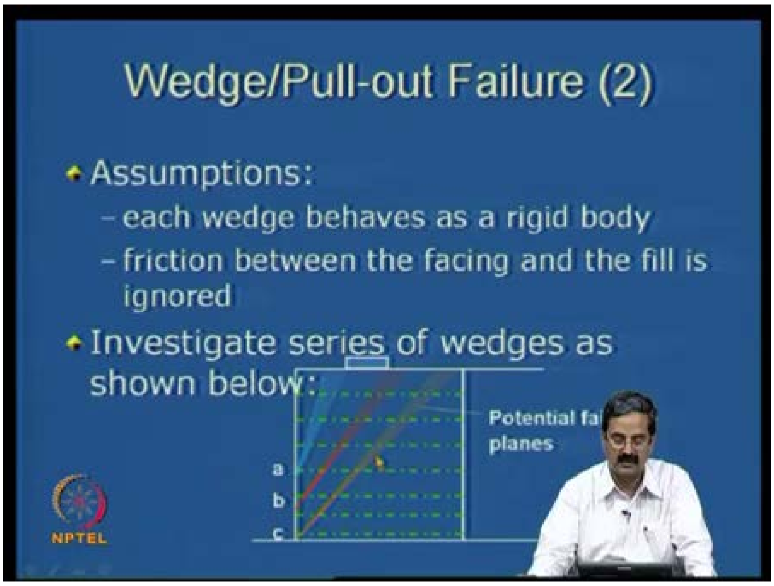

What we do is that, we have to we will make some assumptions, we each wedge behaves as a rigid body friction between the facing and the fills is ignored we investigate a [se/series] series of wedges as shown below.

Like you know ,we take a number of wedge failure conservations here, like you know see even very important is that see say for example, you have So, much reinforcement 1, 2, 3, 4, 5, 6, 7, 8 we have all one two this is all.

So, in this wedge, if we are trying to look at this wedge stability I should see that there should be the tensile force should be so much that this wedge should be in under stable conditions that is what we will investigate in a series of wedges.

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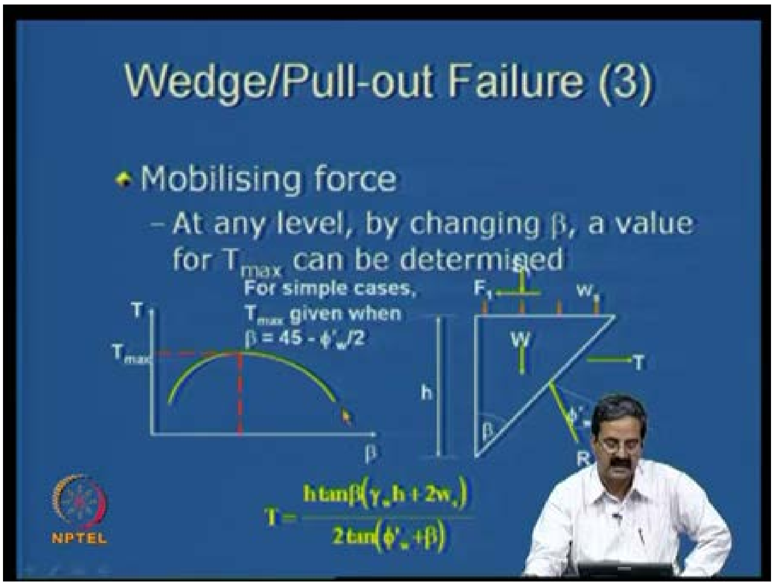

This is what we do, I said the force polygon right, you can see here and, these are all the forces that can act and for a simple case of only surcharge acting and you can simple expression can be you know just based on force polygon one can calculate this expression imagine that, you know resolving into vertical forces and horizontal forces in the direction of you know appropriately you can do that. So, for a simple at any level by changing beta you know what we do is that ,we investigate this T max for different betas like as I just showed my in my previous diagram.

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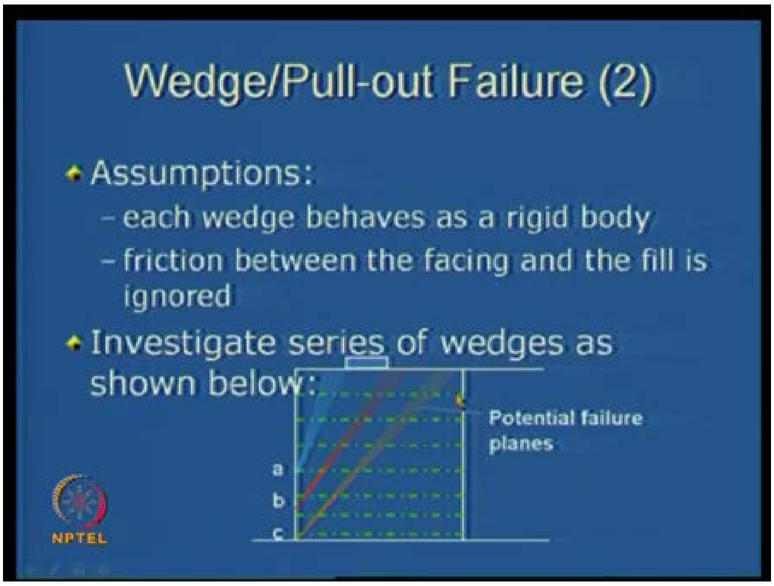

Betas can be vary from so may betas here say then there could be many betas here.

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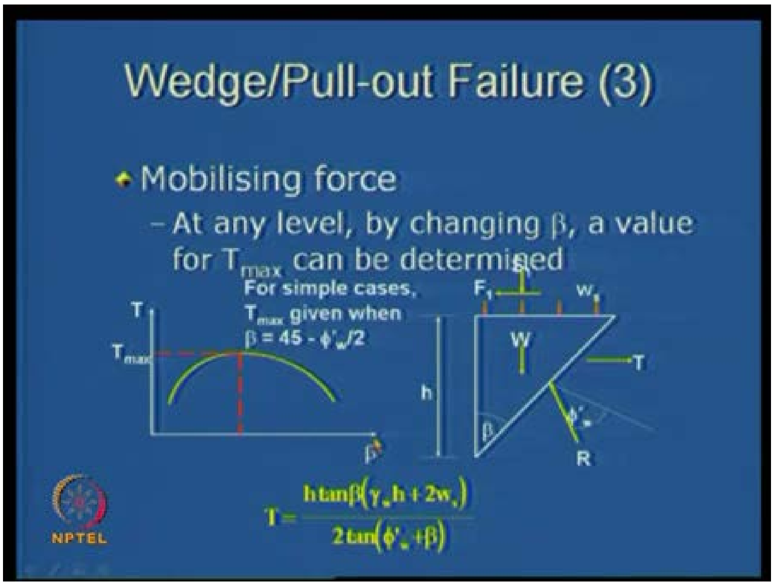

So, all that betas we investigate is a simple simple excel program one can write, to have all this information and then plot like this ok.

And then once you plot that you will have the maximum value. So, you take the maximum value as the tensile force required to keep all the wedges in equilibrium. That is what is required it is a very simple case where you try to calculate the maximum tensile force required to keep all the wed[ge]- the you know all the. So, that the wedge failure do will not occur. That is a principle here like all this wedges or all contain you know put in this form right ok.

So. In fact, for a simple case where, there is only a surcharge you know one can it is a simple equation you will get t t is nothing but, h tan beta into gamma h and if h is the maximum, you know say for example, height height of the retaining wall is say 7 meters I put 7 meters here and surcharge I know surcharge is nothing but, say for example, 20 k p a as per IRC or 22 k p or whatever. So, you can put that number you will get the maximum tensile force required in the its actually total reinforcement force total reinforcement force required we will see that.

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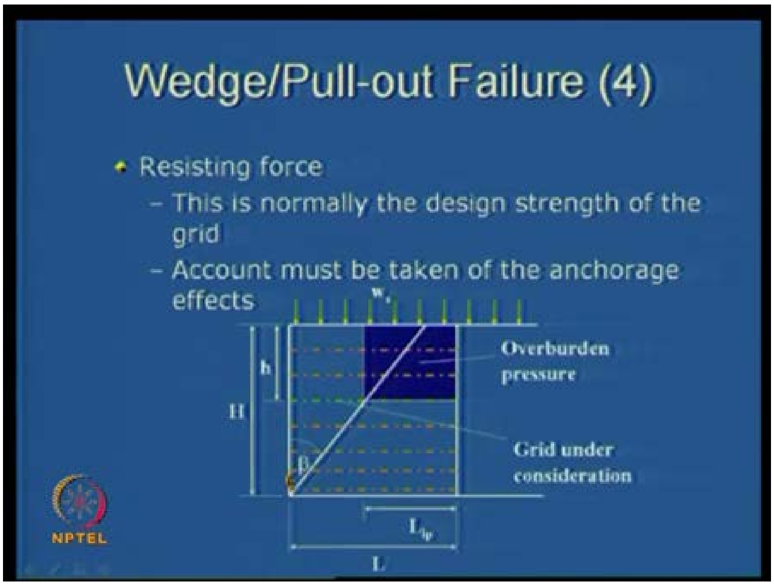

So, now, the other important thing is that, the wedge pull out failure you know it is also a function of the overburden, right the thing is that the.

This is all that Overburden pressure and whatever is that you know there should be a sufficient length beyond the failure actually if this is the failure surface that, we assume,and there should be enough length to see that the tensile failure you know we have see fact of safety you know the tensile force we calculate and the pull out resistance, also we calculate there should be adequate factor of safety there otherwise I mean the pull out resistance should be higher than the tensile force mobilized maybe two times ok.

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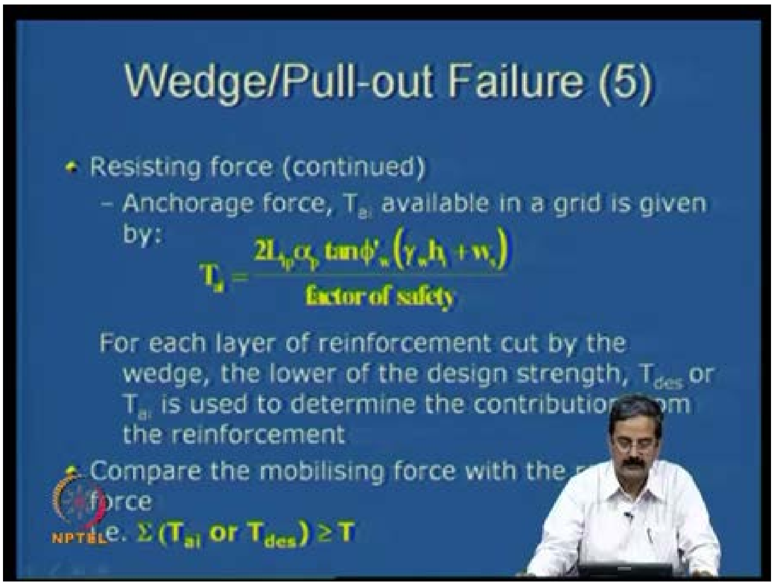

This is another one that one can have you know. So, what is the Anchorage force you can develop you will get is also given by you know actually that length that you have you know, the length this is called the Anchorage length you know.

That length at any point ,one can calculate and that is given by this expression and the Anchorage force or the pull out resistance there are two terms, one is one is called a tensile resistance tensile force mobilize in the reinforcement, now, you have to calculate the Anchorage force, anchorage force means pull out resistance so, there is nothing the nothing but, it is a function of the length of the reinforcement below the beyond the failure zone and also there is a coefficient alpha then tan phi w depends on the surcharge also.

For each layer of the reinforcement cut by the wedge ,the lower of the design values T design or the Ta is used to determine the contributions from reinforcement.

So, what we do is that we we calculate whichever is lower and then we try to then again compare the mobilizing force with the resisting force we have to see that we may call this calculations of say, what is said earlier previous section was that,

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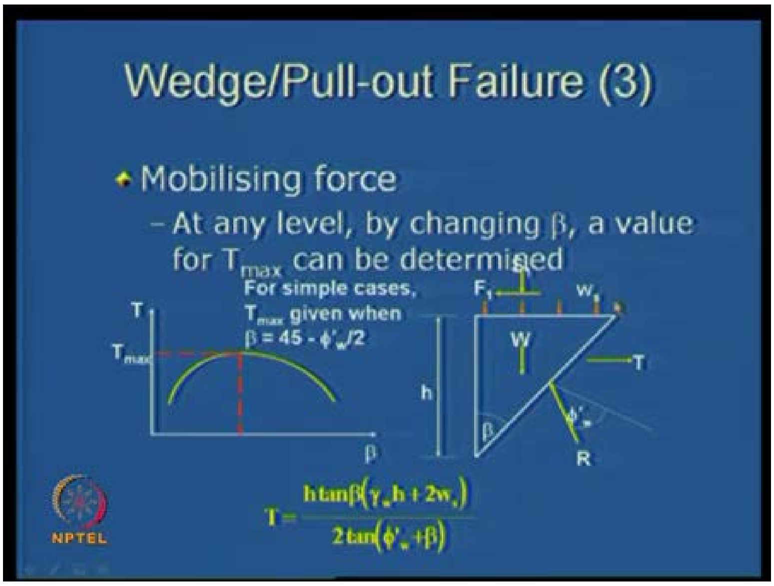

you calculate the no this is in terms of the again the wedge wedge failure stability and there are,

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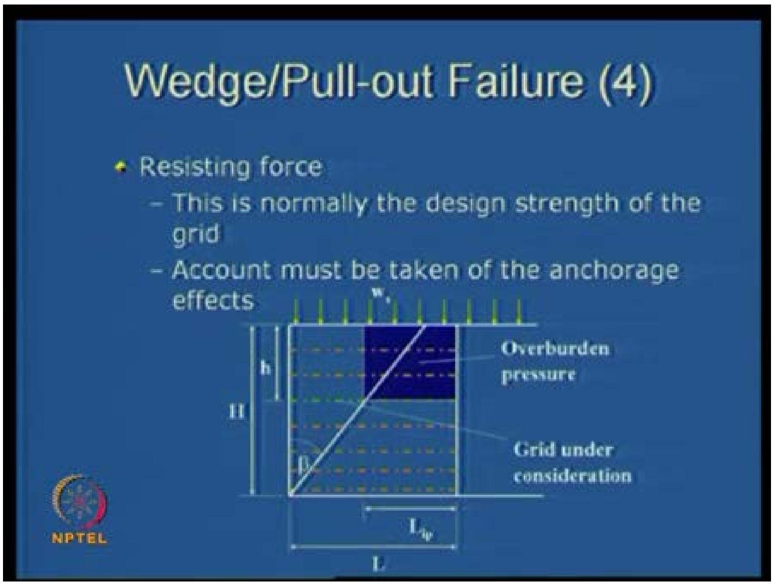

this is in terms of the anchorage ok; and the previous case was in terms of the tension ok

So, what we try to see is that all the forces we try to compare and see that the sum of all the forces should be more than or equal to the total tension mobilized, the total tension is nothing but, the total tensile force required for the wedge stability right.

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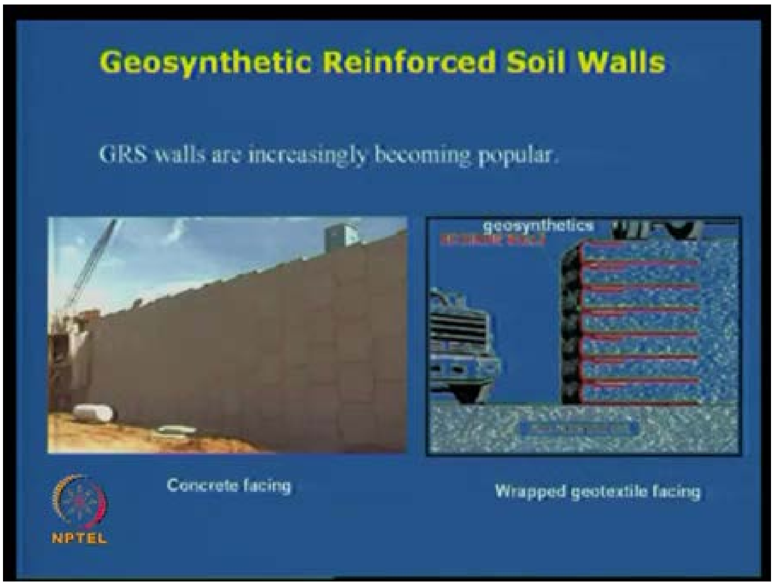

So, this is we will see that in an example that you will get much more clarity on that and this is a typical case of a GRS wall constructed with face you know, like pre precast concrete facing and you have a wrapped geo-textile also one can have, you know there are many types of facings are possible.

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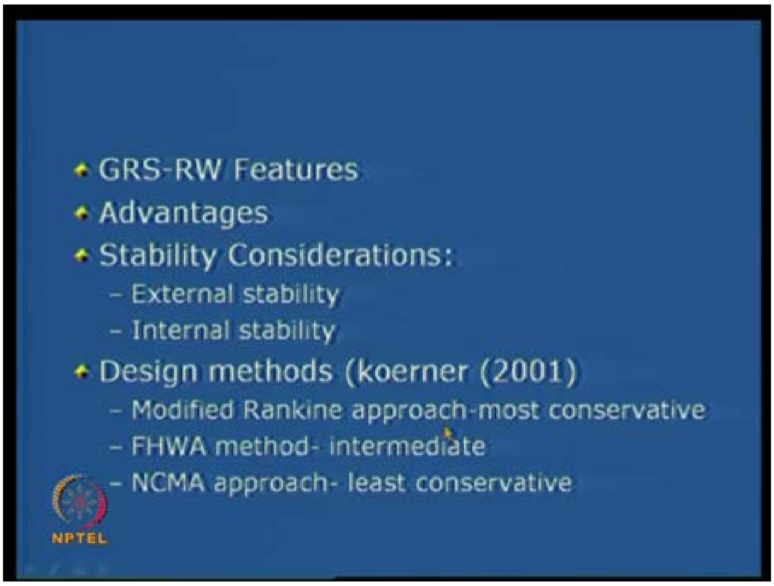

So, there are number of design methods. In fact, as I said GRS walls have been very useful and they are they have been very cost effective.

And; So, that design approaches that are developed and essentially the two design methods that we follow, actually Rankine approach is one thing like 1 minus sine phi that type of approach we use.

And we have a Federal Highway approach ,which is by you know one standard code then we have NCMA approach another one and we also have BS 8006 UK code these are all from UK, US actually and then you have a US code BS 8006 is another standard code and many of most of the codes in the world, they follow many of this codes and then sometimes they follow in a in different countries they have their own codes also.

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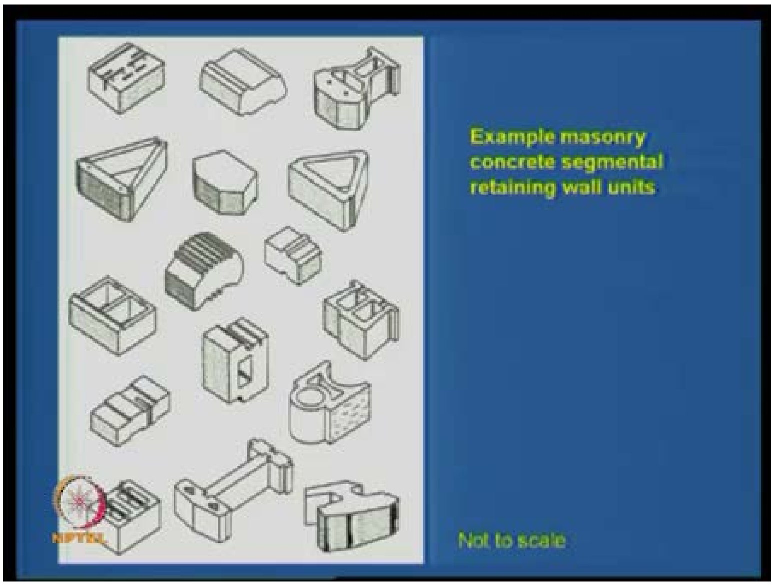

So, before I go further I want to illustrate a few more points here that as I said facing is can be anything.

So, people have tried different facing blocks, because people these are all very simple actually, you know the one can carry it with hand like if you are familiar with some wall structures that are constructed you know in a concrete panel that we have you know it needs lot of [cra/cranes] cranes and all that here we do not need cranes you know, we just have simple equipment and also the a simple company that manufactures this types of facing blocks ,it is called Segmental Retaining Wall units like they are quite useful like you know these are all facing blocks you can see that.

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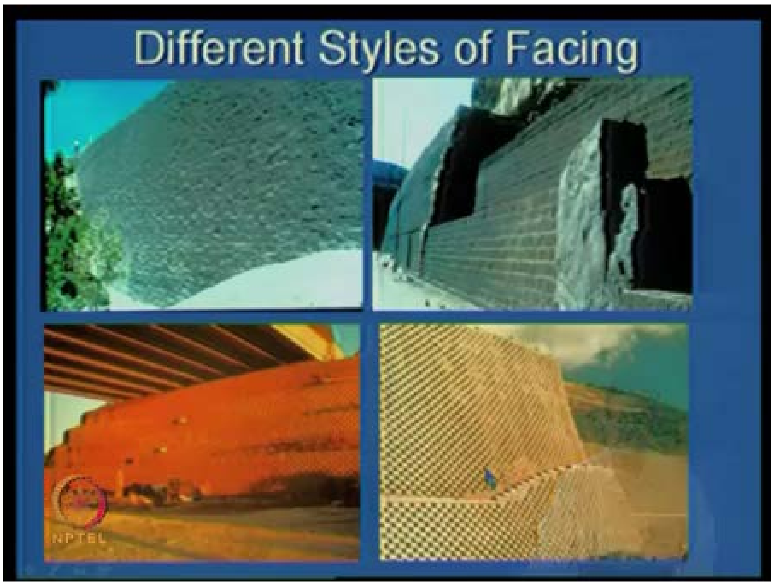

You know you can construct like this simple facing like this is a typical example, that we have seen in many place in India , some place at least this is a facing you know it is called Segmental Wall design this is another type. So, you the advantage is that, it is easy to construct the you can have a nice finish and the see it is also cheaper, that is one thing, because the overheads you know, because of the [high/heavy] heavy equipment are not there.

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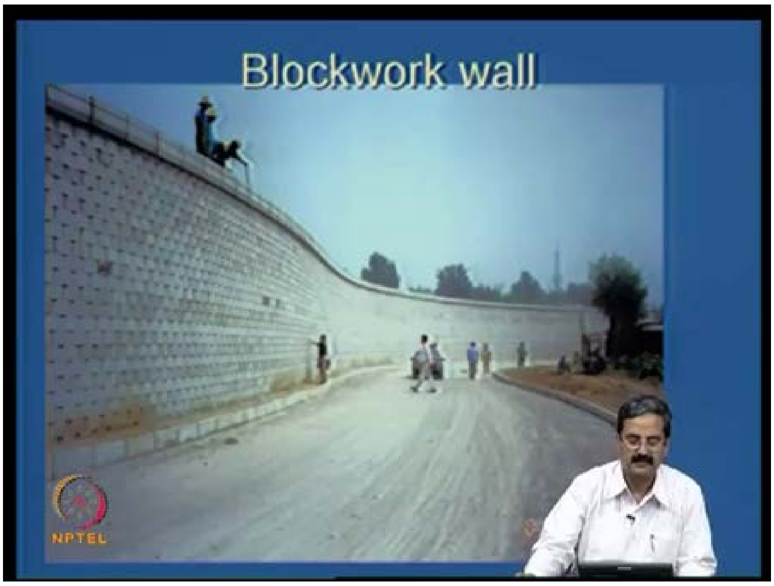

This is another type, you can see simply blocks only are kept compared to you have panel of 1.2 or 1.3 meter you know the panel will be 1 meter to one 1.2 meters it depends you know.

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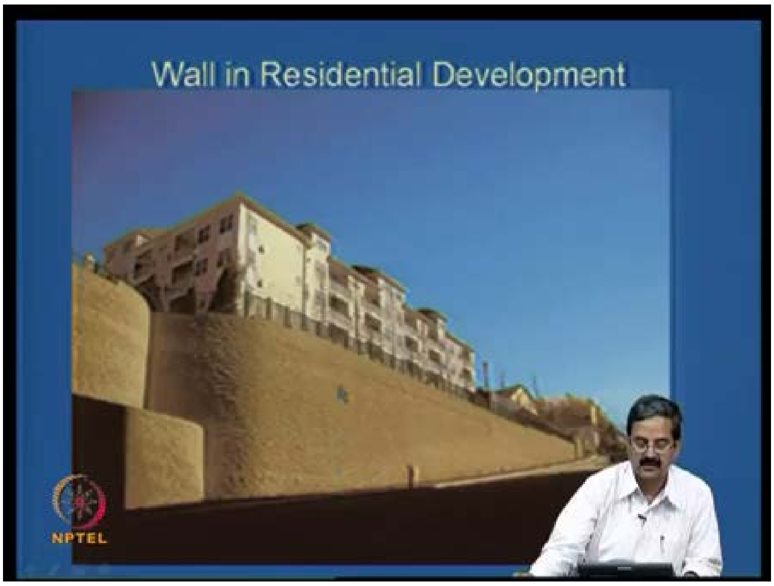

This is another one you can just see many types of structures one can have.

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So, the way that we construct is that see it is like these are all simple blocks they can be handle and this weight is you know shear key as I just mentioned ,and this is another one you know the type of thing we have, So, this is how it is done ok.

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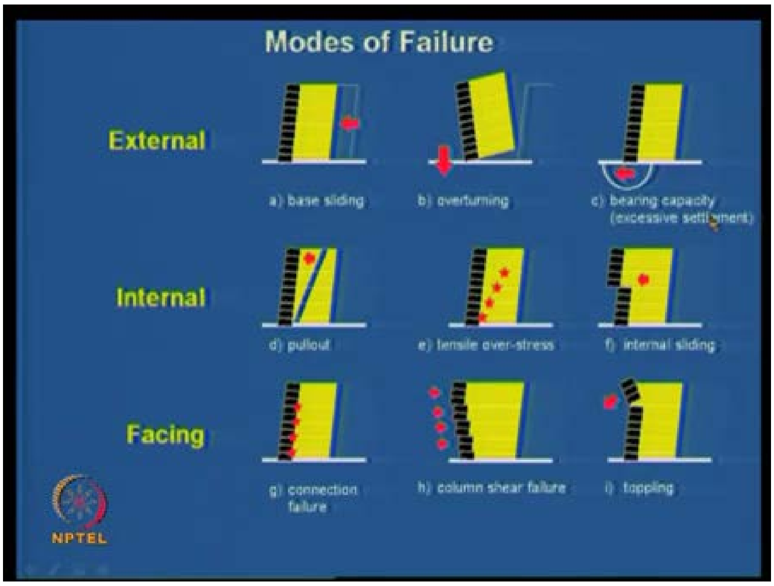

So, very importantly actually the you are since you are putting face face shear blocks one should understand that it can they can fail also.

Like it is it is not easy to simply stack one over the other. So, like a similar to a regular retaining walls, you should do for base sliding, overturning and bearing capacity calculations, internal stability calculations.

Pull out, tensile resistance, internal sliding particularly like this I have seen couple of failures like this, because we think that simple construction is easy, but its not easy, then facing, there could be a connection failures, there could be column you know it it fails as a column here, you know it then there could be some toppling failures many things are possible.

So, one though they facing looks very impressive, one should be very careful, because one should look at all this possibilities.

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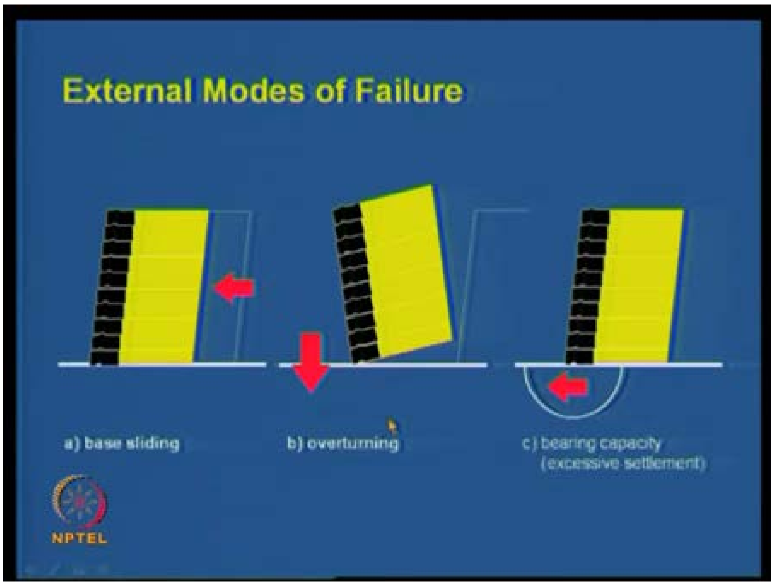

So, this is what I just mentioned

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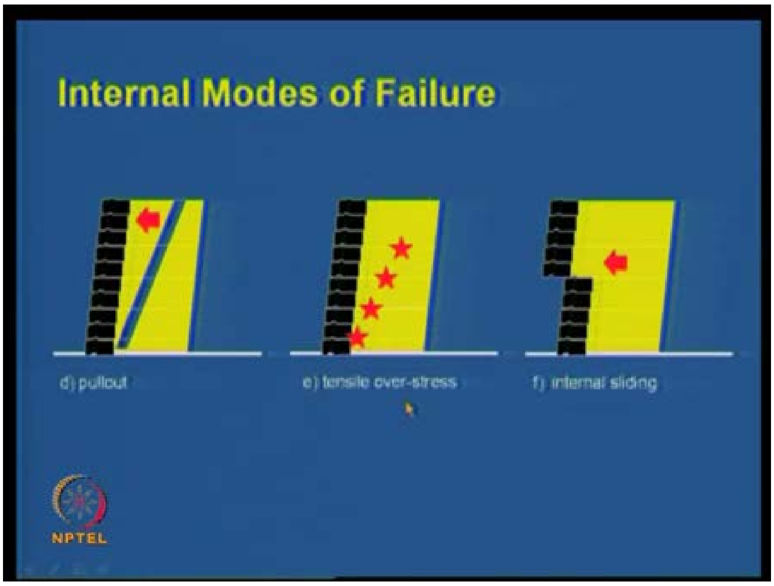

Like the it can fail and all that this another type failure.

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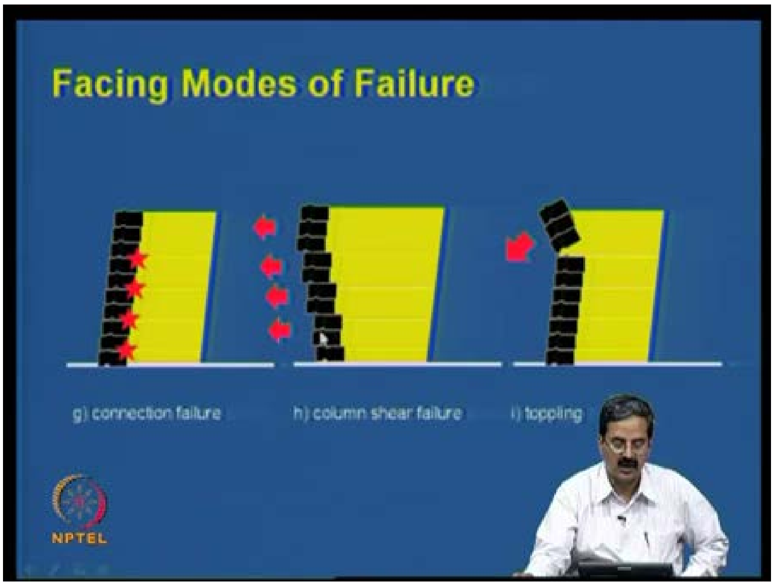

So, this is a column shear failure toppling we have seen many cases in India, actually because what they do ok this is all simple precast block. So, I can get from they try to do well poor quality then the possibility is that it can lead to failure ok.

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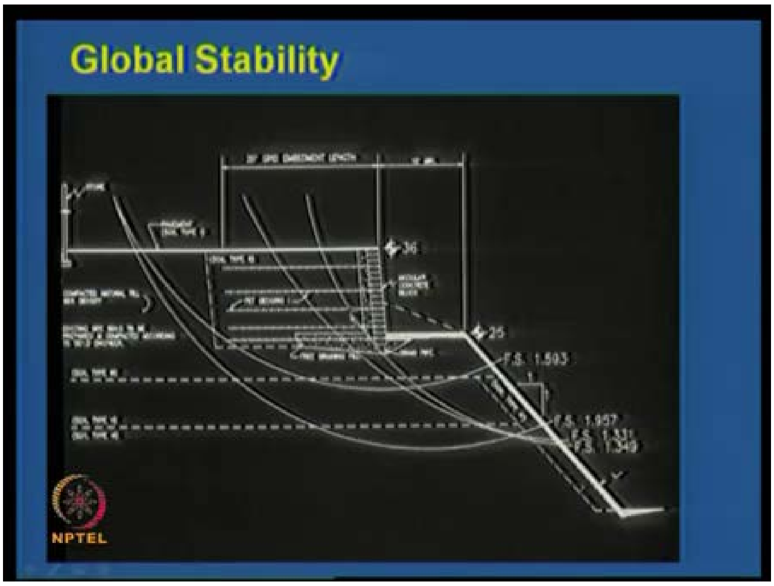

So, this is a simple example of Global Stability like you know you have to investigate may be this is a nice say for example, this is a typical what is called segment Segmental Wall, what is called Modular Concrete Blocks you can have it.

This is a reinforcement layers ok ; and you have a drainage here ,drainage pipe is here and geo grids are placed and this is how it is there right I just want then, we have to investigate the like you know, because it is forming this part of the slope right so, you have to investigate all the failure surfaces you can see that 1.33 one point you you have all this numbers definitely its more than 1.3. So, it is ok ; like that. So, you have to do some sort of analysis like this.

So, the typical factors that we recommend

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are , you know it could be like this you know base sliding 1.5, bearing capacity, tensile over stress all that you have to verify you know toppling and one should calculate and do that global stability 1.3 to 1.5 in the previous case its more than one point three. So, it is ok.

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So, the construction details yes, be

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This one way, this is other way like this is a drainage element.

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Actually you know this is another blocking Locking Bar .

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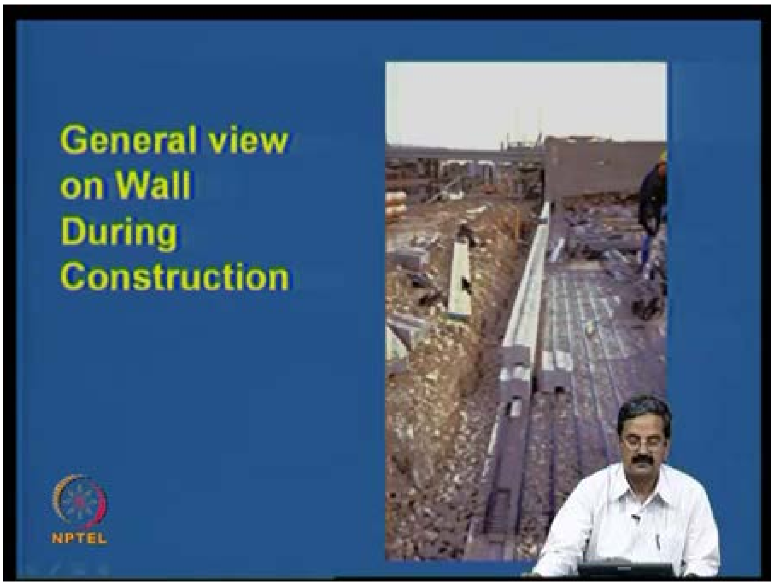

This is a General view of the Wall Construction.

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Placing blocks see you have a thread here varying

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wall ties fixing false facing, you can have you know false facing also.

This maybe actually required facing this can be a nice facing whichever you want like

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people have false roofing, locking geo grid between blocks these are one type.

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So, Sometimes you know Safety Barriers on the Walls at the top of the wall also should be done, because once you construct the wall people should not just you know at least should not lead to any problems. So, this is like that.

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So, many you know one can have a Nice Fencing and the anything's are possible like examples of finished structures.

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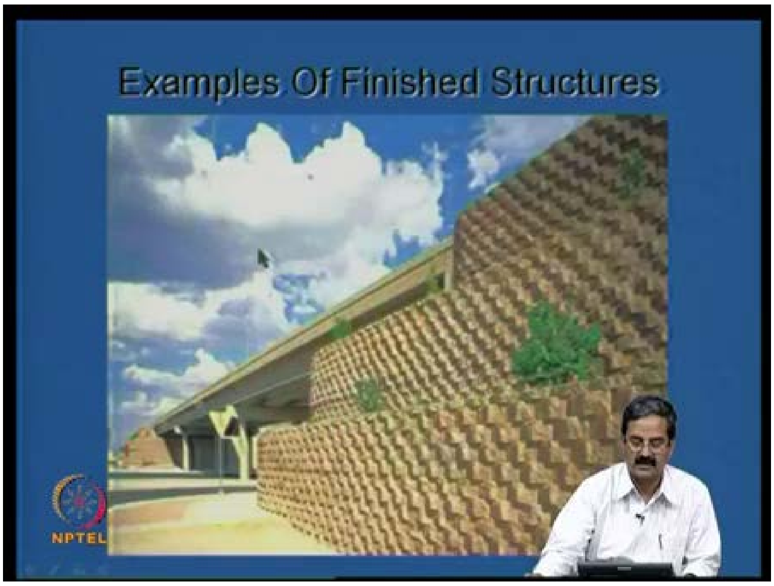

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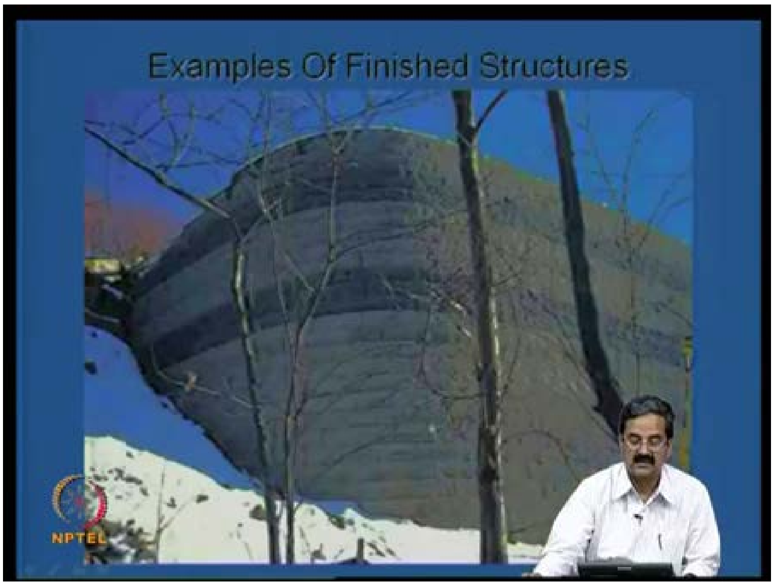

This is another one.

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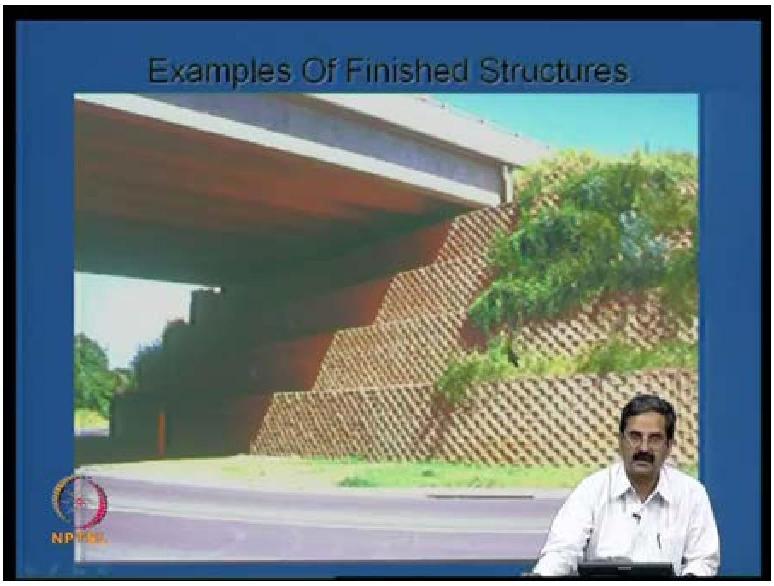

This is a nice treatment that one can give this is I just want to show, you the influence of the because of the Earth quake, the possibility is that you know one of the Railway lines in Japan has yielded and that was [reco/reconstructed] reconstructed later with a horrible technique ok.

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And geo grid reinforced soil wall along the JR you know Japanese Railway Kobe Line you know Kobe Line is an Earth quake that occurred and the thing is that it is before before the Earth quake occurred,

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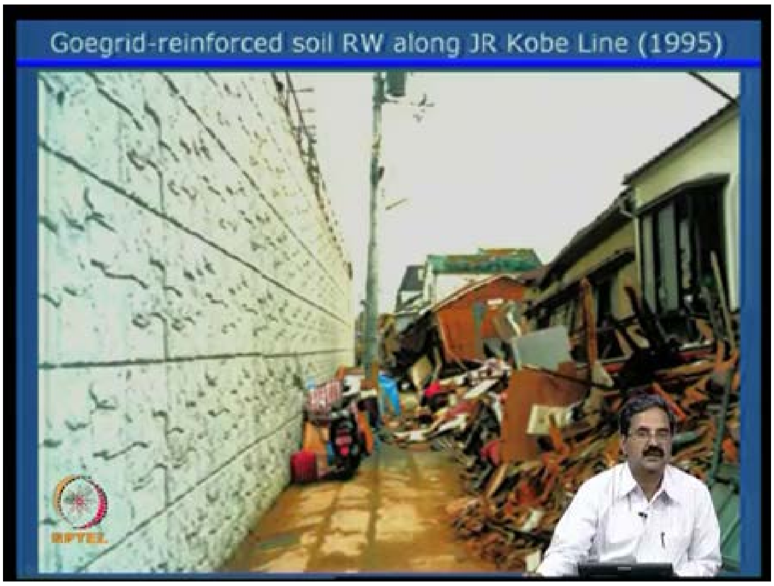

and you can see the same photo, after the Earth quake you can see that there is a collapse of all the structures, but RE wall is still same ok.

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So, this is another one damaged [mason/masonry] masonry wall reconstructed to GRS with a Full Height Facing, you know this is one masonry wall type of construction that again it did not fail in the Earth quake.

But they reconstructed with you know, Full Height Facing I told you know full height facing; that means, the Facing is fully there. In fact, we did many one is full height facing is also possible like a Simple Facing, fully put a one number no do not worry about simple blocks like that, right.

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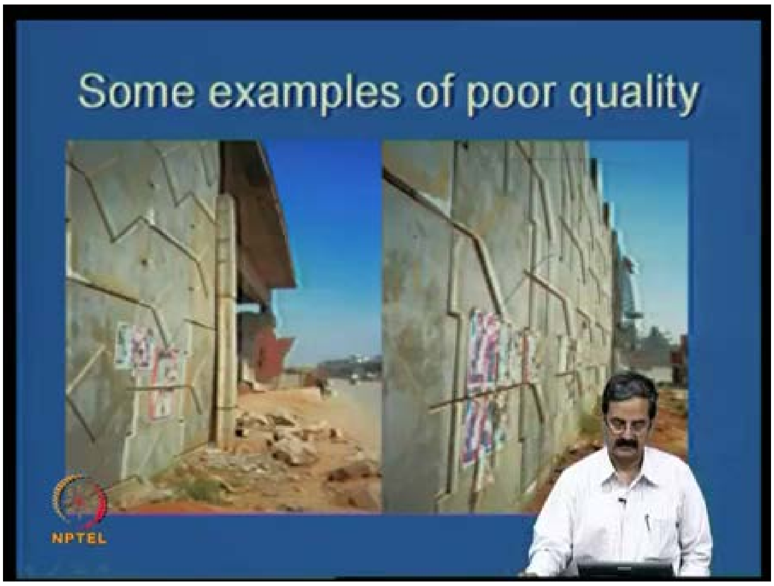

Another example of poor quality in Bangalore. This is one case where you know the it was not well done you can see that. So, you you this technique is quite simple.

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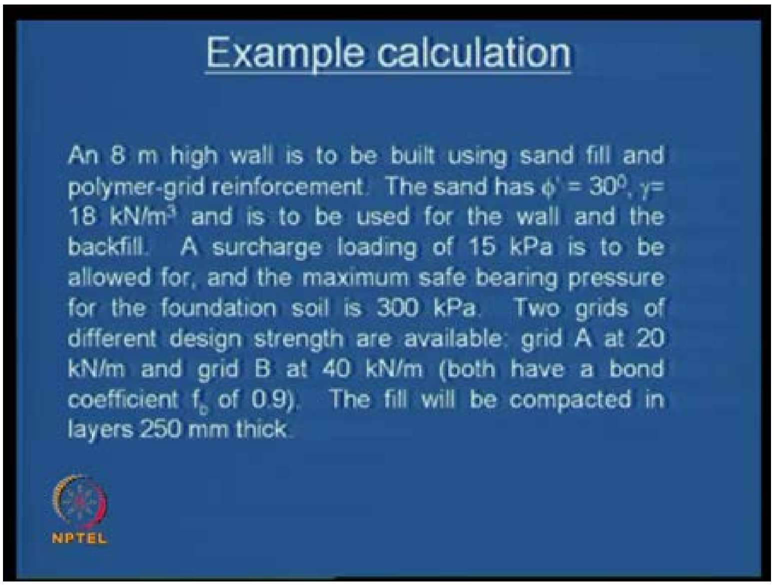

I would like to just now illustrate with a simple example this is where I would like to end.

We have an 8 meter high wall to be built using the sand fill and polymer grid reinforcement the sand has a friction angle 30 degrees ,bulk density is 18 meters and surcharge load of 15 kPa is there and bearing capacity is about 300 kPa you have two geo grids available grid A 20 kilo newton per meter and B equal to 40 kilo newton per meter both have a bond coefficient of 0.9 ok.

These are all we known and then the fill has 250 centimeters of compaction which you know why this is required is that, you compact the sample and put a geo grid. So, next one should not be you know it should be multiples of 250 only any placement should be in terms of 250 only, because the thickness is important here.

And the location of the geo grids you have to redesign say for example, you have even your facing block, if you are using a modular blocks it would be 250 mm then put to all heights this is a very important parameter, if you decide this then spacing design of your facing blocks all depend on that ok.

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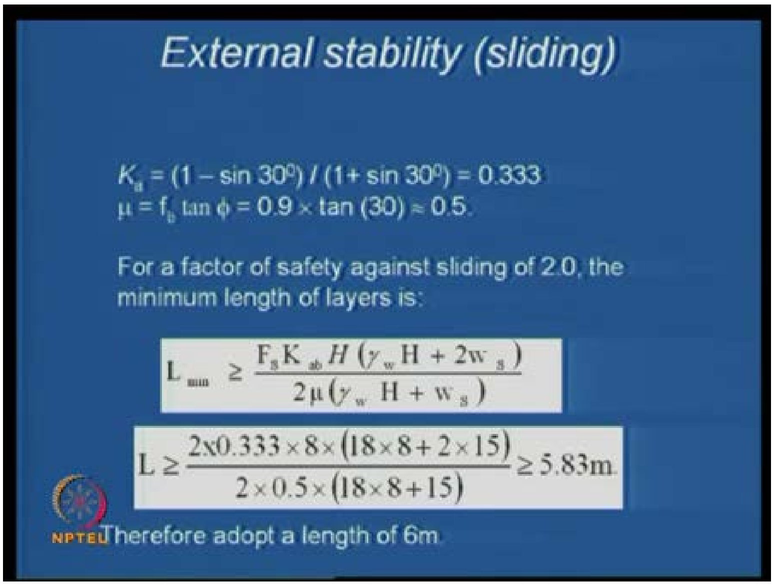

As I just mentioned this is all the once you know the quantities and fact of safety I give an expression for the sliding stability like, if you use previous formula that we discussed to avoid sliding stability, the factor of safety of minimum is 2.

So, use that number and all the quantities like Kab height and surcharge everything is known you substitute back in the equation and the minimum length required is about 5.8 meters.

So, you can take 6 meters, the height of the wall is 8 meters and 6 by 8 is 75 percent. So, 7.75 is the length of the 0.75 L is a length of the reinforcement ok.

Actually, this very important you know this was sliding stability.

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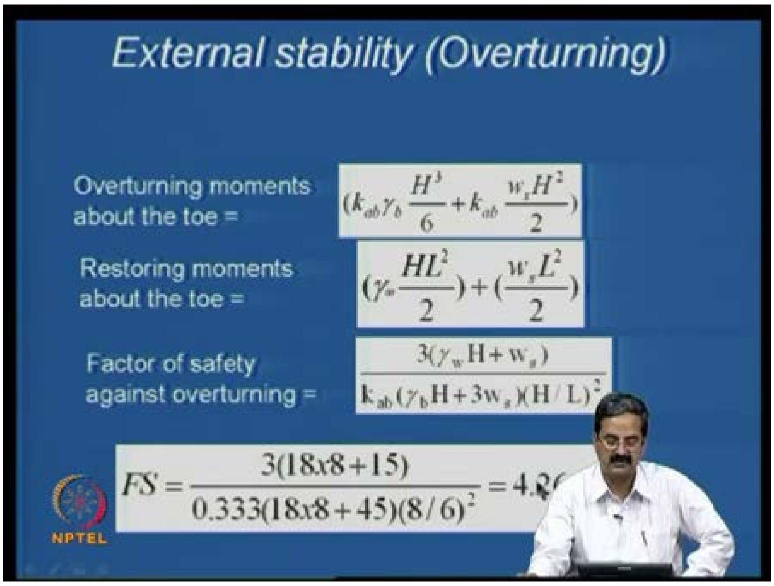

is taken care similarly you can do the overturning stability like you know you can put all this numbers it is actually given in my book also, this particular examples and the factor of safety with respect to overturning is you know if you just put all the numbers its 4.26 little more than 2.

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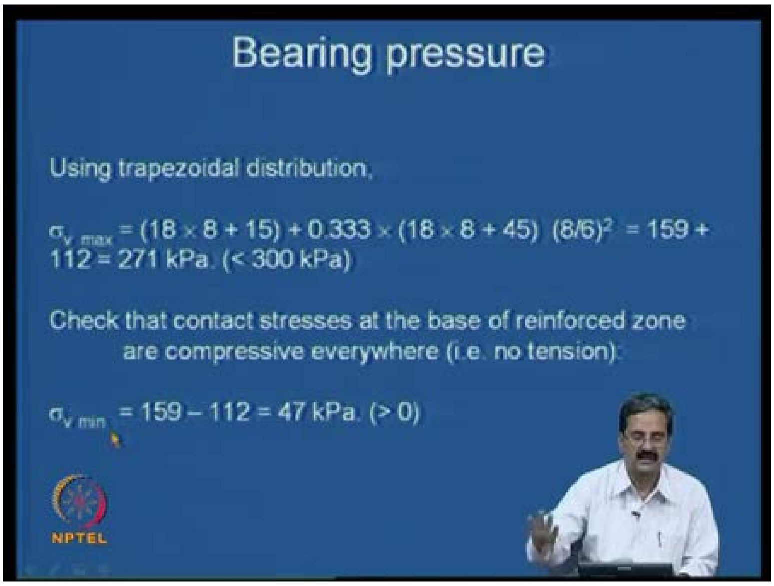

Now, using Trapezoidal distribution you calculate, you know you I said you can do Meyerhoff distribution or even Trapezoidal distribution and use for example, in this case I would like to show the use of Trapezoidal distribution one can see that and you get maximum vertical stress as 271 kPa which is less than the bearing capacity of the soil.

And minimum value is 159 ,maximum minimum value is its more than 0 which means that there is no tension developed.

Actually, if you are using why you use this Trapezoidal distribution is that, we would like to satisfy the no tension criteria also but, remember the reinforced soil is foundation is a flexible structure.

So, we better use a Meyerhoff distribution that leads to actually, if you use a Meyerhoff distribution then this value match will be much lower.

So, will be instead of telling you telling that its 271 is less than 300 kPa this value will be much lesser, because there is a readjustment and this sigma v minimum will be zero it will also come down, because there is a readjustment.

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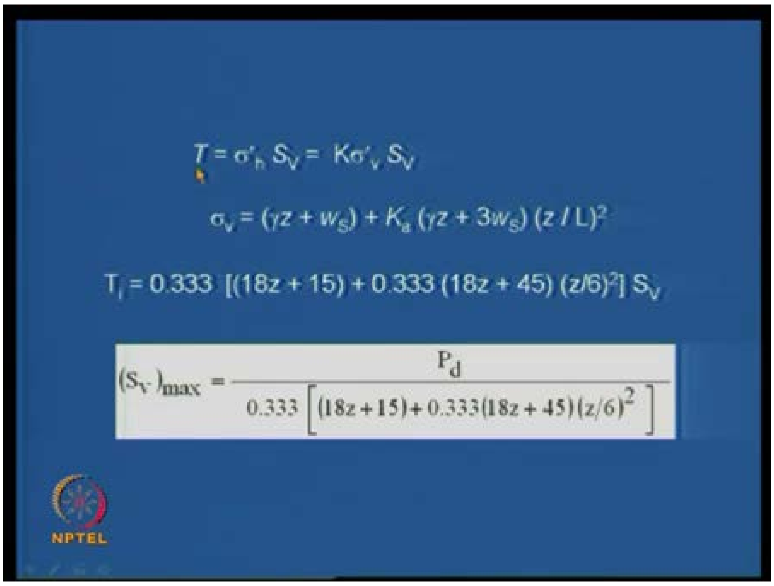

Now, as I just mentioned how to calculate the tensile forces right, this is that horizontal force into Sv is the spacing right; and this is say for example, we assume a spacing of Sv and this is a horizontal force, this is a tensile force required to keep that place in position Ka this is what the this thing and sigma v is nothing but, this formula is there right. So, you substitute all the quantities and then you know put in terms of the Sv like you know see the Ti is nothing but, the design strength values like you know I just have geo grid materials and that design strengths I know like 20 and 40 like and the previous example I in the statement of the problem I just mentioned.

The two grids of different design strengths are available [g/grid] grid at 20 and 20 and 40 ok.

This point nine are available this we should remember ok.

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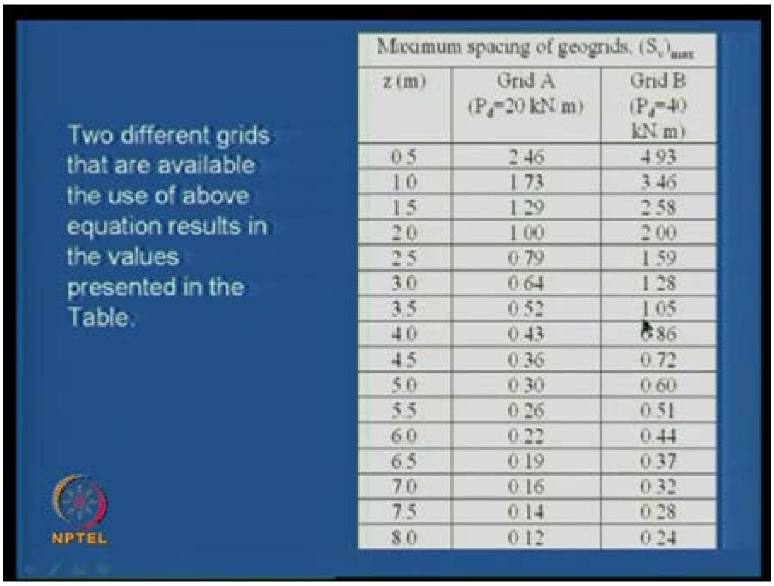

Maximum spacing of geogrids, $(S_v)_{max}$		
z (m)	Grid A (P_d=20 kN/m)	Grid B (P_d=40 kN/m)
0.5	2.46	4.93
1.0	1.73	3.46
1.5	1.29	2.58
2.0	1.00	2.00
2.5	0.79	1.59
3.0	0.64	1.28
3.5	0.52	1.05
4.0	0.43	0.86
4.5	0.36	0.72
5.0	0.30	0.60
5.5	0.26	0.51
6.0	0.22	0.44
6.5	0.19	0.37
7.0	0.16	0.32
7.5	0.14	0.28
8.0	0.12	0.24

So, you put it here, using the see your putting it here that number

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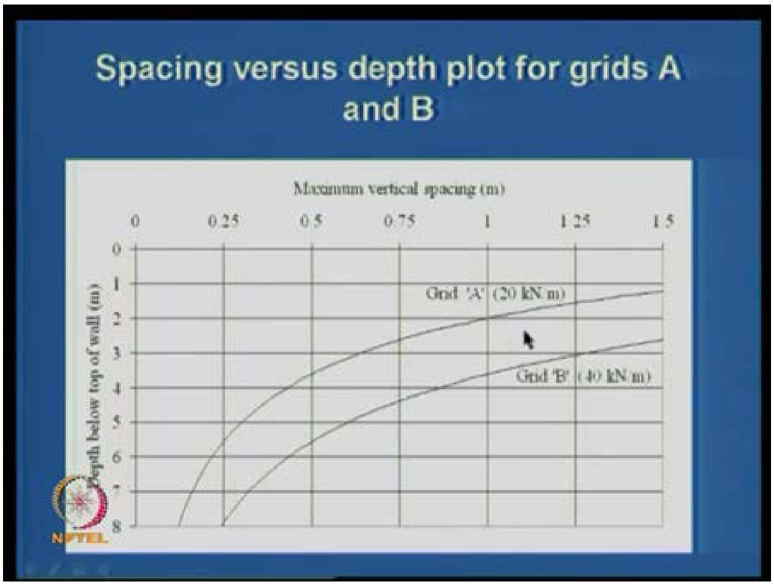

and then try to just put this sort of equation and you will get a grid like this grid A, grid B you just get depending on the spacing and all that you will get some sort of simple diagram like this and; actually, we are only going for space close spacing's only what it means is that, if you are using a geo grid of A you know which is somewhat weaker compared to this you know 40 kilo newton is bigger stronger. So, you can have 0.25 spacing right up to then you know up to a depth of about this this much length. So, here grid a you know 20 kilo newton 20 kilo newton per meter we can just it starts with you know you you have to go for lesser than which is not possible here. So, what it means is that Grid A you cannot use bottom at the bottom, because its less than 0.25 it is going here. So, I can start using 0.25 only from here at 6.5 between 5 and 6 say 5.5.

That's what it means ok. So, once you do this then this helps you know in the fashion. So, one can construct you know 0.5 you know just put in a simple excel program and then get this this thing and plot like this, you will get that information, but essentially we are going for this case and Wedge stability check can also be done and we can trial wedges can be done and calculate the total required force is the one thing I just mention.

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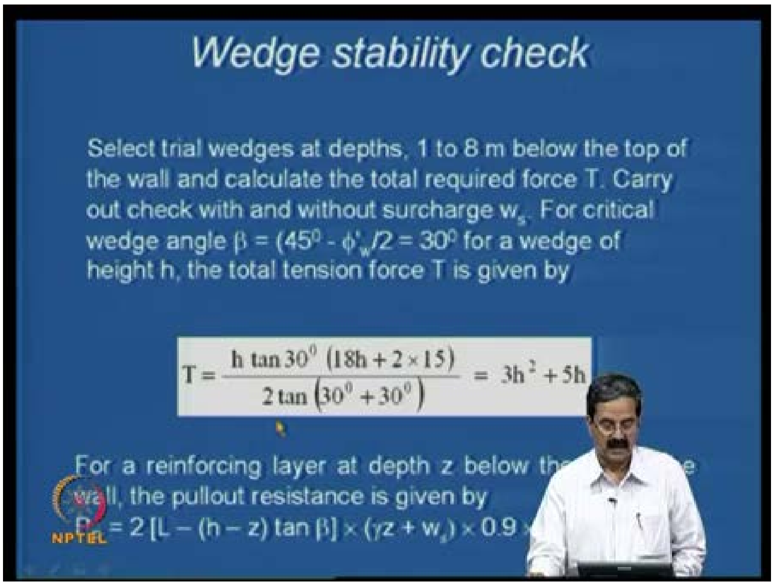

And you have to calculate checks with and without surcharge and as I just mentioned this is an equation for a critical angle that you have and this is an expression, that we have,and for any reinforcing layer at depth z below the top of the wall the pull out resistance is given by this number.

So, this is you know behind the retaining wall the behind the failure zone or the you know in the Anchorage length we call it you [calu/calculate] calculate the passive resistance.

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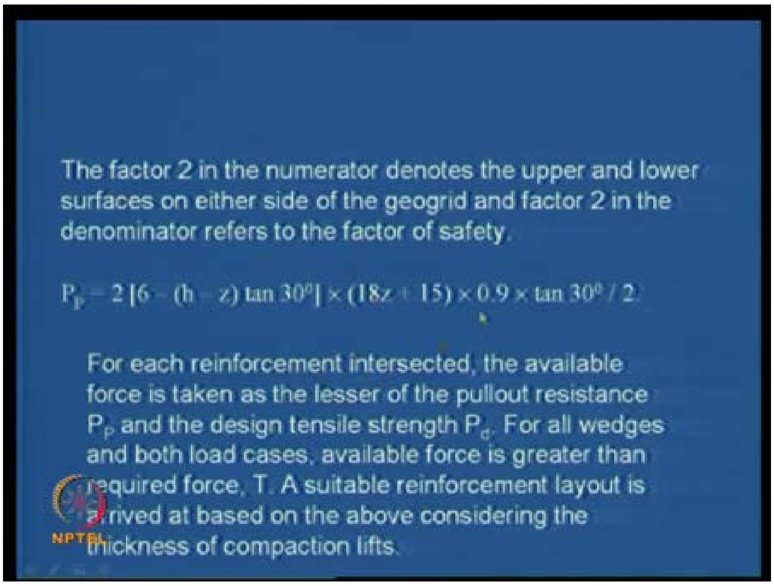

So, you get all this information and what we do is that we try to make all this calculations and say for example,this is the diagram that I would like to show here wedge depth you have wedges at different depths 1, 2, 3, 4, 5, 6, 7, 8 meters and force to be resisted, total force that you have to resist will be, if it is 0 surcharge is 8 and if it surcharge is 3 so, you calculate all these numbers this is all the force to be resisted by the members.

Then, you know the geo grids you know like you know I just mention you have to just put some numbers here in the sense that so, if I have 2 2 geo grids, we have A and B and you have a JAJ grid is a twenty kilo newton’s this I put to 40 and this is one member.

And, pull out resistance is we have an equation that I just mentioned pull out resistance you are getting, you know with and without surcharge we calculate without surcharge pull out resistance is 42 with surcharge is this and whatever is minimum say for example.

You have to take here right ,and then see that whatever is available ok. See the that you have to compare you know both of them you have to compare available force, minimum of Pd and Pp ok 40. So, here its 80 ok. So, all this things we maintain and see that.

This is now this is this is a minimum this is what is we have and, the design strength you compare actually ok.

So, they have to be more than that you know any stage like, pull out resistance have to be higher.

This pull out resistance have to be higher say for example, the at 0 can be w s equal to 0 say, this is 5639 is a pull out resistance available the design tensile force is 700.

So, that is what we see that at all the time, the design requirement is satisfied here in terms of the tensile forces and the force to be resisted say for example here ,192 you can get from this combination only 15 into 20 plus 10 into b b is 40. So, that comes to totally 700 and that 700 will be higher than this. You know this is this will higher. So, essentially one one needs to formulate sort of you know evaluate like this and; In fact, there are many software available on to calculate.

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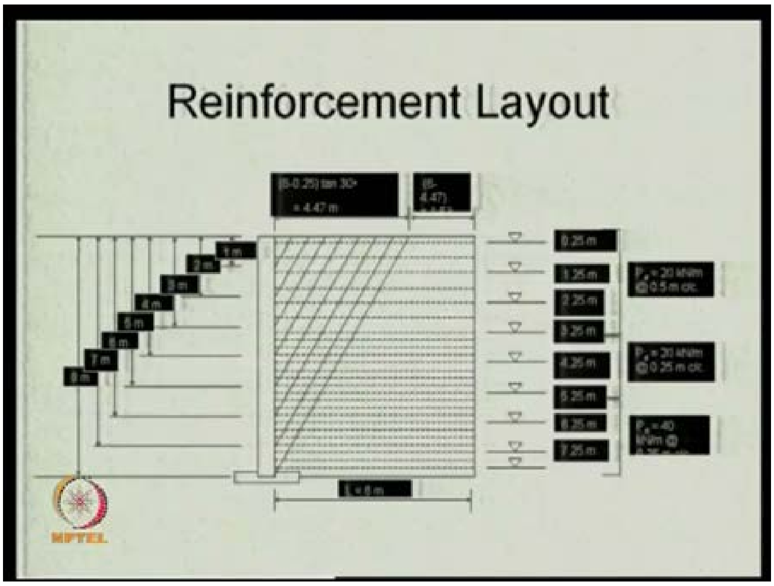

In fact, if you just do this you know this is the way that it should be provided like you know 1 meter 2 meters and all that and you know spacing can be avoided and [de/design] design spacing it should be 0.25 it should start here and then with you can have spacing and length is l is a length of reinforcement. So, one should be able to design a suitable reinforcement layout and there are many number of software that are available they they are company specific they are also, one can design systematically using an excel program and all that.

So, essentially, we what we discussed so far is that ,yes some short of design. If reinforced soil walls is possible, using a given type of reinforcement or you can even recommend a given type of recommend you know check the stability of this reinforced Earth walls considering Internal Stability as well as External Stability and all that and with this I will conclude Thank you.