Geosynthetics and Reinforced Soil Structures
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Lecture - 21
Geosynthetic Reinforced Soil Embankments – I

Good morning students in the previous lectures, we have seen how to design vertical retaining walls. And now let us look at how to design the embankments or slopes.

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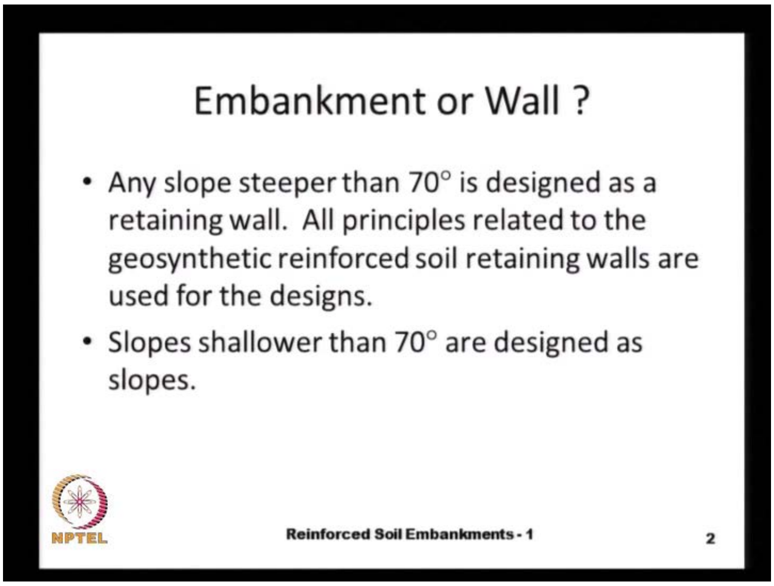

And what are the design approaches and especially when it comes to definition what is an embankment, and what is a wall slopes that are steeper than seventy degrees designed as a retaining walls. And the slopes that are shallower than seventy degrees are designed as slopes, and the we will see some of the principles applicable for these for the design of slopes in in the lectures to follow.

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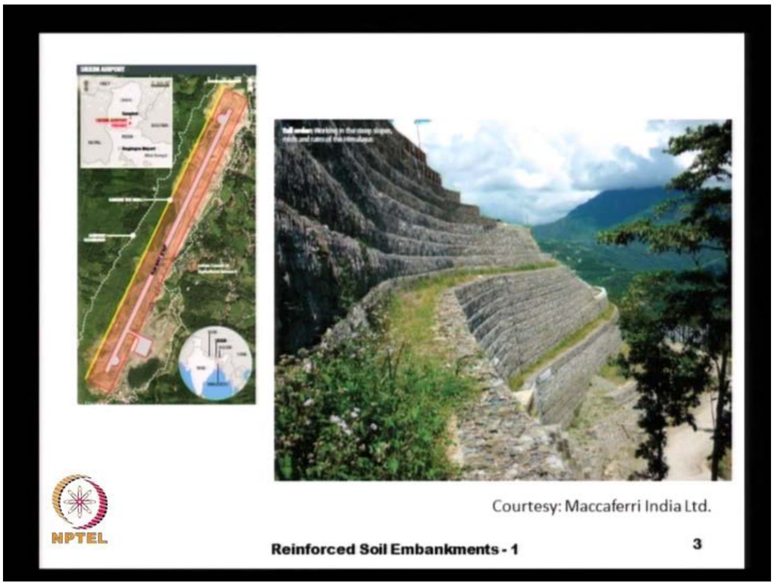

Here is an example of an extreme case of a slope it is the airport that is being constructed at at Sikkim. This is the view this is the the schematic view of the airport runway and this being a hilliterrian there is no flat ground. And we need to make up a ground, and in order to make up engineers had to built up this slope all around these dotted lines all around and the cross section. You can see here the height is about nearly 110 meters it is a very steep faced embankment as you can see, and it is a it it is one of the most challenging projects that has over been taken up in India and this work is being carried out by maccaferri India.

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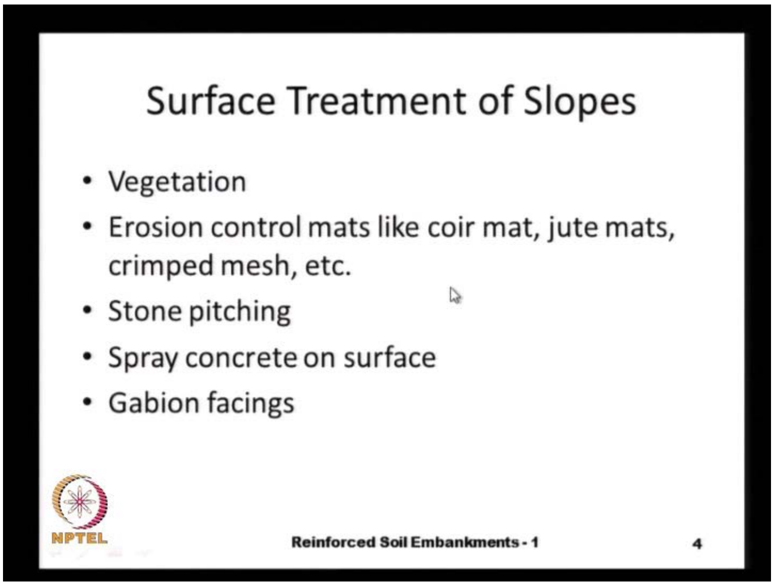

Well, whenever we have a an embankment or a slope. As you can see on the road sides or railway embankments, the surface is free to the rain water or window erosion and so on. And how do we protect the the surface on the slopes, there are different methods the best method is by for growing the vegetation. And we can use erosion control mats like coir mat jute or crimped mesh and so on or we can use stone pitching, but the effectiveness of the stone pitching is doubtful especially, when you are face is very steep the stones may start start falling down just simply creeping down. Because of several reasons or we can use spray concrete on surface or we can give gabion facings and so on.

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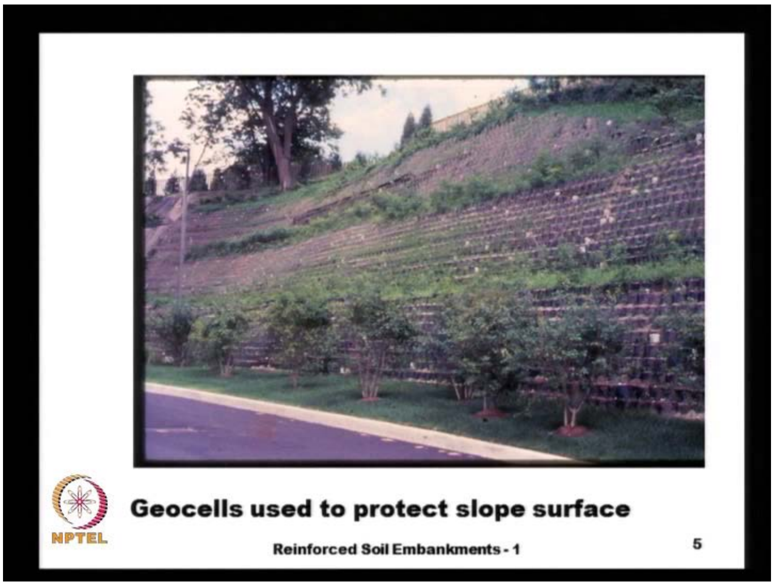

Here is an example on the face treatment using combination of geocells that we have seen earlier, and and then the vegetation that is growing through the through the pockets of these geocells.

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And here is an example of of a a crimped mesh, and a polymeric textile that can be used to to protect the surface of this slopes.

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And these are different examples of a coir and a jute that can be used for controlling erosion on the on the slopes, the rain water induced erosion usually results in galli formation like this, that we frequently see on the on the Indian roads and embankments and once it is treated with a coir or jute cover. And If we can promote the vegetation the surface look something like this is actually in the inside, you can see at the coir mat that is exposed and by for the growth of vegetation is the best solution for controlling the erosion on the slopes.

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And here we see an example of using spray concrete, and sometimes the spray concrete may not stay on the surface on the some slope surface especially of the slope is very steep in such cases. We use the geocells which are the three dimensional form of geosynthetics that we have seen earlier, we can spread them and fill these pockets with cement concrete. So, that we provide a good erosion control on the surface, and this particular photograph shows the the erosion control within in within a canal slope.

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And what do we do with existing slopes, we have many slopes that are existing already constructed, but which show signs of distress. And we can use different techniques like the soil nails is actually nail is nothing but a steel rod, that we drive into the into the slope to connect the active part that is moving part of the slope with the passive part that is the resisting part of the slope. And here we can see the the nails being driven or we can use a grouted anchor is actually we drill a hole and then fill with them in a cement concrete it could be quick setting type.

Then we can also use a pre-stressed anchors is actually here you see an example of the pre-stressing of anchor we install an anchor, and then we pre-stress. So, that the inside soil is in compression and we know that if the soil is kept in compression it behaves like a very strong stiff material.

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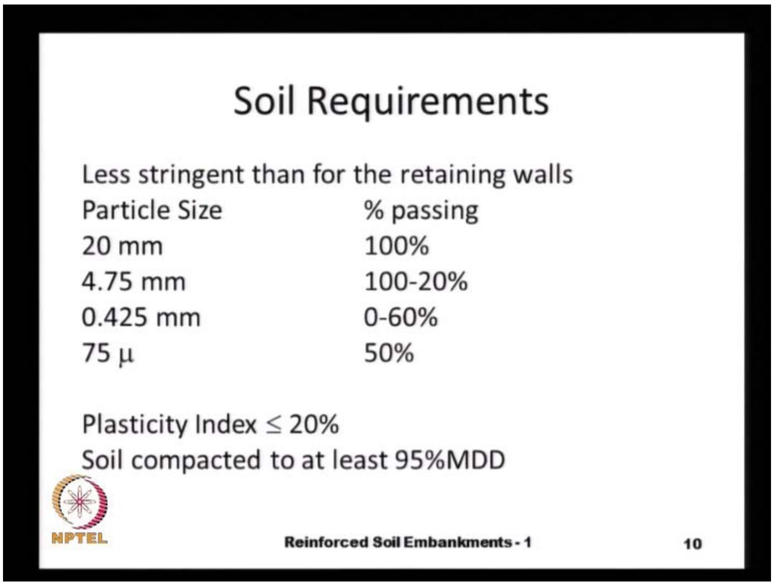

And what are the requirements of the soils for construction of embankments or the slopes the requirements are bit less stringent as compared to the to the vertical retaining walls mainly because these embankments or the slopes they can tolerate larger deformation’s, because they spread over very large area the the gradation is given here. But one thing that we need to see is we can have about 50 percent of the fines passing through 75 micron sieve in the previous case for retaining walls. We have seen that this percentage is not more than about 10 to 15 percent, and then the plasticity index it should be less than 20 percent it is a bit more tolerant, whereas in the previous case the plasticity index was limited to 6 percent, and the soil should be compacted to at least 95 percent of the maximum drain density.

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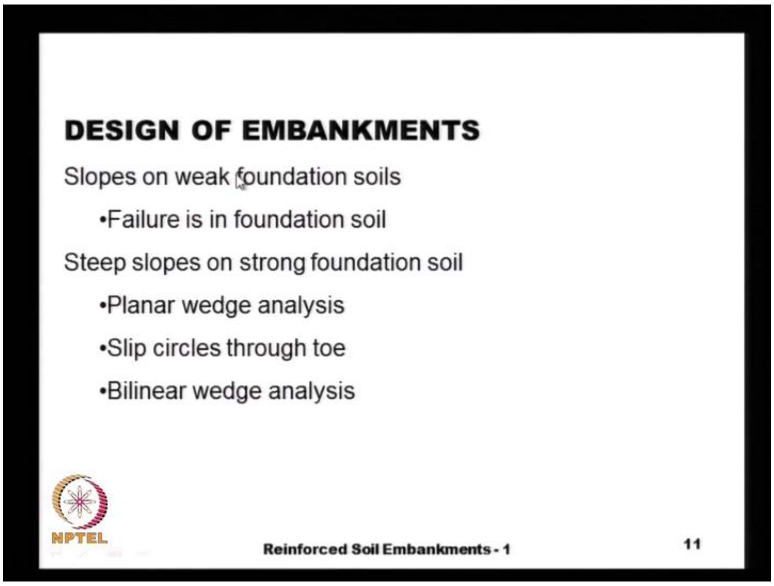

And what are the design methods that we have we can have for design purposes the slopes are categorized into into two different categories those slopes. That are built on weak foundation soils where in and the failure is happening within the foundation soil. So, our we we say that the embankment soil is strong, but then the foundation soil is weak or the other case could be construction of very steep slopes on a competence soil on a very strong foundation soil, where in the foundation soil itself is strong. And there are different methods for analyzing the steep slopes planar wedge analysis the slip circle passing through the toe or the bilinear wedge analysis, we will see all these methods bit later.

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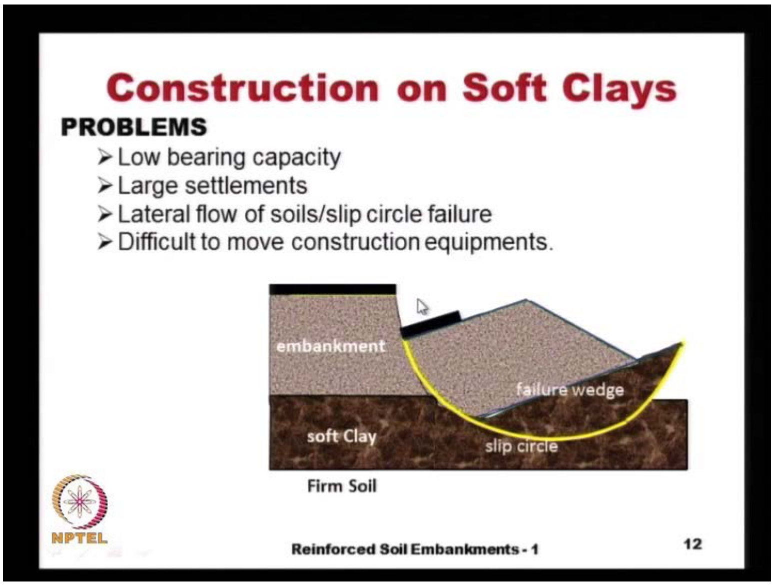

Let us first a look at how to construct the embankments are soft soils or soft clays usually the most of the problems are because of the construction an soft clays the what are the problems that we can encounter in the soft clays, they have very low bearing capacity. That means, that the height of the embankment or the slopes that you can construct is only limited and you should expect very large settlements and both total and differential and then lateral flow of the soils, that leads to the slip circle type failure. And in some cases the soil and site may be soft that we cannot even bring in our construction equipments and the result of large lateral movements could be a slope failure like this. Originally the embankment was like this, and because of the the lateral movement, and because of the formation of the internal slip surface the slope could collapse something like this.

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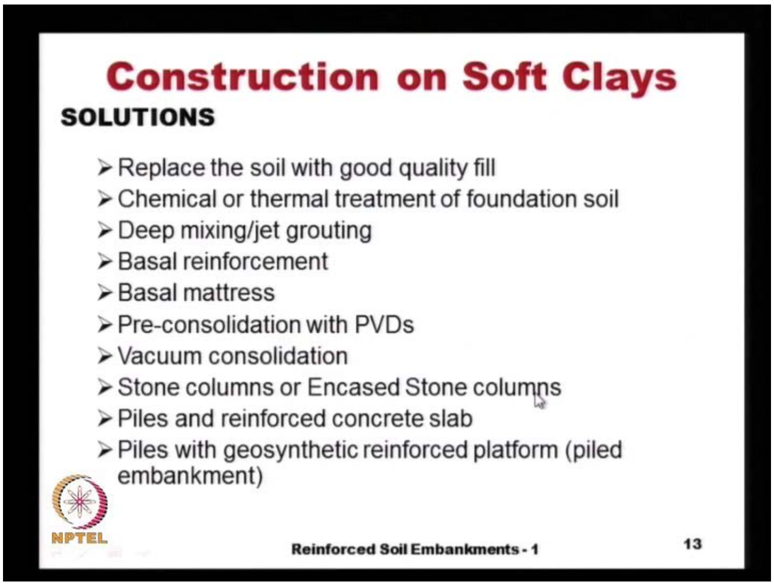

What are the different alternative soil construction in the soft clays the if the thickness of the soft clays not very much the easiest solution is replace the soil with a good qualities of soil. We just simply remove all this soft clay and then replace it with some good granular soil or we can use a chemical or thermal treatment of the foundation soil. So, that we can increase the strength that is the the one simple form is just simply pumping in the concrete the cement ground deep mixing and jet grouting, and then basal reinforcement or the basal mattress or sometimes a planar reinforcement may not be sufficient, because of the height of the embankment in such cases. We can provide a three dimensional type of mattress that could be filled with stone aggregates or some other very strong materials.

So, that we form a a semi rigid mat or we can use pre-consolidation with pre-fabricated vertical drains or through the vacuum consolidation or we can use our traditional stone columns or the encased stone columns. We can have piles with reinforced concrete slab which is by for the most expensive one, because we know that concrete is much more expensive than use in just soil alone or we can going for piles with geosynthetic reinforced platform. These are called as piled embankments and offlet this the last alternative has become very popular because we do not need to wait for the pre-consolidation to be completed, we can go in and do the construction as as the ground is being treated this we will see in some other lecture.

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And what are the shear strength properties that we can use for design of slopes the we should realize even before we design that these slopes especially those resting on on soft soils, we should expect that they will undergo very large deformation's and because of that we prefer to use or it is recommended in the design codes. That we should use the shear strength properties corresponding to the constant volume state or the constant volume strength parameters, and these happen at very large deformations and the embankments are the slopes that are built on very strong soils we can use the peak friction angle pi the peak shear strength parameters.

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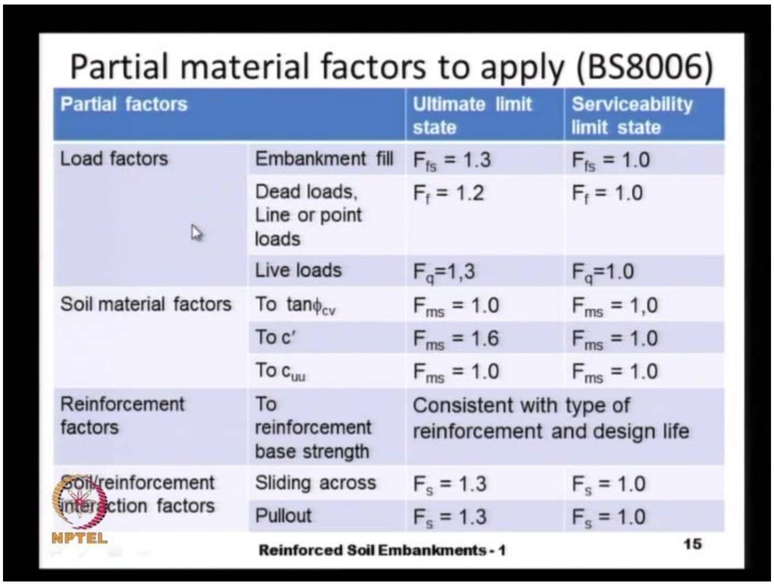
Partial material factors to apply (BS8006)

Partial factors		Ultimate limit state	Serviceability limit state
Load factors	Embankment fill	F_{fs} = 1.3	F_{fs} = 1.0
	Dead loads, Line or point loads	F_f = 1.2	F_f = 1.0
	Live loads	F_q=1,3	F_q=1.0
Soil material factors	To $\tan\phi_{cv}$	F_{ms} = 1.0	F_{ms} = 1,0
	To c′	F_{ms} = 1.6	F_{ms} = 1.0
	To c_{uu}	F_{ms} = 1.0	F_{ms} = 1.0
Reinforcement factors	To reinforcement base strength	Consistent with type of reinforcement and design life	
Soil/reinforcement interaction factors	Sliding across	F_s = 1.3	F_s = 1.0
	Pullout	F_s = 1.3	F_s = 1.0

Well just as we had very large number load factors to consider in the case of retaining walls even for the embankments. We have table that is given by the BS 8006 code to that gives different material factors for example, the load factors to consider for two different cases one is the ultimate limit state and the other is the serviceability limit state the load factor. 1.3 is recommended for the embankment fill then other dead loads and live load the point loads the load factor of 1.2 is given then for the live loads slightly higher 1.3 and the serviceability limit state as we have seen earlier that relates to the to the regular service condition. So, all this factors are one and then the soil material factors especially when we use the phi C v because its already factored factoring in lot of parameters like the loss of strength and then other parameters, we do not apply any other additional parameter on the phi C v.

So, this factor is just simply one, but then if you are using any c prime for effect of stress analysis, we use a very fact of safety or the reduction factor 1.6, and if it is an unrained cohesive strength corresponding to large strains we we use a fact of one and even and the reinforcement reinforcements strength. We apply lot of factors and this should be consistent with the type of reinforcement and the design life and. So, on and the factors of safety that we aim for for sliding is 1.3, and against pullout is 1.3 is actually, if we combine this factor 1.3 against this live load. And and then the fill factor of 1.3 if you combine both of them it works out 1.3 times 1.3 that is one nearly 1.7. So, that is the that corresponds to the factor of safety of 1.7 in the working stress design methods.

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Well, in the case of very weak foundation soils we go for an ground improvement. So, that we can improve this soil properties to some reasonable level where in we can have economical solutions otherwise the treatment could be. So, expensive the construction could be, so expensive. So, the requirement of very large amount of reinforcement the plane the in the form of geogrids or the geocells, and so on.

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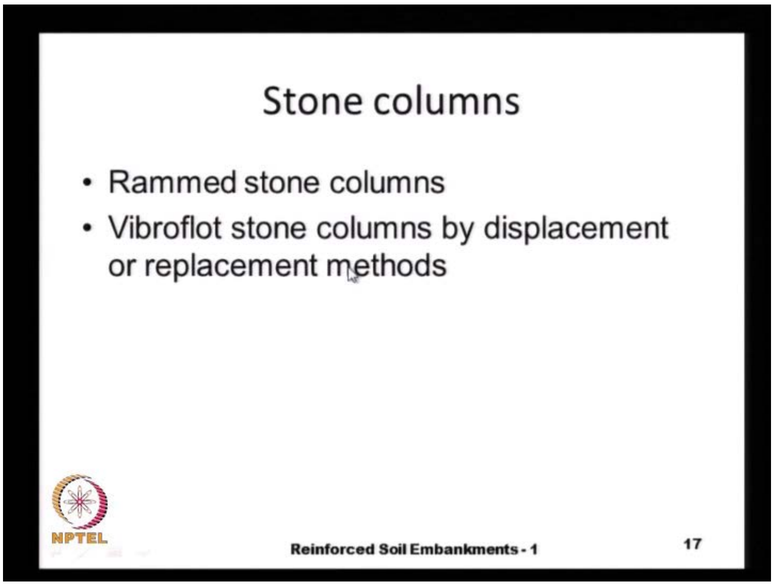

Some of these ground improvement methods are very briefly stone column is one method; there are different types the rammed stone columns, and the vibroflot stone columns, that can be formed either by soil displacement or by soil replacement this also we will see a bit later on in some other lecture.

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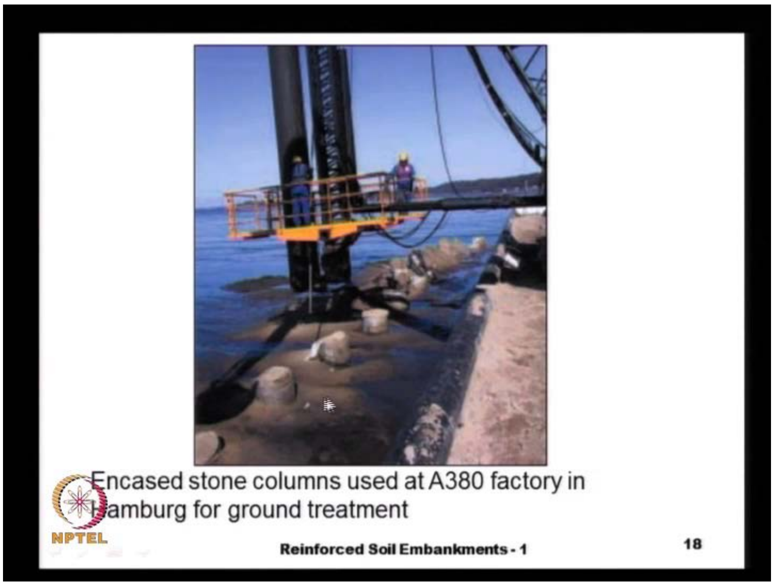

Here we see an example of an encased stone column, where in we have a granular column, but that is placed inside that cube of geotextile or geogrid. So, that a combination of this granular material that is encased within the geosynthetic behaves like a very strong and stiff column this, we will we will see in the some other lecture and the particular photograph that you have seen this is the ground treatment that was given to the A 380 factory in hamburg Germany.

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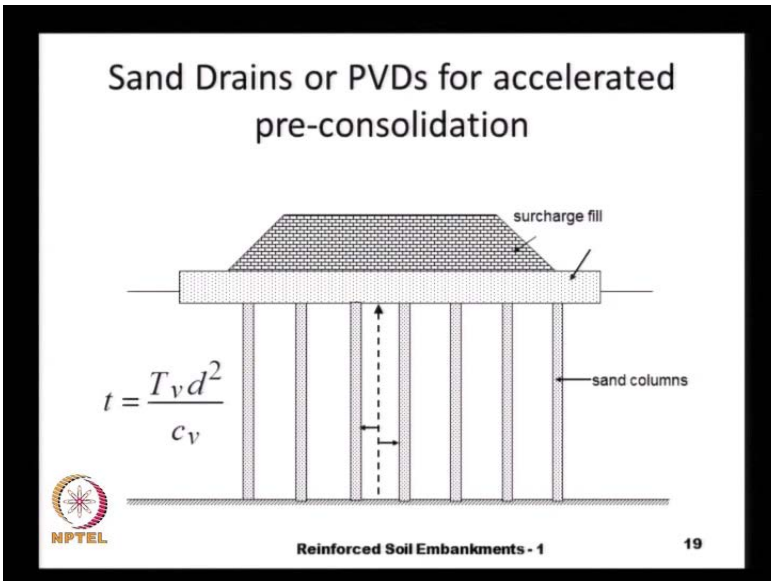

And another popular method that is traditionally used for for ground improvement is the pre-consolidation or we call it as accelerated pre-consolidation, and in the early days when this technique came into being people used the sand drains or the sand columns, where in we drill a hole bore hole. And then fill it with highly permeable material x sand or some aggregate, but with advent of geosythetics, we started using pre-fabricated vertical drains are p v d's and the principle that is used in accelerated consolidation is we reduce the drainage path length, because we know that the time for consolidation t is related to the t v. That is the time factor that is related to degree of consolidation and then the square of the drainage path length divided by C v, in this case in the equation the C v is a constant. And the t v is also constant, because it is related to the degree of consolidation say for example, if we want 90 percent consolidation the t v.

We can get from the charge corresponding to the 90 percent consolidation and the only quantity that is variable is the drainage path length d, and if we do not have any sand drains the water particle has to travel this much length to escape from the ground. Whereas, if we install these sand columns the maximum length that a water particle has to travel is only this much where is where is small length, and because of that the time for consolidation reduce drastically, because the time is directly proportional to d square.

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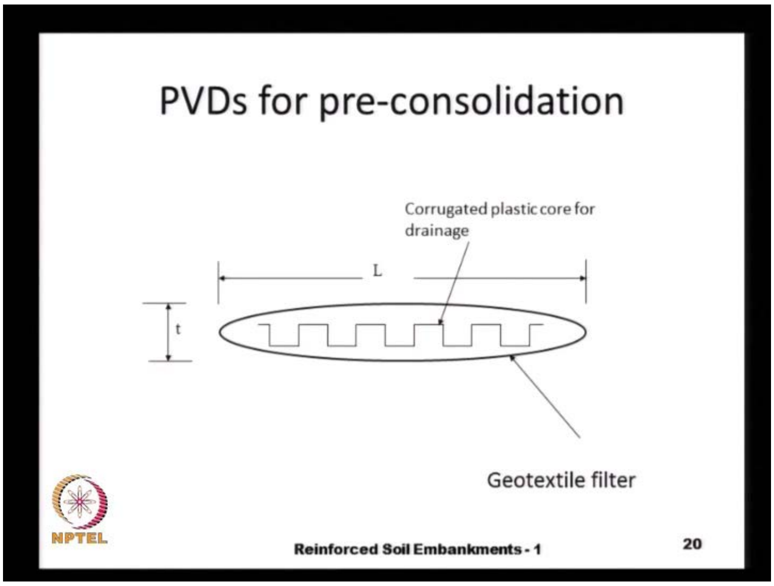

And here is a schematic of the pre-fabricated vertical drain it consists of a inner core, and then an outer textile that acts like a filter.

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Here we see the instillation of a pre-fabricated vertical drain is actually it comes in narrow strips of about 100 m m wide, and 2 to 3 millimeters thick, and this comes in length of about 100 meters, and here we can see these p v d’s installed it one site.

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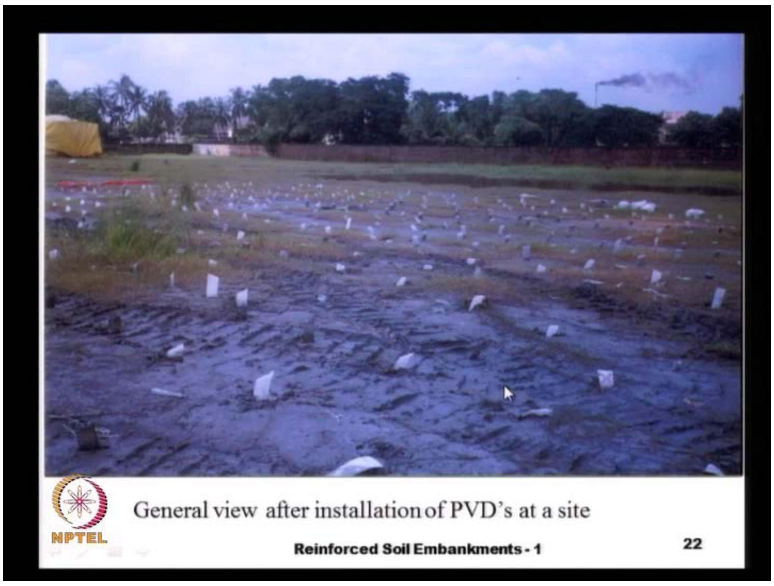

Here you can see the ground treated with p v d’s, then on top of this once we apply the surcharge load either an embankment or our foundation the soil quickly consolidates, and during the construction time itself we can achieve the all the settlements.

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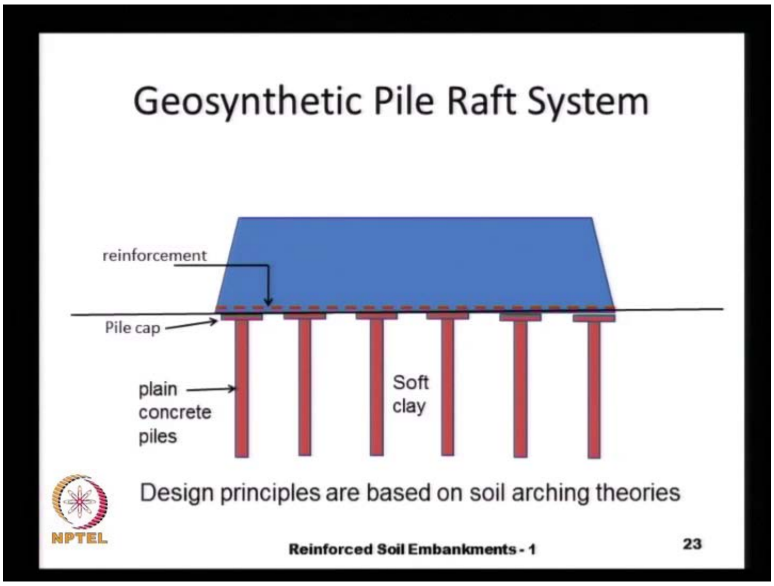

The other popular method is the geosynthetic pile raft is actually the pile raft is a very common foundation engineering treatment that we give for a transferring heavy loads into into soils with highly variable straighter or where the the expected settlements are large here. The the instead of the raft what we do is we use a geosynthetic reinforcement either a geocell or or a planar reinforcement to form a a relatively stiff mat, and we use a small piles with a pile cap. And in variably the piles that we use in the geosynthetic pile raft their plane concrete elements they do not have any steel reinforcement mainly, because there is no bending here our slab that we construct a does not have any bending stiffness. Because it is all made up of flexible materials and then the the design itself is based on the arching theories that we will see later on and this concept of the geosynthetic pile raft system has successfully being used at several places and its it is found to be very fast and also very economical compared to so many other alternatives.

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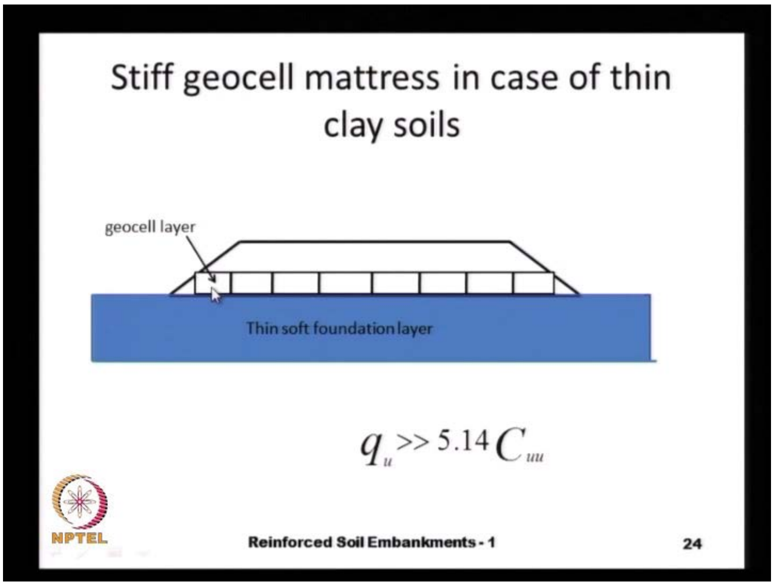

The other alternative is it use a very stiff mattress that is by using a three dimensional geosynthetics like geocells. And this option is especially true, when the thickness is is a thin is thin compared to the base width of the embankment and if this is the case say let us say that we have a very strong foundation soil here. And at the top also we have very strong and a stiff geocell in this case the q u that we can expect is much much more than 5.14 C u that is the the normal terja base bearing capacity equation that is the ultimate bearing capacity is about five times the the unrained cohesive strength. But once we confine it like this.

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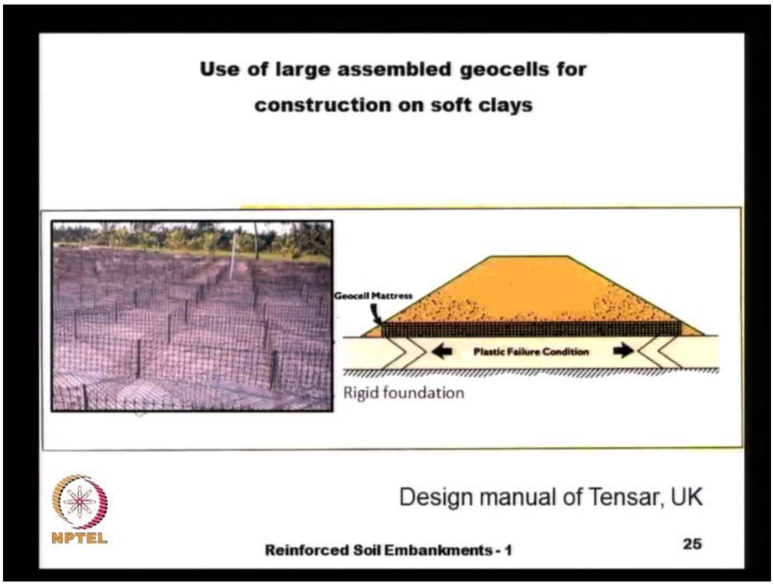

Ah is actually here is a schematic and how and and how the bearing capacity increases, because of the this squeezing of the soil between two solid and rigid under rough plates one surface made up of the geocell. And the other surface made up of the rigid foundation we have the the slip surfaces formed like this and because of this our bearing capacity factor increases to almost 15 to 16. And here on the left hand side you see an example of of open geocell mattress being fabricated at the site, which will be later filled with stones or or boulders aggregates to form this stiff geocell mattress this also the design and construction aspects we will see in some other lecture.

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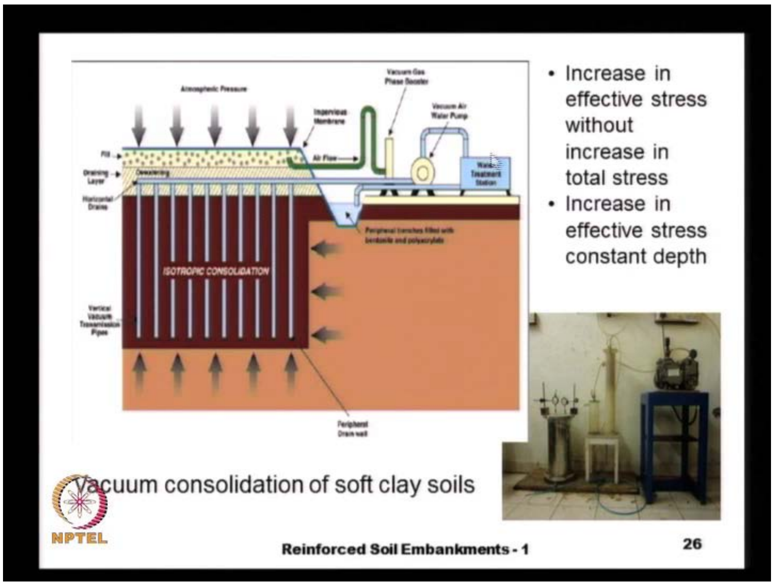

Another very popular method is the use of vacuum pressure for accelerated consolidation here what we do is we seal the the the soil to be treated completely by using geomembranes or some other a techniques by digging in trenches and filling with with some bentanite and polymer polymer mixed bentanite slurry and… So, that the entire volume of soil that is to be treated is a sealed. And we apply vacuum and once we apply the vacuum the atmospheric pressure that is actually basically we are removing the atmospheric pressure from inside this volume of soil that needs to be treated and the atmospheric pressure starts acting. And the main advantage here is we achieve the increase in the effective stress to drive our consolidation without any increase in the total stress.

That means that we do not need to bring in the soil, and dump it at the place to achieve the consolidation. And then the increase in the effective stress is constant with depth that is the major difference between this method of treatment, and the and the other methods, because in the normal in the in the conventional surcharge method we need to bring in this soil. And put it in and because of that the stresses that are generated the un-isotropic the stress is more the vertical direction compared to the lateral directions and because of that we generate shear stresses, whereas here the vacuum being an isotropic stress there is no generation of shear stresses. And the right hand side bottom you see a small example of laboratory test being performed to achieve the vacuum consolidation.

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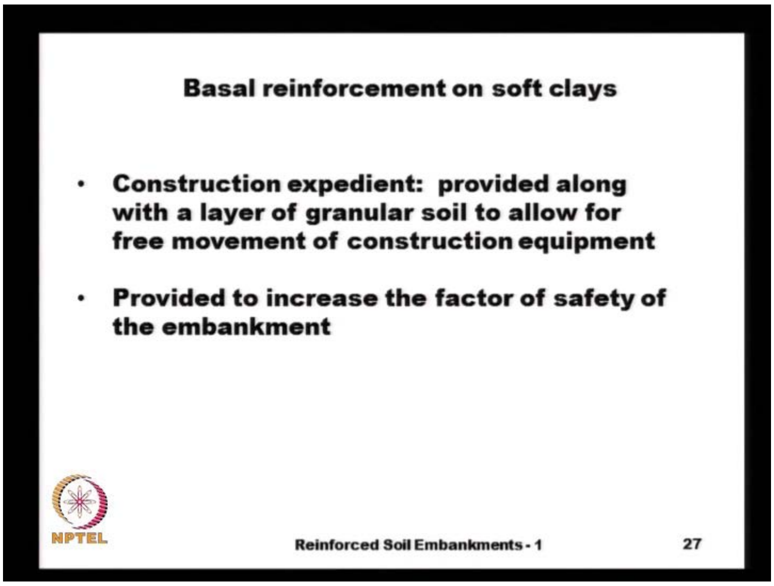

And now let us come back to the to the design of a basal reinforcement and in many cases the basal reinforcement is also used as a construction expedient because some places the the soil may be. So, soft that we cannot even bring in our construction equipments for doing the the minimal construction work in such cases what we do is we provide a very strong and stiff basal reinforcement along with a sufficient sufficiently thick granular soil. So, that we can freely bring in our construction equipment and start the construction process, and we can also provide it to increase the factor of safety of the embankment.

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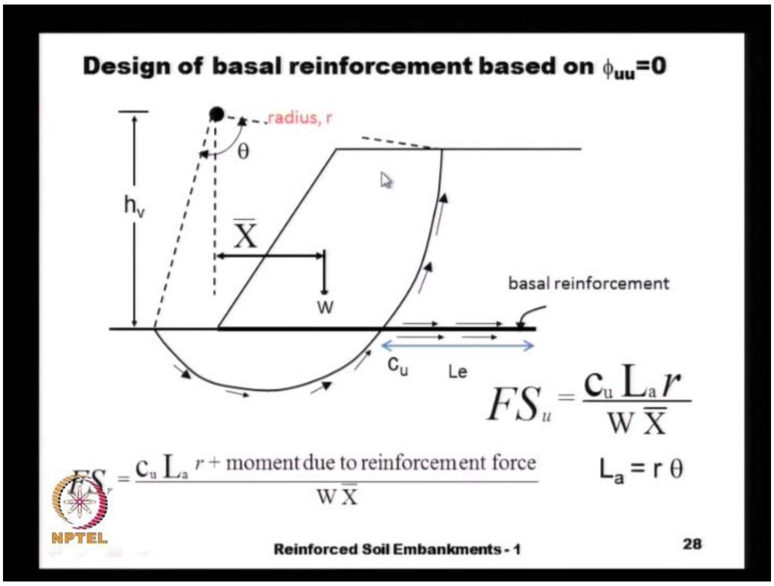

And the design methods, they are very similar to the standard design methods that we that we normally use in the in the soil mechanics courses. And let us first look at basal reinforcement design for phi equal to 0 or the unrained analysis or total stress analysis that we normally study in in the soil mechanic courses, and because the the soil is purely cohesive we can assume a circular slip surface like this. And for any given slip surface like this and we can calculate the weight of this soil wedge that is that is within this wedge that is the w that is trying to destabilize, and that destabilizing moment. See if you a draw the slip surface with respect to a centre here and radius the at this value.

We can easily calculate and that the weight of the the soil is just simply the volume of the soil multiplied by corresponding unit weight, and multiplied by this x bar, that is the distance of the centre of gravity of this area from the centre point. That is the disturbing moment and then the resisting moment is because of the a cohesive force that is developed along the along the slip surface length. So, it is just simply C u multiplied by length of the arc L a and that is the resistance force and this multiplied by this lever arm or the radius r that gives us the resisting moment.

And so our factor of safety against the failure is the resisting moment divided by the upsetting moment in this case our resisting moment is, because of the the cohesion. That is developed along the along the length of this slip surface c u times L a times r and our L a is nothing but the length of the slip surface that is equal to radius times this theta in radiance. And suppose this factor of safety is not adequate for our construction purposes we can adding some basal reinforcement and that can increase our factor of safety and the typical factors of safety that we aim for or about 1.3 to 1.5 depending on the importance of the structures that are building. And after providing this basal reinforcement the factor of safety increases, because of this additional movement the stabilizing moment that we get at the additional stabilizing moment is added on to the stabilizing moment, because of the the soil resistance that entire quantity divided by w times x bar is our factor of safety of the reinforced slope. And in variably as we know at the slope stability analysis is very tedious process we need to consider different slip circle centre points and then the radius. So, that we we identify the most critical slip circle and it is not necessary that the critical slip circle for the unreinforced soil is the same as that for the for the case with basal reinforcement and. So, we we tend to use some computer programs that can automatically do all these design calculations.

And there are two cases that we can consider because sometimes the basal reinforcement could be provided in the form of steel strips or or welded wire mesh’s and in such cases where the reinforcement is very stiff, we can assume that the reinforcement remains horizontal.

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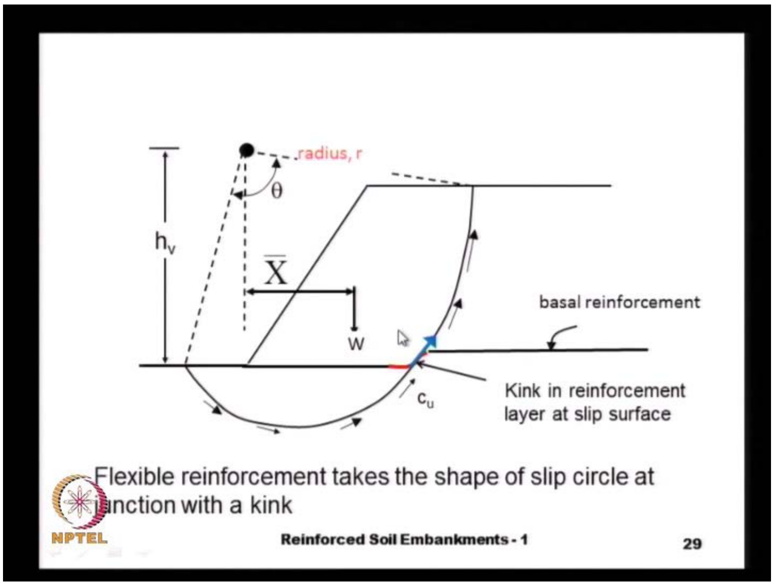

Whereas if you provide a flexible type reinforcement like the geosynthetic or a geotextile it is possible that at the at the point of on the contact with the slip surface, there will be kink formed within the geosynthetic. And in the at this point the we can assume that the reinforcement force is acting along the slip surface or tangent to the slip surface, and this we call this type of reinforcement is a flexible reinforcement. And because the reinforcement force is acting tangent to the slip surface the lever arm for, this is the radius or whereas for the previous case where the the reinforcement force is acting horizontally the lever arm is the the vertical height from the level of reinforcement to the centre point of rotation.

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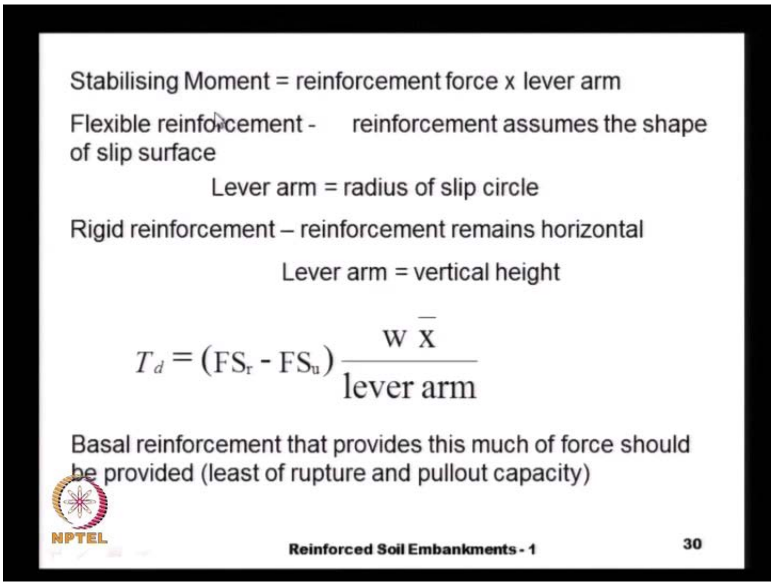

And the depending on the type of reinforcement, we can calculate the stabilizing moment where the reinforcement force provided times lever arm, and this reinforcement force is actually as we have done in the case of a retaining walls it is the minimum of the tensile strength or the pullout resistance. And so this the and we can can actually we by looking at this equation that the moment due to the the reinforcement is just simply the the t times, the t is the reinforcement force multiplied by the lever arm. And by a from this equation is actually here the first term that we have the C u l a r by w x bar is nothing, but the factor of safety of the unreinforced slope, and by using that relation we can calculate the the magnitude of the the reinforcement force. That needs to be provided as in the form of basal reinforcement is at the difference between the factor of safety of the reinforced slope minus the factor of safety of the unreinforced slope multiplied by w x bar by lever arm.

So, we should provide this much of basal reinforcement that develops this much of force, and sometimes we may not be able to provide it in one single layer, we may provide multiple layers say some two or three layers to increase the, and to provide sufficient force. And as I mentioned before the reinforcement force that we consider is the lower of either the tensile strength or the pullout resistance.

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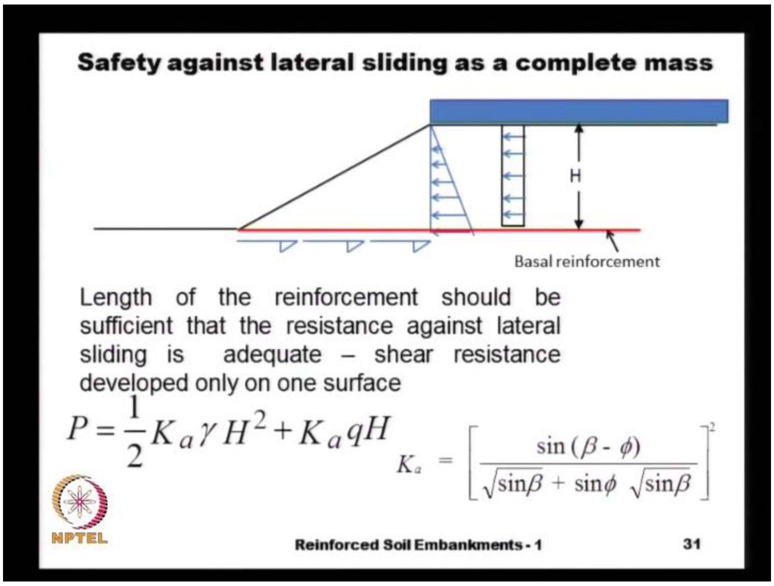

And when we do this calculations we should also consider the case of the sliding of the entire reinforcement mass of the entire soil mass like this, say let us say that we have built a built a slope with some basal reinforcement based on our slip circle design. And we should also make sure that the the extreme case where in the lateral force, that are acting inside the embankment should not push out the the entire slope like this. And the length that we have it should be sufficient to resist the lateral sliding, because of this the different forces the triangular distribution of forces, because the sulfate and this rectangular distribution of forces. Because of the uniform surcharge and in this calculations, we see that the shear resistance is developed only on one side on one surface. And this lateral force P that is trying to push our slope away from the resist of the soil mass is one half H a gamma h square plus K a times q H, which is the same as earlier except that the H a here is different because our the rankine's H a is applicable for vertical retaining walls.

But here our slope is not vertical, but it is its incline at an angle of beta, and our K a is given as sin of beta minus phi by square root of sin beta plus sin phi times square root of sin beta the entire thing to the square and if you substitute beta of 90 degrees. That is corresponding to vertical retaining wall this comes to 1 minus sin phi by 1 plus sin phi and in variably when beta is less than 90 degrees this K a is much less than what we had earlier.

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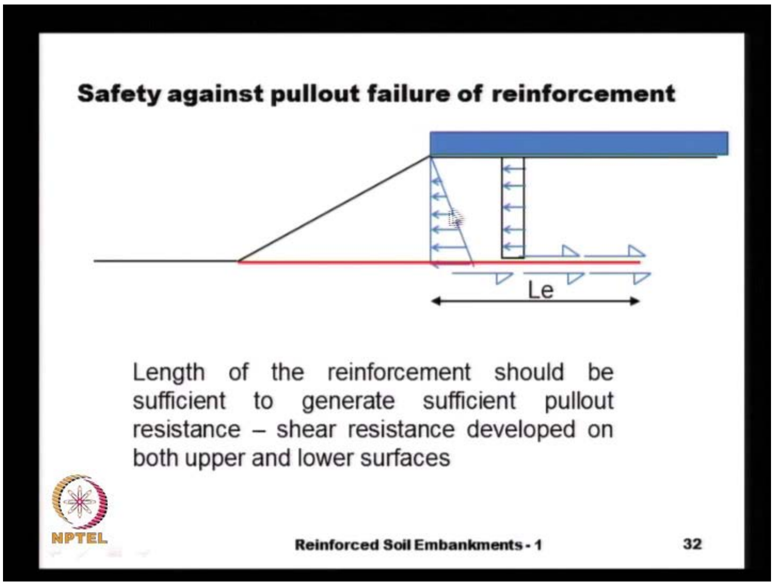

And we should also consider the possibility of the the provided reinforcement pulling out of the soil and let say that the the length of reinforcement beyond this beyond this, this position is l e. And we should make sure that this length L e is sufficient to generate the pullout resistance against this lateral force with some sufficient factor of safety. And even in the earlier case when we do this slip circle analysis the length of the reinforcement that is generating the pullout resistance is only the length of this the reinforcement beyond the rapture surface. And the quantity of reinforcement is not only a function of the the the rotational stability, but also a function of the the lateral sliding forces and pullout forces.

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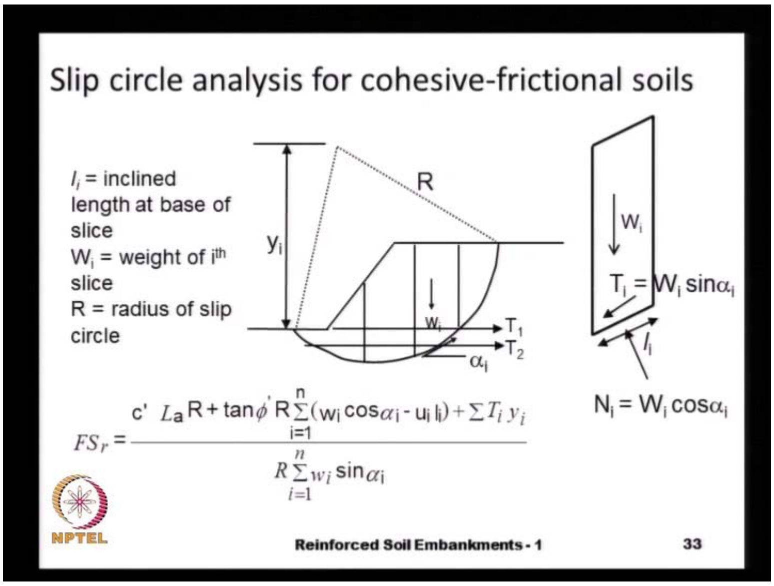

Previous analysis is only valid for phi equal to 0 type of soils or unrained behavior of the the clays. But sometimes the soil may have both cohesion and a friction angle and in that case our strength varies with depth of the soil. And we can use our conventional slices method and this is the ordinary method of slices or the felonious method or we can also use the bishops method of slices, where in we do not consider the entire soil surface as one single mass, but we divide this into certain number of slices usually at least about 6 to 10. And the more number of slices we have the more accurate is is our result and we look at the equilibrium of each of these slices like this.

Let us say that W i is the weight of the soil within this slice i’th slice, and because of this there is a normal force n. And and then a tangential force t that is the sliding force, and n is nothing, but W i times cosine alpha i where alpha i is the is the inclination of this base of the i’th slope i’th slice. and the T i is W i times sin alpha i. And for a general case where we have pore water there could be some pore pressure u because of C phase or some other factors and. So, we can write our factor of safety against slip circle failure in the same manner like earlier by taking moments about this point the C prime that is the affective cohesive strength multiplied by the L a that is the length of the slip surface.

That is the R times theta times r that is radius of the of the slip circle plus the moment that is generated, because of this resistance by by this n the normal force that is tan phi times W i cosine alpha; that is the normal force minus u i. That is the pore pressure multiplied the base length L I, that is our resistance force, and that multiplied by R the radius will give us the the resistance force. And then at together with this we add some the the resistance that we get, because of this reinforcement layers, and if we provide multiple layers.

We do a summation the T multiplied by either the vertical height Y i or or the the radius depending on the type of reinforcement that we provide your rigid reinforcement or flexible reinforcement this entire thing divided by the by the upsetting moment that is the W i sin alpha i multiplied by R and. So, this the this will give us the factor of safety of the of the reinforced slope and as I mentioned earlier the target factor of safety is about 1.3 to 1.5. And we need to do some trial and error analysis and find out the quantity of reinforcement that we need to provide here the analysis is trial, and error because the the resisting moment also depends on the anywhere you place the reinforcement. If you place the reinforcement at a at a slightly lower depth than the base of this embankment, and you get a higher resisting moment.

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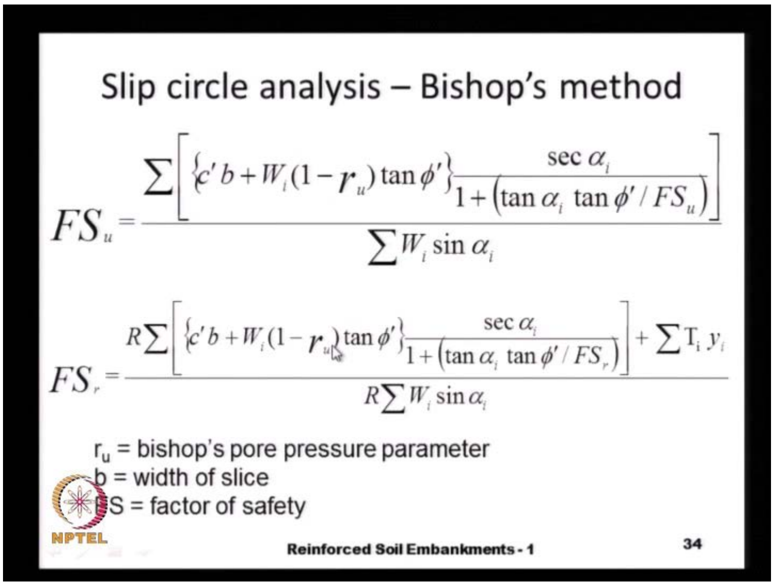

And more accurate way of a doing the design calculations is through the bishop's equation the bishop's equation is given like this, which is a very similar to earlier one except that we have the factor of safety. And both left hand side, and the right hand side is actually it is an implacity equation we we need to do some trial and error like we first assume some factor of safety based on the felonious analysis. And then substitute that and the right hand side and the factor of safety. That we get from the first analysis is once again substituted back and we do this trails until both left hand side, and the right hand side are equal whatever is assumed is equal to the to the calculated value.

And here all this parameters are the same as earlier except our b is the horizontal width of the slice and r u is the is the pore pressure parameter bishop's pore pressure parameter a typically this is about it depends on the type of soil and then the type of a drainage conditions and. So, on it could be anywhere from 0 to about 0.4 to 0.5, and our F S is the factor of safety F S u is the factor of safety of the unreinforced slope, and then F S r is the factor of safety of the reinforced slope and by using these equations. We can come out with the quantity of reinforcement, and all these calculations they are done by using some computer programs.

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And here you see an example of a computer program result, and this computer program you will get it as part of this course, and here you see the factor of safety of an unreinforced slope, and with some tension crack especially when you have a clay soil. We should expect in the formation of tension crack the tension crack height we know that this height is a 2 C by a gamma square root of K a, and in this particular case the factor of safety is only 0.66. So, we need to bring it up to say about 1.3 or 1.4 by doing some trails and by putting in some reinforcement of different strengths or different locations. So, we will some numerical examples to illustrate these procedures bit later on.

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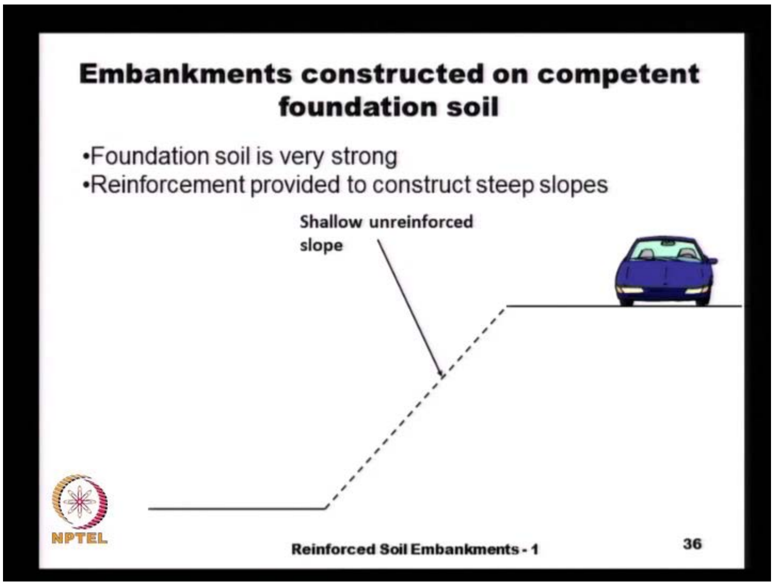

And now let us go on to the construction of embankments on competent foundation soils the case in point could be very something like this, we have a foundation soil that is very strong and, but we want to construct a very steep slope using the existing soil. Let say that the given soil at a site is stable at this shallow angle, and but then if you use a very shallow slope the required space is is very large. And if we if you want to increase this the slope angle, we cannot do it because the friction frictional strength and the cohesive strength they are not high enough to support a steep angle.

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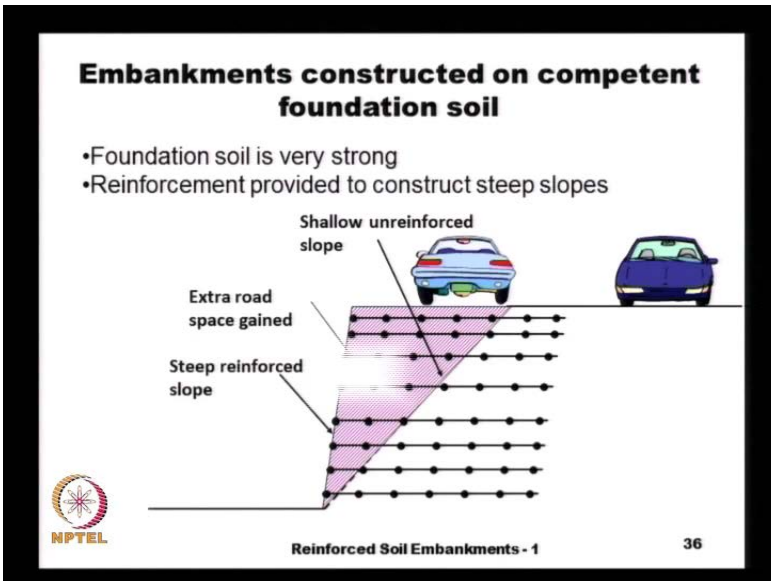

And in that case, what we do is we can provide some layers of reinforcement like this, and we can either say that we can we get extra space for our road or or if you if your line of properties only up to here from here. We can construct a very steep slope and and then finish our construction without acquiring any land, and here we see the shallow and reinforced slope here and then a very steep reinforced slope. And the quantity of the reinforcement that we provide here is the is the variable that that needs to be decided, and there are several methods that we can use that is the the planar slip surface method or the circular slip surface method or bilinear wedge method of analysis and so on.

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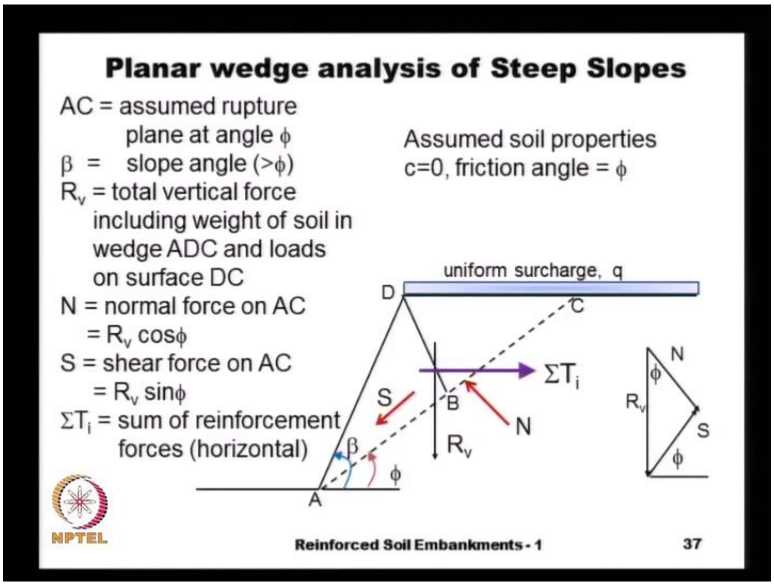

I think we will take up in some other some other lecture.

Thank you very much.