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ADVANCED GEOTECHNICAL ENGINEERING

Prof. B. V. S. Viswanadham
Department of Civil Engineering
IIT Bombay

Lecture No. 44

Module – 5

Lecture – 5 on Stability of Slopes

Welcome to course entitled advanced geotechnical engineering in module 5 stability of slopes.

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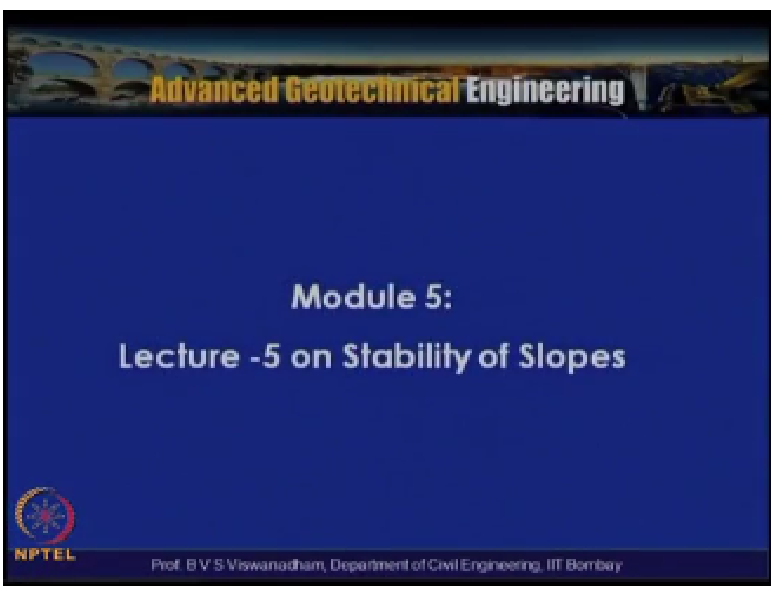

So this is module 5 lecture 5 on stability of slopes, so in the previous lecture we have understood about the effect of rainfall on stability of slopes and with an increase in rainfall intensity we have seen that the factor of safety decreases upon increase in the pore water pressure within the slope, and having understood about the different causative factors for this slope instabilities in this lecture we will look into various methods for enhancing the stability of slopes this means slope stabilization techniques what are the various means of ensuring that a slope is can be maintained stable.

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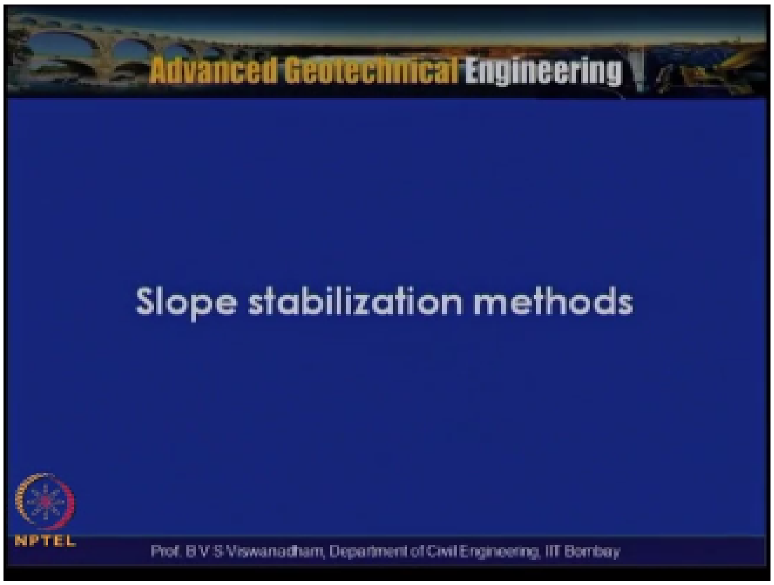

So this lecture deals with the slope stabilization methods or methods for enhancing stability of slopes. So we have various methods of slope stabilization invoke.

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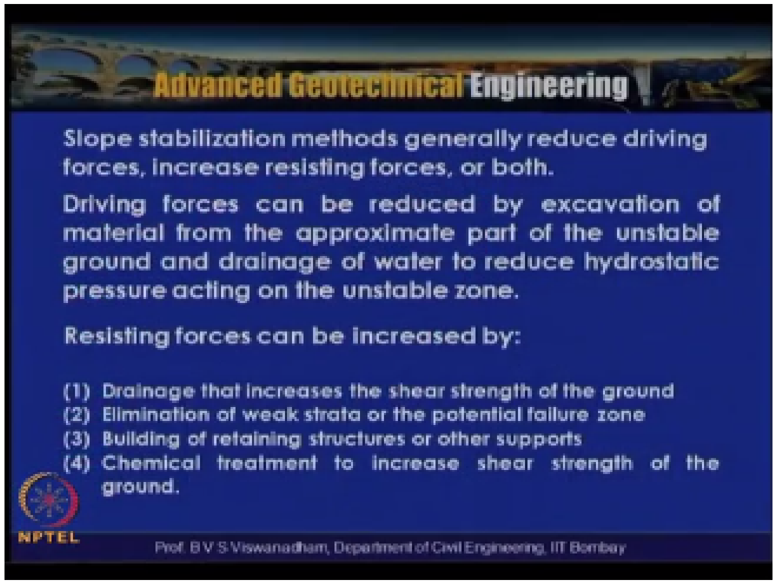

The slope stabilization methods are generally reduced driving forces and basically increase the resisting forces are sometimes both, so the slope stability stabilization methods generally reduce the driving forces which are causative forces for instability and increase resisting forces. The driving forces can be reduced by excavation of the material from the unstable portion what it is called as head portion, and the drainage of the water to reduce the hydrostatic pressures acting on the unstable job.

So if we are able to do removal of the material from the unstable zone and the draining of water to reduce the hydrostatic pressure acting on unstable zone one way this can lead to reduction in the driving forces the resisting forces can be increased by various means, primarily the drainage that increases the shear strength of the ground the draining of water reduces the hydrostatic pore water pressures and thereby increasing the shear strength of the ground, and elimination of the weak strata or the potential failure zone.

So elimination of the weak strata are the potential failure zone or you know in away subject some of the techniques what we do is that we reinforce the unstable zone with a stable job and the building of retaining structures or other supports by retaining by retaining the soil with an appropriate retaining solution there is a possibility that the resisting forces can be increased.

Another method which is chemical treatment to increase the shear strength of the ground one of the prominent method which is used being used these by line stimulation that is called by line columns or some lime slurry injection which results in the sort of hardening chemical hardening.

So these slope stabilization methods generally reduce driving forces increase the resisting forces are both then the resisting forces can be increased by you know primarily by drainage but that increases the shear strength of the ground illumination of the weak strata or the potential failure zone.

And building of retaining structures at an appropriate location and there are also some techniques where if in case if the if there is a deep seated failure then you need to adopt a technique where the forces are transferred to the deeper strata and this is called pile the slope stabilization, and to retain the soil at the surface level there is a method which is used for called suppressor walls which are attached to these piles, and the fourth method what we said is that the chemical treatment which actually can results in hardening and increase the shear strength of the ground.

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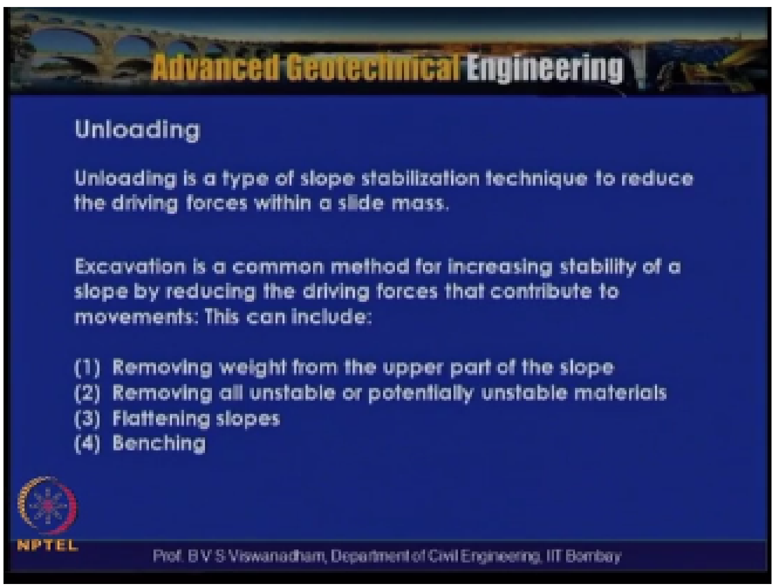

Unloading which is one of the method to reduce the driving forces within a sliding mass, suppose if there is a portion which is being subjected to slide or then unloading is one type of a method where the slow stabilization technique to reduce the driving forces. So next leasing is excavation is a common method to increase the stability of a slope by reducing the driving forces that contribute to the movement this excavation in the sense that this includes removing the weight from the upper part of the slope that is called head of the slope and removing all unstable or potentially unstable materials all unstable or potentially unstable materials and a flattening of slopes and benching of slopes.

So flattening of slopes in the sense that the slope which is actually having a steep inclination can be made flattened and this you know reduce increases the you know also the stability of a slope and benching basically the provision of benches are breams increases the stability of a slope. So with in appropriate design there is a possibility that the stability of aslope can be enhanced by removing the weight from the upper part of the slope or removing all unstable or potentially unstable materials and flattening of slopes and benching of slopes. The flattening of the slopes basically in this particular figure a cross section of a slope is shown.

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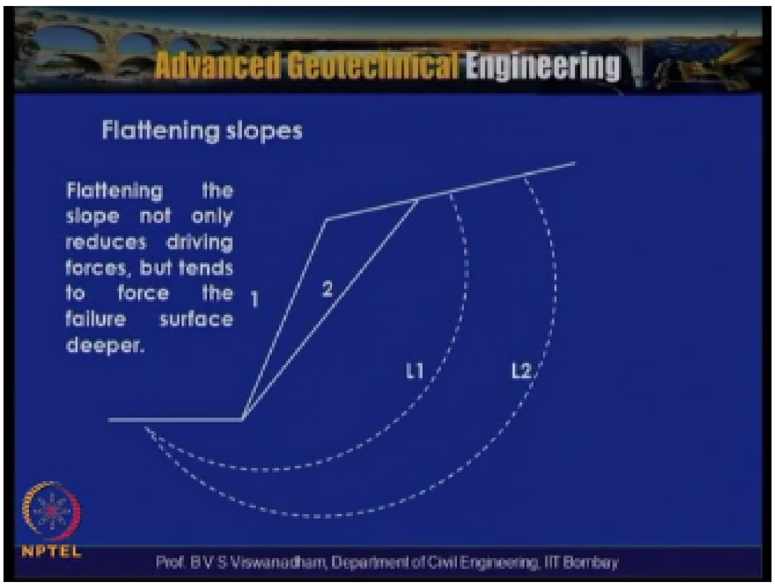

The slope which is the profile which is actually shown here is a one which is actually steeper than the slope section which is shown here to which slightly flatter let us assume that with the with slow cross section one this is the potential failure surface L1 and with the slope cross section two that means that the slope of 2 is flatter than the slope of 1 and the slip surface or potential failure surface is n 2 so the flattening of the slow not reduces the driving forces but also tends to force the failure surface deeper into the ground.

So the flattening of this slow not only reduces the driving forces but also tends to force the failure surface deeper into the ground, so one of the options is that flattening of the slopes but many times if any structures which are actually present close to the you know surface of the slope there is a possibility that the flattening option may not be viable.

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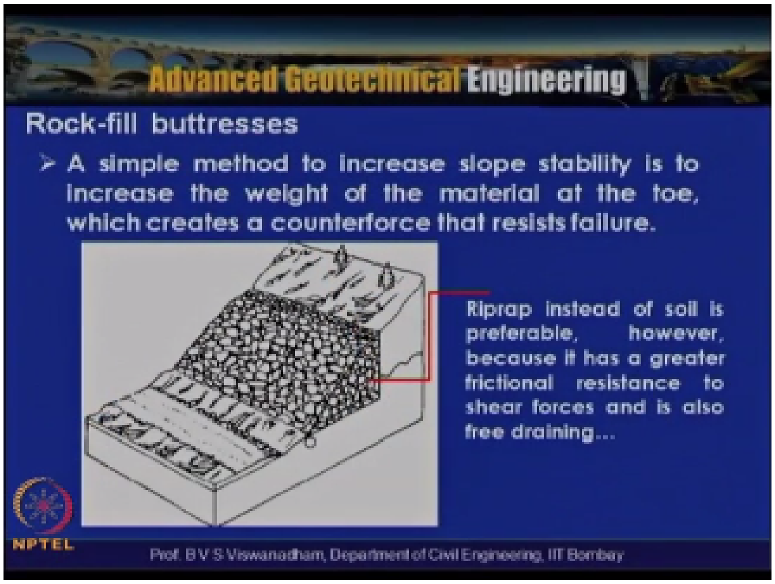

The another popular method to increase the stability of a slope at the downstream particularly is to prevail to do is the provision of rock film buttress the rock fill buttress, the provision of Rock will buttress is nothing but a simple method basically to increase the slope stability and this is basically to increase the counter reaction at the downstream of the slope that is especially at the toe of the slope and which counter force the resisting failure.

So the Rock will buttress basically consists of with the stones rather than soil if you use this buttress material or ever riprap instead of soil it is it is preferable because the frictional resistance between the these granular or stones is high and has the you know resistance again good resistance against the shear forces are disturbing forces and same time the slope is actually divided of water because of the free draining capability of these buttress materials which are nothing but the stones.

So rock fill buttress is basically a simple method to increase the slope stability basically this is done in hilly areas where you know particularly when the slopes are actually constructed or a highway or transport a highway or railway networks are constructed by using cut and fill methods in order to increase the stability of a slope at downstream and it is advisable to provide broken buttresses depending upon the necessity which you may need to increase the slow stability and to increase the weight of the this basically is to increase the weight of the material at the toe and which creates the counter force that resists the force.

But this is riprap which is provided is to be in the form of stones instead of soil because it has a greater frictional resistance to the shear forces and this also has excellent fin training capabilities, then another very recent technique which is coming up we said that the removal of material from the head of the slope but if sometime we need you know a certain elevation to be maintained and but at the head of the slope we need you know the so called the flow profile has to be maintained the one of the you know very recent techniques is to use lightweight materials traditionally sawdust and other materials are used.

But this artist actually is prone for biodegradability, so in view of that it is to be it has to be protected against the biodegradable dump to some extent, so in the recent past there is a technology which is called use of geo foam in slope stabilization.

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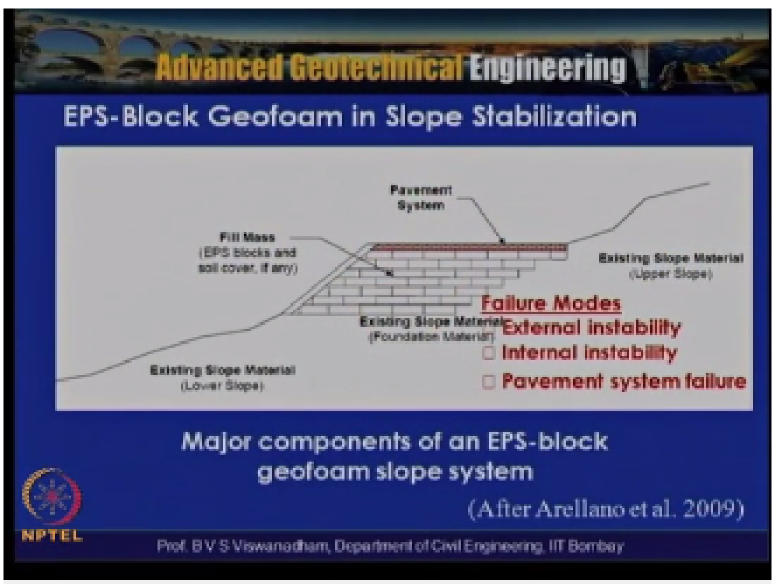

Particularly EPS is nothing but expanded polystyrene which is the which comes in blocks of different sizes and they can be placed one above the other like which is actually shown here and the film mass volume can be achieved and then this pavement system and other aspects can be provided. So here this should have a cover which actually prevents you know the intrusion of any other into matter into the into this particular zone and these geo foam is actually available indifferent densities basically varies from 12 kg per meter cube to about 40 50 kg /m^3 and depending upon the type of application one need to select you know a particular type of geo foam and for this type of application reasonably as there are compressive high compressive stresses it is maybe it advisable to go for high-density geo foam materials.

But however there are by using this material it is a very advantageous to reduce the weight at the head of the slope and but it actually has got you know a particular failure modes and the failure modes can actually happen within the soil without interacting or interfering with the blocks so there can be external fire strip instability internal stability and permit system failures. So the major components of an EPS block geo foam system after Arellano at all 2009 is actually shown here.

So this is a portion this is the film mass which is with EPS blocks and a soil cover you can see that the soil cover and sometimes here also they provide in the soil intermediate soil cover so depending upon the requirement and this is the pavement system and this is the existing slope material which is regarded and provided and the benching is provided to you know ensure the enough resistance along the this particular surface and this is the lower slope and this is the upper slope. So one way is actually used very widely nowadays with you know particular type of materials called EPS block geo foam.

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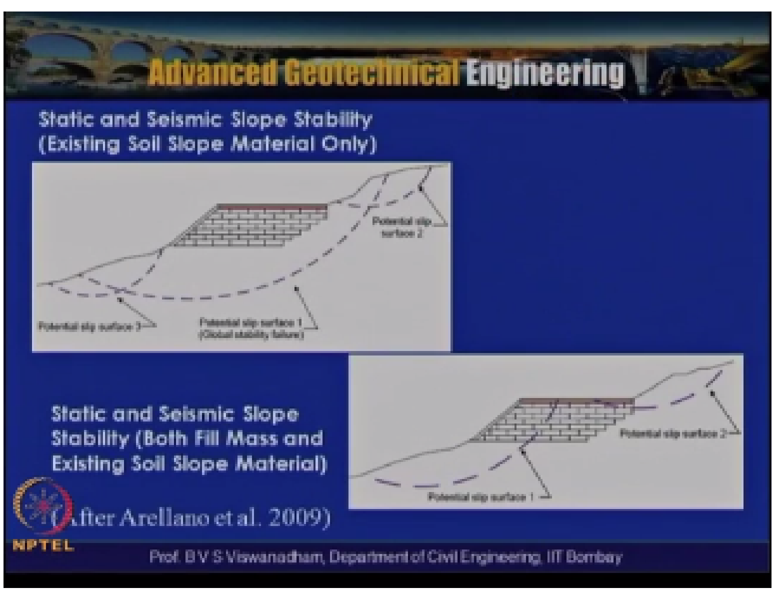

But as we said there are different types of failures the first and foremost is the you know from the you know localized failures within the you know soil that is the downstream failure and a global failure here and they upper slope failure that is above the this thing above the this portion where you know lightweight material is and this particular type of venue is film is actually failure surface passing through the blocks as well as the downstream surface as well as here also in the upstream portion.

So there can be you know possible potential failures, so while designing this failure surfaces have to be ensure now to be checked so that the liquid stability can be ensured. So while using for the stability analysis the appropriate strength properties of the geo foam need to adopt it and as well as you know the unit weights can be obtained and can be used in the analysis.

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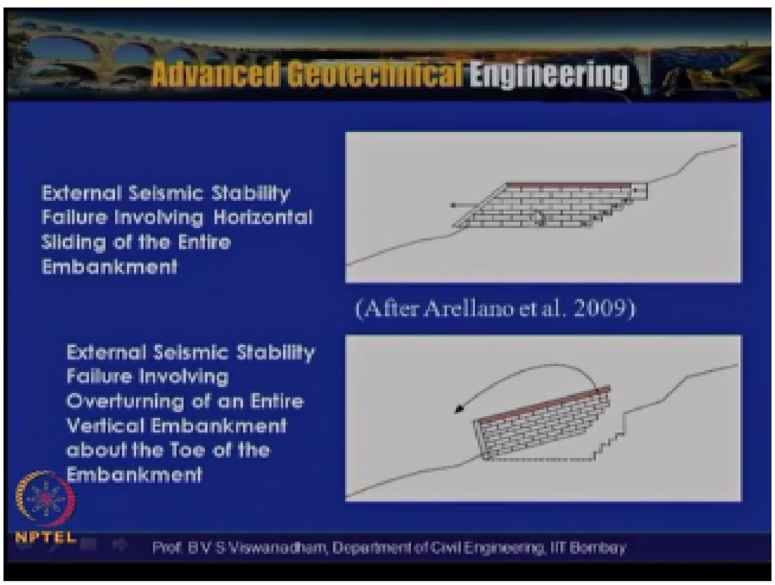

The other failure which is in case of seismic instability the blocks can actually stay you know slide all to them that means that if there is an excitation force because this the resistance is very low as the weight is very low there can be you know force which actually can make the blocks to slide. So involving the horizontal sliding of the entire embankment, so this is one danger in case of you know seismic stability and this is an external seismic stability failure involving water turning of an entire you know geo foam portion.

So this part of the figure which is below in this slide you know ensures shows the external seismic stability failure involving the water turning of an entire vertical embankment about the toe of the embankment.

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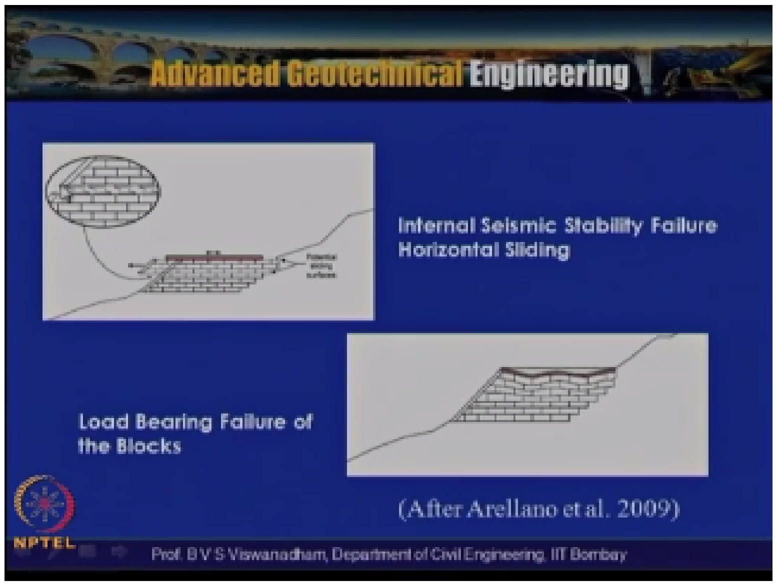

Then in this particular slide there is a this is a type of internal stability failure where the internal seismic stability failure where there is a slippage between the blocks that means that the magnified version which is actually shown here where the cow soil will be subjected to disturbance and there is a simple which actually happens between these two blocks block surfaces. So these need to be ensured and there are some means of in the field means of ensuring the stability by an appropriate anchoring from one block to one so that entire system behaves like a, the monolithic unit.

And this is another type of internal failure where local bearing failure of the blocks will happen and this is actually you can cause them because the external load or stress which is actually more than the compressive strength of the blocks, then there is a possibility that these you know bearing failure of the blocks cancan occur and which can lead to you know an internal stability failure as far as the EPS geo foam slope system is concerned. In addition to that there can be some pavement cracking failures which can cause because of this.

So these are then you know as a with the technology there is also the different modes of failures are discussed basically to you know make aware of the need of you know understanding which is required in this area. So then another appropriate technique for enhancing the stability of the slope what we discuss it is the drainage, so that the drainage of water reduces the hydrostatic pressure.

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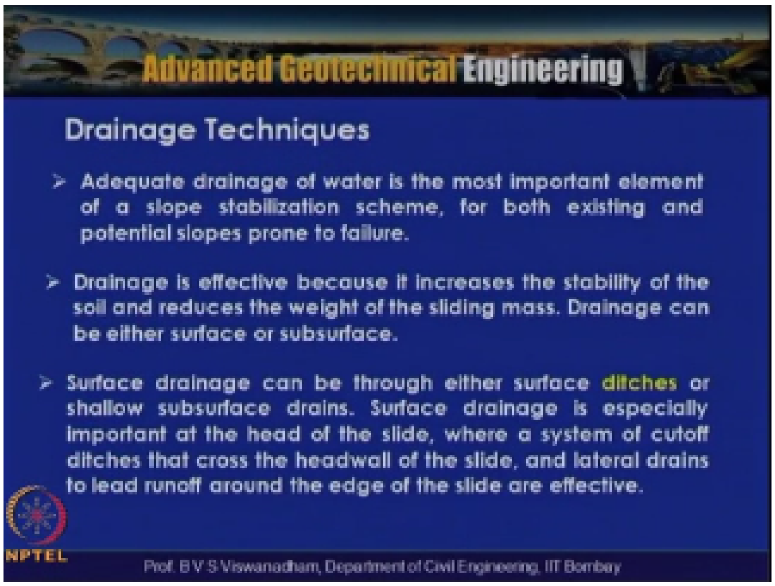

And so the shear strength of the ground can be enhance d so it requires adequate drainage of the water is the most important element of a slope stabilization scheme for both existing as well as the potential slopes prone field failure. So the adequate drainage of water is the most important element of a slope stabilization scheme for both existing as well as the slopes which are actually prone for failure.

So drainage is effective because it increases the stability of the soil and reduces the weight of the solid, so that is sliding mass and drainage you know the way of you know providing this draining of water from this slope there can be two ways one is called surface strains and subsurface strains the surface drains can be through either surface ditches along this slope which is done in highway embankments shallow surface subsurface trains or surface drainage is especially important here at the head of the slide basically so that the water is diverted when a system cut a very system of cut off string ditches that crossed the head well of the head wall of the slide.

And lateral drains to read the runoff around the edge of the slide basically they are effective, so the drainage techniques are basically the two types one is a surface drainage other one is the subsurface drainage, the surface drainage can be through the either surface ditches or shallow subsurface strains the basically surface drainage system is actually at the head of the slide that is at the top where the system of cutoff being chair ditches that crossed the head wall of the slide and lateral drains lead to the runoff and the edge of these slides basically they are effective.

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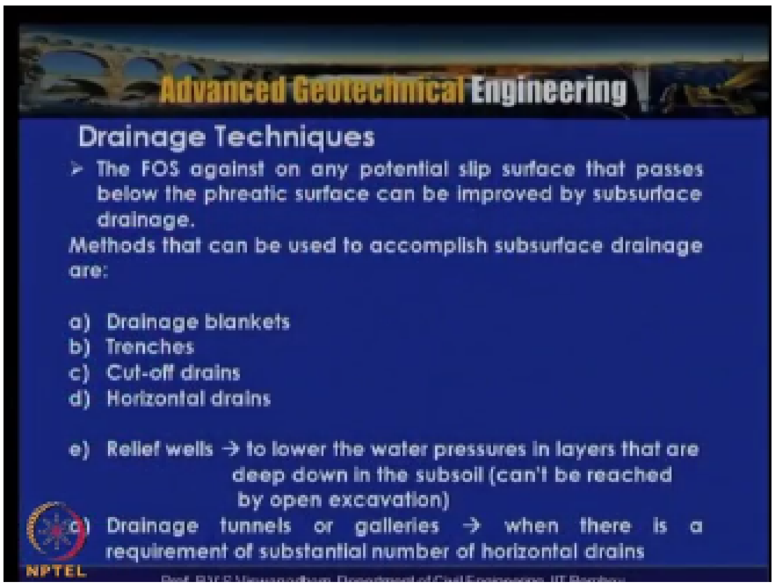

So the drainage techniques in continuation the factor of safety against any potential self surface that passes below the poetic surface can be improved by you know a subsurface drainage. So that means that in the subsurface drainage the methods which can be used are the drainage blankets trenches cut-off drains and horizontal drains. So factor of safety of in any potential surface subsurface or a failure surface and that passes below the periodic surface can be improved by subsurface drainage the methods that can be used to accomplish subsurface drainage or drainage blankets and in the form of princes and cut-off drains and horizontal drains.

And another method is called relief wells basically the function of these relief wells is to lower the water pressure in layers that are deep down the down in the subsoil, so these primarily these subsoil layers where the water has to be drained cannot be reached by open excavation system so in such situation relief wells is a type of subsurface drainage technique which is adopted the primary function of this is to lower the water pressures in layers that are deep down the in to a sun soil.

And the another technique is the drainage tunnels or galleries when there is a requirement of substantial number of horizontal drains and this is actually substituted by a drainage tunnel too you know drain the water. So various subsurface drainage techniques or drainage blankets and trenches cut-off drains horizontal drains and the relief wells and drainage tunnels and we said that the relief wells which are you know when it cannot be reached by open excavation for a particular sub soil layer then relief wells are install.

And the drainage tunnels are galleries basically they are provided when there is a requirement of substantial number of drains horizontal drains then it is substituted by a tunnel or drainage tunnel or a drainage gallery. Then as I said another prominent and popular technique of retaining the soil is slope stabilization using retaining walls.

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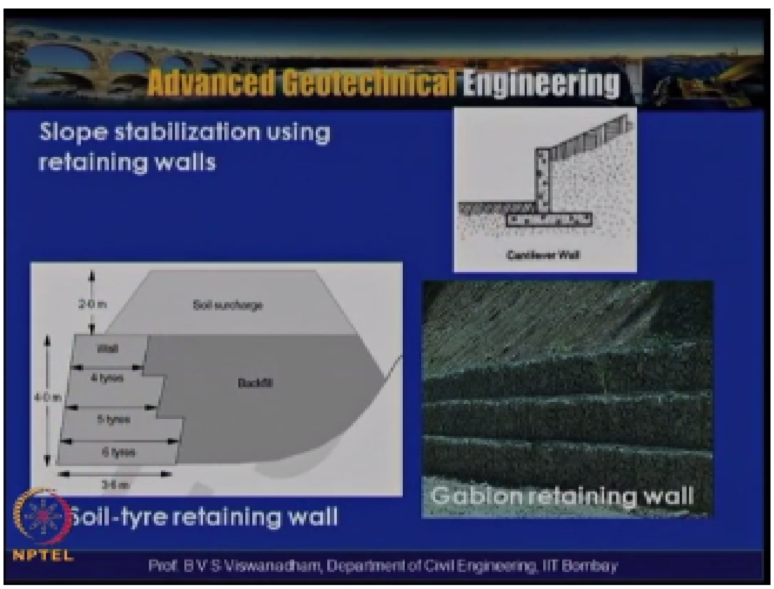

The different types of retaining walls are used at the gravity retaining walls which is a common application, the other application is to use cantilever retaining walls or reinforced concrete and once I sometimes when there is you know availability abundant availability of this stones locally then nowadays the gabion retaining walls are also very popular and very recently the soil tyre retaining walls which are also becoming popular.

Wherein the used or the tiles which are the waste materials like the tiles which are actually used in a fashion to with the tile material actually forms the facing of the facing of the wall and then they are come they are actually used with a particular technique to basically to construct soiled a retaining wall to retain the slope or to you know in ensure the sloe stabilization using a particular type of retaining wall.

So this position of the gabion walls is nothing but it has actually has gabion baskets and they are filled with the selected amount of stones which are actually shown here and which actually ensures you know because of the excellent drainage characteristics they ensure the drainage of the you know water and to prevent at loss of the fine soil particles there is a requirement of provision of a filter layer which is right behind the surface. So that this ensures this is done in the form of a nano geo statically fabric right behind the you know this surface, so that this will not allow the water to take a very fine soil particles.

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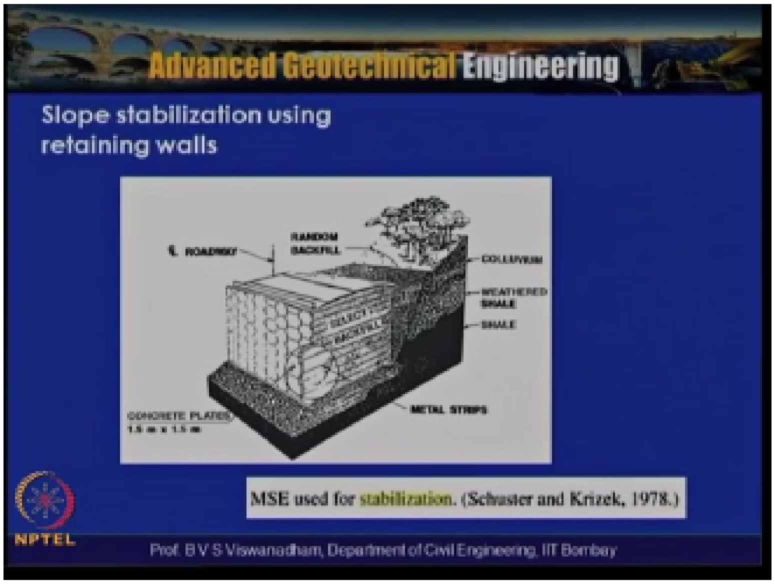

So this is a as I said another type of stabilizing the slope by using the retaining walls and these retaining walls previously started with steel reinforcements nowadays we have the steel reinforcement elements are substituted by the polymer strip reinforcements and which are high-strength in nature and they are used for retaining constructing these retaining walls and in addition to that they are also now the polymer materials like polyester geo grids which are actually used particularly reaction geo grids are used to retain the slower slope mass.

And also in this technique there is a possibility that because of its flexibility that it does not require any nominal foundation because if the soil which is available is actually having adequate bearing capacity then it does not require it requires a simple foundation about a man-depth of about one meter and it ensures also a vertical phase, so that the additional roadway and there is a possibility of you know at the upstream and downstream end the right-of-way can be used for other applications at highway transitions and all.

Though we provide these retaining walls but if the failure surface is such that it is traversing beneath the retaining wall then the provision of this retaining technique may not be useful.

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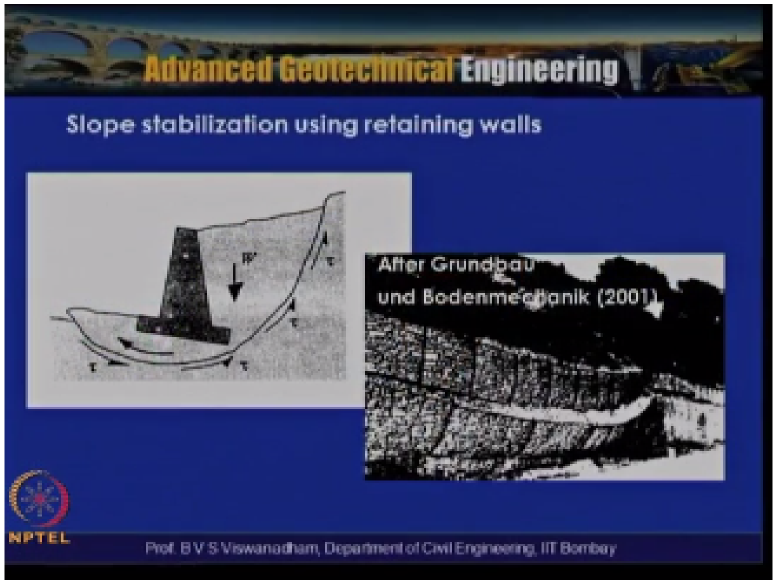

So here after Grundbau Bode mechanic handbook 2001 a gabion retaining wall which is subjected to excessive forces can actually see here the deformed gabion wall can be seen here this particular portion and this is the failure surface which is actually passing right below the retaining wall. So in such situation the slope stabilization is using right retaining walls maybe not in appropriate solution.

So in such situations popularly techniques called the slope stabilization by using vertical Pines are an option wherein it allows one to transfer the loads to the deeper status.

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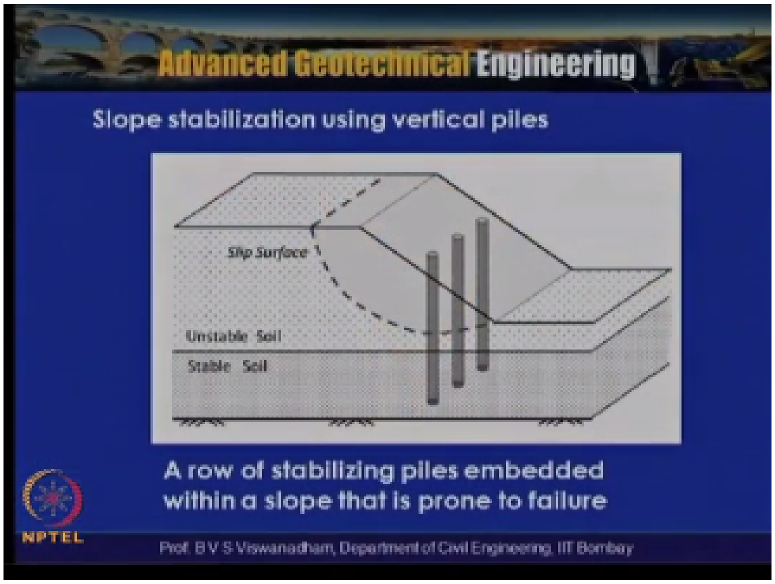

So this particular technique by name slope stabilization using vertical piles, so in this typical cross section which is actually shown here a slope cross section having a certain slope and this is the toe of the slope and this is the unstable soil and this is the say stable soil and this is the slip surface or a failure surface. So assume that the piles the question is that and the piles are you know placed in a row a row of stabilizing piles embedded within the slope which is actually prone for failure.

So that is what actually this sketch is actually shown the distance between these two that is called the spacing of these piles and D is the diameter, so this technique works in a way it actually mobilizes the resisting forces and by transferring the forces to the deeper status. So in such situations what will happen is that where the retaining structures survived abilities question and this particular technique by using vertical piles is a viable option.

So here it is very important to realize and to understand is that where to locate these piles particularly whether at the toe or whether at the crest of the slope or in the mid distance and another question which is required to be understood is that, what is what should be the spacing, so some of then you know studies which we are actually carried out at IIT Bombay and the studies in the recent past studies which are actually being carried out at elsewhere, indicates that a phenomenon called arching plays a trivial no role in ensuring the mechanism of this pile slope stability technique, so here according to Yoon and Ellis 2009.

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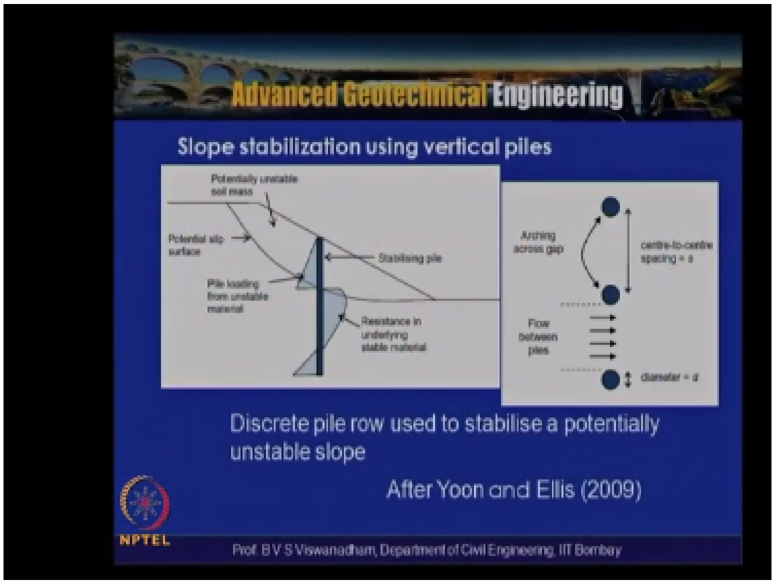

So here the similar cross section is shown here and this is the you know pile loading from the unstable, so the unstable mass actually has accepted a loading and this is the stabilizing pile and this is resistance in underlying stable material. So if the piles are located at a distance yes from the center to center, so here what actually happens is that the material flows between the piles and if the piles are close enough then there is a possibility that the development of arching can take place.

So arching is nothing but the transfer of transfer of the loads from the leading portion to the non annealing portions, so here what actually happens is that the arching across the gap develops in a way what actually happens is that the pile become active in supporting the you know are restraining the unstable soil mass. So here and another way of arrangement of these piles is also called a staggered arrangement, in this case what will happen is that you actually have two piles which are actually in place and then there will be a pile which is actually placed at the center.
So like this so when this when this actually has a portion the arrangement when it is done like this then what if then it is called as a staggered arrangement, so then it is not called as a discrete row it is actually called as a staggered arrangement. So there are two patterns one is called discrete row of vertical piles or otherwise a standard arrangement of the vertical pipes.

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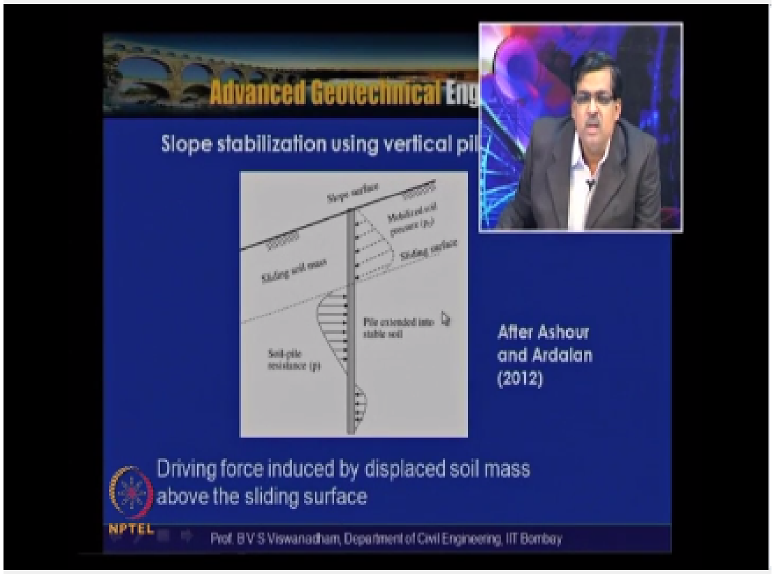

And so here this is again a similar typical picture which is actually shown after Shore and Delyn 2012, where the load which is actually applied on the pile surface pile, on the pile and the soil pile resistance which is actually shown here. So the driving force in useful by disparate soil mass about the sliding surface is actually shown which is used in the analysis to derive these things. So the next method which is also by the reinforcement or conclusion is the slope stabilization using anchors basically the.

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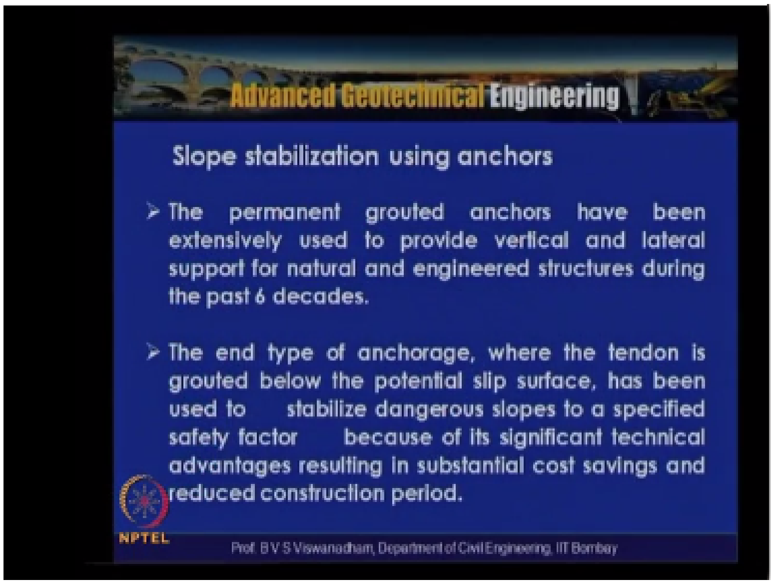

This is B this is basically the permanent grouted anchors have been extensively used to provide vertical and lateral support in natural and engineered structures during the past six decades. So these slope stabilization using anchors basically here a row of anchors when they are actually placed at certain inclination and the possibility that they slope actually can have, you know can have cannon you can have a better stability. So in this case grouted anchors with fixed length and the free length and basically provide a vertical and lateral support to the natural and engineered structures during the past six decades.

So the end type of Anchorage where the tendon is grouted below the potential surface has been used to storage the dangerous slopes to a specified a safety factor because of the significant technical advantage the resulting do substantial cost savings and the newest reconstruction video, we are in it involves simply a driving of these making a borehole and driving installing tendon and the grouting the fix event portion and then making the anchor active by applying a desirable force.

So which makes the slope, so this is basically an active anchor wherein it generates then you know resistance because of the embedded Anchorage with the resulting due to grounding which actually done in the fixed length portion. Sometimes if there is a bedrock or a rock or rock is there then the soil is actually anchored to the rock or prop, otherwise if it is done in soil it is mandatory to do a verification test particularly a bloke test at the flattest of the anchor basically to check the anchor capacity for which is designed and available at the site is in order or not.

So in this particular slide what we are we have studied is that we try to introduce ourselves to the stabilization using anchors, now here in this particular slide a cross section of this slope is shown.

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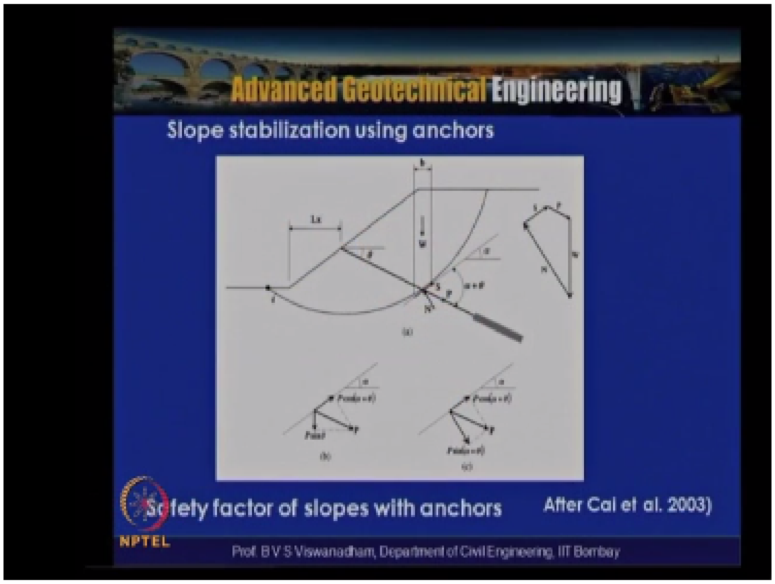

Wherein we have the inclination of the anchor which is at an angle θ with the horizontal and the this is the potential failure surface which is actually assumed and this is the angle with α with the horizontal and this is the particular slice having width B and weight W, so here s is the thing but the soil shear strength and this is the normal reaction which is actually from the soil. Now here this particular force P which is nothing but the anchor force of tension in the anchor acts in this direction.

So here there is there two approaches which are actually use one is that the using the reaction of their solving the forces like this P along failure surface, as well as taking it vertical that is that P sine θ in this direction and peak cos $\alpha + \theta$ along the surface in this direction. So there is also the another school of thought too you know instead of this is the instead of resolving like this resolving in the form of like resolving like along the horizontal surface that is $\alpha + \theta$ and this is this is nothing but P sine $\alpha + \theta$ which is normal to the failure surface normal to the failure surface.

So it actually p n + α θ - n that is the net force which actually acting at the base of the slice, so this we will try to see one is conventional effect is vertical effect vertical approach other one is the normal approach. So the safety factor of the slopes stabilize it with the anchors can be calculated by the following two approaches.

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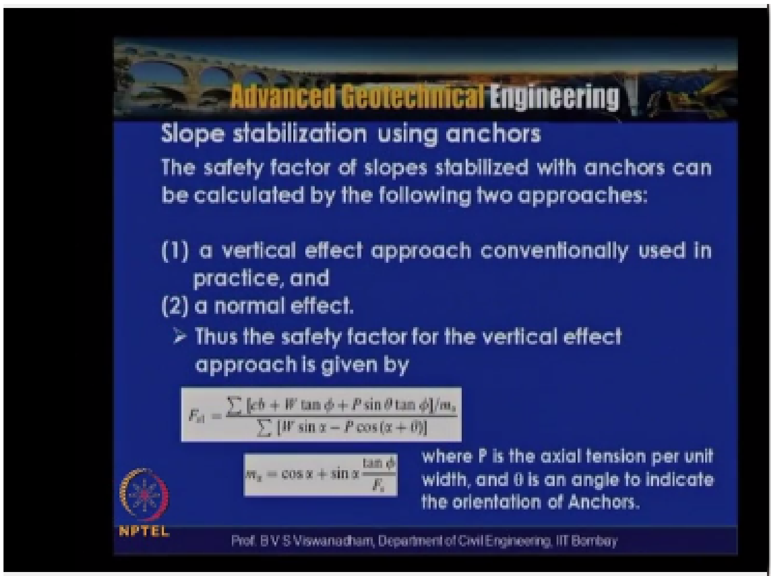

What we said is that vertical effect approach conventionally used in practice and normal approach that is what resolving with slopes with resolving p one of the components is normal to the slope surface. So thus this after of safety factor for the vertical effect approach is can be given by factor of safety 1 is equal to see this is with the modified bishops method and the M α is nothing but cos α+ sin α x tan π by a factor safety.

So here where P is the axial tension per unit width and θ is the angle to indicate the orientation of the anchors, so we also required to know what is the position of this anchor from the t of the slope and for a given slope inclination and what is the inclination of the anchor with the horizontal that is θ which is optimum which actually which can ensure the highest factor safety.

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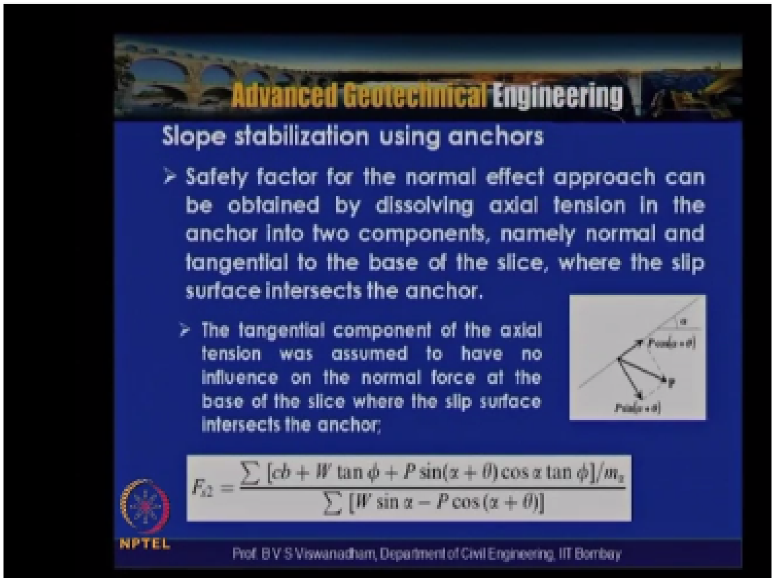

So thus the safety factor for the normal effect with the particular solution like has been discussed is that P sine + α θ P cos + A θ there is a safety factor for the normal effect approach can be obtained by dissolving axial tension in the anchor x two components, namely normal and tangential to the normal and tangential o the base of the slice where the slip surface interested intersects the anchor way the slip surface intersects the anchor.

So at this portion where we actually dissolve the forces as normal to the slope surface that is P sine α+ θ that is the component of P and this is nothing but P cos of α+ θ, the tangential component of the axial tension was assumed to be have no influence on the normal force at the base of this race where the slip surface intersects with the anchor. So the factor of safety of the slope which is reinforced with the anchors can be obtained by normal approach, normal pro normal by considering this particular type of resolving with the considering the normal component of the anchor tension.

We get this expression like this where summation CD + W tan π + P sine α+ θ cos α tan π / M α, so here you can see they're both resisting forces and driving forces are getting modified so this is actually likelihood of giving the higher factor simply.

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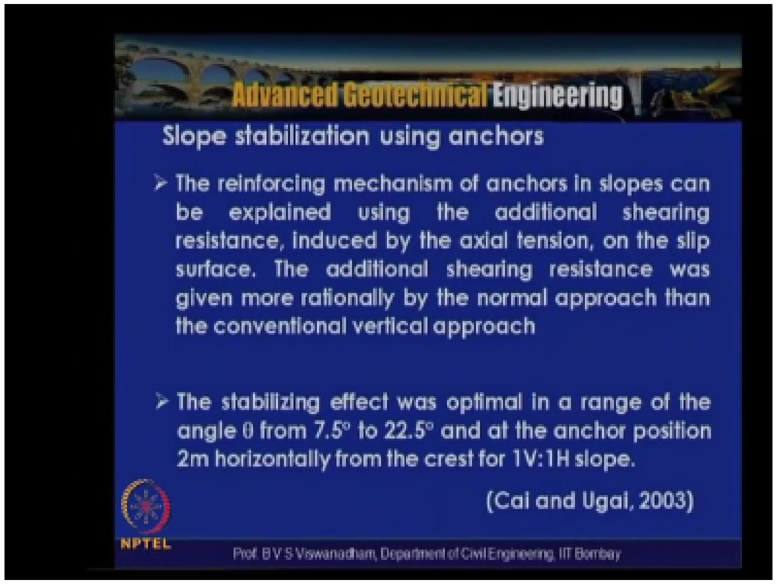

So the reinforcing the mechanism of anchors in slopes can be explained using additional shearing resistance induced by the axial tension on the slip surface, the additional shearing resistance was given more rationally by the normal approach than the conventional vertical approach. So in this what we would like to impress upon is that the normal approach is actually is actually provides additional shear resistance induced by the axial tension, than the conventional vertical approach.

And for a type which is actually considered by Chi and μ by 2003 type of slope with the type of material what they have used with one vertical one horizontal slope for that it is found that from their analysis that all the stabilizing effect was optimal when θ is in the range of 7.52 to 22.5 and the anchor position is 2meter horizontally from the crest of the one vertical one horizontal slope. So in stabilizing the slope with anchors what we understood is that this stabilizing effect will be optimal and we found to depend upon the sloping donation and the anchor position which is also need to be doctored looks it upon.

So that the optimum angle of inclination optimum position of the anchor along the slope surface ensures a better slope stability by using anchors.

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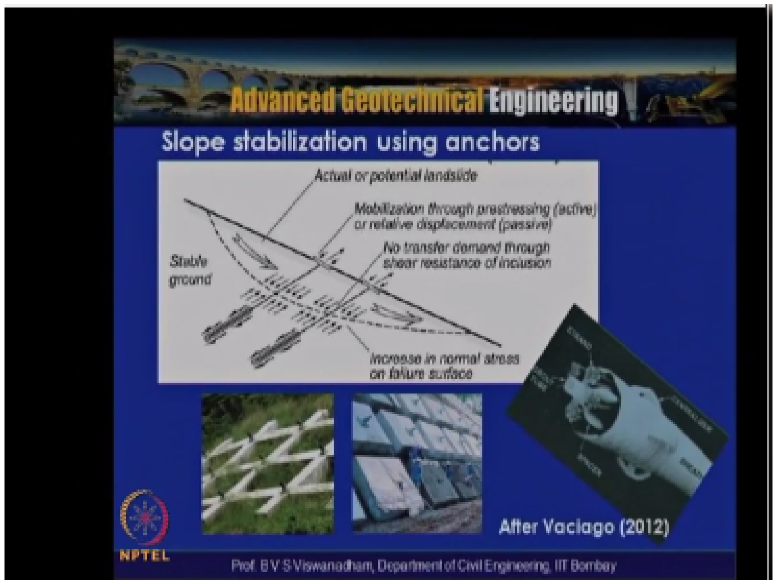

So here this particulars like a typical application was actually shown and this is the sliding portion and this is the result with the you know the anchor which is actually in place an active anchor and where you can see that the failure surface is actually subjected to a so-called compressive force, which actually makes the unstable force and to feel like tied with the stable ground and this is the fixed length portion this is the free length portion.

And the this particular anchor the this is actually a sheet and this is the anchor with spacers and is actually shown so basically this ensures the stability by providing the frictional resistance at the you know beyond the failure surface. So mobilization through the pre stressing in case of active and the relative displacement in case of passive, so basically here there are active anchors and passive anchors the passive anchors in the sense that the soil movements make the mobilization of the tension.

In case of pre stressing or what you call is active is that without any soil moments where in what we tend to do is that we apply pre tension to these anchors and lock you know the arrangement which is actually shown here, this is a concrete slab arrangement on this loafer surface this is the anchor after applying adequate pre tension and these are Locker here, so this actually ensures these are the active anchors and this is something like to have both green vegetation as well as you know a support this is some something like called a grid type of beams which are actually used in popular nowadays in number of applications.

So this type of this thing is actually after work I go2012 where in this type of you know applications are actually happening in the practice.

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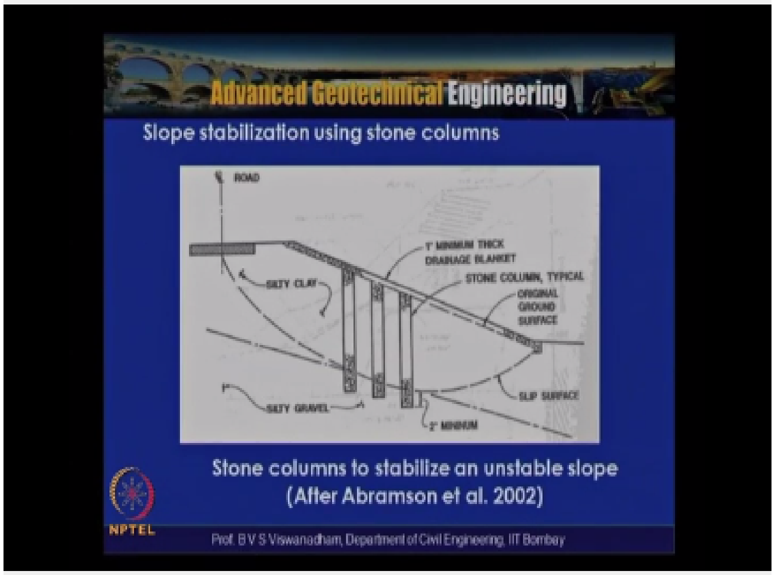

The another technique which is actually used for establishing slopes particularly clay slopes soft clay slopes or silty clay slopes wherein, so basically these stone columns is are placement technique and which is used for improving the ground and the load carrying capacity but there is because of the in the stone columns what will happen is that are a granular column or a the replacement of, the soil actually happens and the soil is replaced with a stone charge or granular material the these stone columns are basically having a diameter of about ranging from 400 mm.

Basically here what will happen is that the soil borehole which is actually play done with a drilling and sometimes fibro float which are actually used and then they it really is actually supplied so in this way the use of the it is done on the downstream of the road the existing road can use it for the placement of the Rings and then drilling the more holes for installing these stone columns, so basically here in this particular slide a typical slope which is actually stabilized with the stone columns which is actually shown here and if this is the potential failure surface.

And it has to be ensured that you know this stone column traverses at a certain depth beneath the failure surface and it is also required to understand the lateral stability of these stone columns particularly when they are subjected to shear, so it will be interesting say for example to perform certain tests wherein whether this particular you know the this interface and whether it is required to have you know adequate restraining forces or not, but in this also there are different types of patterns of arrangements.

One is the like what we use in soft ground improvement the squirrel layout or staggered pattern, so in the staggered pattern or what we say that the it is also called as the in plan they look like the stone columns are placed and are positioned at equal at a triangular pattern wherein what will happen is that you have s is the spacing and each side of an equilateral triangle is actually having a size of S, so with that what will happen is that that actually equilateral triangular pattern and M square arrangement out of this for as far as the soft ground improvement is concerned the equilateral triangular pattern was found to have superior performance.

So here also for this slope stabilization using stone columns the equilateral triangular pattern may provide you know adequate resistance and then provide higher average shear resistance, so this is actually designed by using the similar concepts.

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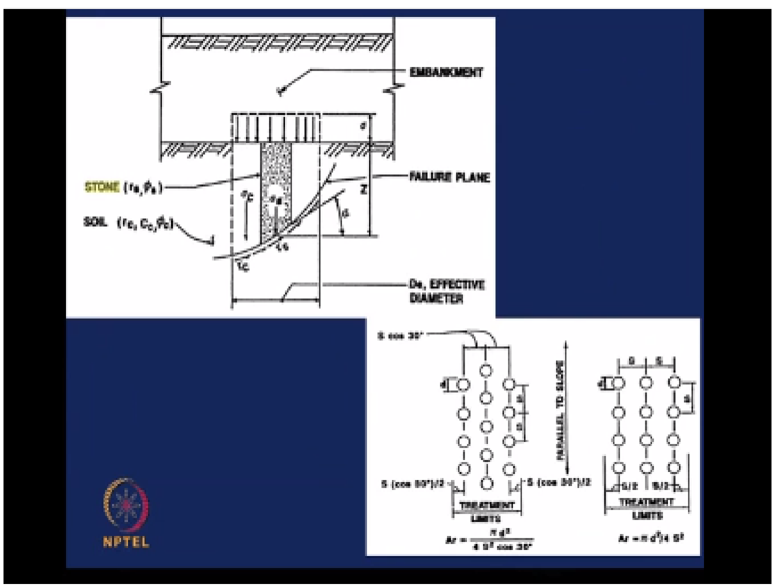

Directly adopted that is the here this is the load which is actually a portion by stone as well as the ground, so this ratio which is actually called as the stress concentration and here in this portion the there are two methods one is the average Houston method the other one is that to estimation of the sheer stone by involving this you know the stress portion by the stone column and the ground. So this is the equilateral triangular pattern arrangement which is actually shown here and here this is the square arrangement pattern s is the spacing and here also s is the spacing and D is the diameter of the diameter of the stone column.

These are in the plan and this is in the cross-section, so the another approach which we are actually going to discuss which is actually called the average shear Stearns approach which is the popular and once we get the average shear strength parameters based on the type of layout which is actually adopted for improving the stability of a slope, then those average shear strength parameters can be used and then conventional slope stability analysis can be performed and which actually can be used for getting the effect of the stone columns on the slope stability.

So there are the software's which actually can you know adopt this scheme and then give the factor safeties one of the examples is the Talon which actually has got a facility to incorporate stone columns and then different layouts to induce to calculate the factor of safety of the effect of the stone columns.

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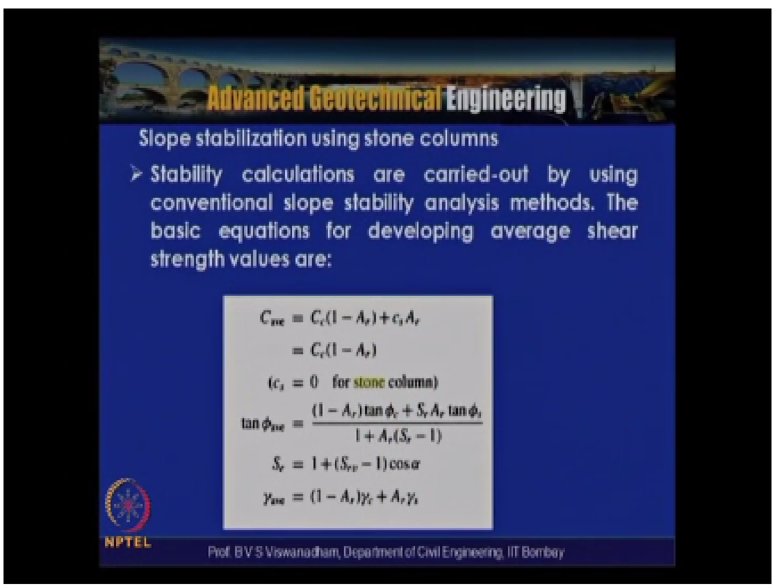

So here in this the stability calculations are carried out by using conventional slow study analysis once we get the average cohesion and friction, so here C average is actually given as CC x 1 - AR + CS x AR where CC = 1- AR and CS = 0 for stone column so CS is equal to 0 for stone column, so tan π average which is nothing but 1 - AR x tan π C + SR x y a tan π s / 1+ C AR x SR - 1 when sr is nothing but 1 + s RV - 1cos α and γ average is nothing but 1 - AR x γ c + one + AR x γ S.

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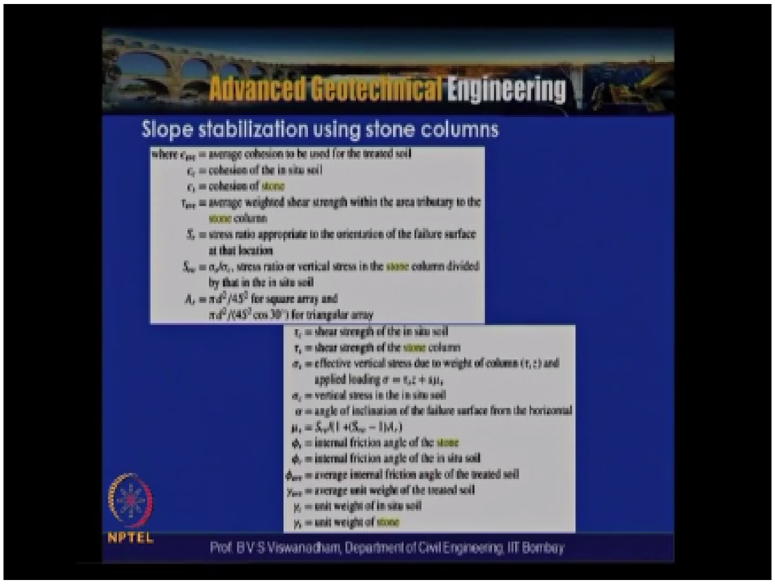

So the different notations we look x each, so the rotations are nothing but C average is nothing but average coefficient to be used for the treated soil and C is the cohesion of the Institute or the ground and coefficient of the stone CS in case of a stone charge it is zero that is what they actually told in the previous slide, so average is nothing but average very shear strength within the area to build tree to the stone column that is within the unit cell and SR is the stress ratio which is also indicated as small inappropriate to the orientation of the failure surface at the location.

And SRV is nothing but the ratio of σ C to σs 2 σs the stress ratio or vertical stress in the stone column / that in the x the soil being the strong material the stone column actually apportions a higher portion of this truss than the surrounding soil and here is nothing but π d ^{2} where d is the diameter / 4 s square for square array and then the error is equal to π d ^{2} / 4 s 30 this is for triangular pattern of arrangement.

Then we have the some other rep variables which actually we have used tC is equal to shear strength of the institution and tau s is the shear strength of the stone column then σY s is the thing but the effective stress due to weight of the column and the applied loading where γ and s us and the various other parameters like vertical stress in the institution and α is the angle of inclination of the failure surface from the horizontal and Mews is the thing but SRU + 1 + s RB - 1 x AR where π is the internal friction of the angle of the stone.

Generally these stone columns are actually having a stone charge which is ranging from 10 mm to 40 50 mm size of the particles and then they are the basically in that gravel our in that particular range. So were in it actually has got excellent friction angle depending upon the type of the stone so it actually can have friction angle ranging from 38 to 40 to 44^0 and the internal friction angle of the Institute South I see in case of undrained case where saturated then π C is equal to 0 and then π average is the average internal friction angle of the treated soil and γ average is nothing but the average unit weight of the treated soil.

That is actually composite soil which is nothing but stone column reinforced ground unit weight and the γ C is nothing but the unit weight of the introduced oil and γs is nothing but the unit weight of the stone, so these were the this was the method where the average Houston parameters are estimated by using the method which is described below and this allows us to perform the stability analysis by using stone columns with that there is a possibility that we can actually ensure.

And then one of the other attributes of using stone columns is that because of their excellent drainage characteristics the stone columns actually has then you know a possibility of having you know allowing for excellent drainage.

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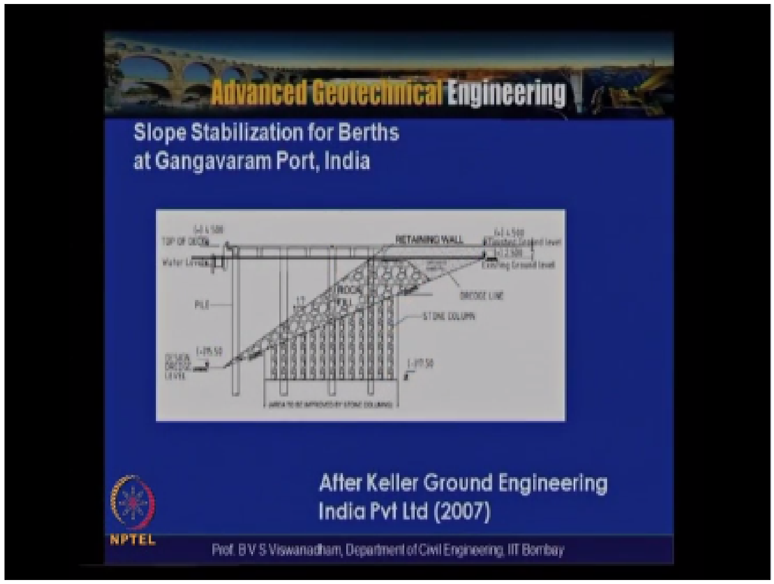

So this is a particular case study which was done by Keller India that Keller ground engineering India Private Limited in2007 in one of the ports below the berthing structure particularly below the berthing structure, when the what happens is that the slopes which are actually excavated x a certain depth basically these are these are excavated up to - 15 - 16 depending upon you know the requirement of the heavy duty ships to come close to the berthing structure, so with that what will happen is that the slopes basically of clay in nature and a very soft in nature.

So what will happen is that there is a possibility that the slurps undergo failures there are cases of failures which are actually reported in Carla port rest wherein in the seventh birth because of the instability caused you to failure of a ground which is actually beneath the birthing structure resulted in the failure of piles of diameter equivalent to about one meter and led to the led to the you know the disturbances which actually have caused to the failure of the you know these particular slopes.

So one of the viable options is to you know use this replacement method the replacing a stone replacing the you know the clay soft clay with this particular stone charge. So this is actually successfully used by here for a stabilizing a slope below the below the a birthing structure and in order to ensure the stability here the rock field actually is provided that is that makes actually you know, the ensures the adequate stress concentration actually applied to the these stone columns and with that so here in this they actually provided the you know these are the battery structure piles which actually have gone and this is the you know the stone columns which actually have been drilled.

Basically to ensure the stability of a particular slope, the another technique which what we discussed is the slope stabilization by using lime slurry.

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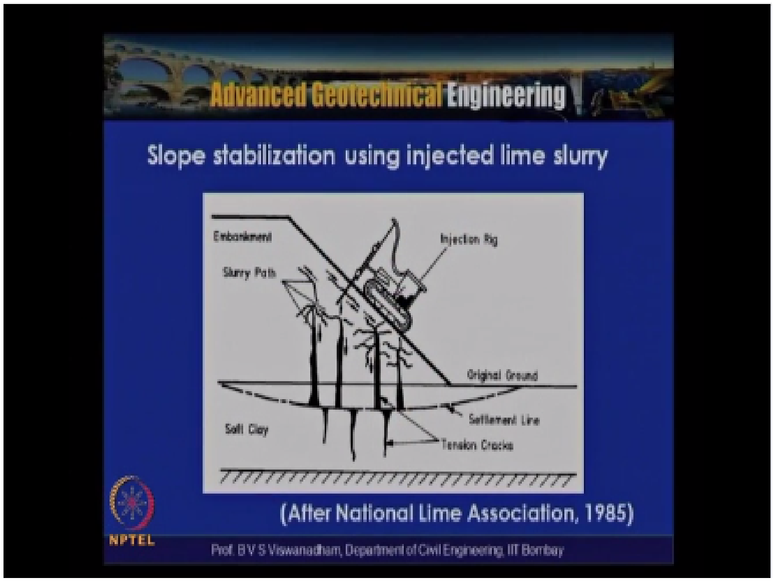

So here basically here if the slope is actually having any quit its suitable for this type of the soil in the slope is suitable for this type of technique, then there is a possibility that the slope stabilization using injected lime slurry is used to pump the lime at high pressure. So this is one of the popular technique wherein if you are actually having existing slopes with for example with black cotton soils which are actually having low sulphate then there is a possibility that you can actually use this injected lime slurry is one of the in situ method wherein we can actually you use this technique to enhance the stability of a slope.

So the more about the slope stabilization using lime slurry and time the another form of you know inducing or improving the assistance of the soil particularly for a marine clay using lime columns slope stabilization using lime columns and lime slurry is where in the lime is injected with the high pressure, so in this particular lecture we try to understand about methods for enhancing stability of slopes we have been introduced to different types of slope stabilization techniques.

And we actually have seen the mechanism of reinforcement by using anchors and in case a deeper failures do occur then we said that one of the methods which can be used as the slope stabilization using piles where the forces are actually transferred to the deeper and the piles here are used as retaining elements and used as a retaining elements to restrain the slope movements.

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NPTEL
Principal Investigator
IIT Bombay

Prof. R. K. Shevgaonkar
Prof. A. N. Chandorkar

HEAD CDEEP
Prof.V.M.Gadre

Producer
Arun Kalwankar

Project Manager
M. Sangeeta Shrivastava

Online Editor/Digital Video Editor
Tushar Deshpande

Digital Video Cameraman
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Jr.Technical Assistants
Vijay Kedare

Project Attendant
Ravi Paswan
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