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NATIONAL PROGRAMME ON TECHNOLOGY ENHANCED LEARNING

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ADVANCED GEOTECHNICAL ENGINEERING

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Lecture No. 40

Module – 5

Lecture – 1 on Stability of Slopes

Welcome to lecture series on advanced geotechnical engineering course in this lecture series we are going to introduce ourselves to module 5 and which is on stability of slopes so this is the lecture 1 on stability of slopes in module 5.

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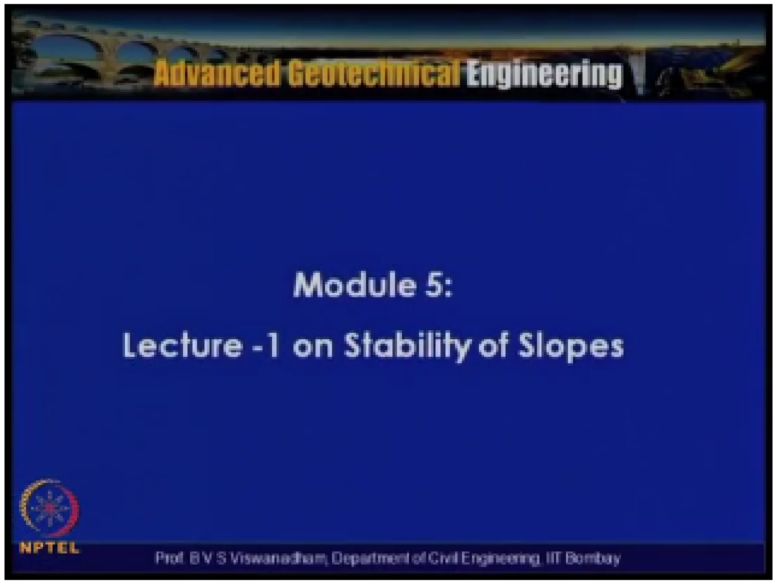

In this module we are going to discuss about the stability analysis of a slope.

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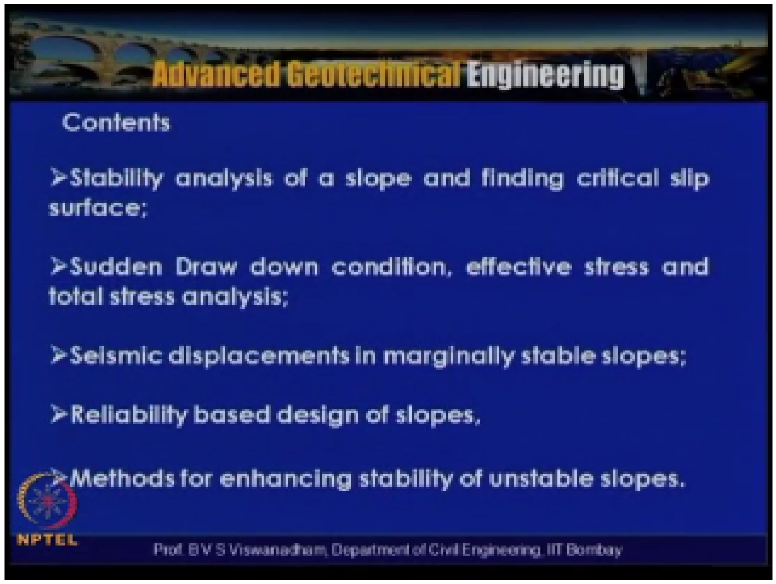

And finding critical slip surface or a potential failure surface and some special conditions like Sudden draw down condition and effective stress and total stress analysis that is from long term and short term point of view and seismic displacements in marginally stable slopes that is to some extent on the seismic stability of slopes and relevant reliability based design of slopes and finally after having discussed different methods of analysis of slopes the methods for analysis enhancing the stability of unstable slopes.

How these stability of a slopes can be you know enhanced so in this module 5 we are going to discuss about different analysis methods on slope stability for both infinite slopes and finite slopes and some special conditions like sudden drawdown condition effective stress and total stress analysis seismic stability of slopes and reliability based design of slopes and slope mitigation methods.

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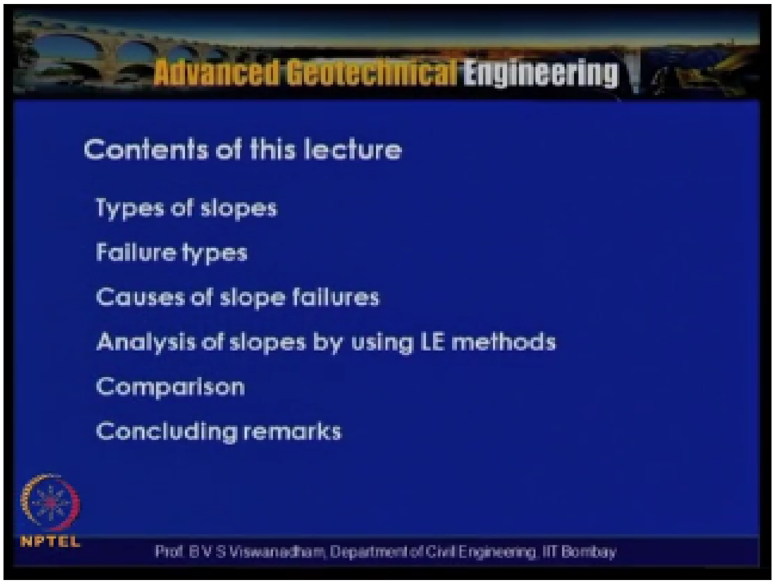

So this lecture we can say that module for couple of these lectures is divided into what are the types of slopes like which I said they are finite slopes and infinite slopes and what are the different types of failures like failure types and what are the causes of these slope failures what combinations makes it to fail and what are the analysis methods which are available then we will take some examples we will try to do by using different methods.

And compare the different analysis methods and concluding remarks based on this module what we are going to discuss so after having discussed about the sheer strength and you all agree that the sheer strength has got two applications broad applications one is that pressure theories.

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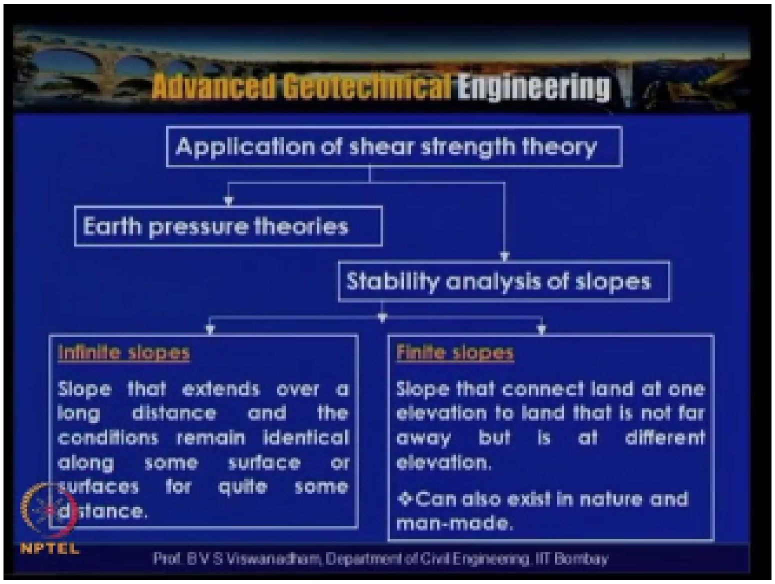

And other one is the stability analysis of slopes in the stability analysis of slopes you need to know what is the shear strength mobilized by the soil and shear stress which is actually induced by the disturbing forces, so the ratio of shear strength available shear strength to the shear stress mobilized is referred as factor of safety if this factor of safety is adequate then we can say that the slope is stable if this factor of safety is inadequate then the slope is on the verge of failure.

So as far as the stability analysis of slopes is concerned there are two types of slopes one is infinite slope and other one is finite slopes the infinite slopes are basically classified as in slopes that extend over a long distance and the conditions remain identical along some surface or surfaces for quite some distance so these slopes can be for examples like landfill slopes or slopes which are actually along hilly terrain with very flat sloping collations.

So these are slopes they extend over a long distance and the conditions remain identical along some surface or surfaces for quite some distance finite slopes basically these are man-made slopes that connect the land at one elevation to the land at other elevation they can be like approach embankments they can be road embankments there can be highway embankments there can be ash pond embankments.

So these are the you know most existent slopes the finite slopes and can exist also in nature as well as some Hill slopes they can also be finite slope and man with slopes so after having discussed about the slopes then the slopes are basically again natural and man-made natural.

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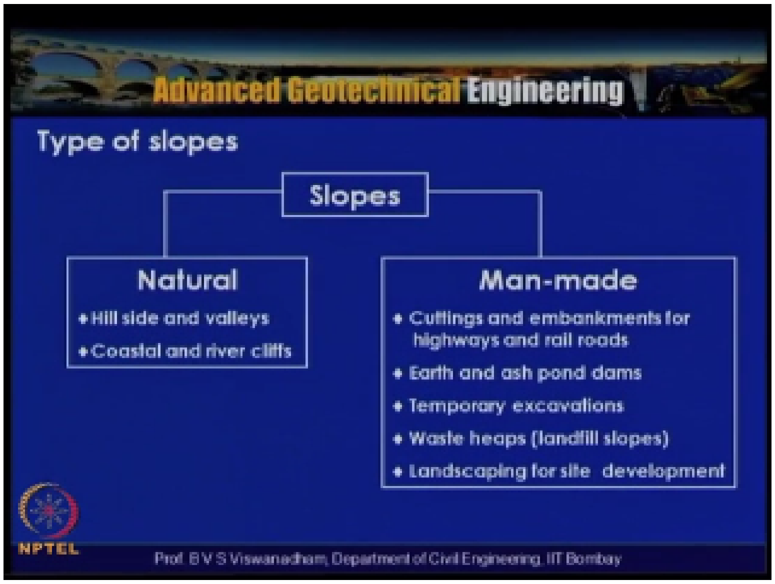

The examples are hillsides and valleys and coastal and River cliffs they are the natural slopes and as far as the man-made are concerned slopes in cuttings and embankments for highways and rail road's and earth and ash pond amps and temporary excavations and waste heaps which are nothing but the landfills and landscaping for the site development so they form the examples of manmade slopes.

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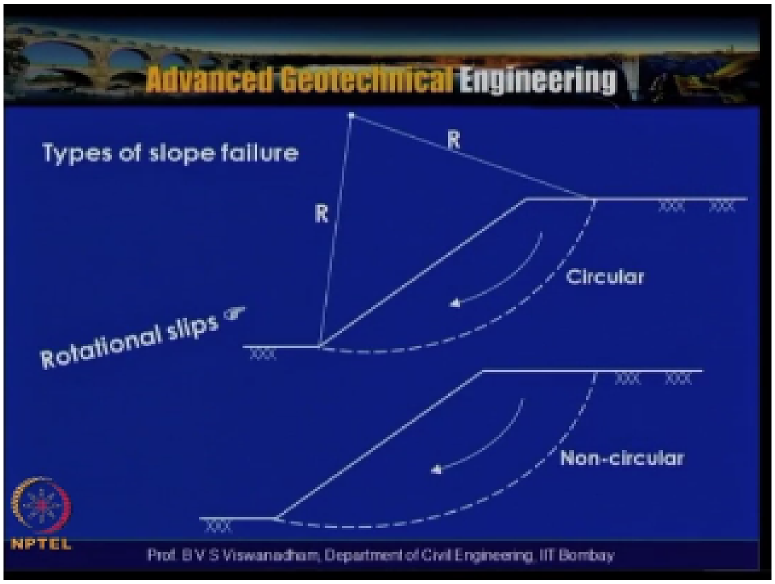

So if you look into the typical types of slope failures the typical failure which is termed as a circular failure and where you have identical radius at both the ends at entry point and exit point this is called the entry point of a slip surface and this is the exit point and with identical radius of rotation and this particular failure surface is referred as a circular failure surface and there can be failure surfaces which are truly non circular they generally occur if you are having you know different stratifications of soils and particularly these both circular and noncircular they are actually called as rotational slip failures.

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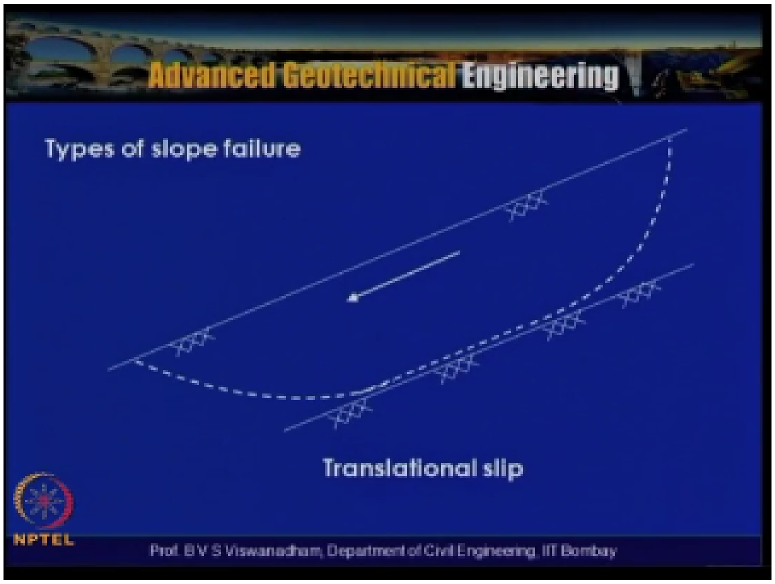

And there are also some translation slip values that means that it actually commences with a circular failure and then it remains in the value surface in contact with the firm surface and then the translation and slip failure takes place so the typical failure surface which is actually shown in this figure is called as translational slip failure.

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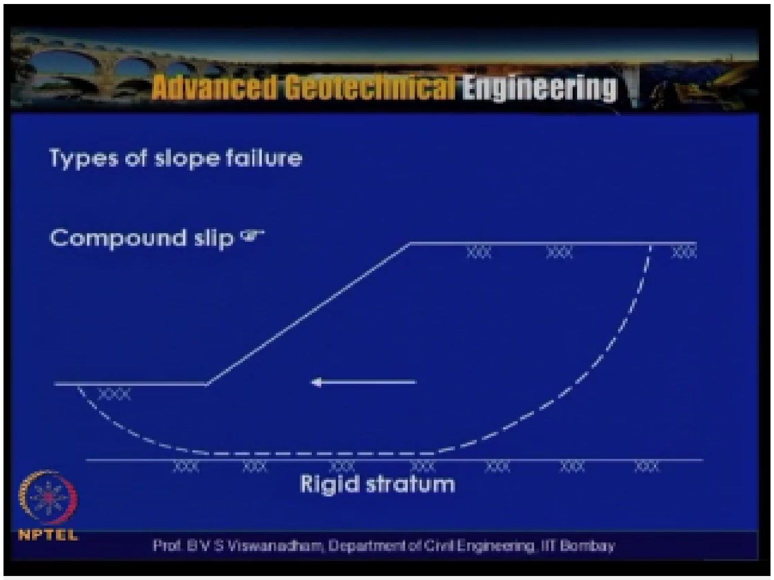

And another type of failure which is a compound slip failure or also called as a base failure in this case what will happen is that if the sub-base are a sub grade soil which is not having any inadequate strength then there can be possibility that the base failure which actually extends and the failure surface remains tangential to the rigid stratum so that means that this value surfaces can occur in a surf on a surfaces where you actually have very soft soils and then the constructions on them may be in the form of embankments can lead to a compound slip failure surfaces.

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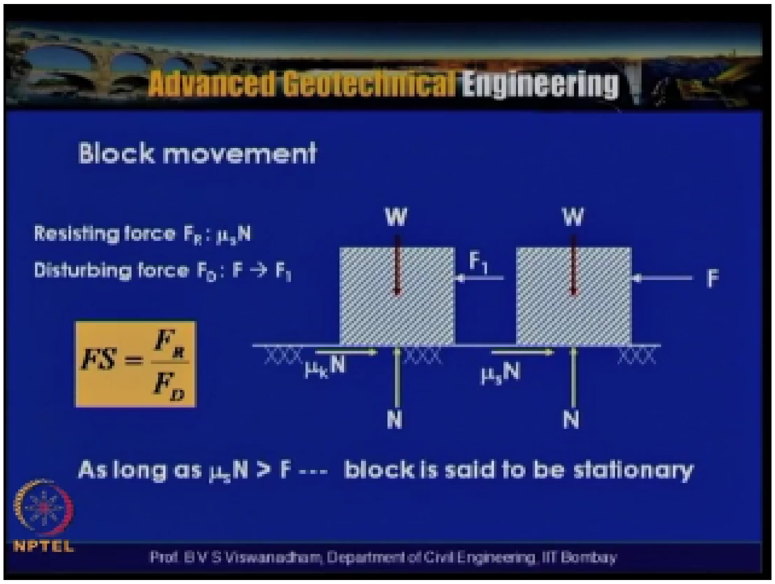

So consider in this example a block movement so here if you see before introducing the method of slope instability let us see this example where when the whenever a block of weight W is resting on a surface having certain friction static friction let us say μ_s then the for the force F the resisting force is nothing but μ_s N and disturbing force is nothing but F_1 that means that disturbing force is nothing but F tends to become $2F_1$ then there is a possibility that you know the block can move.

Say let us consider in this case when F tends to become $2F_1$ then the block actually tries to set to be you know in a when F_1 you know or comes this force for your resisting force then there is a possibility that the destabilizing activity has commenced that means that factor of safety here is nothing but resisting force by driving force the resisting force is indicated as fr and driving force is indicated by F_D so as long as μ_s N > F then the block is said to be stationary otherwise the block which is actually under instability and are in the process of movement.

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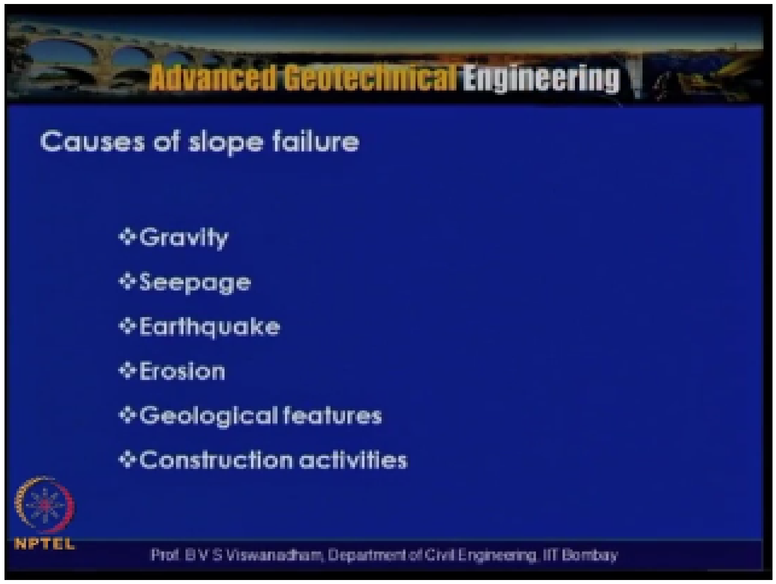

So the causes of slope failures are basically gravity so one is the predominant causes of slopes of failures is gravity and seepage that is the seepage are seeping of water through the slope earthquake, erosion, geological features and construction activities the construction activities are nothing but the construction at the downstream side of a slope or geological features are nothing but different stratifications of soils erosion when a slope is designed with certain slope inclination when erosion happens there can be possibility that the slope tends to become steeper and then will attain failure because the slope which has not been designed for that particular slope inclination.

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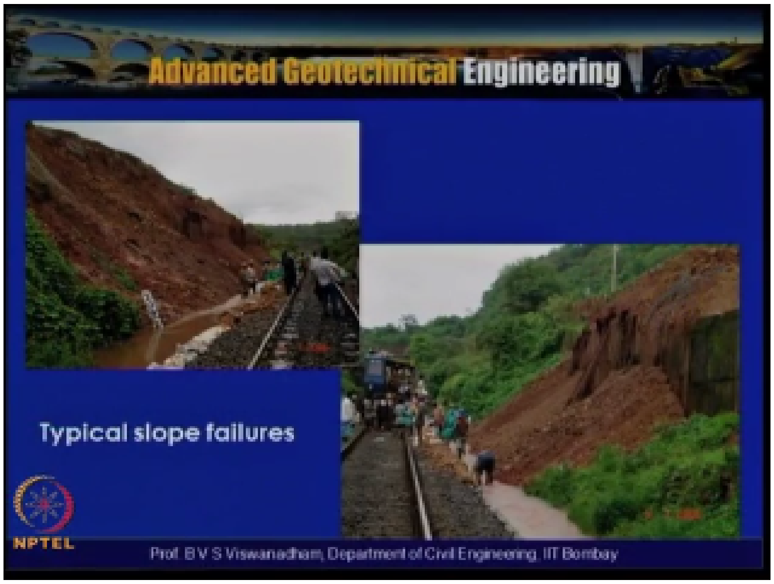

So before discussing analysis methods let us see some typical slope failures so in this case a typical slope failure which actually reported in the region because of the seepage or in the rain in the monsoon season can be seen here wherein you can see that the soil which is above the rock drop is subjected to instability.

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And here this is a typical slope failure where in these highway slope is subjected to instability because of a slip.

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And this is a typical slide which actually shows the landslide damage adjacent to a residential structure so this is a landslide damage adjacent to the residential structure so that means that the safety of the structures you know lying are constructed close to the slopes need to be you know and short and this is atypical slope failure beneath the building.

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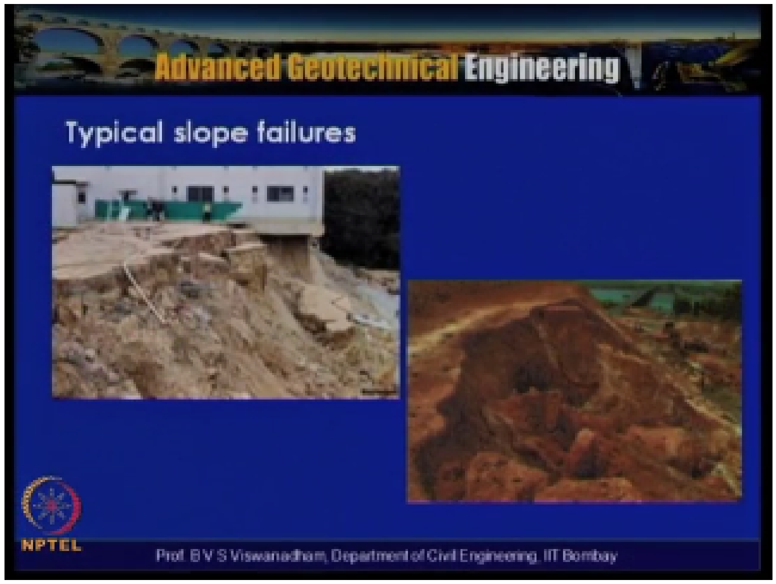

Where it can be seen that the part of the building is remaining hanging and the slope is actually subjected to instability and then you this is a typical coarse grained slope failure which is right bottom side of the slide which is shown here where in the slope is active subjected to failure because of the presence of some soft soil strata at a certain depth from the surface of the slope.

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So this is atypical highway slope failure in the hill slope failure and where it can be seen that the landslide which actually has caused as created distress because of the instability.

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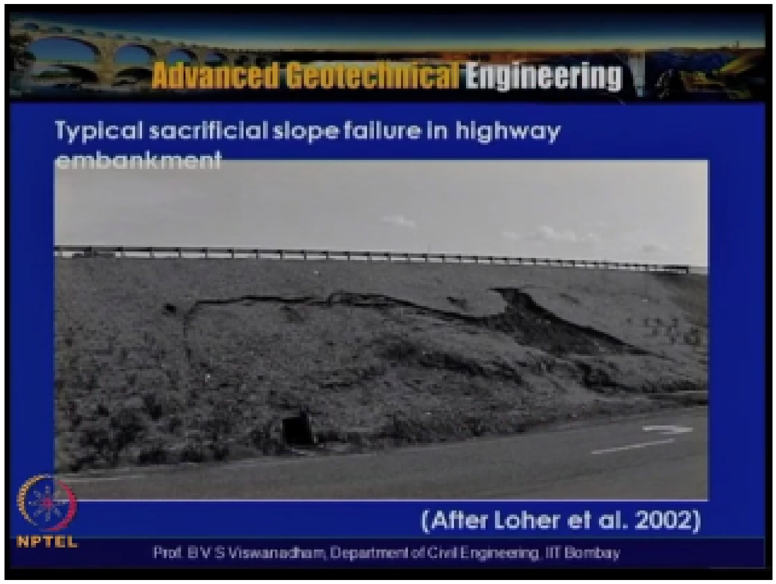

And this is atypical sacrificial slope failure in highway embankment wherein it can be seen that the part of the highway embankment is subjected to slip which is predominantly can be seen in this slide.

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So this is the recent Uttarakand (2013) slope instability failures which actually occurred so it can be seen that one of these structures how the slope failure can create it and disrupted the transportation networks.

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This is a typical landslide in a urban area in Hong Kong where it can be seen that very close to the construction activity the building very the prevalence of the existing of the building the part of the slope is subjected to see page and then failure due to seepage and then resulted in a slow failure so you can see that this is the portion of the area which is subjected to a slip and then this is the mass movement which is actually occurred up till this so this type of situations which are actually can endanger the buildings which are lying close to the slopes.

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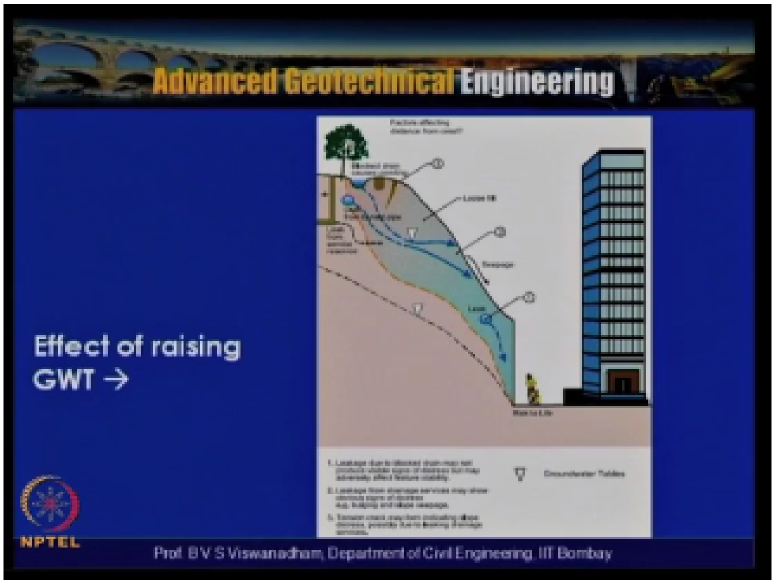

So this is a typical schematic view of a building which is lying close to close to a particular slope and then if there is a ingress of water either due to some utility pipes or due to some tension cracks or due to some rays of groundwater table within the slope can cause failure and can lead to instabilities.

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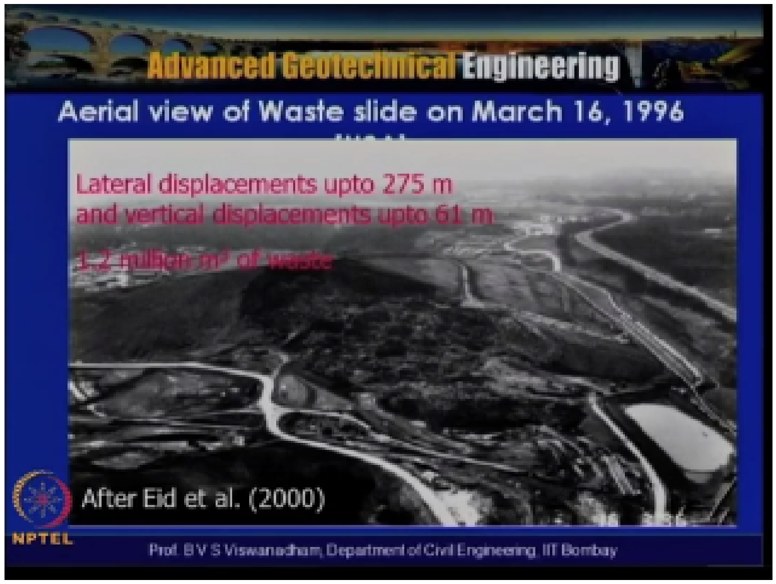

So this is a typical view of a waste slide in a landfill which is reported by Eid et al. in 200 this failure which is actually occurred March 16 1996 and this is a typical failure which occurred in a landfill where in the lateral displacements were reported to be about 275 meters and vertical displacements are reported to be up to 61 meters and 1.2 million meter cube of waste was reported to me you know displays are subjected to movement. So this type of failures can occur in a man-made slopes which are with a material like municipal solid waste.

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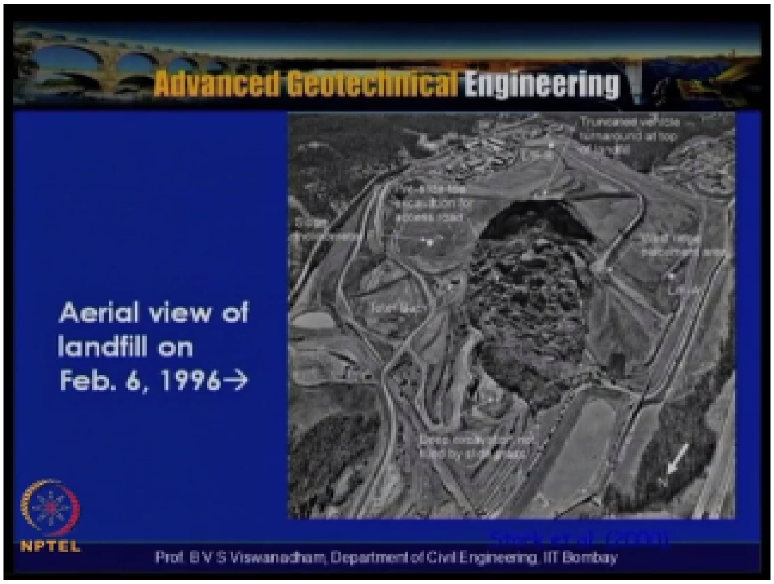

So this is a the another typical failure which is in a aerial land fill and this was reported by Stack at all 2000 where in you can see that a part of the landfill is subjected to a translation slip and can lead to the failure.

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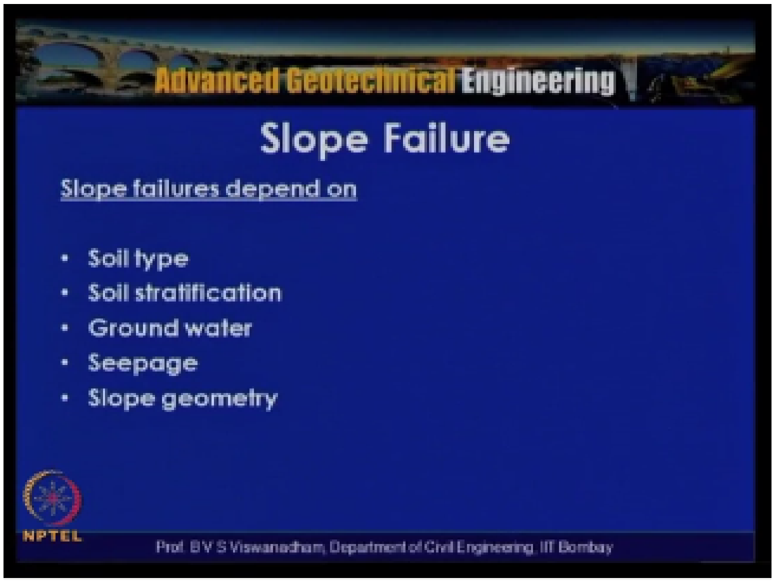

So after having seen different sets of you know when I have failures which are either in natural slopes or in man-made slopes let us try to understand about how this slow failure they basically depend upon what are the parameters the first and foremost thing which is comes into our mind is the soil time and the soil stratification and groundwater the presence of groundwater and see page and slope configuration or geometry.

So the soil type particularly if you are having a bit you know soil which is having some expansive soil type of minerals there is a possibility that the slopes which are actually in during wetting and drying seasons they can be subjected to instabilities particularly the soil stratification in the sense that the major portion of the soil can be with cause dense soil but geologically there is a soft soil which is lying underneath can lead to instabilities.

And presence of groundwater or a raising of groundwater table within the slope can lead to failures in one way the raise of groundwater table within the slope is also caused and termed as in a particularly in some loose field slopes and this is called as static liquefaction where in the total stress will be equivalent to the pore water pressure and then the effective stress reduces to zero and the soil mass tends to become like a fluid and then undergoes a failure.

And particularly the seepage induced failures which are actually possible in case of a magma dams or it can be and slopes which are actually subjected to in a very high rainfall areas and slope geometries particularly when the slope geometries are constructed with the cutting or with embankments with the certain configuration and they can lead to you know failures so the slope values are basically depending upon the soils type stratification groundwater and seepage and slope geometry.

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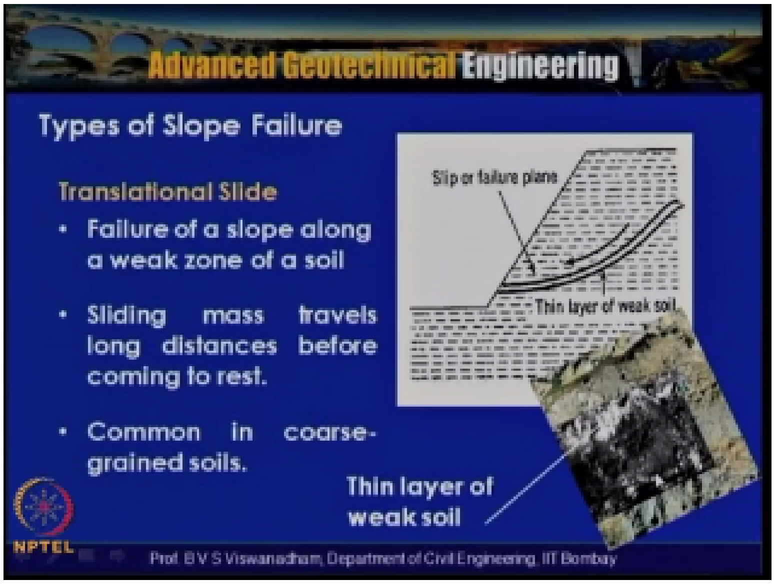

The one of the if you say the types of slope failure the if you are having a thin layer of weak soil a thin layer of weak soil and there is a soil over burden which is above that then this particular block is sub is going to undergo a translational slide so where in this thin layer of weak soil which is actually not having adequate shear strength so can undergo the possible translation style failure that is the failure of a slope along the weak zone of a soil and the sliding mass travels long distances before coming to rest and it is common in coarse grain soils particularly in coarse grained soils and this is possible.

So this is atypical thin layer of weak soil how this can actually induce failure like a translation slide which is actually shown pictorially here so this particular portion is enlarged and shown here.

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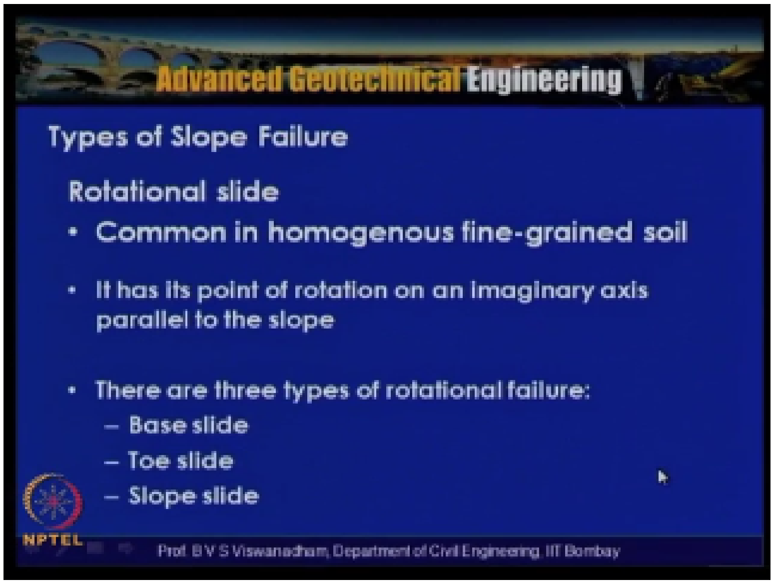

The rotational slide is one of the common failure in a homogeneous fine-grained soils it has its point of rotation the space on an imaginary axis and parallel to the slope so there are three types of you know slope values basically one is the base slide or base failure that means that when the soft when the soil sub base soil is soft in nature and then the soil undergoes failure predominantly in the within the soft soil.

So that is called the base line and toe slide which is nothing but the failure which is actually passes through the toe and the slope slide which is nothing but failure which is actually occurs within the slope surface.

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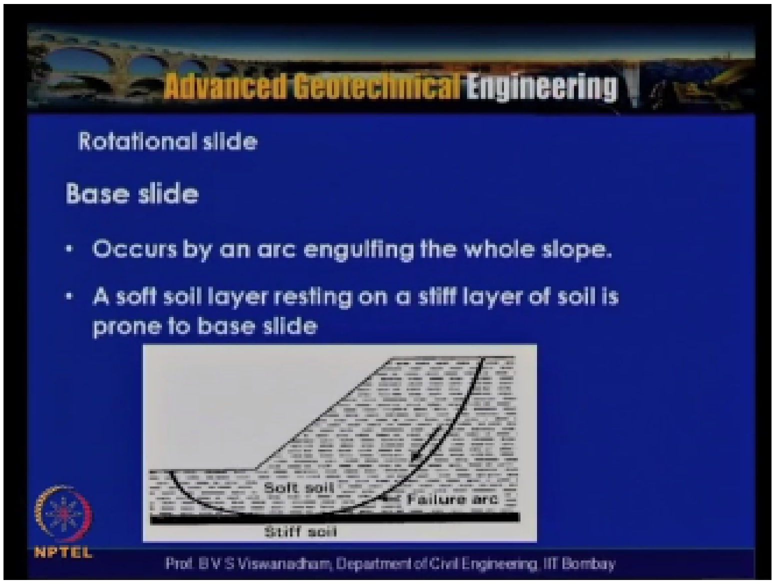

So the base slide occurs by an arc and engulfing the whole slope that is the predominant portion is in the soft soil this is the portion which is there in the soft soil because this soil is being stiff the failure surface abridges along the a weak zones where the stress or substances are low and distances are low and then this portion in virtue of this entire zone is actually mobilized and undergoes is so called a base failure so a soft soil layer resting on a stiff layer of soil is prone to base slide similarly a soft soil resting on a clay surface and when it is loaded without any ground improvement there is a possibility that it can actually undergo a failure.

And toe slide the basically the failure surface passes through the toe of the slope so in this picture the slide which is actually shown here this is the failure surface and the failure surface predominantly passes to the toe of aslope and this is called the cost of the slope.

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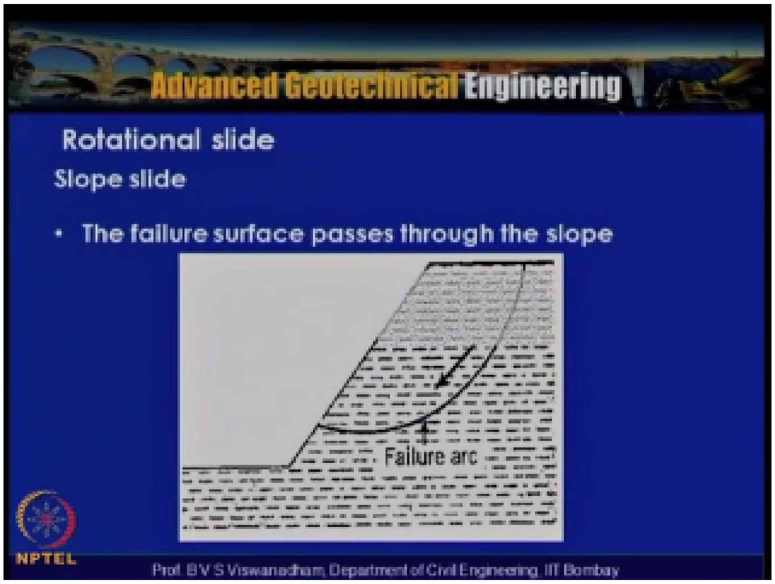

And rotation is another type of a rotation slide in a finite slope is called slope slide the failure surface passes through the slope so this can be because of the low quality control or you know because of the virtue of you know the loading on the top of the slope are due to inadequate you know properties for the material which is used for constructing the slope.

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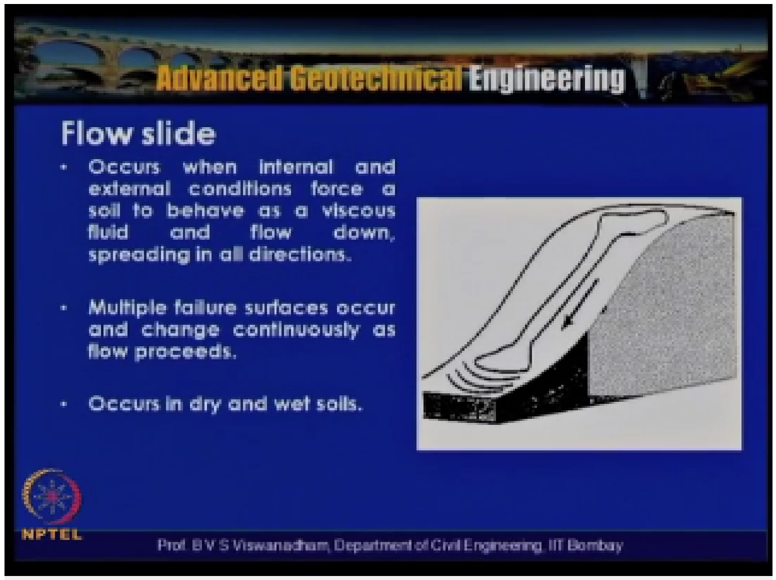

And in this particular slide a typical flow slide is shown the flow slide which actually occurs in certain type of sensitive with soil sensitive soils you can see that this zone which is because of certain perturbance and this causes this type of failure the occurs when internal and external conditions for soil to behave as a viscous fluid and flows down spreading in all directions some sensitive soils when they are subjected to some disturbance and they actually behave in this particular manner and the typical failure which actually takes is called as a flow slide and a multiple failure surface occur and changes continuously as the flow proceeds and basically this occurs in dry as well as some wet soils.

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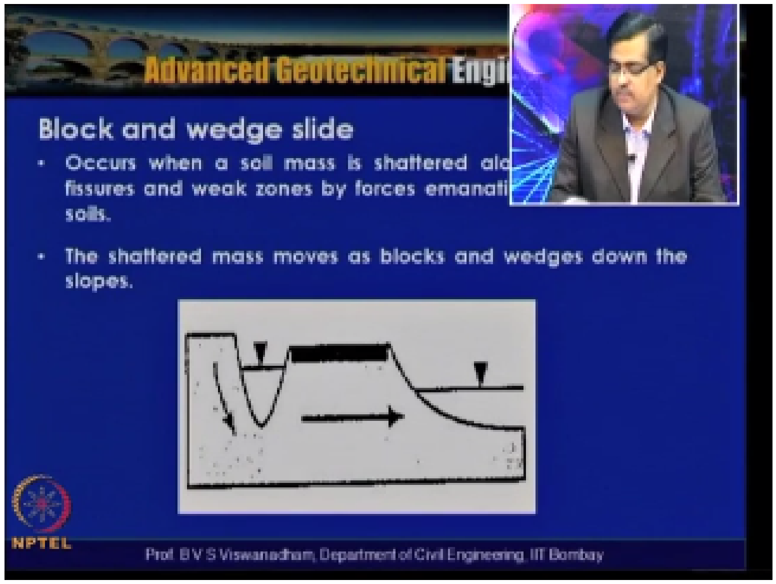

And some block and which slight failures this is basically occurs when a soil mass is shattered along joins and seams and fissures and weak zones by forces emanating from adjacent soils are some excavations are wedging which actually happens in some clay soils under undrained conditions they actually also undergo some block failures so this shattered mass moves as blocks and wedges down the slopes so the slope masses moves in form of a blocks are wedges.

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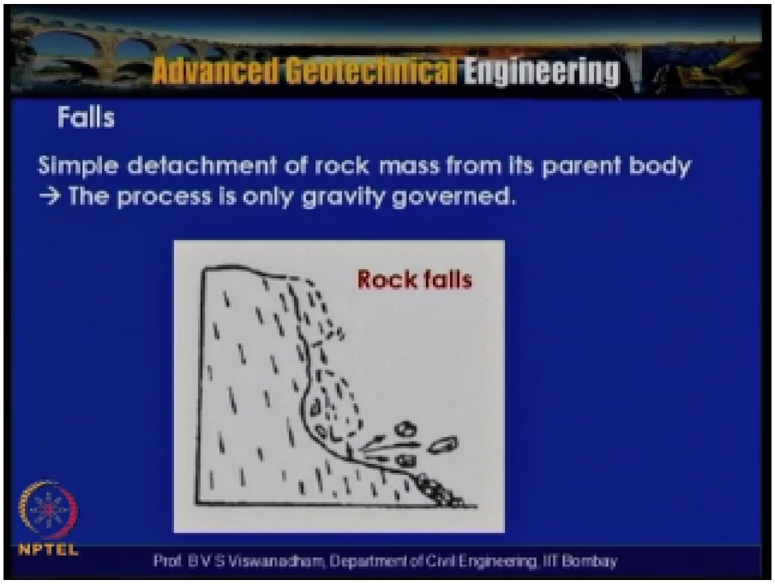

And this is also classified as a typical slow failure and which is and called as rock Falls and this can be triggered because of you know a seeping water and can create an instability in the soil base and the on which these rock fragments or rocks are resting and then can lead to a you know a rock fall.

So simple detachment of the rock mass from its permanent body and can lead to rock falls so this process is only gravity governed and which is very alarming in the sense that if you are having a transportation network along this certain area then there is a possibility that this Rock Falls can actually endanger the likes of you know people so this need to be addressed by an appropriate rock fall mitigation methods.

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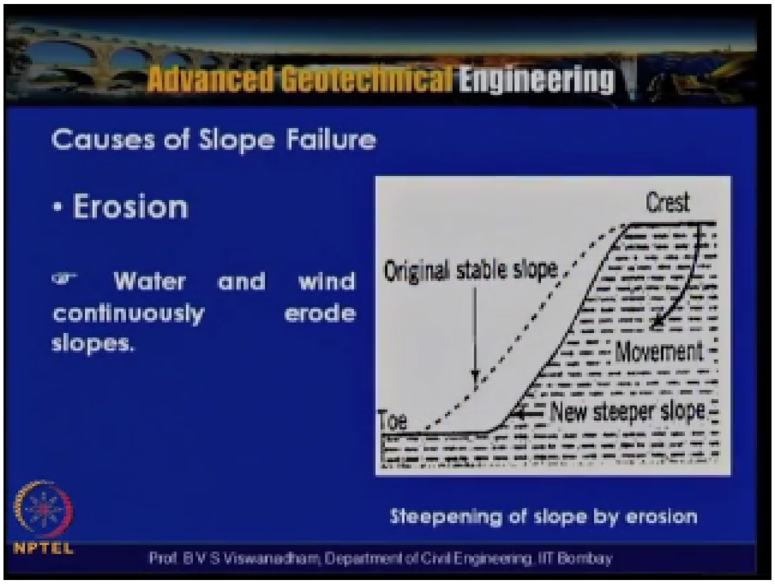

So if you look into the causes of slope failure one cause we have actually address it is that erosion in this particular slide where in the original slope surface or configuration is shown here like this and here this particular slope surface is attained because of the erosion of the soil because of the either because of the water agency our wind agency so because of this attainment of this steeper slope can lead to instability because the slope which is actually not been designed for that particular type of steeping relation can lead to failure.

So one of the reasons of the slope failures is erosion and water and wind continuously erode slopes can make the flat slopes into steeper slopes and can lead to failures so erosion changes the geometry of the slopes and resulting in a slope failure of our a landslide.

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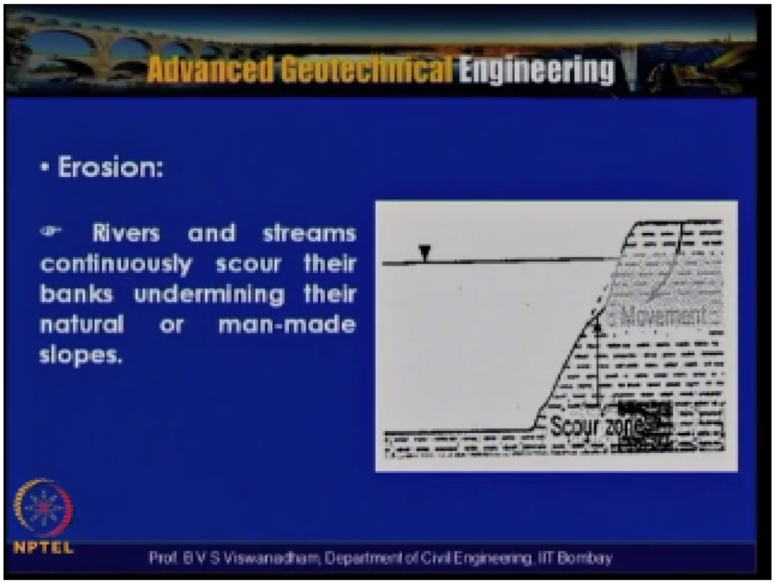

And particularly if the slopes are facing reverse our ponds the rivers or streams continuously cover their banks because of the wave forces and these undermine their natural man-made slopes and the slopes which are actually subjected to wave forces are the streams continuously in contact with these sloped surfaces can lead to scours and that zone which is actually shown here from the water surface this is actually called as a scour zone and this can lead to movement and instability to two slopes.

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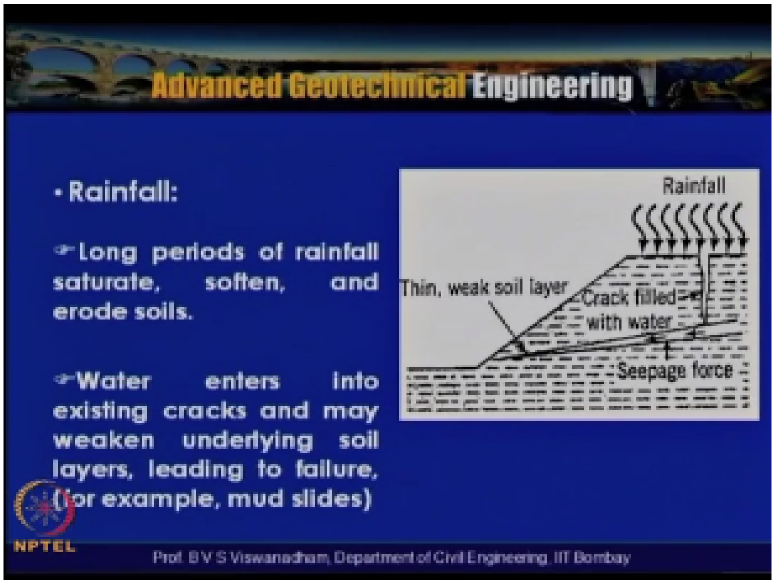

The another major cause of slope failure is the rainfall if we are having a rainfall basically of rainfall intensities ranging from say 10 mm per minute to 8 mm per minute and 80 mm per minute we said to be very high intensity of rainfall and if this rainfall occurs or a certain period of duration the long periods of rainfall saturate and soften and Road these soils and can lead to slope instabilities so the water and can enters through a water enters the existing cracks and may weaken the underlying soil and layers leading to failures basically it causes mudslides.

So the rain falls basically they trigger failures particularly because of the ingress of rainwater into these slopes and in a saturated state and they make these slopes in essence saturate tend to saturate and soften and then erode the soils so a typical slope failure due to rainfall which is actually shown here the another you know major cause of slope failures is the earthquakes.

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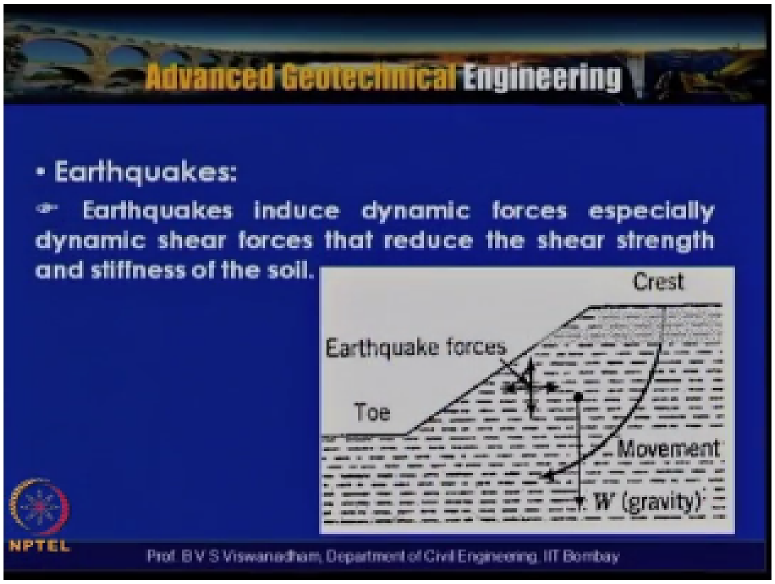

If you are having a structure which is resting on certain zone where earthquake actuation is expected then earthquake induce the dynamic forces and particularly in addition to their weight in the vertical direction they can be possibility of horizontal forces and these forces can trigger the instabilities to the slopes the earthquakes induce dynamic forces especially dynamic shear forces and reduce the shear strength and stiffness of the soil.

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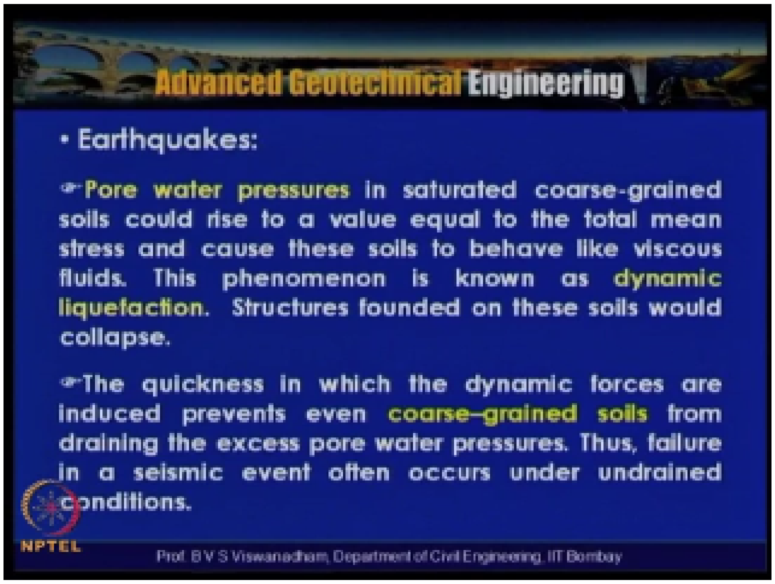

So these things can lead to failures these earthquakes particularly the pore water pressures in saturated soils saturated caused grained soils could raise pore water pressures in saturated coarse grained soils could raise to a value equal to the total mean stress and cause the soils to behave like a viscous fluid and this phenomenon is called dynamic liquefaction so at the onset of earthquake the pore water pressure rises rapidly and becomes almost equivalent to a total stress and this lead to a dynamic liquefaction.

And the structures are formed on these soils would be collapse and then the structures Foundered on these soils would tent to collapse and the quickness in which the dynamic forces are induced prevents even caused grained soils from draining the excess pore water pressures so even the coast grain soil is as you all know that has highly high permeability but even these soils they are not able to drain in a short duration of the earthquake so because of that what will happen is that the seismic event can lead to failure under undrained conditions the another slope cause of failure what we discussed it is the geological features.

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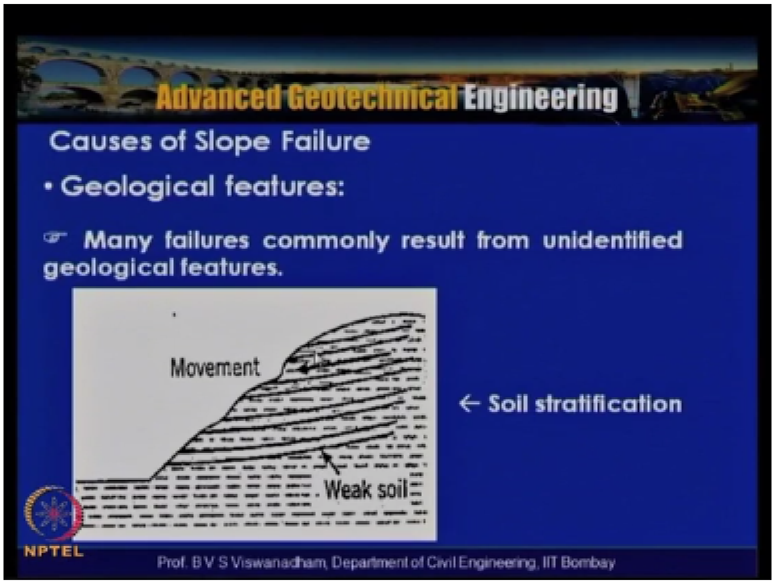

And menu fuel use commonly result in an identified geological features, so that means that if you are actually designing a slope and appropriate soil investigation is required up to the depth which is influencing the construction, so this can lead to a proper design of a slope so many failures can commonly result in a I unidentified geological features, so a typical soil stratification zone where you have got a reasonably good soil and weak soil and soil and good soil and weak soil and can lead to failure so this is another type of slope failure.

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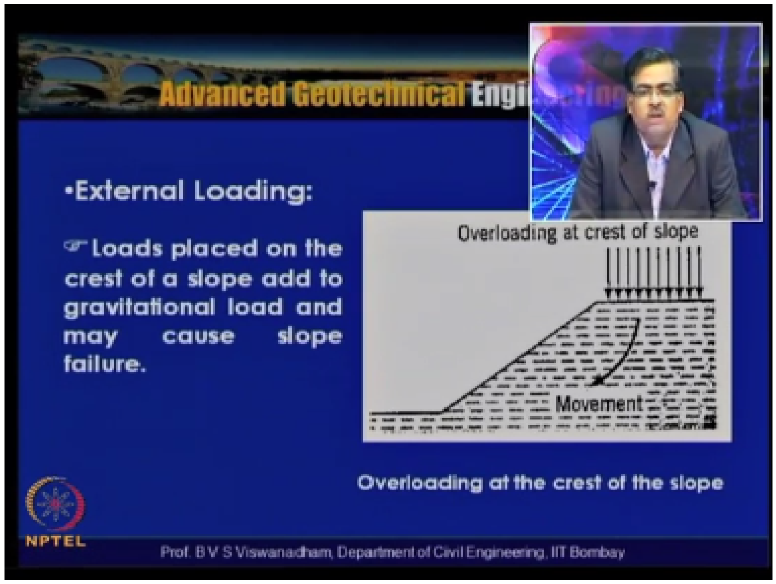

Then the another problem already you know cause of slope failure is the external loading suppose if the slopes which are actually loaded either because in the form of a soil heaps or in the form of a construction which is close to the crest of the slope can lead to instability, that means that the loads placed on the crest of a slope add to gravitational load and may cause slope failures that means that if a construction takes place or water loading at the crest of the slope texts suppose if this loading takes place far away from the crest.

That can be you know we can say that the external loading will not have any influence on the slope, but if the warm Larry happens close to the crust of the slope then the loads placed on the crest of the slope add to gravitational load and may cause the slope failure the construction activities is another cause of slow failure.

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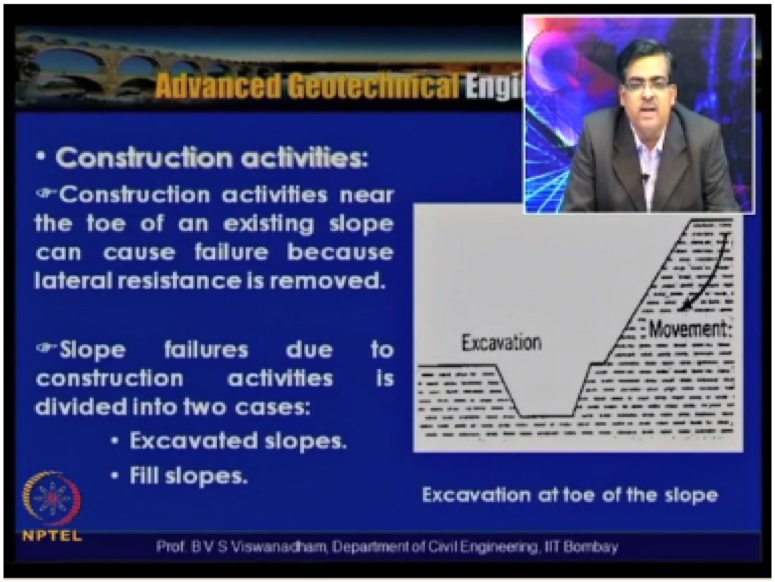

So previously we have said that what are the different types of slope failures which are you know factors causing the slope failure, now we are actually causing we are seeing different types of reasons for this slope failure the another one is the construction activities this is a construction activity where excavation actually has taken place in cutting, so in this situation if the slope inclination which is actually meant for excavation is steep then can lead to failure the construction actress near the toe of an existing slope can cause failure because of the lateral the lateral resistance is removed here.

So excavated the slope failures due to construction activities is excavated slopes and fill slopes so the slope failures, so due to construction activities divided into two cases basically excavated slopes and fill slopes in the fill slopes also if the slope is inclination is not properly designed can also lead to failure.

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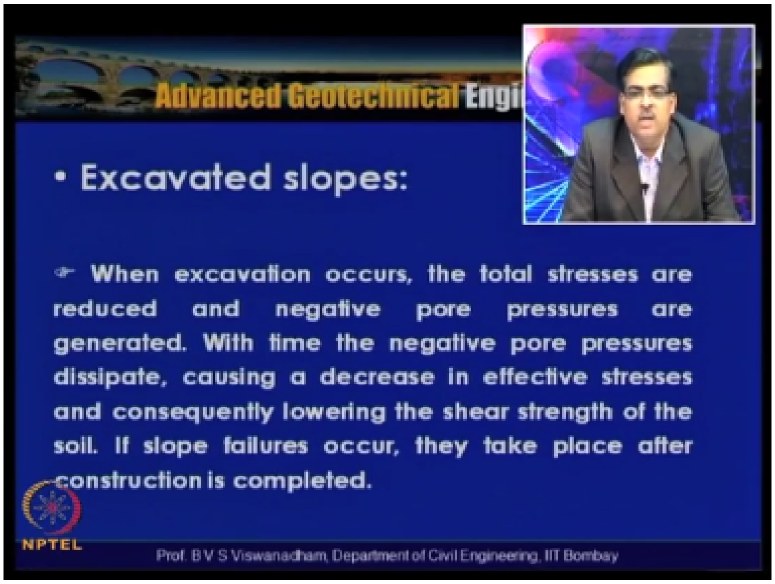

So in the case of excavated slopes this is what we said is one of the reasons for the construction activities for the slope failure when an excavation occurs the total stresses are reduced, so because of the excavation the total stresses are released and the near pore water pressures are generated with time what happens is that the native pore water pressures tends to dissipate and causing a decrease in the effective stress and consequently this lead to the lowering of the shear strength of the soil.

So if the slope failure occurs they take place after construction is completed so incase of excavated slopes we observe or tend to observe these failures once the construction activity is completed the reason is that the total stresses are reduced because of the excavation and the negative process pore water pressures are actually generated, and with time these new pore water pressures tends to dissipate and causing a decrease in the effective shear strength and which leads to the lowering of the sharing strength and this is one of the reason for during the slope values particularly for excavated slopes.

After the completion of construction in case of filled slopes basically they are common in embankment construction that is embankment is nothing but construction above the ground.
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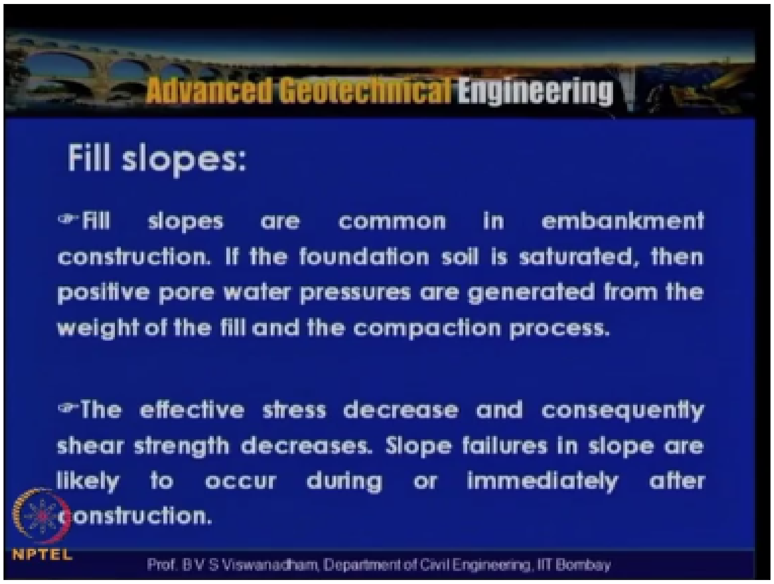

If the foundation soil is saturated then positive pore water pressures are generated from the weight of the film and they in the compaction process, so the effective stresses decrease and consequently the shear strength decrease and the slow failures in slope are likely to occur during or immediately after construction, so in the case of field slopes basically if the foundation soil is soft in nature the pore water pressure tends to increase because of the weight of the fill material and also compaction process.

So the effective stresses decrease and then consequently the shears and the decreases, so this lead to the slow failures in slopes are likely to occur during or immediately after consumption.

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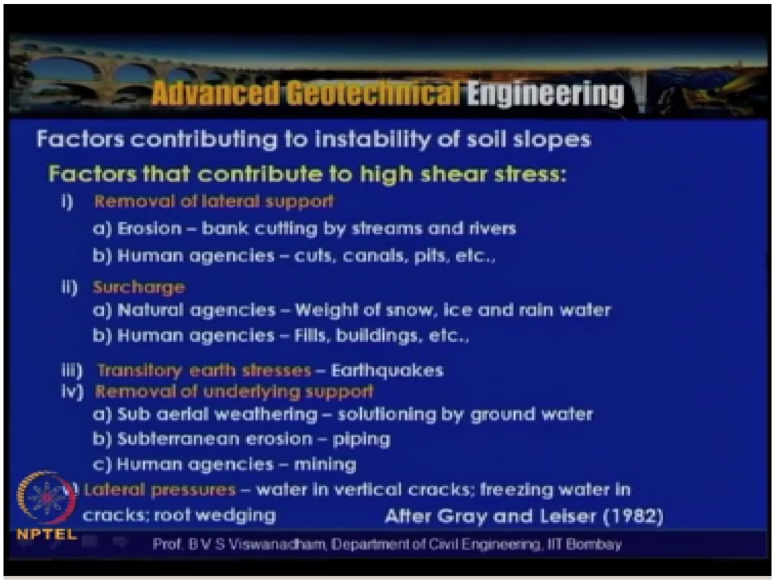

So we can actually list hereafter gray and laser 1982 the factors contributing to instability of soil slopes they are the factors that contribute to high shear stress higher high shear stress is nothing but the shear stress which causes you know disturbing forces removal of the lateral support either due to erosion band cutting by streams and rivers or humans agencies like cuts and canals and pits or excavations and another factor which contributes to high stresses is the surcharge natural agencies weight of the snow ice rain water human agencies like fills, buildings, constructed close to the slopes.

And can we can make the surcharge increase are high and then lead to the you know high stresses and transitory at stresses like earthquakes because of the earthquakes these stresses are transitory at stresses increase tremendously and removal of the underlying support the sub-aerial weathering like solutions by solution by groundwater suppose if there is a cavities which actually formed within the slopes and then can lead to instabilities like people of underlying supports and the subterranean erosion.

That is a piping which actually happens can also trigger the you know underlying some of underlying support and can lead to failure and human agencies like mining and remove of the you know soil from the excavations are a activities which are close to the slopes can lead to removal of the underlying supports can lead to the contribute to high stresses lateral pressures the water in vertical cracks freezing water in cracks our roof root wedging.

So root wedging or water in vertical cracks or freezing water in cracks can lead to increasing the lateral pressures and another way according again after grain laser 1982 factors that contributes to low shear step that is the initial state composition.

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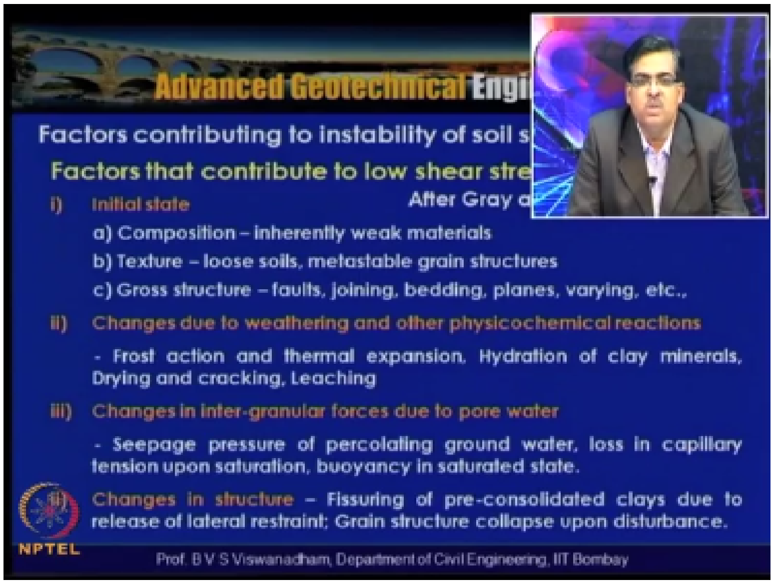

Image inherently soil actually has got weak materials and texture basically the soil is having a loose soil meta stable grain structures and the grass structures particularly, if it actually has got some faults jointing bedding planes and warming of soil status can lead to you know low strengths and changes due to weathering and other physical chemical reactions like frost action and thermal expansion hydration of clay minerals and drying and cracking and leaching particularly this actually happens in literate basal slopes.

And can lead to you know the slope low shear strength because of leaching phenomenon where the slopes tends to become unstable and this is this is primarily predominantly occurs because of the weathering and physical chemical reactions and changes in inter granular forces due to poor waters pore water pressure that is seepage pressure of per loading groundwater or loss in capillary tension upon saturation suppose if you are actually having a capillarity which is with the negative pore water pressure.

And if it is subjected to loss because of the pond saturation and by unseen saturated soils can lead to low shear strength in aslope and changes in structure like fissuring in pre consolidated clays due to release of lateral restrain grain structure collapse upon disturbance this place this basically happens insensitive place where sincerity is very high sensitivity is defined as qu or unconfident compressive strength in undisturbed to disturbed state, so in some soils are which are called as sensitive soils.

The collapse of the grain structure occurs upon disturbance and that lead to the failure so these are the factors contribute to the low shear strength, so in the slope stability analysis now what we do is that we try to address upon the methods for analyzing these slopes and before addressing about the sudden draw down condition and some measures for critical locating the critical failure surface the slope stability analysis basically.

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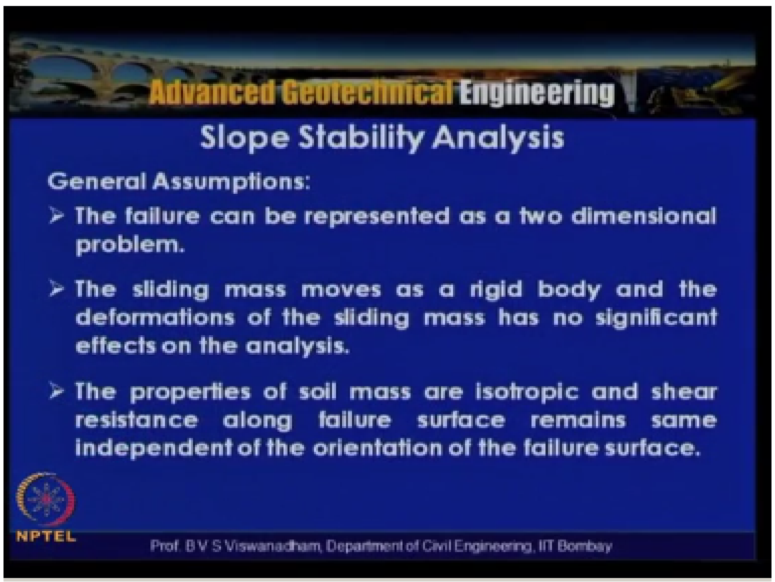

Is with the general assumptions the failure can be represented as a two dimensional problem because a slope or an embankment a railway embankment which is a finite slope which actually extensor long lengths can be treated as a plane strain structure, so hence two dimensional analysis is relevant but in certain cases now the three dimensional stability methods are also available so the failure can be represented as a two dimensional problem the sliding mass moves as a rigid body and the deformation of sliding mass has a significant effects on the analysis.

So the sliding mass moves as a rigid body and the deformations of sliding mass has no significant effects of the analysis and the properties of soil mass are isotropic and shear resistance along failure surface remains same independent of for orientation of the failure surface, so the properties of the soil mass are isotropic in nature the shear strength along the failure surface remains same independent of orientation of the failure surface so the basically the analysis is based on the limit equilibrium methods.

Of course now there are also many other methods based on finite element methods or finite difference methods.

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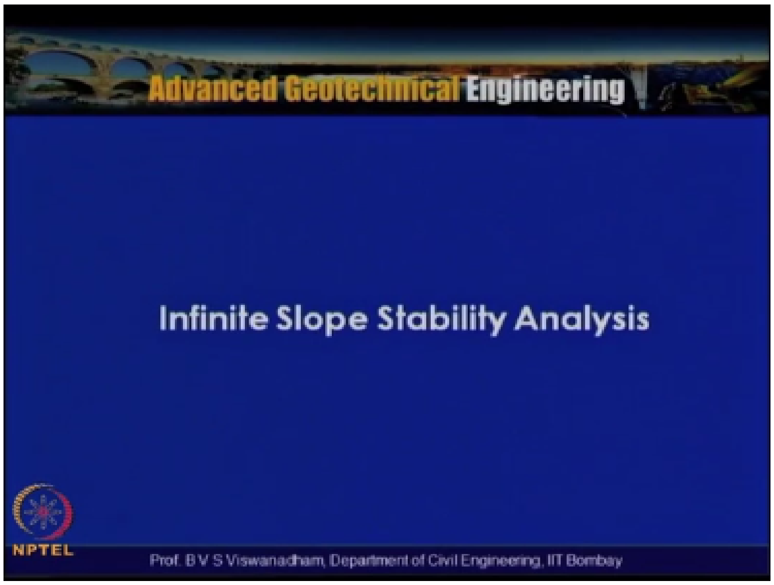

So before discussing the finite slope stability analysis methods let us look into the infinite slope stability analysis method particularly this infinite slope stability analysis means this we defined the these slopes.

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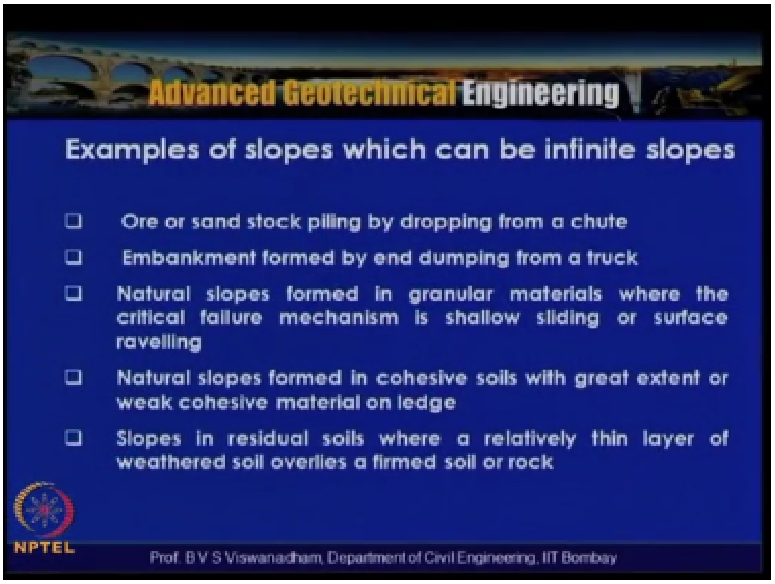

They can be natural or man-made the examples of slopes which can be infinite slopes are given below here they can be war or sand stock piling by dropping from a root and the slope which actually takes the form of the slope which actually takes is a can be regarded as an infinite slope and embankment formed by and dumping from a truck is also regarded as an infinite slope and natural slopes formed by granular materials where the critical failure mechanism is shallow sliding or surface traveling time.

So basically it occurs in some certain types of shear slopes wherein the slope surfaces remain parallel to the slope failure surfaces remain parallel to the slope surfaces and shallow in nature and can lead to failures, so the natural slopes formed by granular materials where the critical failure mechanism is shallow sliding or surface traveling which actually happens and the natural slopes formed in cohesive soils with a great extent or weak Kozue soil material on the ledge is also you know regarded as a infinite slope.

And slope in residual soils very relatively thin layer of weathered soil or derisive a film soil rock so this is an example which I was giving for a shale slope where the shear slope in the process of under because of the saturation can though it actually has a film oil or a rock and beneath that if there is a soil which actually has a you know nature of weathering which actually undergoes underneath the soil and where the slope failure is are the slope is actually also said to be an infinite slope so in this particular slide.

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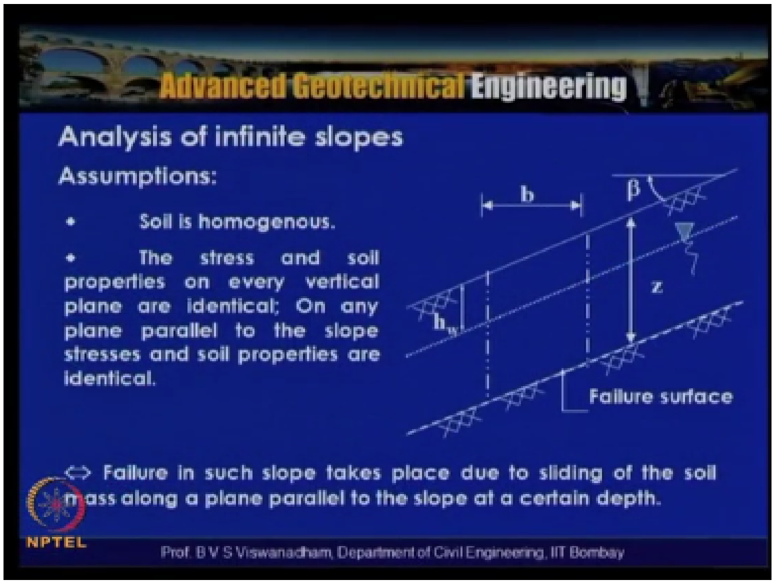

A typical cross-section of infinite slope is shown and the another example of infinite slope is also here a slope which is actually formed for a man-made structure like for certain type of elements in a man-made structure like landfill where in the some of the elements are actually designed based on the infinite slope stability analysis theory particularly the covers are a landfill cover or lining system which is based on the infinite slope stability analysis of course when the structure is actually concerned when considered as a hole then one ten to one has to do the global stability analysis.

Where in considering entire cover system or lining system along with the waste body in a landfill so in the analysis of infinite slopes in this particular slide a typical cross section is shown here and this is the slope surface which is inclined at an angle β and this is the location of a failure surface which is at a certain depth below the slope surface that is the Z depth which along the vertical direction.

So which is shown here and let h_w is the depth of the groundwater table and it is measured from the top surface of the ground surface, so if a hw = 0 that means that the water is at the ground surface where hw is equal to Z that means that the water is at the failure surface or a surface for which the failure is occurring and the β is the slope inclination which is shown here and it is assumed that there is a failure surface which is actually occurring here, so consider a block B with small B is the horizontal distance.

So the perpendicular to this length is a per meter length or unit length is considered so the area or which this block is sliding is B into one units that is B meter square units the soil is assumed to be homogeneous and distressed and soil properties on every vertical plane are assumed to be identical and on any plane parallel to the slope the stresses and soil properties are identical that means there this block can be constructed here block can be constructed here, so the stress and soil properties on every vertical plane are assumed to be identical on any plane perpendicular.

To slope stresses and soil properties are integral so the failures in such slopes takes place due to sliding of the soil mass along a plane parallel to the slope at a certain depth in this case the depth is indicated as a z.

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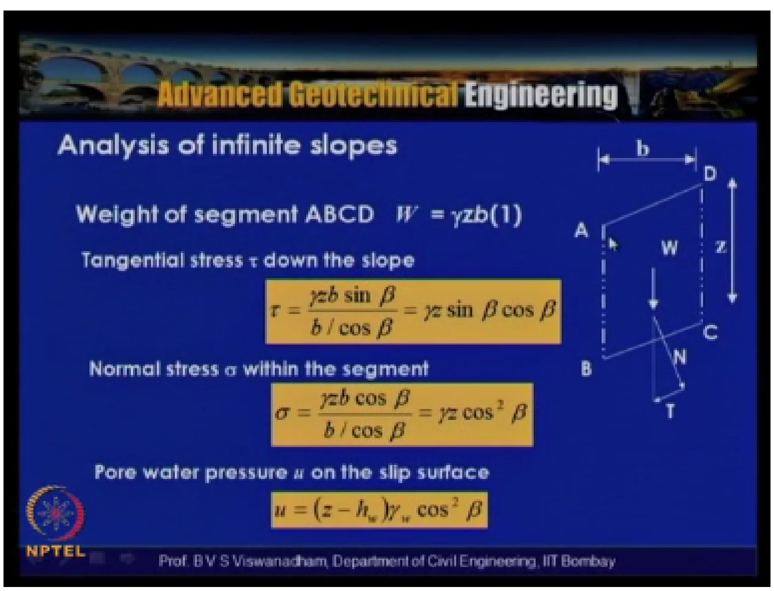

Now consider this particular the free body diagram of that particular block where W is the self weight of the block and this line a B A B C D is the block which is actually considered and B is the horizontal width and z is the depth and this is the portion along which the position where the failure surface is actually occurring so the weight of segment ABCD which is W is equal to γ z into b x 1 that is nothing but the weight of the area of the parallelogram which is actually shown into the unit weight of the soil.

Now the tangential stress tau down the slope can be obtained by this particular expression which is nothing but the tangential force the tangential force divided by this area this particular length this is horizontal distance is B, so this distance is B by Cos β because this inclination ad is inclined with horizontal with β in correlation, so this along length of BC or ad is equal to B by Cos β so this component along this surface is taken over a horizontal distance B by Cos β into one so is nothing but a shear force over that area.

Wearing τ = γb Sine β / B Cos β with that we can write τ = γz Sin β Cos β the normal stress σ within the segment that means the normal stress σ that is the N which is actually acting here and or a again this particular area which we can give as γz B Cos β/ B / Cos β in 1 into 1 so by simplifying the normal stress can be obtained as γz Cos / β similarly with the presence of water like if water is from surface a d hw units vertically down that means that the water pressure which is nothing but γw into z – z hw in the pressure over that area which is actually given by pressure pore water pressure U on the slip surface which is nothing but z – hw into γzw into Cos β / B by Cos β which actually simplified as z – hw into hw into γw Cos^2 square β now this you know further actually simplified with the normal effective stress which is nothing but σ-.

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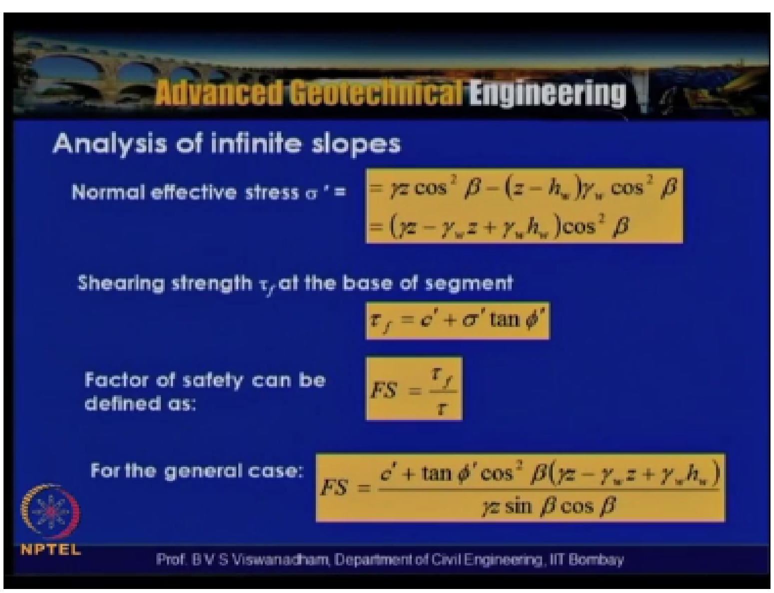

= σ which is nothing but the normal stress which is here and the pore water pressure here now which can be written as now $\gamma z \cos^2 \beta - z - hw$ that is within parenthesis $\gamma w \cos^2 \beta$ so by simplifying we get this $\gamma z - \gamma w + \gamma h \cos^2 \beta$, so this is the normal stress σ - now the shear strength of the soil along the failure surface tau Fat the base of the segment that is the resistance offered by the material at the interface of the soil above the block the failure surface and soil below the failure surface.

So that is nothing but τf = c- + σ- Tan ϕ - so now the factor of safety can be defined as nothing but tau F which is nothing but the shear strength available to the shear stress which is induced so what we have done is that we have written τf = c- + σ- Tan ϕ - now here for substituting for σ- the $\gamma z - \gamma w\ z + \gamma wh \cos^2 \beta$, so that is substituted here divided by the shear stress which is obtained in the previous case.

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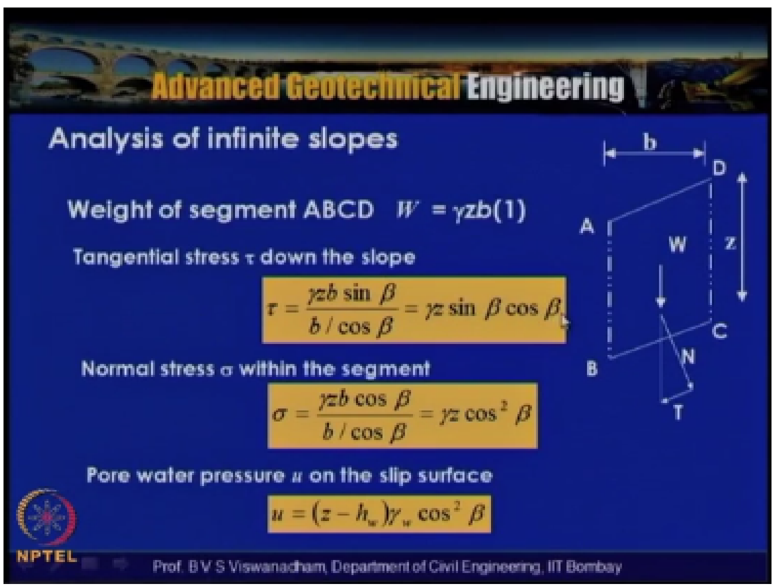

Because of the movement of the block it is nothing but γz Z sine β Cos β and the C that is actually obtained and substituted here and then the for the general case the expression reads like this the factor of safety is equal to c- + Tan ϕ- $\cos^2 \beta$ into γ Z – γw/ γz Sine β Cos β, so this is the general expression now this expression when it is actually sub let us say that when you are having with water without ground water or when there we have a saturated slope then different cases can be reduced.

But this particular expression which is shown in this slide factor of safety is equal to nothing but the shear strength available to shear stress that is τF / τ and this is expressed as c- + Tan ϕ- into Cos^2 β into γz – γwz + γhw Sine β Cos β.

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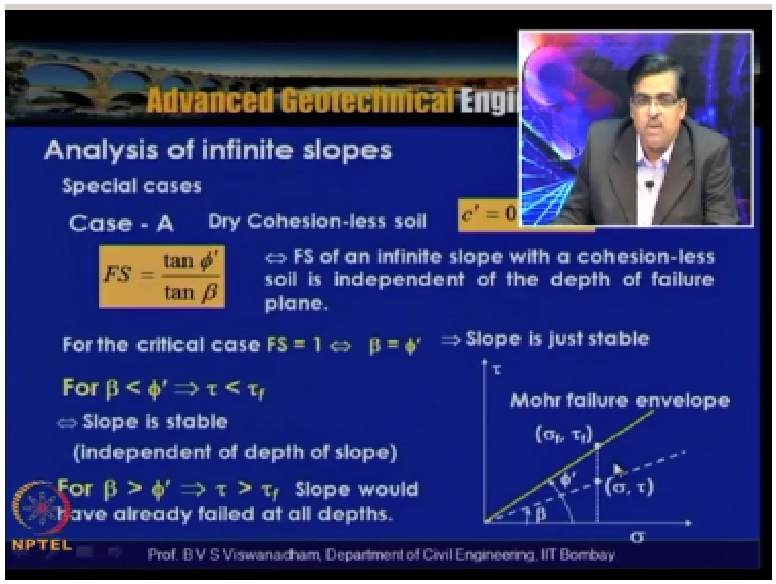

Now in this particular slide the in this particular slide the analysis of infinite slopes which is actually shown and the special case wherein in the previous expression, if you put this c- = 0 wh W = z in case of a dry cohesion less soil the expression gets simplified to factor of safety is Tan ϕ- by Tan β, so basically this is factors if in an infinite slope with a cohesion less soil this can independent of the depth of the failure surface, so if you look into this for a critical case the factor of safety is equal to 1.

That means that the slope inclination equal to the friction angle this is nothing but you know the also called as the angle of repose that means that when the slope inclination is equal to the you know the angle of internal friction of the soil then that is you know the called as angle of repose and this particular expression is actually independent of the depth of the failure plane, so this can be explained here and a Mohr circle plot where normal stress is on the x-axis and shear stress on they-axis wherein this is the more failure and elope with friction angle ϕ- and the slope inclination which is actually shown here.

So for β less than ϕ- as long as β as then ϕ- the slope is actually stable independent of the depth of the slope even the depth of the slope is 2000Km are more than that and this can lead to ensure the stability to a slope so this is the slope is said to be stable as long as β less than P ϕ- and if β is equal to ϕ- the slope is on the verge of the failure or in the critical factor of safety which is actually called as 1 the slope said to be just stable when β greater than ϕ- that means that when this line lies above this then it is actually called as the slope would have already failed at all .

That means that it would have said to this particular slope inclination so here if you look into this y-you know when β less than ϕ- the slope is you know said to be stable and independent of the depth of the slope, so at a particular normal stress if you if we consider and if you notice here that for a given normal stress this is the shear stress mobilized but the soil actually has got a shear strength which is much higher than the shear stress mobilized, so because of this unless the failure the slope inclination meets this failure analogue there is no possibility of a failure surface so as long as this slope inclination is actually less than this internal friction angle of a soil then the slope is actually said to be stable.

In the case of a analysis of infinite slope but this is a case of a saturated cohesion less slope where c- = 0 hw = 0 when you substitute in this general expression then factor of safety is given by γ - Tan ϕ- / γ Tan β that means that factor of safety of a saturated cohesion less slope is about half of the slope without saturation, so we have idea we have said that in case of a saturated slope the factor of safety is 50% of a slope without saturation and a case see when we substitute hw is = 0 in the just expression.

What we derived for infinite slope stupid analysis we get for a cϕ soil factor safety is equal to c- Tan ϕ- into Cos^2 β into γ- / γz Sine β Cos β where β is the slope inclination ϕ- is the angle of internal friction of soil and CD ash is the effective cohesion of a side, so in this particular lecture what we studied is that we are understood that what are the different factors which actually can cause slope failure and what are the different types of slope values and what are the different types of loop's like infinite slopes.

And finite slopes and we have addressed it about the infinite slope stability analysis which is based on the block which is actually considered and then we have deduced a general expression then afterwards we have considered three cases case a which is a dry slope and case B is a saturated slope and which is a saturated cohesion less infinite slope and in case of a cohesion less C that is where ϕ-c soil is there in this case when you look into this where cϕ- soil when you consider.

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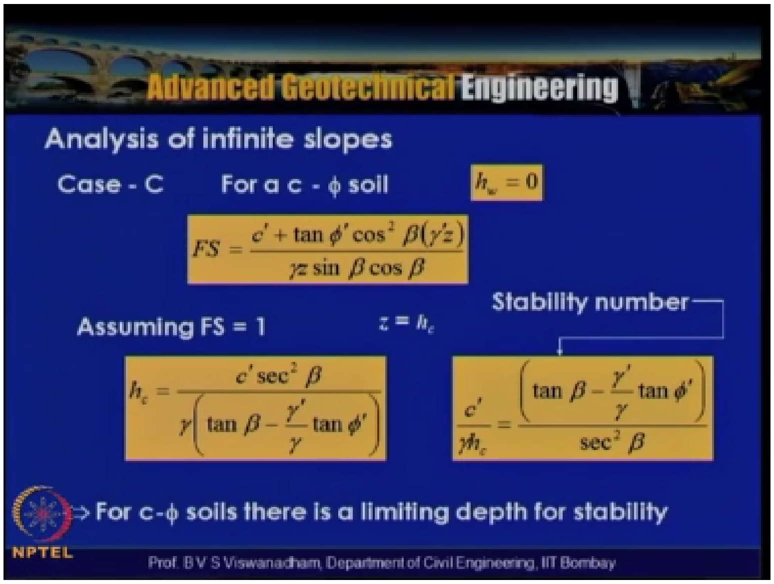

With a factor of safety is equal to 1, so here for a ϕ- soil there is a limiting depth of the stability so this particular expression when we put factors of region 1 and z tends to hit C hit C is given as its HC is equal to C dash secant square β into γ within parentheses tan β - γ - / γ into ϕ- so this C dash by γ hit C is referred here as stability number tan β - γ dash by γ into Tan ϕ- by secant square β, so only for cϕ- soil there is a limiting depth of stability, so this is particularly represented here.

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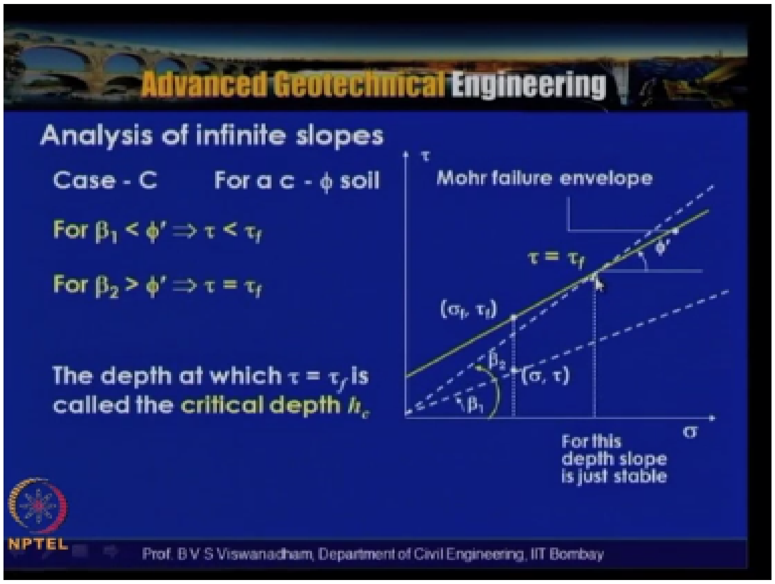

Where in for this when you represent this in Tan plot that depth at which τσ is actually called as the critical depth so that is what we have discussed that when z tends to z so here if and it meets the failure and elope the shear stress is equivalent to failure this the shear strength of a soil and lead to the failure here, so when for β one less than ϕ β 1 less than ϕ- which is actually here and tau is less than τ F but when β2 is less than β2 greater than τ then at a certain point it meets this failure envelope at that point at which the you know the τ tends to tau F is actually called as the critical depth.

So in this lecture we have actually discussed about the infinite storage analysis in the forthcoming lectures of in this module we will discuss about the finite slope stability analysis methods.

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