Soil Mechanics
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Lecture – 55
Stability analysis of slopes – I

Welcome to lecture number one in stability analysis of slopes. In previous lectures we have seen the applications of shear strength theory that is earth pressures now let us look into how we can analyze slopes with the knowledge that we have learnt. In this lecture we look into predominantly types of slopes, failure types and causes of slope failure and some analysis methods for slopes.

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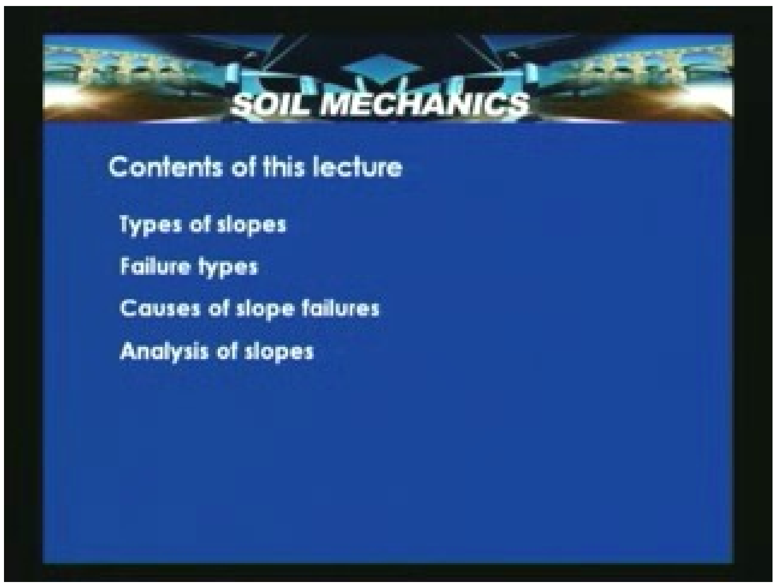

So you might have learnt this shear strength theory. The two possible aspects which are very important one is earth pressure theories and stability analysis of slopes and these two are entirely rely on the shear strength of a soil. So in earth pressure theories we understood how we can compute earth pressures on a retaining wall. Now in this lectures what we look into is how we can analyze a slope or arrive at a safe slope. In case if the slope is unstable and we look into methods for enhancing the stability of a slope.

So predominantly there are two slopes, one is infinite slope, other one is finite slopes. The infinite slope that extends over a long distance and the condition remain identical along some surface or surfaces for quite some distance that is the slope which can extend over a long distance and conditions remain identical that means properties remain identical along some surface or some surfaces for quite some distance, whereas finite slopes that connect land at one elevation to land that is not for away but is at different elevation that means these connects the land at different elevations.

This can be natural or man made that is this can be a natural hill slope or a man made slope like highway embankment or railway embankment or railway cutting or so. So in this slide what we learnt is that the shear strength theory can be applied to earth pressure theories and stability analysis slopes and we said that predominantly there will be two slopes and one is infinite slopes and finite slopes. Infinite slopes we define as a slope that extends over a long distance and a condition remains identical along some surface or surfaces for quite some distance.

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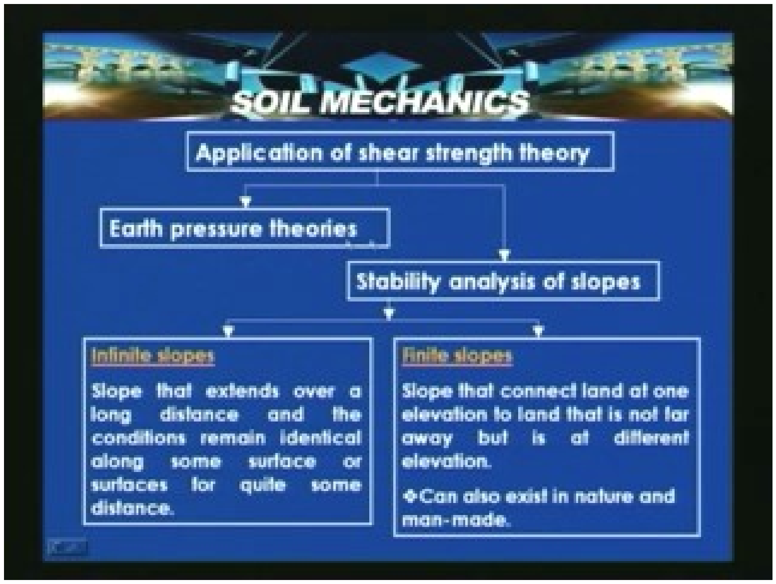

Similarly finite slopes, the slope that connect the land at one elevation to land that is not far away but is at different elevation, this can also exist in nature and manmade. So types of slopes when you look into it, now let us categorize them they can be natural and man made slopes like hill side and valleys and which form the natural slopes and coastal and river cliffs are examples of the natural slopes.

Examples of manmade or artificial slopes are cuttings and embankments for highways and rail roads, earth and ash pond dams where we store coal ash and that is called ash pond dams and temporary excavations, waste heaps or landfill slopes which are increasing in the moderant world and landscaping for the site development that is for the development of the site the landscaping can create artificial slopes.

So the manmade slopes they predominantly cuttings and embankments for highways and rail roads and earth and ash pond dams and temporary excavations, waste heaps the predominantly they are called landfill slopes and landscaping for the site development. How these slopes fail? We look into the typical types of failure then we also look into some typical slope failures which can occur in the field.

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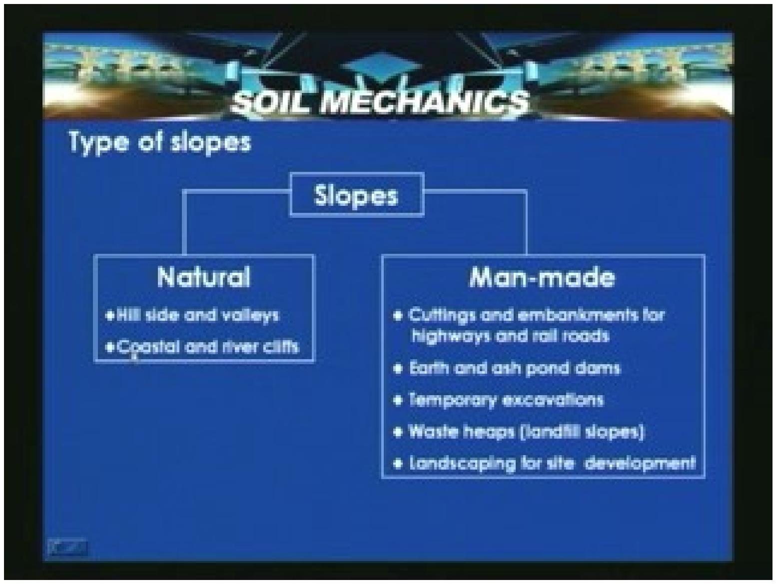

So types of slope failure this is a typical circular failure can occur as if like a scoop, so in this particular mass is moving about a certain point in the space. So there will be instability, the moment there is instability then slope tries to move from higher elevation to lower elevation, tries to adjust to a safe slope. So this is called a rotational slip and this can be non-circular and circular. Suppose in case of stratifications were the soil varies from place to place and in such situations some non circular failures types are possible.

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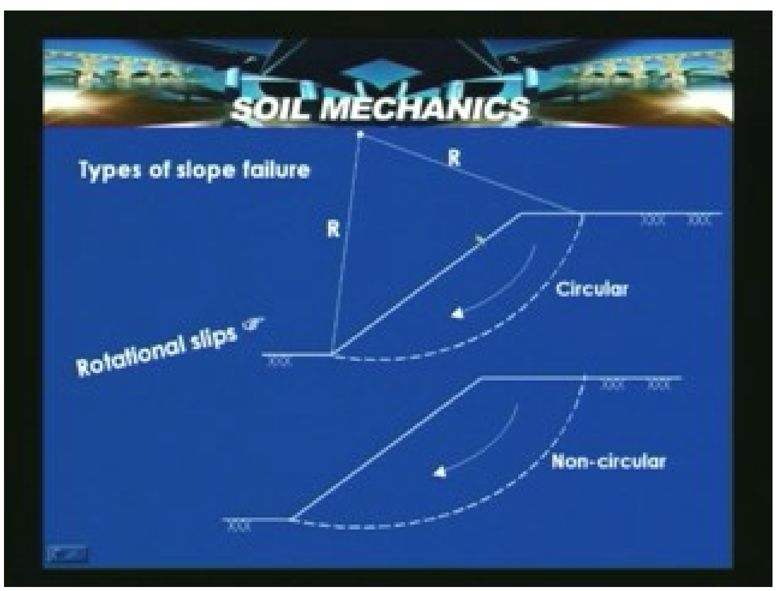

So typically the slope failure is characterized as a circular failure for convenience and also the assumption that with the mobilized shear strength is uniform with that assumption which can be said as circular failure can be predominant. Some type of slopes which are flat but can have a translational slide like this which is shown. This broken line indicates a failure surface almost parallel to the slope surface. So this quite resembles an infinite slope so this is a transitional slide which actually shows in this type of failure, the detachment here and then the detachment here and the entire slope moves down the slope.

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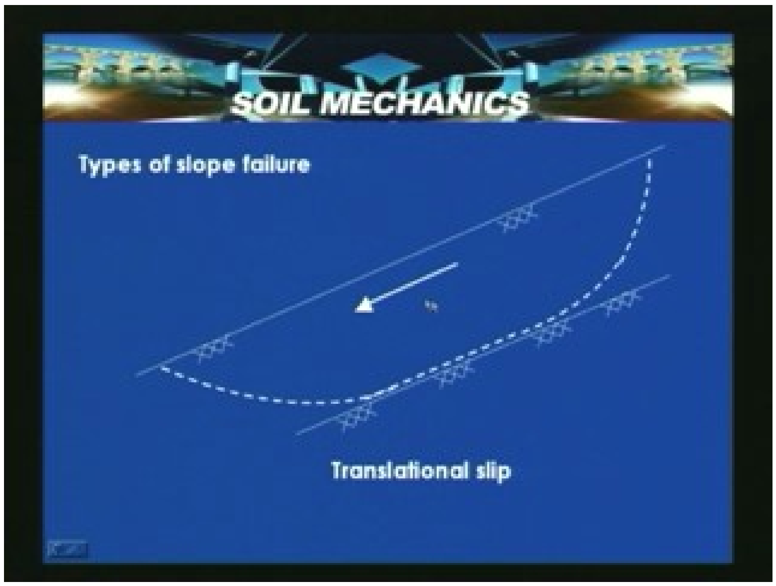

In some cases if there is a rigid stratum that is like stiff clay or a rock and then it’s over laid by soft clay or embankment which has been constructed with that, what will happen is that a compound slip can take place. So this is how that slips take place, this indicates that this particular portion of the soil is getting detached and moving away from the original soil mass. This compound slip is shown here which occurs in a typical mode and as it cannot penetrate through a rigid stratum, it actually will be tangential to the rigid stratum and it erupts out here.

So when this takes place there will be some settlement here and because of this when the failure takes place there will be a development of a heaving of soil takes place here. In this portion the soil will be subjected to compression like the way we have conducted in direct shear to get the soil properties that means if you take a sample from here and this is the possible failure plane which actually soil can experience under stresses.

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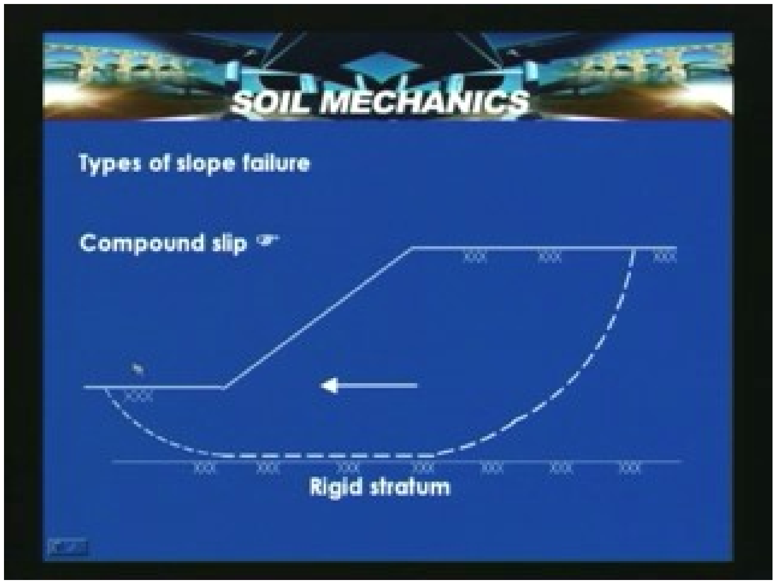

Here the soil will be subjected to tension or extension here. In this case this particular interaction almost resembles the way in direct shear test. Now this resembles something analogous to block movement we studied in engineering mechanics. Here as long as this force is less than mu_s N the block will be stable. So consider a block of weight W and its normal reaction is N. Once this block is subjected to a force F_1 greater than F, it will be subjected to a movement and it will be continued to move. Moment this F causes this mu_s N the block will be subjected to the direction of a movement in the direction of a force.

The similar analogy happens when the slope portion moves on a certain surface. The resisting force is the frictional force which is offered by the particular material, it so depends up on the type of the interface this block has. So under static conditions mu_s N but once it is under movement say F_1 is causing the movement to the block then we can say that mu_s changes to mu_k that is kinetic friction. So in this case a factor of safety can be defined, a term which is used for knowing whether the slope is stable or not or on the wedge of failure. Say this we can define by using the simple analogy what we use say that is factor of safety is equal to F_R by F_D where F_R is the resting force and F_D is the driving force.

So in this case the driving force is F and resting force is mu_s N. As long as this factor of safety is greater than certain value then the slope is said to be, that is as long as the resting force is greater than driving force the particular block is said to be stationary. As long as mu_s N is greater than F the block is said to be stationary and there will not be movement, moment this crosses then what will happen is that a block will be subjected to a movement.

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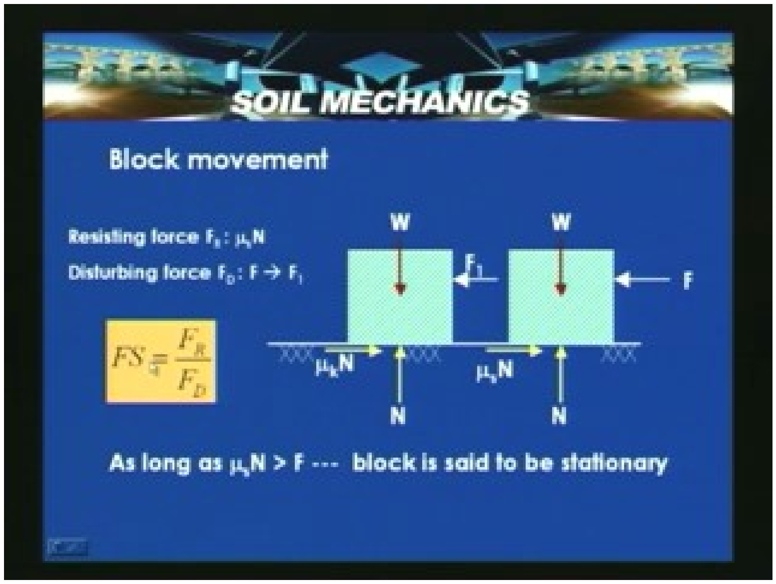

Similarly the similar analogy happens in the field for slopes but only thing is that the orientations are different and types of failure surfaces are different. So what are the causes of slope failure? Many causes are there, the first is the gravity that means the block or soil tries to move from higher elevation to lower elevation. So re adjustments takes place from higher elevation to lower elevation. Seepage that is one thing where the water tries to flow through the soil then it causes seepage stresses and induces failure to the slopes. Earthquake, erosion, geological features, construction activities like cuttings, disturbing the natural slopes or fillings that is constructional of an embankment or a bund on a soft soil can create failure.

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So the causes of slope failure can be summarized as gravity driven one, seepage driven one, earthquake, erosion, geological features, the way stratifications are there, the way dipping is there, the way the layers have been found, they actually govern these particular slope failure and construction activities. We look into one by one how these activities can create a slope failure so before that let us see a typical slope failure and these are the typical slope failures which are shown because of the continuous inundation of the rains. We can see that how dangerous they are with the on set of the rain fall. This is another case which is shown here a road portion after a slope failure. This picture also shows a portion of the slope after failure.

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So these pictures are shown just to indicate how severe this particular slope failure can cause to a live transportation utilities for us. Similarly this particular picture shows landslide damage adjacent to a residential structure, so you can see here there is a structure or a building very close to that and the slope surrounding one fails, so the building which is at the crest of the slope can be subjected to distress because of the slope failure which can induce a failure of the or over topping of the building also. In this case a road subsidence cause and with that how that portion of the road which has got fail is shown and the cracks development can be noted in the picture on the right hand side of this slide.

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Similarly some typical slope failures even the building which is hanging here, part of the building which hangs here is shown. So this building shows how the portion of the building is hanging on a failed slope and this is a 25 meter high failed slope were this particular slope is underlying by a soft clay though this material is having a good quality soil but its underlined by soft clay that has induced a movement of the failure. So though the entire portion of the slope contains a good soil but if it is underlined by a weak soil layer that can induce a failure. So slope failures depend on soil type, soil stratification, ground water, seepage and slope geometry. So these things are very important, slope geometry in the sense the stiffness of a particular type so soil type, soil stratification, ground water, seepage and slope geometry.

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Examples of slopes which can be infinite slopes like we have just discussed that two types of slopes and one is infinite slopes and another one is finite slopes. There are some cases where these slopes can be categorized as infinite slopes and can be used for analysis like ore and sand stock pilling by dropping from a chute and embankment formed by end dumping from a truck, natural slopes formed in granular materials where the critical failure mechanism is shallow sliding or surface raveling and natural slopes formed in cohesive soils with great extent or a weak cohesive soil material on ledge and slopes in residual soil where relatively thin layer of weathered soil overlies a firmed soil or rock. So these particular slopes which are formed by this process can be considered as an infinite slope and analyzed by using the method which we are going to discuss for infinite slopes stability analysis.

Now as we are discussing the types of slope failure let us see a translational slide. In this what happens here is that a failure of a slope along the weak zone of a soil can takes place that can induce a portion of the soil above it. So this is a slip or a failure which is indicated then this can occur, once these resting forces were dominated by driving forces that is driving stresses get induced by the failure along that weak plane.

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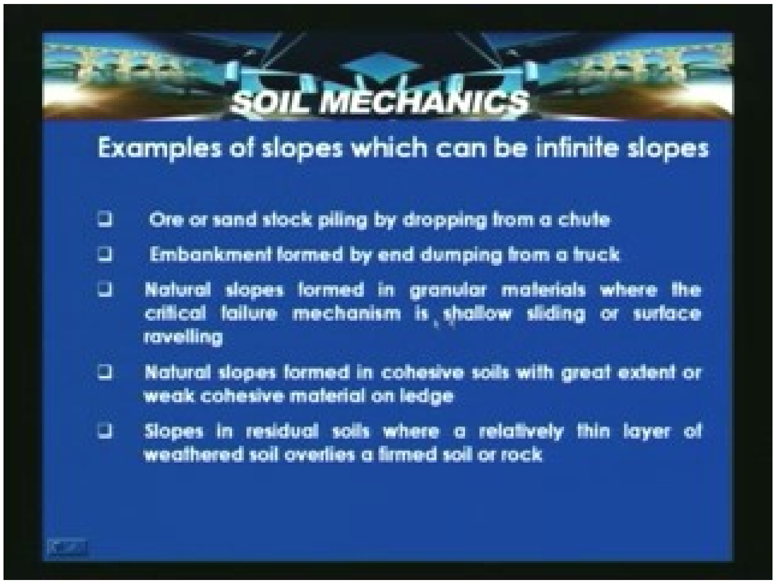

So in this translational slide, failure of a slope along the weak zone of soil so in this case there is a thin layer of weak soil if it exists and that can induce a translational slide. Sliding mass travels long distance before coming to rest and common in coarse grained soils.

This is quite common in coarse grained soils or sometimes it deposits where there is a rock outcrop and then there is a deposit of soil above it that can actually create along that interface because of the rainfall with the lubrication along the surface can have a weak plane along that particular interface. So this type of thin layer of soil can induce that example of water whatever we said is the transaltional slide which can cause. So which is shown here this darkened portion shows that how this thin layer of soil has induced a failure in a certain case.

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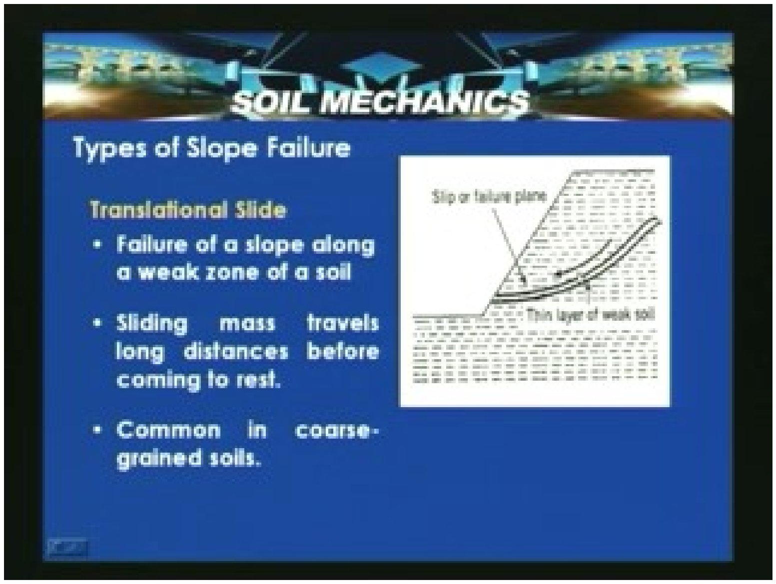

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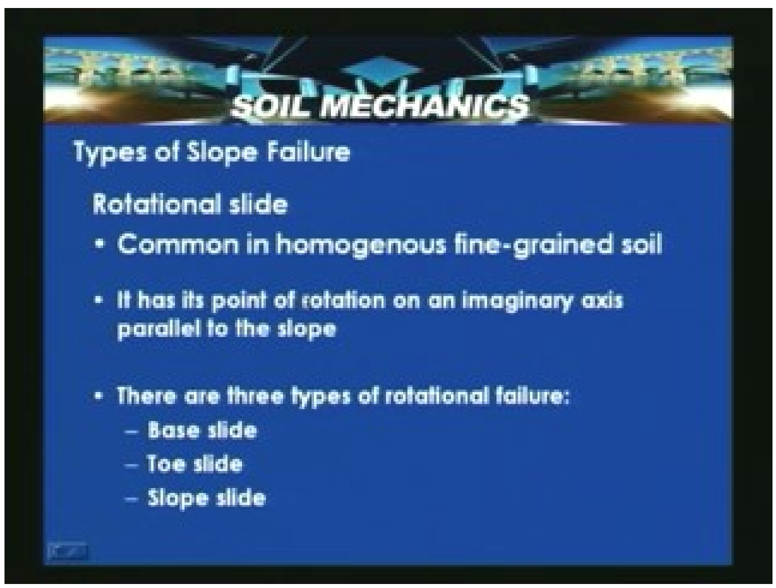

Another type of slope failure is rotational slide common in homogeneous fine grained soil and it has its point of rotation on an imaginary axis parallel to the slope. So this rotational slide has got a point of rotation on an imaginary axis parallel to the slope and somewhere in the space to rotate a portion of the soil to adjust to a safe position. So there are three types of the rotational failure, one is the base slide other one is the toe slide and slope slide. Let us look how the base slide failure can take place. This is one of the types of the rotational slide, base slide occurs by an arc engulfing the whole slope that is arc engulfing the whole slope and this can occur when there is a soft soil layer resting on a stiff layer of soil or suppose you have got a soft foundation soil and then you construct a embankment with a strong soil or a stiff soil or a good quality material.

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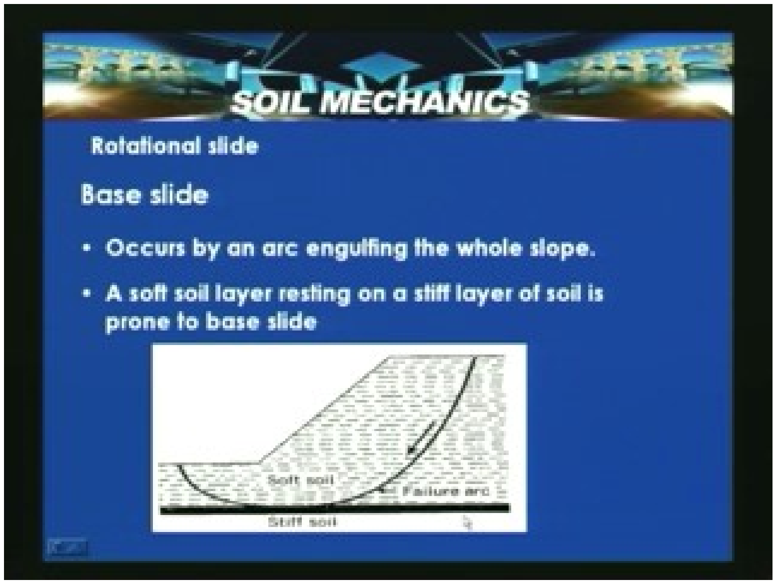

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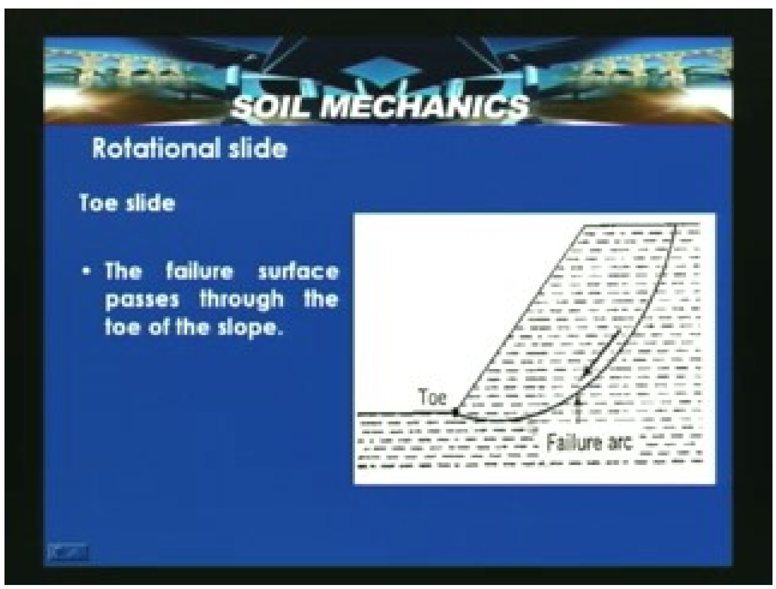

In such situation we can have embankment resting on soft foundations a classical failure base failure can takes place. So occurs by an arc and engulfing a whole slope and a soft soil layer resting on a stiff layer of soil is prone to base slide. So you can see that how this is the failure arc which is shown and so these particular portions of soil gets detached and then get tangential to the stiff soil portion which is there. Then the other type of the rotation slide is toe slide that is the failure surface passes through the toe of the slope. So this type of failure can occur if there is an embankment which is constructed, manmade embankment constructed with poor quality material or with poor compaction conditions.

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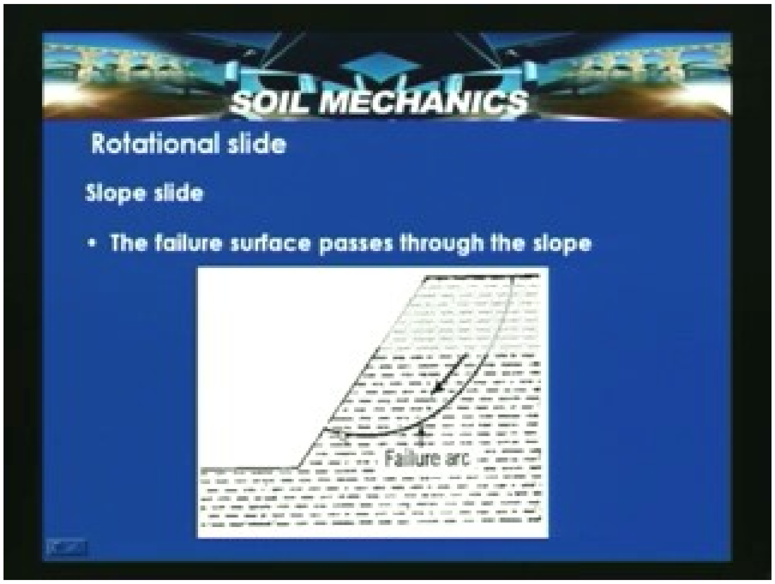

So the two failures which actually can occur and then passes through the toe of a slope and the slopes slide in this case the failure surface passes through the slope that is the slope portion itself, the failure surface passes and then the slope will be subjected to failure. So we have seen the base slide, toe slide and slope slide. They are the forms of the different types of the rotational slides and we have seen how different they are; one is actually passing though a soft soil and then will be tangential to a stiff soil and another one is actually within the slope material itself. The other slopes are a failure surface passing through the toe of a slope.

Another which is classical example in this case of this subject which we are not going to discuss in detail but we can look into this. This is called flow slides or these types of slides are also possible in some mud slides which is also called. And here occurs when internal and external conditions force a soil to behave as a viscous fluid and flow down spreading in all directions. So we can see that this flow slides occur when internal and external conditions force a soil to behave as a viscous fluid and flow down spreading in all directions and multiple failure surface occur and change continuously as the flow proceeds.

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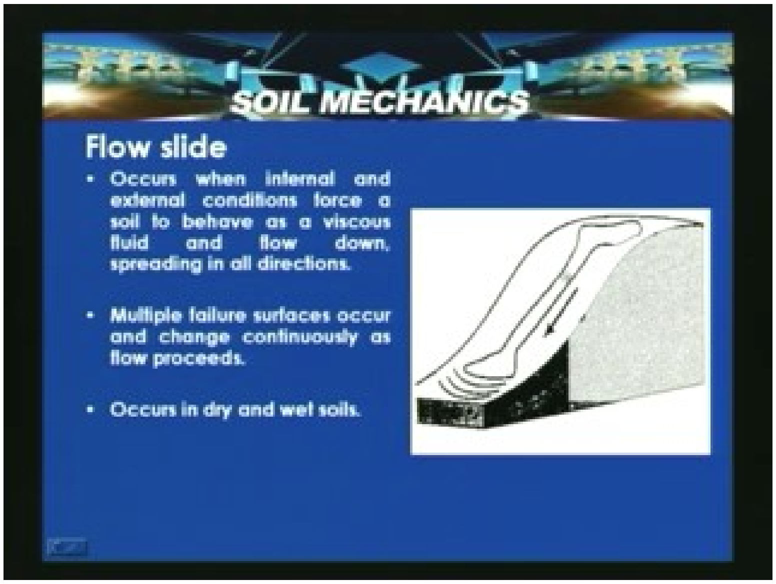

Multiple failure surfaces are possible and they change continuously as the flow proceeds, occur in dry and wet soils. So the flow slides are possible in dry and wet soils but this is beyond the scope of our lectures. The other one is the block and wedge slide. In this case block and wedge slide occurs when a soil mass is shattered along joints and seams fissures and weak zones by forces emanating from an adjacent soils. The shattered mass moves away as blocks and wedges down the slopes so this gets detached and moves away from the slope in the forms of blocks and wedges.

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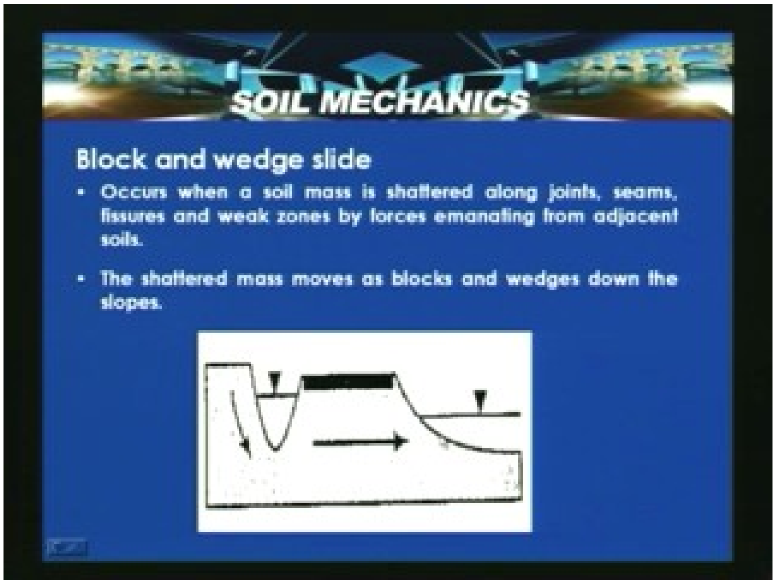

Then other typical type of failure which is possible along the hilly terrain slopes so simple detachment of the rock mass from its parent body this process is a gravity governed, what will happen is that in case of any minute movements within the slope and these movements can induce rock falls.

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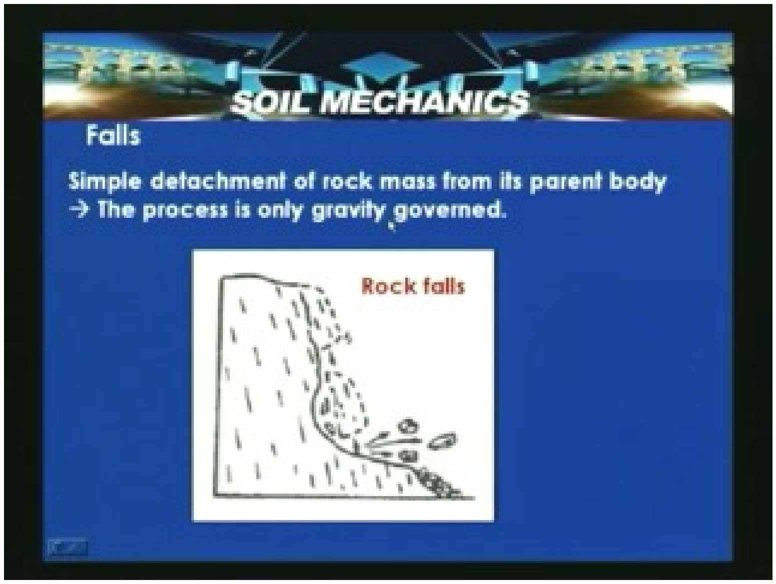

So for this lot of research work is going on to understand or to arrive at the safe distance for locating the transportation utilities otherwise this type of rock falls can create danger to the human lives along that particular area.

Some of the methods are to induce or to exhibit rock fall warning boards, sign boards or to provide some rock fall catching fences. So causes of slope failure in the previous slide we have seen the types of the slope failures. Now let us discuss into the different causes of slope failure. First cause let us discuss this erosion and as we discuss water and wind continuously erodes slopes.

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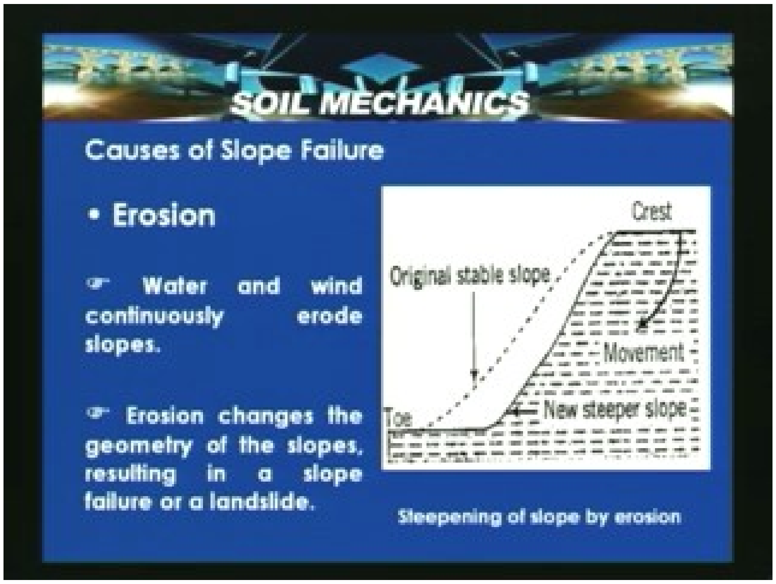

So this erosion can change geometry of slopes resulting in a slope failure or a landslide. In this particular picture this is the original stable slope configuration once this being unstable so what happens is that, this being a stable configuration and this is the toe of the slope and this is the crest of the slope but due to erosion of a soil either due to a agency with a water and wind what will happen is that it tries to form a new steeper slope which may be unstable from the material strength point of view.

So this can induce a movement and induce slope failure so water and wind continuously erode slopes and make this stable slope an unstable slope that is they convert the original stable slope into an unstable slope. Erosion changes the geometry of slopes resulting in a slope failure or a landslide and other type of erosion which can cause a slope failure is rivers and stream erosion. So rivers and streams continuously scour their banks undermining their natural or manmade slopes.

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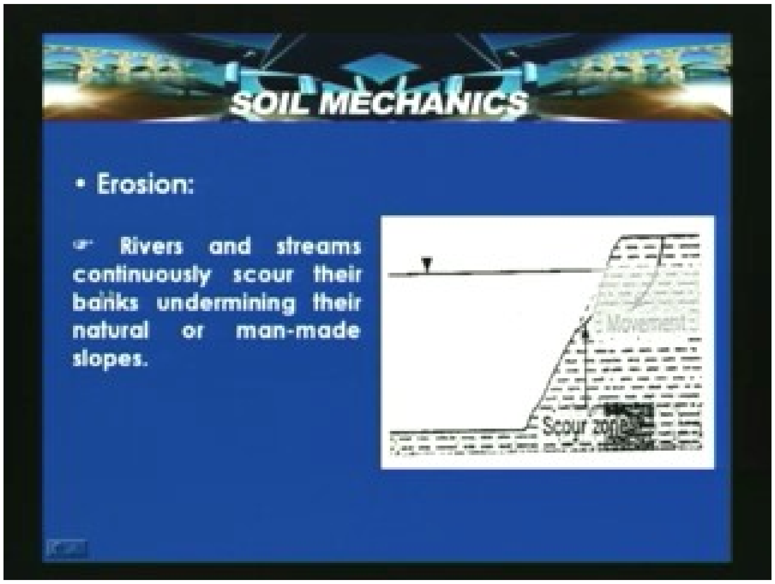

So if there is an embankment constructed along a river and if the stone pitching is not proper then it can erode that embankment and endanger the stability of a particular slope. In this picture where a water level is shown, this can be either be river or a stream where the local scouring which is shown here which induces movement in this direction. Rivers and streams continuously scour their banks undermining their natural or manmade slopes, the scour by rivers and streams which we have shown. Another cause of failure what we discussed is rainfall, many times longer periods of rainfalls saturate slopes soften and erode soils.

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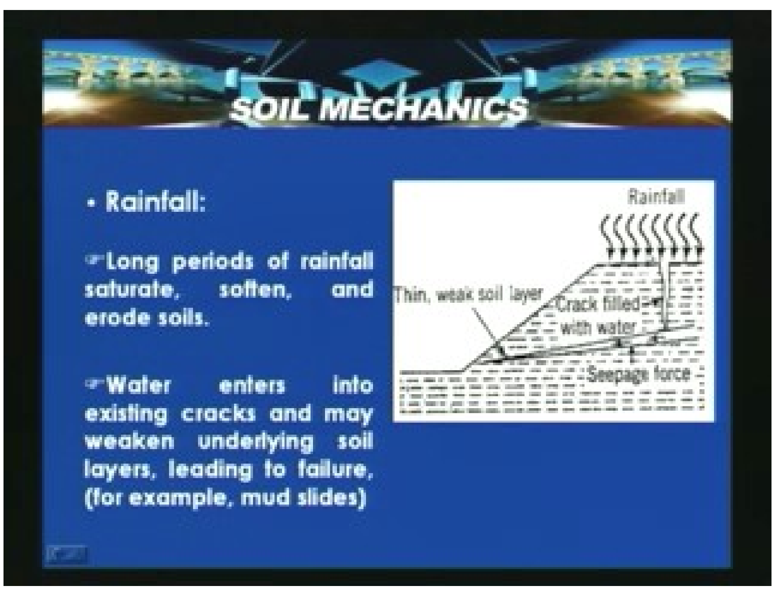

So this is quite frequent phenomenon which occurs along hilly slope areas subjected to a continuous inundation. So water enters in to existing cracks or tension cracks which are already formed and may weaken underlying soil layers leading to failure for example this mud slides. So here in this case a picture which is shown here and this is the continuous rainfall with certain rainfall intensity and this is already existing crack. So water enters through this crack, enters a weak layer and induces a seepage force and because of this the crack fill water induces a water pressure and then this water entering the weak soil layer tries to lubricate this particular surface and creates and make this entire mass of soil mass as an unstable mass.

Another cause which we discuss is earthquakes, earthquake induces dynamic forces especially dynamic shear forces which can occur in very short duration and that reduce the shear strength and stiffness of soil.

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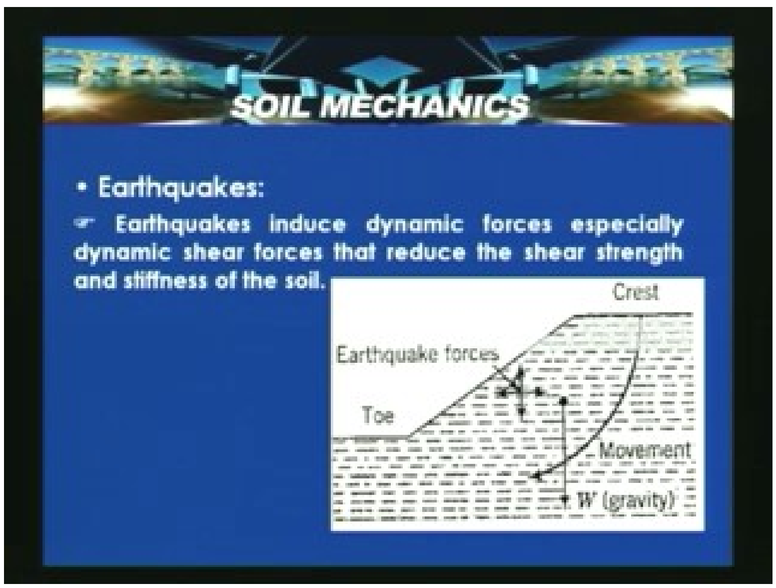

These earthquake forces can have, either in vertical direction or in the horizontal direction and can induce the movement and then induce failure to a particular slope. So this is the toe and then this is the crest and this is the movement which is actually initiated because of the earthquake forces. So earthquakes induce dynamic forces especially dynamic shear forces that reduce the shear strength and stiffness of the soil which actually causes a slope failure. So in the earthquakes the phenomenon we should discuss were one major phenomenon which happens is that called dynamic liquefaction. Here pore water pressure in saturated coarse grained soils could rise to a value equal to total mean stress that is the pore water pressures almost will increase up to whatever the total stress is there at a particular point and cause these soils to behave like a viscous fluids. Whenever this total stress equals to the pore water pressure, the soil uses its shear strength or because effective stress is zero. So this phenomenon is known as the dynamic liquefaction. So structures founded on these soils would collapse. Simply the structures or say there is a building or a resting on a slope and initially before this attenuation of this dynamic shear forces if it is stable, it will activate on to the unstable because of this phenomenon dynamic liquefaction phenomenon.

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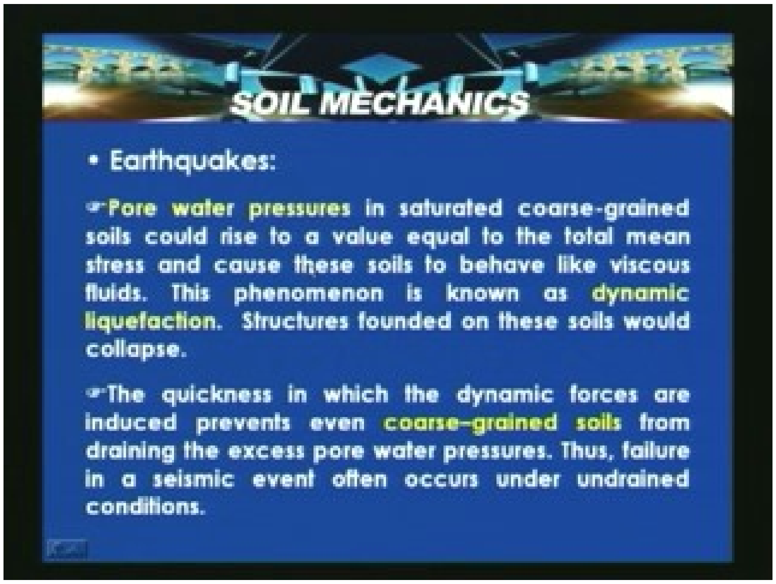

The quickness in which the dynamic forces are induced prevents even coarse grained soils from draining the excess pore water pressure. Thus the failure in a seismic event often occurs under undrained conditions. So what will happen is that because of the short duration even for the coarse grain soils is very difficult despite the pore water pressure. In such situations this we can say that under this undrained conditions where there is no possibility or time duration for the drainage then it can occur in undrained conditions.

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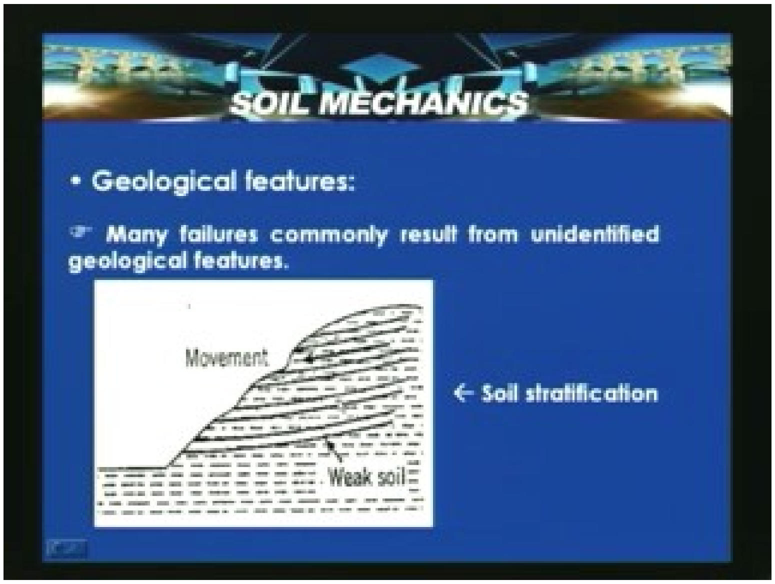

So one major factor or the phenomenon which actually governs this earthquake endures to the failure for a slope is the dynamic liquefaction and the quickness in which the dynamic forces are induced prevents even coarse grained soils from draining the excess pore water pressure. Thus the failure in a seismic event can often occurs even under undrained conditions. Another one is that we discussed about the geological features, many features commonly result in unidentified geological features like the deposits vary from place to place and region to region. So what will happen is that there can be a stratification or like war hood clay, we have got a weak soil and then there is a stiff soil and weak soil and stiff soil and if these stratifications are dipping towards down the hill slope and these weak soil layers can actually become like a failure surface. Particularly this type of soil stratification and if the portion of the soil is homogeneous can have a number of planner failure surfaces, possible in type of shear slopes and as the construction activities cannot be stopped because of the development infrastructure development and all. So we tend to load this slopes with external loads either due to building loads or due to construction of a certain structure on a particular slope, so these external loading induce instability to the slopes.

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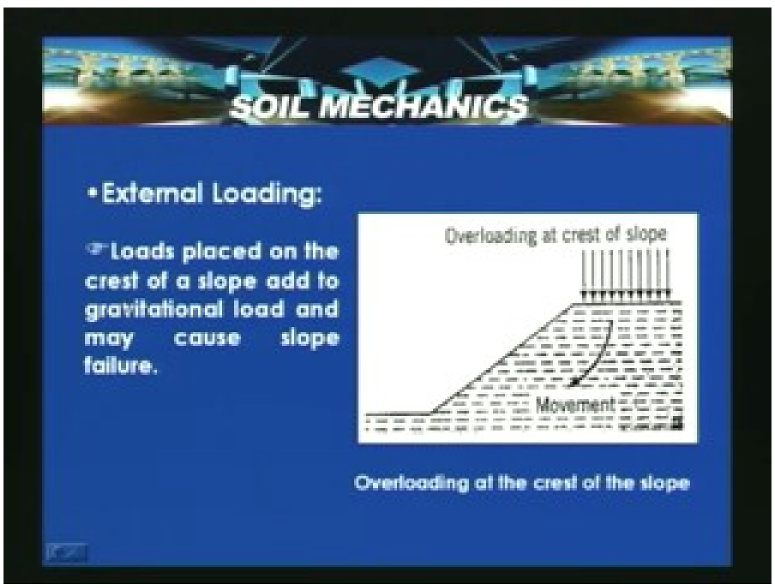

So if there is an over loading at the crest of the slope that this over loading adds to the instability and creates the movement. So over loading at the crest of the slope creates a failure also causes failure. So load placed on the crest of a slope adds to gravitational load and may cause slope failure. So this external loading which is added at the crest of the slope, if this overloading occurs at far away from the crest of the slope then we can say that the influence is minimal but if it is within the vicinity of the crest of the slope then its effect cannot be ignored.

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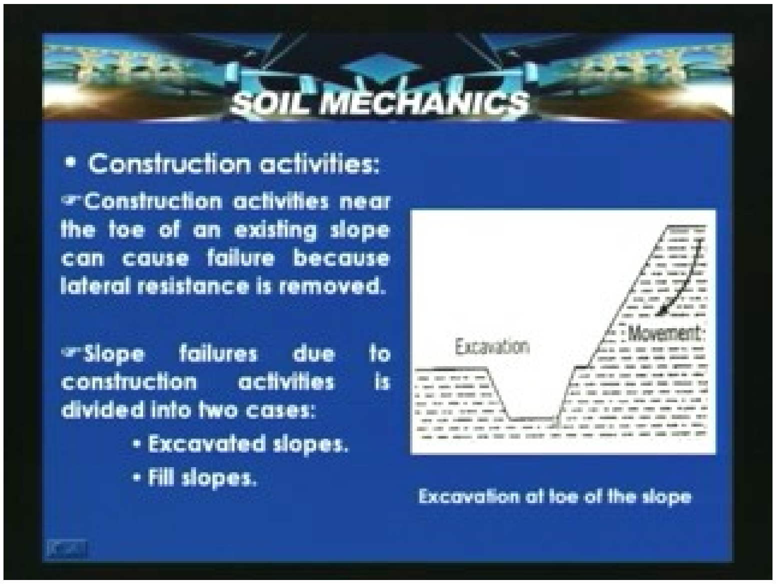

Another aspect which we discussed is that construction activities near the toe of an existing slope can cause failure because lateral resistance is removed; sometimes we do excavations at the toe excavation. So when the excavation is carried out at the toe then we are actually undermining the slope and what will happen is that it induces a failure. Slope failures due to construction activities divided into two cases, one is excavated slopes and in case of a fill slopes. So this is an excavation at the toe of the slope. Suppose if the excavation is deep enough and fit causes this instability a compound failure can takes place and which induce this movement entire cutting portion can become unstable.

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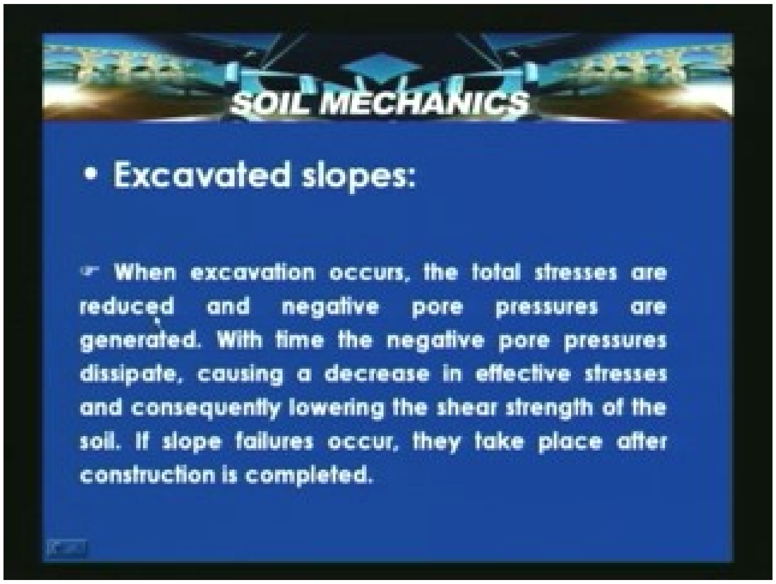

So when excavation occurs the total stresses are reduced because of the removal of the material and negative pore water pressures are generated because of the removal of the total stress. With time the negative pore water pressures dissipate causing a decrease in effective stress and consequently lowering the shear strength of the soil. If the slope failure occurs they take place after the construction is completed so the slope failures generally with this type of excavations they occur once after the construction. So this almost the danger that means within the life time of the structure and can experience a failure if this process is unstable. Fill slopes are common in embankment construction, if the foundation soil is saturated then positive pore water pressures are generated from the weight of the fill and the compaction process because of the weight of the fill and compaction process, the positive pore water pressures are generated. So the effective stress decreases and the construction consequently shear strength decreases.

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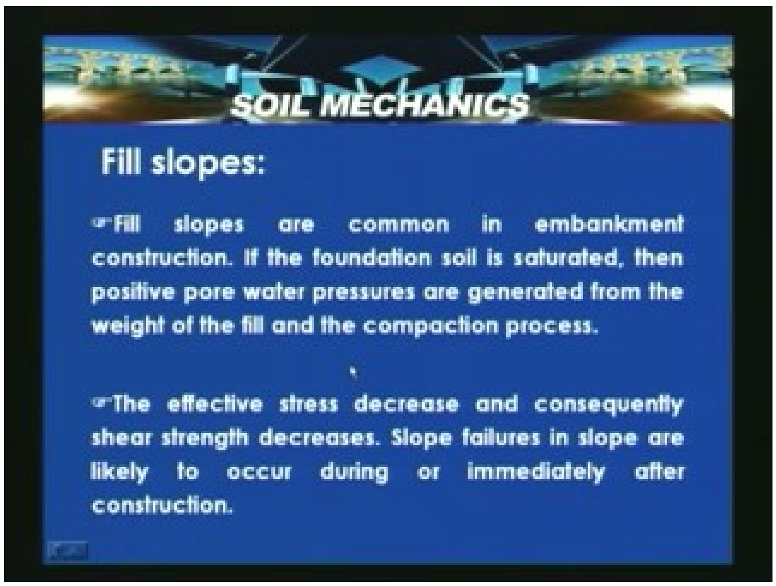

So the effective stresses decrease and consequently the shear strength decreases the slope failures in slopes are likely to occur during or immediately after construction. So we have seen different types of failures and causes of failures, let us now try to summarize this factors after gray and leiser 1982. These are factors that contribute to the high shear stress. The shear stresses are high that means these shear stresses can cause the disturbing shear stresses or disturbing forces. So with the disturbing forces are more then the stability of a particular slope is in danger, so what are the factors that can contribute to the higher shear stress.

So removal of lateral support that is erosion that is bank cutting by streams and rivers that we have seen, so that can actually create because of the erosion by streams and rivers can cause something like removal of lateral support and human agencies cuts canals pits etc can cause this particular failure and surcharge natural agencies like sometimes the slopes get deposited because of the weight of the snow, ice and rain water.

That is when the rain water get stored because of some reasons and weight of the snow thus when snowfall takes place when it is stored for a given duration so because of these natural events then the slopes can get surcharged.

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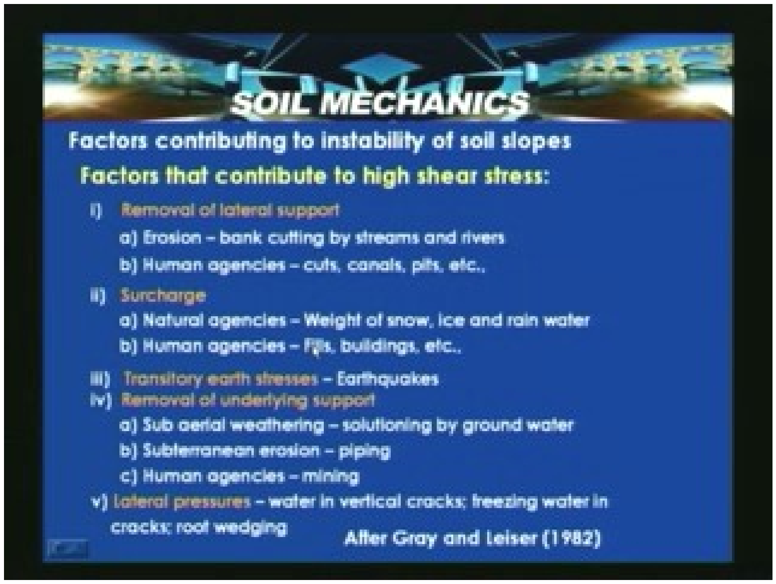

Similarly human agencies like construction of a fill on an existing slope or construction of a building on an natural slope or any particular slope can create or cause external loading to a slope and transitory earth pressures that is called earthquakes that we have discussed that can contribute to the higher shear stresses and causing failures to the slopes. Removal of the underlying support sub aerial weathering that is solutioning by ground water that is because of the ground water minerals and can cause sub aerial weathering and subterranean erosion that is called piping when the water which is flowing through the slope can cause a piping failure and can erode the soil.

Human agencies like mining can create removal of the underlying support factor, lateral pressure, water and vertical cracks freezing water in cracks and root wedging can contribute to a reduction in high that is contribute to higher shear stresses that is so the major factors if you summarize one is that removal of lateral support and surcharge transitory earth pressures and removal of the underlying support and lateral pressures these factors contribute to the higher shear stresses and ultimately they cause instability to a soil slope.

Having seen those factors let us see that what are the factors that contribute to the low shear strength. Ultimately they affect the instability of a slope, cause the instability to a soil slope. Initial state compositions inherent to the weak materials suppose if they are inherent weak materials the composition can cause and have low shear strength texture loose soils and meta stable grain structures which are like say honeycombed grain structure.

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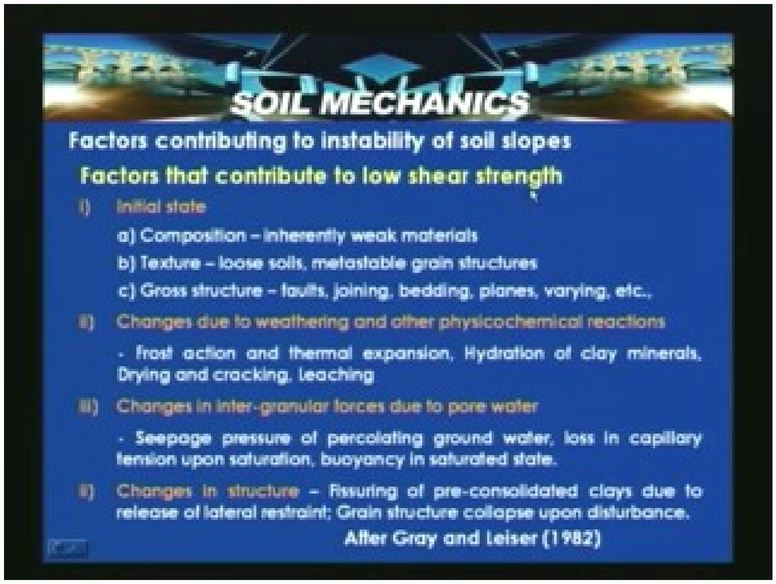

So these things can cause texture of a soil like loose soils and meta stable grain structures can contribute to the low shear strength and gross structure like faults jointing bedding planes varying etc this varying are a planes bedding and jointing and faults then these are the gross structures within the soil. Changes due to weathering and other physico chemical reactions; frost action and thermal expansion hydration of clay minerals and drying and cracking and leaching etc can cause and contribute to the low shear strength and changes in inter granular forces due to pore water pressure. Seepage pressure of peculating ground water losing capillary tension upon saturation buoyancy in saturated state.

So these particular factors can contribute to a low shear strength and another thing is that changes in structure like fissuring of pre consolidated clays due to release of lateral restraint grain structure collapse upon disturbance. So what we have seen is that factors that contribute to the low shear strength they are initial state particularly composition, texture and gross structure, halting and dipping and changes due to weathering and other physico chemical reactions, changes in inter granular forces due to pore water and changes in structure and these factors can contribute to the instability of a soil slope.

Now having same types of failure and causes of failure, we have to learn how this stability analysis of the slopes can be carried out. Basically this particular method which we are going to discuss can be adopted for existing slopes or to the slope which is due for construction like an embankment or a slope for a particular flyover or an approach embankment bund which is coming. So if you wanted to decide what is the safe slope and for that we need the knowledge about particular topic which we are going to discuss that is the slope stability analysis.

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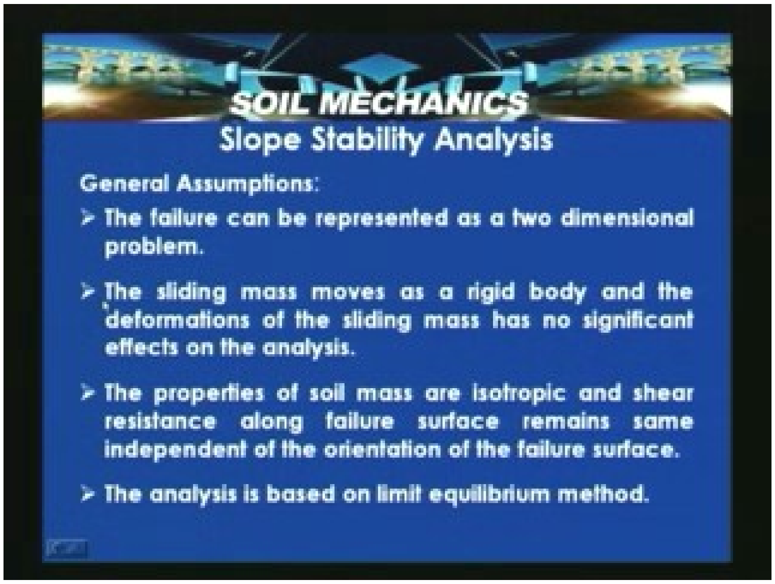

General assumption is that the failure can be represented in a two dimensional problem so here because like in earth pressures and these particular say a particular slope or say a canal bund or a cutting or railway cutting which runs over kilometers and we can considered this as a plane strain structure. What we do is that the one of the prime assumptions, even now today the three dimensional slope stability analysis are available but for a sake of understanding or the convenience the failure can be represented as a two dimensional problem. The sliding mass moves as a rigid body and the deformations of sliding mass has no significant effects on the analysis, so the sliding mass moves as a rigid body wherever it gets detached it assumes that the sliding moves as a rigid body and deformations of sliding mass has no significant effects on the analysis.

The properties of soil mass are isotropic and shear resistance along failure surface remains same independent of the orientation of the failure surface. So there can be a many orientations which are possible but the properties of soil mass are isotropic and the shear resistance along failure surface remains same independent of the orientation of the failure surface. The analysis is based on the limit equilibrium method and these are the general assumptions what we listed, the failure surface can be represented as a two dimensional problem and the sliding mass moves as a rigid body and the deformations of sliding mass has no significant effect on the analysis and the properties of soil mass are isotropic and shear resistance along the failure surface remains same independent of the orientation of the failure surface and the analysis is based on the limit equilibrium method.

So with these assumptions what we are trying to look into is that first we will try to see how the infinite slope stability analysis can be carried out and based on that we considered, we look in to the different infinite slope stability analysis methods. Once this is discussed then we can see how a finite slope can be analyzed.

Once finite slope can be analyzed then we will be in a position to arrive at a safe slope or if there is a existing slope and we can estimate whether the slope is in danger or whether is having a ridicuvate factor of safety against instability or not. So let us look into the infinite slope stability analysis method. In this the basic assumptions which are once again is highlighted, soil is homogeneous and the stress and soil properties of every vertical plane are identical, on any plane parallel to the slope stresses and soil properties are identical.

So in this case on the right hand side of this slide a drawing is shown where this is a rigid stratum or say assume that this is a rocky surface and then there is a soil and this portion from here to here z depth is the soil and inclination of this surface, slope surface is beta with horizontal and this surface is also assumed that is a beta with horizontal and consider a block say b of width horizontal distance is b and let us assume that this portion is assumed to, we are actually look into the stability of this particular block. Say let us assume that this is the failure surface and the failure surface is a planner surface parallel to the slope surface and this is the location of the water table and assume that the unit weight of the soil is identical above the water table and below the water table. So this z is the depth and h_w is the water depth in this direction which is shown here.

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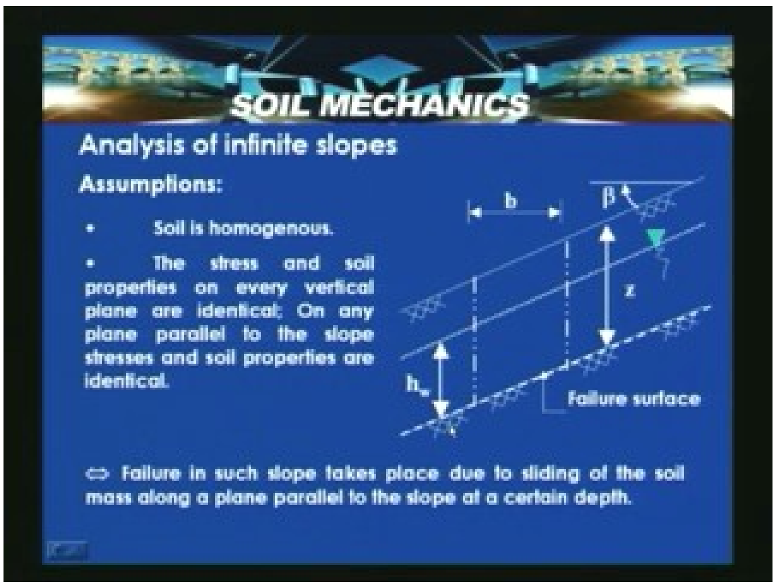

Please note this direction which is shown here that is with this particular distance from here to here this is h_w and from here to here this is z and b is the horizontal distance and beta is the slope inclination. So what it means this assumption is that the stress and soil properties on every vertical plane are identical, on any plane parallel to the slope stresses the soil properties are identical. So on any two vertical planes between a soil portion or between any two vertical planes can be considered, so on any plane parallel to the slope stresses and soil properties are identical; failure in such slope takes place due to sliding a soil mass along a plane parallel to the slope at a certain depth.

If this assumption is valid so then the failure takes place like a due to sliding of soil mass along a plane parallel to the slope at a certain depth. Having discussed now let us consider this block having A B C D is the block and z is the depth and B is the horizontal distance and beta is the inclination of the line BC with horizontal and tangential stress tow down the slope and normal stress sigma within the segment ultimately we determine but let us look how the weight of the block can be determined, weight of the segment A B C D is equal to gamma is the unit weight. We assume that the unit weight of the soil is identical above and below the water table, z is the depth and B is the horizontal and per meter width so this is the volume into unit weight that is the weight of the segment A B C D.

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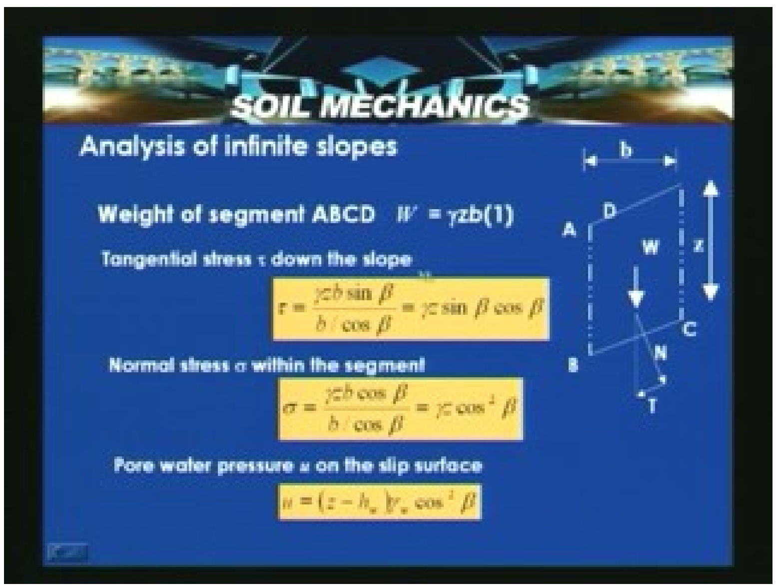

Now the tangential stress tow down the slope can be given by gamma z b sin beta that is weight that is t is equal to w sin beta that is which causes driving shear stresses and that is tow is equal to gamma z b sin beta acting over by this area is b by cos beta because this inclination is beta with horizontal. So after simplification this changes to gamma z sign beta cos beta. Normal stress sigma within the segment can be given as sigma is equal to gamma z cos beta that is this particular portion that normal force divided by b by cos beta that is this area. With that what we will get is that gamma z cos square beta is a normal stress sigma within the segment. So pore water pressure u on the slip surface that is along this surface u so this is h_w is this portion and z is the depth so pore water pressure u on the slip surface is given by z minus h_w into gamma_w cos square beta.

So analysis of infinite slopes we can write normal effective stress sigma dash is equal to total stress minus pore water pressure. Once we do what we get is that gamma z cos square beta that is total stress minus this pore water pressure we get gamma z minus gamma w_z plus gamma_w h_w cos square beta. Shear strength tow_f at the base of the segment that is at the base of the segment can be given as tow_f is equal to c dash plus sigma dash tan phi dash.

So c dash is the shear strength effective cohesive of a material and phi dash is the effective angle of internal friction, sigma dash is this effective stress. So substituting this what we get is the shear strength at the base of the… (Refer Slide Time: 46:27). So factor of safety as we know from the shear strength when we discuss, factor of safety can be defined as a available shear strength of material divided by shear stress that is factor of safety is equal to tow$_f$ by tow; tow$_f$ is available shear strength and divided by shear stress which is tow.

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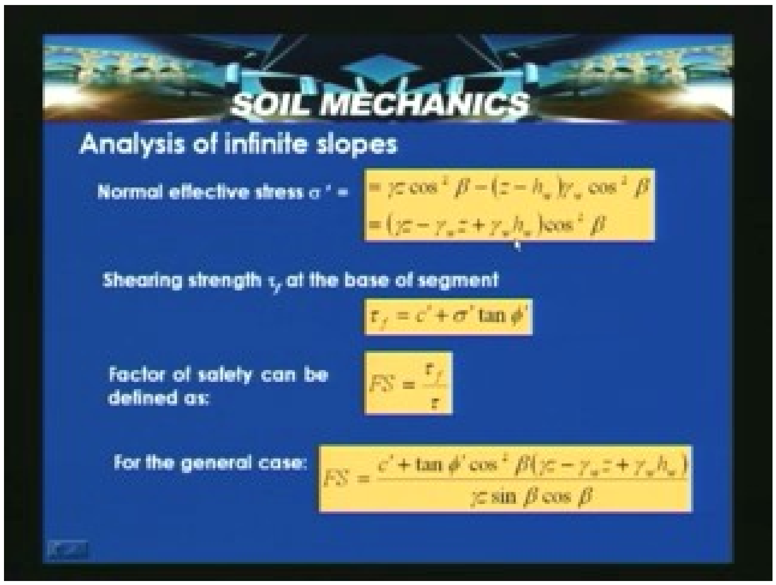

So substituting now for the general case we can write this expression were factor of safety as c dash plus tan phi dash into cos square beta into gamma z minus gamma w$_z$ plus gamma w h_w divided by gamma z sin beta cos beta which is the disturbing shear stress which we calculated in the previous slide. So with these we have got a generalized expression. Now we consider different special cases like let us consider in the analysis of infinite slopes, a case like we have a dry cohesion less soil where c dash is equal to zero and h_w is equal to z that is c dash is equal to zero and h_w is equal to z that means it is at the bottom of the failure surface or where there is a rock layer is there at the full depth from the top of the slope surface water table is there.

So in such situation when you substitute in this particular expression c dash is equal to zero and then there is z is equal to h_w then what we finally left out is that factor of safety is equal to tan phi dash by tan beta. So this indicates that the factor of safety of an infinite slope with cohesion less soil is independent of the depth of the failure plane. So factor of safety is equal to tan phi dash by tan beta so factor of safety of infinite slope with cohesion less soil is independent of the depth of the failure plane.

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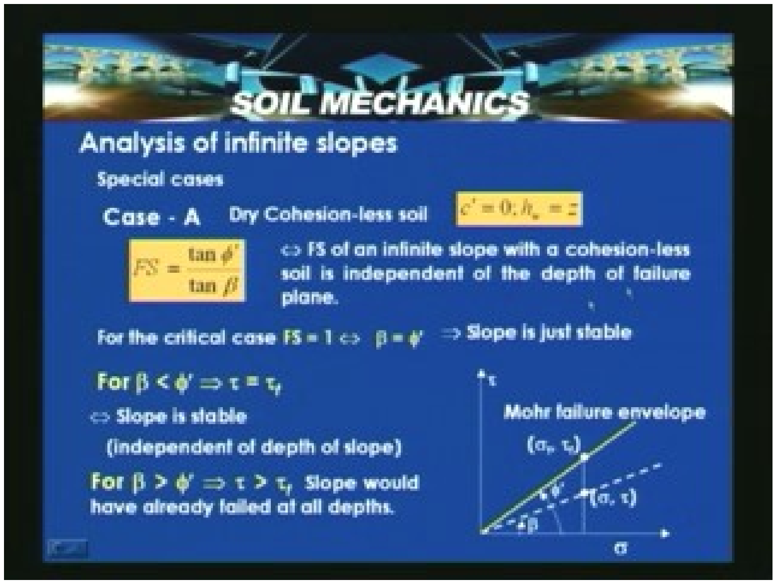

So for the critical case the factor of safety is equal to one, beta is equal to phi dash the slope is just stable. That indicates the slope is just stable. So this is a classical example for angle of repose suppose if we wanted to form a dry sand heap then you will not able to make a slope steeper than it's angle of repose. So this is nothing but factor of safety is equal to tan phi dash by tan b dash or a classical example which can be sited here is formation of sand dunes. Of course it varies from the windward direction and lever direction and all but the one governed here is that the tan phi dash by tan beta were phi dash is the angle of internal friction of the material and beta is the inclination of the slope surface. So what we can say that factor of safety of infinite slope with cohesion less soil is independent of the depth of the failure plane. For the critical case, factor of safety is equal to one that is beta is equal to phi dash the slope is just stable for beta less than phi dash. So let us now plot this particular situation on a tow versus sigma that is in a Mohr circle tow versus sigma plot.

Let us assume that this yellow line indicates the Mohr failure envelope and this white broken line indicates the slope surface. Thus beta is the inclination which is shown here, this phi dash is the slope surface; this is the angle of internal friction that is phi dash. So now if you look at a certain depth then let us assume that this particular point the coordinates are sigma and tow and this point is sigma$_f$ and tow$_f$. So for beta less than phi dash, tow is less than tow$_f$, the slope is stable independent of the depth of the slope. For beta greater than phi dash, tow is greater than tow$_f$ the slope would have already failed at all depths, it indicates that the slope would have already failed at all depths. So in this particular lecture we try to introduce a subject called stability analysis of slopes which is very interesting part in geotechnical engineering.

Particularly in the analysis of soil slopes for understanding about arriving at a safe factor of safety for a structure under conditions like with rainfall and with earthquake and other external loading conditions and then we looked into the types of failure and types of slope failures and causes of slope failures and we summarized the factors which can contribute to the reduced shear strength which can also contribute for the factors which can cause instability to a soil slope. We looked into an analysis for an infinite slope stability analysis and we have actually derived a generalized expression and that expression has given as how we can analyze an infinite slope. So these infinite slopes can even can be natural or sometimes a man made because of like waste heaps or over stacks which are formed and so these can be can be analyzed.

So a case where case A what we discussed is called dry cohesion less soil and we said that factor of safety of infinite slope with a cohesion less soil is independent of the depth of the failure plane. So here we have derived factor of safety is equal to tan phi dash by tan beta so which is a classical example for a sand dune or a classical angle of repose which we, suppose if we wanted to form a steep sand heap that can ever be formed, we observe that always the slopes gets adjusted and reaches to that angle beta is equal to phi dash.