Engineering Geology
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Lecture - 35
Geologic Hazards - Shoreline Processes and Landslides

Hello everyone and welcome back. Today, we are going to finish the unfinished discussions that we left in the last lesson, and then we are going to move ahead with geologic hazards related to landslides.

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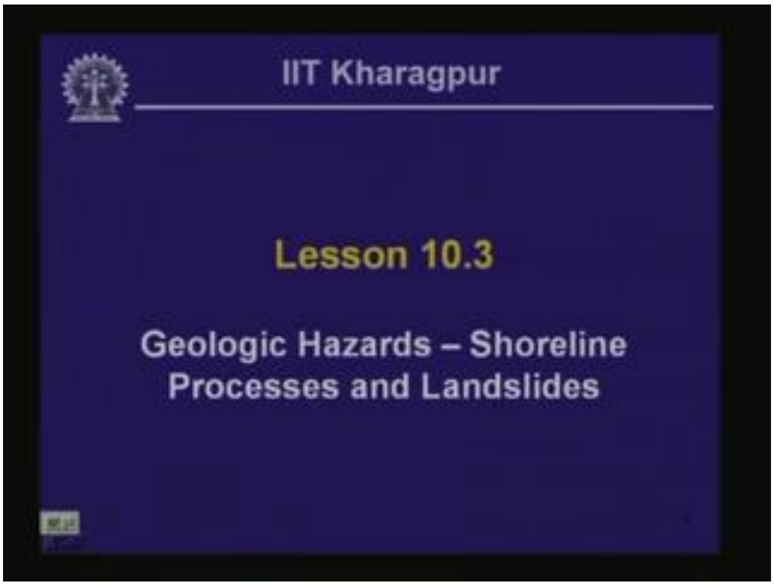

So, first of all we are going to talk about geologic hazards related to shoreline processes which were really an unfinished business from the last lesson, and then we are going to move ahead with new topic, okay.

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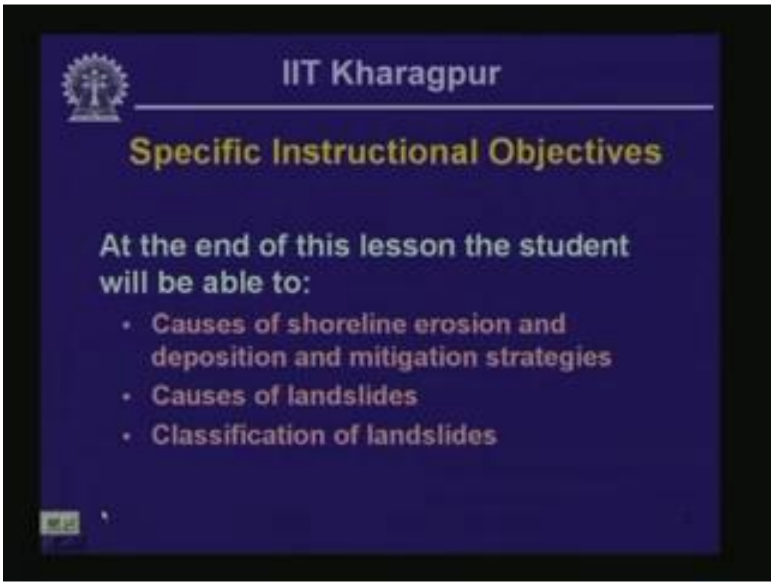

So, instructional objectives of this particular lesson are as follows. St the end of this lesson, we would like to be able to list the causes of shoreline erosion and deposition and the relevant mitigation strategies that are used to go around these problems. Then we are going to look at the causes of landslides. And we are going to wrap this lesson up with classification of landslides. So, these are the topics that we are going to cover in this particular lesson.

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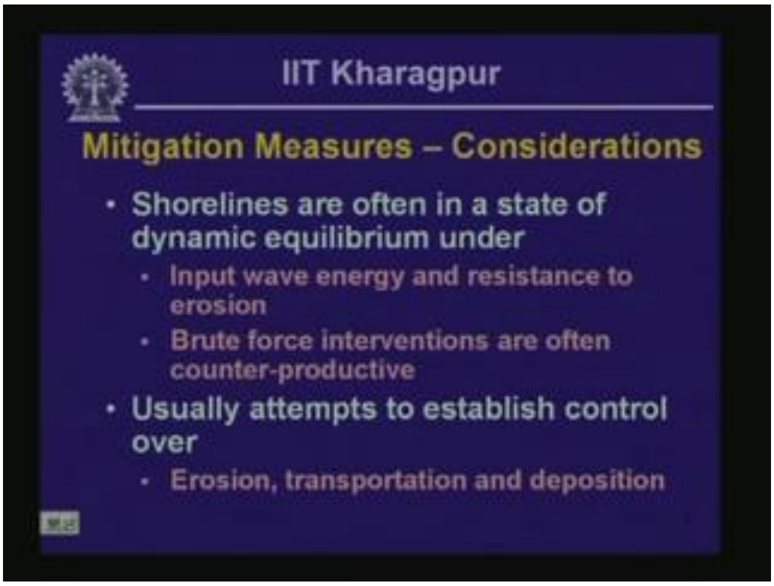

And now getting back to the discussion that we left unfinished in the last lesson; we were looking at mitigation measures against shoreline processes. So, essentially what we were looking for we were looking at the erosion and deposition due to wave actions really and here our concern is to look at the mitigation processes that are required to go around these problems. Now in order to identify a proper mitigation measure, you need to have a few considerations, and these are extremely important.

What you need to realize is that shorelines are often in a state of dynamic equilibrium under the input wave energy and resistance to erosion. So, what it means is that if you alter the balance between the input energy and the resistance to erosion, then the system is going to try to regain the balance by some means, and if the alteration is too much. In other words if you disturb the balance between the input wave energy and the resistance to erosion by too much, then the balance will be disturbed by quite a significant margin. And as result, the detrimental effect of that unbalanced situation is going to be visible at some location may be other than the location where the mitigation measure is is undertaken.

So, what we have to ensure during identification of these mitigation measures is that we want to actually disturb the balance by as little as possible. So, that is really the second point under the first main point which is brute force interventions is often counterproductive. That means you need to realize that if you disturb the balance between input energy and the resistance to erosion by too much, then the effect may be detrimental; although, the detrimental effect will not be visible at the location where the intervention is being completed, but the bad effects are going to be felt probably elsewhere in that area.

Second point to consider is that we need to really establish a control in the usual scenario over erosion, transportation and deposition under the different types of waves that are going to affect the coastal area namely the onshore current which are the waves that are directed towards the shoreline offshore currents. These are the waves that are directed away from the shoreline. And long shore currents which are the waves that move parallel to the direction of the shoreline. So, erosion accordingly is going to take place under the action of each one of these waves.

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So, we have to look for mitigation measures depending on which type of wave action is prevailing. So, here are the details, long shore erosion and deposition. This type of erosion and deposition process affects navigation channels, and this is quite obvious if you consider a sketch.

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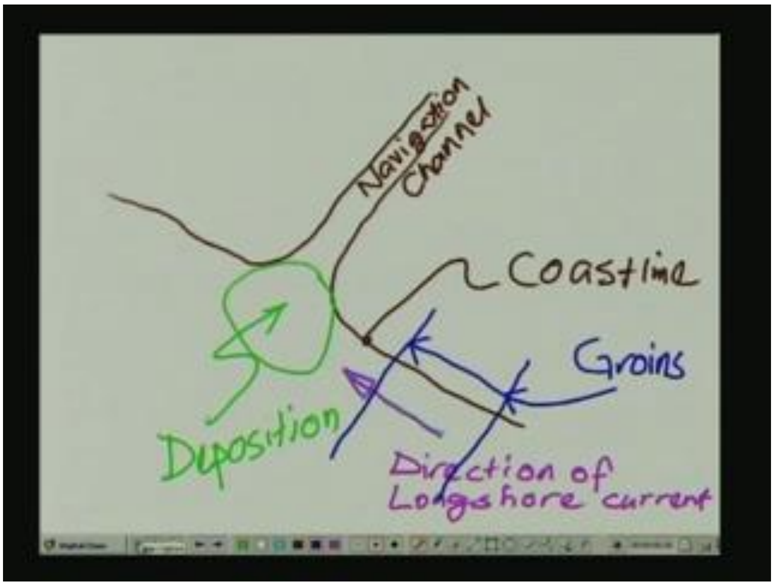

Let us say you have got a navigation channel that goes inland into a harbor, and this is our coastline where the long shore current is directed in this manner. And if this particular current deposits sediments at the mouth of the channel, this is the navigation channel that we were looking at. By the way this particular sketch I am showing a plan view of a harbor work. So, this our navigation channel, and this is the direction of long shore current. So, this one here is the direction of long shore current.

And this is the location where the main deposition is taking place under the long shore current which is our interest, because this is the area which is going to affect the draft necessary for movement of different water vessels different vessels that would like to utilize this particular harbor. So, what we do in this case? Typically, you need to have a control over the long shore deposition process, and typically, what is done here is a series of groins are constructed in this manner. So, groins are essentially wall like protrusions almost perpendicular to the coastline.

So, this is our coastline if you recall; this one is our coastline. So, we install a series of groins so called groins to control the long shore current and the deposition near the mouth of the navigation channel. So, this is one of the intervention scheme as we are going to see in the next little bit, and onshore and jetties are also similar structures to groins basically. So, they really cut down the long shore current velocities or wave action near the mouth of a navigate navigation channel.

Now onshore and offshore erosion and deposition, this actually takes place under the action of onshore and offshore currents. And they really reshape coastlines if the main environment in a particular area is erosional. So, the coastline is going to recede landward, whereas if the area is a depositional environment, then the coastline is going to move further towards the water. Now in order to control the movement of the coastline, typical measures include bulkheads, revetments, boulder pitching and rubble mound seawalls. Let us look at these measures. So, here we are looking at a few cross sections.

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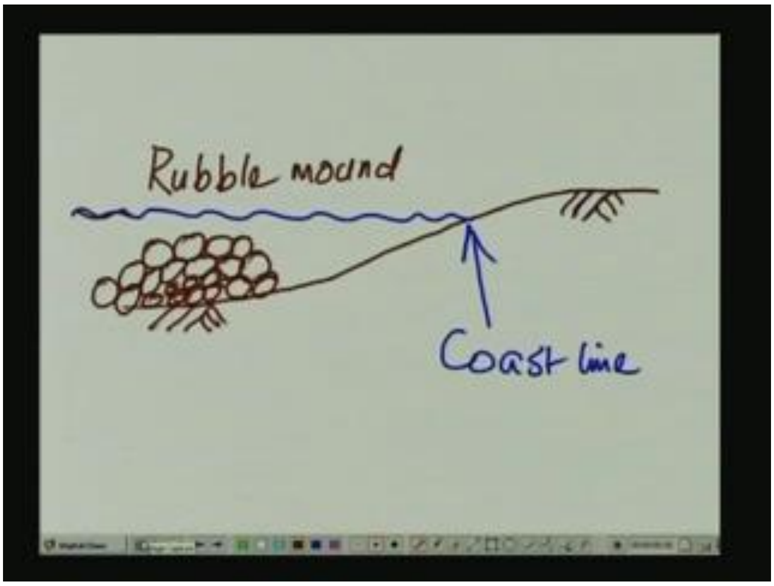

So, basically boulder pitched seawall is a trapezoidal wall constructed little bit offshore, and they have got heavy boulders at the surface and little bit finer ones within the core areas. So, this is the typical details of a rubble mound, and the water is like this. So, this is our coast line then. And here as I mentioned, we are looking at the cross section of the coastal area. This is a typical rubble mound. And then we have got other measures such as bulkheads revetments; bulkheads and revetments let us look at what are those.

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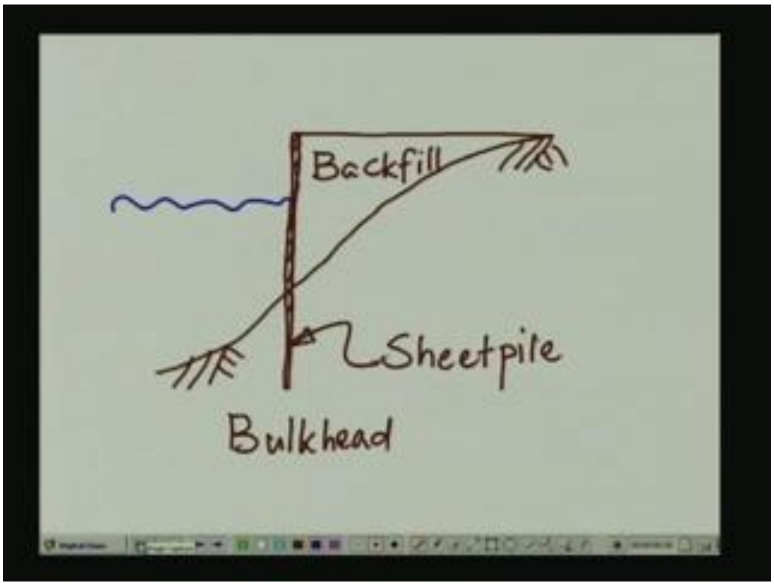

So, in a incase of a bulkhead if this is a coastline, what you are going to have is to install a barrier which may be comprised of a sheet pile wall such as the one that we looked at some time back when we are talking about groundwater. And then behind the wall, you construct a backfill; you backfill this area behind the wall, and this is basically a shore line stabilization measure. So, this one here is called a bulkhead. This is not visibly very appealing, because at the shore line, you are going to see the face of the sheet pile wall or any such wall that you might actually construct along the water front. So, in this case, the water is going to be like this, and the coast line is going to be reshaped like that. And the other measure was that of boulder pitching that is also carried out quite often.

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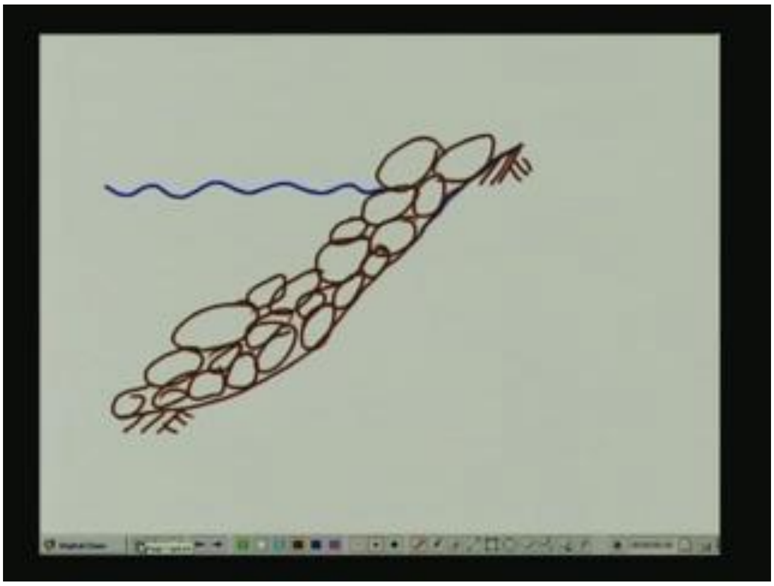

In this particular case, what you do is the shoreline, the water front, the face of the soil slope typically is pitched with heavy boulders up to the height where the wave action is going to be felt in this manner. So, since the boulders are too heavy for the water wave to erode, as a result erosional areas of a coastline can be stabilized in this manner. And instead of boulders, sometimes special concrete blocks which are specially which are structurally erosion resistant, they are also sometimes used. So, this is the other means of controlling onshore and offshore erosion and deposition, alright.

Now we move on to our new topic, because we are now at an end of the discussion that we were having about wave action. We are now going to move ahead with the discussion on landslides, or first of all we are going to look at the different types of landslides and the causes of those landslides. And in the following lesson, we are going to look at the mitigation processes that are normally utilized in order to minimize the landslide hazards or mitigate or minimize the risk related to landslide hazard.

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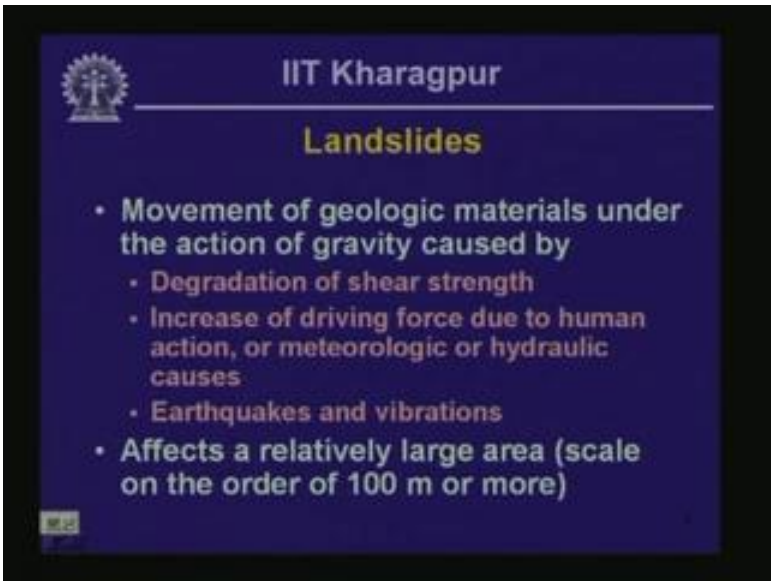

Now what is landslide? That is the first question that comes to mind. So, landslide really is movement of geologic materials such as soil, rock or mixture of those under the action of gravity. And such movement can be caused by degradation of shear strength, increase of driving force due to human action or meteorologic or hydraulic causes or because of earthquakes and vibrations. Now landslides I am going to actually distinguish landslides, although some other researches may not agree on in this matter with me, but I am going to say landslides are those slope instabilities which affect a relatively larger area.

Typically, we are looking at a few hundred meter area as if bare minimum in order to classify that particular mass wasting process as a landslide. And slope stability on the other hand is basically of a smaller scale; although, you may say that both slope stability and landslide from mechanistic point of view or from engineering perspective, they are often handled in the same manner by engineers, okay.

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So, those are the definition part; that was the definition part of landslide. Now we look at the types of landslide. There are several different ways in which you could classify landslides. The first mode of classification uses whether the landslide is structurally controlled or not or whether the process is taking place through pre-existing planes of weaknesses such as if the movement is taking place along pre-existing joint set, then we are going to call that particular landslide as a structurally controlled landslide.

Now there are three types here. One is called consequent landslide. Here the landslide is structurally controlled or the landslide could be asequent or insequent. An asequent landslide is essentially a slope instability that arises in massive formations which does not have any joints or cracks. And insequent landslide is a process that takes place in blocks which could be jointed or cracked, but the instability or the surface through which the instability is taking place actually cuts across those joints. So, that type is called insequent landslide. Let us look at what are these things.

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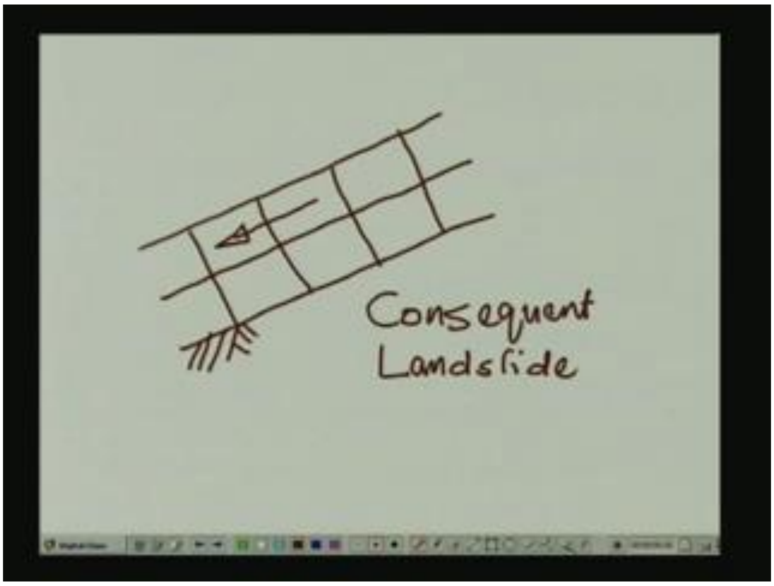

So, let us say you have got a slope where there are joint sets like this. This is a schematic picture of a cross section run through a particular slope, and the material underneath this jointed rock is massive and quite stable. And if this rock slides down slope in this manner, then this particular landslide is going to be called a consequent landslide, okay. So, then let us go and look at the other extreme.

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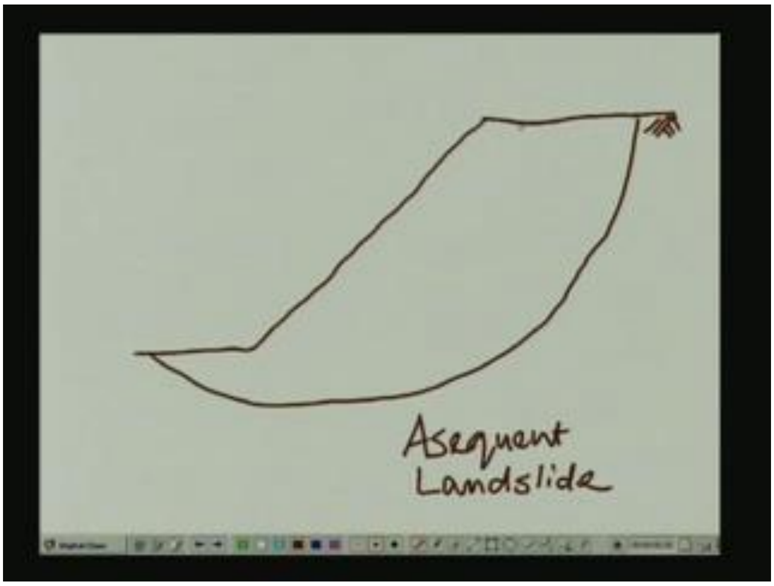

In this case, let us consider a slope in clay where there are no cracks or lenses or soft lenses or weak lenses through which the landslide can progress; it is a deposit of massive clay. In this case, often what happens? The failure surface takes the shape of a circle, and this type of landslide is going to be called an asequent landslide.

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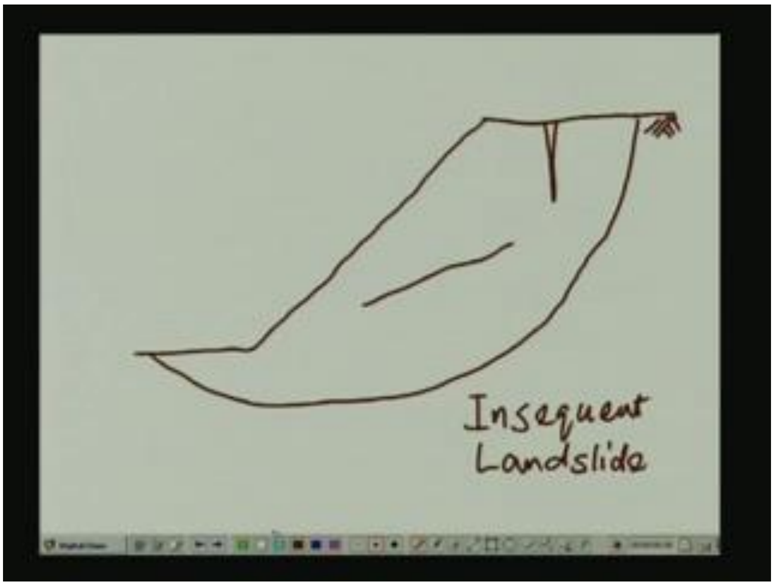

An insequent landslide is one where there could be cracks in clay like this. Let us say there is a crack in clay, and there is a slicken side like this, but still the failure is taking place not through these planes of weaknesses but across or away from these planes of weaknesses. Then this type of landslide is going to be called insequent landslide. So, three types then based on whether the landslide is structurally controlled or not. If it is not structurally controlled, the landslide could be the asequent or insequent. And if it is structurally controlled, then it is going to be called consequent landslide.

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There are other types of classification as we are going to see here. We are going to call a landslide an active landslide if we have got recent movement; it is going to be called a dormant landslide where at the present time there is no movement, but if the area is is likely to be destabilized, then that is going to trigger a movement. That type of landslide is called a dormant landslide. And inactive landslide is basically a pre-existing landslide that has moved so much that at the present time or in the present geometry, the landslide has stabilized.

So, active landslide, what are the indicators of an active landslide? Let us say it could be if it is due to a recent fast movement, then you are not going to find any vegetation on the slope face. If it is a young active landslide which is also a fast moving one, then there would be young trees and shrubs. And if there is a slow moving slide ongoing slow moving sliding, then the trees are going to be a tilted because of the movement. And some of the trees might even have a bent trunk, because the movement is too slow, or it might have been stabilized at some point.

Then another indicator of an active landslide is that the scarp because of landslide is going to be visible. Now you should recall the definitions of these different terminology that we are using here from the lessons that we had quite a few lessons ago we discussed about these terms. So, in order to jog your memory a little bit what is meant by a scarp is this.

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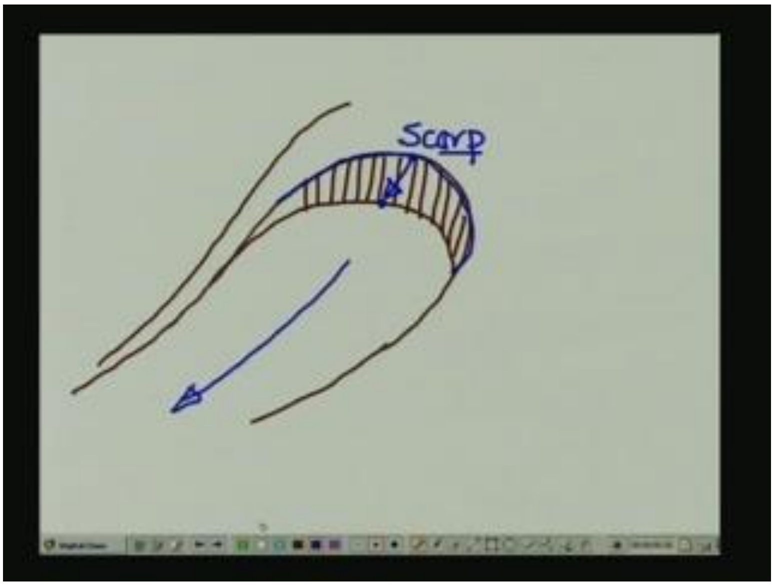

And let us say you have got a landslide that is taking place like this. The slope has moved downward; the material has moved downward leaving a relatively steep surface behind. This particular movement began from this location. So, this is the direction of movement, and the landslide has moved in this manner. So, this particular line here if you recall, in this particular drawing trying to draw an isometric view of the slope. So, this particular surface or this particular line is called the scarp of the landslide if you recall from the discussion that we had some time back.

In case of an active landslide, the time available for erosional processes to obliterate the presence of this particular scarp has caused this scarp to be visible on the map, and from visible scarps failure scarps, often presence of an active landslide is inferred. Now comes the dormant landslide which is somewhere in between the other two extremes active and inactive.

In case of a dormant landslide, there are going to be some vegetation growth, and this growth could be as much as the vegetation growth in the area not affected by landslide around the landslide, and in this case, the scarp which was there in the beginning that might have been obliterated by the erosional process. So, the scarp may or may not be visible on the geologic map or geomorphologic map. Then comes inactive landslide. This particular type of landslide, they are going to be very little visible sign at the surface and often an inactive landslide is identifiable only from a very detailed and careful subsurface exploration.

And actually speaking, inactive landslide is not of a great engineering interest, because they have already stabilized. So, they are not going to be of any consequence in the construction in and around that particular area.

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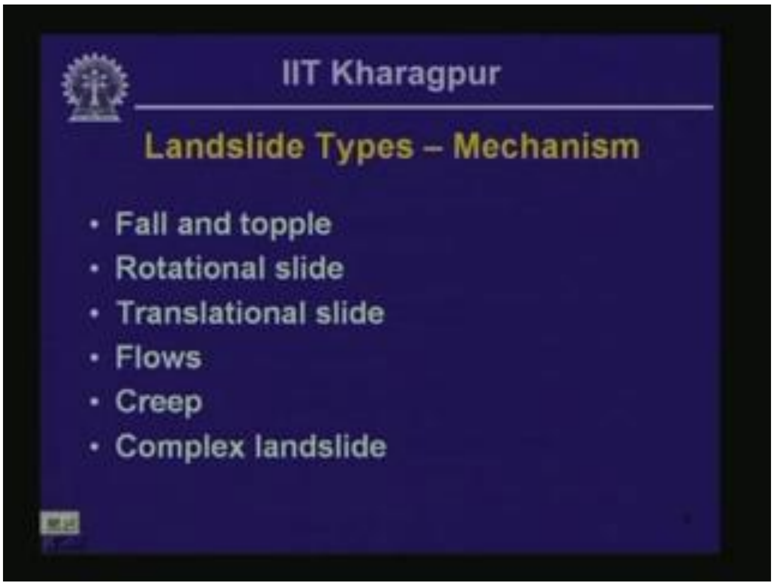

Then there could be other types of landslide classification, and this typing adhere looks at the mechanism that triggers the landslide. So, landslide could be classified as a fall or a topple. There could be a rotational slide. There could be a translational slide. Then there could be flows, creep and complex landslide. A complex landslide is really a combination of more than one of the types that precedes in the list, okay. So, let us look at what are these things one by one.

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Fall and topple, what it means is that it involves free fall or toppling of rock mass; usually, this involves weathered or jointed rock mass. This type of landslide could be extremely fast, and this is triggered because of pre-existing joints undermining frost wedging, crack propagation, vibration and tumbling of perched rock or erratics. We are going to look at each of these things one by one, and some of them are explained in the cartoons that are going to come now.

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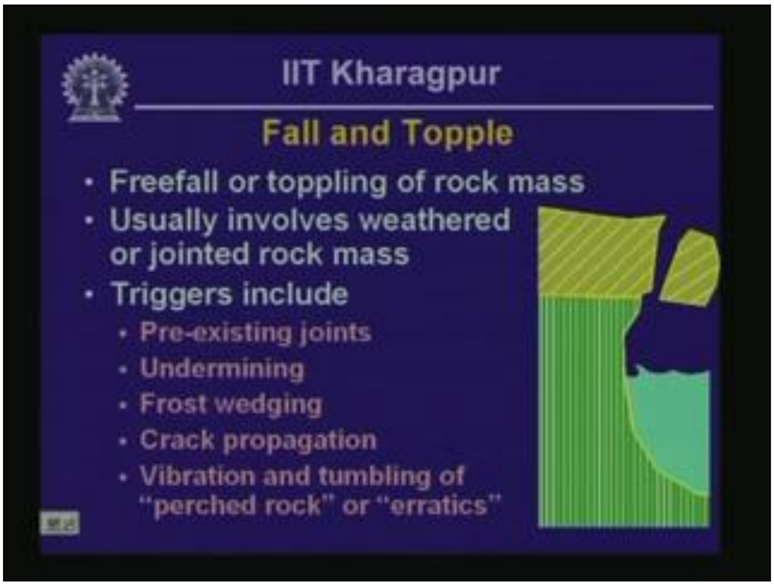

So, this one here shows a section of a water front where the water is on the right hand side of this particular cross section. And what is here is that at the surface, you have got erosion resistant rock such as sandstone or compact limestone. And underneath the erosion resistant rock, there is a softer variety which is exposed to the wave action of the water, and it is erodible as a result. And because of that, what has happened? It is the water has eaten into the softer bed bedrock underlying the surface rock which is more resistant to weathering and erosion.

And this process continues until the the protruding slab of the surface rocks can no longer resist its weight, and in that process at that instance, this slab is likely to break off, and this mechanism is going to initiate a rock fall.

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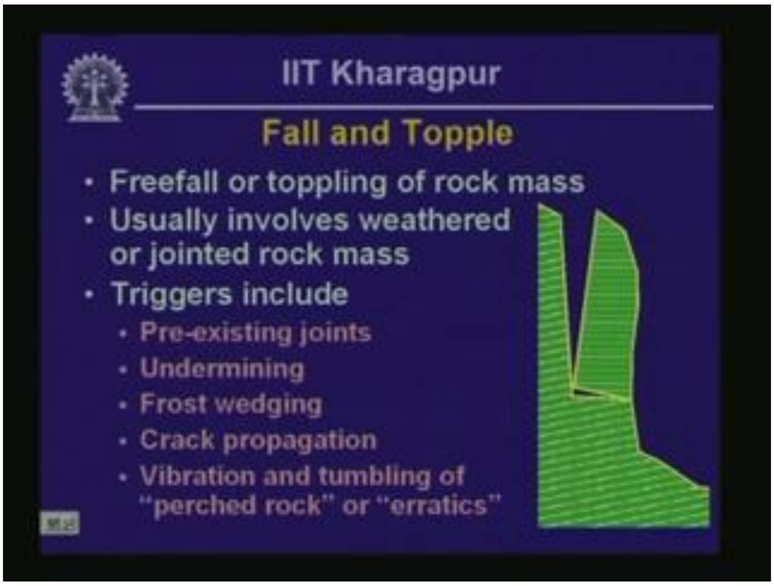

Then we have got fall; we have got this particular section this particular cartoon actually illustrates the process of toppling. What has happened here is cracking of bedrock near the top of the slope as is seen here. And what could happen is water could enter into the cracks there, and that water pressure could destabilize the rock at the top corner of the slope in this particular case. And also what could happen in addition to it is the water that has entered into the crack near the surface of the bedrock near the top surface of the steep slope, it might actually get frozen become frozen during winter time.

And because of the fact that frozen water has got a larger volume than the original water that infiltrated into the crack; that expansion volume could exert lateral pressure. And that pressure could also destabilize the rock, and in the process, the rock could tumble down the slope. During the fall, it is going to break into small pieces, and this is one of the processes which is responsible for the development of talus slope on very steep rock faces in many arid areas arid regions of the world, okay.

So, this particular process is called toppling. We need to look at the explanation of a few other things. So, frost wedging is already explained, undermining and pre-existing joints; these are the processes which is illustrated in the previous case where we considered the erosion related undermining of the softer rock layer underneath the sufficial more compact and strong and weathering resistant rock where we were illustrating rock fall. What needs to be explained here is really the definition of perched rock and erratics before I move on to the next slide.

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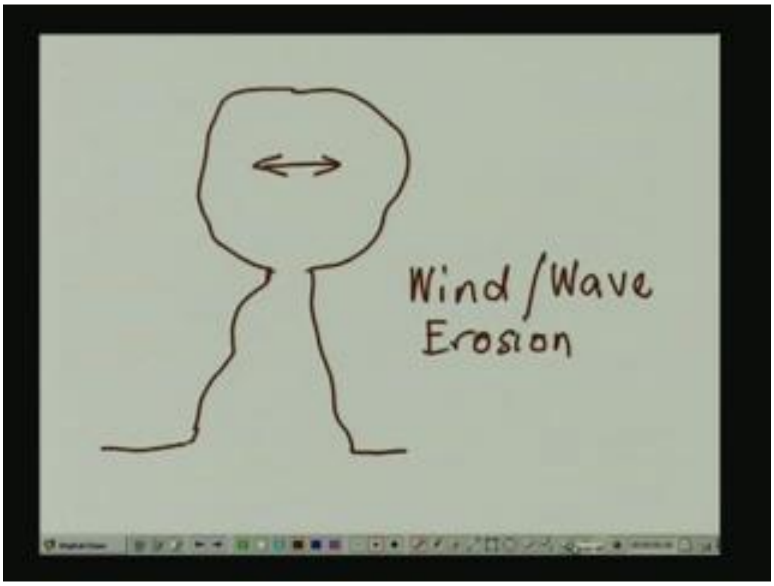

So, perched rock really is a precariously balanced huge huge piece of rock huge mass of rock at the surface of another formation. So, this one could be a perched rock and such type of weathering formation could be because of wind or wave erosions. And this heavy perched rock is easily destabilized during an earthquake involving transient lateral movement. So, that back and forth, shaking in that direction actually could dislodge that huge piece of rock near the head of the column. So, that is one way of of triggering rock fall.

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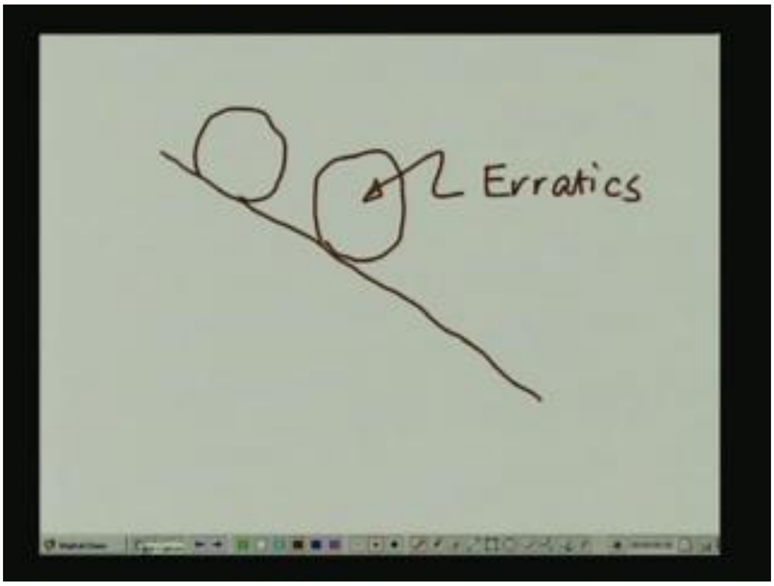

And another more common way is when a slope overlain by erratics is destabilized because of, say, vibration due to earthquake. So, these are called erratics. What are erratic? Really they are huge boulders deposited on the slope when glacial advance ice advance was taking place through the slope and ice melted. And in the process, these huge boulders which were being carried by the ice, they might get deposited on a slope face. So, these types of rocks are also precariously balanced. These slopes are typically very gentle, but they are steep enough to cause the rock to tumble down slope in the event of a disturbance such as those caused by an earthquake. So, these are called erratic, alright.

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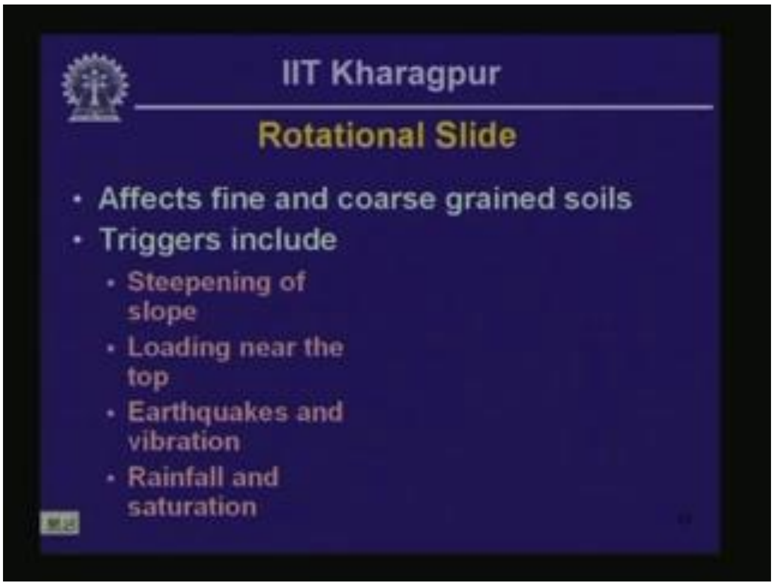

Rotational landslide, these types of landslide typically affect fine or coarse grain soils not so much; they do not occur so much in rocks. They are triggered because of steepening of slope, loading near the top, earthquakes and vibrations, and rainfall and saturation. How these mechanisms cause the landslide to get initiated. We are going to look at that in the next little bit, but before that lets look at the features of rotational landslide.

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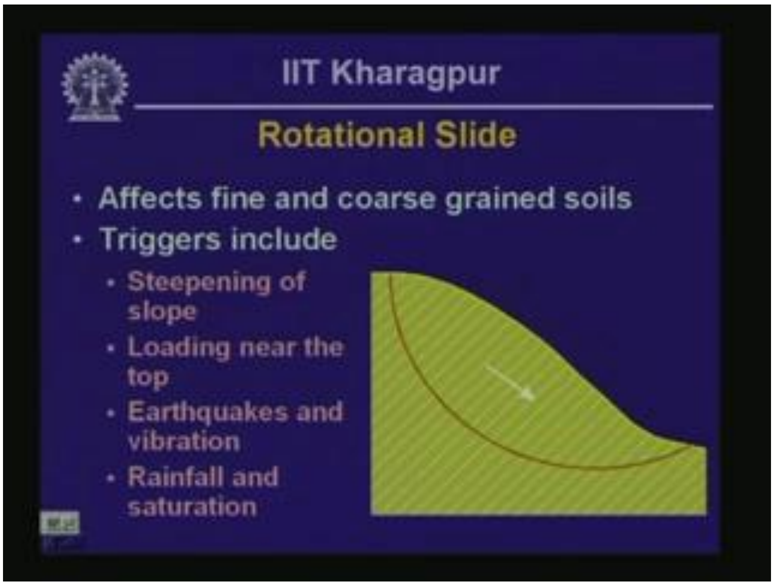

So, this is really a rotational landslide in which we are looking at a cross section of a slope underlain by relatively homogenous soil or rock. In this case in many cases, the slope failure it is going to have a circular failure surface as is indicated by the orange line there. And the mass of soil or rock above that particular circle is going to start tumbling down slope.

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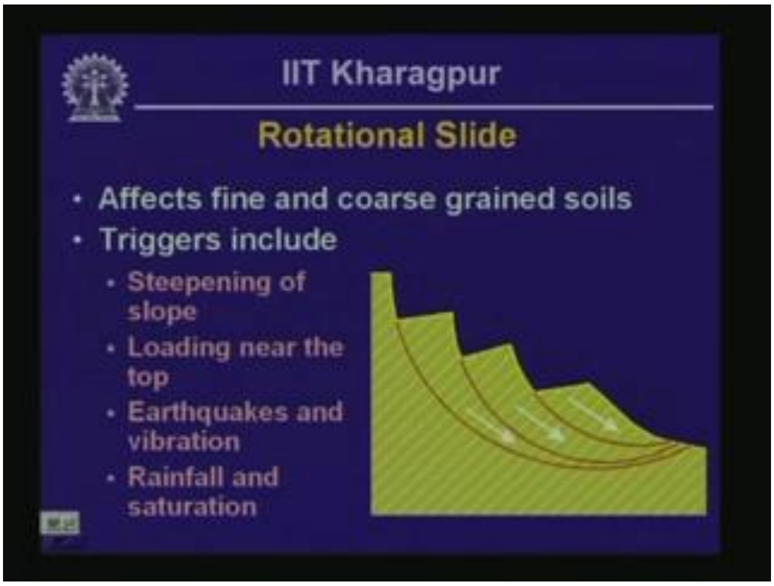

Or there could be in the process of tumbling down, the block could breakdown, and there could be in the process, a progressive or retrogressive failure taking place because of the breaking action. Typically, what happens? These slopes are most unstable near the bottom of the slope. So, a small failure is triggered near the bottom of the slope, and this particular failure leads to the slumping of a small mass near the toe of the slope. And it leaves a small failure scarp if you will near the bottom portion of the slope.

And as you recall from the discussion that we had before, failure scarp is really a very steep face of soil or rock, and since the face is steep, it is going to be relatively unstable. And because of that instability, another failure is going to be triggered this time from a little bit further back along the slope or further up along the slope. And in that manner, the slope failure is going to be progress backward, and eventually, a relatively much larger mass is going to be involved in the failure. So, let us look at the triggering mechanisms that could lead to this type of failure.

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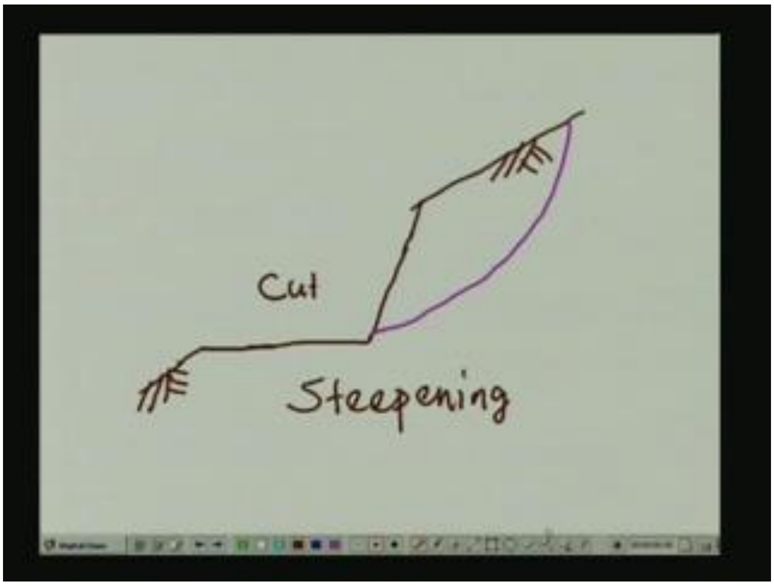

First, we talked about steepening of slope. So, let us say you have got a hill slope which is of this geometry. If for some reason we excavate a steep slope on the face of the natural hill slope and remove the rock like this, then because of this steepening, you can easily see that the portion of the slope out here; in this portion, this area is likely to be affected by slope in still potential slope instability because of the steep cut that has been installed in this particular construction. So, that is steepening.

Here again, we are looking at a cross section of the slope. So, this was the original hill slope, and this here is the cut. Some time back we looked at the stability issues associated with this type of cut which could be constructed in the first place to accommodate a hill road for that matter.

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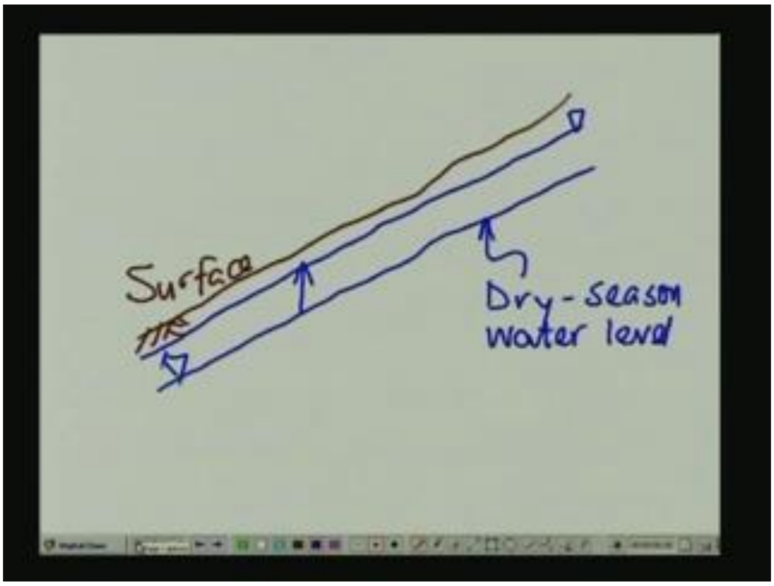

Okay, then there could be a situation in which a slope that is otherwise stable during dry season, because the water table underneath the slope occurs at a depth like this and let us say during the rainy season. So, this is the dry season water level. Now if for some reasons, the water table goes to a shallower depth, and this one is our slope face surface, then what happens? If you recall from the lessons that we had before that the effective stress within a soil element at some depth is going to decrease when the water table goes up in this fashion.

And because of the decrease in effective stress, the frictional strength of the soil is also going to decrease. And this event could actually if the decrease in soil strength is quite enormous quite large, in that case this particular process of of raising a water table is going to cause the slope to get destabilized. So, this is how a slope could get destabilized during rainy season or during wet season.

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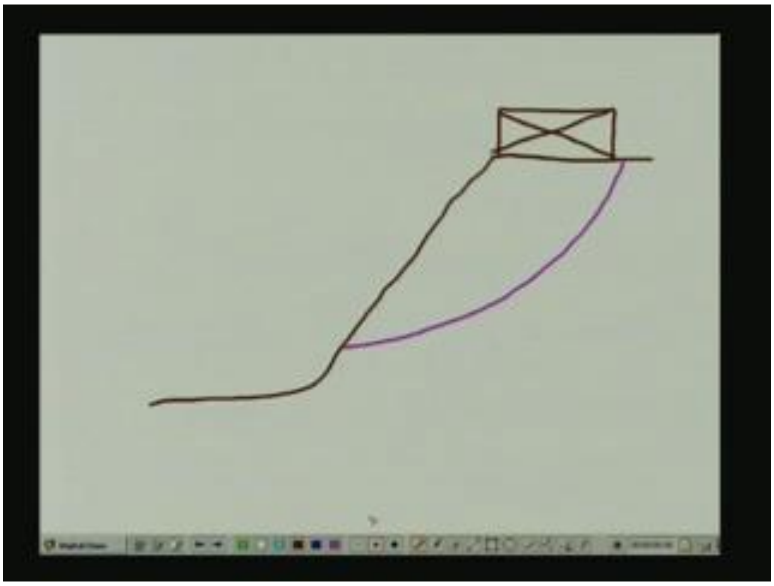

And then there could be other causes like there is a pre-existing stable slope, and we construct a very heavy structure near the top of the slope. And this also is going to increase the destabilizing force, and this in turn could lead into a failure in this manner. There could be another reason. Let us say a slope which is stable it is afforested. The slope face has got a lot of vegetation on it, and because of some reason, the vegetation is it has died out or it has been removed because of some human action or because of natural wildfire or other reasons.

Then what happens? The binding power that strengthens the near surface soil because of root penetration and because of the suction that the root actually enforces within the near surface of soils; these two reasons are going to going to lead to the destabilization of the slope in the event of loss of vegetation from the face of the slope. So, that is the reason why in many situations if there is deforestation following deforestation in the hilly areas the instance of landslide also increases quite substantially. Actually these triggers could also affect the other types of slides that we are going to see in the next little bit.

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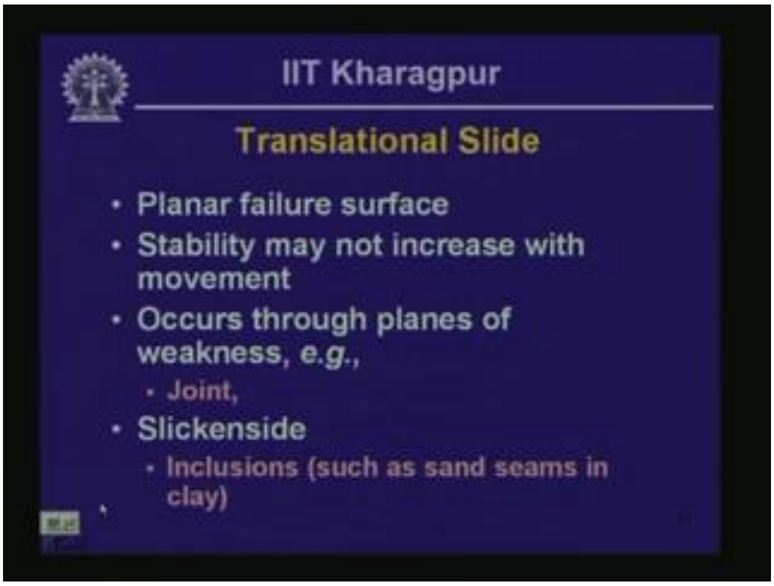

The next one that we are going to consider is a translational slide. In case of rotational slide, the movement was movement of the unstable soil or rock mass was rotational, but in case of translational slide, the movement is really translational as the name suggests. And there is an essential difference actually between translational slides and rotational slides; in that incase of rotational slide, normally what happens? As the movement progresses, the slope surface become less and less steep, and as a result, stability increases as the movement progresses.

But in case of translational slide, stability does not increase with the movement because the slope remains quite as steep as it began with. Typically, translational slide occurs through planes of weaknesses such as joints or slickenside; at many occasions translational slide is triggered through planes of weaknesses such as joints, slickenside and inclusions such as sand seams in clay.

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Trigger and types of translational slide, how translational slides could be triggered? They could be due to pore or pressure increase or steepening or increase of driving force because of a construction near the top of the failure surface or because of loss of vegetation as we looked when we are considering the rotational slides. Now types of translational slides include block slide, slab slide or multiple slab slide. What are these? We are going to come to that in the next little bit.

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This is an illustration cross section really of the illustrating the process of block sliding. So, here what you see is pieces of rock, they are mobilized down slope near the slope face. This type of slide is called block slide.

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Slab slide on the other hand is like this. And there could be multiple slab slide where during sliding the slab that is sliding down slope that breaks apart in small pieces. So, these are the different types of translational slides.

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There is another class of landslide which is called a flow slide. In this particular case, material flows like a viscous fluid. So, called it moves just like a liquid but which has got some viscosity. The movement could be slow in some type of flow slide where the movement is because the fact that the material has come to near failure and the material is strain hardening. In that case the movement is very slow, but typically, this type of the flow slides are very fast and far reaching if the material starts to soften progressively as the movement takes place.

In this case, you could reach a velocity of between 15 to 60 kph, and this type of flow slide could reach several kilometers down slope. And one such type of flow slide, we have already looked at when we were talking about volcanic hazards, and we were considering the hazard due to pyroclastic flow. So, pyroclastic flow is a fast down slope movement of this category. Now before we move on, let me explain actually what is meant by strain softening and strain hardening.

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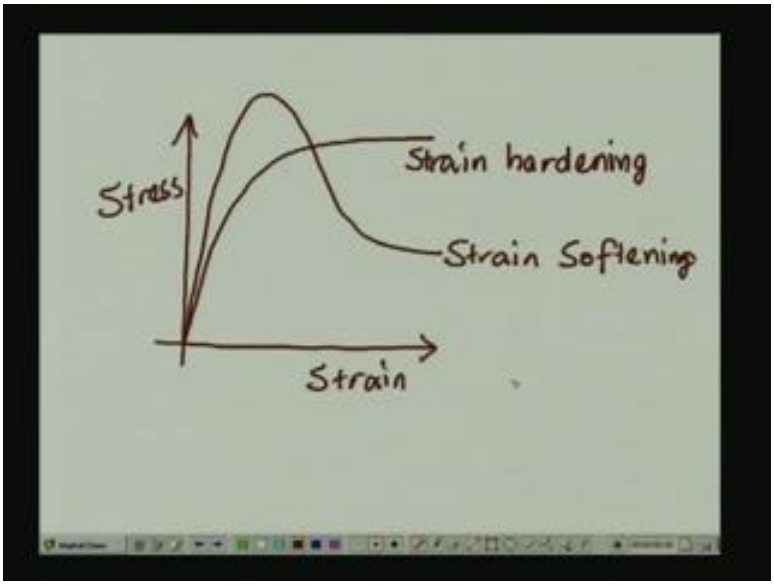

Now if you plot the stress strain curve of a particular material. So, this is the stress, and that is strain, and the response is like this. So, this is called strain hardening response. So, this type of material becomes stronger as the strain takes place, whereas if you have got strain softening material, then the response is like this; here the material looses strength as deformation progresses. So, that is the reason why incase of strain softening material, the movement could be quite catastrophic if a flow slide is triggered to that type of material, whereas in case of strain hardening material, the movement is not typically catastrophic.

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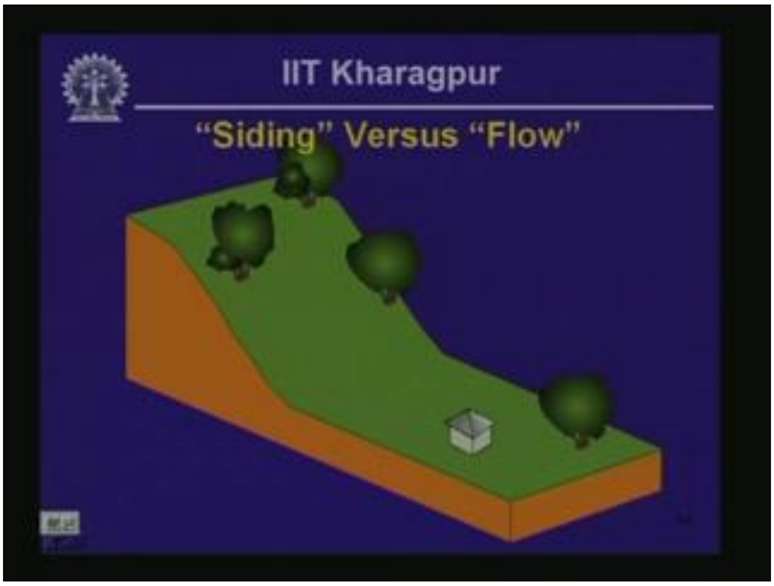

Now you need to realize the difference between siding versus flow slide, typical siding versus flow slide.

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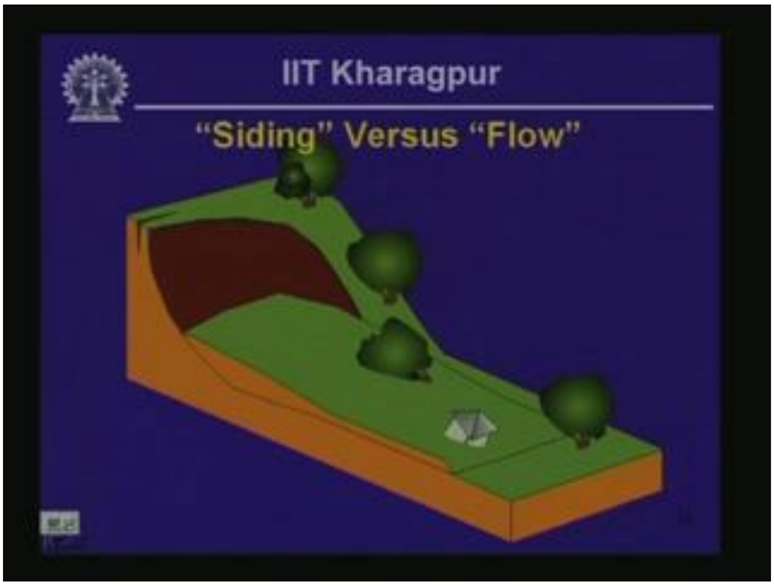

If you recall, sliding is of this type; in this case typically the movement is relatively slower, and the movement does not proceed to a great distance. Whereas in case of flow, the soil becomes liquid like or the failure mass becomes like a liquid, and you can realize liquid always tries to find a relatively flat surface. As a result, the slide is only going to stabilize after the surface has become extremely flat a few degrees from horizontal. And you should also look at the damage that this type of slide could cause which is illustrated by the tumbling by the tree that has tumbled down slope and the building which was constructed a little bit down slope.

So, this illustrates what could happen, and you can see from here from this schematic sketch is that in this case because of the fact that the unstable mass actually behaves like a liquid, the objects could float on top of this particular this stabilized mass, okay.

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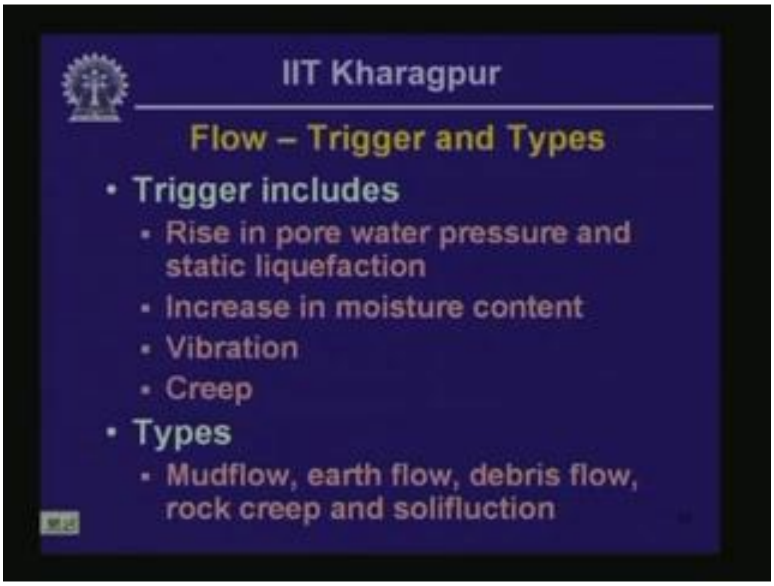

Now how flow slides could be triggered? Triggering of flow slide could be due to rise in pore water pressure and static liquefaction. As you recall liquefaction this is the phenomenon in which because of increase of pore water pressure, the effective stress becomes almost zero, and that could be triggered even without an earthquake; it could be triggered on the static scenario because of rise of pore water pressure. Increase of moisture content could soften many different types of of particularly cohesive soils. Vibration and creep, these are typical triggers of flow slides.

And types of flow slides include mudflow, earth flow and debris flow, rock creep and solifluction. Mudflow is a type of flow which involves basically very fine grain material. If you have got flow taking place comprised of coarser grain size, it is called earth flow. Debris flow involves mixed grain sizes involving boulders as well as fine grain soils.

Rock creep is when a rock is deforming under no increase of driving force without any increase of driving force, because of the fact that under existing driving force, the rock mass is near failure.

And the material in this case, if you recall from the discussion that we had a few minutes back is of the strain hardening type. And solifluction is a scenario in which there is a shallow intermittent down slope movement caused by snow melt in fine grain soils. Because of snow melt, the water content within the shallow soils has become larger, and the soil becomes soggy. And soggy soil relatively becomes softer, and that triggers intermittent down slope movement. The last two categories of this group that we are discussing here are slow movements, whereas, mudflow, earth flow and debris flow are quite fast.

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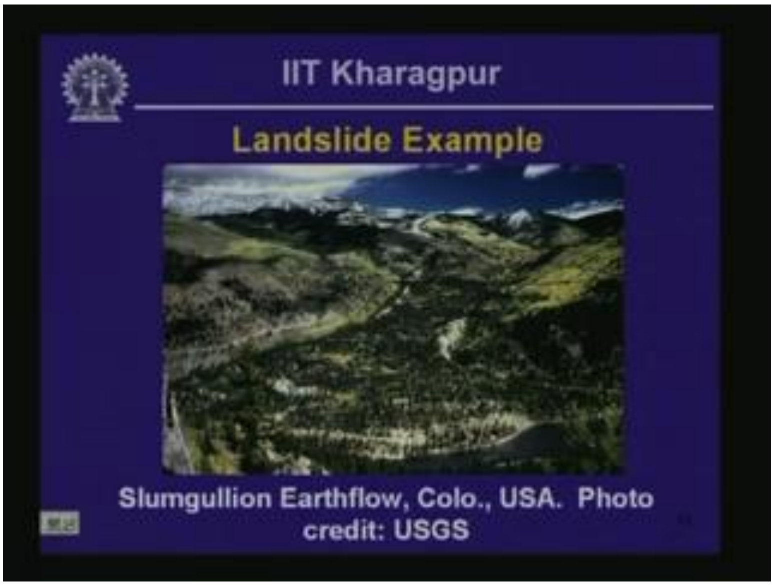

A few pictures I am going to quickly go through these pictures. This is a picture of Slumgullion earth flow in Colorado, United States. This is actually the flow characteristic is quite obvious from the failure mass which is visible here near the middle of this particular picture.

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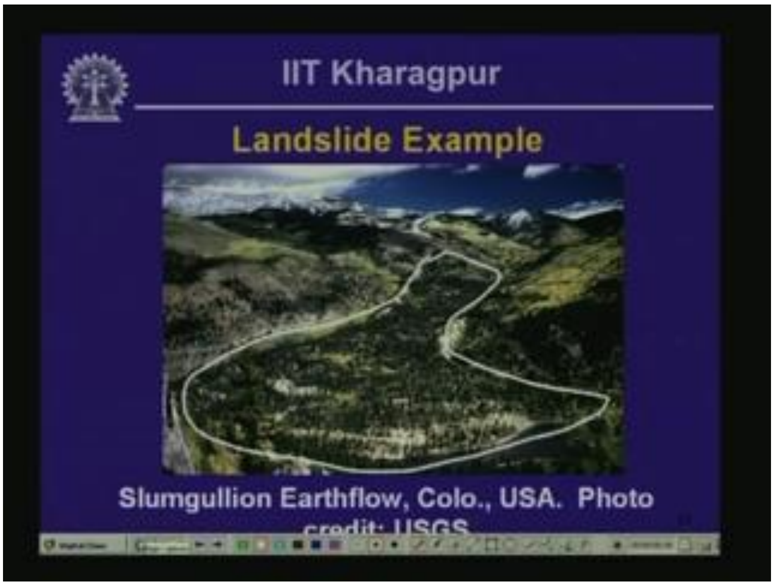

Let me show the failure mass here. So, this is the failure mass. You can see you can easily infer the fluid like property when it failed, fluid like property of this mass when it failed.

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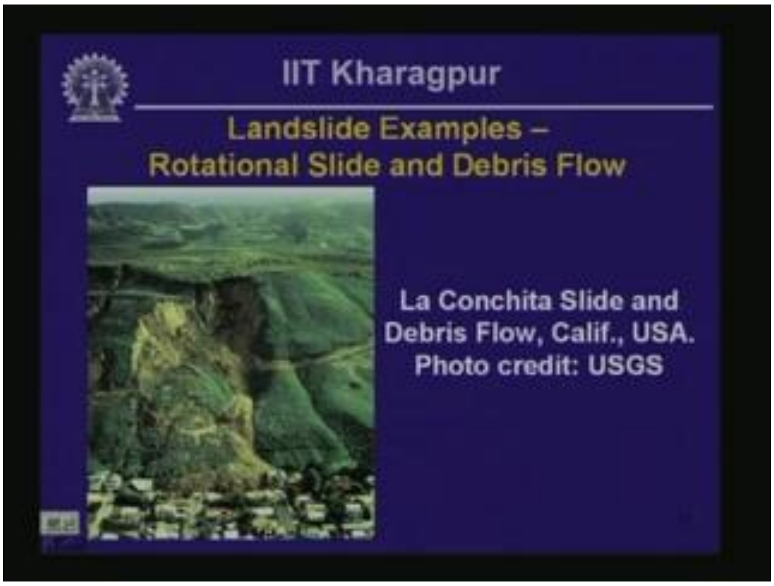

This is an example of a landslide involving rotational slide as well as debris flow. This slide was initiated as a rotational slide as is evident from the failure scarp, and the blocks near multiple rotational slide in fact involving blocks near the top.

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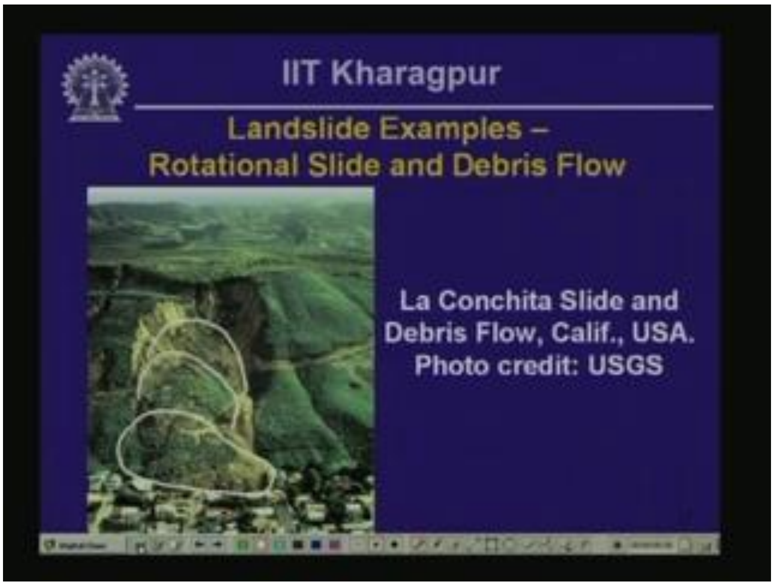

And the bottom portion of this particular slide, it has got a flow like characteristic. So, these are the blocks that I am trying to refer to.

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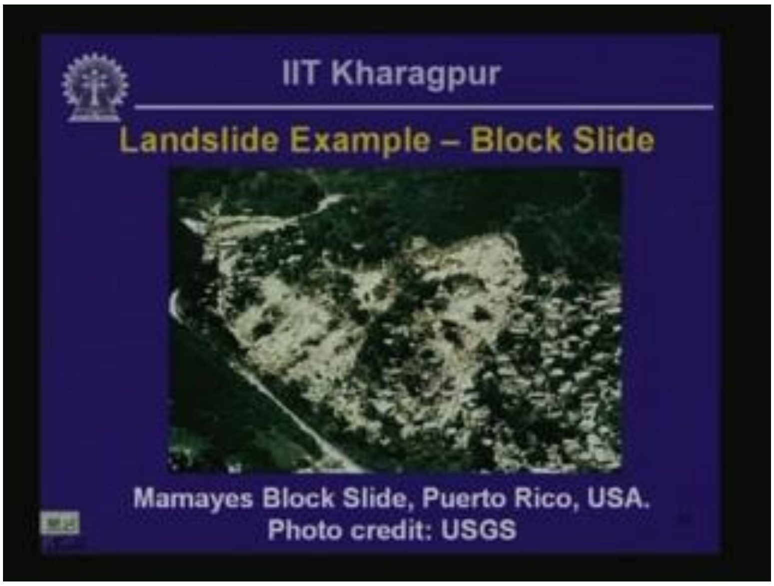

Then you have got this is an example of a huge block slide in Puerto Rico. The previous picture was from California actually. This one here is a huge block slide that involve in more than a hundred depths in Puerto Rico. It is a block slide which we have schematically illustrated earlier.

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Now that really brings us to be end of this particular lesson. Let us summarize what we learnt. We looked at nature and mitigation strategies again shoreline erosion and depositional processes. We looked at causes of landslides, and we looked at classification of landslides.

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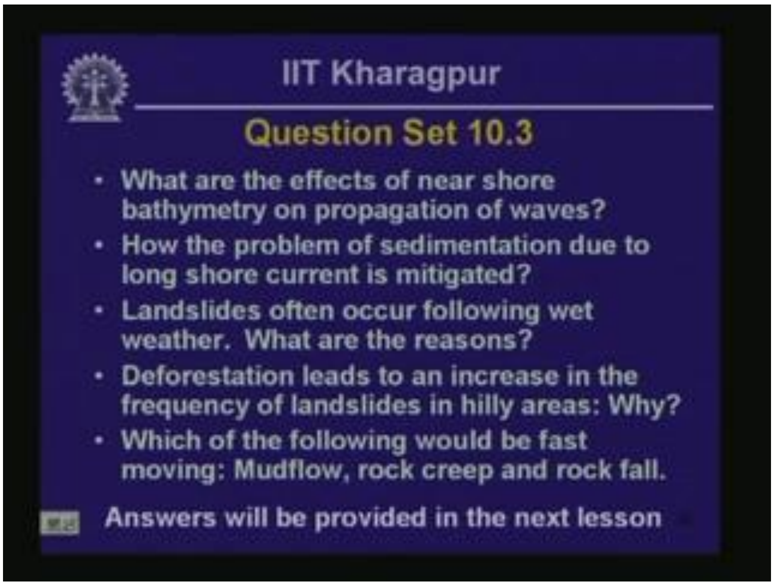

We are going to wrap up this particular lesson with a question set. Some of these questions are from the previous lesson because I did not have a chance of giving a question set with the previous lesson. So, first question is what are the effects of near shore bathymetry on propagation of waves? Second one, how the problems of sedimentation due to long shore current is mitigated? Third one, landslides often occur following wet weather, what are the reasons?

Deforestation leads to an increase in the frequency of landslides in hilly areas, why? And the fifth one, which one of the following would be a fast moving slide? Mudflow, rock creep and rock fall. Try to answer these questions at your leisure. I am going to provide you with my answers when we meet with the next lesson. So, until we meet with the next lesson, bye for now. Thank you.