Foundation Engineering
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Module - 3
Lecture - 6
Stability of Slopes

Welcome viewers, today we are going to start a new chapter Stability of Slopes.

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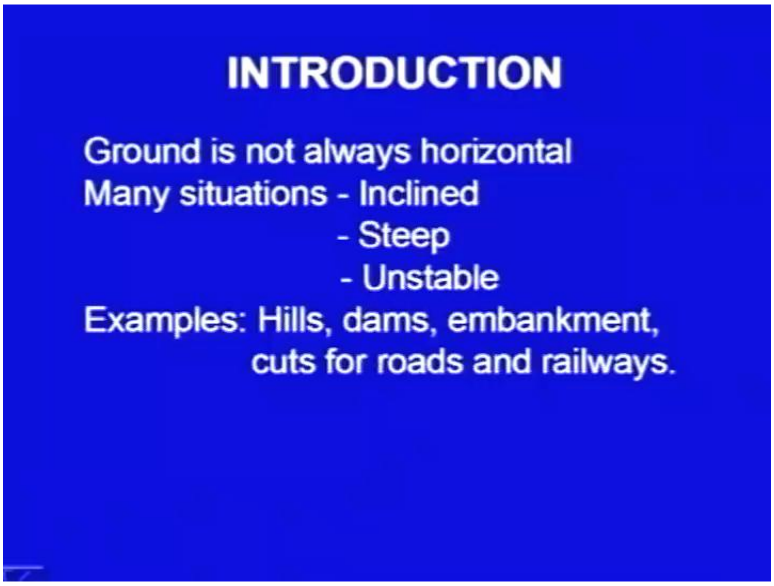

As you might have seen that the ground is not always horizontal, there are many situations where you will find there is some inclination of the ground, there is some gradient for example, in hills you will find the slopes are there, the ground is inclined. So, if this gradient becomes steeper, if it becomes very steep, then it may become unstable, so all these kinds of the problems they come under the category of stability of slopes.

And we shall be discussing in this chapter, how to analyze those conditions and if they are unstable what we can do about to improve those situations. The, examples of the slopes are you can see you might have seen the hills, there the ground is not horizontal it has certain inclination with the horizontal, dams, dams are the barriers which are constructed across the rivers to divert water or to store water. Then embankments are manmade structures, where the slope is there the ground has the surface ground level has certain inclination with the horizontal and cuts for roads and railways.

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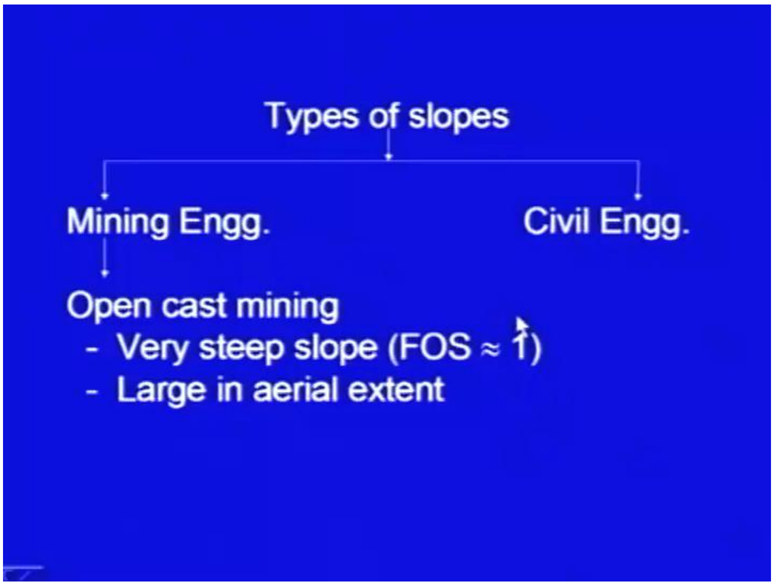

We start with the classification, so as far as the classification is concerned all the slopes can be categorized into two major categories, I am giving here two categories, one belonging to mining engineering and second one is civil engineering. We shall be concentrating more on civil engineering aspects, but to have some idea to differentiate between mining engineering slopes and civil engineering slopes, some discussions I am going to give here.

You might have seen in case of the mines there are open cast mines, what we do there is we extract the ore, the ore is extracted and it is extracted by excavating the ground. So, ground is required to have certain slopes there and those slopes you can see you will watch that, you can have very steep slopes. And another thing about the mining engineering slopes is they are very large in extent, so there is a basic difference, the basic difference between civil engineering and mining engineering slopes is that.

Here, we our purpose is not to make the slopes stable as such, we are extracting the ore and we shall be keeping the slopes stable for that much time for which we will be extracting the ore. So, the our main purpose is to extract the ore, so it is not our purpose that we keep it safe for certain structures for example, in case of civil engineering structures, we have to keep the slopes stable to for a very long period.

So, the factor of safety, factor of safety is nothing but, it is a margin of safety the margin of safety in case of the mining slopes can be very near to one, they can be just stable. Whereas, in case of civil engineering projects we have to have a very good margin of safety because, it is concerned with life it is concerned with property a lot of damage can happen if the slopes fail, so these are the two major categories.

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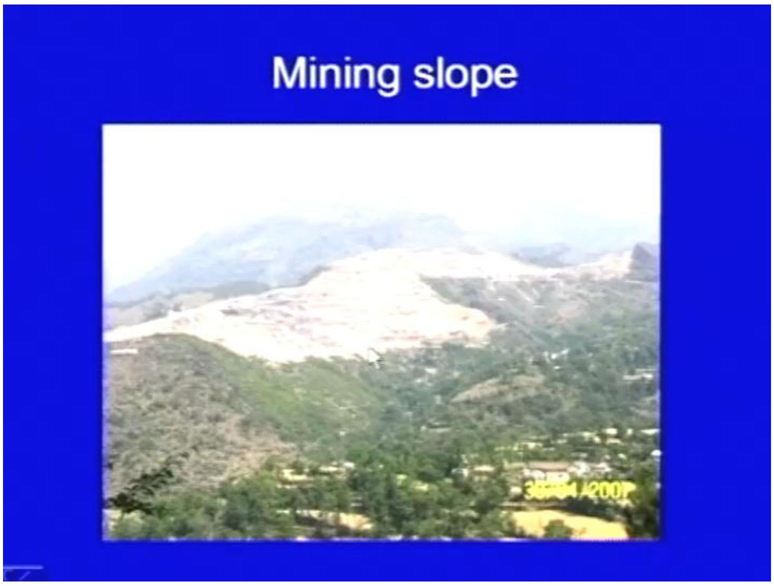

And here I have given an example of mining slope, you can see this entire hill is being cut and the ore is being extracted. So, here there are benches, there are slopes, there is a particular sequence of excavation, sequence of excavation means depending on the stability of slopes then we start excavating from one side or the other side and the purpose is to extract as much as possible, the purpose is not to make it stable.

So, this is a mining slope and you can see the area, because you have to extract large amount of the ore, the area generally is very large whereas, in case of civil engineering structures the area generally is small.

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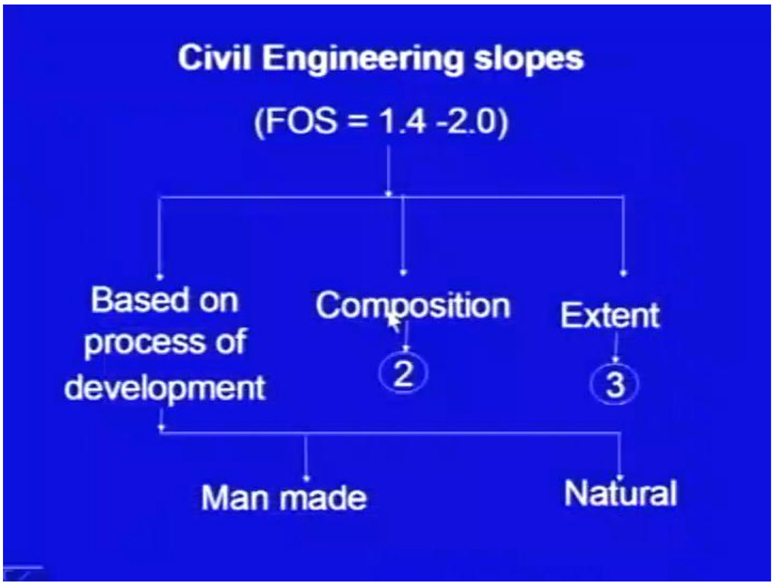

Coming to civil engineering slopes as I told you, the margin we keep very high, so factor of safety is 1.4 to about 2.0 we shall be discussing what factor of safety is presently you can think that it is a sort of confidence how much margin for the safety we are taking. Now, civil engineering slopes I am dividing further into three categories, first is based on process of development, second one is based on composition and third one is based on it is extent.

The first one is based on process of development, this means how the slope has come into existence, whether it was a man made structure or was it a natural kind of the structure. So, therefore, again it is being divided into two categories, man made means the man is making that structure, it is manmade structure and natural slope means a slope which is constructed by nature for example, hills they are not constructed by us. So, natural slopes in general they are having large extent, man made slopes will be having smaller extent.

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Here are some of the examples of manmade slopes and natural slopes, first one is to give you the idea, cutting and embankments for highway and railroads. Cuttings means, you are cutting the soil, you might have seen for highway for example, national highways which are very important highways and for rail road's, if when they pass through an area which is near to a river, you might have seen that the highway is kept at a very little bit higher level.

The idea is it is, we try to keep it above high flood level, so that during the floods also this highways they are not blocked this is the idea. So, to do that what we have to do is we have to make some sort of arrangement, we have to make some sort of embankments and on that embankment then highway is placed. So, this embankment is constructed of soils or rocks or both of them and then there is stability of this embankment is very important, so there are the other embankments.

Secondly cuttings are there, wherever you have the ground is undulating and the road is passing through that or rail road is passing through that railway track, in fact in case of the railway tracks you have to have very gentle gradient, you cannot have very steep radiant's on the railway tracks. So, where the ground is uneven you have to make the track on smooth surface, so there sometimes you have to cut the slopes cut the ground and by cutting the ground and then you have to keep the railroad at the almost same level.

So, cuttings and embankments both they come into picture, so here when you cut the ground and have a section through that, that section should be safe that it should not happen as you might have heard for many railway tracks, that the landslide has occurred and the geological material has come down on the real. So, it may create lot of hazards, so cuttings and embankments are these are the first kind of the manmade structures.

Then, there are earthen dams and earth and rock fill dams, dam is a structure which is constructed across the river and the purpose of the dam is either to divert the water or to store the water during the monsoon season. So, it is a very important structure which is constructed in the river and it has to resist huge amount of forces, forces due to water, forces due to some other agencies also.

So, the dams if they are constructed of earth, they may be earth dams, they may be earth and rock filled dams and they may be gravity dams also. So, stability of slopes from soil engineering point of view is important in case of earth dams because, earth dams will be resisting it will be storing water on upstream side of it, water will be seeping through the body of the dam. And because of the seepage there are certain forces, which act on the dam body and then stability is a major concern.

So, for earth dams as well as earth and rock filled dams, you have to consider the stability of slopes, you have to design them in a such a manner, so that they are safe. Then, there are temporary excavations if you are going by a road side you can see sometimes there are temporary excavations. For example, suppose to lay a pipe line temporary excavations are made and those excavations how deeper those excavations can be made safely, you have to have some idea of the slope stability analysis.

So, for temporary excavations also slope stability analysis comes into picture, then spoil heaps and municipal solid municipal waste dumps, this is a very burning topic these days if you happen to go to the metropolitan cities. You might have seen there is lot of municipal waste, which come out of the city and this waste is dumped at some place. So, there when you dump it there is a heap which is formed it is a kind of small dam or an embankment. And again it should be stable, it should not happen that when the rainfall occurs, this municipal waste material it flows away these fields.

So, stability of these dumps is also very important, so slope stability analysis comes into picture there also. Lastly, landscaping operations for development of sites for many sites when we develop, we make certain slopes there, land for the landscaping purpose. So, they should be stable, so here I have given few examples of the man made slopes, there can be many more beside this. Then, natural slopes as I told natural means it is constructed by nature not by human being.

For example, hills, hills are very good example and you might have seen the lot of landslide problems in the hills and the valleys, the landslide problems have to be analyzed through the principle of stability of soils, as well as stability of rocks. So, these are the natural examples, these are the examples of natural slopes hillsides and valleys. Then, coastal and river cliffs when the river passes through geological media, there is a fast flowing water, that water is associated with energy and it can do wonder cutting and the cliffs can form and then one has to look into the stability of those particular sections.

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Here are some examples I am giving for example, this is a road cut in hill side, this was the natural ground, you can see I have drawn a small dotted black line, this was the natural ground level it was going like this. So, in itself the what was the stability of this hill slope that is another question, but above that now we have done this cutting, we have constructed a road here and this particular material, now you can see we have removed this particular material from the site.

So, actually this material, this soil mass or the rock mass was being supported by the excavated material, which we have excavated. So, there will be a tendency of this particular geological media, whether it is a soil or rock to try to slide to this direction, because of the gravity. We there you can see some measures have been taken here or returning wall has been constructed, returning wall is one of the ways using which the slopes are stabilized.

So, the idea is that here it is now left unsupported, it was being supported by this soil mass here now it is unsupported. So, it will try to move here, so this particular problem you have to analyze using mechanics of slope stability, point is how much height you can keep vertical, safely whether it is safe or not or if it is not safe, what is the margin of safety and what should we do can we support it using returning walls etcetera, so these are the questions which have to be answered.

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Here is another example of a man made structure, it is a dam here you can see it this is the downstream side of an earth and rock filled dam, upstream side is above that, water will be storing, water will be stored on the upstream side, a reservoir will be formed there and water will be exerting pressure on this dam. It will be seeping through it and the seepage pressure will also be acting on the dam body, inside the dam body, so here the stability of this particular structure is our concern.

Secondly, it is not only the man made structure, but you can see here, these are the steep banks which have been cut, again they are manmade plus natural. So, you can have a problem which is having man made plus natural slopes both, so here you can see the naturals slopes are there, and there are very steep cuts in the rock mass here, steep cut on this side. So, stability whether it is stable or not, whether it is failing, what is the margin of safety that is the point of concern.

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Here, I have taken an example of a natural slope, it is a site in hills you can see it is a steep hill here, steep hill and there has been a landslide passing through this huge area. In fact, it caused lot of damage to life and property on the downstream of this particular landslide. So, this is a natural slope and this has failed probably water was one of the reason, seepage of water was one of the reason for this instability.

So, point is we should be able to analyze if I consider this particular section, we should be able to tell why this particular soil mass has failed, what is that problem which is creating instability and whether we can improve this situation or not.

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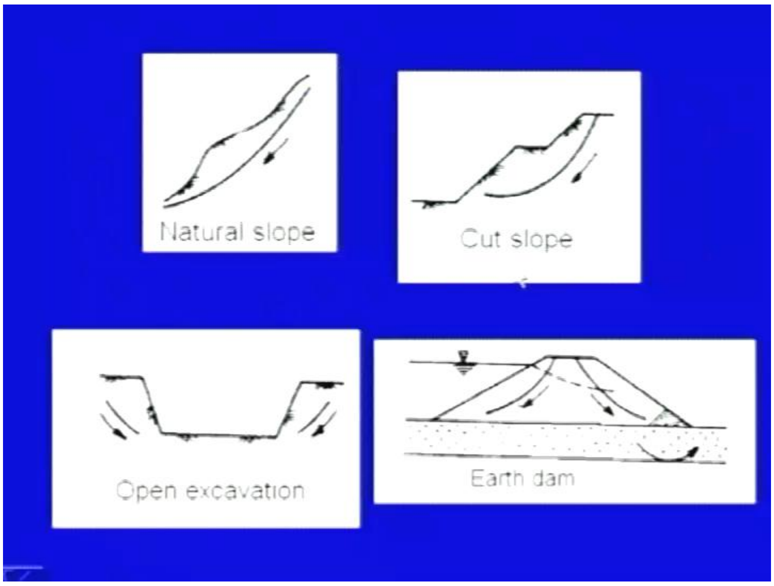

Here are the sections I have shown, so for example, this one is a natural slope, this is the ground surface. And here, it is one of the assumed slope sorry failure surface, this mass is failing along this surface, in fact in the field the phenomena is very complex, but we can standardize it and we use some standard types of the failure surfaces. So, this particular soil mass is moving down or it is at the verge of moving down, it is a cut slope in the manmade structure. So, there is a cut it may be in the hill or it may in the canal something like that.

And this particular mass, you can see here this particular mass is trying to move in this direction. So, it can come out here, here is an example of open excavation may be a canal or may be some other excavation, so this is the original ground level and it has been excavated. And now these sites, these sites may be very steep, this angle may be very large and depending on this angle, then this particular bank or this particular bank, they may fail depending on what is the kind of material is there, what is the kind of seepage situation is there, what are the properties of the mass and so on.

Here is an example of earth dam I have taken, this is an earth dam and this is the water on the upstream side. Water is seeping through this, this is the line and on upstream side this slope may fail on the downstream side, this slope may fail or even the failure can occur at the base at here below the two of the slopes somewhere here, this mass can also try to come out, if this mass is if this soil is weaker this can also fail.

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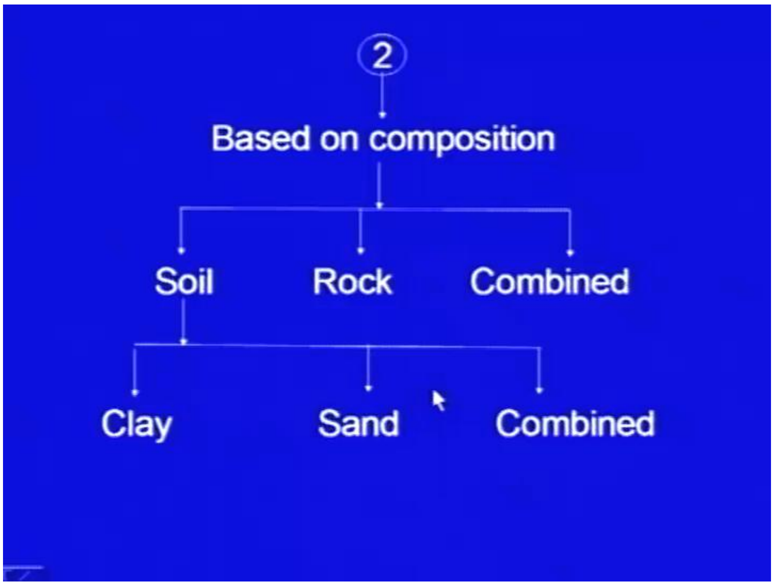

So, that was the first category of the slopes, now second category of civil engineering slopes is based on composition. And here, based on composition I divide them into three parts, there may be a slope which is composed of soils only, there may be a slope which is composed of rocks only, our this particular course will be mainly concerned with soils or there can be a combination of both of them. For example, in case of landslide problems it is not enough that you know soil mechanics, you have to know the principles of rock engineering also.

Coming to soil slopes, where we are concentrating more, the material can be only clay it can be a clay material. For example, when we construct the slopes in case of embankments, etcetera you can have only clay, the section which we are analyzing may be only clay or it may be a sand or in general for the embankments it will be a combined situation. So, from theory theoretical analysis point of view we have to know each of them and from practically for embankments most of the times you will be having combination.

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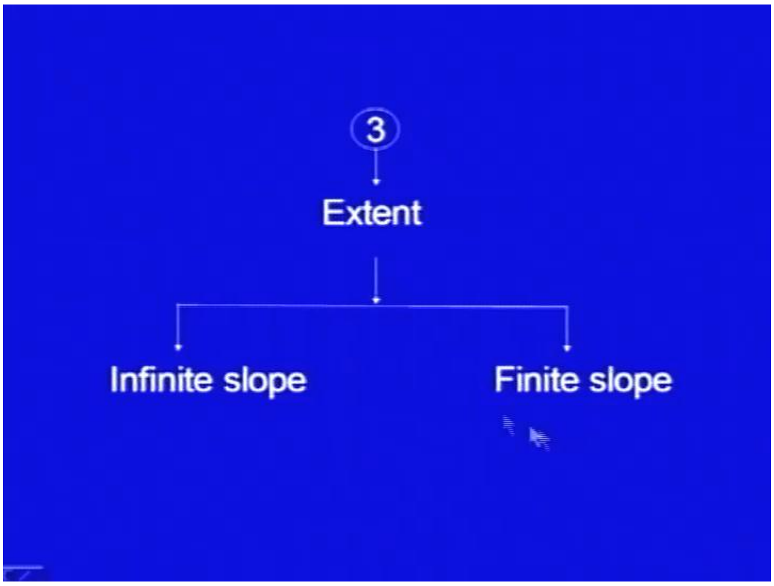

The third category of the classification is extent, based on extent they are divided into two categories infinite slopes, infinite means extent is very large and finite slopes, finite slopes means extent is small. So, infinite slopes are for example, the hills, hills are having very large extent, so we can consider them to be infinite for theoretical analysis. And the examples like embankments, they are having smaller extent and we will be considering them as finite slopes.

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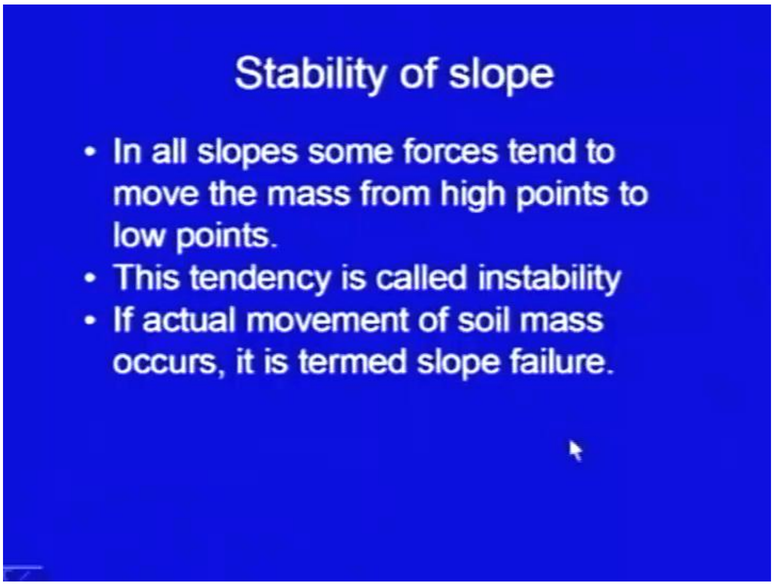

Now, after having the idea what are the slopes and what are different kinds, what is the classification. Let me now come to the point, what we exactly are going to do what this stability of slope term means, now in all slopes some forces tend to move the mass from high point to low point, it is very natural you as mechanics as a student of mechanics. You know, because of the gravity if there is a soil mass or if there is any body which is at higher level and the another body at the lower level.

Then, there are some actuating forces, because of the gravity there will be component of gravity forces, that will try to move the mass from the higher points to the lower points, this tendency is called instability. So, it is trying to be instable and if actual movement of the soil mass occurs, then this is called as slope failure.

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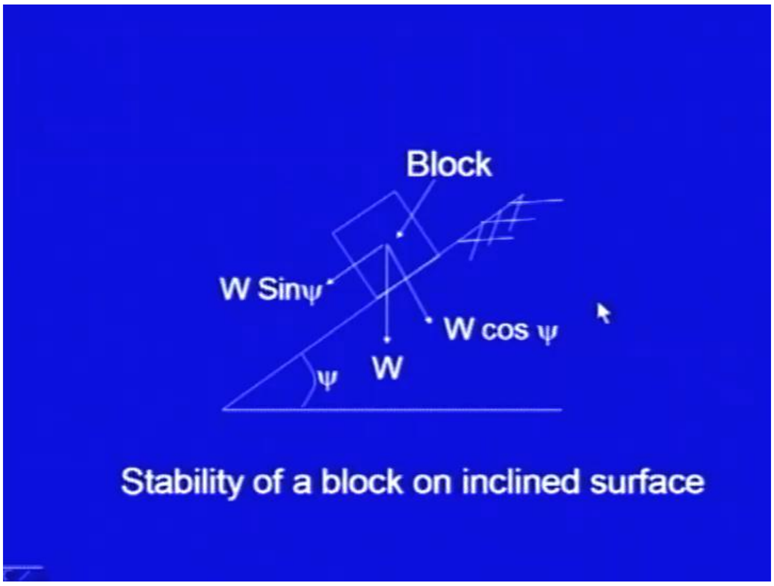

Let me try to explain you, the stability how we look at stability, it is a simple example not from the slopes, but to make it clear I have taken a simple mechanics problem, which you have solved in your intermediate classes. It is an inclined surface having some roughness and that roughness let us say is represented by friction, coefficient, mu and there is a block, which is kept over this surface, this inclined surface is making some inclination psi with the horizontal.

And let us say, the interface between the block and this particular plane is having no cohesion, it is having only frictional component that is mu. You have solved these kinds of the problem in your intermediate classes, what we used to do you, if you remember the weight of the body is known to us and this weight will be acting in downward direction, I can resolve this weight into two components, one component will be acting normal to the plane, and second component will be acting tangential to the plane.

So, if this angle is psi, this line is perpendicular to this line, this line is perpendicular to this one, so this angle will also be psi and you can find out what is this component. So, if this angle is psi, this component comes out to be equal to W cos psi and the tangential component comes out to be W sin psi. Now, as I just now discussed there is a component of this force which is trying to create instability, this is that component W sin psi is that component, which is trying to create instability.

If this psi angle is small, let us say very small angle let us say 0, if the psi becomes 0 this plane becomes horizontal, this component becomes 0. So, there is no component which is trying to create instability, so W sin psi will be creating instability and if this psi is almost 90 degree you will find that this component becomes very large. Coming to this, if it is psi is almost 0, this component will be tending towards a larger value and when the psi becomes 90 degree, this component will become almost 0.

Now, if you remember what we used to do for the analysis was, this is the force which is acting normal, there will be a reaction R in the opposite direction. And because of this reaction R there will be a frictional force, which will develop against the actuating force in upward direction and it is value will be equal into mu into R; that means, mu into W into cos of psi. So, if this psi is small what is going to happen is, this value will be small and the developed force the there is going to be a force, which is going to develop here the frictional force.

The maximum value as I told will be mu into R, but that will be the limiting value, the mobilized value will depend on this particular component. If this component is small, the mobilized frictional force will be small it will be equal to this and the block will remain stable. So, what I want to say is for smaller psi value, there will be smaller actuating force and there will be some mobilized frictional resistance, which will mobilize here, which will develop here it is value will be equal to this much and the system will remain stable, the block will remain stable.

But, if this inclination becomes large this actuating force is very high, this mobilized friction it will take it is ultimate value that is equal to mu into R and if this value is more than mu into R, this is going to slide.

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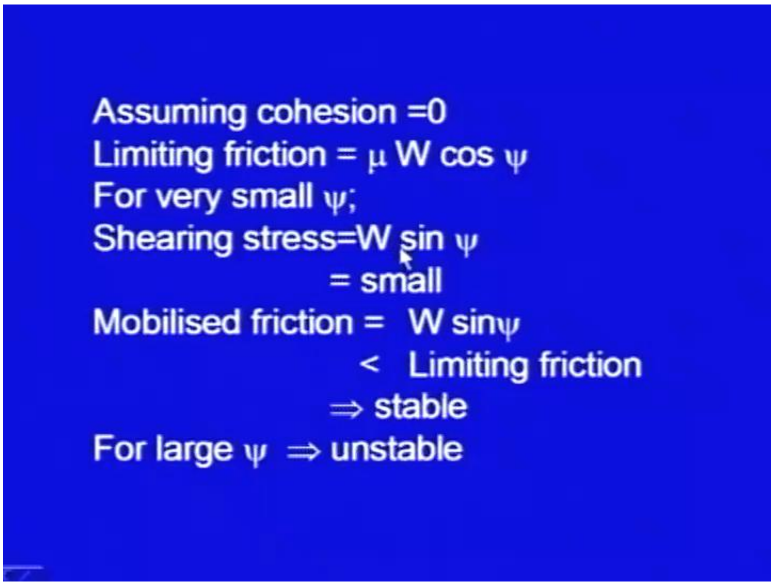

So, in nutshell let me summarize it that for a small inclination, the shearing stress, the tangential stress the tangential force will be equal to W into sin of psi it will be a small quantity. And there will be mobilized friction, which will be equal to W sin psi it is maximum value can only be equal to limiting friction. So, if psi goes on increasing this will also go on increasing, but it will increase up to certain maximum value, that will be the limiting case and if psi becomes large it will become stable ((Refer Time: 27:41)).

So, let me finally, summarize the conclusion, if I keep this psi small it will be stable, why it will be stable because, the mobilized friction is equal to the actuating force. As you go on increasing this angle psi, the actuating force the destabilizing force goes on increasing and the mobilized friction also goes on increasing. At a certain value of psi, this W sin psi becomes equal to the limiting value of the mobilized friction mu into R beyond that if you increase this particular value, if it is steeper than that, then W sin psi will be very large and this block will slide.

So, this is the basic thing which we are going to use in stability analysis, we are going to compute what is the mobilized value of the shearing, resistance what is the limiting value of the shearing resistance and based on that we will find out what is the margin of safety.

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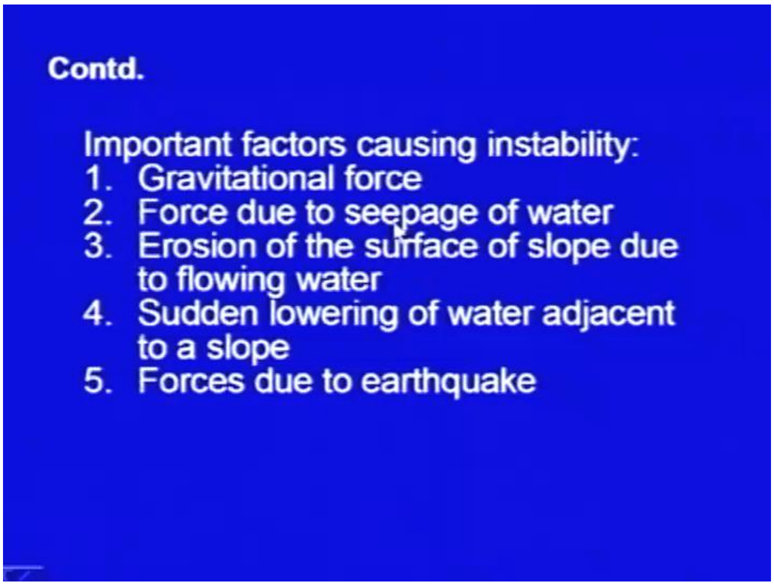

There are certain important factors, which governs this instability let me discuss them one by one. These factors are gravitational force, you saw just now that W was coming picture into picture W sin psi was coming into picture, so this was causing instability.So, the gravitational force is going to cause instability it is one component is going to cause instability another component is going to enhance the stability, so we have to see that relationship.

Then, there are other things I have not I did not discuss, force due to seepage of water, the seepage of water if the water is seeping through the soil mass, then there are additional forces which will come into picture. Then, there may be erosion of the surface of slope due to flowing water, the erosion of the surface will have effect on the gravitational forces, it can reduce the gravitational force, but the water itself can have seeping effect.

So, these are the things which have to be considered, then sudden lowering of water adjacent to a slope can cause instability and also there are forces due to earthquake, which can cause instability.

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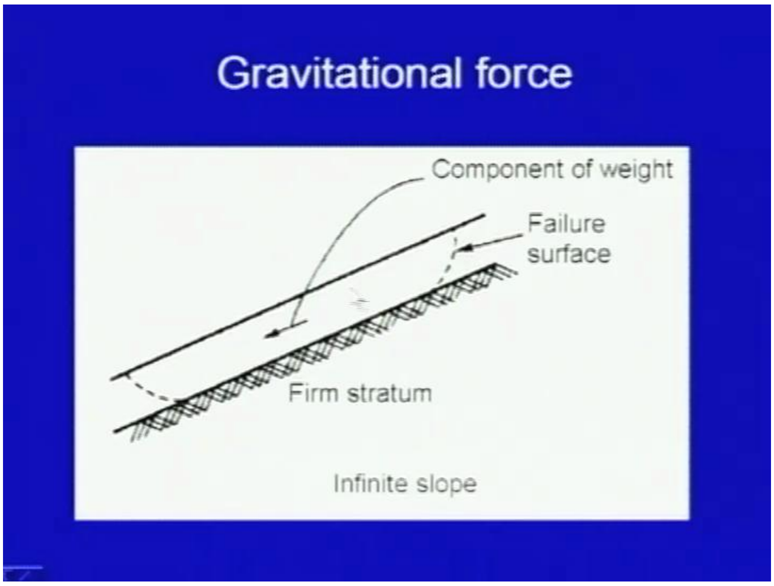

This is the first force the gravitational force, here I have taken an example of an infinite slope it is hard stratum, firm stratum available at certain depth. It happens in case of the infinite slopes, in case of the hills, generally the firm stratum will be available at certain depth. And here, it is the ground surface and this entire mass if you look the failure generally has been observed direct occurs like this, so this particular entire mass is trying to slide over this hard stratum.

So, it is a problem similar to what I discussed block you can consider this mass to be a block and that is being tried and this weight of this block, the component of weight of this block this component is trying to destabilize it. So, this is the gravitational force how the gravitational force comes into the picture, this is the importance of that.

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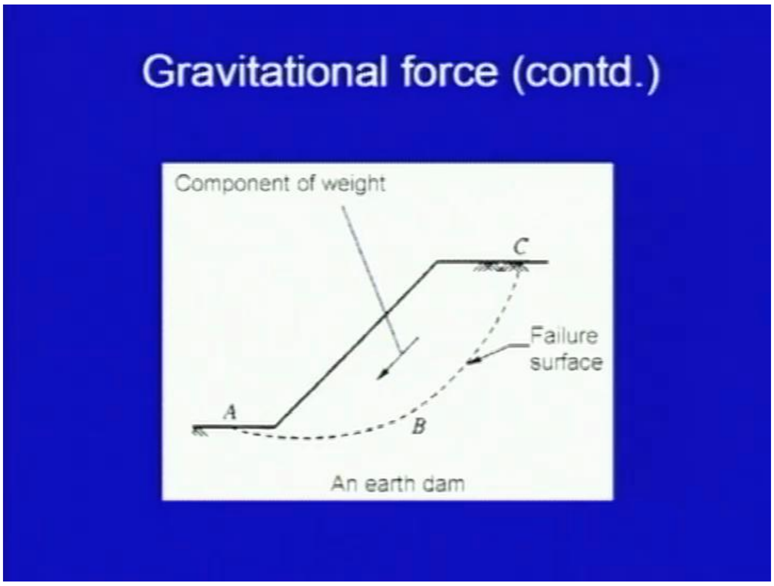

Now, here is an another example of the gravitational force, here I am taking an earth dam and it is section is drawn here. Now, in this case in this man made structure, the failure surface generally has been observed to be a curved surface, most of the time it is taken as circle and this mass tries to slip in this direction. So, again if you look at the weight of this particular body, this particular body, the weight will be acting in the downward direction, one component is acting parallel to this failure surface, another component will be acting perpendicular to the failure surface. So, as a whole if we take this body, you can see the component of weight this component of weight is trying to destabilize trying to create instability in the slope.

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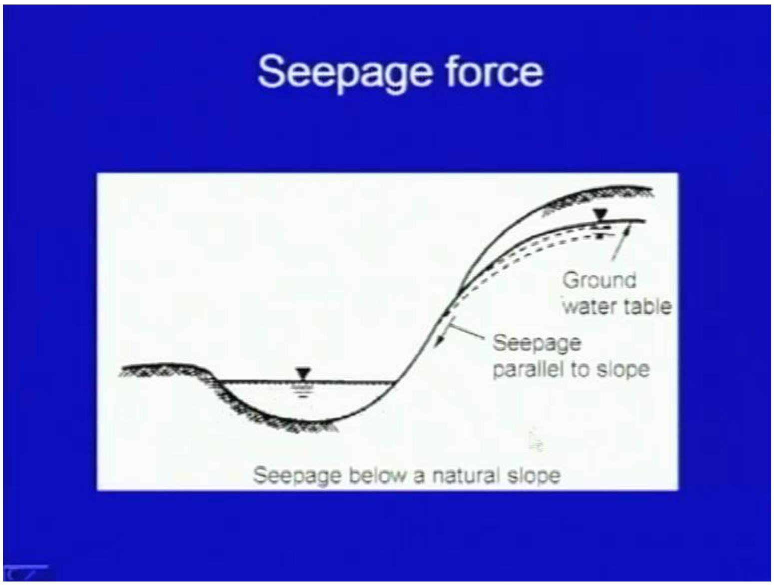

This is the example of seepage force, here it is low lying area and ground water table is here, this is the ground surface and seepage is taking place. So, when the water table comes at the ground water, table touches the ground here, so this entire area, this entire area is completely saturated and seepage is taking place in this direction and seepage is almost parallel to the slope. So, these situations have to be analyzed in different manner and here then it this seepage’s joins in the water table, so we will be considering these details how to take into account this seepage forces.

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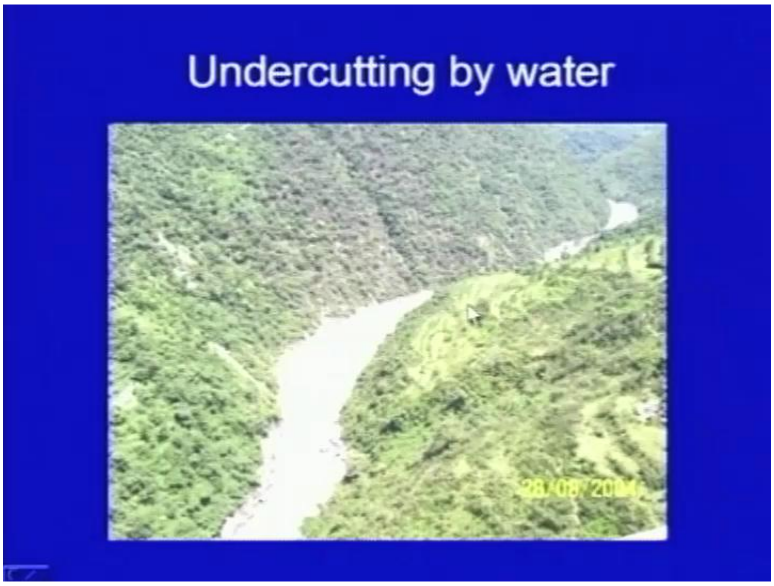

This is an example of undercutting by water, here this photograph I have taken from the hills. You can see there is fast flowing water here and the sides whole these banks it can cut these banks, so whether they are soil slopes or soil ((Refer Time: 34:00)) field slopes or may be sometimes rock slopes. So, there is lot of undercutting by water and this is one of the main reason in the hilly regions, many a times which create instability and creates landslide problems.

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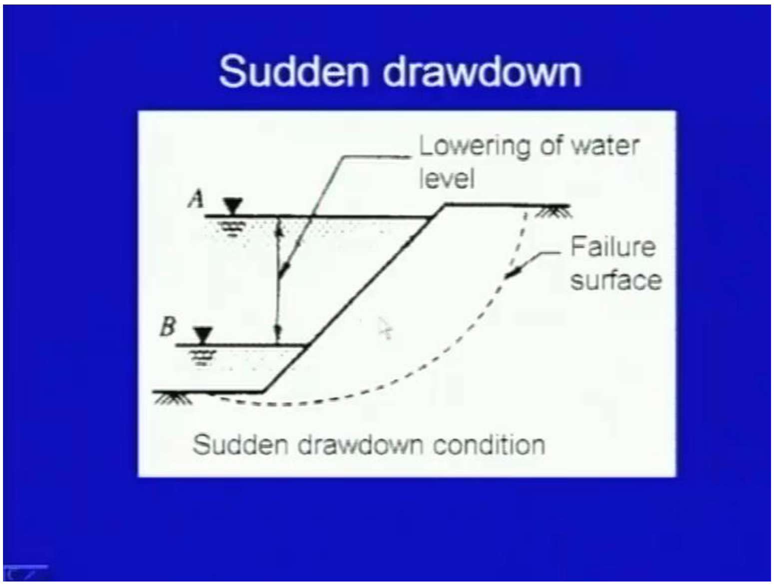

Here is a problem, which is quite common in case of the dams are the dams it is called as sudden drawdown problem. Sudden drawdown means, there was an embankment here there is an embankment here and there was this water table, this water table was there for long period. So, the system was in equilibrium, the seepage was taking place from this side to the downward side, so you can draw the flow net and you can have the idea of the seepage.

Now, all of a sudden there is lowering of water level, so from here water level goes up to this place. So, what happens to this saturated soil mass, which was in equilibrium, which was being exerted force due to seepage force due to water was present here, so water was having stabilizing force over this particular soil mass and this was under equilibrium all of sudden this particular pressure, the pressure due to water has been removed, but this is completely saturated, the soil is completely saturated, so water is present there.

So, there is a flow which starts from the soil mass towards this side and instability is created, because of sudden lowering of water level, this is called as sudden drawdown condition.

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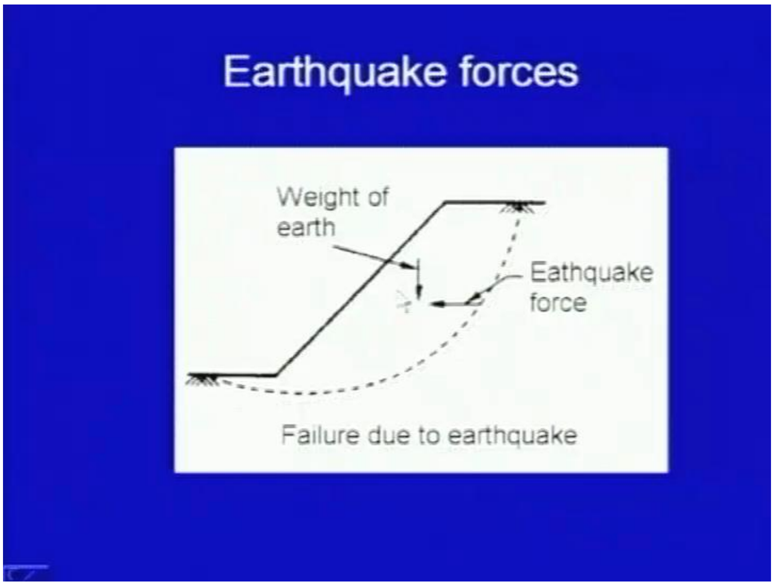

Earthquake forces, what the earthquake forces do is there will be a severe shaking of the soil mass. So, here is an embankment it is weight is acting in this direction, and the shaking of the earthquake forces, the earthquake forces can be resolved into two components, they will be having horizontal component as well as the vertical components. So, when the acceleration is in this direction, the force due to earthquake will be acting on this particular soil body in this direction.

So, what it is going to do is, it is going to decrease the effect of normal stress, it is going to decrease the stabilizing forces and in other words it is going to increase instability.

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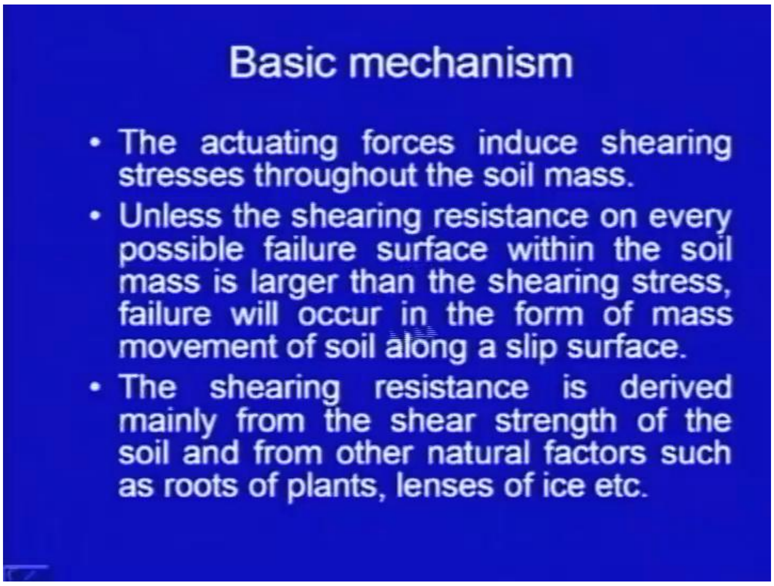

Now, let me come to the basic mechanism we have discussed what a stability problem is, the actuating forces induce shearing stresses throughout the soil mass. So, this is what we I have been discussing there are certain actuating forces, most common force is gravity and those actuating force induce shearing stresses throughout the soil mass. Now, we will be talking in terms of shearing stresses, the stress is there, there is some stress which has been applied.

Now, unless the shearing resistance on every possible failure surface within the soil mass is larger than the shearing stress, failure will occur in the form of mass movement of soil along a slip surface. So, what is going to happen is as I told you that there are actuating forces and those actuating forces are going to create shear stresses, now these shear stresses have to be registered by the shearing strength of the material, and there can be infinite number of possible potential failure surfaces.

So, on all these potential failure surfaces, if the slope is stable; that means, the resistance being offered by the soil in terms of shear strength is larger than the actuating shearing stresses. And this shearing resistance is derived mainly from the shear strength of the soil mainly it is the shear strength of the soil, which is going to resist the applied shear stresses and some help is available from other natural factors, for example, roots of plants.

So, in fact if the roots of plants are there, if the plants are there or lenses of eyes, etcetera, so in fact, the plantation of roots is very effective measure in case of the natural slopes. Because, the roots of the plants will be adding to the shear strength of the soil mass, and they will be opposing the actuating shearing stresses, so basic mechanism is this that there are actuating shear stresses and those actuating shear stresses have to be registered by certain resistance.

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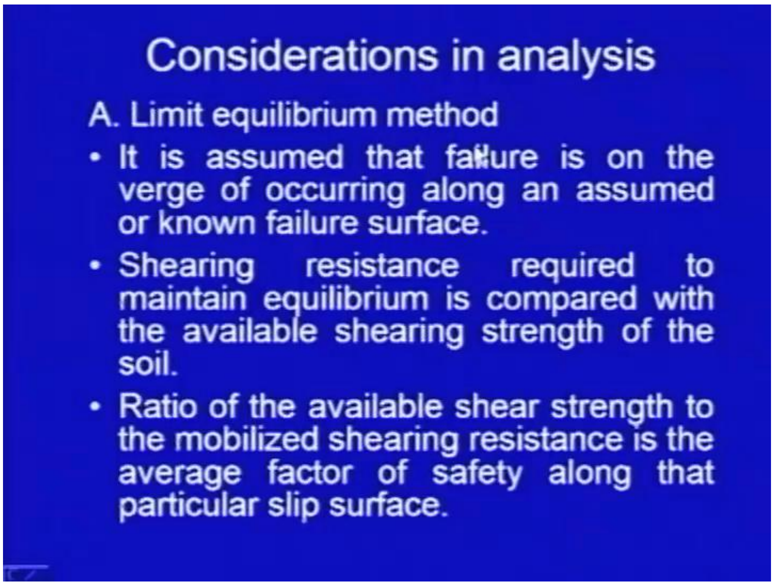

We shall be using limit equilibrium method in this analysis, in this particular course and this particular method assumes that the failure is on the verge of occurring along an assumed or known failure surface, as I told you there are infinite number of possible potential failure surfaces. So, in this method we assume a potential failure surface, it may be a planar surface, it may be curvilinear surface and then first of all we assume for particular failure surface. Then, second step is shearing resistance required to maintain equilibrium is compared with the other level shearing strength of the soil.

So, in this method what we do is first we take a failure surface, on that failure surface we find out what are the shearing stresses. Once, the shearing stresses are known to you, you can find out what is the required shearing strength, required shearing strength will be equal to the applied shearing stresses. So, the required shearing strength is compared than with the available shearing strength, available means what is the maximum value with that particular soil mass can offer.

So, here two things come into picture, one is mobilized that term which I used earlier was mobilized shear strength. So, mobilized means for example, let me talk in terms of units, the maximum shear strength that can develop it is five units and suppose applied shear stress is two units. So, the mobilized shear strength will be two units only because, it is less than five, so mobilized shear strength is two units available is five, so it will be safe.

Then finally, ratio of the available shear strength to the mobilized shearing resistance is the average factor of safety along the particular slip surface. So, finally, we talk in terms of the available shear strength and how much is mobilized, so if available is more than mobilized it will be stable. If available is less when you need more you need to mobilize more, so it is not going to be a stable slope it is going to fail. So, factors safety is defined as the ratio of the available shear strength to the mobilized shearing resistance.

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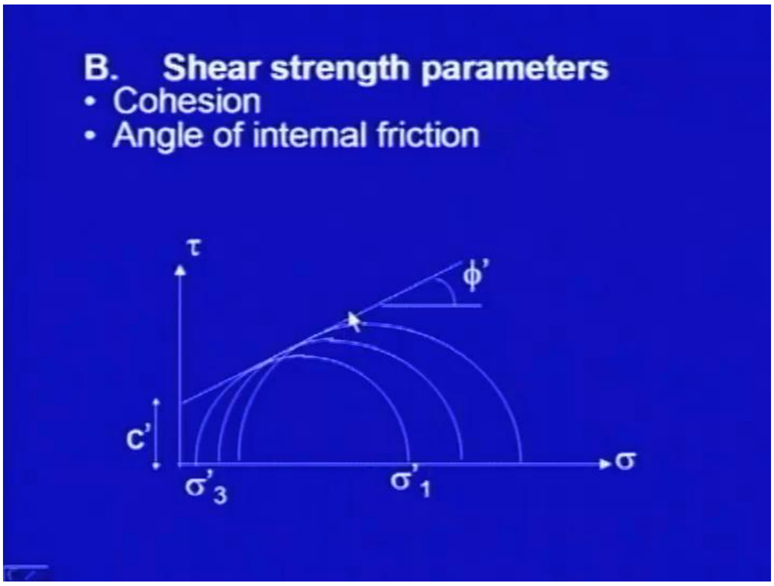

Coming to the shear strength parameters because, all these stability analysis whatever stability analysis you are going to do now, it has to be very it will be very sensitive to these parameters, these parameters are very important. There are two shear strength parameters which we use, this you know them the first is called as cohesion and second one is called as angle of internal friction or angle of shearing resistance.

How we get it, you have already studied in your soil mechanics course, we do some tri axial tests from the tri axial test we get data between confining stress, and major principle stress at failure, from those data we plot the Mohr circles. So, these are the Mohr circles, from these Mohr circles then we plot a common tangent, this represents the failure envelope. And the significance of this failure envelope is it tells you, what is the relationship between the normal stress and the shear strength at failure.

So, far any given normal stress you can calculate the shear strength, so here we are using a straight line variation. So, it will bean an equation between C dash and phi dash, so Y is equal to m x plus C that is the form of an equation, so tau will be equal to m, m becomes tan phi into x, x becomes sigma and C dash is the intercept. And the significance of this particular failure envelope, this failure envelope is that it tells you about the stability also.

If there is a stress state which is represented by this point it means the point is stable, if there is a stress state which is represented by a point on this failure envelope; that means, that it is in the limiting state, shear strength is exactly equal to shear stress. And if there is a if point which is here it is not possible because, you cannot have shear, shear stress is exceeding shear strength. So, we will be using this these shear strength parameters, they are very important cohesion and angle of internal friction, these are the important parameters.

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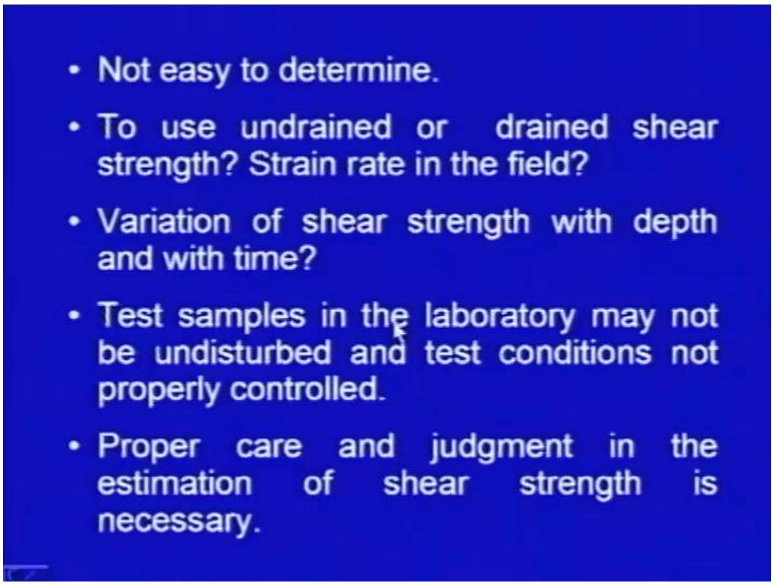

Some discussions about these parameters is necessary, first point about this parameters is it is not easy to determine these parameters, though we take it granted sometimes we do that test. And we take the C phi values, but it is very difficult to determine these parameters, in the sense that representative value of these parameters, what is that value which is actually applicable in the field it is difficult.

You have to decide whether to use undrained or drained shear strength, we will be discussing this point later on also. Undrained and drained conditions depend on this strength read, this read of strain at which the failure occurs and what is the permeability of the soil. If the permeability is very large for example, if it is a sandy soil, you can treat it to be a drained, you can use the drained shear strength parameters.

But, if it is clay soil, if it is even it is silty soil then what is the rate of strain compared to the rate of dissipation of pore water pressure, that is very important. So, drained condition and undrained conditions they are complex, phenomena and we have to give reasonable solution we have to think in terms of these things. Then, variation of shear strength with depth and time, we in most of the analysis which we will be discussing we will be taking this shear strength parameters to be constant throughout the soil mass.

We will be treating the soil mass to be homogeneous, as well as isotropic, homogeneous means the properties are same at different points and isotropic means properties are same in different directions. So, these things these conditions are not actually true for real field conditions, in the field you will find that as the depth increases, the shear strength the soil becomes more and more stronger, so those points if possible should be considered.

Then, next point is we take these parameters from laboratory tests and laboratory tests are supposed to be undisturbed samples. And also the test conditions which is stimulate in the laboratory should be properly controlled and they should indicate, they should represent the field situations or sometimes this is not possible. The samples may not be disturbed undisturbed samples, and those conditions which we are trying to stimulate in the field, they are not properly stimulated, test conditions may not be properly controlled.

So, there will be lot of variation in the shear strength parameters, so finally, this is the statement which I am giving that proper care and also lot of judgment comes into picture, your experience will also come into picture in estimation of the shear strength parameters.

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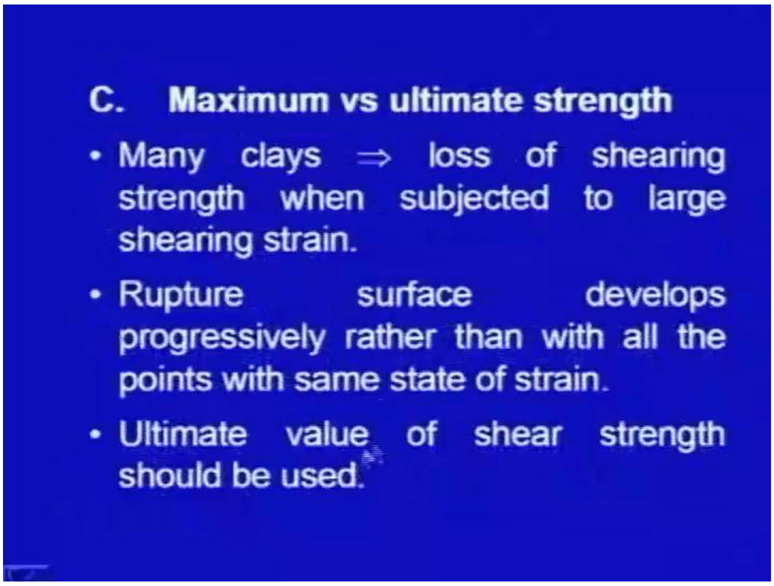

The next point, which you will have to answer is whether we should use maximum shear strength or the ultimate shear strength. You will find, that it happens in case of the clays especially that as the shearing strength increases the soil loses its strength, if you draw stress strain curves and if one case the shearing strain is very large, as the shearing strain goes on increasing the strength goes on decreasing.

And in the field, it has been observed that rupture surface is it does not develop in one go, it is a progressive phenomena, the same strain does not develop at all the points, but it develops progressively. So, the rupture surface develops progressively, rather than with all the points with same state of strain, so and it happens in case of the clays as I told you, especially over consolidated clays. So, it is preferred that ultimate value, ultimate value is at a very large strain that value should be used instead of the maximum value in the analysis.

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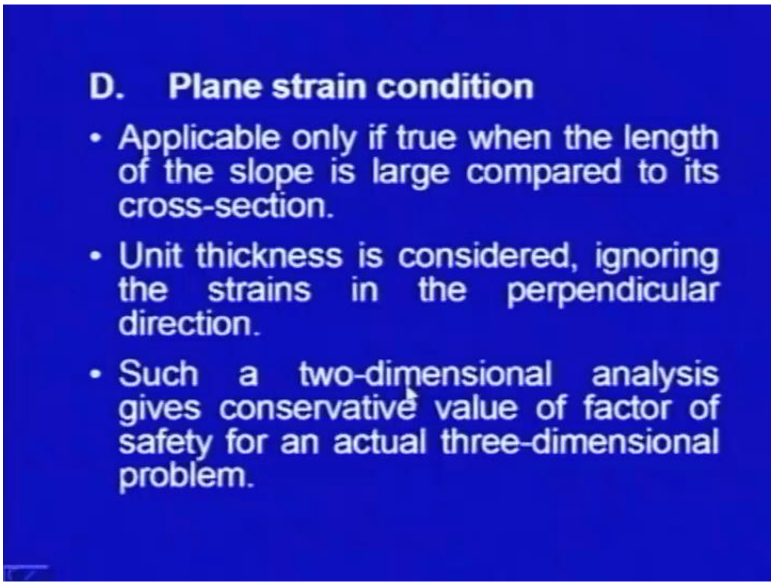

The next point, which we will be discussing is plane strain condition, in all the problems in hole the analysis which we are going to do most of the times we will be using a two dimensional analysis, it is called as plane strain condition. Plane strain means, all these strains are occurring in one plane, out of plane strains out of plane deformations are ignored they are not considered.

So, these 2D formulations are applicable, if the length of the slope and it is true for any other structure also for foundations also it is true, that if the length of that structure is quite large compared to the cross section. Then and only then, you can use this 2D formulation, if the length, length means the dimension of the slope perpendicular to the plane of paper. So, if that dimension is very large, then you can assume that plane strain condition will be applicable, otherwise you have to do three dimensional analysis.

So, that is first thing you have to keep in mind, that when we do the analysis all these analysis we are doing in two dimension. That means, in three dimension the structure same geometry of the section is continuing for a large distance and in the analysis, we consider unit thickness. So, unit thickness is considered ignoring the strain in the perpendicular direction, so for analysis purpose we will be taking the dimensions which are perpendicular to the plane of paper as unity, and then taking that unity or we will be analyzing the slopes.

Now, this is a two dimensional analysis and as I told you, if it is not meeting the requirement you have to do the 3D analysis. And this two dimensional analysis in general gives conservative values of the factor of safety for an actual three dimensional problem. So, I am stopping here itself, today we have discussed, we have started the introduction of the slopes, we talked about what are the different types of the slopes, we gave the examples of different manmade and natural slopes.

So, after classification then we started discussing the mechanics, we discussed what mechanically how mechanically we are going to tackle the problem of stability of slopes. And then, we discussed some considerations about the shear strength parameters and other problems, and we shall continue with these considerations in the next lecture also. In the next lecture again we shall discuss about, what are the other points and then we will go to the actual analysis of the slopes.