Application of Soil Mechanics
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Lecture – 28

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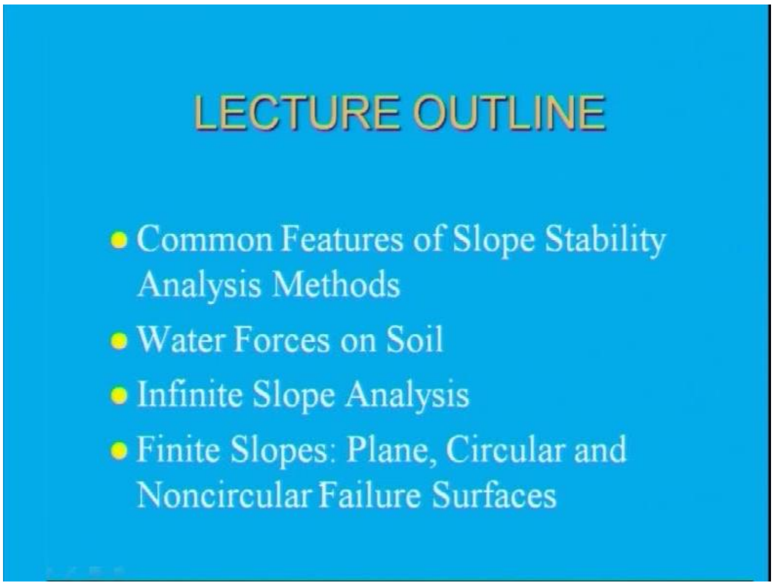

Last lecture we have finish this basic introduction to this slope stability analysis; that means, different modes of slope failures, and what is the reason, and in this part we are going to discuss about this slope stability analysis in this lecture outline will discuss this common features of slope stability analysis method water forces on soil infinite slope analysis, and finite slopes I have discuss also last class plane circular, and noncircular failure surfaces.

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Now, common features of slope stability analysis method if I say the factor safety s f is equal to s by s m where s is equal to shear strength s m is equal to your mobilized shear strength shear resistance. So, if this factor safety is equal to one for particularly slope stability analysis if this factor safety is equal to one, then you can say that it is slope is, and slope is in failure it is in failure if it is one, then you can say that it is fill fail; that means, slope has been failed factor safety should be greater than one for stability analysis point of view this is the basic requirement, then shape, and location of failure surface is not known a priority, but assumed generally we do not know the shape, and this location of the failure surface generally it has been assume by trial, and error by trial, and error method this what I what I mean this shape, and location of failure surface is not known to us. So, let us start with a simple.

Slope with a slope you start with this with this slope what we are suppose to do you assume this failure surface different failure surface is you assume with respect to different failure surfaces by trial, and error method find it out the factor safety suppose for example, case one, and case two case three these are the three assume failure surface for one two three if the factor safety for one if the factor safety is one point one for two if the factor safety is one point two let us say for three failure surface factor safety is one point three; that means, out of these three the minimum factor safety minimum factor safety is comes out to be one point one; that means, this failure surface generally considered is your limiting failure surface, then your static equilibrium static equilibrium is a equilibrium forces, and moments on the sliding masses; that means, equilibrium forces, and whatever the moments on the sliding masses that has to be consider, then you are two dimensional analysis this is the outline of this slope stability analysis methods or features.

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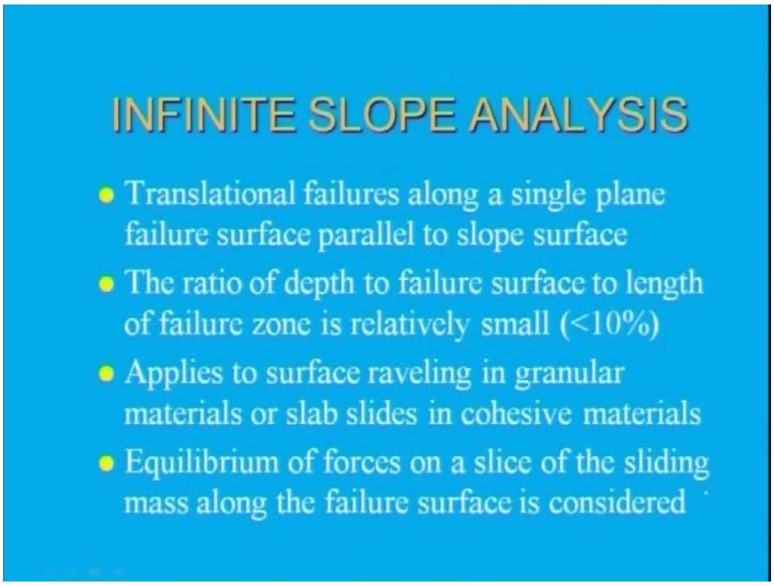

Now, in case of infinite slope analysis as I said earlier this set it will be infinite. So, translational failure along a single plane failure surface parallel to your slope surface in case of infinite slope analysis a translational failure along a single plane failure surface parallel to slope slope surface the ratio of depth to failure surface to length of failure zone is relatively small the ratio of depth to failure surface the ratio look at this the ratio of depth to failure surface to length of failure zone depth to length of failure zone is relatively small in case of infinite slope analysis applies to surface raveling.

In granular material or slab sliding in cohesive material, if you look at this apply to the surface; that means, in granular material or slab slides slab slides, in case of cohesive material, in case of cohesive material particularly slab slides, in case of cohesive material equilibrium of forces on a slice of the sliding mass along the failure surface is considered equilibrium. Look at here equilibrium of forces on a slice of the sliding mass on a slice of a of the sliding mass on a slice of the sliding mass along the failure, surface is considered along the failure, surface means whatever along the failure surface this equilibrium condition has to be considered.

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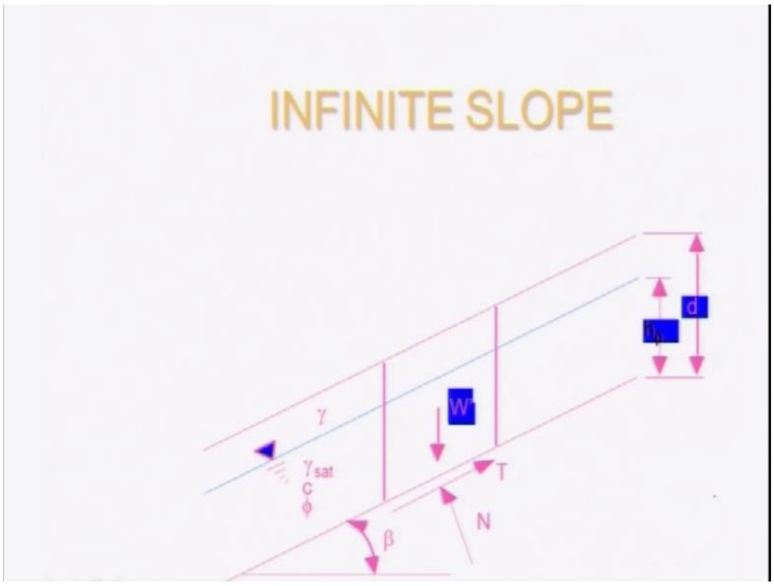

Now, take this case of infinite slope in this infinite slope like on consider a small part in the infinite slope let us say gamma is unit weight above this, above this water table there is water table below this water table soil property is gamma saturated c, and phi, and w is your weight of your mass, and normal force as well as tangential force these your depth of your infinite slope. Now force is a function force is a function if you look at your c prime phi prime gamma beta d, and u. So, if you if I come back to here beta is your angle look at here beta is your angle at what angle this infinite slope makes to respect to your horizontal.

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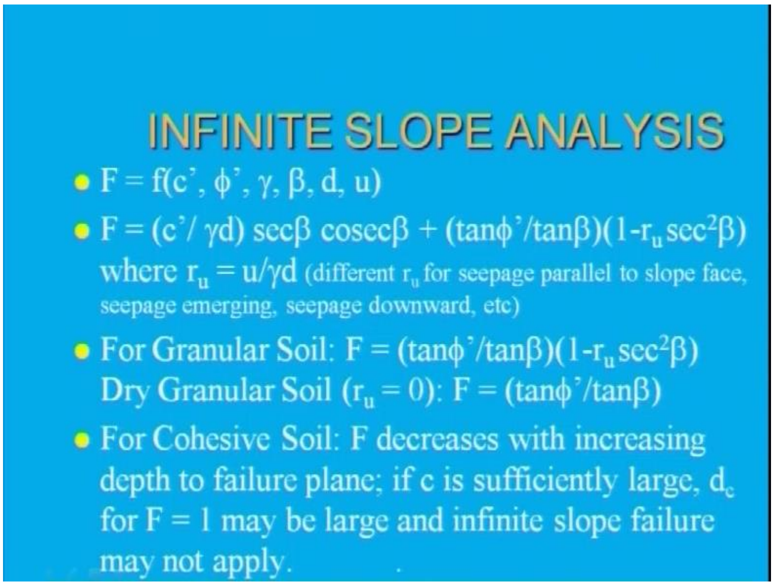

So, now this is a function of c prime phi prime gamma this is your properties of this soil beta is your angle d is your depth e is your pro rata pressure. So, with respect to that where you can find it out r u r u is your different r u for seepage parallel to the slope surface seepage emerging, and seepage downward etcetera for granular soil factor safety particular it is factor of safety this f granular soil in sorry, in case of infinite slope analysis this factor of safety is a function of if you look at here it is not force this is a factor safety it is a function of function of c phi gamma b beta d, and u.

So, for granular soil f is a function of tan phi prime by tan beta one minus r u sec square beta for dry granular soil where there is no water table r u is equal to zero f is equal to tan phi prime by tan beta factor safety is equal to tan phi prime by tan beta tan phi is your it is your property of soil in an angle of this soil, then beta is your angle with this slope has make. So, for cohesive soil factor safety decreases with increasing depth of failure plane factor safety decreases with increasing depth of your failure plane that is; that means, if c is sufficiently large small c is sufficiently large that is your unit cohesion is sufficiently large, and d c, then for factor safety one may be large, and infinite slope failure may not apply in these case infinite slope may not be apply if c is sufficiently large.

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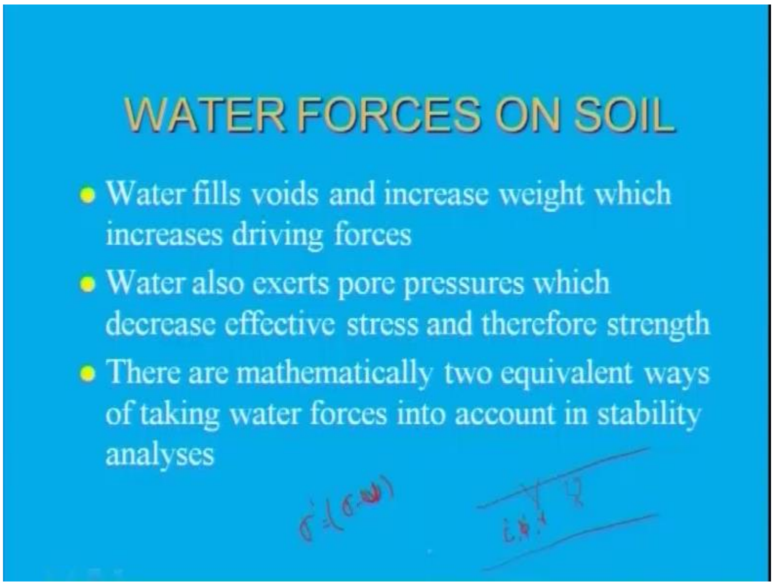

Now, next part is your water forces on soil water fills the voids water fills the voids, and increase weight, which increases your driving forces particularly what happen in inside the void voids base water fills once water fills inside the voids base. If this is my if this is the case of this, this is my this is your infinite slope, if there is a crack or maybe there are the voids inside the voids inside the voids.

What will happen? Water fills the voids; that means, earlier this is a soil mass this might means c prime, and phi prime, and your gamma gamma is your unit weight of soil, and if water pore inside the voids what will happen it increase the weight of it increase the weight means it will increase this driving force water also exerts pore pressure as we know water also exerts pore water pressure, because of water which decreases your effective stress therefore, the strength if I take into effective stress like sigma prime is equal to sigma minus u. So, u is your u is your pore water pressure once water fills this voids the pore water pressure increases; that means, it decreases your effective stress therefore, this strength also it will happen effect your strength there are mathematically two equivalent ways of taking water forces into account in stability analysis there are two ways to take consideration of water forces.

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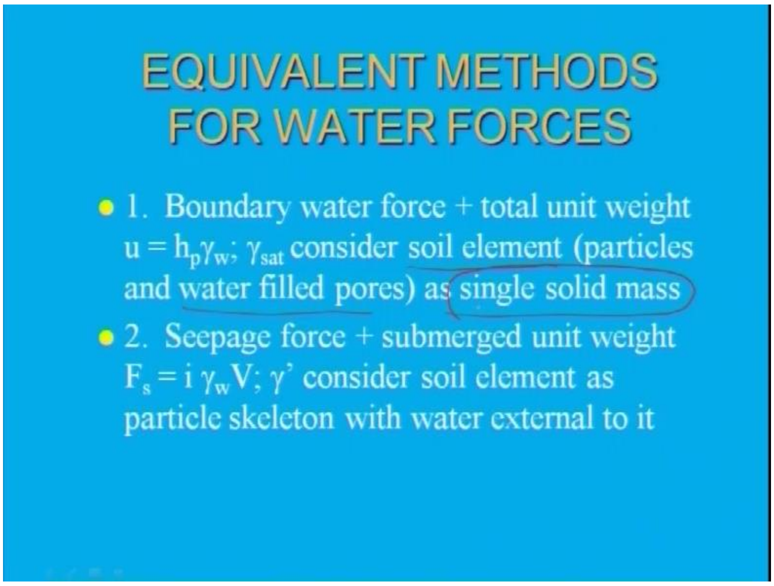

First one is your equivalent methods for water forces, first one is your boundary water forces plus total unit weight boundary water forces plus total unit weight u is equal to h p into gamma w gamma saturated gamma w or gamma saturated consider soil element particle, and water filled pores as a single solid mass considering soil element considering this soil element considering soil element as well as; that means, particle soil element means particle of this soil along with your water it consider as a one single solid mass one single solid mass, then case two second conditions seepage force plus submerged unit weight submerged unit weight; that means, your factor safety will coming I gamma w v, where r gamma consider a soil element as particles skeleton soil element as particles skeleton with water external to it with water external to it.

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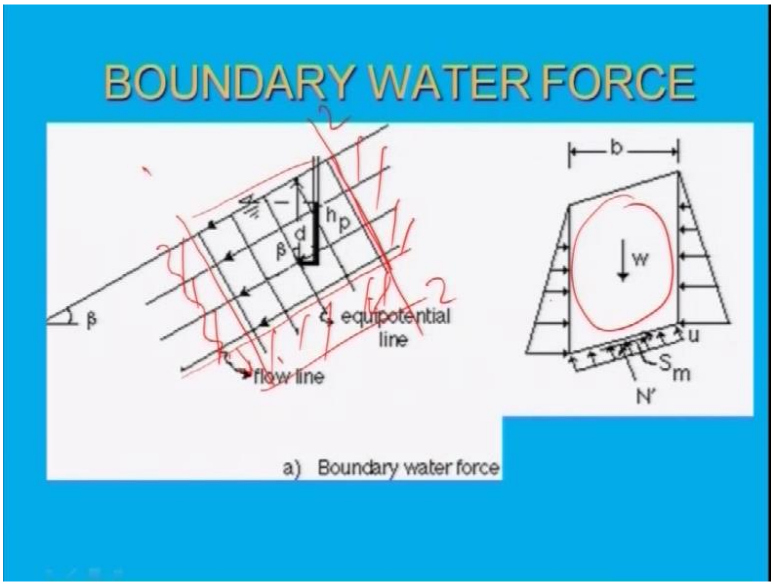

Now, if you look at here if you look at here this this is an infinite slope at angle beta, if you look at here; these are this is my eco potential lines, and these are my flow lines, if I make it into flow net. If I make the flow net in the infinite slope, and these are my this is your flow lines this is your flow lines, and this is your eco potential lines this is your flow line, and this is your eco potential line case one where discussing that is your boundary water forces. If I consider a small element of this part, if I consider a small element of this part, if this is your width is b, and this is your weight w acted.

If you look at here, both the sides both the sides how the water pressure generated, and at the bottom also here pore water pressure at the base as we as a same, and normal force will be acted on this. So, what is the case one in this case one boundary water force plus total unit width in the case one we are considering a small element with the small element of soil we are taking the boundary at the boundary what is the water forces acting, and plus your total unit weight we have consider in this case what will happen soil element soil element means insides soil element. If I if I consider if you look at here; first case this is a boundary, if this is my if this is the this is the soil element I am going to consider this is a soil element. Let us say one one, two two in this soil element what will happen? If I go to back boundary water forces; that means, these are my boundary water forces.

These are my boundary water forces here, one boundary here, other boundary here, other boundary at the bottom. So, these are the boundary water forces at the left hand side at the right hand side at the bottom the boundary water forces consider, and another assumption is that water inside the soil, if this this part I have taken into consideration; that means, within this part there is a soil mass within the soil mass what will happen? Water also there this has to be this has been consider as a one solid element. So, this is your this is your one solid element of weight w width b, and these are will have all of your boundary water forces this is your lateral water forces lateral at the bottom.

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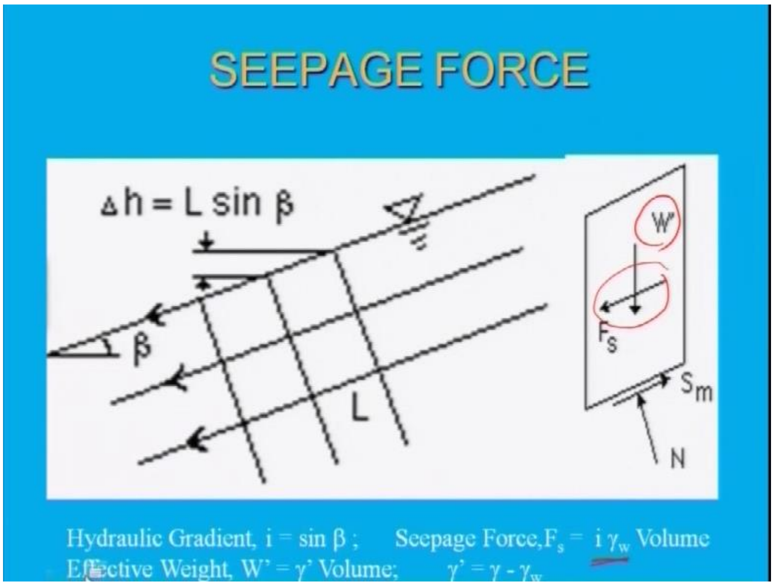

So, this is your case one considering your water forces. Now if you look at this beta hydraulic guardian case two. If I take into consideration of case two what is the case two, case two is your sip case two; there are two methods you can find it out, one is your considering your boundary water forces second is your seepage force either of the two method you can solve this seepage force plus submerged unit weight consider soil element as particle skeleton with water external to it particle skeleton with water external to it particle skeleton with water external to it particle skeleton with water external to it now if this is your infinite slope in case two; that means, seepage force seepage force plus submerged unit weight to be consider. Now here hydraulic guardian I is equal to sin beta with respect to that seepage force, if I take this soil element here this is my seepage force.

So, this seepage force this seepage force will be acting this way. So, this seepage force is I w I into gamma w I is your hydraulic guardian gamma w is your unit weight of water in terms of volume, then effective weight effective weight is your nothing, but is your w is your effective weight which is equal to gamma into volume effective weight w is equal to gamma is equal to gamma is equal to unit weight of the soil mass for volume unit weight of the soil mass for volume means mass into or weight into the volume from there you can find it out effective weight, then gamma prime submerge unit weight is equal to gamma minus gamma w or substituted minus gamma w from there you can find it out your by means of second method you can also find it out.

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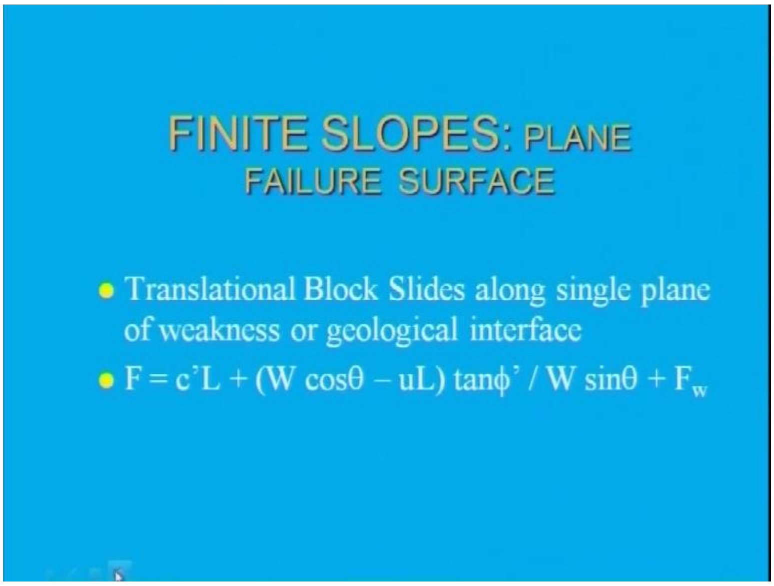

Now, these are this is the case we have discussed particularly if I remove it again this is the case we have discussed particularly taking into consideration of infinite slope I have also discussed this infinite slope infinite slope by taking this infinite slope what first you consider a small element, and take the equilibrium into consideration; that means, I have taken this element of these, then equilibrium consideration point of view this is a weight, then this has been acted at an angle beta, then tangential force, and normal forces acted on these. So, with these infinite slope there are two two analysis are come into picture as per as water forces are consider case one, we have consider as a water field void case one we consider one is your boundary water forces with your total unit weight other, there are two equivalent method; one is your boundary water force plus total unit weight second case is your seepage force plus submerge unit weight, we have discussed also now proceed to finite slope.

This is the case infinite slope has been over now proceed to finite slope in this finite slope first case is your plane failure surface. So, where the plane failure surface occur; that means, it is a translational block slides along single plane of weakness or geological interface translational block slides along single planes of weakness or geological interface. So, factor safety f is equal to c prime into l length w cos theta minus u is equal to pore water pressure into length into tan phi divided by w sin theta plus f w.

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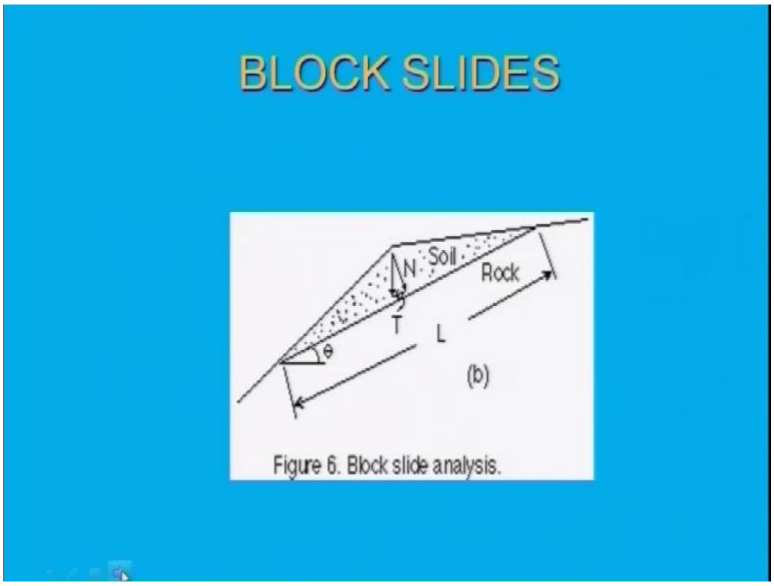

Now, if you look at this block slide analysis block slide analysis; that means, a planner or plane failure surface in these case in case of, if I take into consideration. If I take into consideration this flow, as like this, this flow as like this. If I take into consideration in which case is generally occur suppose there is a rock mass above the rock mass there is a soil slope. So, what will happen? It will fail in a plane failure surface in a plane failure surface it will fail so; that means, what will happen it, it makes an angle with this theta, this is your plane failure surface with these if this is my length. So, there will a weight weight as well as normal force with respect to your theta.

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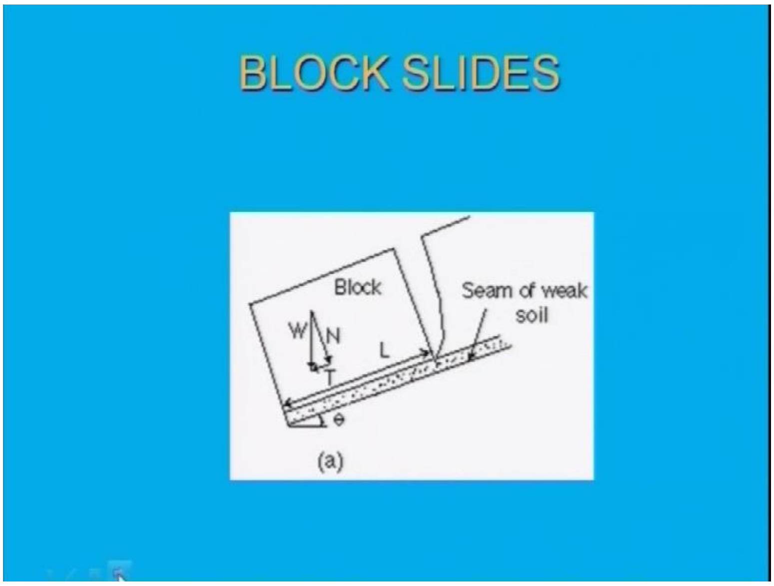

This is called block slides, now another case of this seam of weak soil there is a hard soil of this, then below this there is weak soil in that case also plane failure surface suppose to be occur. So, there is a block in these block there is u unit weight; that means, your weight of the soil mass as well as weight of the soil mass plus normal component as well as tan tangential component with respect to that will have to find it out this factor safety. So, case tow seam of weak, sorry we are discussing right. Now where this block slides occurs case one if there is rock mass rock mass above rock mass there is a soil is there what will happen there is a block slide.

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That means plane failure surface will occur now, in these case case two; if there is weight soil above the weight soil there is a soil mass what will happen again? There is a block slide will occur this is a case we are discussing now for your plane failure surface where it occurs second is your finites slope, that is your circular failure surface are circular failure surface are generally we do by means of rotational slides rotational slides by method of slices method apply to slopes containing cohesive soil apply to the soil the condition here.

The slopes particularly the slope where it has where it has cohesive soil it has been apply to your cohesive soil ordinary methods of slices it has been solve by ordinary method of slices this has been given by your felonies method, then also there are other methods this is called bishop's simplified method or spenser's method these are also other methods available.

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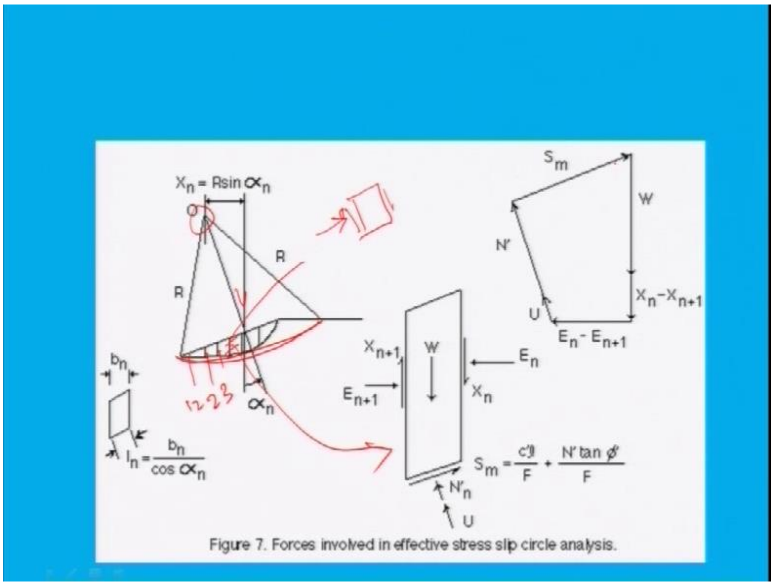

Now, if you look at this forces involved in effective stress slip circle analysis what are the forces involved if you look at here there is there is circular slip particularly in case of cohesive soil. So, will have to find it out where is your center potation where is your center potation o with these center potation o these are my radius with that with respect to that, With respect to that that your circular surface is there. So, then if this is o. So, then if this is my c g if this is my c g how for if o r this is the w will be acted how for from your center that is your r sin alpha, if I consider a slices. Now you take into consideration of a slices of any n slices if I name into one two three four five six it may be n number of slices I can do it also. So, if you take it into say let us consider a one slice, let us consider one slices that is your n slices n n x slices. So, in these case n x slices if you look at this this slices have taken into in a bigger picture. So, what will happen in this slices what are the forces suppose to act. If you take it here this slices will be acted by a lateral force what what happen? One it has been post. So, one one way it will be these are all your frictional resistance arounding two sides weight of your soil lateral resistance, then bottom bottom is your normal as well as pore water pressure pore water pressure. So, what will happen? So, you take all this make it into a equilibrium conditions equilibrium conditions means all the forces once it will be in equilibrium conditions. So, all the forces would meet if I draw it by head, and tell it should be emerged it should satisfy this equilibrium condition from there you can find it out your factor safety.

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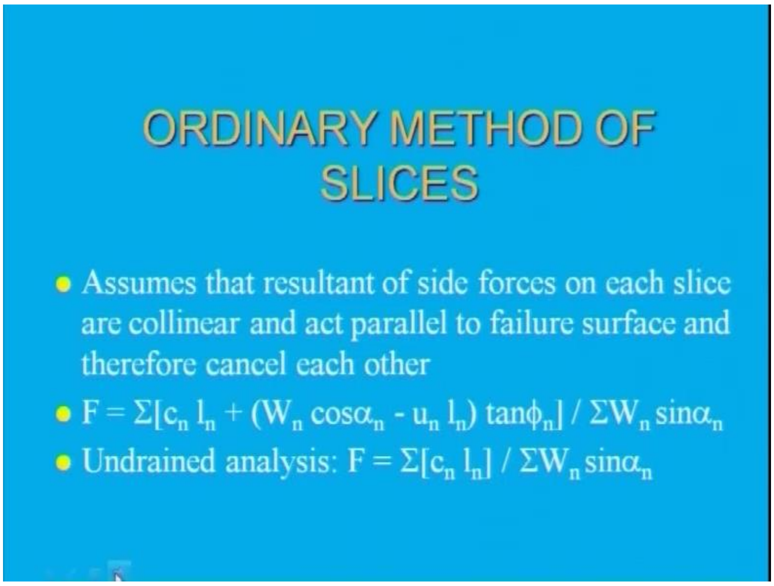

Now, go to this ordinary method of slices as proposed by Helenius in this case assumption that the resultant of side forces on each slice are collinear look at here this assumptions resultant of side forces resultant of side forces, on each slice on each slice are collinear resultant of side forces; that means, resultant of side forces on each slices are collinear act parallel to failure surface, and therefore, cancelled each other resultant of side forces.

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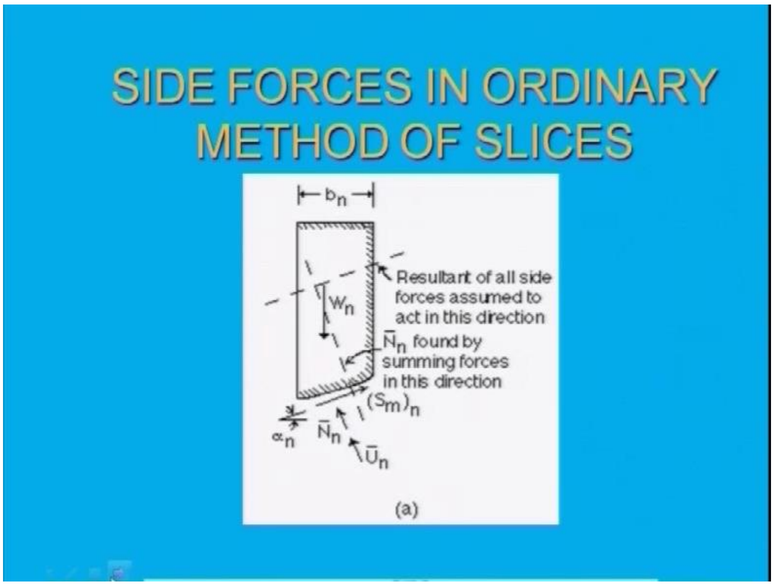

If you look at your what is your slide forces this is your side forces this side forces. So, what is it mean resultant of side forces resultant of side forces on each slices are collinear, and act parallel to failure surface act parallel parallel to your failure surface, and therefore, cancel each other one is up other is down. So, therefore, it cancel each other now once it has been cancel each other. So, what are the forces remaining now in simple method of ordinary method of slices.

In this case, if you look at here, if this is my slice one slice has been consider only weight w n normal forces as well as tangential forces as well as pore water pressure. So, what will happen this is my normal forces this is my normal forces this is your shear stress or tangential forces, then along the normal forces also pore water pressure act into picture. So, this makes angle at an angle alpha, and on theta, and it depends on that. So, other force is your weight of these slice, and this side forces cancel to each other in case of ordinary method of slices. So, here it is retained that resultant of all side forces assumed to be act in this direction. So, n n normal force found out by summing forces in this direction particularly particularly.

In this direction what is a normal forces summing up where they are meeting to your c g. Now this is your ordinary slice method who has given this ordinary slice method it has been given by means of a felonious felonious is the person who has given this solution it is called ordinary method of slices. Now come back to second one is your bishop's simplified method bishop's simplified methods in case of bishop's simplified method assumed that the resultant of slide side force forces on each slice act in horizontal direction assume that resultant of side forces assume that resultant of side forces on each slice resultant of si side forces on each slices, act in horizontal direction. And therefore, vertical side forces vertical side force component can c component cancel each other. So, this is their assumption the assumption they have given with that resultant of side forces on each slices act in horizontal direction, and therefore, vertical side force component cancel each other. So, factor safety comes out to be c n b c is your unit cohesion b is your width plus w n minus u n, and b n u is your pore water pressure tan phi n one by m alpha divided by summation of w n sin alpha. So, m alp an alpha is equal to cos alpha n plus sin alpha n tan alpha n divided by f for untrained analysis factor safety if this si for untrained analysis c n l n by w n sin alpha n.

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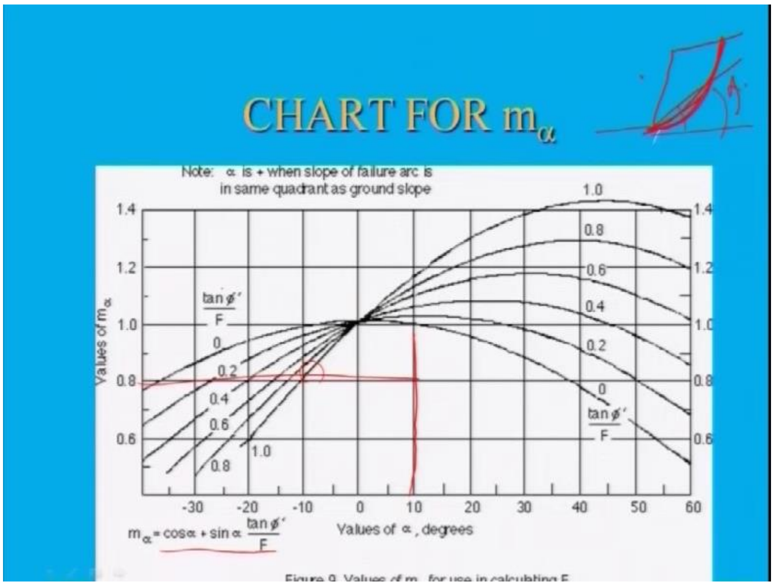

So, bishop they have given chart to find it out m alpha alpha is positive when slope failure are is same quadrant as ground slope, you see alpha is positive when slope failure are slope failure are if this a slope alpha is positive when slope failure are when slope failure are is same quadrant is same quadrant as ground slope in the same quadrant as ground slope. If suppose this ground slope is this in the same quadrant quadrant one quadrant two quadrant three quadrant four, then it is considered to be positive. So, based on that based on that positive and negative values of alpha they have given the charts they have consider the value of alpha from zero degree to plus sixty degree, and zero degree to minus thirty degree, and with respect to that they have given this values of m alpha barring from zero point six to one point four. If you know this value of m alpha we can calculate from this cos alpha sin alpha ton phi prime by factor safety. So, alpha is your slope angle means slope is at what angle it makes with your ground surface cos alpha plus sin alpha ton phi prime by factor safety. So, alpha is degree is given you take this alpha what degree it is there, then with respect to that you calculate your m alpha one suppose for example, alpha is equal to ten degree I am taking with this, suppose value of m alpha is point eight point eight now where it where it inter set, if you look at it inter sets of from my reals from where you can find it out tan phi prime by factor safety.

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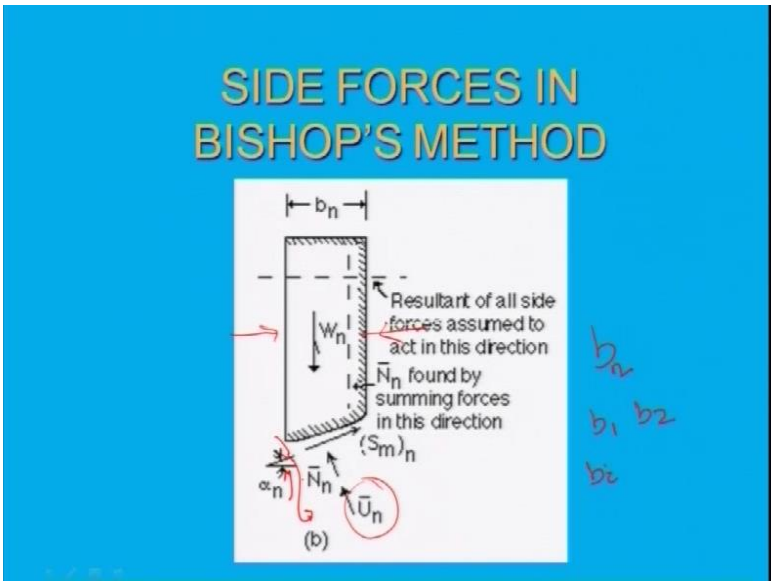

So, you know the phi. So, you can find it out your factor safety this is the chart for your a m alpha has been given, then side forces in boshops method side forces in boshops method. As I said earlier resultant of all side forces assume to act in this directions resultant of all side forces side forces resultant of all side forces resultant of all side forces are assume to act in this directions, and n n found by summing forces in this direction n n is found by summing forces in this directions your u n is pore water pressure in normal direction s m is your shear forces, then b n is your width width of that n. If you look at here b is equal to width n is equal to, if I consider one number slide. So, this will be b one. If I consider number two slide this will be b two, if I consider number I slide is it would be b i. So, alpha n here alpha n if you look at here, it makes an angle this looks makes an angle with your horizontal at the ground surface.

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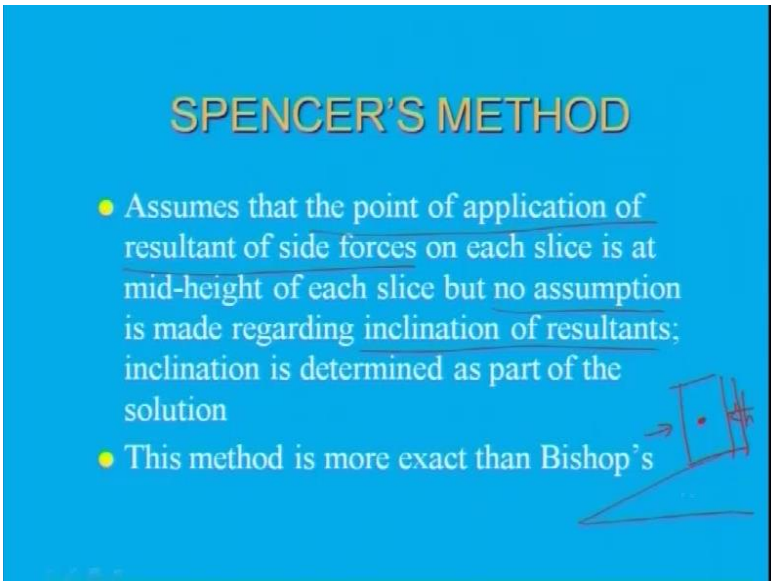

Now, last one is your that is your spencer's method, in these spencer's method assumes that the point of application of resultant of side forces point of application of resultant of side forces on each slices is at mid height of each slices, look at here this assumption. It is a modified of that earlier two method; first one is your by simply slice method, second is your bishop's method, third is your this your spencer's method. In this case the assumption is that point of application the point of application of resultant of side forces the point of application of, if this is my slice point of application of resultant side forces on each slice resultant side forces on each slice is at mid height of each slices; that means, if this is height is at mid height.

It will act at mid height of these slice, but no assumption is made regarding inclination of resultants look at the look at these draw backs particularly in case of each method in case of spencer's method there is no assumptions there is no assumptions made regarding inclination of resultant inclination of resultant means the moment I implied the slope, if inclining the moment the slope will be inclining; obviously, the resultant of your side forces will be inclining. So, there is no assumptions whatever the slope angle they say with respect to that slope angle they have consider a resultant forces of each slices is at mid height of each slice resultant forces of each slice is at mid height; that means, whatever the angle resultant of this forces will act as mid height, and this method if I compare with these method, which is your bishop's method this method is more or less you can said that more exact more appropriate.

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Then your bishop's method will discuss more in the next class about this finite slopes noncircular failure surface in the next class.

Thank you.