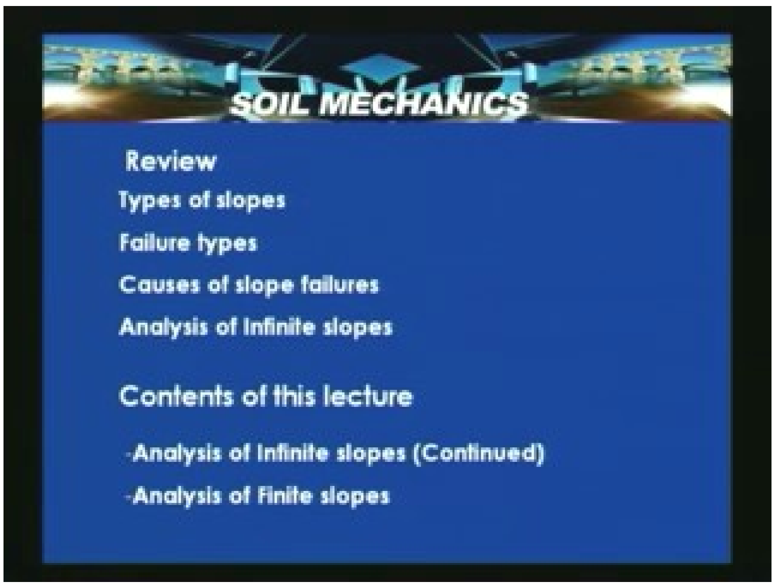
Soil Mechanics
Prof. B.V.S. Viswanathan
Department of Civil Engineering
Indian Institute of Technology, Bombay
Lecture – 56
Stability analysis of slopes – II

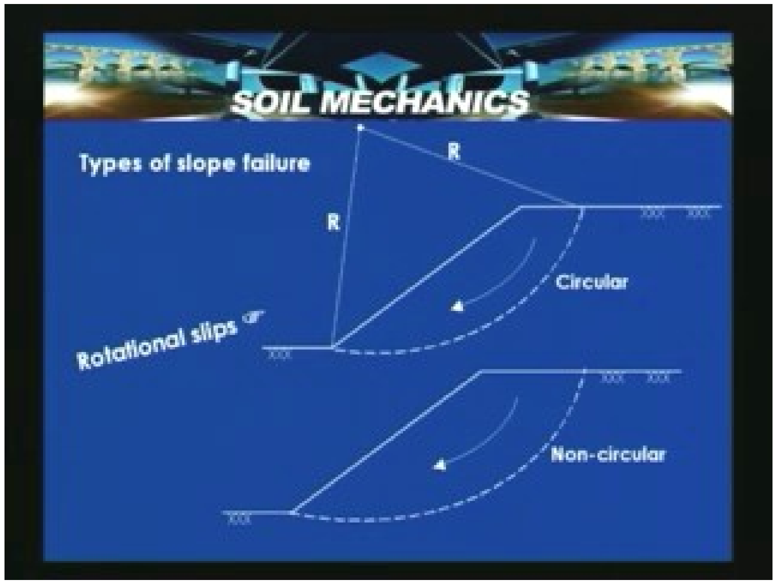
Welcome to lecture two on stability analysis of slopes. In the previous lecture we have introduced stability analysis of slopes and we discussed about types of slopes, failure types and causes of slope failure and analysis of infinite slopes we just introduced. Contents of this lecture we will discuss further on analysis of infinite slopes and thereafter we will try to look how a finite slope can be analyzed.

(Refer Slide Time: 01:15)

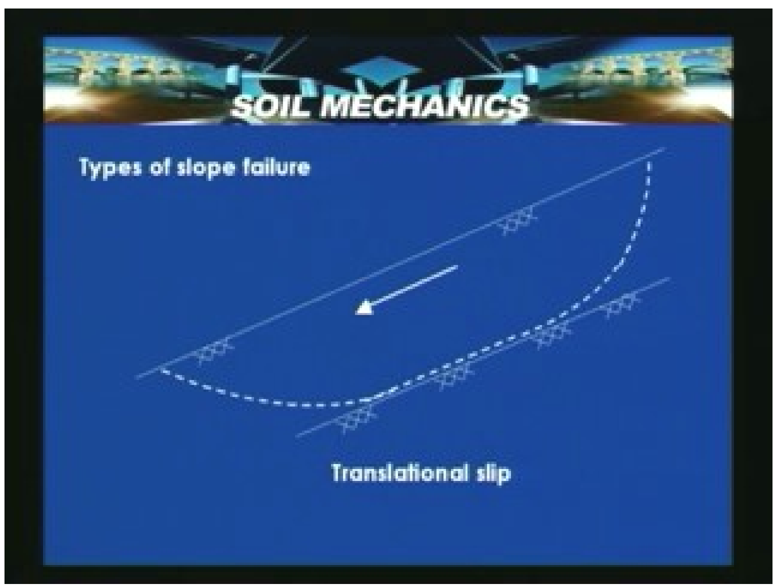


In this slide we can see two typical types of failure for a slope, they are circular and non circular and in this slide a transitional failure was shown that is either particular type of slope failure.

(Refer Slide Time: 01:21)

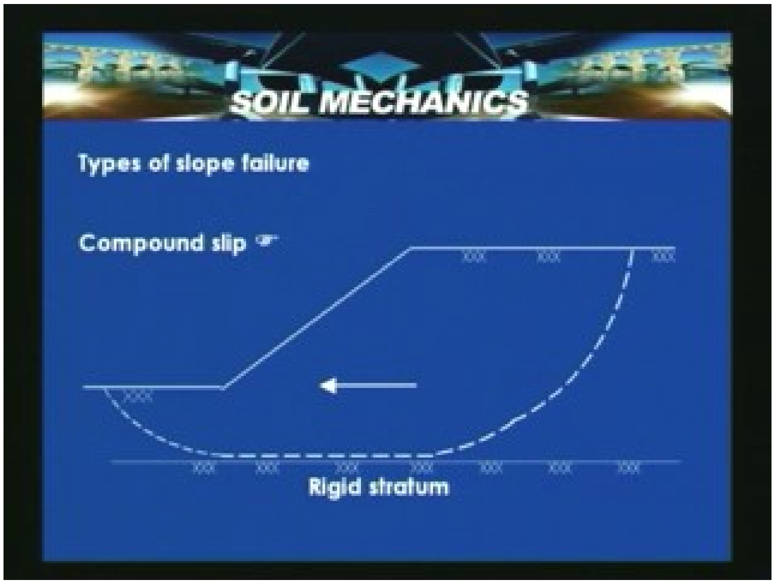


(Refer Slide Time: 01:35)



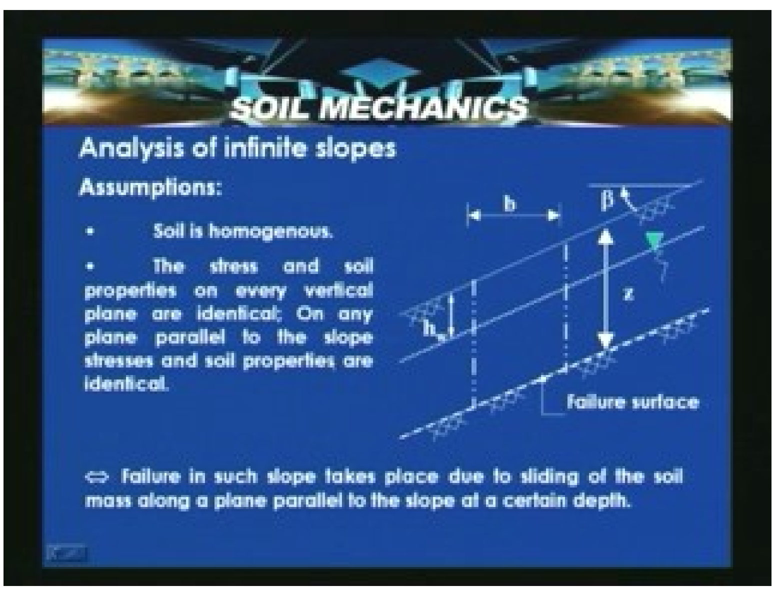
In case if there is a rigid stratum at a certain depth below the ground level then the particular slope failure is said to be a compound slip or a base failure.

(Refer Slide Time: 01:53)



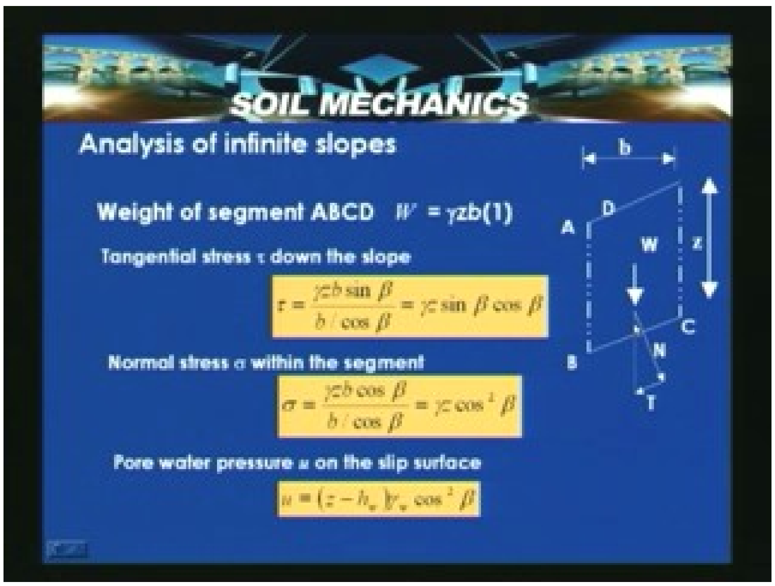
Now let us look in detail about the analysis of infinite slopes. The assumptions involved are soil is homogeneous; the stress and soil properties on every vertical plane are identical. On any plane parallel to the slope stresses and soil properties are identical. So the soil properties and the stresses are same. This implies that failure in such slope takes place due to sliding of the soil mass along a plane parallel to the slope surface at a certain depth.

(Refer Slide Time: 02:10)



So here a typical cross section of an infinite slope is shown and here is the slope surface which is inclined at an angle beta with horizontal and this is a rigid stratum and here with a broken line, the failure surface which is shown here at a depth z below the slope surface. The failure surface is parallel to the slope surface and h_w is the height of the water from the slope surface. Consider a block of width b horizontally which is shown in this slide and z is the depth of the block under consideration. This is the water table which is h_w units below the slope surface. Now let us look into the weight of the segment ABCD where this can be given as, w as the weight of the segment ABCD gamma that is unit weight, z is the depth, b is this horizontal width and then 1 is the per meter length of the section under consideration.

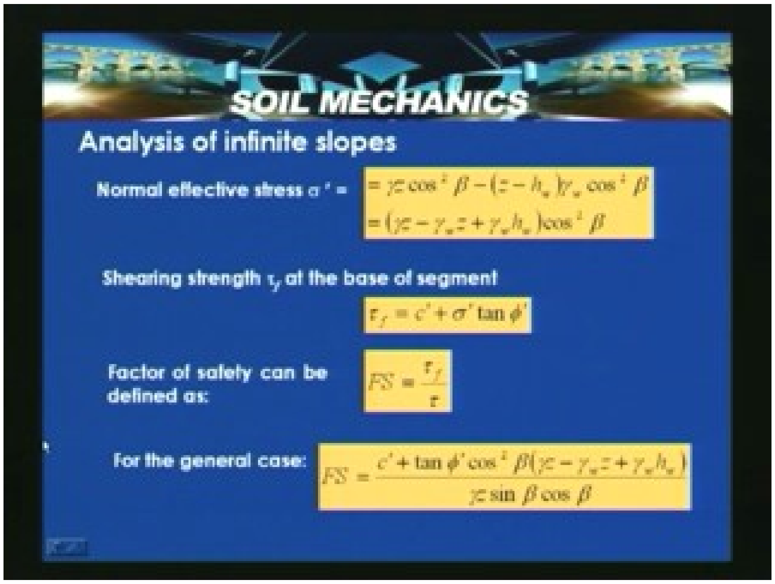
(Refer Slide Time: 03:47)



So based on that the weight of the segment ABCD can be given as w is equal to gamma zb, tangential stress tow down the slope can be determined from the tangential force t which is a component of weight of this segment ABCD which is given by tow is equal to gamma zb sin beta divided by b by cos beta which gives rise to gamma z sin beta cos beta that is tangential stress tow down the slope is tow is equal to gamma z sin beta cos beta. Normal stress sigma within the segment is sigma is equal to similarly gamma z cos square beta.

Now the pore water pressure u on the slip surface that is this particular surface is here, failure surface is here, h_w is the water height from the slope surface, the top surface of the water is h_w units below the slope surface. Hence this height is z minus h_w so u is equal to z minus h_w gamma_w cos square beta along the surface. So now the tangential stress tow and normal stress sigma within the segment and pore water pressure u on the slip surface. From this we can calculate normal effective stress sigma dash that is total stress minus pore water pressure. With this we will get gamma z minus gamma_wz plus gamma_w h_w cos square beta.

(Refer Slide Time: 05:25)

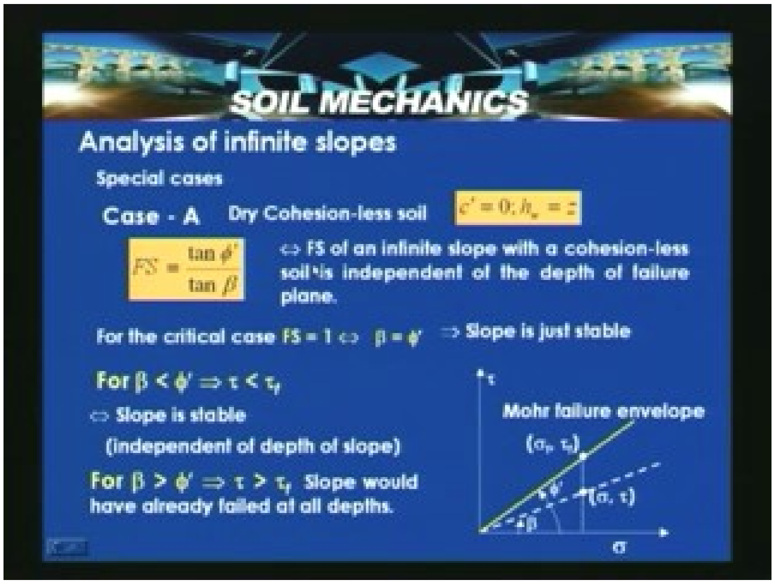


Shear strength available tow$_f$ at the base of the segment can be written as tow$_f$ is equal to c plus sigma tan phi. In case of effective strength parameters tow$_f$ is equal to c dash plus sigma dash tan phi dash. So factor of safety can be defined as tow$_f$ by tow, this tow$_f$ is the shear strength available and tow is the shear stress which is caused by the disturbing forces. So for the general case we can write now tow$_f$ substituting sigma dash here, we will get this expression which is factor of safety is equal to c dash plus tan phi dash into cos square beta into gamma z minus gamma$_w$ z plus gamma$_w$ h$_w$ divided by gamma z sin beta cos beta. So this is a general expression for an infinite slope stability analysis.

Let us look into different cases and we see that how the factor of safety varies. Now considering the special cases with an infinite slope, case A is a dry cohesion less soil where c dash is equal to zero, h$_w$ is equal to z that is the water level is at the failure surface that is along the rock stratum surface at a depth z from the top surface. In this case if you substitute in the generalized expression whatever just we introduced with c dash is equal to zero and z is equal to h$_w$ we get factor of safety is equal to tan phi dash by tan beta.

This expression indicates that factor of safety of an infinite slope with a cohesion less soil is independent of the depth of the failure plane. So this implies that factor of safety of an infinite slope with a cohesion less soil is independent of the depth of the failure plane. So for a critical case the factor of safety is equal to one indicates that beta is equal to phi dash that is slope inclination equal to the internal frictional angle of a material. This is actually nothing but an example how sand dunes formation in nature. So for a critical case if in case beta is greater than phi dash the slope tries to fail and adjust to an angle which is that angle of repose that is in this case phi dash will become phi angle of repose.

(Refer Slide Time: 07:03)



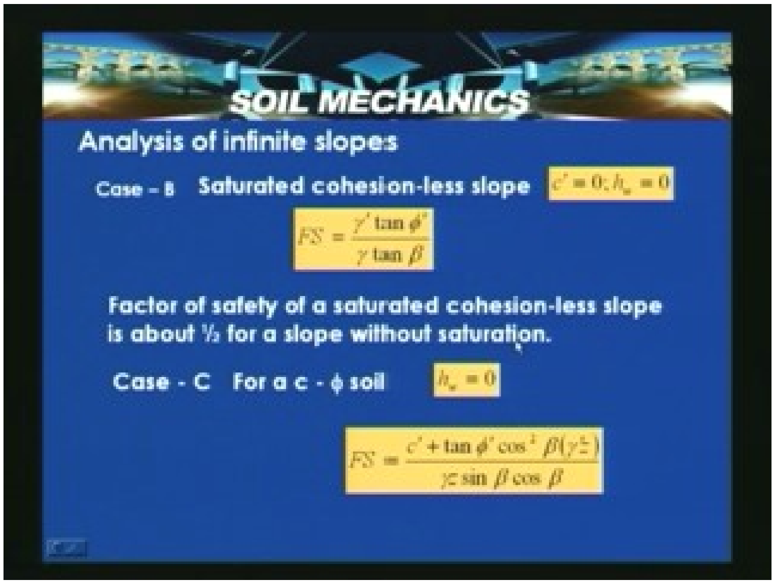
So for critical case the factor of safety is equal to one so beta is equal to phi dash, the slope is just stable; for beta less than phi dash that means the driving shear stress are less than the available shear strength. Let us look this in the tow sigma plot, let us consider a tow sigma plot which is shown here and slope inclination is indicated with broken line here and Mohr failure envelope is indicated with yellow line which is shown here.

As long as beta is less than phi dash, the tow is less than tow_f, the slope is said to be in stable position independent of the depth of the slope. For case beta is equal to phi dash just now we said that the tow is equal to tow_f that means the slope is just stable and the R is attaining or on the wedge of the failure.

When beta say greater than phi dash, if this line is above this line, the tow that is driving shear stress is more than the available shear strength that indicates the slope would have already failed at all depths. Suppose in case if that indication is there that means slope would have already failed at all depths. So for beta less than phi dash, tow is less than tow_f the slope is said to be in stable condition independent of the depth of the slope; for beta greater than phi dash slope tow is greater than tow_f slope would have already failed at all depths.

In case B let us consider saturated cohesion less slope that is in this case c dash is equal to and h_w is equal to zero that means water level is at the slope surface. With this case again in the general expression, if you substitute the factor of safety term is obtained like gamma dash that is submerged unit weight of the soil into tan phi dash divided by gamma tan beta, gamma is the bulk unit weight and beta is the slope inclination.

(Refer Slide Time: 10:18)

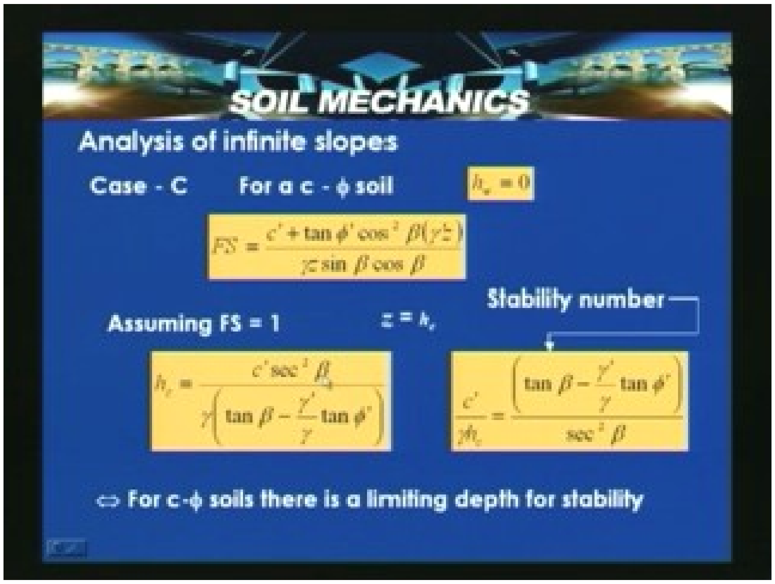


This indicates that factor of safety of a saturated cohesion less slope is about half for a slope without saturation. So that means if a slope is there with factor of safety of a saturated slope which is saturated cohesion less soil slope is 50% of the slope without saturation, if submerged by gamma is equal to approximately 0.5. For a c phi soil with h_w is equal to zero we can write this expression factor of safety is equal to c dash plus tan phi dash cos square beta into gamma dash z divided by gamma z sin beta cos beta. So that means again c phi soil but under saturated conditions, at water table at the top surface that is at the slope surface.

In case see for c phi soil with h_w is equal to zero this is the expression we have derived, a factor of safety is equal to c dash plus tan phi dash cos square beta into gamma dash z divided by gamma z sin beta cos beta. So assuming factor of safety is equal to one then this z becomes the critical height. So that can be obtained, h_c can be obtained by rearranging this expression we can write h_c is equal to c dash sec square beta divided by gamma into tan beta minus gamma dash by gamma into tan phi dash.

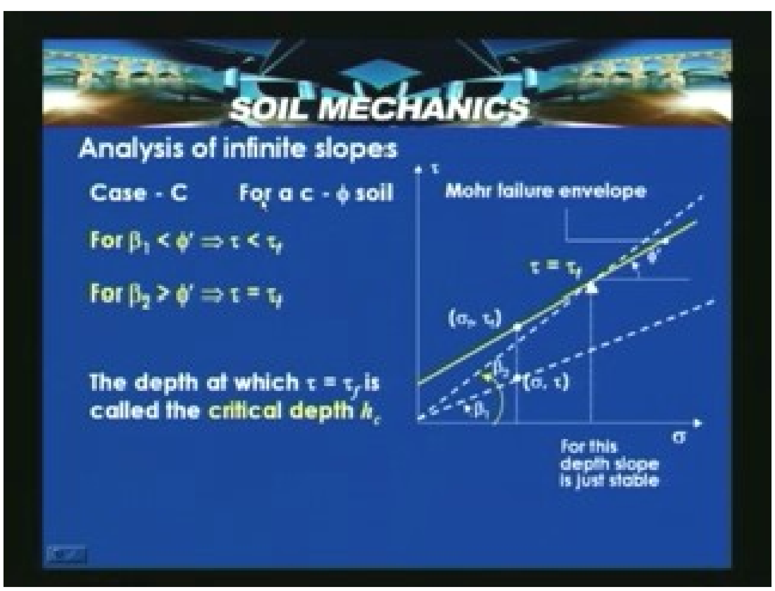
This is nothing but if you rearrange this terms c dash by gamma h_c is equal to tan beta minus gamma dash by gamma tan phi dash whole divided by sec square beta this is nothing but a stability number. So for c phi soils there is a limiting depth for stability so that one should be noted. In the previous case where there is a friction of soil, the factor of safety expression is independent of the depth but in this case for a c phi soil there is a limiting depth for stability.

(Refer Slide Time: 11:23)



Let us consider the case c once again for a c phi soil, now let us consider this is in tow sigma plot. Let us consider beta$_1$ is a certain slope inclination and beta$_2$ is another certain slope inclination and this is that more coulomb failure envelope with c is here and this intercept is c dash and phi dash is the angle of the particular envelope. Now for beta$_1$ less than phi dash, the tow is less than tow$_f$ that means the slope is under stable condition say for beta$_2$ greater than phi dash at certain depth, for this depth the slope is just stable but here in this case the slope is under stable condition but here for beta$_2$ greater than phi dash tow is equal to tow$_f$ that is the slope is just stable condition.

(Refer Slide Time: 12:12)

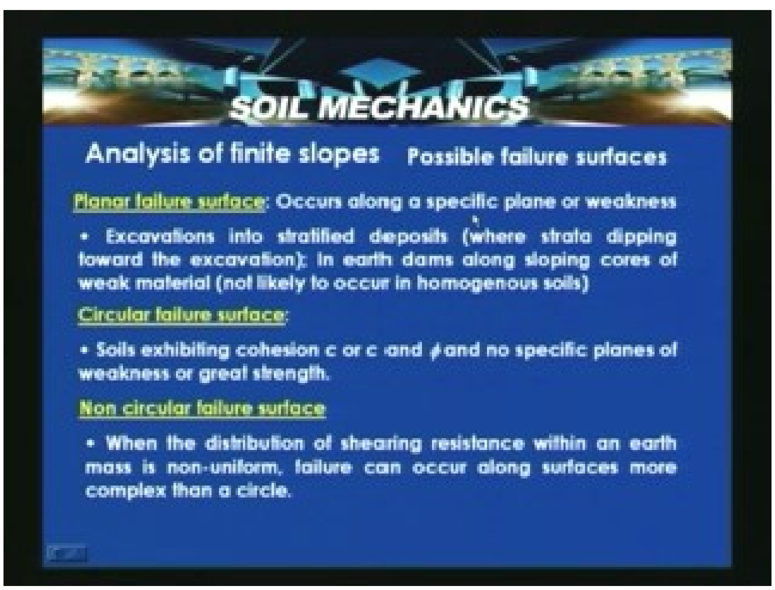


The depth at which tow is equal to tow$_f$ is called the critical depth h_c so in the previous slide we have calculated. So this is the depth we are referring beyond which what will happen is that this indicates that the failure would have already occurred. So here in the tow sigma plot similar to the previous slides what we try to do is that we try to represent more failure envelope and consider soil surface with different slope inclinations and if you look into this here as long as this beta$_2$ is equal to phi then that can say that slope is just attained the failure, once beta$_2$ is greater than phi dash that means somewhere here it actually attains the tow is equal to tow$_f$ beyond which already the slope would have already fail at all depths.

Now let us having looked into analysis of infinite slopes now look how finite slopes can be analyzed. The possible failure surfaces if you look into it, we discussed and we have shown also, there are possible planar failure surfaces, circular failure surfaces and non circular failure surfaces and when this planar failure surfaces will come and when this circular failure surfaces come and then non-circular failure surface can occur let us consider. Planar failure surface occurs along a specific plane or weakness. So in case there is a weak clay layer so the planar failure surface can take that particular path so planar failure surface occurs along a specific plane or weakness.

Excavations into stratified deposits where the strata dipping toward the excavation. Suppose if there is a strata and if it is dipping towards the excavation then the failure plane can be planar and can be in the direction of that weak plane.

(Refer Slide Time: 14:55)

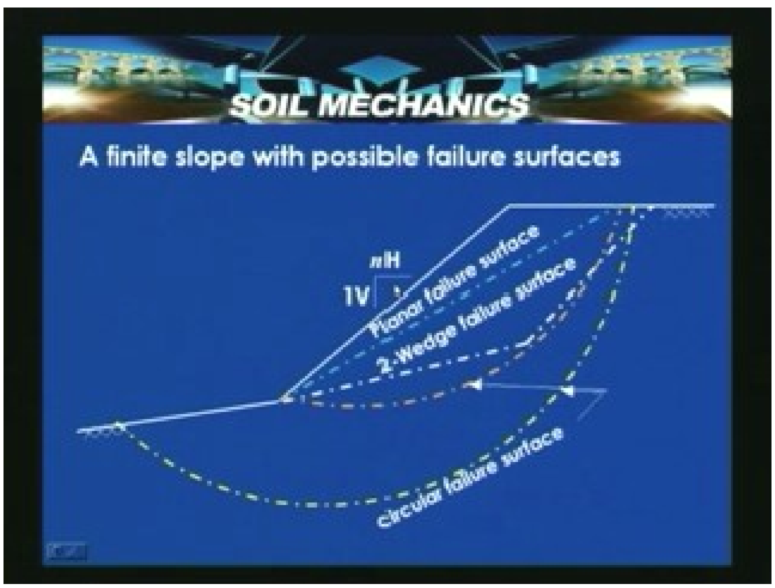


In earth dams along sloping cores of weak material not likely this particular, this planer failure surface may not likely to occur in homogeneous soils. So in stratified deposits or examples like earth dams where there is a sloping core of weak material, core material which generally comprised of low strength material but which is having impervious characteristics.

Circular failure surface, soils exhibiting cohesion c and phi and no specific planes of weakness or great strength. Soils exhibiting c that is cohesive slopes only or soils exhibiting c and phi and no specific planes of weakness and great strength. For the soils which does not exhibit any specific planes of weakness or great strength then this circular failures can take place and non circular failure surfaces when the distribution of the shear resistance within an earth mass is non-uniform, failure can occur along surfaces more complex than a circle.

So when the distribution of shearing resistance is not uniform then it can actually form something like a non-circular failure surface. Now in this particular slope with a cross section is shown and here one vertical and horizontal. So the important aspect here is that what is the safe slope for a given structure under consideration. For example if it is an embankment which is constructed for an approach load so what should be the safe slope. Suppose if the cutting is being made so it has to be pre design based on the available properties of the soils and then conditions, whether they are short term or a long term conditions you need to look into what is the safe slope which can be allowed.

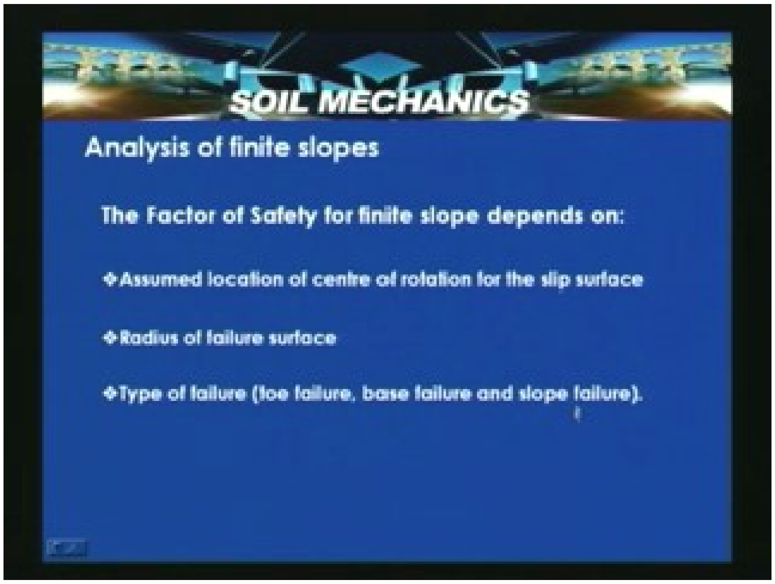
(Refer Slide Time: 16:49)



So here different types of failure surfaces are depicted here, in this case a planar failure surface which is shown, another possible two wedge failure surface is shown. So this can occur if there is a plane of weakness and these two are circular failure surfaces which are shown here. The analysis of finite slopes, the factor of safety for finite slope depends on assumed location of the center of rotation for the slip surface. So assumed location of the center of rotation for the slip surface and radius of the failure surface and type of failure whether it is a toe failure, base failure and slope failure. So the factor of safety for finite slope depends on assumed location of the center of rotation for the slip surface.

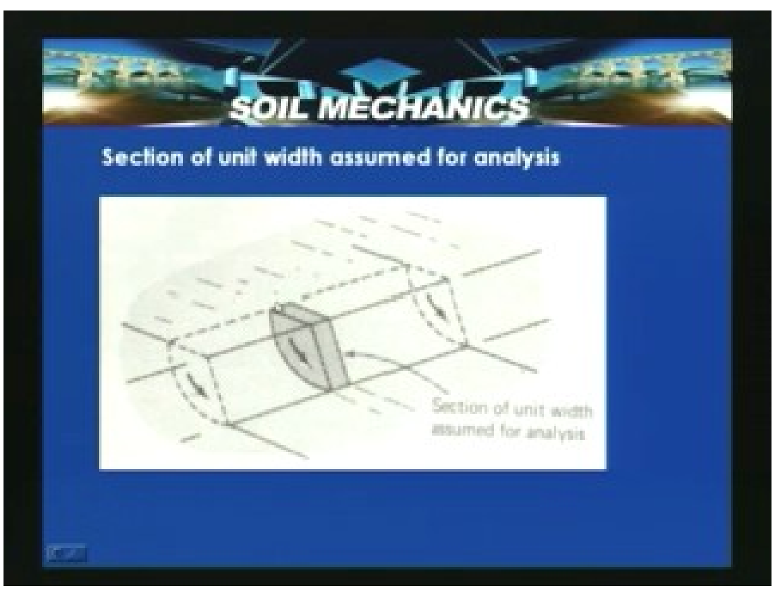
There can be a number of locations of the centers and there can be number of surfaces what we need to find out is that the surface which gives a least factor of safety has to be determined for certaining a safe slope, radius of the failure surface and type of failure that is toe failure, base failure and slope failure.

(Refer Slide Time: 17:54)



So generally as we discussed in the previous lecture, the sections of unit width are assumed for the analysis. So here if the slope or a bund or a canal cut, vertical cut is there or a cut which is shown here and you can see that the section of unit width assumed for the analysis is concerned.

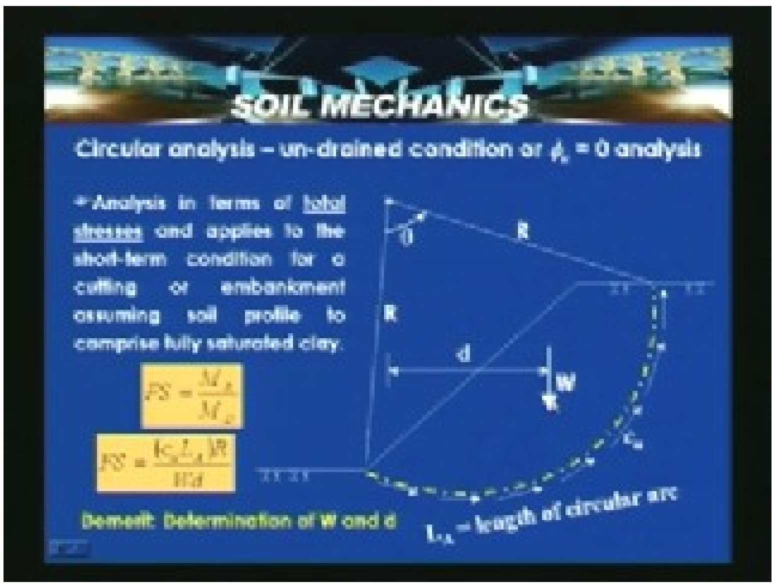
(Refer Slide Time: 18:43)



So the length of this section is assumed as for example if the weight is calculated in meters then we calculate the weight of this section per meter width of this particular reaction. So if this is the slope, this is that section of unit width assumed for analysis and that is considered because this type of structures or this thing illustrates a plane strain condition.

Now let us look different methods, the first method being a circular analysis un drained condition or phi_u is equal to zero analysis. Analysis in terms of total stresses, this basically this analysis in terms of total stresses applies to short term condition for a cutting or embankment soil profile to comprise fully saturated clay.

(Refer Slide Time: 20:04)



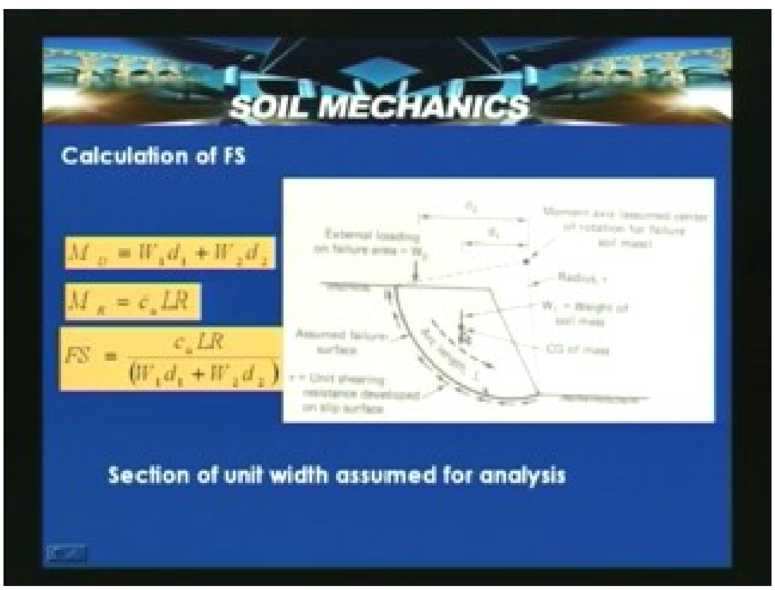
Here a cross section of a slope is shown and this is the failure surface, the possible critical failure surface, R is the radius, W is the weight of the wedge and this is determined by determining the area and per meter width of the section perpendicular to the plane of this figure and that is area into this width into unit weight of the soil yields to weight W and if this location is shown as the cg of the entire section, if that is actually located at a d distance from the center of rotation so this point is the center of rotation and this is the angle theta which subtends. So based on that the length of the circular arc can be determined.

So now if you look into it, if this induces driving moment and now the resisting moment is mobilized by the shear strength which is available. In this case for phi is equal to zero analysis for un drained conditions, the un drained cohesion provides; assuming that un drained cohesion which is uniform here and then have got c_u into l is the cohesive force into multiplied by R gives the resisting moment. So factor of safety here is defined as resisting moment divided by driving moment where resisting moment is c_u L_A into R and driving moment is W into d.

So the demerit of this method is that determination of W and d, so this yields to the method of slices. What we do is that we divide this entire cross section into number of slices and determining the factor of safety. So the demerits of this method is that determination of the W and d that is the center of gravity and its location that is the determination of the weight of the entire slope portion and its location is the demerit of this particular method. Now let us consider similar undrained conditions but there is a load which is acting at the top of the slope and let us consider how we can calculate the factor of safety.

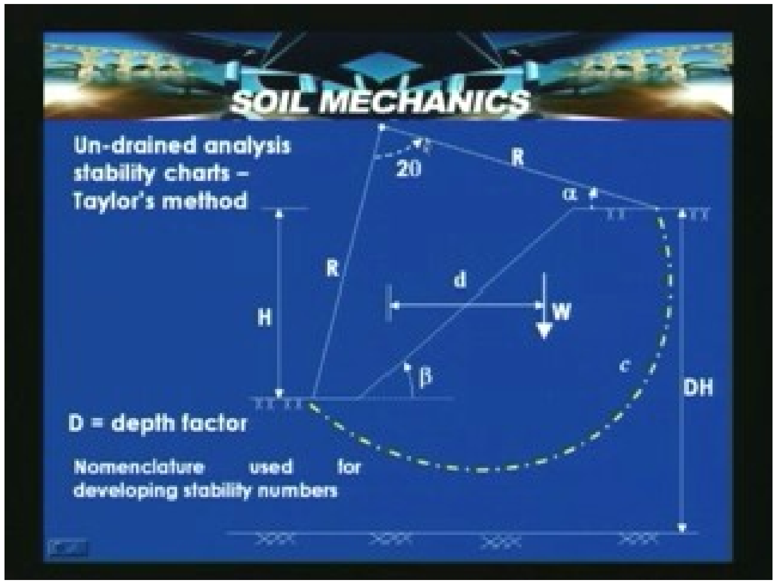
Let us assume that this is a failure surface which is given at a distance R and W_1 is the weight of the soil mass which is acting at the cg of the mass, cg of this portion is this point and this w_1 is the weight of the soil mass and w_2 is the external loading on failure area. That is we wanted to see what is the influence of this external loading on the stability of a slope and this is the moment axis assumed center of rotation for failure soil mass, this is the assumed center of rotation for failure soil mass and this d_1 is the distance of the location of w_1 from center of rotation horizontally and w_2 is located at a distance d_2 from the center of rotation horizontally and tow R c_u is the shear resistance developed along the slip surface or failure surface.

(Refer Slide Time: 22:47)



Now let us look the driving moment which can be given by w_1 d_1 plus w_2 into d_2 that is moment about this point. Resting moment is now only c_u into L into R. So factor of safety is nothing but a ratio of resting moment to driving moment which is c_u LR divided by w_1 d_1 plus w_2 into d_2. So even in the loads which are considered the per meter or per unit width of the analysis is considered and which yields factor of safety.

(Refer Slide Time: 24:08)



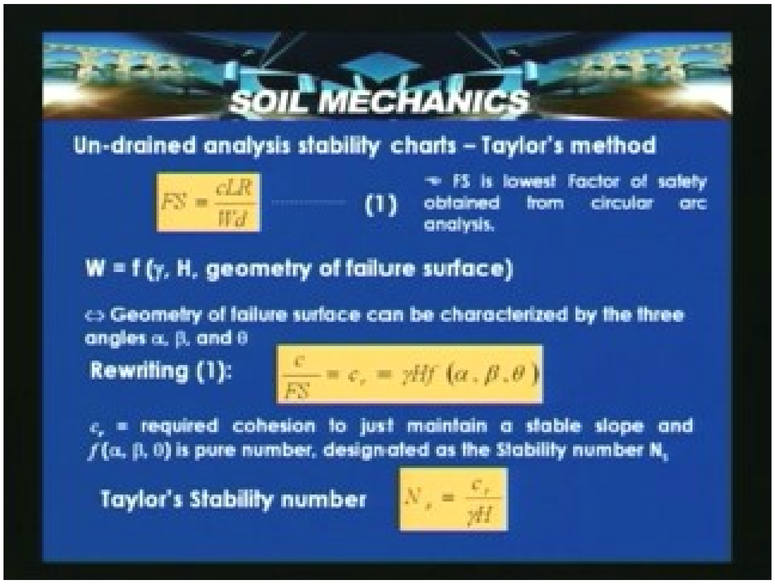
Now let us look another extension of this circular arc analysis for determining and this is popularly known as tailors stability method or Taylor's stability charts. So un drained analysis, tailors stability analysis so here this figure which shows the nomenclature used for developing stability numbers by Taylor 1948. So 2theta is the angle which is indicated here and alpha is the angle with the horizontal that is inclination of this line with horizontal for indicating the geometry of the slope, beta is the slope inclination, W is the weight of this portion of the slope at a distance d which is at cg and DH where D is the depth factor and H is the height of the slope. So this is the nomenclature used for developing stability numbers.

Now let us extend based on the derivation which we already made. Factor of safety can be given as cLR divided by Wd where cLR is the resisting moment and Wd is the driving moment and this is the factor of safety which is lowest factor of safety obtained for the circular analysis. So this factor of safety is the lowest factor of safety obtained from circular arc analysis. Now W the weight is a function of unit weight, height and geometry of the failure surface, the slope inclination and other compounds.

Geometry of failure surface can be characterized by three angles alpha, beta, theta. This alpha, beta, theta are shown once again so this is alpha, beta and theta this is this angle. So rewriting 1 as c divided by factor of safety is equal to c_r that is c_r is nothing but required cohesion to just maintain a stable slope and gamma H that is this portion into f into alpha, beta, theta.

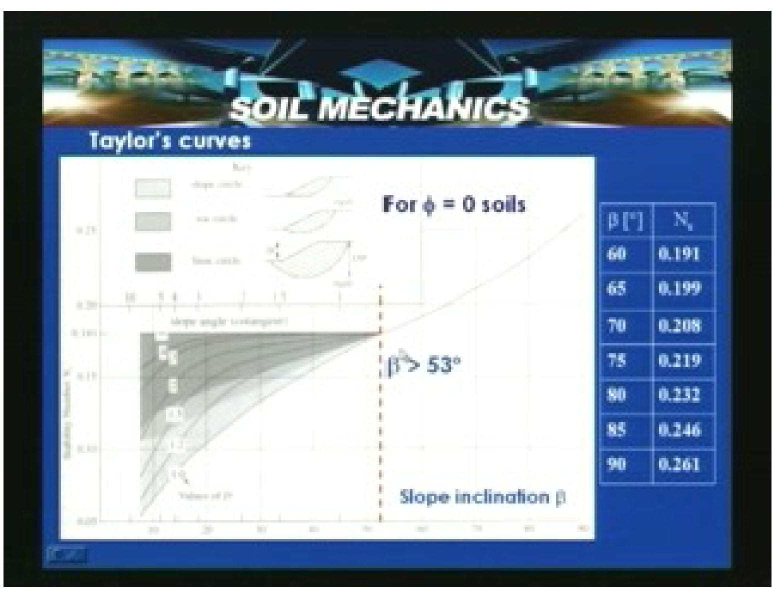
So rewriting 1 you can get c by FS that is cohesion divided by FS gives a value that is called c_r is the required cohesion to just maintain a stable slope is equal to gamma HF alpha, beta, theta where function alpha, beta, theta is a pure number and designated as the stability number N_s.

(Refer Slide Time: 24:57)



The Taylor's stability number is now indicated as N_s is equal to c_r by gamma H the Taylor's stability number N suffix s is equal to c_r by gamma H where c_r is the required cohesion to just maintain a stable slope. Now in this slide the Taylor's curves are shown after Taylor 1948 where you can see here for beta greater than 53 degrees this Taylor stability number is independent of the depth factor. So for beta is equal to 60 degrees, 65 degrees, 70, 75, 80, 85, 90 the stability numbers are given here; for beta is equal to 90 degrees that means this is a vertical cut, the stability number is 0.261 which can be obtained here for beta is equal to 90 degrees.

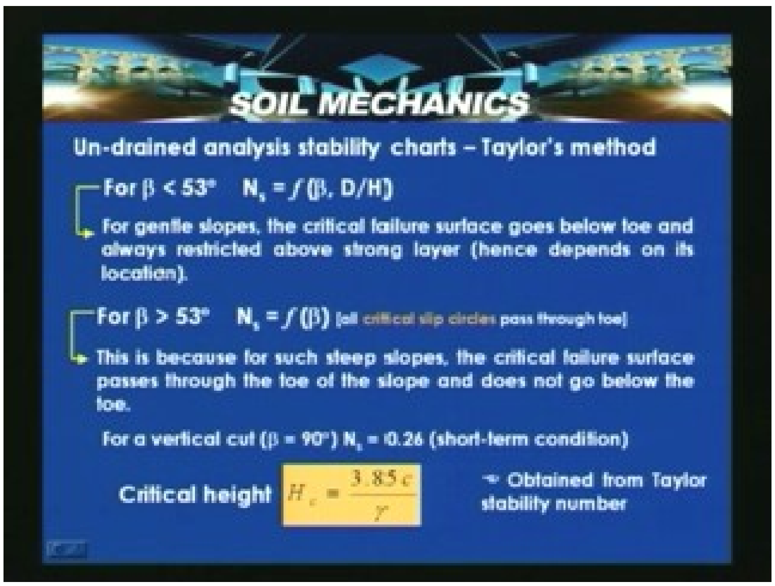
(Refer Slide Time: 26:51)



So here different types of circles are passed like slope circle, toe circle and base circle, the zones are indicated here. This is valid for beta less than 53 degrees and the depth factor cannot be ignored but beyond that this indicates that the depth factor will not come to picture. So this particular curve is for phi_u is equal to zero soils that means these are for the un drained condition that is c_u that is purely cohesive soils or saturated cohesive soils.

The un drained analysis stability charts Taylor method we are discussing and in the previous slide we discussed that for beta less than 53 degrees, the stability number is a function of beta and D by H that means you have seen a stability number is varying for beta and the depth factor D. For gentle slopes the critical failure surface goes below the toe and always restricted above the strong layer hence depends on its location that means as the failure surface cannot penetrate into the strong layer so it restricts along the strong layer.

(Refer Slide Time: 28:45)

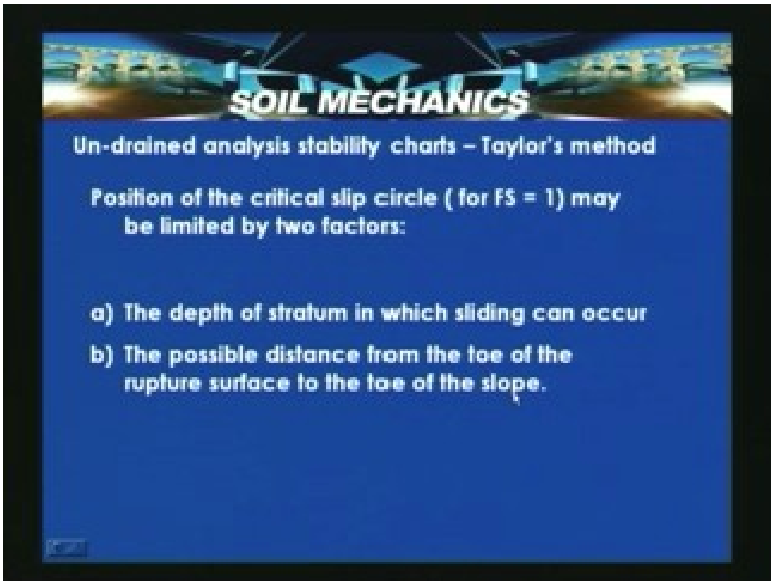


So the critical failure surface goes below the toe and always restricted above the strong layer hence depends on its location. So for this purpose the location is required that's why for beta less than 53 degrees for gentle slopes which is required for the location of the stronger layer. For beta greater than 53 that is stability number is a function of beta only, all critical circles pass through the toe this is because for such steep slopes the critical failure surface passes through the toe of the slope and does not go below the toe.

For a vertical cut beta is equal to 90 degrees, let us consider N_s is equal to 0.26 by short term condition, if you calculate the critical height is obtained as h_c is equal to 3.85 c by gamma. If you remember, we have derived the similar expression in case for un drained conditions while discussing earth pressures and we discussed that critical height of a vertical cut is about 4 c_u by gamma so here we actually obtain same expression from the Taylor's stability number.

The position of the critical slip circle that is for factor of safety is one, may be limited by two factors. So that is the depth of stratum in which the sliding can occur, the possible distance from the toe of the rupture surface to the toe of the slope. The position of the critical slip circle for factor of safety is equal to one may be limited by two factors, the depth of stratum in which the sliding can occur, the possible distance from the toe of the rupture surface to the toe of the slope.

(Refer Slide Time: 30:07)

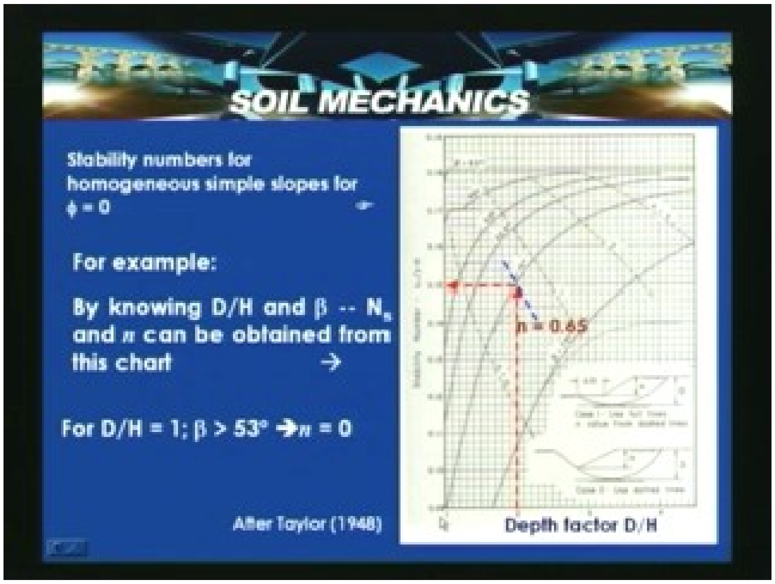


So this is indicated in this particular slide after Taylor 1948 depth factor D by H is given and stability number c_r by gamma H which is shown here and two cases, case one use full lines N value from dashed lines. So this N value is nothing but N times H, if N is equal to zero it passes through the toe of the slope that is a case which actually arises for a case where here D by H is equal to one that means this point beyond beta greater than 53 it passes through the toe of the slope. This is a case 2 use dotted lines which are shown here, these are the lines which should be used for reading this slides. Then in that case this is the height H which is shown and this is the D.

For example by knowing D by H and beta, N_s and n can be obtained from this chart. Say for example for D by H is equal to 1, beta greater than 53 then n is equal to zero. So this if you extend this goes like this, say for D by H is equal to 2 and this inclination beta is equal to 15 degrees you can say this n value will be about 0.65 and stability number is 0.15. So this is how we have to read these charts and then with this we can actually use these charts for calculating and solving the problems. The due course of this lecture, we look into how we can use this charts.

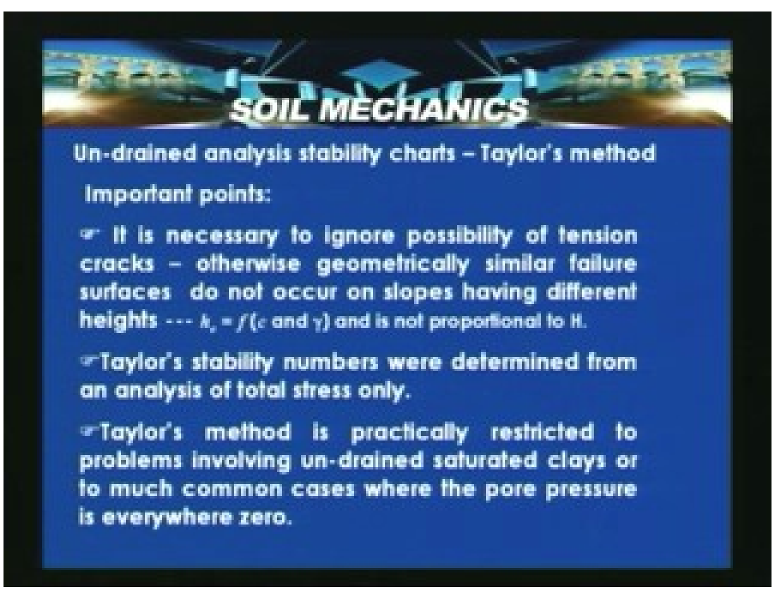
So some important points to summarize for the Taylor's method are it is necessary to ignore the possibility of tension cracks, other wise geometrically similar failure surfaces do not occur on slopes having different heights.

(Refer Slide Time: 30:55)



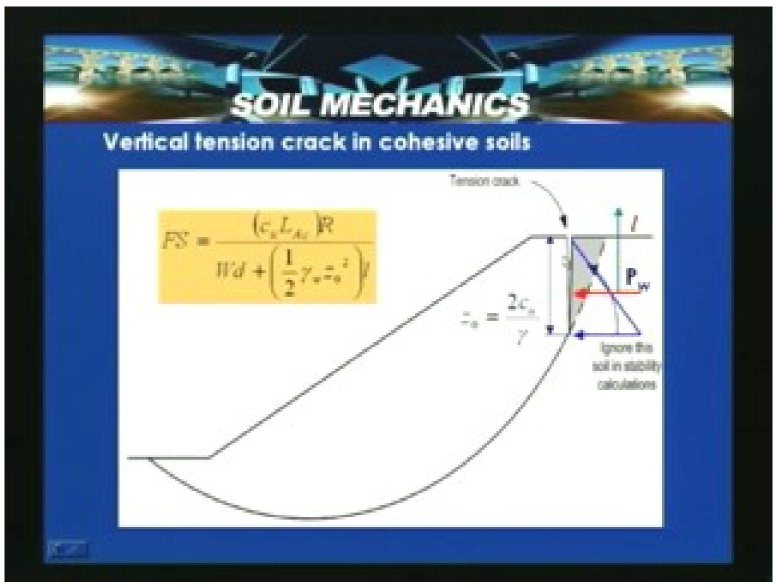
So h_c, because is a function of c and gamma and it is not proportional to height h. It is necessary to ignore the possibility of tension cracks other wise geometrically similar failure surfaces do not occur on slopes having different heights. Taylor's stability numbers were determined from an analysis of total stress only that has to be remembered for un drained condition when total stress only. Though some items have been made for using effective stress but in such situations it leads to serious errors. In such situations Taylor's method is practically recommended or restricted to problems involving un drained saturated clays or in much common cases where the pore pressures is everywhere zero.

(Refer Slide Time: 33:22)



Now let us look, in the previous place in the circular arc analysis these clays when they tend to crack and then suppose in the process if they get filled up with water and they can influence the factor of safety. For example in this particular figure a critical slip surface is shown here and this is the depth of the crack. The depth of the tension crack can be determined by z_0 is equal to $2c_u$ by gamma where c_u is the un drained cohesion of the soil and this is the tension crack. So in this case if this tension crack is filled with water, it exerts the pressure p_w and if l is the vertical distance of location of p_w horizontally from the center of rotation then this can exert a moment about this point to a center of rotation. So factor of safety is resisting moment that is c_u into L into ac, you need to consider in this zone the weight of the soil and the extension of this portion of the failure surface has to be ignored.

(Refer Slide Time: 33:55)

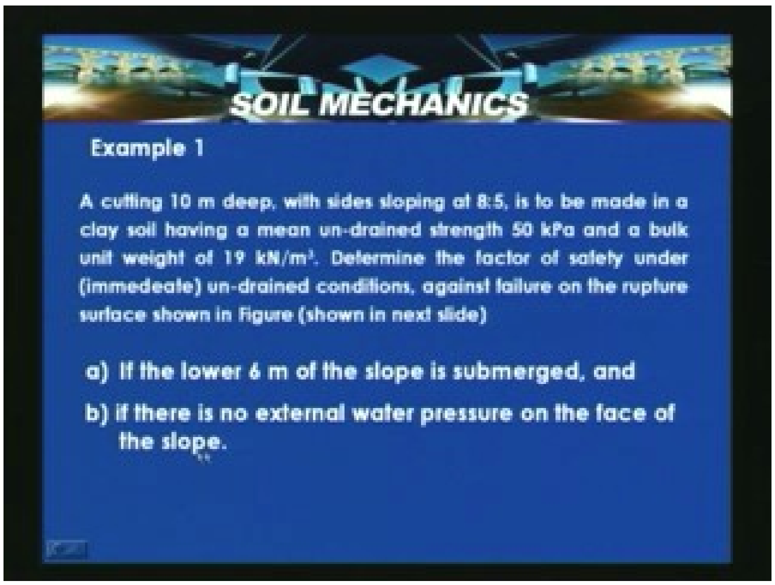


So ignore the soil in the stability calculations and also this length of the arc extending this portion also should be ignored that means after knowing the depth of the tension crack, pointing it on the surface once the slip circle is located, we need to find out the actual length which is involved. So that is given by if a and c is here and L_{Ac} is the length of the arc, c_u into L_{Ac} into R divided by w into D this portion that is weight of this particular portion excluding this small portion plus half gamma_w z_0 square is the water pressure acting at this particular point its central per meter length or per unit length into l. So that gives the driving moment so the driving moment due to water fill in the crack, so factor of safety obtained is given here.

Let us look the similar example whatever we have discussed, how we can solve. Example one a cutting 10 meter deep with sides sloping at 8:5 is to be made in a clay soil having a mean un drained shear strength of 50 kilo pacals and bulk unit weight of 19 kilo newton per meter cube. Determine the factor of safety under immediate un drained conditions against a failure on the rupture surface shown in figure, this figure is shown in the next slide.

If the lower 6 meter of the slope is submerged and if there is no external water pressure on the face of the slope. So this is a figure for example one, so a cross section of the slope. The slope inclination is shown here 8 horizontal and 5 vertical and water table is here and the water is located here as well as here. Suppose if there is water which is located at both the sides then the moment due to water here and here will get nullified. What you need to consider this portion as the submerged weight of the soil that is gamma_{sat} minus gamma_w has to be considered, here this portion if this gamma_{sat} prevails here then this is the weight of the soil above the water table has to be considered. If there is a tension crack and then if this gets spilled with water then the water exerts a pressure here.

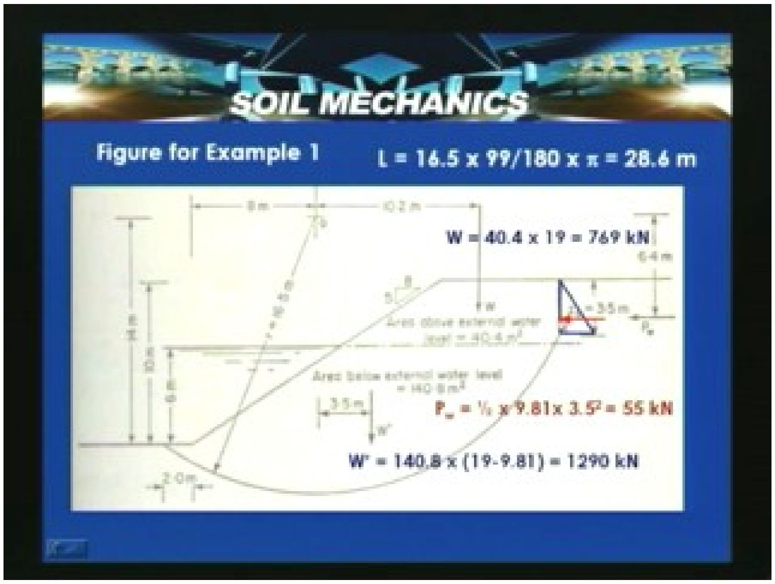
(Refer Slide Time: 36:05)



So from here with the depth zc is equal to 3.5 meters that is determined and w is equal to 40.4 this is the area into 1 meter that is the per meter width of this section of this figure into 19 kilonewton per meter cube is the unit weight of the soil yields to 769 kilonewtons and which is located at a distance of 10.2 meters from the center of rotation o, R is the 16.5 meters and remaining portion which is w dash is equal to 140.8 meter square is the area below the external water level into this is nothing but the submerged unit weight which yields to 1290 kilonewton per meter width of the section which is shown in this figure.

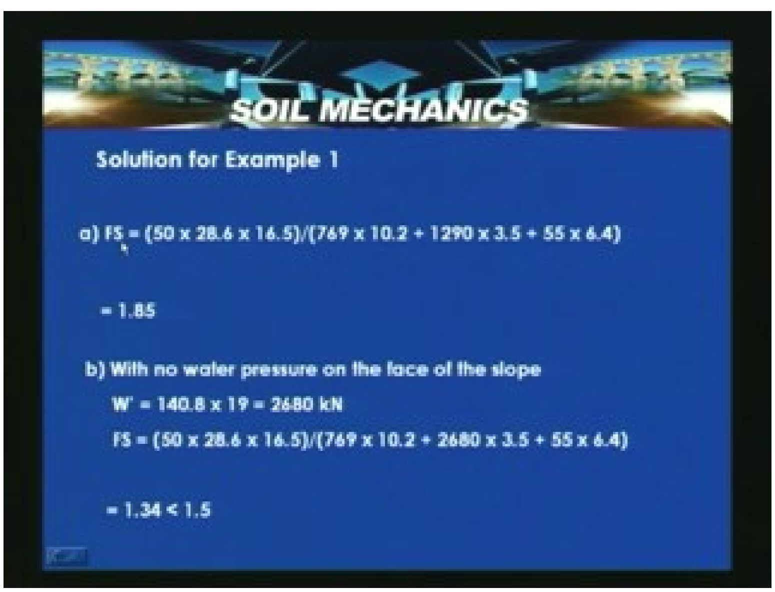
Then p_w is the way pressure due to water which is filled in the tension crack that is 55 kilo newton per meter. Now by solving, solution for the example one works out like this. Factor of safety, resisting moment divided by driving moment; the driving moments are calculated which yields factor of safety 1.85.

(Refer Slide Time: 36:54)



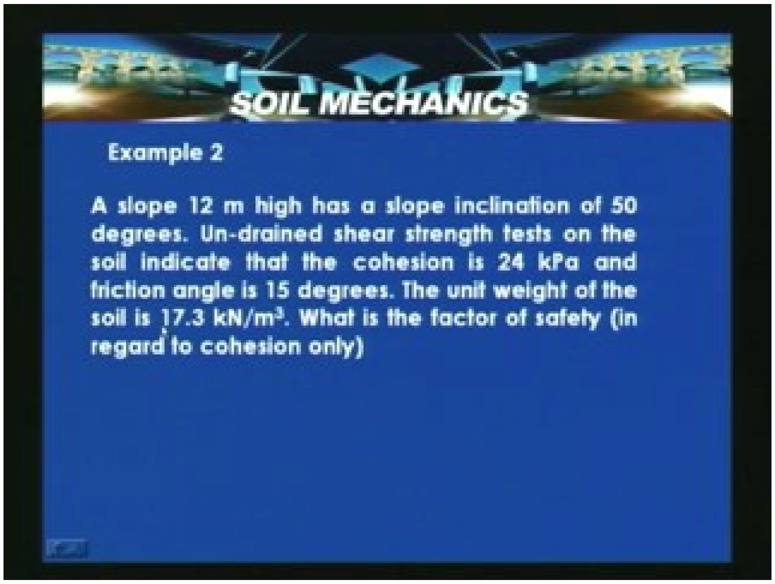
Now with no water pressure on the face of the slope that means assume there is no water on the face of the slope that means the unit weight is no longer submerged and it is only a saturated unit weight equal to 19 kilo newton per meter cube. So with that what will happen is the w dash changes to w_1 and w_1 dash and that works out with 140.8 into 19 is equal to 2680, substituting here we get the factor of safety which is less than 1.35. So the presence of water which actually, if the water is existing in both the sides and increases the safety but in case if there is a fluctuations in the water table that means sudden draw down conditions or these conditions can affect the factor of safety.

(Refer Slide Time: 37:59)



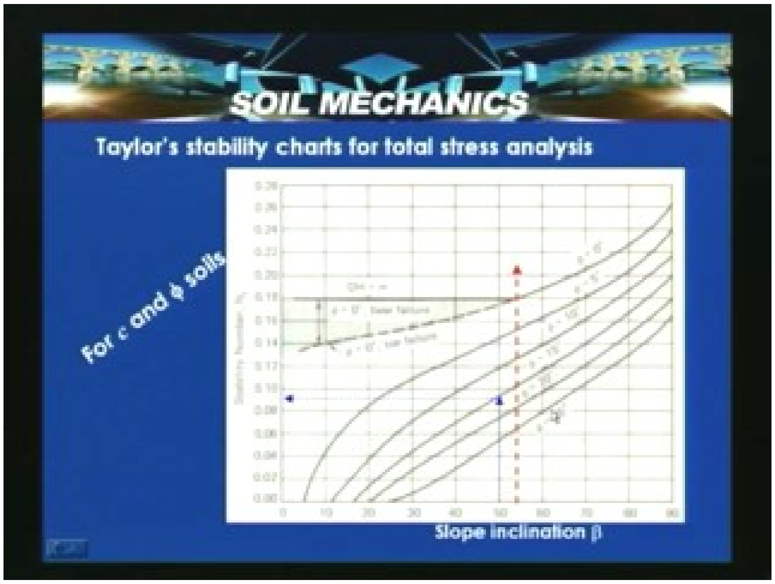
Another example is a slope 12 meter high has a slope inclination of 50 degrees, un drained shear strength test on soil indicate that cohesion is 24 kilo pascals and friction angle is 15 degrees. The unit weight of the soil is 17.3 kilo newton per cube. What is the factor of safety in regard to cohesion only?

(Refer Slide Time: 39:20)



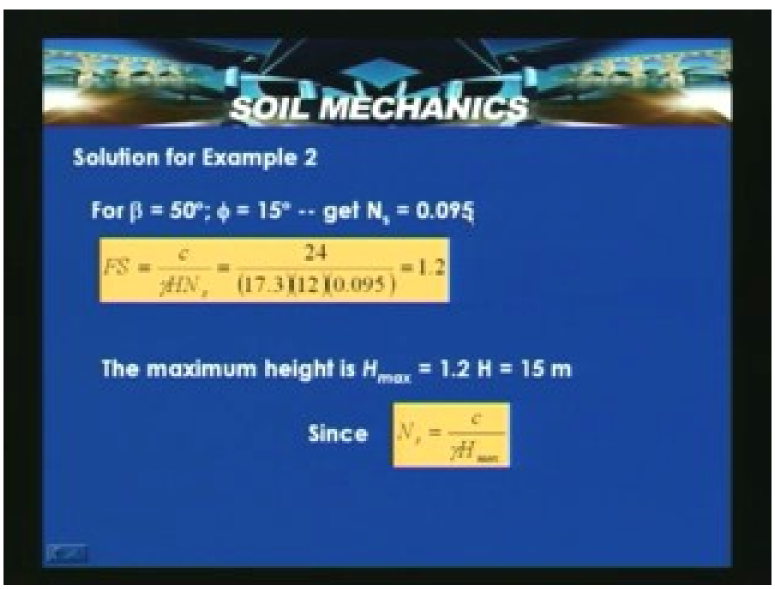
So this is based on the Taylor's stability chart. In the previous slides we have given for phi_u is equal to zero soils, for c and phi soils also Taylor 1948 has given Taylor stability charts for total stress analysis are indicated here where for c and phi soils, in this case you can also see that for slope inclination beyond 53 degrees is independent of the D by H and you can see here this portion and these curves are for the different friction angles, phi is equal to 5 degrees, phi is equal to 10 degrees, 15 degrees, 20 degrees and 25 degrees.

(Refer Slide Time: 40:09)



So DH is equal to infinity here and this is phi is equal to zero that is toe failure and phi is equal to zero, in this zone the base failure occurs. Now by using this chart for beta is equal to 50 degrees and phi is equal to 15 degrees we can get Taylor's stability number as N_s is equal to 0.095. So this 0.095 is obtained here from this chart.

(Refer Slide Time: 40:42)



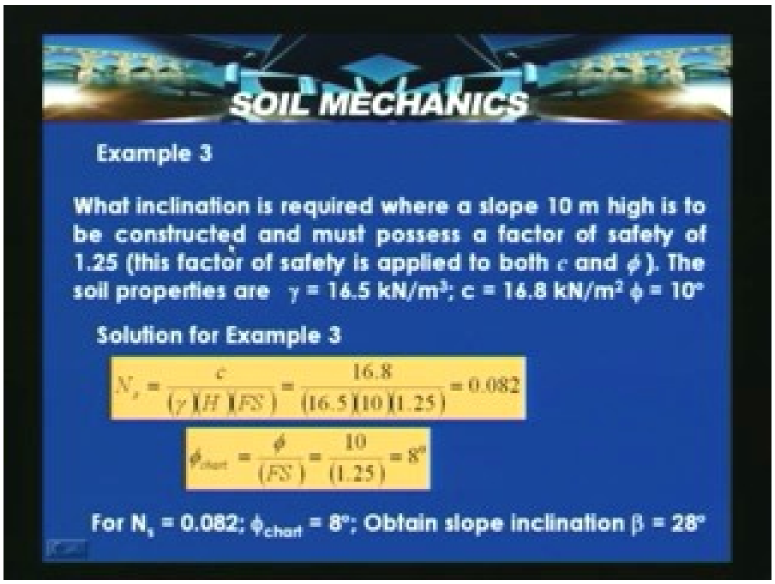
Factor of safety is equal to c divided by gamma H N_s, N_s is the stability number which is obtained as 0.095 based on the given data. So 24 divided by 17.3 into 12 into 0.095 which yields factor of safety 1.2 that's what we are required to determine in this problem, what is the factor of safety in regard to cohesion only. So the maximum height H_{max}

which is critical height is 1.2 times the height of the… (Refer Slide Time: 41:20) H is this actual height which is given in the data. So once this 15 meter reaches that means the slope attains a factor of safety that is the critical height. Since stability number is equal to c by gamma H_{max}.

Consider another example three, what inclination is required where a slope 10 meter high is to be constructed and must possess a factor of safety of 1.25. This factor of safety is applied to both c and phi, the soil properties are gamma is equal to 16.5 kilo newton per meter cube, c is equal to 16.8 kilo newton per meter square and phi is equal to 10 degrees.

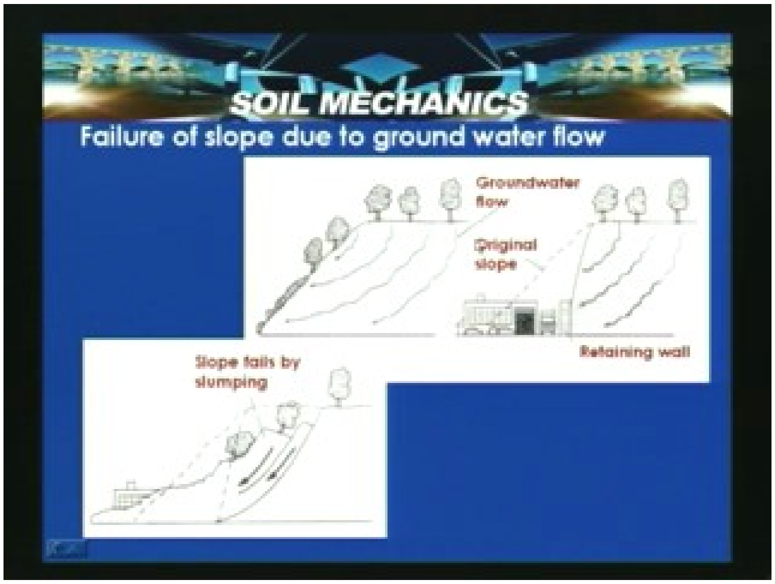
So solution for example three works out like this, stability number in the similar way can be worked out, c divided by gamma H into FS where 16.8 divided by 16.5 into 10 into 1.25. The factor of safety which is given as 1.25 both from the cohesion and friction angle point of view which yields stability number 0.082. So the friction angle after allowing for factor of safety is friction angle divided by factor of safety which is equal to 1.25 which is about 8 degrees.

(Refer Slide Time: 41:47)



So now having known stability number 0.082 and pie chart 8 degrees, now you can get the slope inclination as 28 degrees. So from this chart again, the same chart which is shown here for N_s is equal to 0.082 and pie chart is equal to 8 degrees we can calculate the slope inclination. So somewhere around here 0.082 and 8 degrees, the beta is equal to 28 degrees can be obtained with base failure which is shown here. Now we have discussed some methods and in the next lecture we will be discussing about the remaining methods which are there for finite slopes.

(Refer Slide Time: 43:41)

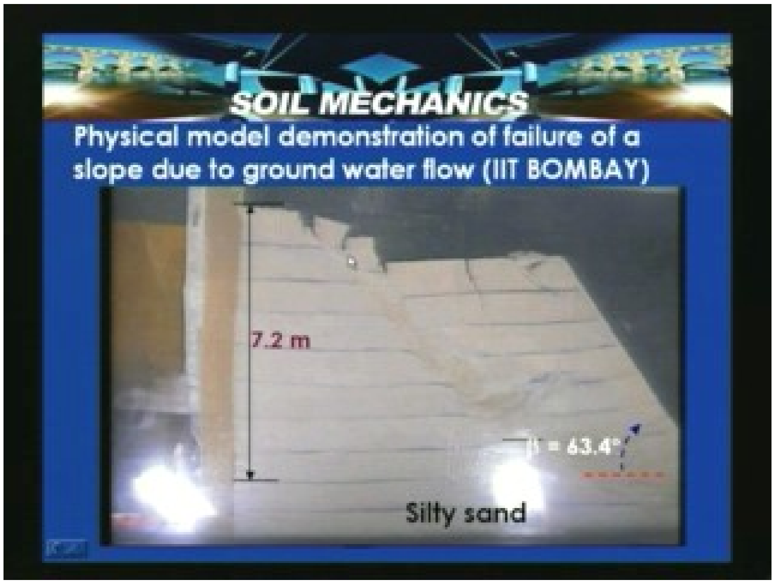


So before that we look into how water flowing through a slope can endanger the stability of a particular section. So here in this particular slide, failure of slope due to ground water flow is shown; so here when the water or a ground water steeps through a slope this is natural, how the ground water steeps to be slope. So this causes a slope failure like soil slope fails by slumping and endanger the structures which are within the vicinity of the structure. So this is the original cross section of the slope and then as it is unstable it tends to adjust to a stable configuration.

In order to arrive that this particular soil mass undergoes a movement and fails so this is a failed portion which is shown here schematically. Suppose with the remedial measure the retaining wall then exerts, this can be used for retaining the soil but what is this influence on the stability of the slope can be seen through physical model which is shown as a demonstration experiment, when the water flows through the soil how it can endanger the stability of a slope.

So in this section as you see a physical model demonstration of failure of a slope due to ground water flow which is carried out IIT Bombay I have shown. As the water reaches the toe you can see that the slope attains failure. So this is the formation of tension cracks, this soil is equivalent to a silty sand and having height equivalent to 7.2 meters and constructed with silty sand which is moist compacted and the slope is having an inclination of 63.4 degrees.

(Refer Slide Time: 45:02)



So let us look into the details again. In this case a typical slope failure is shown here, a physical model here this is after university Bochum Germany where we can see a typical slope failure and a formation of cracks. These are tension cracks and this is a typical slip surface which is formed in a homogeneous clayey soil and you can see that this portion here is subjected to heaving where you can see that the heaving portion of this particular soil, the stretch or extent of this failures can be felt up to a structures, up to this particular portion.

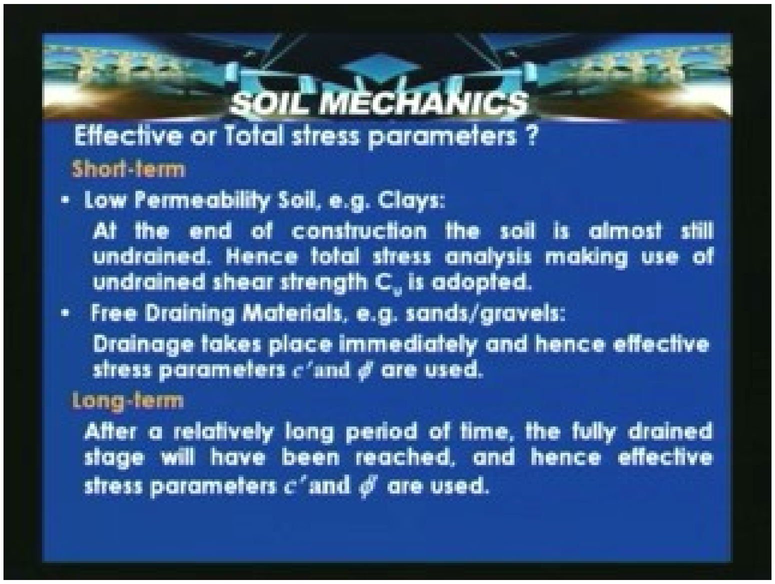
So this is the physical model which is shown at the end of the test. So this is the initial cross section of the slope and after failure it is actually at this particular point and what you are seeing these are the marker grids, these things enabled to identify the failure surfaces. Now having discussed and if you remember there are the 2 stress parameters which are coming into picture, one is short term stress parameter other one is the long term stress parameters.

(Refer Slide Time: 46:23)

So these are referred as in soil mechanics as for long term conditions they are effective stress parameters and for short term condition they are total stress parameters. When to adopt these things they depend up on the short term stability conditions and long term stability conditions. The short term stability conditions basically this is valid for low permeability soil that is example in clays, at the end of the construction the soil is almost still un drained. Hence the total stress analysis is making use of un drained shear strength is adopted. In case of low permeability soil, the clays at the end of the construction the soil is almost still un drained hence the total stress analysis making use of the un drained shear strength c_u is adopted.

In case of free draining materials that is sands and gravels, drainage takes place immediately hence the effective stress parameter c dash and phi dash are used. If the material is free draining type then the drainage takes place immediately hence the effective stress parameter c dash and phi dash are used. So even for the short term stability conditions also, if the material is say sand and gravel then we use c dash and phi dash. In case if the material is low permeable as the drainage will not occur so the total stress analysis used for the purpose of the analysis.

(Refer Slide Time: 47:12)



For the long term conditions, after relatively long period of time the fully drained stage would have been reached hence the effective stress parameters c dash and phi dash are used. So in the next lecture we look into how this c dash and phi dash and c and phi total stress parameters and effective stress parameters can be considered and we also look into the remaining methods of the analysis like we have this bishops method of slices and felniers methods of slices and other methods we will discuss and we look into the merits and demerits of these methods for the finite slopes analysis and we also look into some example problems in using these methods.

In this lecture what we try to understand is about analysis of the infinite slope stability and we discussed about the different cases for a cohesion less soil slope with dry condition and completely saturated condition that means water is steeping parallel to the slope surface and the case where c phi soil with a saturated case and we discussed that in case of c phi soil, the depth is critical height, there will be a certain depth and that depth is actually referred as a critical depth which is determined and we also discussed based on tow sigma plots about the stable conditions and unstable conditions. Thereafter we introduced methods for stability analysis of finite slopes basically we looked for un drained conditions that is basically for short term stability considerations.

In this short term stability we have looked into like circular arc analysis that is phi_u is equal to zero analysis and secondly we also looked into the Taylor's stability method and then we solved some couple of problems like how this charts can be used, like phi_u is equal to zero soil chart and or for c phi soils, the chart which is proposed by Taylor 1948 that is strain stability number versus slope angle for different friction angles. So based on this we will enable us to understand this stability analysis of slopes.