Foundation Engineering
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Module - 03
Lecture - 14
Stability of Slopes

Hello viewers, welcome back to the lectures on the Stability of Slopes. Today, we are having our ninth lecture on this topic.

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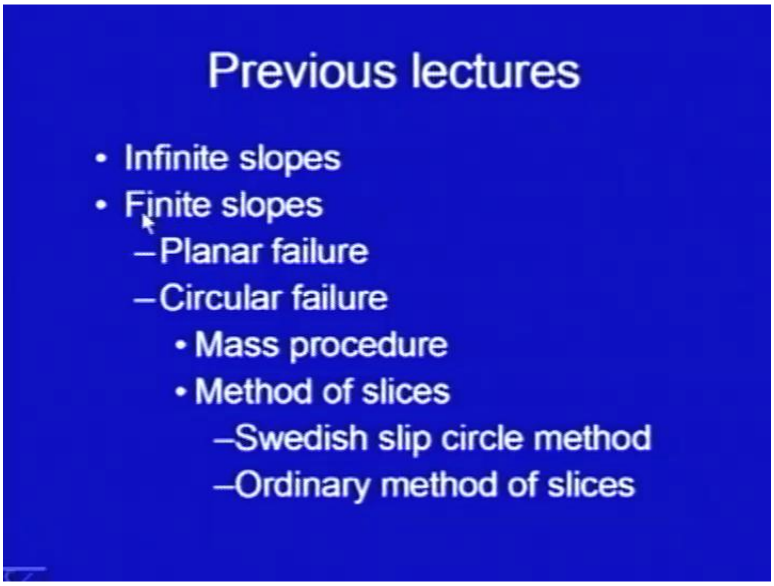

In our previous lectures, we discussed the infinite slopes then we started discussing the finite slopes, here we have already covered the cases where planar failure surface was possible and then, we started discussing about the circular failure surfaces. These methods were broadly categorized into two broad categories, mass procedure and method of slices. We discussed the mass procedure and, we were discussing the method of slices in which Swedish slip circle method has already been covered and in our last class, we had covered ordinary method of slices also.

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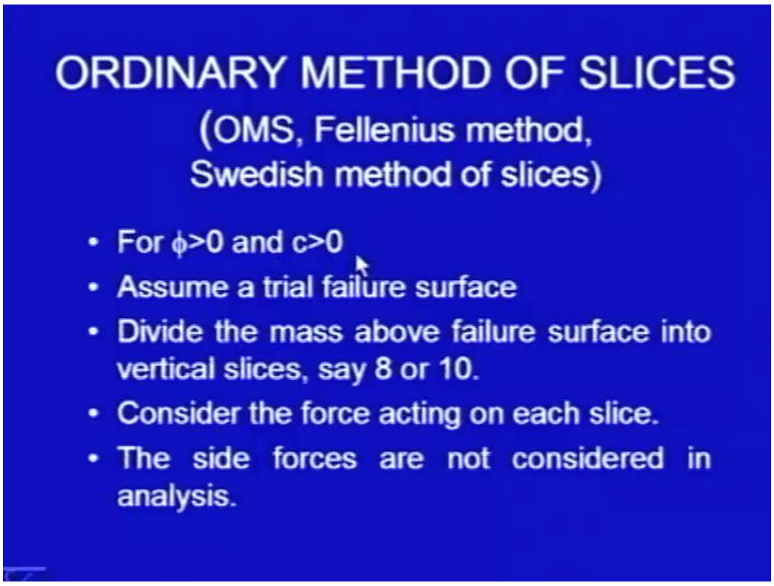

Let us just refresh, what we did in that case, the method was applicable for the soils which were having c and phi both greater than 0 and a trial failure surface which was circular was assumed. Perpendicular to the plane of paper we took 1 meter length of the slope and then, mass was divided into number of vertical slices and forces on this each of the slices were considered, this side forces were not considered in this analysis.

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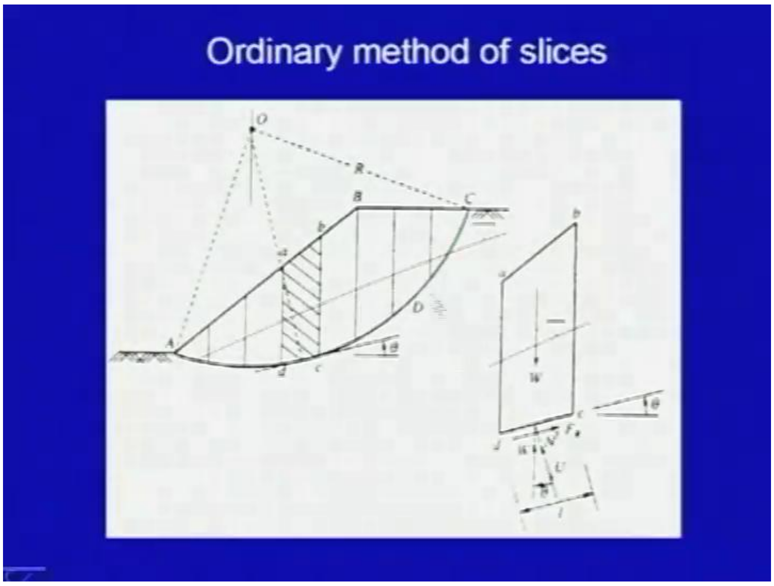

So, here this is the slope and it has been divided into number of slices, this is one slice and here, on the sides we did not consider the force and we considered the forces. The other forces which were acting on this slice to find out the equilibrium and this was the factor of safety expression.

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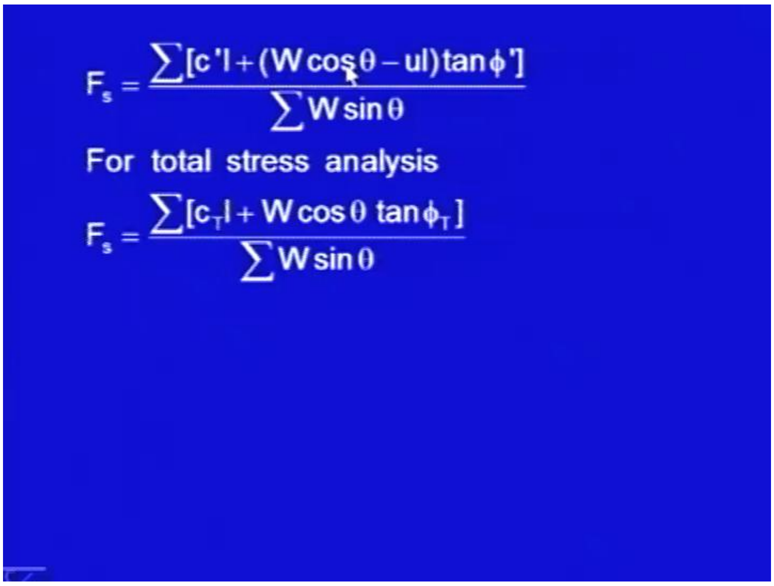

F s was equal to summation of c dash l plus W cos theta minus u l multiplied by tan phi dash upon W sin theta.

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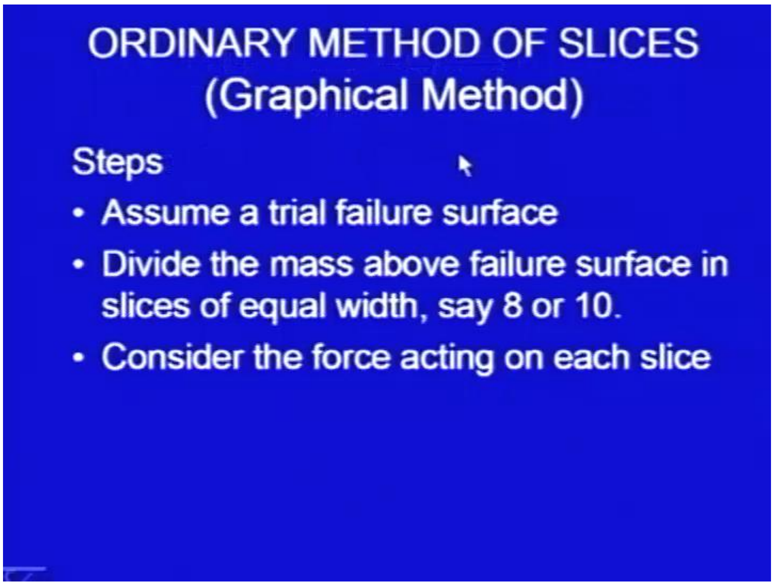

Then, we also discussed how we could solve this problem using graphical method basic procedure, is same a trial surface is assumed.

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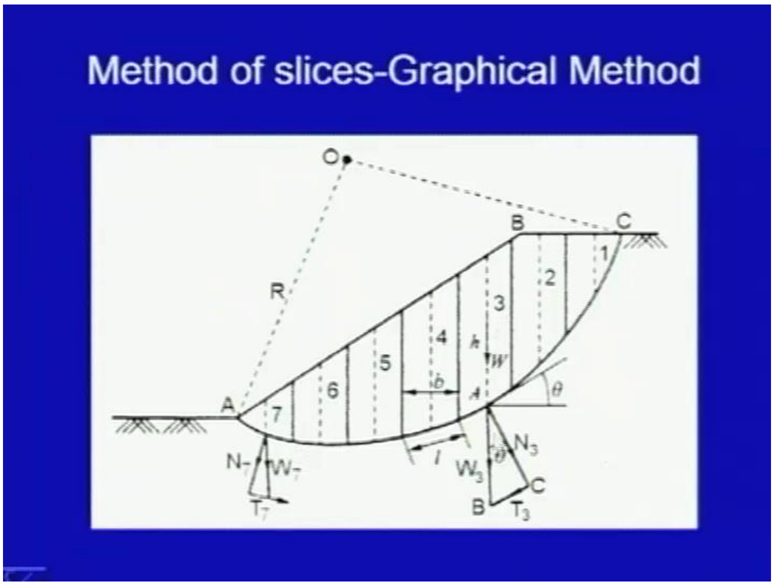

This is the trial surface then, for each slice we find out the forces graphically.

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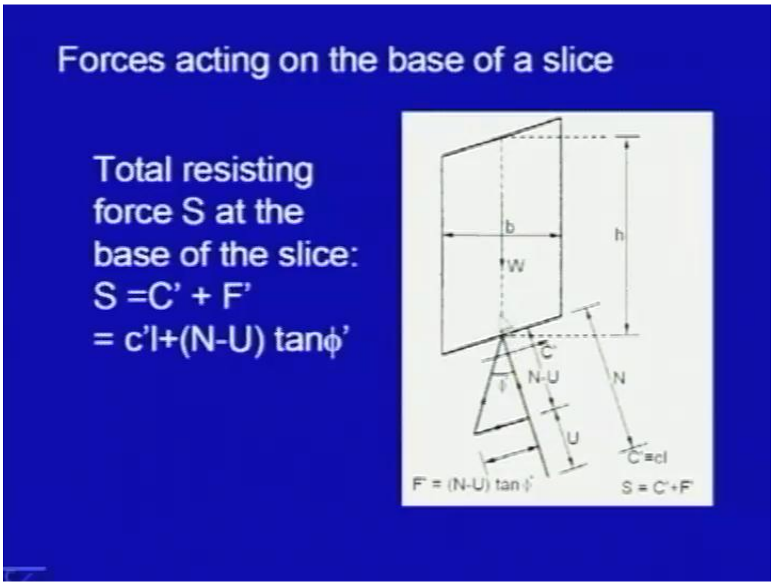

And, this is the slice shown here and the, the forces on the slice, the total resisting force was found out.

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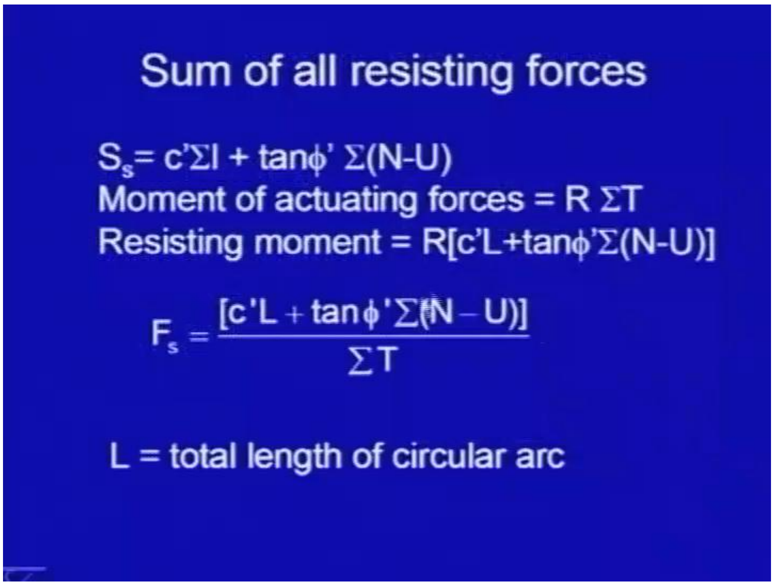

And, this was the expression for the factor of safety.

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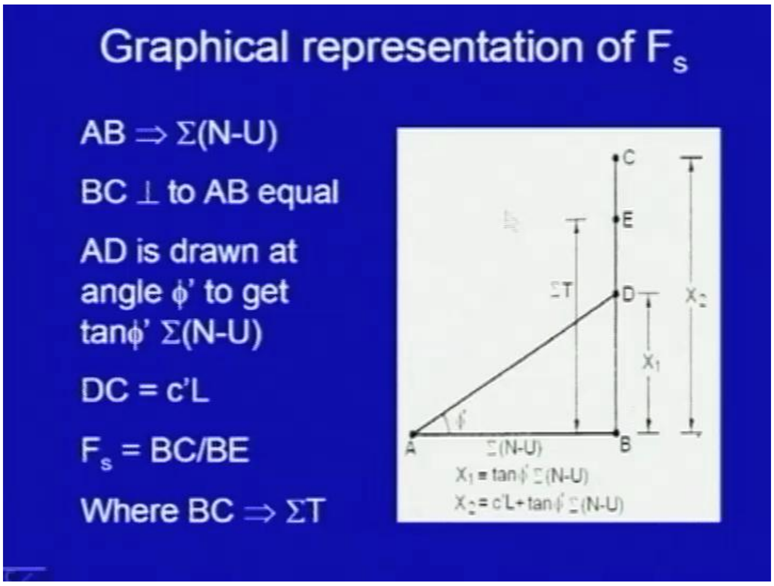

And, this is the graphical expression of the calculation of factor of safety which we discussed last time. So, we can find out the factor of safety for the trial surface and then, we had to take number of trials, number of surfaces and then, minimum has to be selected.

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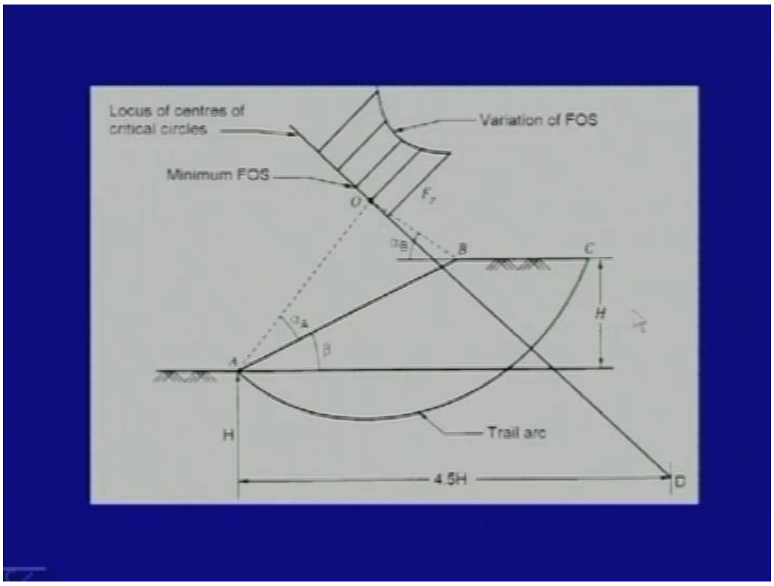

The procedure was very tedious because, large number of circular surfaces have to be considered, so we had discussed one more method which reduces the computations and here, we could find out this is what we discussed we could find out the a line a method was discussed in which a point is taken here at a depth H and distance 4.5 H away from the toe and join this with the point. So, with this point O, this point O was obtained by drawing a triangle in which these angles alpha A and alpha B they were available from the tables.

So, the factor of safety, the circle which is having minimum factor of safety was it is, it will lie on this line. So, this is what we had discussed last time and we had just started discussing the bishop's method which we are going to do in detail today.

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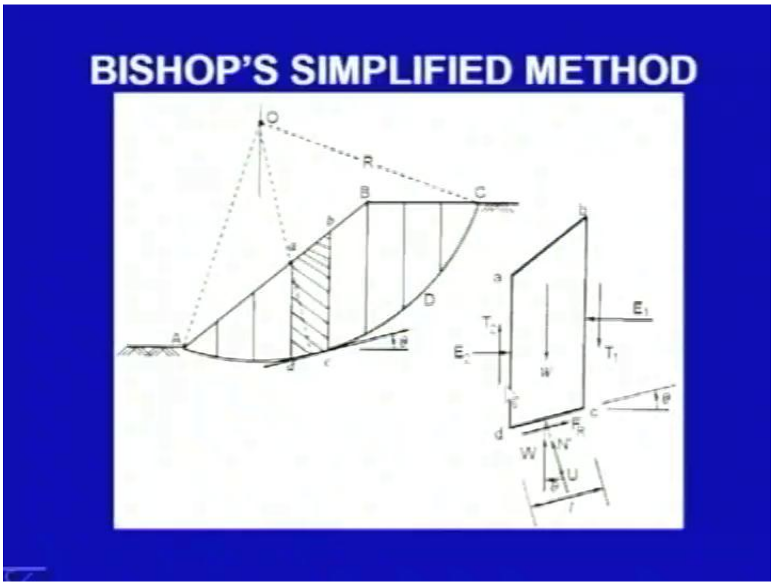

The basic procedure is same we consider large number of slices, so here these are the slices, it is the slope here it has been divided into number of slices. Here, it is the equilibrium of one slice is shown, weight W is acting here, the additional component in case of the bishop's method is that, the side forces are also considered. So, E E 2 from this side and E 1 from this side these are the normal forces and T 1 on this side and T 2 on this side, these are the shear forces which are acting on the sides and their signs will be negative.

So, T 1 here it is acting in this direction, so T 2 will be in the opposite direction, so their signs will be opposite to each other, E 2 is acting in this direction E will be acting in this direction. So, and here at the base FR, this is the resistance, this is the force due to frictional due to the, the force which is being offered by the soil and U is the water pressure and N dash is the normal reaction, here at the base.

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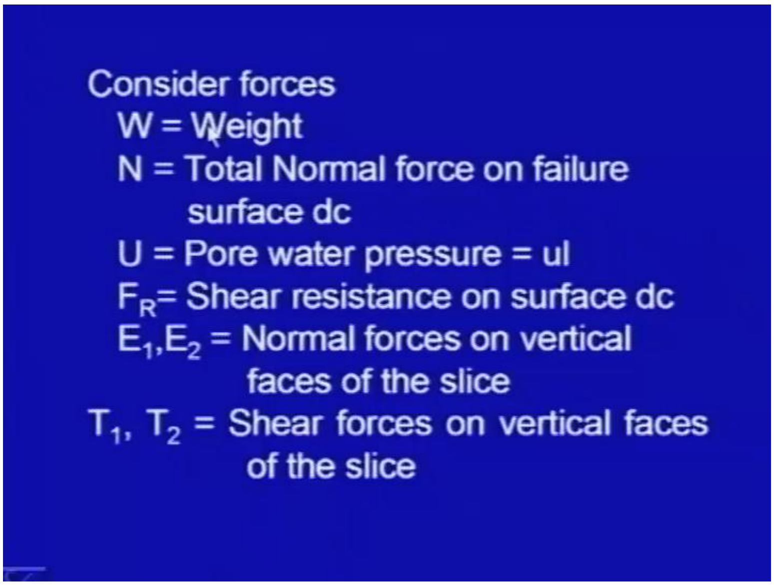

So, these are the forces which are considered in this analysis, W is the weight, N is the total normal force on failure surface dc, this surface is dc, N is the total normal force and N dash is the effective normal force. U is the pore water pressure that is equal to u into l and it will be acting normal to the surface of dc. F R is the shear resistance on surface dc, this is the force which is being offered by the soil and E 1 E 2 are the normal forces on vertical faces of the slice that is, these are the side forces on the sides of the slice and T 1 T 2, these are shear forces on vertical faces. So, this is T 1 and this is T 2.

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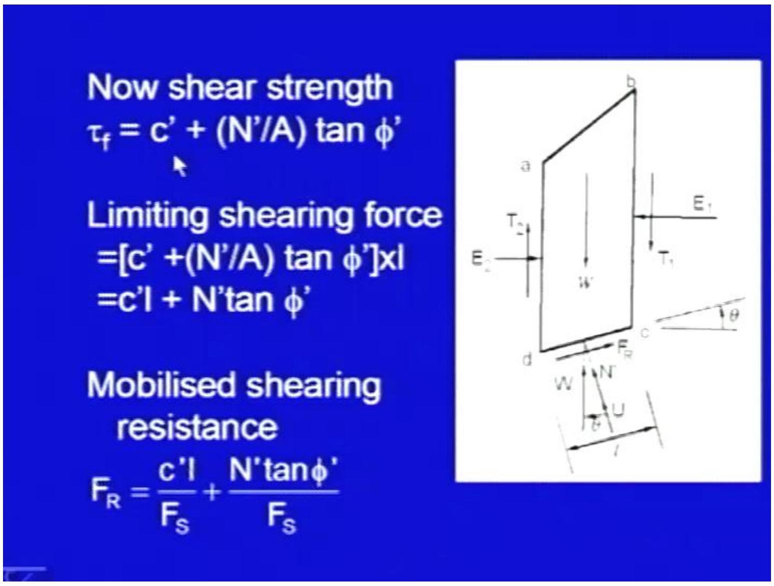

Now, the shear strength of the soil, here it will be tau f will be equal to c dash plus N dash upon A N dash is the effective force N dash upon A that gives you effective normal stress into tan of phi dash. The limiting shear force from this, you can get by multiplying it by area, so c dash in plus N dash upon A tan phi into area is l into 1. Let us say, the length of this base is l and perpendicular to the plane of paper we are taking 1 unit dimension.

So, limiting force will be c dash l plus A cancels out, so c dash l plus N dash tan phi dash, now we consider the slope to be in equilibrium and let us say the factor of safety is Fs. So, the mobilized shearing resistance will be c dash l upon F s plus N dash tan phi dash upon Fs, we have to divide it by Fs. So, that will be the mobilized shearing resistance.

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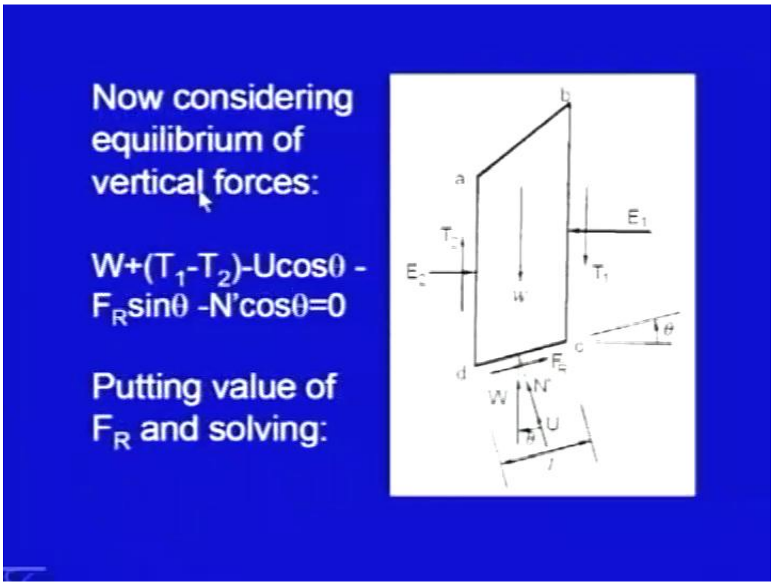

Now, considering the equilibrium of the vertical forces, this is important in this particular method that, this particular equation expression which we are going to derive is based on the equilibrium of vertical forces. So, when you consider the equilibrium of forces vertical forces these E 1 and E 2 these forces will not come into picture and we will have W acting in downward direction plus T 1 minus T 2 and then, component of U in the vertical direction, this face sliding face is inclined at an angle theta.

So, the component of U which is in vertical direction will be U cos theta in opposite direction and also component of this force of resistance F R in the vertical direction. This will be F R sin theta and its, it will be in upward direction, so here in this equation, it is negative and also the component of N dash. N dash is equal to N minus U, so that will also be acting in upward direction, the component will be N dash cos theta.

So, when we consider the equilibrium, we are going to get this equation, W plus T 1 minus T 2 minus U cos theta minus F R sin theta minus N dash cos theta equal to 0. Now, putting the, in this equation putting the value of F R from here, F R is equal to c dash l upon F s plus N dash tan phi dash upon Fs, put it in this equation and solve it.

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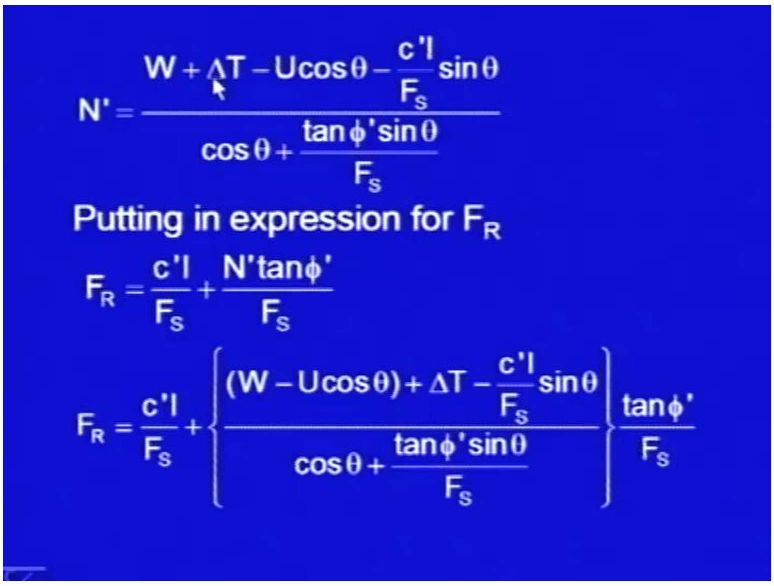

We will be getting, N dash is equal to W plus delta T is we have replaced T 1 minus T 2 by delta T minus U cos theta minus c dash l upon F s sin theta upon cos theta plus tan phi dash sin theta upon Fs. This is the expression which we are going to get for N dash. Now, we put this expression once again in this equation for the FR, so F R comes out to be, this was the expression which we had earlier F R is equal to c dash l upon F s plus N dash tan of phi dash upon Fs.

So, put N dash here, so when we put N dash here, F R will become c dash l upon F s plus this expression W minus u cos theta plus delta T minus c dash l upon F s sin theta upon cos theta plus tan phi dash sin theta upon F s and this whole multiplied by this by this, and this quantity tan phi dash upon F dash, so this is FR.

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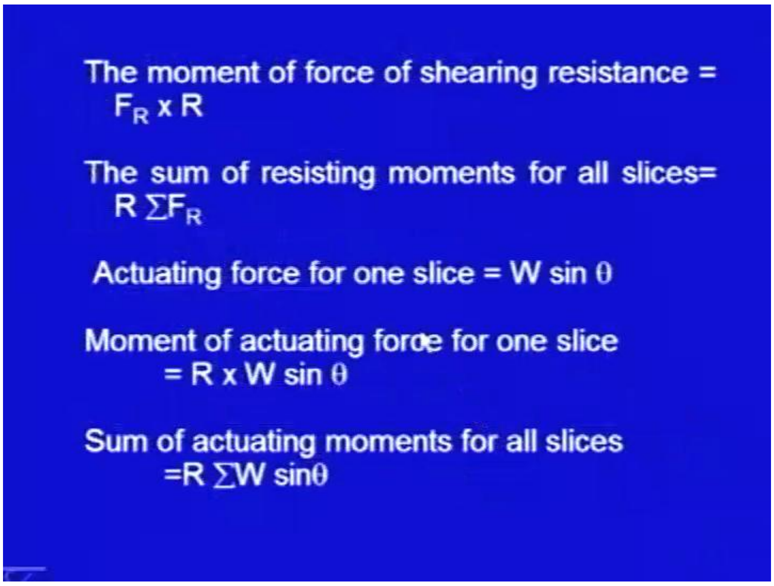

Once, we know the F R value, the force which is being offered the resistance which is being offered by that particular slide, by the soil at the base of the slice, we can find out the moment of force of shearing resistance. So, that will be F R into R, so this is the moment about the center of the trial circle and some of the resisting moments for all slices will be equal to summation of F R into R, because R is constant for all the slices. So, R will be come out, R will come out and the sum of the resisting moments will be R summation F R, similarly we can find out the actuating forces.

So, actuating force for 1 slice is this much, this is W and the actuating force will be the force which is acting here, it is trying to destabilize it, so that will be W sin theta. So, actuating force for 1 slice is equal to W sin theta and this moment will be again multiplied by R. So, that is the moment of actuating force for 1 slice and sum of all the actuating forces sum of actuating moments, for all the slices will be summation of this quantity and again R is constant for all slices R comes out and this is the expression which will be left, with sum of the actuating moments will be R summation W sin theta.

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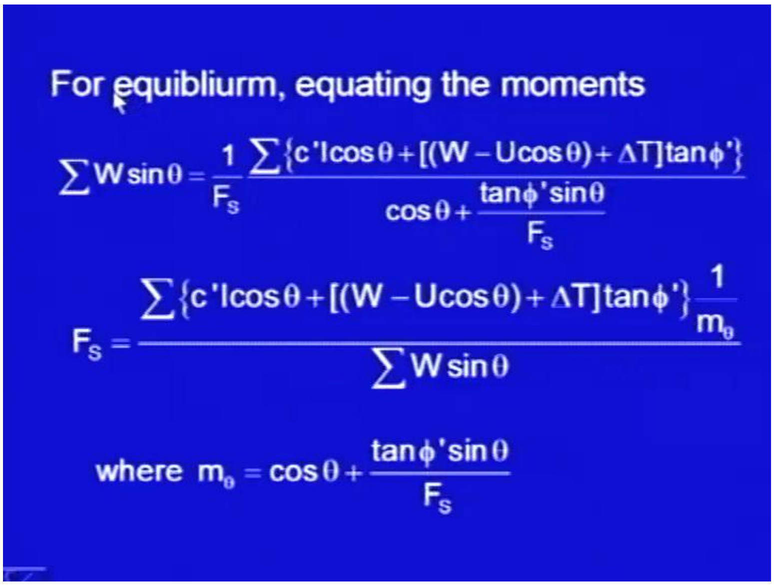

Now, for equilibrium equating these moments because, we are considering the force to be in equilibrium we have taken the force the mobilized force. So, R into summation of W sin theta will be R into this expression. So, R R cancel out and we will be left with this expression, summation of W sin theta will be equal to 1 upon F s summation c dash l cos theta plus bracket W minus U cos theta plus delta T tan phi dash divided by cos theta plus tan phi dash sin theta upon Fs.

And, we can now write this expression in a little bit simpler form, F s is equal to summation c dash l cos theta plus bracket W minus U cos theta plus delta T tan of phi dash and this multiplied by 1 upon m theta divided by summation of W sin theta. So, this quantity is brought here, F s is brought here, so this is the final expression for factor of safety, where m theta is equal to this m theta is nothing but, cos theta plus tan phi dash sin theta 1 Fs.

So, this is the final factor of safety expression and you can note down that, so far we were getting F s on the left hand side only. In this expression, we are getting Fs, here as well as in this expression also there is Fs. So, the solution has to be found out by trial and error, by taking by adopting iterative procedure.

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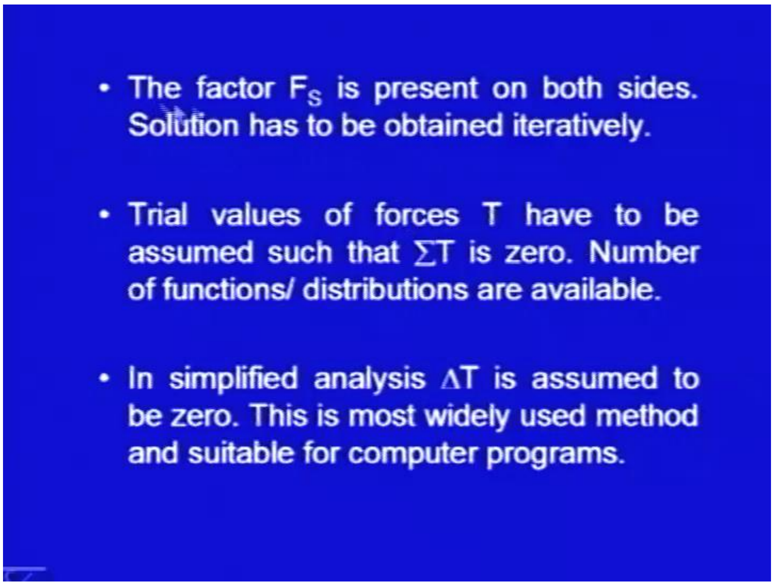

So, the factor F s is present on both sides, so solution has to be obtained iteratively because it is coming on both the sides. Now, the trial values of forces T have to be assumed such that summation T is zero, so we had assumed T acting on the sides of the slice, the total sum should be equal to 0 and there are number of functions and distributions which are available for assuming T.

Now, in the simplified analysis we make this, this analysis simplified this T 1 minus T 2 or delta T is assumed to be 0, this is called as simplified bishop's method and this method is the very, is the most widely used method and it is very suitable for computer programs and gives reasonably accurate results. So, even without these T values, where with neglecting these T values, it gives quite reasonable values.

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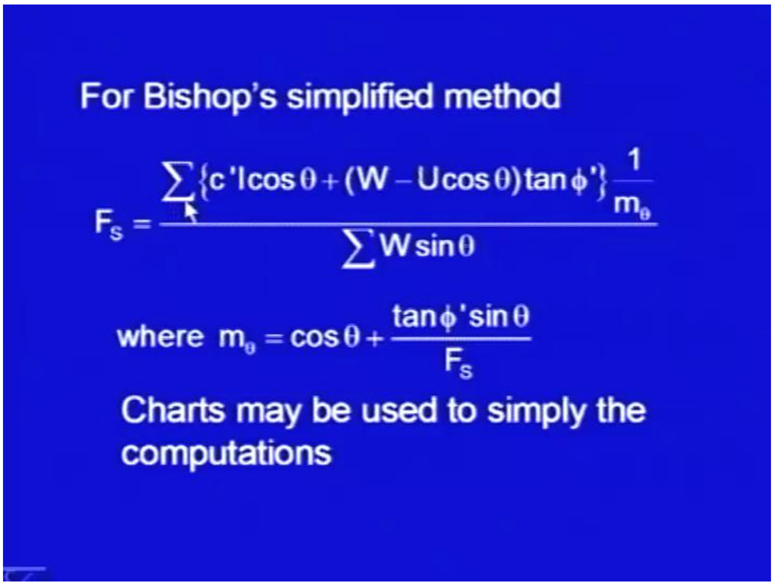

So, for this simplified method, bishop's simplified method we ignore T 1 minus T 2 and the factor of safety is obtained as summation of c dash l cos theta plus W minus U cos theta tan of phi dash 1 upon m theta divided by summation of W sin theta, where m theta is equal to cos theta plus tan phi dash sin theta upon Fs. So, this is the expression which we will used to find out the factor of safety and it is very suitable, you can solve the problem using the computer programs also.

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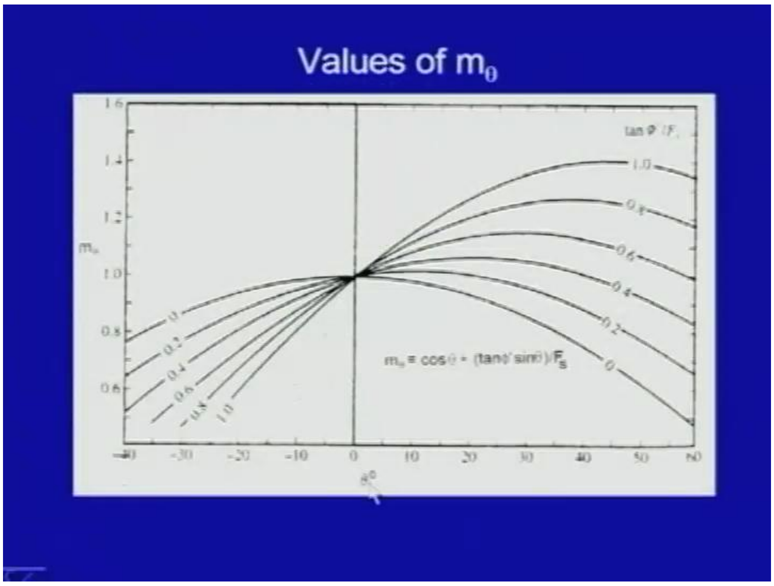

Some charts are also available, so to simplify the calculations, but nowadays the computers are preferred, you can do these calculations very conveniently using the computer program.

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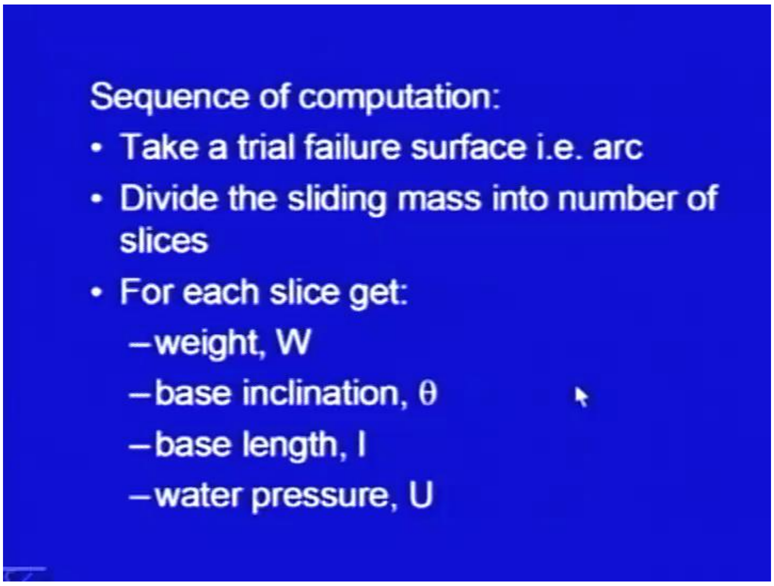

Here are the sequence computation sequence, how to do the calculations, so we take a trial failure surface as usual for all the methods of slices. This is, what we have been doing we take a trial failure surface and it is a circular arc then, we divide the sliding mass into number of slices. Then, for each slice we get weight, we get what is the inclination of the base, you can for the sake of simplicity, the base can be instead of having the arc, you can have the cord, you can have the straight line and its base inclination can be found out base length l and water pressure W, U.

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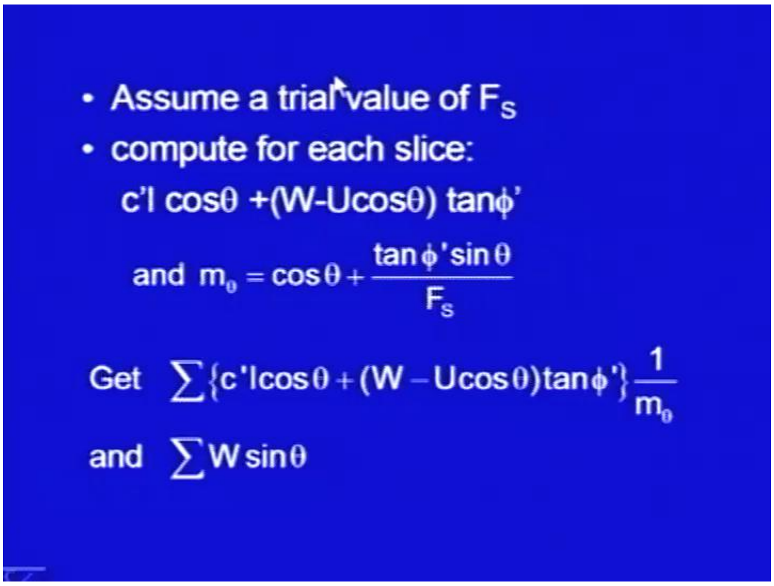

Then, what we do is, we assume a trial value of F s as I told you, we have to solve the problem iteratively. So, we start with a trial value of F s and for each slice then we compute this expression which comes in the numerator c dash l cos theta plus W minus U cos theta tan phi dash and also, m theta is equal to cos theta plus tan phi dash sin theta upon Fs. Then, we get this x, this the value of this expression which is there in numerator, summation of c dash l cos theta plus W minus U cos theta tan phi dash 1 upon m theta and also, we get this value summation of W sin theta which is there in the denominator.

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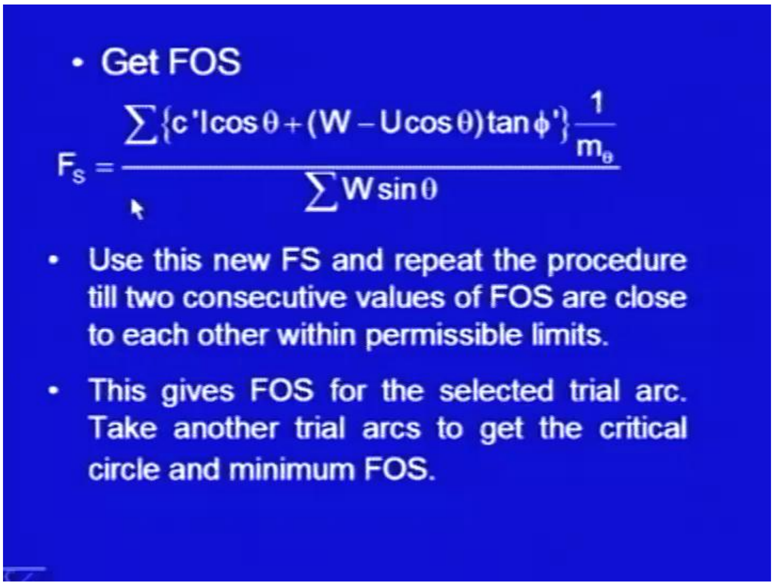

Then, put it in the factor of safety equation, F s is equal to this numerator divided by denominator. So, you will be get, you started with 1 value of F s and you use that value for all the slices and then, we get a new value of Fs. Again, you use this new F s new factor of safety and repeat the entire procedure keep on repeating it, every time you will be getting new value put it in the expression again put it in the procedure again and get consecutive value of F factor of safety.

And, this procedure is repeated till, the two consecutive values are quite close until they are within they, their difference is within the permissible limits, whatever limit you have decided. So, once they are approximately equal to each other then, we can stop the calculations and this, this particular factor of safety is only for that particular selected trial arc, it is not the factor of safety of the, of the slope. We have to now take another trial failure surfaces and, we have to repeat the entire procedure once again to get the minimum factor of safety and critical failure surface.

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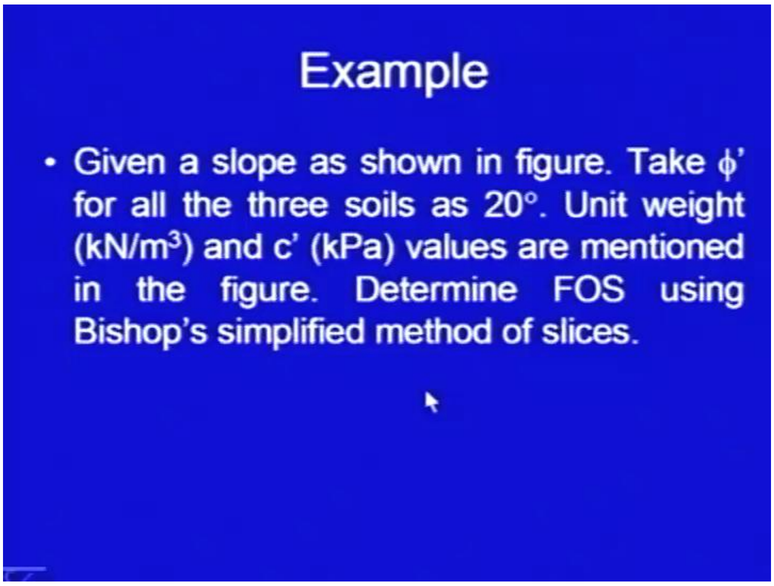

Let, us take an example to demonstrate this method, it is given here a slope as shown in the figure, take phi dash for all the three soils as 20 degree, it has the same problem which I have been solving for other methods also. Unit weight and c dash values are mentioned in the figure, determine the factor of safety using bishop's simplified method of slices.

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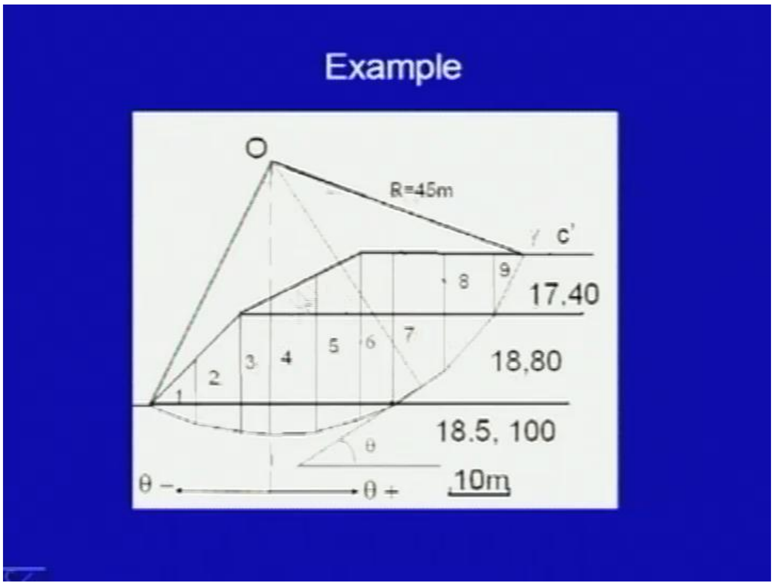

This was the slope given to us, it was not a homogenous slope and we have already taken up this problem and I had discussed that, how you should take the slices you can takes equal width also, there is no problem in that but, wherever this profile is changing, I have preferred to take the slices there. So, the computations become little bit easier, so here this was a slope then, we have drawn this circle.

And then, I have joined these cords by straight, these two points by straight lines and for any slice, let us say slice number 7. Let us say, let us take this slice then, this is the length of the base of the failure surface and inclination of the failure surface is theta. You can draw this line perpendicular to this is the radial vector and in fact, this angle will also be theta. The gamma values for different soils are here 17, 18 and 18.5 c dash values are 40, 80 and 100 k p a.

And the force, the component of the force which is trying to destabilize which is trying to actuate the slide, is in this direction. So, theta for this slice, this slice, this slice, this slice and up to number 4, this will be taken as positive in our calculations whereas, this component in slice number 1 2 and 3, this component the tangential component is trying to stabilize the slope. So, we will be taking theta as negative.

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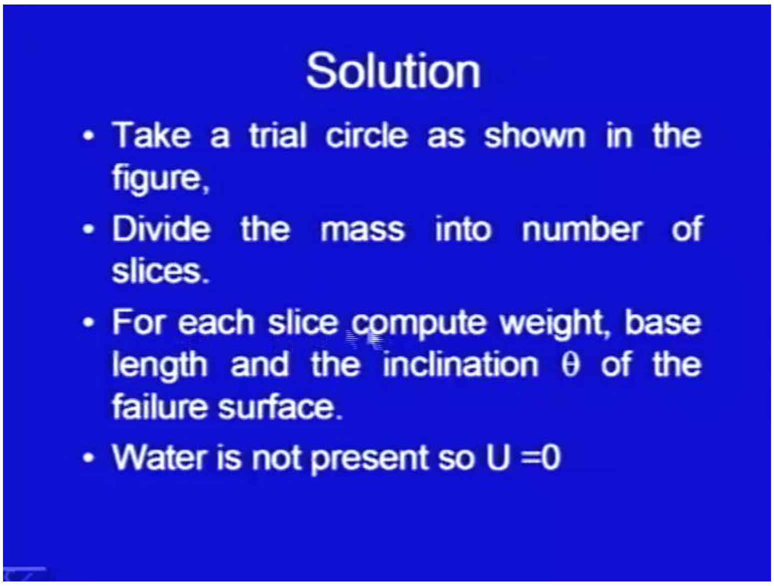

Take a trial circle as shown in this figure and then, divide the mass into number of slices, now for each slice compute the weight, how to compute it, we have discussed in previous cases. You have to take two different for example, if I take slice number 5 then, this component, this component of weight this component of weight have to be taken separately and perpendicular to the plane of paper, you can take 1 meter dimension.

So, for each slice compute weight also compute weight, the base length inclination theta of the failure surface. So, in present case of water is not there, so U is equal to 0 otherwise there will be some U value. We have already discussed how to find out U value if it is, if see page is there and you can calculate from the flow net etcetera.

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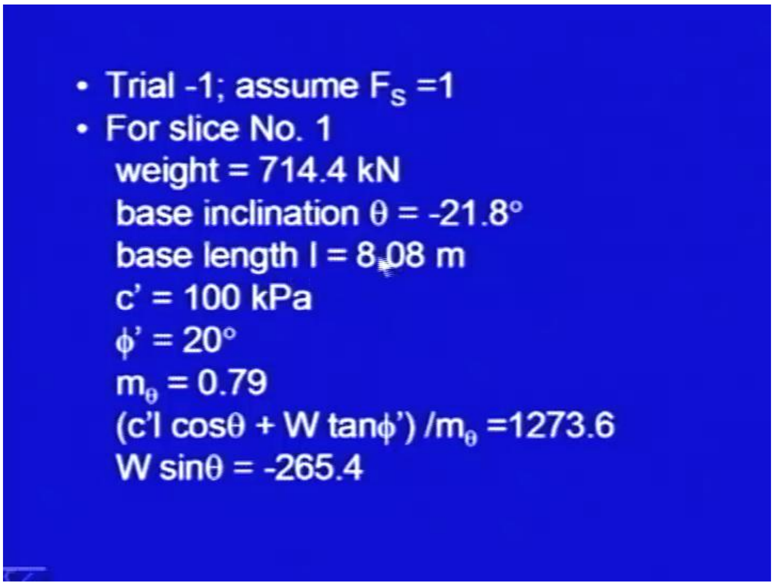

So, let us take the trial 1 and, the first trial we are taking at factor of safety 1, so we have taken factor of safety initially as 1, now for slice number 1, this is the weight, weight is 714.4 kilo Newton, base inclination is minus 21.8, base length comes out to be 8.08, c dash at the surface is 100 k P a, phi dash is 20 degree, m theta we have calculated using the expression, it comes out of to be .79 and c dash l cos theta plus W tan phi dash upon m theta comes out to be 1273.6 and W sin theta comes out to be minus 265.4.

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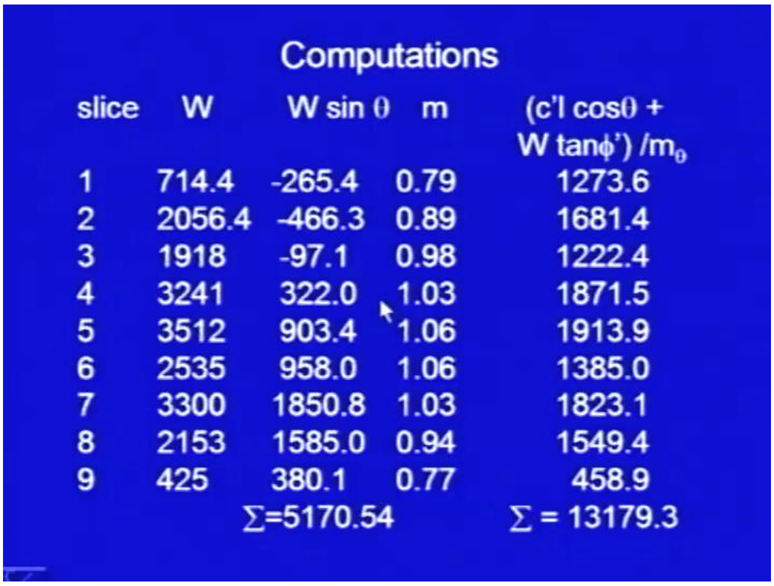

Computations

slice	W	W sin θ	m	(c'l cosθ + W tanϕ') /m_θ
1	714.4	-265.4	0.79	1273.6
2	2056.4	-466.3	0.89	1681.4
3	1918	-97.1	0.98	1222.4
4	3241	322.0	1.03	1871.5
5	3512	903.4	1.06	1913.9
6	2535	958.0	1.06	1385.0
7	3300	1850.8	1.03	1823.1
8	2153	1585.0	0.94	1549.4
9	425	380.1	0.77	458.9
		Σ=5170.54		Σ = 13179.3

I am not showing all the calculations here, they are, they are given in this tabular form slice number 1 2 3 up to 9, these are their weights 714.4, 2056.4 five and so on. W sin theta, theta is negative for first few slices, so these are the W sin theta values, in fact, you can make one more column here which indicates the theta value then, the factor m and then c dash l cos theta plus W tan phi dash upon m theta, their sum and sum of the W sin theta values.

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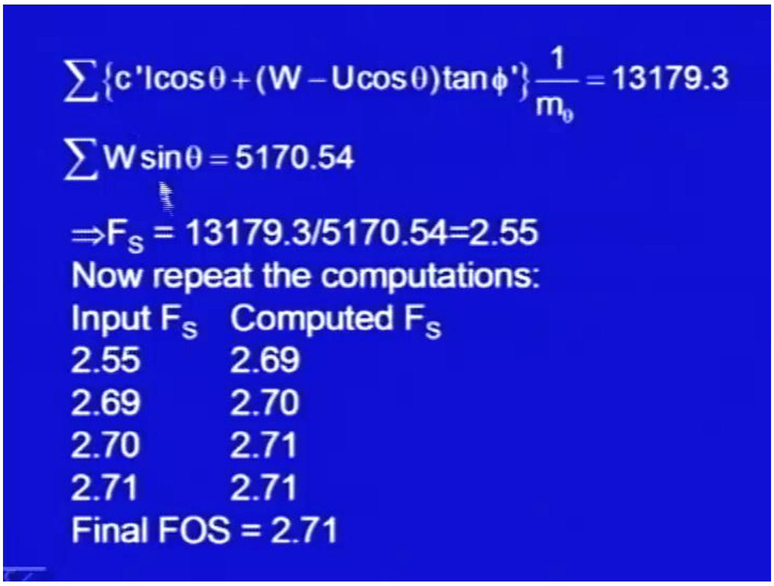

The factor of safety is computed from these expressions, so this is the numerator which comes out to be 13179.3, the denominator comes out to be 5170.54 and the factor of safety, then comes out to be 2.55. Now, our first trial was F s is equal to 1 and we got 2.55, now I have made another trials for which, I am not showing the calculations here.

So, when I put 2.55 next trial, the value I got was 2.69 then, I put factor of safety 2.69 and I got value 2.70. So, after few trials I am getting a constant value, so F s on both the sides, now in this equation is 2.71. So, final factor of safety of this trial circle is 2.71.

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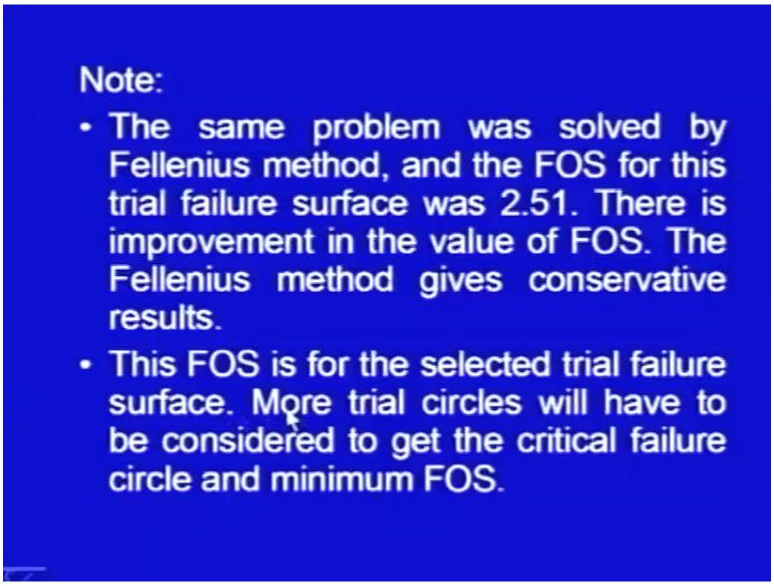

Now, you can note we sometime back, we solved the same problem using Fellenius method and factor of safety for that for the same trial surface we had taken the same trial surface in that case also, and it was obtained to be the factor of safety was 2.51 and presently it is 2.71. So, there is gain in the factor of safety, there is improvement in the value of the factor of safety, the Fellenius method gives conservative result.

So, in fact, this assume this bishop's method simplified bishop method is you can use it and it gives reasonably accurate values and there can be lot of improvement in the factor of safety. Finally, this factor of safety is for the selected trial failure surface, again we have to do the same exercise with more number of trial circles and then, we have to get the critical failure surface and minimum factor of safety, that will be the factor of safety of the slope.

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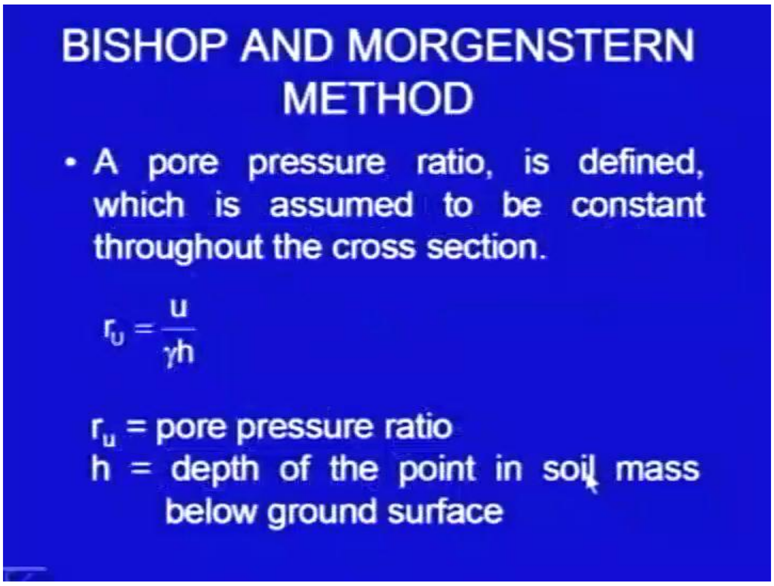

Now, let me come to the next method, the method is Bishop and Morgenstern method, in this method a pore pressure ratio is defined which is assumed to be constant throughout the cross section, r u is equal to u upon gamma h, where u is the pore water pressure, ru is pore pressure ratio, h is the depth of point in soil mass below ground surface.

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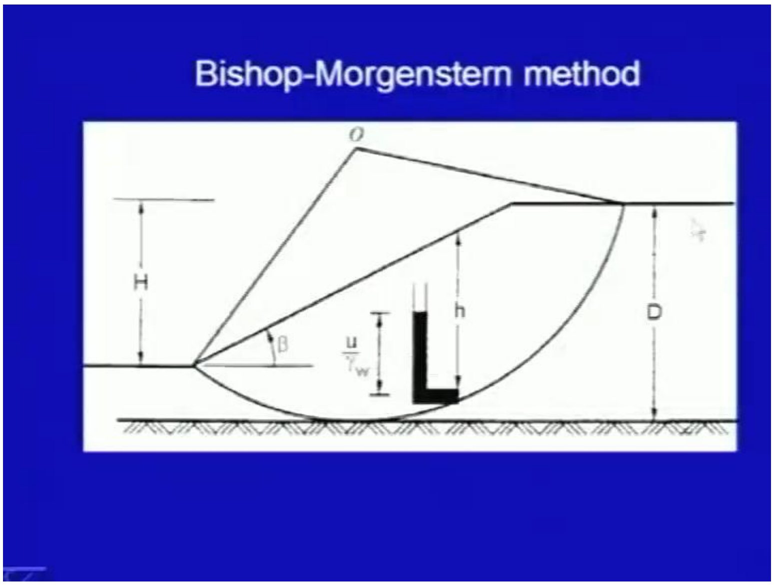

Here, this is the diagram which explains the different parameters, this is the depth D and the depth D of the, a base, hard base and H is the depth of the slope, slope angle is beta and here, u upon gamma w, this is the head of the pore water pressure, h is the height of the slope here.

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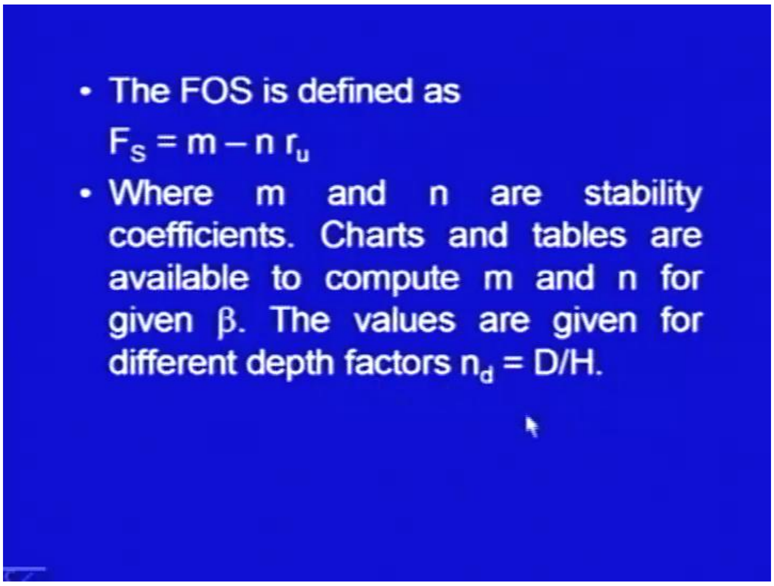

And then, they have solved the problems and they have given the solution in terms of tables and charts. The factor of safety is defined as factor of safety F s is equal to m minus n times r u, where m and n are the stability coefficients which are available for, from the charts, charts and tables are available to compute m and n for given beta. The values are given for different depth factors n d, n d is equal to D upon H, so this is D this is H.

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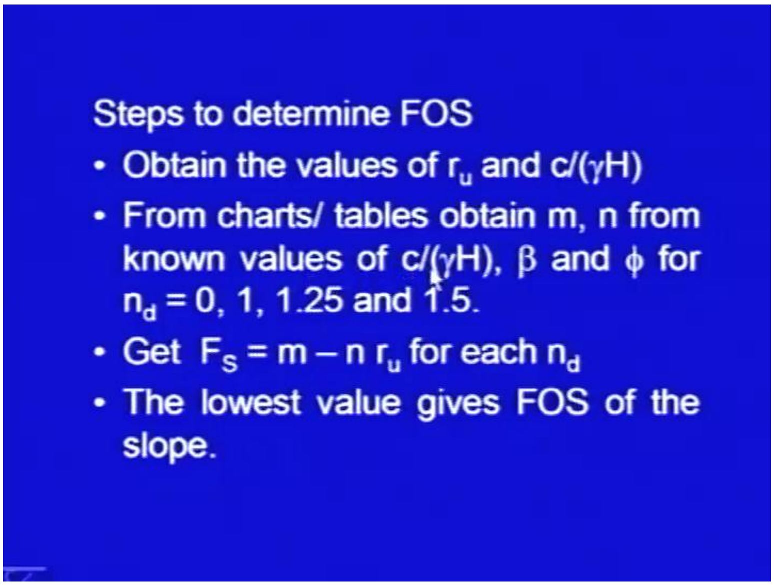

So, for different these factors, these values are given, here are the steps obtain the value of r u and c upon gamma H then, from charts or tables obtain the parameters m and n from no for the known values of c upon gamma H beta and phi for different values of n d, n d is 011.25 and 1.5. These are the values which they have given and then, get F s is equal to m minus n times r u for each n d and the lowest value gives the factor of safety.

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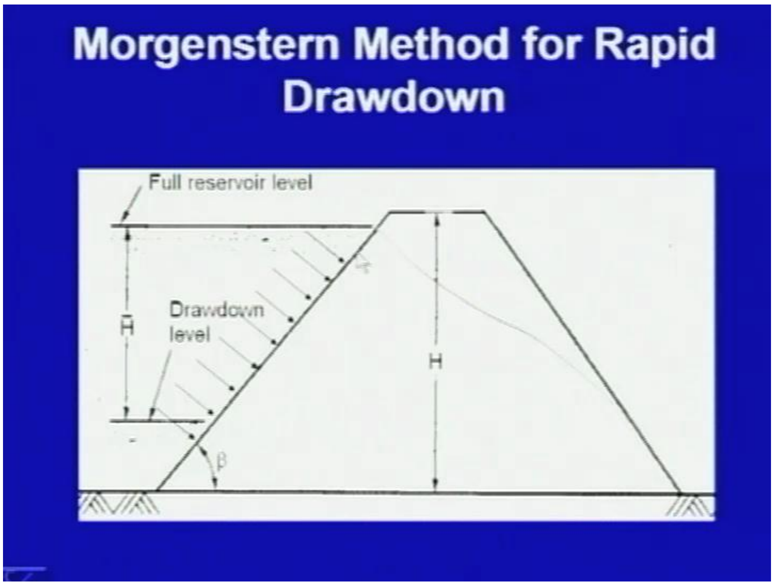

There is another case now, I would like to consider it is the case of the rapid drawdown, this happens this is a considered in cases of the dams, this is an amendment dam, earth dam and, what happens is there that, when the water is here and it is standing here for a quite long period and as you know the equilibrium will develop up here there will be phreated line which will be developed at this place.

So, phreatic line will be like this and, the seepage will be taking place from the upstream to downstream direction and this mass will be saturated and water will be seeping through this mass. Now, what happens is if all of sudden there is reduction in the water level here, this was the full reservoir level and all of sudden the water level drops to this. Because of certain reason then, what happens here in this saturated mass is that, the pressure now this water which is available here, it is exerting some sort of pressure, it is exerting a force here and there is equilibrium here.

So, when this force is removed, this and the hydraulic conductivity of this soil if is it, it is not high then, this force is removed, but inside the, inside the dam body that pore pressure remains there because, it will it takes time to dissipate and the permeability is low. So, water pressure is available here inside, which was acting against the outside pressure. So, there will be instability in this region and that instability can be checked up using this method, Morgenstern's method of rapid drawdown.

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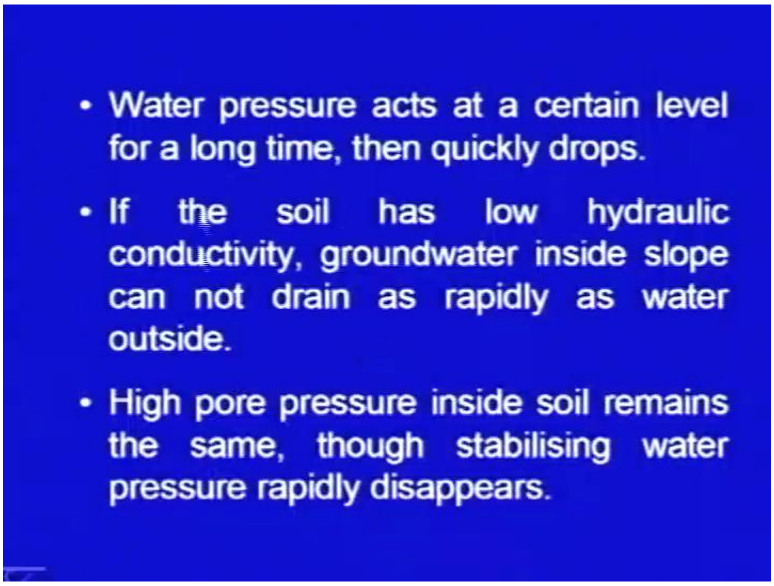

So, here it is the first explanation for this, when water pressure acts at a certain, so what happens is that, water pressure is there for a long period and then, there is a sudden drop in the, in the water level and let us say that, the soil has low hydraulic conductivity then, ground water inside the slope cannot drain as rapidly as water outside and high pore pressure inside soil remains the same and it will be, it will try to destabilize the dam, the body.

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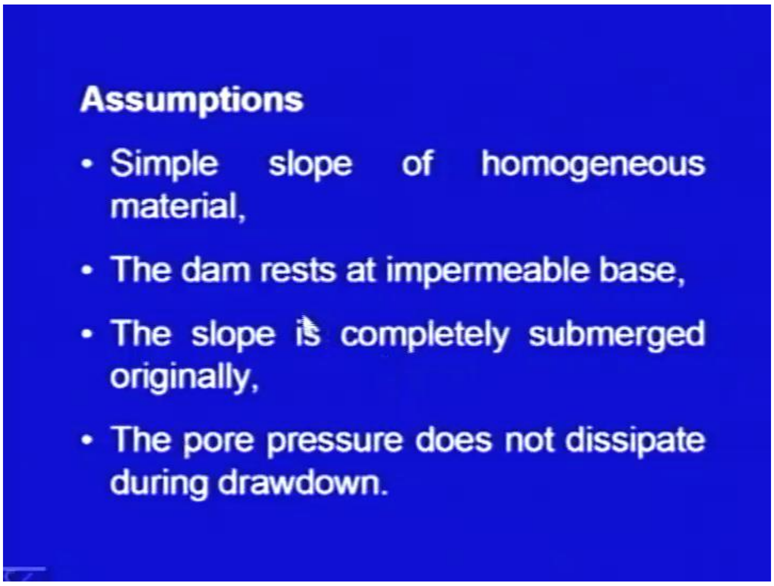

So, in this method, these are the assumptions simple slope of homogenous material, it is assumed to be homogenous and dam rests as at an impermeable base that is, the second assumption in this method slope is completely submerged originally. This is the assumption, it is there is no free board completely submerged and pore water pressure does not dissipate during drawdown.

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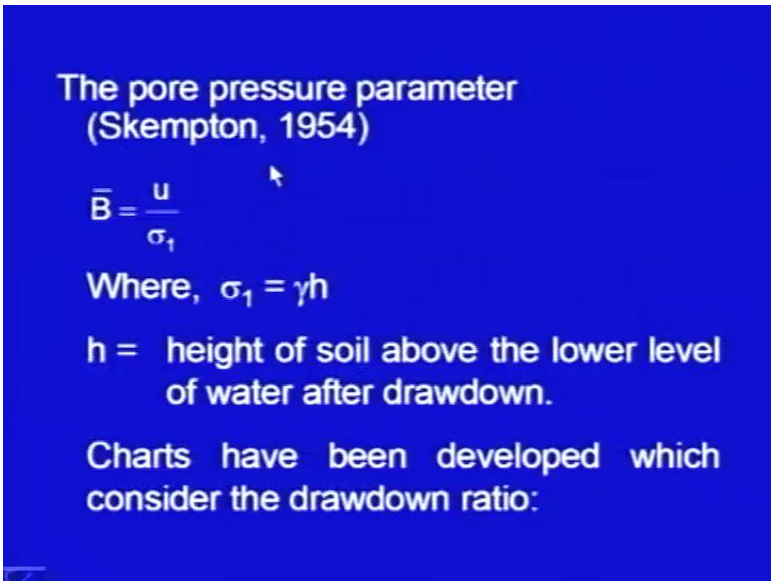

And, the skempton pore pressure parameter B bar has been use this analysis, B bar is equal to u upon sigma 1, where sigma 1 is equal to gamma h, h is the height of the soil above the lower level of water after drawdown and finally, the method is available in terms of charts.

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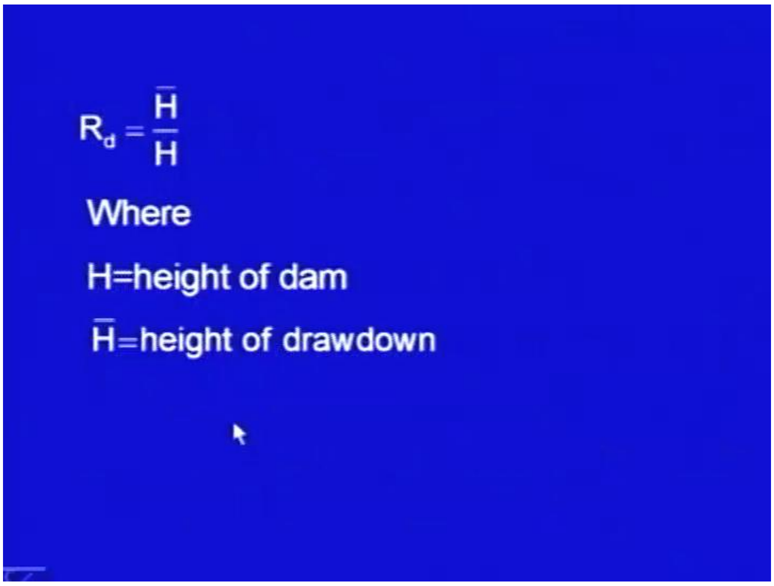

So, in this charts, this factor Rd is calculated as H bar upon H, where H is the height of dam and H bar is the height of drawdown.

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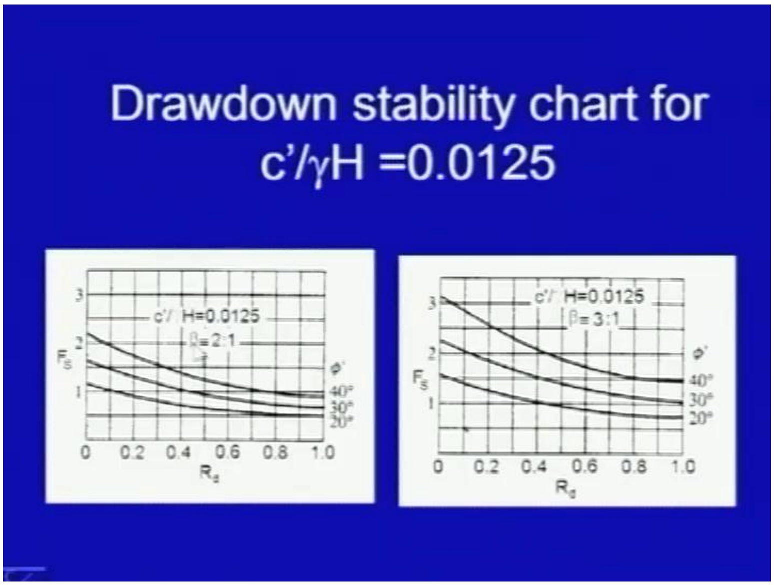

So, here this is the chart for c dash upon gamma H is equal to 0.0125, there it is factor of safety is here on y axis and on x axis, Rd value is there and this particular chart is for slope having two horizontal is to one vertical as the slope angle. Similarly, this is the chart for beta is equal to three horizontal and one vertical slope.

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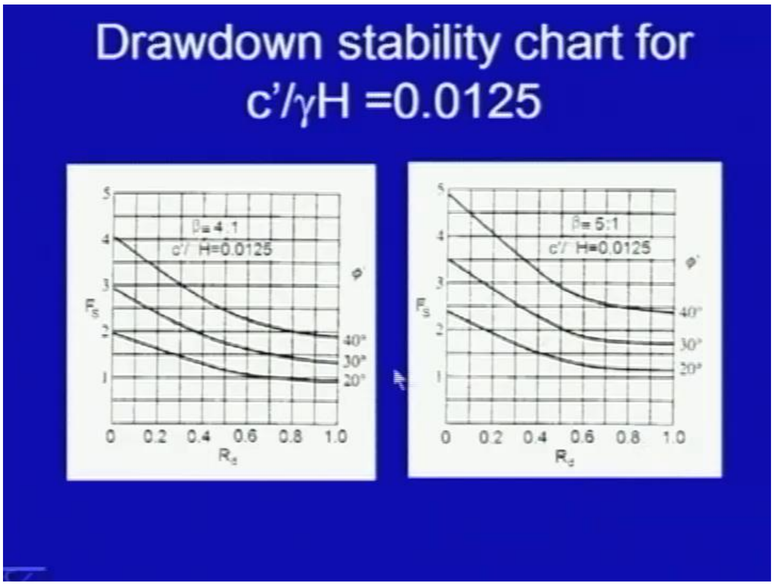

This is the chart for beta is equal to 4 is to 1, this is the chart for beta equal to 5 is to 1. So, all these were having the number c dash upon gamma H is equal to .0125.

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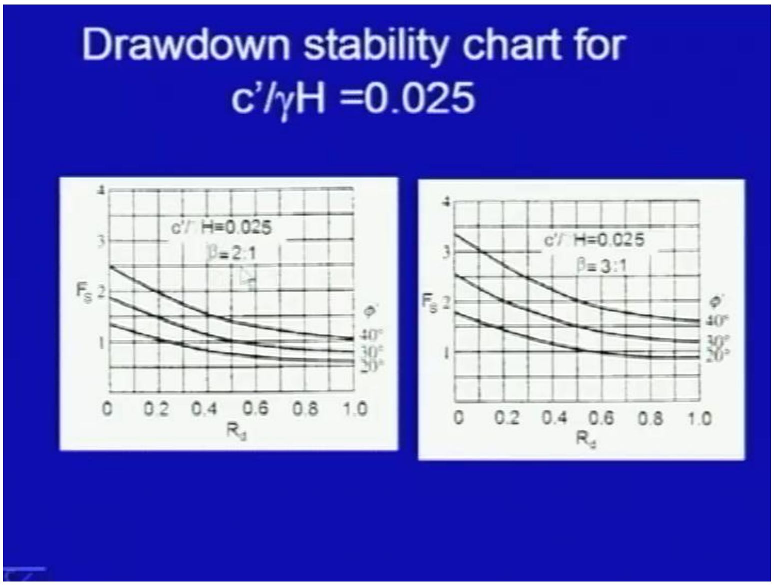

Similarly, the charts for different slopes have been produced for these values c dash upon gamma H is equal to 0.025 for 2 is to 1, 3 is to 1, 4 is to 1 and 5 is to 1. So, these charts are available in standard books, one can refer to these charts and c dash upon gamma H, here is .025.

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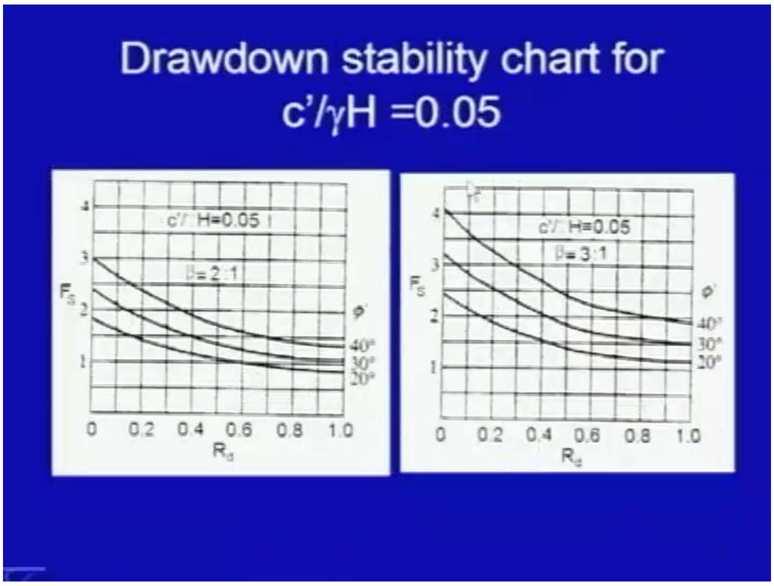

And, third chart is available third series of charts is available for c dash upon gamma H is equal to 0.05, here beta is equal to 2 is to 1 beta equal to 3 is to 1, 4 is to 1 and 5 is to 1.

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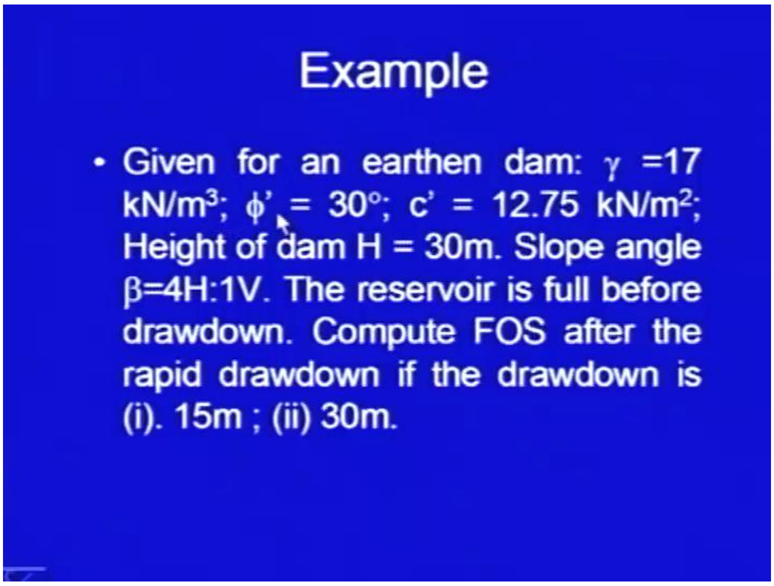

So, these are the charts using which you can solve the problem and, let us have an example, it is given for an earthen dam, gamma is 17 kilo Newton per meter cube, phi dash is 30, c dash is 12.75, height of the dam is 30 meter and slope angle is 4 is to 1. The reservoir is full before drawdown compute FOS after the rapid drawdown, if the drawdown is 15 meter, in second case it is 30 meter.

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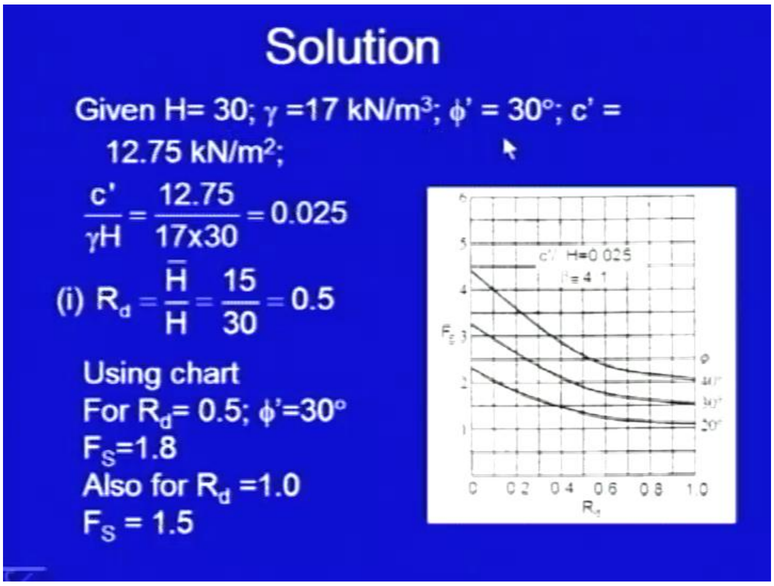

So, all these parameters are available with us, we calculate the value of c dash upon gamma H. So, c dash upon gamma H comes out to be 0.025, incidentally this is exactly

0.025, in this case if it is some other value, we have to interpolate the results. Then we calculate the Rd, in the first case the drawdown is equal to 15 meter, so 15 upon 30 Rd is equal to 05, so consider the appropriate chart. So, c upon gamma H is equal to 0.025 and beta is equal to 4 is to 1 here.

And, as I told you if the slope is, let us say something else c dash upon gamma H is also something else, then you have to interpolate the values by taking different sets. So, here Rd is .5, so let us take .5 is this and phi dash corresponding to phi dash equal to 30. This is the 30 value and some where here, this value is read, this value comes out to be 1 point 8, so straight way you get the factor of safety.

Similarly, when there is complete drawdown, H bar is equal to 30, so Rd will be 1 and you can again check this diagram. So, Rd is 1 here, so .6, .8, .1 and corresponding to 30 degree, the factor of safety is 1.5. So, one can find out the factor of safety due to rapid drawdown.

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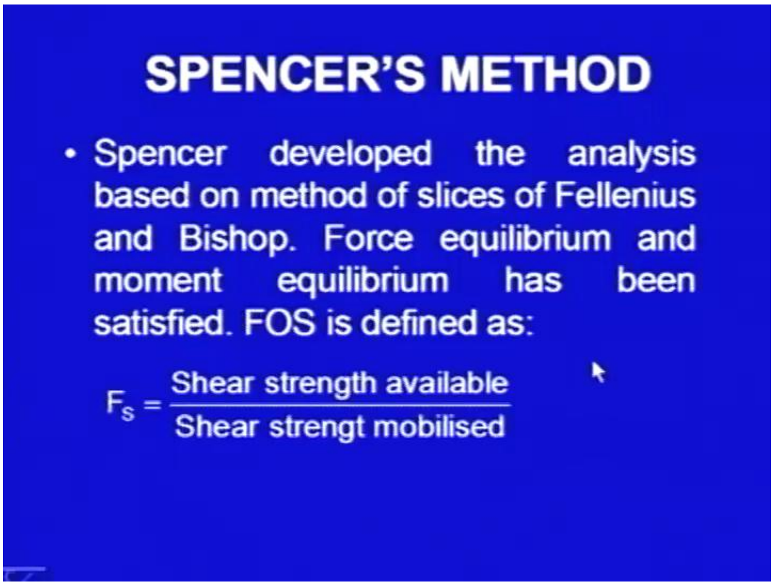

There is one more method, I would like to discuss that is the Spencer's method and again we are not going in much detail we will be just using the method, how to, we will just discuss how to use this method. He developed the analysis based on method of slices of Fellenius and bishop's methods, force equilibrium and momentum, moment equilibrium has been satisfied the factor of safety is defined as shear strength available upon shear strength mobilized this is the factor of safety expression.

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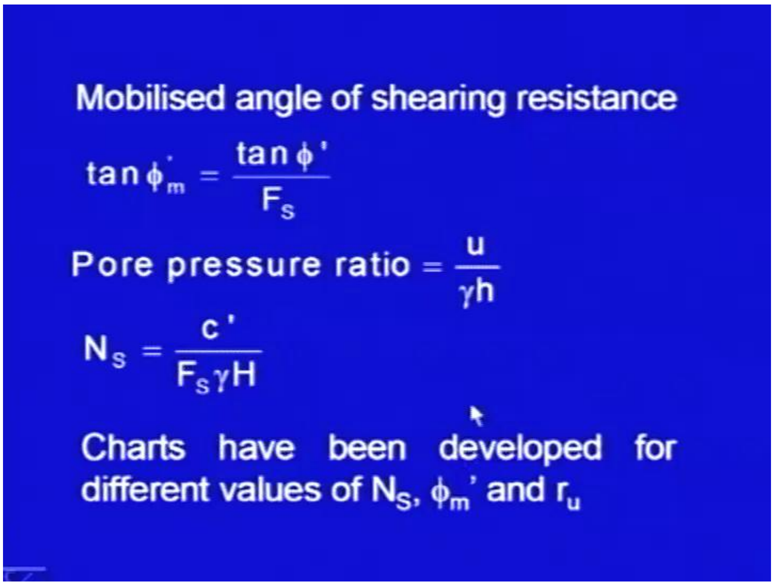

These are the parameter which will be used in those charts, mobilized angle of shearing resistance is tan phi m dash is equal to tan phi dash upon Fs, pore pressure ratio is u upon gamma h and stability number N s is equal to c dash upon F s gamma H and charts have been developed for different values of Ns phi m dash and r u.

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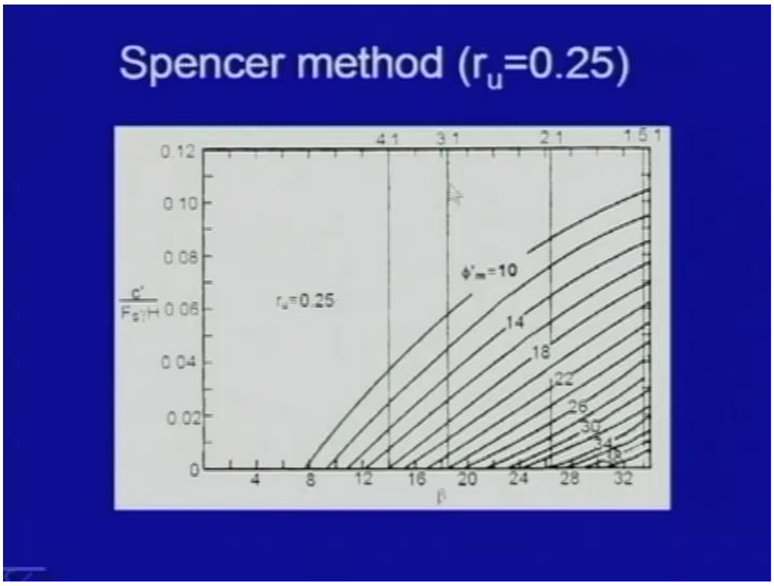

This is the first chart for r u is equal to 0, on y axis you have c dash upon F s gamma H on x axis, you have beta, these are the beta in degrees and also these are these in terms of the gradients 4 is to 4, as horizontal is to one vertical, three horizontals to vertical, one vertical and so on, and these are the phi m dash values.

So, corresponding to any, if you have c dash F s gamma H and r u and phi m dash, a relationship, a correlation, a link between all these parameters can be developed using these chart, these charts. This is the say similar charge, but for r u is equal to .25 and here it is the chart which is for r u is equal to .50.

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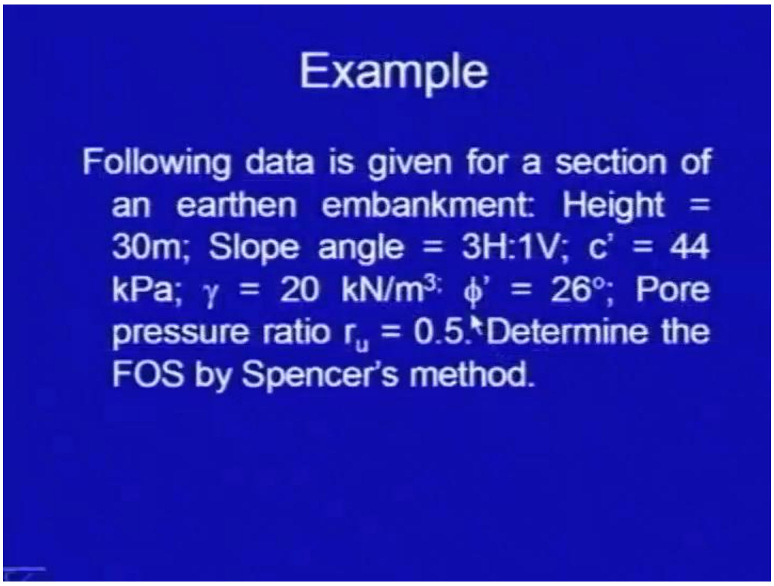

Let us, again take an example here following data is given for a section of an earthen embankment, height is 30 meter, slope angle specifically we have taken directly 3 as is to 1 vertical, if some other slope angle is given. We have to do the interpolation c dash is 44 k P a, gamma is 20 kilo Newton per meter cube, phi dash is 26 degree and pore pressure ratio r u is equal to .5 and we have to determine the factor of safety by Spencer’s method.

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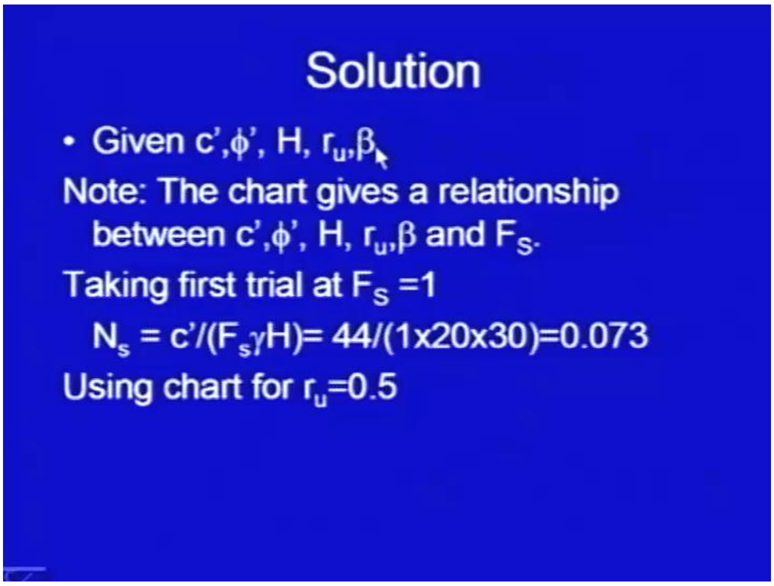

Now, in this problem we have been given c dash, phi dash, H r u and beta these are the values available and as I told you, the chart gives the relationship between c dash phi dash H r u beta and factor of safety. In this case also, we will have to take different trials and we start our first trial with F s is equal to 1. So, Ns is equal to c dash upon F s gamma H and this value comes out to be 0.073, now use the chart for given r u value.

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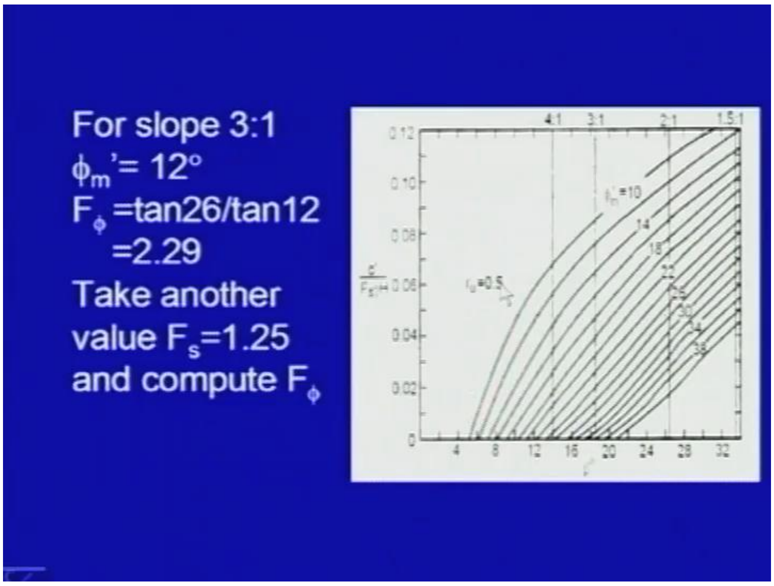

And, here it is the chart given to you for r is equal to .5 and also for slope, 3 is to 1 this is the vertical line, this that represents the slope 3 is to 1 and for the value of the Ns which we obtained in the previous slide, Ns was .073. So, let us take .073, somewhere here and you will be getting the intersection with 3 is to 1 line here, somewhere here and this gives you the mobilized value of frictional resistance phi m dash.

So, here I am getting this value as 12 degree, now you can calculate the factor of safety against phi, that will be equal to tan 26 upon tan 12 and that comes out to be 2.29. Now, take another trial, see what we are trying to find out is, we are we will be finding out that factor of safety for which F s and F phi, F s F phi F c all are equal. Now, we take another trial value, F s is equal to 1.5 and then again compute F phi in this manner.

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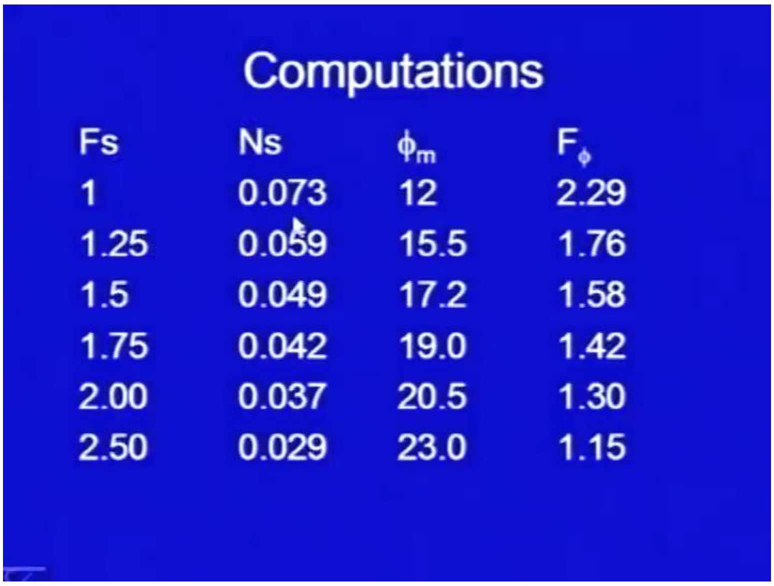
Computations

Fs	Ns	ϕ_m	F_ϕ
1	0.073	12	2.29
1.25	0.059	15.5	1.76
1.5	0.049	17.2	1.58
1.75	0.042	19.0	1.42
2.00	0.037	20.5	1.30
2.50	0.029	23.0	1.15

So, here I have shown the computed values, this was our assumed values, this was Ns and this is phi m and this was computed F phi. So, for different F s values, these are the values of the F phi, in fact, these are the F c values.

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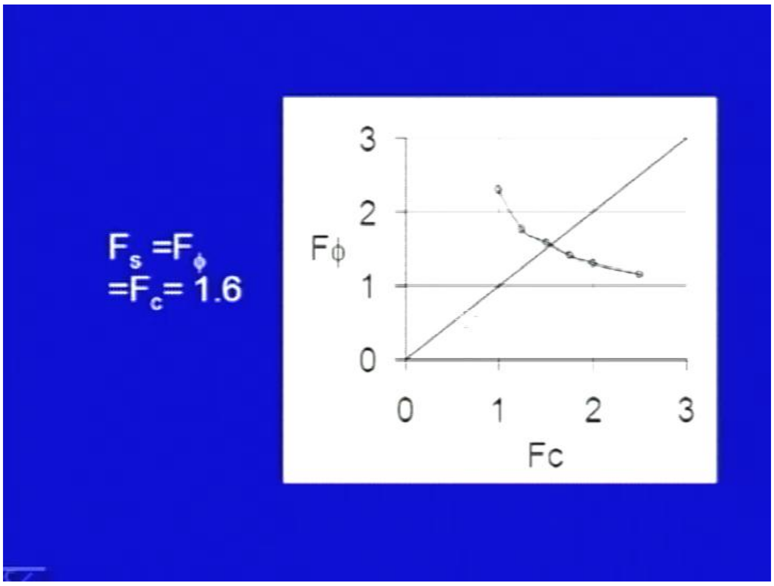

So, for different F c values, you are getting these F phi values and finally, we do the same thing, we plot a graph between F c and F phi, this is the graph and draw a line which is having 1 is to 1 slope, 45 degree slope and where it intersects, this curve that gives you the factor of safety. So, for this point F s F phi F c all are equal and the factor of safety we are getting is about 1.6.

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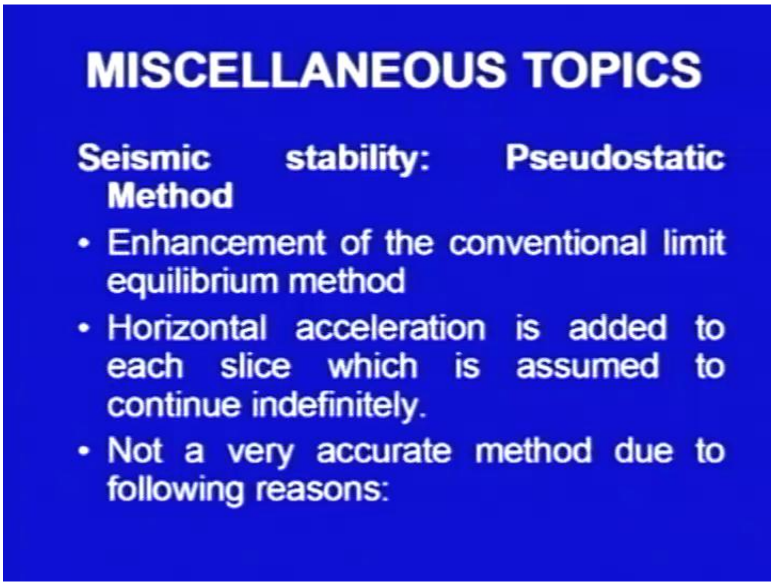

So, friends I have discussed various methods of the slopes stability analysis and now few minutes I would like to devote on some miscellaneous topics, the first topic which I am taking up is seismic stability, we took this case for one example and the method which we are using here, it is called as pseudo static method, this is nothing, but it is an enhancement of the conventional limit equilibrium method.

And, as we did in that problem what we do here is, horizontal acceleration is added to each slice, each slice we add some component which is assumed to continue indefinitely. So, we have we take some factor, we take some coefficient and multiplied by g and that is the acceleration we take up in the horizontal direction, and we assume that it is, this particular acceleration is acting there for infinite period for indefinitely or as long as the earth quake is acting there. And then, we calculate we take up that as additional force additional destabilizing force and then, we do the stability analysis, it is a very very crude method, it is not a very accurate method.

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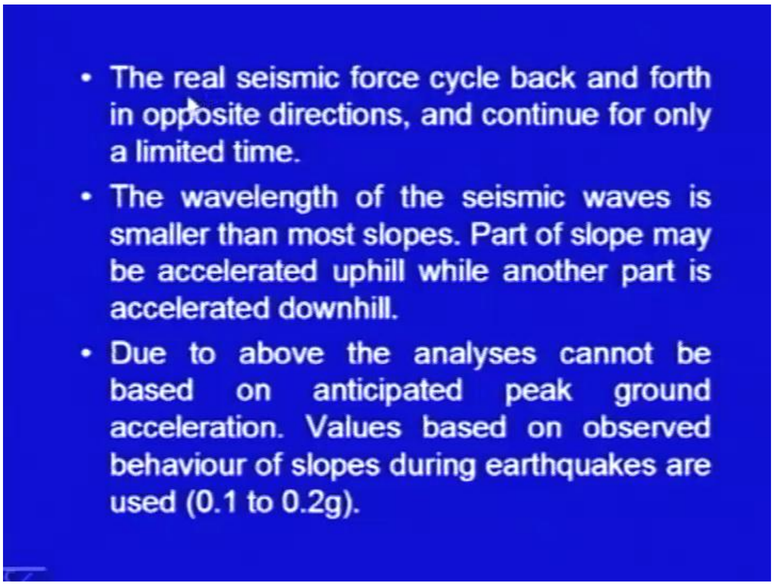

The reasons are as follows, the real seismic force cycles back and forth in opposite directions and continues continue for only a limited time. So, it is it is cyclic in nature the force is cyclic in nature it does not act for the same for the entire period. So, that is one thing and secondly, the wave length of the seismic wave is smaller than most of the slopes and part of the slopes may be accelerated uphill while another part is accelerated downhill.

So, one part may be accelerated, in one direction the another part is accelerated in other direction. So, the assumption which we had made that, all the slices are having the force in the same direction that is not valid and, this is the reason using this method, we get very very highly conservative results.

So, due to the above, due to the above reasons the analysis cannot be based on anticipated peak ground acceleration, rather the values based on observed behaviors of slopes during earthquakes are used and these values vary this coefficient varies roughly between .1 to .2 g, so this is an approximate method.

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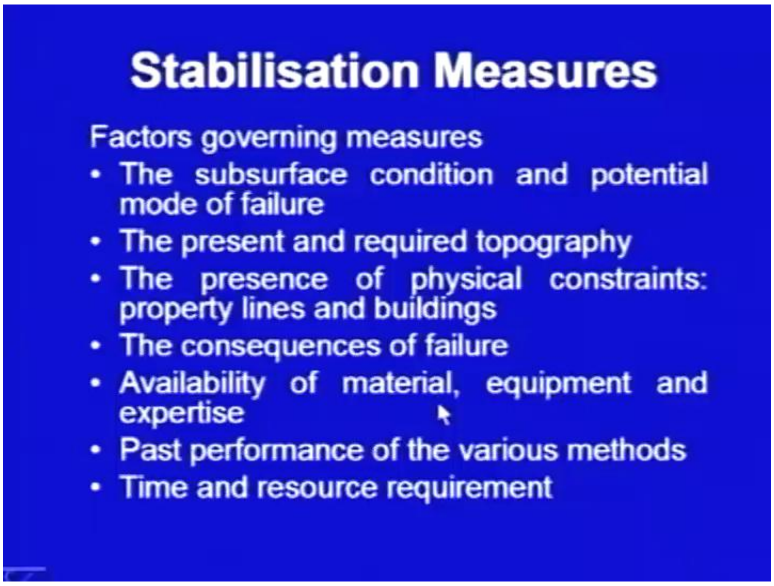

Second point, which I would like to discuss is about the stabilization measures, we have discussed that the factor of safety, some permissible values of the factor of safety will be there, let us say 1.5 or 1.2. So, whatever the factor of safety is there, based on this then, we will decide whether we have to stabilize the slope, whether it is stable whether it is safe or unsafe and if it is a natural slope, let us say where we, we cannot change the. So, many things then, we have to stabilize the slopes, if it is a man made structure then, you can redesign the slope.

So, the factors there may be, we may need to stabilize, we may take to we may require to adopt some stabilization measures. So, I am only giving very brief idea and not discussing them in very detail, these are the factors which will govern these measures. The subsurface condition and potential mode of failure what is the kind of the failure that you are going to have, whether it is plainer or circular.

Secondly, the present and required topography, so if you want to make a, we want to make it stable and we want to change the topography that, topography we, we have to consider how much area it really needs and so on. The presence of physical constraints, there may be so many physical constraints in the field. Physical constraints means for example, property lines may be their buildings may be there, you may not be allowed to work beyond those lines and the area may be limited. So, there may be several limitations and constraints in the field.

Then, the consequence of failure, consequence of failures means what is the damage we it is likely to occur, there if the failure occurs, if the life is endangered, if the property is endangered then, you have to locate different weight age. If there is no danger to life or the property then, maybe we can adopt some other measure. Then the availability of the material, if you want to stabilize it availability of the material, the availability of the equipment and also equip availability of the expertise is very very important.

And also, we have to see in that particular area what is the past performance of various methods because, stabilization measures it will be a side specific solution, it is not a standard solution that you can give one solution to every place. So, the solution will vary from place to place, so what is the performance of various methods, various techniques there in the past, that is also very important and finally, what is the resource available, do you have, do you really have money to stabilize and also what is the amount of time available.

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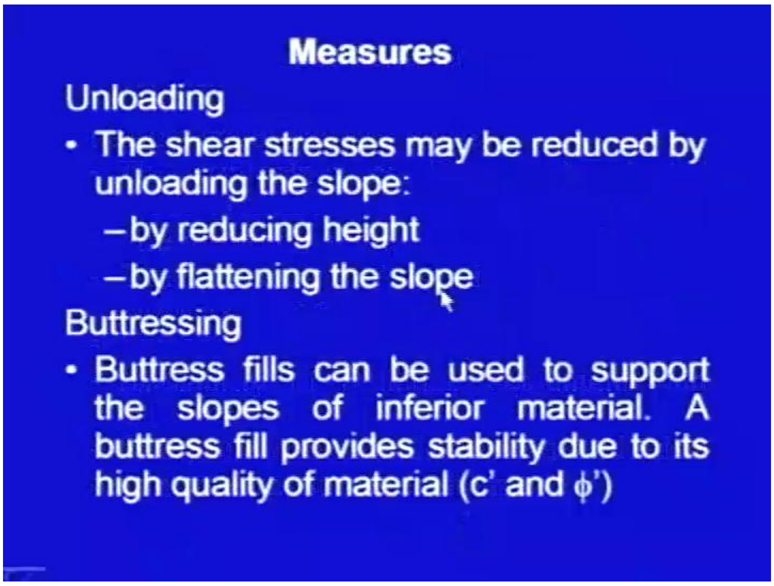

Now, these are some of the measures, the first thing is we can try to reduce the shear stresses, you see it is a mechanistically it is a very simple problem, there are actuating forces and there are stabilizing forces. So, if we try to reduce the actuating forces, if we try to reduce the, the shearing stresses and that can be done by unloading, that can be the first approach. So, it can be done you by reducing the height, one can try to reduce the height of the slope, its possible.

If possible for example, in case of the manmade structures it is possible, in case of the natural slopes it may not be possible and also by flattening the slope by changing the slope angle, you if the, if it is very steep it may be it may be unstable. So, we can adopt the lower the flatter slope, second is buttressing, buttress fills can be used to support the slopes of inferior material. Buttress fill provides stability due to its high quality of materials.

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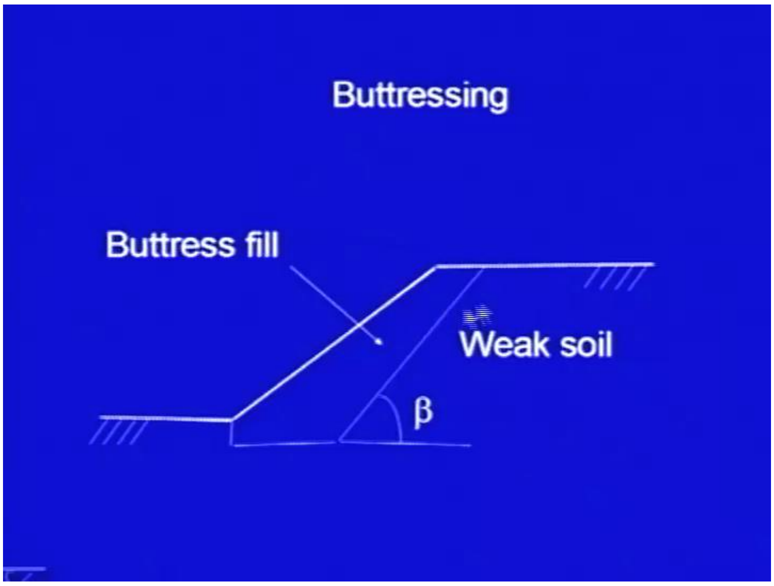

So, it is something like, here it is a steep slope of the weak soil and some buttress fill is made, here it is pushing the weak soil, the soil the weak slope and it is making it stabilized. So, this is the weak soil and this is a good quality of the material and here one key is provided means, you are putting it up to some depth. So, that force the, the reaction is also available from the other side.

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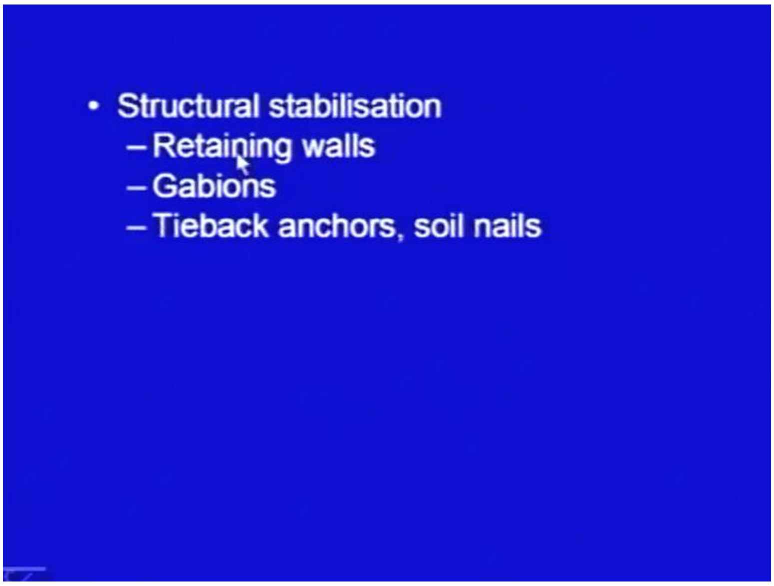

Then, you can use the structural stabilization, here the retaining walls can be used, gabions can be used, tieback anchors and soil nails can be used, they can be properly designed.

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Here is an example, this is a slope here which is having retaining wall, this is the road on the side and this slope. This retaining wall is still under construction and this retaining wall is, is being constructed to retain this slope.

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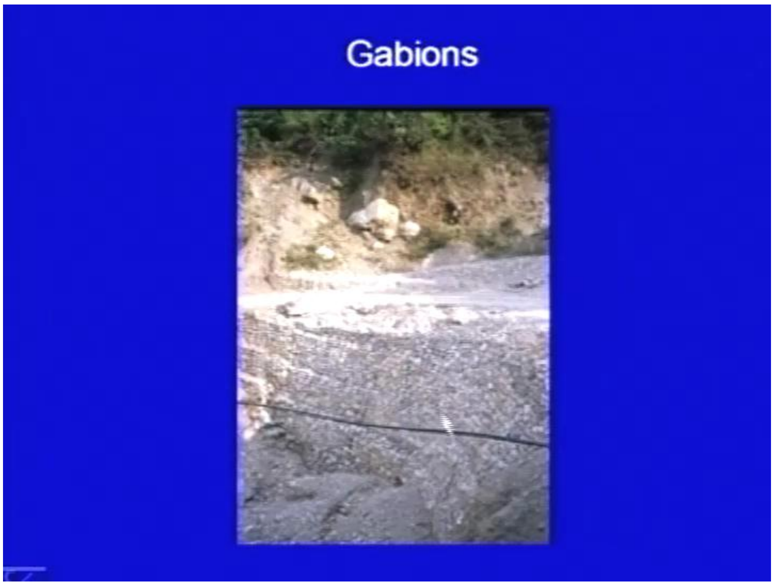

These are the gabions, gabions are constructed of broken bolders and rock pieces, stones and these are the gabions which are kept one above the other and here, it is the slope which is being stabilized using these gabions. So, this is another technique which can be used for the natural slopes.

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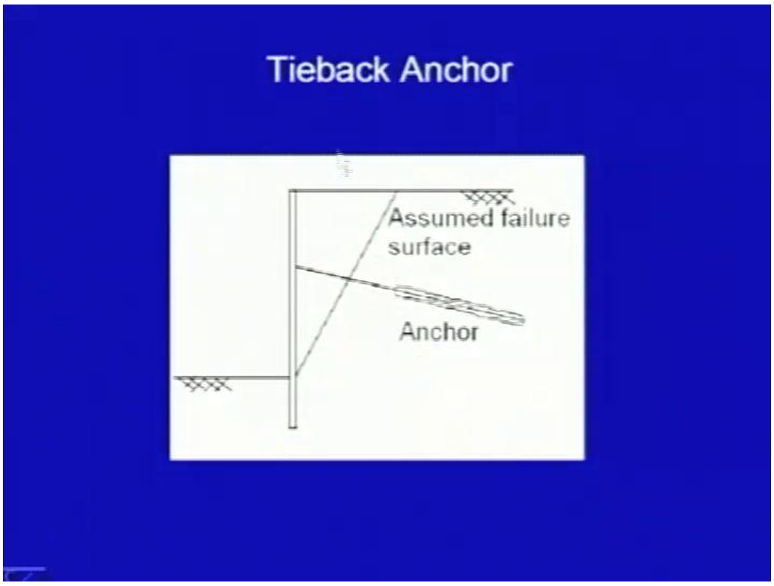

Then, this is a tieback anchor, so here the anchors can be provided and also I discussed in the planar failure case of planar fails, where there also you can provide the anchors and then, those anchors can be used, they will try to stabilize this mass. So, here it is the assumed failure surface and the anchor is here, so anchor will try to polate and it will try to give some stabilizing effect on this, on this slope.

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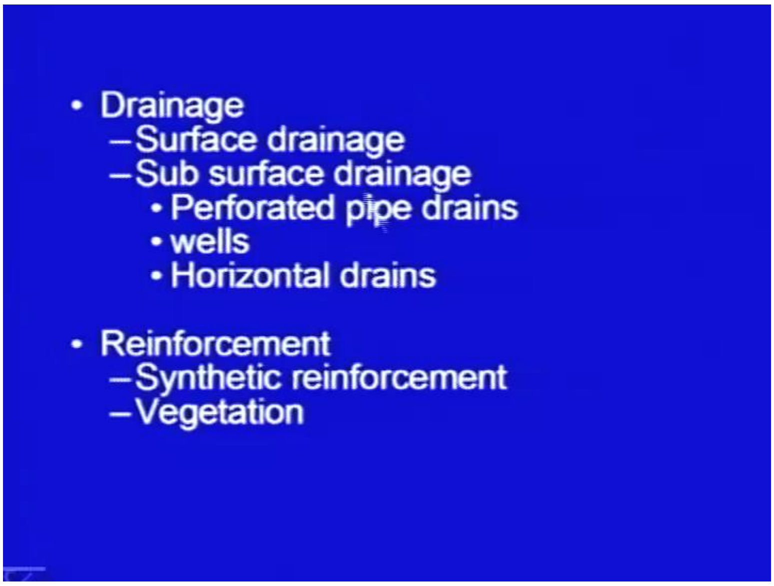

Then, drainage you can improve the drainage, you can, then the water pressure is the biggest enemy in case of the slopes. So, the good drainage can be provided and drainage will reduce the water pressure and effective stresses will increase once the effective stresses are increased then, the shear strength is automatically it is going to increase.

So, drainage is one of the very effective measure and the drainage can be provided at the surface where the surface drains can be provided a system of drainage, drains can be designed which will take the water to some safe place and also, one can provide the sub surface drainage, inside this soil the sub surface drainage can be provided. It can be done using perforated pipe drains, these pipe drains will collect waters and then, that water can be carried away to safer places.

Wells can be used, this is a little bit costly affair, so it depends how much resources are available. So, the water table can be kept under limits, so that it does not rise to a level where it can cause the failure then, horizontal drains can also be provided inside the soil mass. Then there are latest techniques, where the reinforcement is being used in the slope stabilization measures, so it can be synthetic reinforcement like geo synthetics, sometimes some other kinds of reinforcements are also used or even vegetation can also be used at some places to weak, to improve the quality of the soil.

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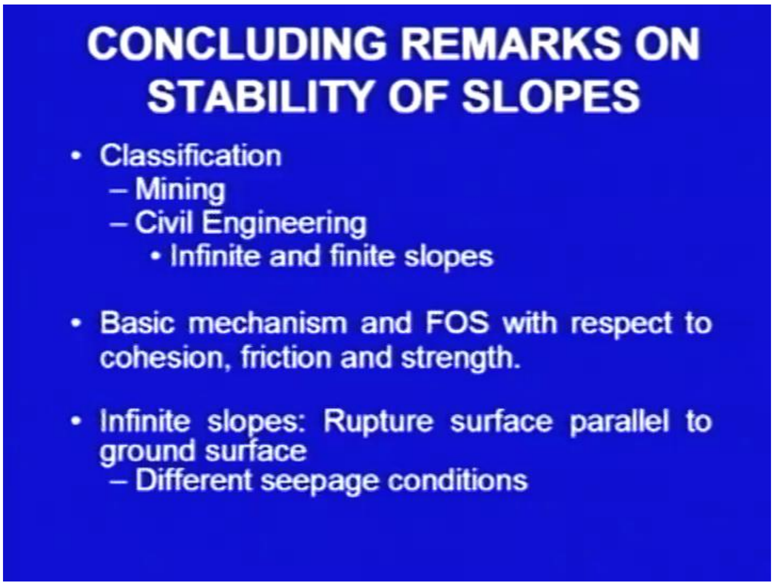

So, friends if finally, some concluding remarks on these all lined lectures on the stability of slopes, I started with the classification of the slopes, there I discussed about the mining slopes and civil engineering slopes and then, we consent we concentrated on civil engineering slopes. In civil engineering slopes we discussed infinite slopes and the finite slopes I started with the basic mechanism where the mechanics is important what is the mechanics, how it is used.

we discussed about the factor of safety, what is the factor of safety with respect to cohesion with respect to friction and strength, this is what we discussed then, we took up the cases of the infinite slopes in detail, in finite slopes I have their rupture surfaces parallel to the ground surface and we considered several various types of seepage conditions there.

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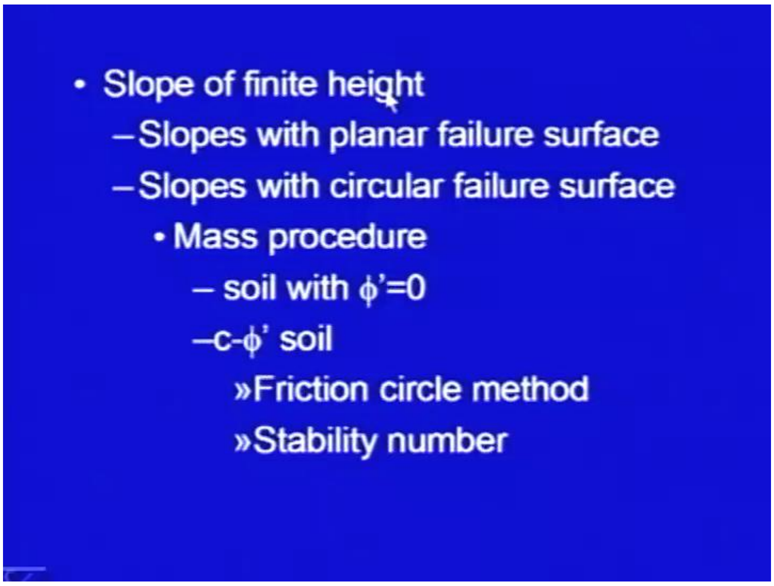

Then, we started the finite height slopes there we discussed the slopes with planar failure surfaces, where discontinuities are present in the mass for example, in case of the shells and rocks, the rocks. Then we started the slopes with circular failure surfaces, where the material is homogeneous.

And here we discussed about the mass procedure, when which entire mass was taken as a whole. So, value with phi dash is equal to 0 was taken separately then, we discussed the c dash phi dash soil and here, we discussed the friction circle method and stability number approach.

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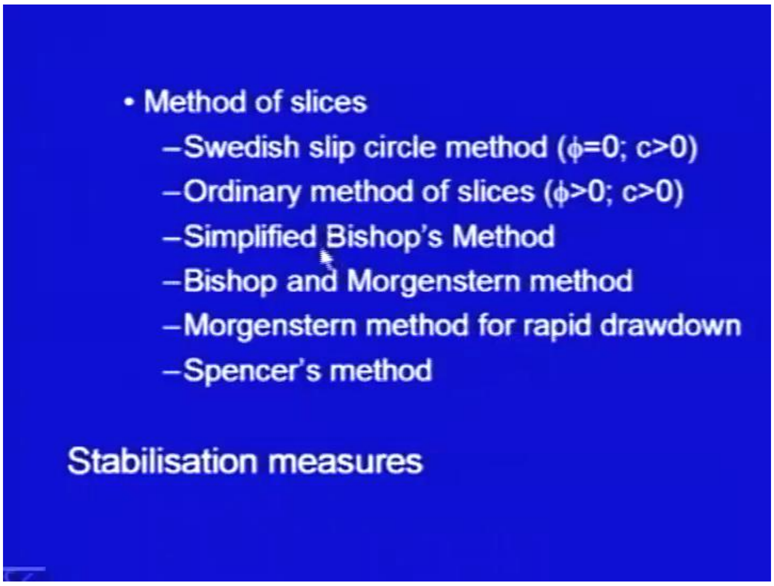

Then finally, we went through the most popular methods, the method of slices here we discussed the Swedish slip circle method, ordinary method of slices, simplified bishop's method which I have covered today then, bishop's and Morgenstern method, Morgenstern method for rapid drawdown and Spencer's methods. So, these methods can be used to find out the factor of safety using the method of slices then, we also gave some very brief discussion about the stabilization measures.

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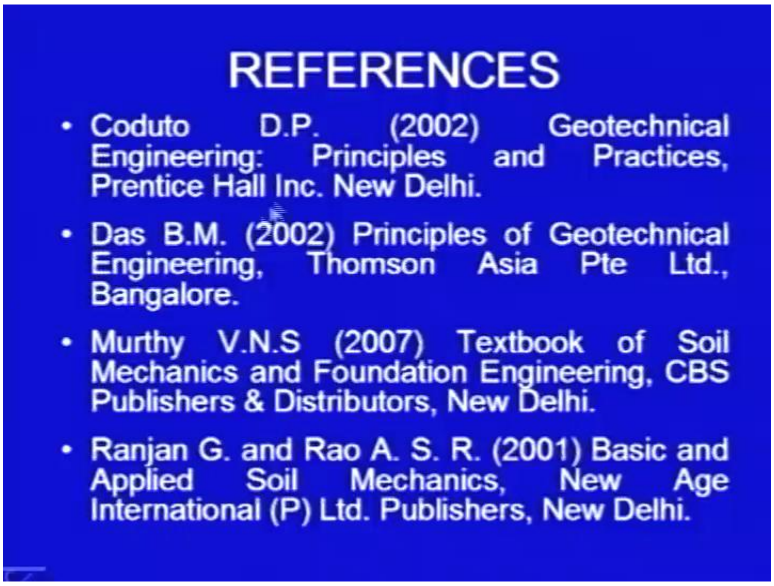

These are the books which I have referred during my lectures classes, one was Coduto, second was by das, the third was by Murthy and by Ranjan and Rao. These are the books and all most all material you find in these books, these are the references which I have used during all my lectures. First is Coduto, it is geo technical engineering principles and practices, second book I have referred is by Das, which is principle of geo technical engineering.

Third is by Murthy, text book of soil mechanics and foundation engineering and last one is Ranjan and Rao basic and applied soil mechanics. So, all the material, all the tables and text you will be getting in these books. So, with these words I thank you all for being with me.

Thank you very much.