Geotechnical Engineering - II
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Lecture No. 52
Slip Circle Method

So, having done the slip circle or method of analysis of finite slopes, I will be talking about now the slip circle method, which is the simplest possible form of analysis of the slopes, for finding out their stability.

Slip circle method, simplest possible method. Of course, totally stress analysis, undrained analysis. Two things are important to understand here. Saturated conditions of soils, number one, and this is also known as conventional method of analysis, total stress analysis, saturated soil conditions. Strength of the soil is supposed to be because of mobilisation of cohesion only, pure cohesion. Skempton's method, normally this is known as Skempton's 1948. These are very old classical methods which are still being followed by the Geotechnical Engineering fraternity. So, what we do here is, we consider the slope. The axis of rotation we have to show and let us say this is the slip surface.

So, this is let us say r, it is the radius. Suppose if I consider an element over here, in such a manner that this is suppose this is the i^{th} element, or sometimes we also known as slice, the entire system has been considered to be made up of several slices. So, later on you will be studying the method of slices also. We are discretizing the entire slope in such a manner that the slope constitutes of several infinitesimal sized strips, slices, elements. So, suppose one of the elements which I consider of this slice is i^{th} slice is w_i. The way we define this as suppose if I take a perpendicular from here, the point of application of w_i with respect to this is x_i.

So, if I connect this point from here this becomes α_i for that particular surface. Now, pure cohesion. So, this is the cohesion, which is getting mobilised, yes. So, this is the centroid you may say of the slice. Now, there are 2 ways of defining the factor of safety. One is in the form of the forces which are acting on the system. So, the first form of the factor of safety is in terms of the forces sigma of resisting forces which are trying to resist the movement, what are those forces? So, the tendency of the slope is to slide like this, fail like this. What is resisting? C_m, mobilised shear strength. So, shear strength happens to be a resisting force, divided by summation of disturbing forces, yes. Sometimes we also call them as stabilising forces, and disturbing forces would be destabilising forces. Rest is all simple mechanics.

$$(FS)_{forces} = \frac{\sum resisting\ forces\ \ (stabilising\ forces)}{\sum disturbing\ forces\ (destabilising\ forces)}$$

Another way of defining this would be, factor of safety in terms of the moments, which you have been doing in your Engineering Mechanics course, you take the moment of the forces and then try to see whether the body is in equilibrium or not. So, these classes of problems are also known as limiting equilibrium problems. So, I can take the moments of these forces, and then I can say sigma moments of resisting forces, R divided by sigma of destabilising forces or the disturbing forces, both are correct, but normally we do not use the word destabilising forces, we say overturning moments. So, this M_R will be yes what would be this M_R? Resisting moment.

$$(FS)_{moments} = \frac{\sum M_{resisting\ moment}}{\sum M_{disturbing\ moment}}$$

Now, this C is acting on that length in terms of the force. So, if I want to take the moment what will be the moment of resisting forces? This will be equal to r into C_m into length, and summation of all this, and what about your disturbing moments? The disturbing moment is coming because of the w_i. So, that means M_d will be equal to w_i into x_i, is this clear? So, what is the factor of safety? This will be equal to r into sigma c_m into l divided by w_i into x_i. So, this will be equal to C_m into *l* summation sign remains there because these are all small, small segments which you are taking and you are integrating over or summing over. So, this will be equal to I am sorry this should be submission.

So, this will be equal to w_i into x_i, and this r_i can take down. So, what is the value of x_i upon r? This will be a... So, this is x_i. And then r term, so what this term would be? This would be a function of sine term, $\sin\alpha_i$, x_i over r is going to be a function of a sort of a sine term. Now, how are you going to do this? This α can also be defined as an angle of inclination over here. So, is this, okay? So, that means W and this line through which is passing through this will also be α_i. So, this is one way of defining the whole thing. So, I have got the factor of safety term.

$$FS = \frac{r \sum c_m l}{\sum (w_i x_i)} = \frac{\sum c_m l}{\sum w_i (\frac{x_i}{r})} = \frac{\sum c_m l}{\sum w_i \sin \alpha_i}$$

The beauty of this method is that even if suppose there is a layered system, I have to just ensure that the slips are first passes through suppose this is soil 1, 2, 3 and so on. So, I have to just consider the slip surface let us say like this, I can go by parts, first slip surface, second slip surface, third slip surface, and so on. And I can obtain the same relationship only thing is everything will get added up over there. In these methods you must have noticed we are not taking into account the influence of the forces which are acting from the sides of the slices. What have we done? We have just taken the weight; we have mobilised the cohesion. And we are ignoring the effect of side forces, thrust as well as the side friction, simplified method, very simplified method that is why this is what is known as simplified method, mostly valid for cohesive soils.

But when you are dealing with the frictional material you cannot do so, then you have to compute the forces which are acting on the sides, lateral thrust, shear forces which are acting on the system, and so on. And of course, the normal stress will also come. Yes. There could be another situation when you are dealing with your cohesive soils, what is going to happen? What is the biggest problem? Tension cracks. Yes, you are right. So, that means what is going to happen here is pure cohesive material we are talking about C_u case, undrained analysis. So, what is going to happen here? You have a component of this is the tension crack, we have defined this as z_0 if you remember, this is approximately taken as 1.33 times c over γ, depth of tension quick c by γ multiplied by some factor, 2 C by gamma is also correct, but then this is a more accurate value, people have obtained this number by using the limited analysis, that was my PhD thesis by the way.

So, now, what is going to happen? We have done this type of analysis earlier also. This is the shear surface, the tension crack develops, the length on which the cohesion is getting mobilised is reducing, and hence the factor of safety would be decreasing, or increasing? You think about it. More than that the situation which is going to be critical is when the rains come, what is going to happen? This is all getting filled up with water. And I think we have discussed this earlier also. This is what is going to be the pressure from water during rains, this is the weight, suppose this is the axis of rotation. Now, because of introduction of tension crack what has happened? This is a destabilising force, shear strength is a stabilising force, what about the water pressure, look at the direction of movement, it is opposing the stabilising force.

So, basically water pressure also becomes a destabilising force. So, what is going to happen? Your factor safety terms are going to reduce. So, I can always do it like this, that suppose this is the value of water pressure, and I can assume this to be acting at a depth of let us say, distance, not depth, distance of z value. So, this component will be P_w into z, which gets added up to destabilising force. This is another situation which we have created. The third situation could be with another interesting problem or situation could be you have partial submergence. So, partial submergence means suppose, at the downstream side the water is somewhere here. So, what water does? This height of water is going to exert a pressure on the slope, what is the direction of this pressure? It is a destabilizing force or stabilizing force?

So, the way it is acting like this cohesion was acting to stabilise, this destabilizing force, this water pressure is now getting added up to the cohesion. So, what is going to happen? Because of the presence of the water table, the stability is going to get enhanced. Is this part clear? I am sure that now, you will have to use your concept of finding out the weights of these 2 sections, how are these 2 sections getting created? One is above the water table, and second is below the water table, this is going to be submerged, and this could be partially saturated, variably saturated, dry, depending upon the material and the water table characteristics, and the capillary action which we have talked about earlier.

So, you have the component W, you have W_1 let us say W_2, you will be having the lever arms from this point of rotation, pressure, and I can make it more complicated by tension crack also getting developed over here. So, there are 3 components now, 2 blocks of weight W_1, W_2. Cohesion not getting mobilised beyond this surface, there could be a water pressure coming from this, and this is more realistic situation. So, suppose if I keep on filling the water on the left-hand side, what is going to happen? The stabilising force is going to increase, but then the slope is going to be fully submerged, analyse this situation, is this part, okay?

So, this method which we are talking about here, the simplest possible method is also known as Bishop's simplified method, where we ignore the side forces and if I do not ignore the side forces this becomes the rigorous method. Bishop's rigorous method, which method will give you more factor of safety? Why? See rigorous method includes the influence of side forces. So, you are not nullifying them, you are not ignoring them.

So, factor of safety which you are going to get from rigorous method is going to be more than the factor of safety which you are going to get from simplified Bishop's method. Most of these methods are going to be trial and error, why? Simple logic, factor of safety is a function of C mobilised, and C mobilised becomes what this is truly speaking a form of c' over factor of safety, that means, what we are doing now, on the left-hand side also we have a factor of safety term, on the right-hand side also we have a factor of safety term, you got the point, on both sides we have factor safety terms.

So, that means, now you have to do iterations, trial and error. So, as I said during our days, we used to take slip surfaces, plot them on the graph paper analyse them. It used to take days to solve one problem. But now, the world has changed there are several softwares which are commercially available, which can be utilised. So, with this I am going to stop discussion on slope stability, which was the last topic to be covered on application of shear strength theory for geotechnical structures. I wish to show you two websites of the commercially available softwares which you should try to browse learn from them. So, that you can analyse the slope stability problems.

So, if you type on internet geostudio, you will go to geo-studio student edition, and then you can see different features over here. There are several features here like SLOPE/W, SEEP/W SIGMA, QUAKE, TEMP, CTRAN, AIR. So, SLOPE/W is for analysis of slopes, seepage analysis, stress analysis, earthquake analysis, temperature analysis, contaminant transport analysis, air migration analysis for unsaturated soils. So, if you type over here or if you click over here, you will be taken to the SLOPE/W, and then you will see that there is a very good video available over here. What it says is that slope stability analysis is the leading slopes stability software for soils and rock slopes.

SLOPE/W can effectively analyse both simple and complex problems for a variety of slip surfaces, shapes. What we have done so far is we have assumed to be circular slip surfaces, which in real life are not valid, pore water pressure analysis, soil properties and loading conditions. So, this is a trend right now, people are following GEOSLOPE for pore water pressure analysis, rapid drawdown condition, material modelling and so on.

You can click over here different types of solutions for dams and levees, reinforced wall and slopes, excavations, and open pit mines, roads, bridges, embankments environmental protection, groundwater, ground freezing, climate change and so on. So, it is a very comprehensive package, and we are into the module SLOPE/W. So, whenever you get time, please go through this. And you can also see the different types of how the anchors have been designed and, mechanically stabilised earth have been designed and so on. Please explore this package.

The second one which I wanted to bring to your notice is what is known as Soil Vision. So, if you type on Soil Vision database systems for saturated, unsaturated soils you will be taken to this website, and you can see here different types of modules which are available, series of modules which they have added, and you will find several analysis over here, different types of analysis.

And if you go to the slope stability by using SoilVision package, then you can go to the different sites here, and you can see SVslope, different types of analysis you can perform. So, these are the packages which are worth exploring.

They have a very good package SVslope, 3-dimensional seepage and stability analysis for different types of dams, earthen dams, how to create 3-dimensional dykes, and so, on. So, my recommendation would be to adopt one of them, and see what facilities these systems provide to you. So, with this I finished my course Geotechnical Engineering II, and I have tried to cover the most important and critical aspects of the materials, soils, in their different states, and how to utilise these materials in different states as the engineering materials, or how to do engineering with these materials. Thank you.