Geotechnical Engineering - II

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Lecture No. 46

Slope Instability-I

So, welcome to Geotechnical Engineering-II. We have been talking about slope instability and I gave you an overview of what is meant by instability of the slopes and how to stabilize the slopes as a geotechnical engineer in most of the situations. I gave you several examples of what type of failures or the failure mechanisms are considered when we talk about slope instability. There was sliding, there was a block, there was a flow and the creep.

And then we discussed different situation where instability can be caused to the slope just by cutting at the toe or by loading it from the top and I also discussed about how to stabilize the slopes. That means unloading of the slope and providing the drainage provisions and so on. I gave you an idea about what are the internal and external forces that cause instability of the slopes. So, we discussed under two heads as internal forces and the external forces.

External forces are mostly caused by the external agencies and internal forces are because of the shear stress which is mostly stabilizing force rather than destabilizing force which is caused by the external agencies and of course the physico-chemicao-mineralogical phenomena which go on in the soil mass or the rock mass which are the principal constituents of the slopes.

Now having done all this I wish to now discuss about the stability or instability of the slopes and when we talk about this, we normally consider two types of slopes. So, the first category of the slopes is, finite slopes, it is a misnomer that this is of finite dimensions. Most of the time people mistake this they think finite slopes are finite in size and infinite slopes are infinite in size it is not correct. It has something else to do with this, which we will be discussing today.

The second part or the second type of slopes normally we deal with this the finite slopes. Mostly the infinite slopes. Let me say infinite slopes, and the second one is the finite slopes. Mostly finite slopes are manmade. Mostly. You take the soil mass compact it, you remember you are talking about compaction process in Geotechnical Engineering-I. The best possible application of that is to create an embankment.

So, suppose this is the natural formation and I want to create a facility over here for roadways or railways. It could be airstrip also. So, rather than laying the foundations of the pavement on the ground surface, what we do normally is we create an elevation. This is what is known as embankment and in this part, we have discussed quite in details.

This could be made for water retention also and on the top of this, you will be exposing the railways or highways or roadways and so on. Now this becomes a very interesting problem. So, this is the embankment which has been created by compacting the soil mass in layers. You remember we talked about what type of compaction may lead to what type of consolidation and to what type of drainage conditions.

When we are talking about the shear strength parameters. So, depending upon the foundation material and depending upon the embankment material, I might come across a situation where the slow drainage, no drainage may occur, consolidation may occur, consolidation may not occur. We have talked about long term stability of embankment and short-term stability embankment and so on.

Anyway, in context to the finite slopes which we will be discussing in the second half of this course or this topic. I will be taking it up later on. Normally the properties of the material change as a function of depth. So, material properties are a function of depth, more compaction more c, more ϕ, more density.

So, more c, ϕ, γ with more compactions effect more density. These are typically finite slopes. To begin with our discussion on slope stability I will be taking up first the infinite slopes, how do you produce them these could also be manmade. Suppose, you remember the concept of repose angle. Yes, we have discussed long, long back you are right.

So, suppose if I take a granular material and if I pour it from the top with the funnel air pluviation is also a technique. Yes, you are right so air pluviation is also a technique very good. So, if I am pouring a granular material from a certain height, what happens? the grains fall, they form this type of heap where the angle of inclination is going to be angle of repose. It cannot be more than this angle because each grain has a tendency to roll down, instability.

So, whenever you pour materials like grains, granular materials, ores after mining. So, whatever heap is formed this is a classic example of an infinite slope. Yes, this is the angle of the repose concept. Now, what we assume here is that the material is going to fail parallel to the face of the slope always. So, these are the possible slip lines or failure planes.

So, what is that you are observing here? The failure plane is always parallel to the face of the slope. First condition, yes always. Now, if I take an element here. Suppose this is the mass which has failed and if I magnify this, this is how it looks like. This is the mass which has failed, this is the length of the affected portion and normally we defined this as d, the depth of maximum possible depth of the slip surface.

Yes, you are right. Suppose if I draw a tangent here not you will be realizing that this is parallel to this line. So, it so happens that if $d/L<10\%$, this condition should be satisfied. Thickness of the unstable mass *d* is much less than the height of the slope, the height of the slope could be this much. So, thickness of the affected zone is much less than height of the slope and followed by this condition $d/L<10\%$.

The next condition is failure plane is always parallel to the slope. Natural formations are good example of this type of failure. So, if you check on internet you will get several situations where the infinite slopes have failed. The properties of the material along the depth and the state of stress along the depth remains constant. Properties and the state of stress as a function of depth do not change.

So, material properties and stress conditions are not a function of *d*. You may also add here that truly speaking infinite slopes are not an infinite length slope. Soil properties remain constant, stress conditions remain constant as a function of depth. If more than one stratum is present what is going to happen? If more than one stratum is present then everything is going to be again of the uniform characteristics, each plane has to be of uniform characteristics.

So, boundary of each layer is going to be parallel of to the ground. So, suppose if I may say this is the strata number one, strata number two and three. Within the strata the material property remains same. Overall, what happens is the slip surface, the failure plane is always parallel to the slope surface. So, in case of more than one stratum with uniform characteristics each stratum is having uniform characteristics and the boundary of each layer is parallel to the ground surface. The next characteristics would be let us show the state of stress.

So, stress between any vertical element of the soil is identical. So, suppose if I take an element over here or an element over here or an element over here. This becomes my one element, this is another element, this is another element. So, stress between any vertical element of soil is identical. What is the significance of this? Now, suppose if I take it out and zoom it and try to draw the free body diagram.

You have this surface and we have taken a slice, we call it as a slice. This is also *i* this is also *i* draw the free body diagram. So, the weight is acting over here what else is acting over here? Pressure from the base perpendicular. Let us define this as the base pressure what else is going to act? Some resistance from the left-hand side and the right-hand side because what is this going to be.

Suppose, if I say P left (P_L) pressure which is acting from the left to right, but we write normally this as pressure coming in the right direction and then P_L both of them are going to be parallel to the planes or the surface. I hope you can realize if AB is parallel to CD, what should be the condition in mechanics you have studied. For equilibrium of this type of a situation, P_R should be equal to P_L and they must be coaxial.

So, this becomes a typical two-dimensional problem or situation problem is not in real sense problem is a situation. So, this is a two-dimensional situation. The third dimension is going to be perpendicular to the board. So, the third dimension is going to be in this direction let us say it could be like this. It is better to show it over here. This is how the third dimension goes in perpendicular to the plane of the blackboard, green board.

Now, this is what is known as plane strain problem also. We were talking about this situation when we did direct shear test. So, this is a plane strain problem. What is the significance of this? What clicks to you? One layer is sliding against the second layer. Detached surface or detached block and the parent block and the contact surface remains maintained. So, this becomes a simple mechanistic model.

If I want to find out the shear strength parameter which test, I should be doing? Why? You have to think about it. Direct shear box test. So, as long as the material is uniform, it does not matter. You take the material soil mass, compact it in the direct shear box test setup and shear it and get the friction angle and get the cohesion for the granular materials. Suppose this happens to be the layer one, layer two, layer three.

And I want to find out the shear strength parameters along the context interfaces. So, the moment interfaces come what we have to do? again you shear it along that plane. So, I can take a sample of this soil mass from here if it is a c-ϕ material, cut it from this plane, size it, trim it and place it in the direct shear box test box, make sure that this surface is aligned with the cleavage surface of the direct shear box.

Do the direct shear box test and get the parameters, as simple as this. So, in today's discussion I will be talking more about how to use this concept to solve more critical problems. There is one more concept which I would like to introduce over here. When you are talking about this situation, is this free body diagram complete? No. Why what is missing from here? Yes, so one shear stress has to come.

This becomes a normal stress very good. This is a free surface no normal stress, no shear stress what happens on the sides. This side is being resisted passively by the soil mass. So, given a chance, this is going to be the passive resistance. Now, passive resistance means the shear stress going to be acting upwards or downwards? You can find it out. So, generically I will show that the shear stress acting like this let us say.

What is the conjugate shear stress for this? Yes? these two are equilibrated most probably, what about this and this? So, you are defying law of mechanics. This is the state of stress which is acting on the slice and this slice if you remember is nothing, but a portion or a slice which we have cut out from the infinite slopes. So, this condition is correct. Similarly, if I define this as E_R and this as E_L they are also supposed to be equal.

Now, if this shear stress is 0, the conjugate shear stress is going to be 0. how the equilibrium will be achieved? Provided this τ also tends to 0 and hence this also tends to be 0. The moment this shear stress tends to 0 what is going to happen? the slip is going to take place the failure is going to occur. Loss of shear strain causes failure of the slopes. I hope this clears all your fundamentals. Think about it.

So, this is a situation where the normal stress is equilibrating with the weight of the block. So, if you resolve this, what is going to happen? We have W cosi, W sini if i tends to 0 I hope you can understand, or second thing is W itself tends to 0. thin section. So, from this point onwards we have introduced the concept of thin sections, infinitesimally thin sections of the slopes are considered for doing the analysis.

And all these infinitesimally thin sections create an infinite slope. This was an interesting paradox which we have discussed just now. Is this okay? shall we move ahead.

So, suppose if I compute this W what will be the value of W? I have to define something. So, normally the convention is we take the horizontal distance between the two sliced vertical surfaces as the lateral distance. This is *a* and this is *d* because just now we discussed. CD becomes a slip surface shear stress is 0. So this much of the soil mass is vulnerable to the failure and parallel to the slip surface which is parallel to the slope surface.

What will be the value of W? *a* into *d* multiplied by unit weight. You can resolve them in components $\Sigma F_x=0$, $\Sigma F_y=0$. What else can be done? What else, you have an equation there is a relationship between T and N also. What is the shear strength of the material the value of T in the form of shear force is equal to normal stress multiplied by tanϕ. Yes, this equation is going to be very, very useful.

$$W = a.d.\gamma$$

$$\sum F_x = 0\,; \sum F_y = 0$$

$$N = W.\cos i$$

$$T = W.\sin i$$

Now, can I derive from these equations N = W cosi and T = W sini. Let us try to see how would you get this? So, why we are computing N and T because I can compute from N, sigma the normal stress what will be the value of normal stress? This will be equal to W cosi divided by what is the length of the base if this is a, i what is the length of the base? a by cosi and what about the shear stress?

Shear force is known so this is W sini over is this correct check it. What is the magnitude of W? a.d.γ. So, this will be equal to a d.γ $\cos^2$i. a cancels out. What is this γ.d $\cos^2$i and this will be equal to γ.d sini. cosi multiplied by γd. Is this part, okay? So, what we are doing is we are assuming here dry sands, simple example. Simple cases to deal with first.

$$\sigma = \frac{W.\cos i}{\frac{a}{\cos i}} = \frac{a.d.\gamma.\cos i}{\frac{a}{\cos i}} = d.\gamma.\cos^2 i$$

$$\tau = \frac{W.\sin i}{\frac{a}{\cos i}} = \frac{a.d.\gamma.\sin i}{\frac{a}{\cos i}} = d.\gamma.\sin i \cos i$$

Yes, so now can you apply this equation $\tau = c + \sigma \tan\phi$? shear strength envelope? substitute the values and see what we are going to get. Now one question remains if somebody ask you to draw the force diagram, can you do it? True? and then you have T component and N component. What is the included angle between W and N? i. You get easily these equations. I have skipped those steps. If you solve this for pure sandy material c tends to 0. So, what is T?

This is γ.d.sini.cosi and this will be equal to γ.d.$\cos^2$i.tanϕ. Now, the way we put it like this the shear strength for stability has to be greater than σ tanϕ. The moment shear strain drops below this or tends to 0 what is going to happen? The slip is going to happen. So, what this indicates is γ d can be cancelled so we have sini cosi = $\cos^2$i tanϕ.

$$\tau = c + \sigma \tan \phi$$

$$d.\gamma.\sin i \cos i = d.\gamma.\cos^2 i\,.\tan \phi$$

$$\sin i\,.\cos i = \cos^2 i\,.\tan \phi$$

Now let us use the term factor of safety. We discuss this long, long back. What is factor of safety? If factor of safety is equal to 1 this condition is valid. Otherwise, what is the factor of safety? This will be equal to ($\cos^2$i tanϕ)/sini.cosi which is equal to tanϕ/tani. Very interesting relationship we have derived. What is the philosophy behind this? What do you understand from this relationship?

$$F.S = \frac{\cos^2 i\,.\tan \phi}{\sin i\,.\cos i} = \frac{\tan \phi}{\tan i}$$

Factor of safety depends upon the coefficient or the friction angle, internal friction angle and the inclination of the slope, *i*. So, what is the limiting condition of i? i cannot be greater than ϕ. Remember simple block sliding on a surface and you keep on changing the inclination of the surface what is going to happen, after the critical angle of i what is going to happen to the block rather than sliding it has a tendency to topple true.

So, this is the critical value. So, factor of safety for a dry slope is the ratio of friction angle and the inclination angle. So, what we have to realize here gamma is not coming in the picture. What is the significance of this? The depth of the critical surface is also not coming in the picture. Failure can take place along any plane where the shear strength becomes critical. Is this part okay.

Material properties do not come in the picture. Now, from this situation and suppose if I create a situation where the entire slope gets submerged or there is a seepage which is induced in the slope. What is going to happen to the factor of safety? The factor of safety is going to drop because this is the limiting value for the sands c component is not coming here there is no cohesion here this is purely frictional material.

So, for a purely frictional material under dry condition, the factor of safety is $\tan\phi/\tan i$. Now you will realize soon that this function is very, very important and critical because when I say factor of safety at most what is going to happen is some multiplier multiplied by this term is going to emerge. Multiplier cannot be more than 1.

So, all sorts of seepage conditions, all sorts of submergence of the slopes will lead to determination of this multiplier. And that is what we are going to do subsequently. This also indicates that when full shear resistance is mobilizing, and sliding is going to take place your high value will be equal to friction angle.