Soil Mechanics/Geotechnical Engineering I
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Lecture - 27
Shear Strength

Good morning, once again I welcome you to this soil mechanics course and now we are in a very important topic that is shear strength. So far, whatever we have discussed based on that, we will be able to asses qualitatively how will be the shear strength of the soil, but exact quantification is not possible to do.

So, now all details of shear strength, we will discuss now in few lectures may be 8 to 10 lectures including application and I will draw I will start this shear strength is important why it is important, this strength is important for anything when we building is constructed on the soil that soil has to bear the load of structure and obviously, whatever we have seen in the other structural material, it fails generally in tension or compression, but here we will see that soil generally fails in shear and all details of shear strength we will discuss one by one.

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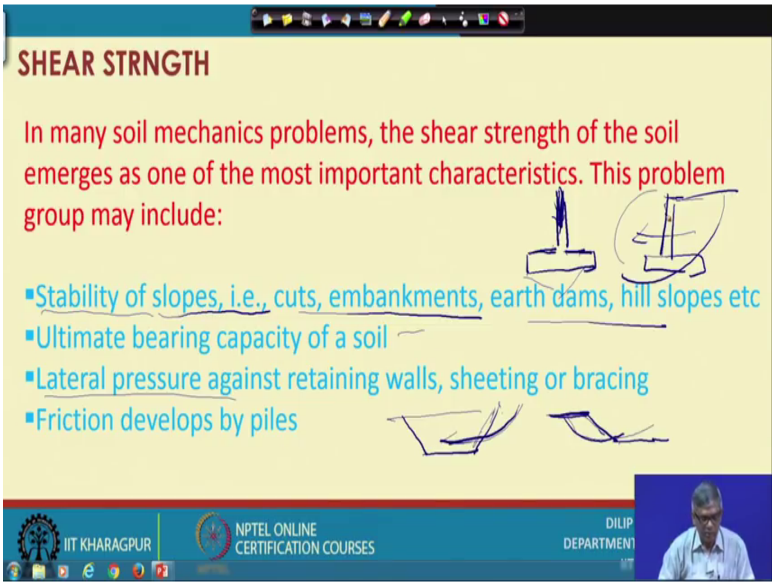

So, let me see this one shear strength, here in many soil mechanics problem shear strength of the soil emerges as one of the most important characteristics, why it is so? And this problem will be I can give you example where there important, there are several problem we will have to deal with in the later stage and you can see those problems are stabilities of slopes that cuts embankments, earth dams; that means, what if there is a embankments like this if there is embankments and like this, and then suppose it is here like this because of the slope and there will be tendency if the slope height is too high then there will be tendency to slide this soil this side. And when it will slide or when it is stable that can be assessed based on the shear strength of the soil.

So, this is one application. So, it can be a cut it can be embankments if there is a cut; that means, this is the example of example similarly there is a example of cut; that means, existing ground is somewhere here, but suddenly I need to cut somewhere like this and develop some facility. So, this is also become a slope and if this is quite high then there will be tendency of moving this part towards this, when it will move or when it will be stable that also can be assessed by the help of shear strength of the soil.

Similarly, ultimate bearing capacity of the soil; that means, when there is a foundation suppose there is a you can see at the end of the column each column, there will be a footing which will be enlarged at the bottom, it will be like this and when load is applied through these load is applied like this, then the mechanism below the below the footing the failure mechanism there number of planes along which there will be resistance and that is that resistance is because of the shear strength of the soil. So, that details will not come here, but this is another example of bearing capacity of soil; that means, that whatever amount of soil will be able to put on the foundation, that comes based on the shear resistance of the soil. So, that is a nothing, but shear strength of the soil. So, we will discuss that part also let us that is another important application that where shear strengths will be useful.

Similarly, lateral pressure against retaining walls. So, again if there is a retaining wall like this earth retaining walls, suppose this side soil is retain and this side is there. So, if there is a soil height of wall is very high, then there will be tendency of there different mechanism it can move this way, it can move this way, it can topple. So, this is all there are different mechanism of failure of this type of wall, but again whether the wall is stable or not that can be assessed based on the shear strength of the soil

So, like that several examples can be given where shear strength play very very important role.

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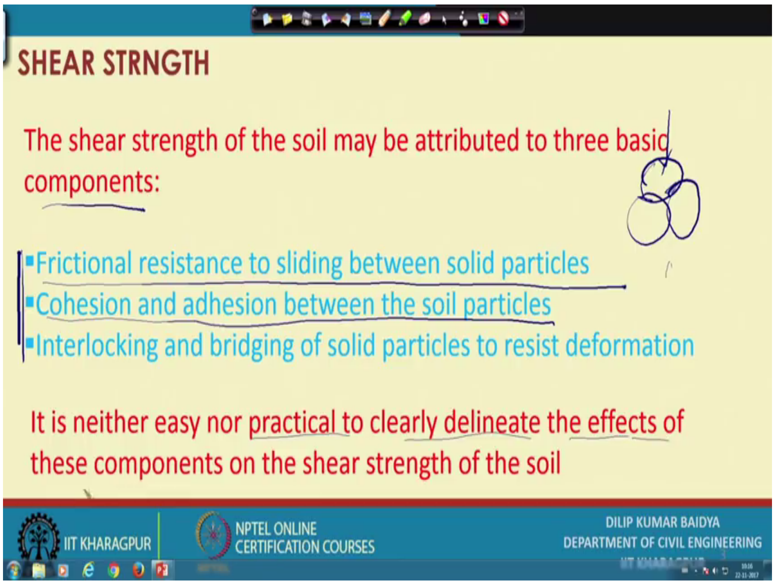

So, with this; so, now the shear strength shear strength of the soil may be attributed to three basic components. So, there are shear strength when there will be shear strength, that is not one type of resistance, there are several types of resistance and that together will be acting as resistance and that is total shear strength, and to we have three components you can see that is a frictional resistance to sliding between the solid particles, if there is a one particle this is another particles and there may be another particle. If the particle they post from here then between sliding occurs between the contact point of these, and based on that it will have some resistance.

The cohesion and adhesion between the soil particles. So, this if there is friction there is some resistance again if like two hand if you dry whatever resistance will get, you put with some oil. So, will be something else. So, that is actually nothing, but adhesion. So, between the particles if there is adhesion that also will contribute, some amount of resistance and interlocking.

If there is a particles are big particles small particle if they arrange arranged in such a way there will be a chance of interlocking a particles that also can give you or contribute some amount of resistance. So, all three together will be the shear strength of the soil.

And it is neither easy nor to practical of course, to find out what is important or what is not important, and what is role of whose role is maximum or whose role is minimum, but we can find out that later on, but right now we will not be able to mention which is what.

So, it is neither easy nor too practical to clearly delineate the effect of this components on the shear strength of the soil.

So, of course, the three components we will study one by one right now we will not be able to make any comment on this. So, next I will go to the next slide.

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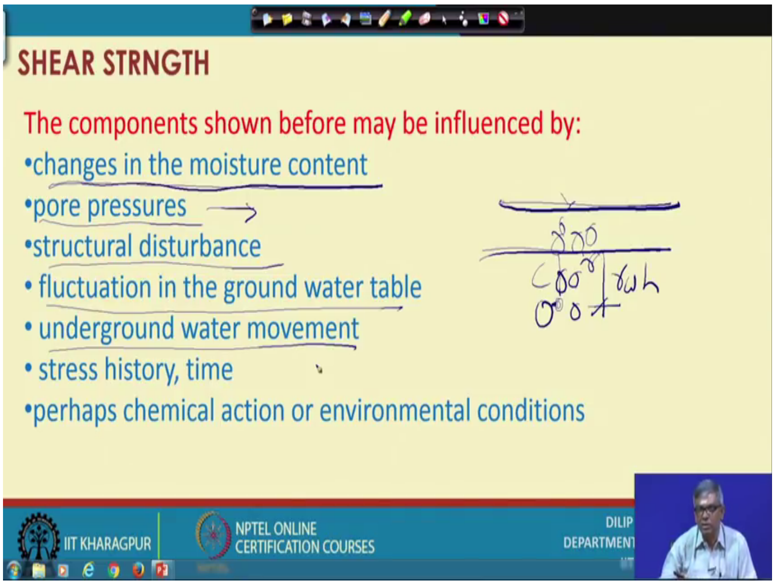

You can see again those I have mention the three there are three components, and again the three components are not unique they are all dependent on many things. And those, what are those many things, you can see the shear strength parameter the changes in the moisture content with changes with the change of moisture content. That means, dry soil whatever strength will be there moist soil or totally summer soil strength will be different. So, that is another one important factor one which shear strength defined is that is change of moisture content.

Another is a pore pressure; that means, pore pressure means if there is a soil mask and suppose there is granular materials here, granular materials and if there is a high water table is somewhere here, then at this point pressure is hydrostatic. So, how much is the pressure. So, you have to add gamma w times h.

Now, if thus water table is very high at the same point whatever pressure will be there and the water table is coming down, the pore pressure will be changing. So, that is the one; that means, the pore pressure so; that means, indirectly it is a height of water table. So, that is another important parameter, on which shear strength also depend.

Structural disturbance another important point the fluctuation in groundwater table that is pore pressure of with their interrelated and underground water movement; as I have mentioned before that flow of water through soil particles, and we have seen how the effective stress changes when flow is in upward direction behaviour is something when the flow is in upward direction it behaves differently. So, that actually will now include now how that effective stress is function of shear strength that is actually we will find then all then we will be able to clearly show the water wave movement how depend on the shear strength how depend on the water movement in the soil.

Similarly, stress history and time. So, suppose stress history means if the soil a particular soil is subject to the high pressure for a long time, whatever shear strength, it will have and if a newly deposited soil and there is no sub pressure on it, then it will have lesser strength. That means older deposit because of many interlocking and rearrangements of particles will have more shear strength than newly deposited soil.

And perhaps there are other important like chemical action or environmental condition; obviously, with change of environmental condition sometimes born between the particles and all be changed and that also finally, affect the shear strength of the soil.

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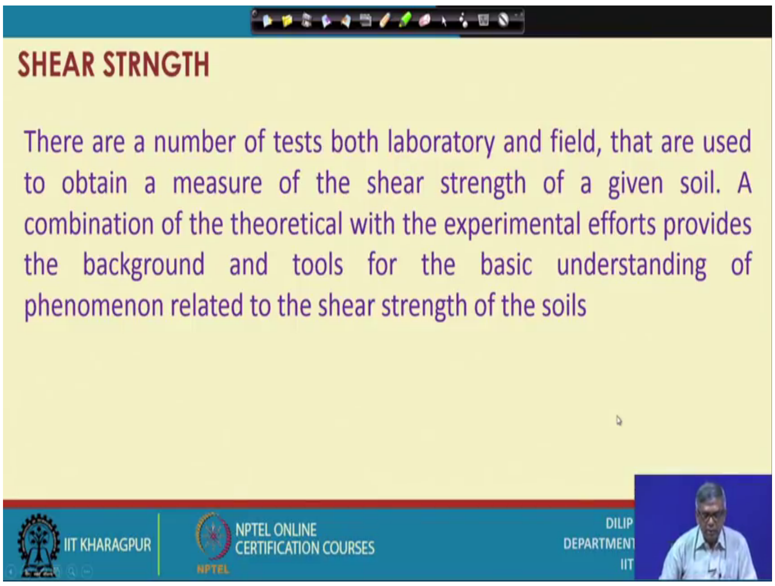

And of course, this shear strength to understand shear strength there are number of laboratory and field test are there, and they are used to obtained the their strength of the soil given soil, and sometime a combination of theoretical and experimental efforts provide the background and tools for the basic understanding of phenomenon related to the shear strength of the soil.

So, only by conducting the test sometime we will not be able to understand how you get some value, but ultimately why I should get that value, there should be some justification how I can do that that can be done by based on theoretical treatment.

So, ultimately suppose we will do a test and you have got some value. So, we have to judge whether the value is appropriate or not and so; that means, in combination with theoretical and experimental we can understand better. So, that is the thing actually soil mechanics throughout the beginning, the soil mechanics develop like that only. So in fact, initially lot of things to developed based on experimental because people observed, and for a large number of tests and finally, they have generalized people have used when there was no sufficient mathematical or theoretical development, but slowly it developed now we understand theoretically, we understand experimentally, and now combining both these we are very successful to understand the shear strength of the soil.

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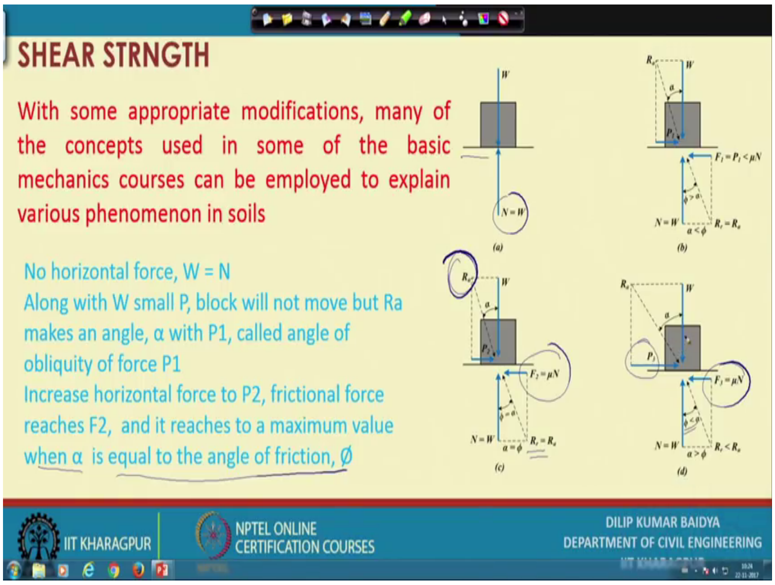

So, now to before going to the shear strength, let us have little bit of mechanics first the course name is the mechanics. So, whatever we have learned in strength of materials some revision type of things I can do, and you can see that if there is a block here and if I on the resting on the floor, and then entire there is no movement no no other force then you can see that the below the block there will be resistance which will be N, and which will be nothing, but equal to the W.

And since there is no horizontal force W equal to N, now along with W small p if you applied a value of p is applied suppose and then block will not move, but that resultant whatever resultant we have the resultant was vertical, now the resultant is making some angle alpha with P 1. You can see P 1 some of this is P 1 we have initially applied the small force P 1. So, if you apply these P 1, then we can see the resultant initially was vertical, now it is now making some angle that is alpha and that angle is called angle of obliquity with the force P 1.

And now with the now we can increase the force P to a value P 2 and then the angle; obviously, the inclusion will increase, and it and at the end that inclusion will reach a maximum value that is called suppose alpha, and which is equal to the phi of the soil. Suppose we have applied the force P 2 in such a way that the angle which is making with P 1 reaching to a value alpha which is equal to 5, and that is the condition where actually and next actually that that is the condition at this point we will have a resistance F 2 equal to mu times N. And if you increase the force P for the from P 2 suppose P 3 is bigger than P 2 and then this angle will not increase further. This angle will not sorry this angle will be greater than the phi, but this frictional force F 3 equal to mu n which will not increase further.

So, as a result what will happen actually if there is no resistance in increasing the resistance, but your increasing the force P that what will be the effect? There will be effect will be that that block will start moving I rightward. So, that means, there is a condition at this stage where alpha equal to phi that is a impending condition, that mean at this stage is about to move and at that point it will develop maximum shear resistance which is equal to mu times N.

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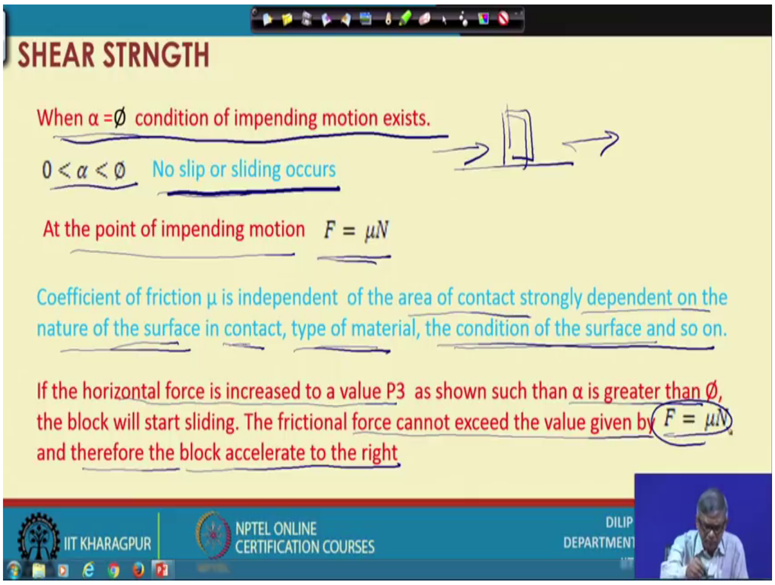

So, you can see when alpha equal to phi, condition of impending motion exists; that means, if you increase little just it will or is about to move that is the condition and 0 and alpha where alpha is between 0 and phi no slip or sliding will occur. So, that is when is alpha exactly equal to phi that is the impending condition, and if it is less than and greater than 0 the no movement will be there, but there will be and there will be no movement. And at the point of impending motion we will have F equal to mu N and coefficient of friction mu is independent of the area of the contact strongly, but strongly dependent on the nature of the surface in contact type of material the condition of surface and so on. So, it is not depend on the contact area how much area it is acting, but it depend on the nature of the surface in contact, type of material the condition of surface all those things are more point are important.

Now, suppose if the horizontal force is increased to a value P 3 that what we have shown in the previous last part, that P 3 as soon such as the alpha is greater than phi. So, we made alpha greater than phi, and then the block will start sliding and the frictional force cannot exceed the value given by F equal to mu N.

So, what will result then therefore, the block will accelerate to the right; that means, with this block was there and it was there you have applied a big force, which is greater than the P 2 which is causing impending motion, then it will start moving this direction increasing without increasing the frictional resistance which is equal to mu times N. So, this will be maximum at alpha and angle of obliquity equal to angle of internal friction of phi friction.

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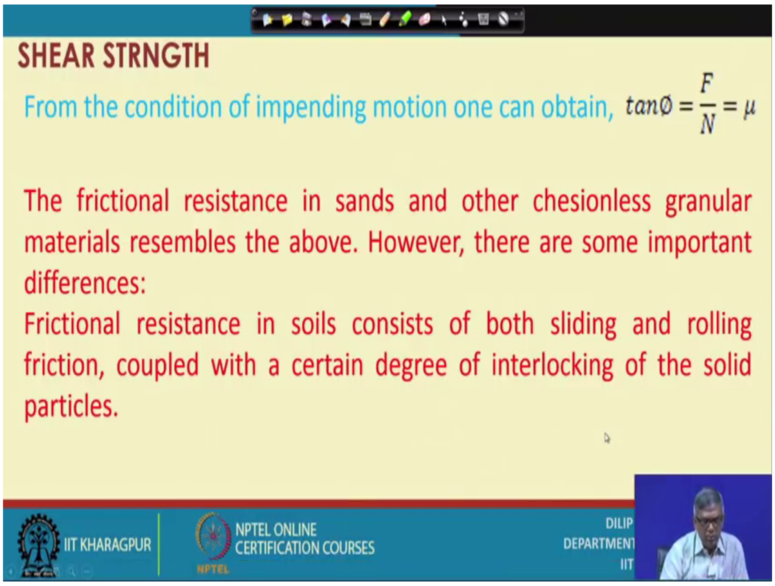

Now from the condition of impending motion one can obtain, this is the one. So, now, you know the F equal to N tan phi or mu n F equal to mu N and that is nothing, but tan phi and so, this is the relation. So, tan phi I can obtain by this tan phi equal to F by N; that means, what is the frictional resistance and what is the normal that ratio will give you the tan phi

The frictional resistance in sands and other chesionless granular materials resembles the above; that means, whatever we have observation we made they are actually almost granular soil is almost behaviour is similar, but there are some important differences and what are those that frictional resistance in soil consist of both sliding and rolling sliding and rolling friction whereas, there is only where whatever the example we have shown there is only sliding where is sliding and rolling is there and coupled with a certain degree of interlocking, which I have mentioned that shear strength comes with 3 4 components. So, sliding will be there rolling will be there and sometime there is a interlocking,

So, though whatever example I have given they are almost similar to the shear strength of the soil mechanism, but little difference are there that not only sliding here, there is sliding and rolling will be there and in addition to that there may be some amount of interlocking.

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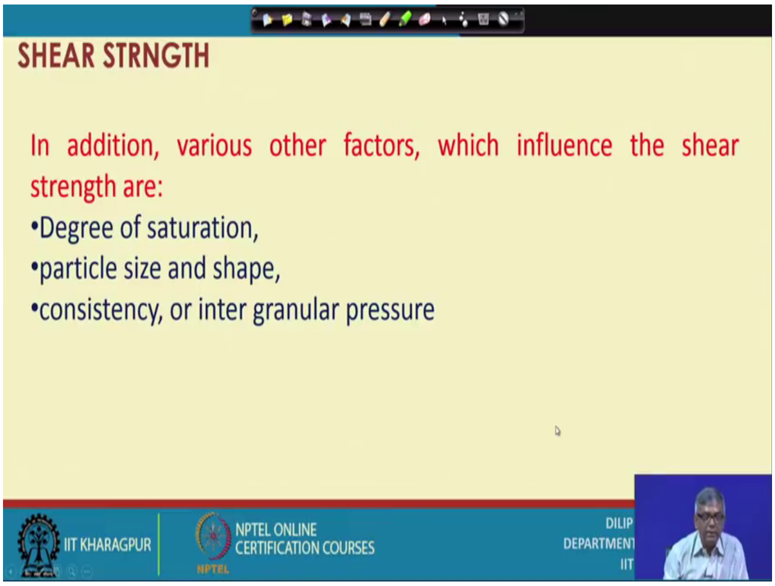

And in addition various other factors which influence the shear strength, that will again I am just giving same thing the degree of saturation and then particle size and shape, consistency or inter granular pressure. So, degree of saturation as I have mentioned that the shear strength will be finally, function of effective stress. So, with the change of water content or degree of saturation, the shear strength also will be changing and that of course, we will be resulting the shear strength of the soil.

And particle size and shape; obviously, that is also important I will show you later on the granular soil will have better strength than the fine granular soil, how and that can be explained later on. And particle size and shape again if the grounded particles and then angular particles they are also behaviour at different and they will give different shear strength and consistency; that means, whether it is sharped or it is stiff, that also influenced the shear strength; obviously, stiffer soil will have better strength than the sharp soil.

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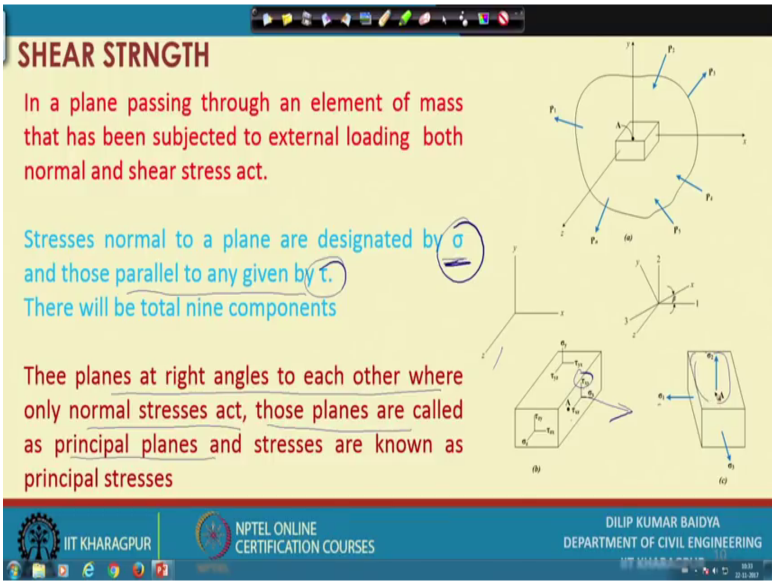

Now, again we will try to understand when the soil mass is there, and I will try to see a point in inside the soil mass, and at that point there will be number of stresses will be acting. Suppose I will take this is the one the point inside a ground mass, and which will be shown slightly enlarged view, and this is the mass entire mass and subjected to a number of forces here, and the body is in equilibrium.

Then if I imagine a point inside a point which that that can be isolated like this, which will have a 6 phases and each phases we can see here, we can see that this phase, there will be normal to this phase there will be a normal stress and parallel to this there will be parallel to x and parallel to y. So, parallel to the plane there will be shear stress then; that means, each plane there will be two shear stresses, what one will be parallel to y another is parallel to z and normal is along x so; that means, there will be three components here, there will be three components also that ultimately total there will be nine components.

So, stress normal to plane are designated by sigma; that means, normal place will be designated as sigma, and those parallel to given that is tau. So, this is the tau actually and again tau x and tau y that is actually you can see the first letter. First letter actually it is perpendicular to that plane; that means, tau x means it is a perpendicular to that plane, but along y second letter is the along which direction, and similarly you can see tau xz this one, this is actually perpendicular to x this plane and it is along z direction.

So, like that you have to have nine components you can write in each phases. So, there will be normal three normal sigma 1, sigma 2, sigma 3 or sigma x, sigma y, sigma z similarly tau xy, tau yz, tau zx and like that. So, three planes at right angles to each other where only normal stresses act those planes are called as principal planes; that means, now I can investigate though at a in general at a point we have nine components that when each plane will have normal and shear, and we can investigate and find out some plane where only where only normal stress is there, there is no shear stress. And those plane where only normal stress is acting, that plane is called principle plane.

So, this is the principle principle now, I can see suppose x direction was this, and y direction was this z direction was this. Now we can get some other inclination we can investigate and find out the plane where actually we only normal stress suppose this is the situation, where with this plane will have only sigma 3, this plane only having sigma 1 and this plane is having only sigma 2. So that means, these are all this plane this plane say there is no shear this plane is called principal plane similarly this is a principal plane see this is a principal plane.

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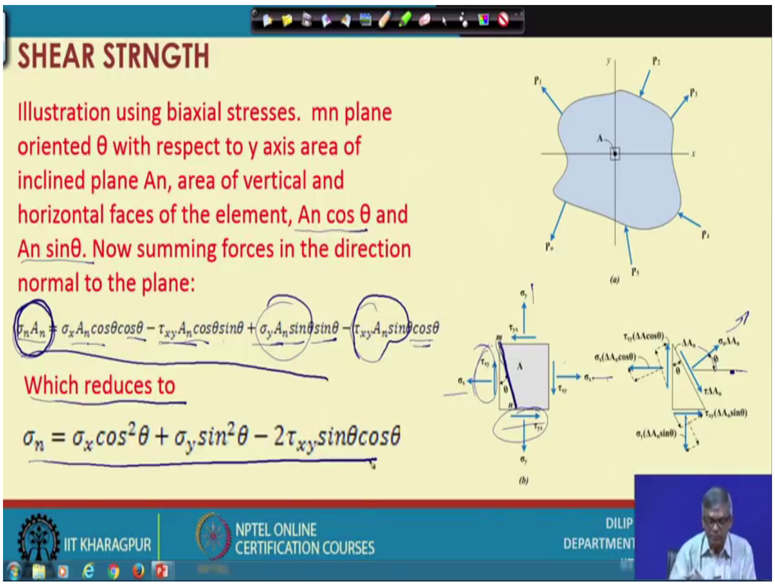

Now, illustration using biaxial stress; that means, whatever we have done that is actually three dimensional some time is not essential always to use three dimensional, most of the soil mechanics problem can be used in by two dimensional, and we cannot try to understand that. So, similar figure I have shown the body, and similar one point I have taken that point I have isolated, but I have considered now biaxial; that means, I have considered x direction, y direction and on that there will be shear.

So, if I take an element biaxial condition that two one element if I draw, then this element is shown this is sigma x, this is sigma y, and this sigma y and then this is tau xy and this is tau y z, yx similarly this is tau xy and tau yx. And now this one is there and now if I consider a any plane. So, this is the state of stress at this point whatever I have given that is the state of stress.

Now, I want to find out stress at any inclination. So, suppose this is the plane I imagine. I imagine a plane here and on that plane what is the normal and what is the shear I have to find out. So, to do that I can isolate this part here and you can see this I have to find out normal to this plane and parallel to this plane. If I draw a normal here I can find out now this angle with respect to the original direction of x. So, you can see it is going value theta.

So, if I do that and then I can force equilibrium I can do; that means, in this phase whatever element I have taken this, this one I consider as area n this direction area A n and then we have horizontal faces. So, vertical and horizontal faces of the element will be A n cos theta and A n sin theta so; that means, what is the area if this is A n what is this, this area and what is this area. So, that is the given A n cos theta n sin theta.

And now I consider the force equilibrium; that means, whatever force acting on this element, I will consider in one direction equal to summation of all forces will be 0, that is the thing I have done sigma n into A n. So, sigma n into A n, I have done and that is sigma x A n cos theta again cos theta; that means, I have taken in the that direction normal direction.

And tau xy into A n cos theta tau xy into A n cos theta and again sin theta I have taken to give component to that direction, sigma A n sigma y into A n sin theta is the force on the element, now sin component if I take to take the in is this direction then similarly tau x into A n sin theta is the force shear force total on the element, and then we are considering cos component to give in this direction component in this direction.

So, like this I have done the force equilibrium on this direction equal to g. So, that is this is the force equilibrium based on this equilibrium. So, these will be this is the force acting in this direction or another forces I just oppose. So, this equal to this and when we have simplified, then it reduces to this for. So, sigma n equal to sigma s x cos square theta plus sigma y sin square theta minus 2 tau xy sin theta cos theta.

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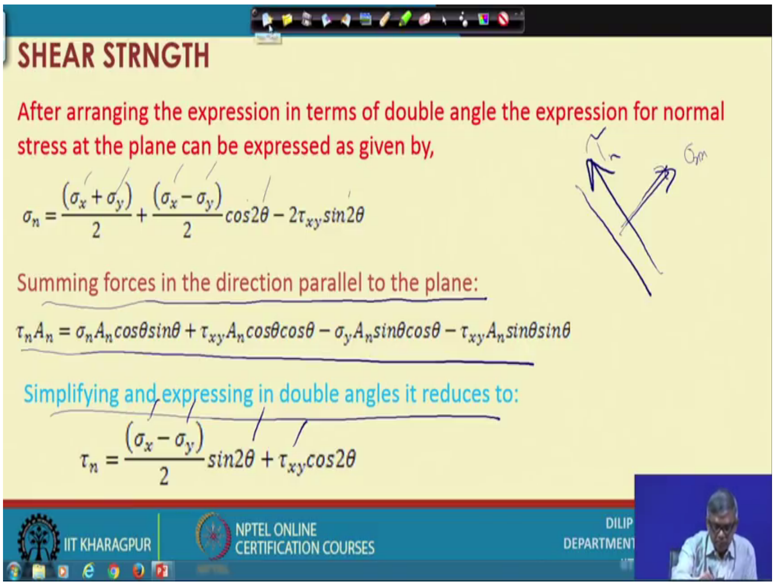

Similarly, this one if I arrange trigonometrically and we can put in a better form with double angle, sigma n become and I mean normal to that plane the sigma x plus sigma y two these are the known already, these all are known and theta also known. So, I can find out what is the value of sigma n.

Similarly, summing forces in the direction parallel to the plane; that means, there is a plane we have done this direction and we have done now I will do this direction all forces in this direction I am sum it and equal to 0 and then this is the equation I will get and if I simplify and arrange then I will get another equation for tau n this is suppose if I say this is tau n this is the expression we will get from this.

So, all are known sigma x is known sigma y you know or know sigma y known theta also known. So, tau xy also known, then I can find out on this plane what is the shear and of course, I have got this one. So, normal will be always together. So, I if I want to find out perpendicular to this what is the normal and sigma x, I suppose this is sigma x n suppose. Then sigma yn I can find out what I have to do? I have to 180 plus 2 theta if I do, then I will get the other component. So, suppose if I say this is sigma x then corresponding sigma y I can get just putting the theta equal to 180 plus 2 theta.

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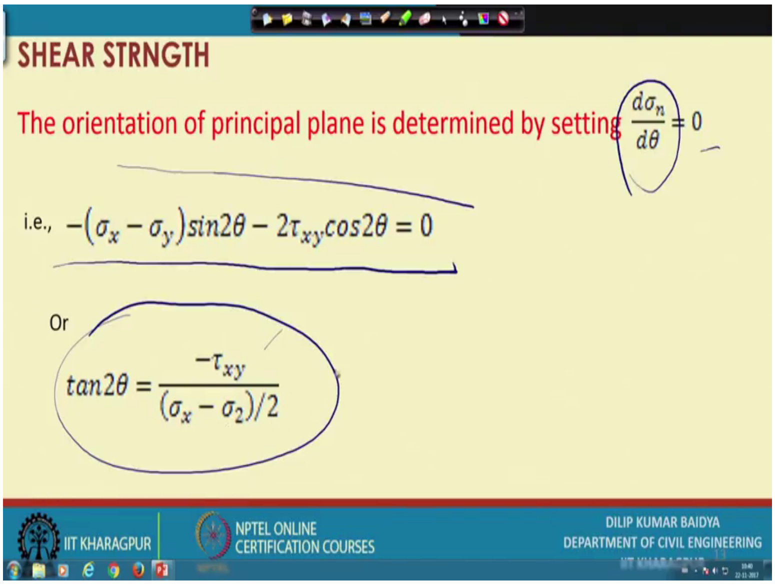

So, like this. So, the orientation of the principal plane is can be determined; that means, I have got now principal stress and we have got shear stress, and that principal stress is the function of theta with the change of theta shear stress actually changing. So, there will be definitely there is a plane, where the shear stress normal stress will be maximum.

How to find out that? I can derivative I can differentiate this d sigma n and d theta and set to 0, and if I do these this expression will come and if I simplify then it will this expression will come; that means, tan theta become minus tau x y by sigma x minus sigma y 2. So, this is the expression; that means, the theta at what angle plane will be that there on which the maximum shear stress maximum normal stress will occur. So, this is the way I can find out the orientation of plane on which the maximum normal stress occur. So, with this I will just stop this part.

Thank you I will again explain for the next topic.