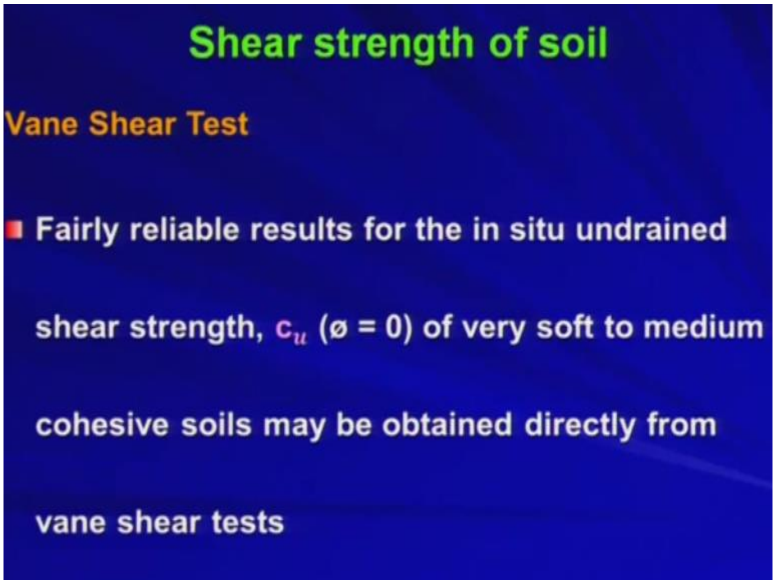
**Geology and Soil Mechanics**
**Prof. P. Ghosh**
**Department of Civil Engineering**
**Indian Institute of Technology Kanpur**
**Lecture - 46**
**Shear Strength of Soil_B**

Welcome back to the course Geology and Soil Mechanics. So, in the last lecture we discussed about the unconfined compressive strength of soil and we discussed about the stress path. So, stress path is very fundamental as we decided as we talked about and today we will be talking about one more type of shear strength determination test that is vane shear test.

**(Refer Slide Time: 00:36)**

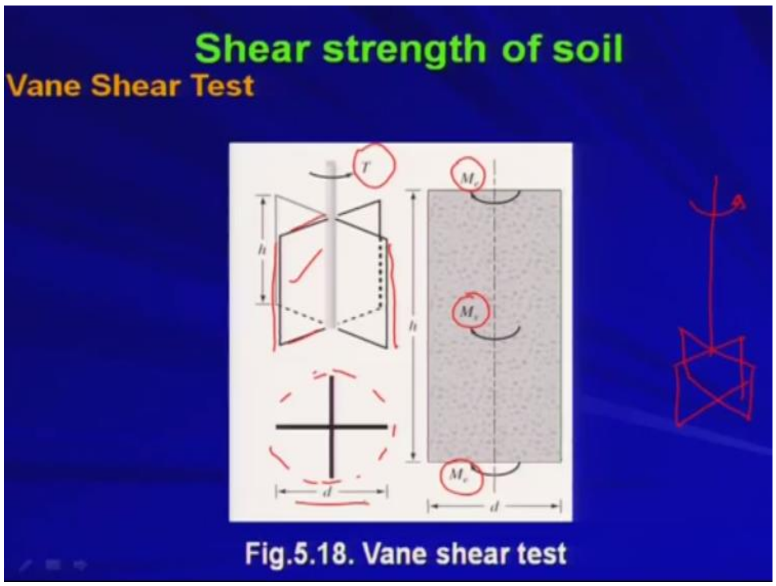



So, this vane shear test is I mean is very versatile in nature that means it can be used in the laboratory as well as in the field. So, wherever you are not able to collect the soil sample properly so they are actually you generally perform vane shear test to get the shear strength directly from the in-situ condition right. So, vane shear test this is fairly reliable results for the in situ undrained shear strength Cu that is phi equal to 0 condition you will be getting a very soft to medium cohesive soils may be obtained directly from vane shear test.

So, basically this this test is generally performed for in situ condition. However, it can be used in the laboratory though we have several different types of sophisticated like triaxial other triaxial different triaxial test diaxial test as well as unconfined compressive strength determination test. So, these are the tests already available in the laboratory. Apart from that you have vane shear test and this vane shear test is only applicable I mean this is the only test which is applicable to the field as well.

So, there from there basically we will be getting the undrained shear strength that is Cu and for very soft so this test is I mean generally used for soft to medium cohesive soil. So, wherever you will be getting very soft to medium cohesive soil if you see the consistency and all after seeing that you can decide that okay I mean you can go for vane shear test in the field itself. So, but please try to remember if you have any cohesion less soil or say gravely soil or maybe very stiff soil in that situation vane shear test will not be that much effective or vane shear test should not be used okay.

**(Refer Slide Time: 02:32)**



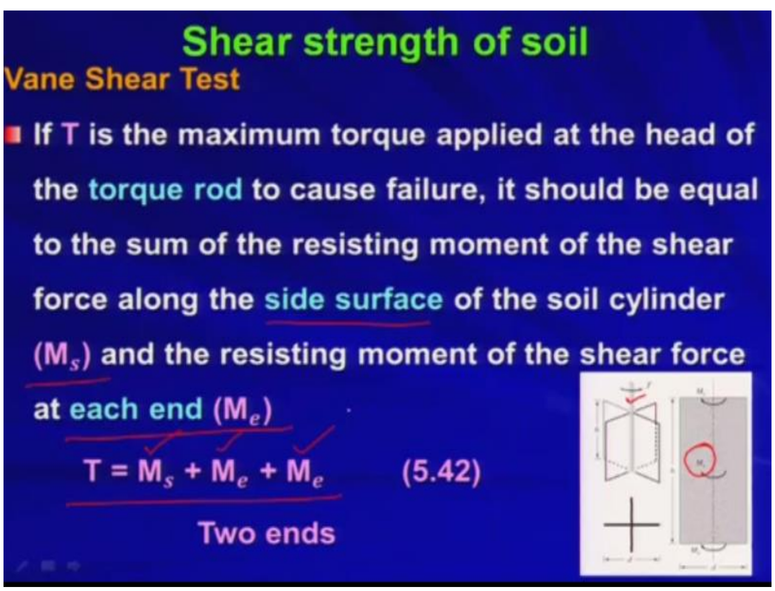

So, this is the typical view of the vane shear apparatus. So, I mean what we have, we have one rod that is the torque is applied on this rod and you have the vanes like this as it is shown okay. So, this is the something like you have the rod I mean cylindrical rod okay and at the end of the rod you have the vanes. These are known as vanes okay. So, these vanes are attached.

The height of the vane will be playing a crucial role that is say small h and we are applying a torque T okay on this torque rod okay so through this rod we are applying the torque and then this is inserted in the ground okay and then we apply the torque. So, I mean if you try to think about the mechanism that I am putting the whole say rod along with the vanes I am putting inside the soil and then I am rotating it.

So, of course this rotation when I am giving some action through the torque through the application of torque basically you will be getting the opposite reaction that is the resistance from the soil and that is purely based on the shear resistance right so and shear resistance will be getting developed along the sides of the vanes because these vanes will be touching the soil okay soil surface as well as you will be getting the resistance at the top as well as the bottom when you will be rotating it on the soil body or the soil surface basically you are rotating it so you will be getting the shear resistance along the surface along the periphery as well as the bottom and the top because that is that we are inserting and then we are rotating it okay.

So, whatever torque you are applying so that torque must be resisted okay by the shear resistance developed at the sides of the vanes okay all the vanes and at the top as well as the bottom. So, that means this torque is resisted by the side movement okay I mean given by the side shear resistance and the movement developed at the bottom as well as the top. So, this movements will be same and the side friction or the side shear resistance will be giving you M s okay and the diameter of the vanes so this is the say if you consider this is the diameter so diameter of the vane say is small d so based on that we will be trying to develop the expression by which you can determine the magnitude of Cu that is undrained cohesion okay.

**(Refer Slide Time: 05:17)**

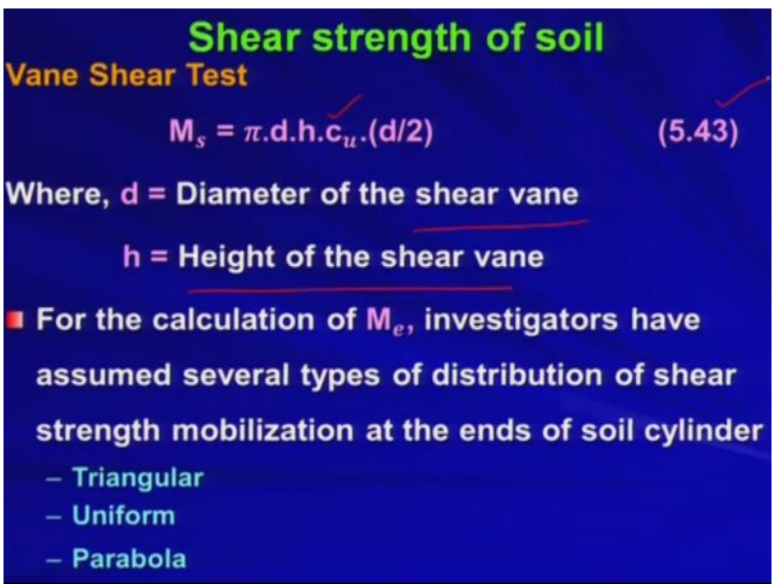



If T is the maximum torque applied at the head of the torque rod so this is your torque rod as I told you. So, if T is the maximum torque applied at the head of the torque rod to cause failure so we are going up to the failure. So, what is happening so you are putting inside I mean the apparatus or the instrument that is torque rod as well as the vanes that is going inside the soil.

Now you are applying the torque so you are applying with some constant rate okay so rate will be a crucial parameter, so rate of application of torque. So, you are applying the torque with some constant rate okay. So, initially you will not be getting any movement of the rod right. Initially you will not be getting any rotation kind of thing in the rod itself. Then slowly when you will be reaching the limiting state that means the soil resistance is I mean the maximum soil resistance has been mobilized at that time you will be getting the rotation. So, that is basically giving you the failure right.

So, and that is your maximum torque which you are applying and which is getting resisted by the shear resistance of soil. So, it should be equal to the sum of the resisting moment of the shear force along the side surface as I told you that is nothing but M s of the soil of the soil cylinder and the resisting moment of the shear force at each end that is M e okay. So, you will be getting the resistance developed at the top of the vanes at the bottom of the vanes and as well as the side of the vanes okay. So, therefore T is equal to M s + M e + M e. So, M s is coming from side M e is coming from top and M e is coming from bottom. So, therefore because you have 2 ends right.

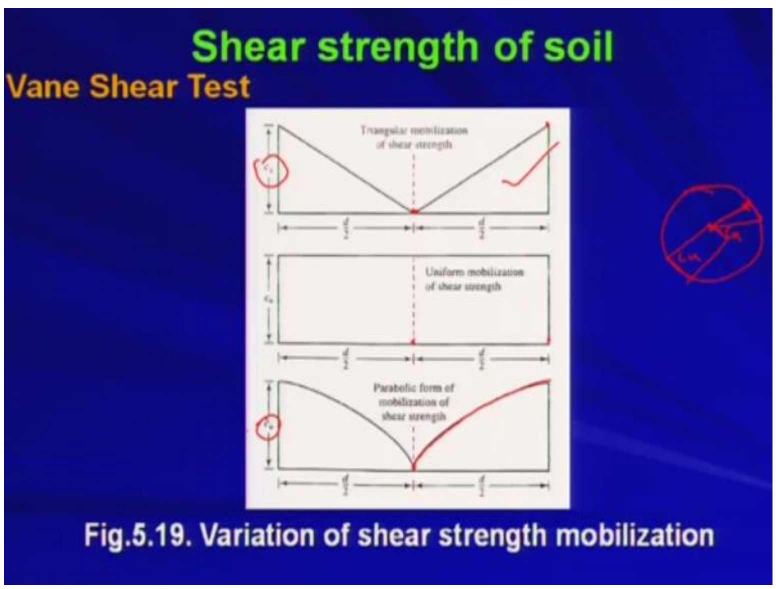
**(Refer Slide Time: 07:11)**




So, now we are going to find out the expression for M s. So, what is M s? M s is nothing but the side resistance developed at the vane surface right vane sides. So, M s is nothing but pi d that is pi into d that is the periphery into h. So, that will be giving you some cylindrical surface okay because the vanes are rotating in the so because you have the height of the vane is small h okay and the diameter of the vane is say small d so pi d into h will be giving you the surface area right the surface area on which you are getting the development of the side friction or the side or the side resistance right due to the I mean shear strength okay.

So, pi d h into Cu will be the total force developed at the surface multiplied by d by 2 that is the lever arm right. So, that will give you the moment which is getting developed at the surface. So, where d is the diameter of the shear vane and small h is the height of the shear vane as I told you. So, for the calculation of M e so now you need to calculate M e. So, M s you have got from equation 5.43 so you can calculate M s once you know the say geometrical parameters for the vanes. Now for the calculation of M e investigators have assumed several types of distribution of shear strength mobilization at the ends of soil cylinder that is triangular, uniform, or parabola. Now what is that?

**(Refer Slide Time: 08:52)**




Basically, if you look at this figure now the investigators I mean say they decided I mean they came out with the say solution that or say interpretation that the shear strength is not getting mobilized I mean continuously from I mean from the center of the torque rod so this is if you consider this is your top surface or bottom surface.

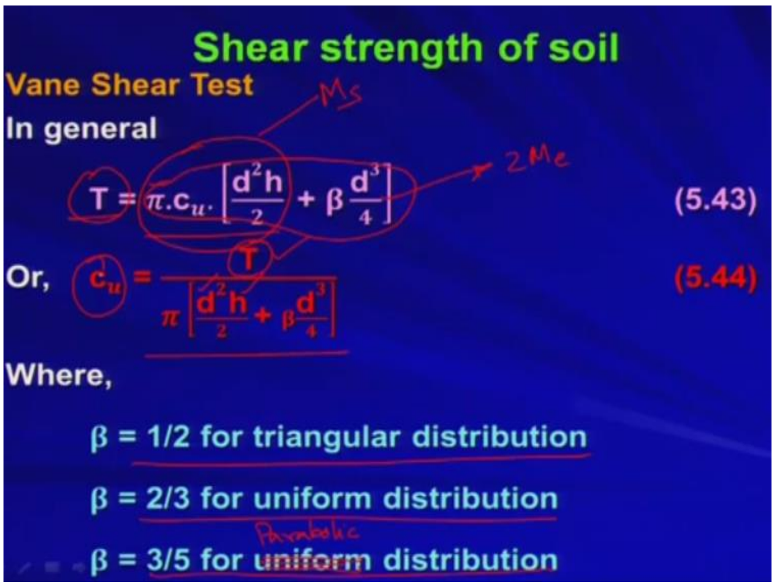
So, at the center of the say torque rod or the vanes whatever shear will be developed that will not be same throughout the radial direction okay throughout the radial direction it will not be same it will not be I mean it may not be same okay. So, there is some uniform distribution also is considered. It may not be same it maybe same. Now based on that you are getting 3 different types of distribution.

One distribution is saying that you have zero shear strength mobilization at the center and you are getting maximum mobilization of the shear strength at the periphery. So, that is given by this distribution that is nothing but triangular mobilization of shear strength. So, at the center you are having zero and at the periphery you are having the maximum shear strength that is nothing but Cu okay Cu is the maximum.

Beyond that you cannot go am I right. That is nothing but the shear strength of the soil. So, it is varying from 0 to Cu linearly so with the triangular distribution. Now another set of researchers or the investigators they are saying no that distribution could should be uniform that means it is Cu at center as well as Cu at periphery okay. So, that means the distribution is something like this okay constant distribution Cu okay uniform mobilization of shear strength okay.

Some set of researchers some set of investigators they are saying no it may not be triangular it may not be uniform rather it should be parabolic in nature. So, parabolic means this kind of say distribution okay where you are having zero at the center and the distribution is parabolic and at the periphery you are having the maximum shear mobilization that is Cu. So, either one of these say distribution you should consider okay to calculate or to determine the magnitude of M e okay. So, we will see that if you consider different distribution how your M e will be varying okay.

**(Refer Slide Time: 11:24)**



So, in general therefore so T is equal to, the total maximum torque is equal to pi into Cu into d 2 h I mean d square h by 2 + beta into d cube by 4. So, now this part is giving you M s and this part is giving you twice M e okay. So, therefore from this expression once you express this T the total torque your maximum torque is in terms of these parameters then Cu that is your nothing but the objective function right.

So, you can determine Cu from this expression that is T by pi into d square h by 2 + beta into d cube by 4. Now what is beta? So, beta is half for triangular distribution. Beta is two third for uniform distribution and beta is 3 by 5 for parabolic distribution. So, this will be parabolic okay. Please correct it. So, parabolic distribution.

So, I mean now you got an idea right. So, if you consider if you say that I will be considering triangular distribution so your beta in place of beta you put half and you calculate Cu because T this thing you are measuring right you are giving the torque with the help of some motorized mechanism. So, from that mechanism you can determine or you can measure the torque which is getting applied on the torque rod.

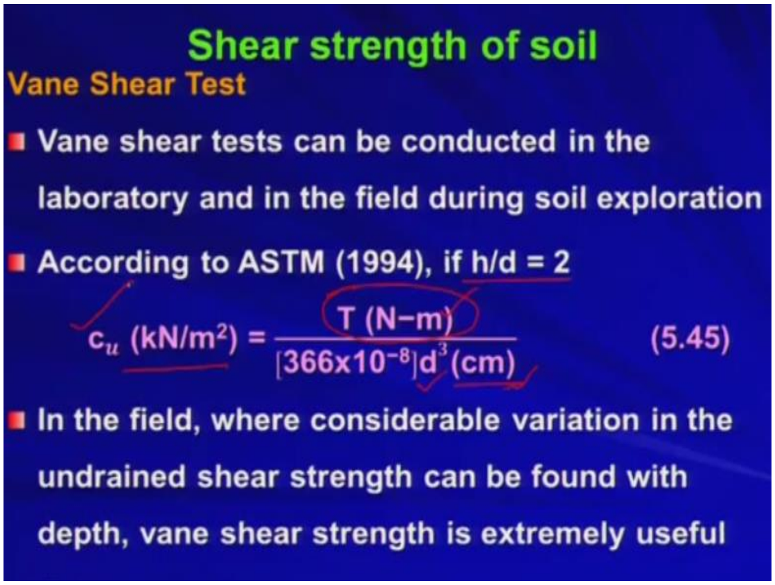
So, you can record the magnitude of T so d and h they are the geometrical parameters for your vanes. So, once you know all those things you can find out Cu from the in situ condition from the field itself which is not possible with some other triaxial test or u c s or diaxial test. Those are purely based on your laboratory experiments right. So, however you can get the shear strength parameter from the field itself.

Sometimes people what people do people find out the Cu value from the laboratory as well as they find out the Cu value from the field and then they match it so if you get I mean quite a significant amount of difference then of course there should be any kind of problem right. So, if you get quite matching say magnitude between these 2 values from in situ as well as from laboratory then of course your test or your determination of shear strength is okay in that way right.

So, this is the way people do the validation or do the comparison kind of thing in the field itself and one more thing say suppose if you are collecting the soil sample basically for your laboratory test you need to collect the soil sample from the soil deposit that is from the field. Now when you are collecting the soil sample at that time during the collection of course the disturbance will be there. So, that will disturb the soil structure so whatever soil is really or actually available at the site it may not be same when you are doing the laboratory experiment right.

So, because of your collection and because of your storing and all those things some structural difference or structural change is happening in the soil so therefore that soil whatever you are I mean taking for the test in the laboratory so that may not be the true representation of the soil which is lying in the field. So, in that situation this Cu that vane shear test will give you the Cu value from the field itself directly and which will take care of the actual soil structure which is lying in the field okay.

**(Refer Slide Time: 15:26)**




Now vane shear test can be conducted in the laboratory and in the field during the soil explosion as I told you so this vane shear test so this when you are going for the field the equipment or the instrument is huge one and when you are coming to the laboratory scale the instrument is very small very tiny so you can see I mean very say it is really looking like a toy okay so you can I mean if you get some opportunity to see this instrument that is field I mean laboratory experiment of vane shear test so basically you must see that okay.

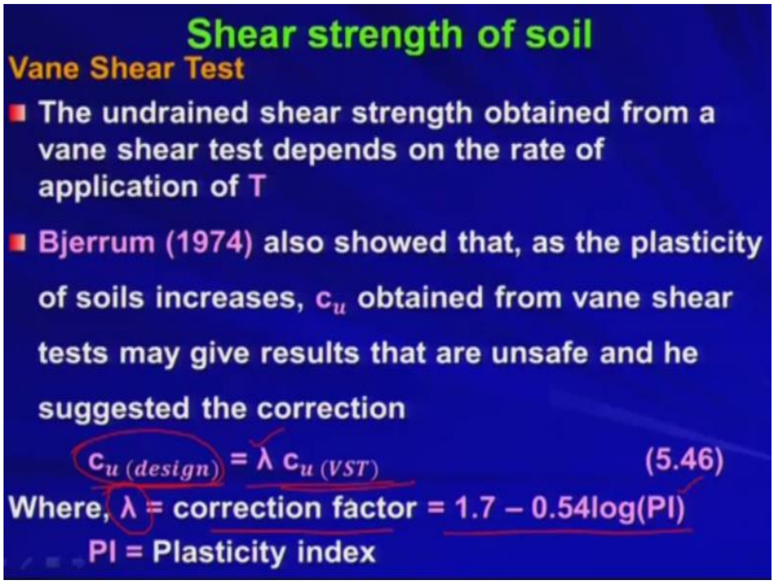
This is very miniature kind of say torque rod and vanes and all those things which will be having some motor on top which will give the torque okay anyway. So, according to ASTM 1994 so if you consider h by d that is height of the vane to diameter ratio is 2 and which u can of course consider I mean generally most of the manufactures they consider this ratio and if it is so then Cu that is given in kilo Newton per meter square that is undrained cohesion is equal to T in Newton meter okay so T is nothing but the torque which you are observing or which you are recording through the instrument okay divided by 366 into 10 to the power minus 8 into d cube and d is expressed in centimeter.

So, if you know d that is if you know the diameter of the vanes okay do not think that this is the diameter of the torque rod. Torque rod diameter has nothing to do with the shear strength. So, this is the diameter of the vanes that means the peripheral diameter of the vanes whatever is touching to the soil surface okay. So, d is expressed in centimeter and torque is expressed in Newton meter. Please try to remember this is in centimeter this is in Newton meter.

So, and from this expression you can calculate Cu which will be coming in terms of kilo Newton per meter square. So, in the field where considerable variation in the undrained shear strength can be found with depth vane shear strength is extremely useful okay. So, what does it mean in the field where considerable variation in the undrained shear strength can be found. So, I mean you have the soil deposit. You do not have any control to govern that soil deposit right. That soil deposit is lying.

Now if you see if you perform some laboratory experiment at different dates at different locations and if you see the undrained shear strength variation at different locations and different depth is significant that variation is significant that means it should not vary that much right. If you consider like that that within a small area the variation is too much or the significant then you must go for this field vane shear test to get it confirmed that okay whatever you are getting from the laboratory or whatever you are getting from the field they are comparable okay. So, that is why this vane shear test is very useful to get the direct magnitude of the shear strength of soil.

**(Refer Slide Time: 18:41)**




The undrained shear strength obtained from vane shear test depends on the rate of application of T which I told you initially that you are slowly you are gradually applying the torque with some constant rate right and this is very similar to your friction chapter whatever you have covered in 10 + 2 standard physics right. So, the I mean if you try to push something on top of some surface right so it depends on the rate also right I mean say if you put this thing very fast then whatever say dynamic friction whatever will be getting developed that will be different than if you push that thing very slowly.

That means slow mobilization of the shear strength will be happening and that rate is very crucial. So, you can apply the torque with very faster rate then basically you will not be getting the proper mobilization of the shear strength along the surface you may get some erroneous result. So, it should be very gradual and that rate will govern the magnitude of Cu okay. So, as you give the torque very slowly so basically if you give the torque very slowly in the torque rod so what will happen you will be getting the reverse direction shear resistance that will be getting mobilized.

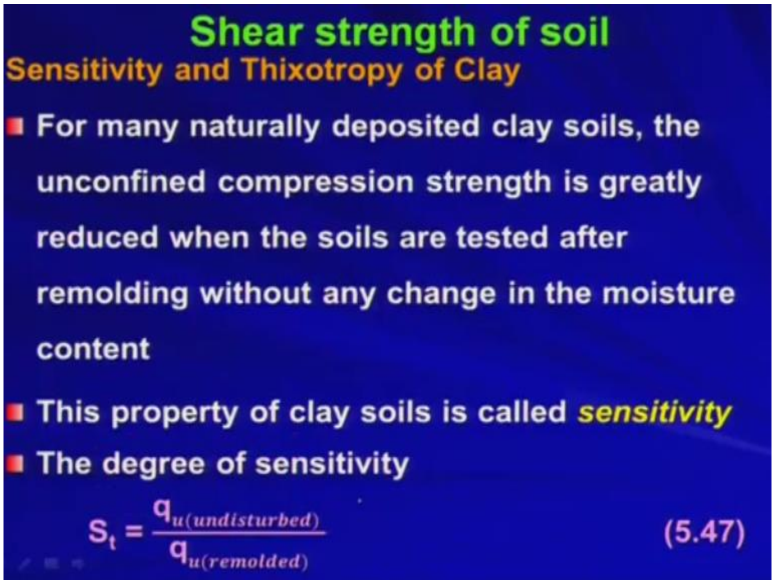
So, slowly the shear resistance will be getting mobilized and gradually so there should not be any jump right. So, if you do it fast so that mobilization will be will not be happening very fast. So, this mobilization needs some slow or the gradual movement of the torque rod or the vanes okay. So, Bjerrum in 1974 also showed that as the plasticity of soil increases Cu obtained from vane shear test may give results that are unsafe and he suggested the correction.

Now what Bjerrum has suggested Bjerrum in 1974 he suggested that if the plasticity of the soil increases and you know how the plasticity of the soil increases and what is the parameter by which you can determine the plasticity of soil is getting increased right. So, plasticity index right whatever you have seen earlier. So, if the plasticity of soil increases then whatever Cu value you are getting from the field by vane shear test that may be little bit unsafe right so that means that will be predicting overestimating the magnitude of Cu.

So, you must apply some correction factor whenever you are getting or whenever you are dealing some high plastic soil. So, this Cu design that means that is the design value of Cu whatever you will be proposing that is equal to lamda into Cu obtained from the vane shear test. So, this is your this lamda is nothing but the correction factor and it is given by this expression 1.7 - 0.54 log plasticity index PI okay.

So, as your plasticity index increases you will be getting different value of lamda and based on that you can find out the Cu design. So, what is that is equal to lamda into Cu obtained from the vane shear test. So, this is your actual Cu multiplied by lamda will give you the design value of Cu okay. So, this is the correction Bjerrum has proposed. Otherwise if you do not do this correction whatever Cu you will be getting that will be giving you little bit unsafe that means it will be overestimating the strength which is not actually available in the soil.

**(Refer Slide Time: 22:18)**




Now we will be learning 2 very important terms one is the sensitivity of soil another one is the thixotropy of clay okay. So, for many naturally deposit clay soils the unconfined compression strength is greatly reduced when the soils are tested after remolding without any change in the moisture content. Now what does it mean? Now suppose you have the clayey soil in the field. Now you are collecting the soil sample okay from the field and then you are doing some unconfined compression strength test in the laboratory.

Now how you will collect the sample? So, you have several options to collect the sample okay. You have the sampler, power sampler which will be I mean which will be which can be attached to the SVT test or you can collect some undisturbed sample so there are several ways to collect the sample so though that is not in the scope of this particular course. That is coming in the soil exploration and investigation.

However, so you can collect the sample okay and your objective or your intention will be always to collect as much as you can collect the undisturbed sample right but it is not always true I mean in the field whenever you will be collecting the sample it may not be true that all the times you will be collecting the undisturbed sample.

So, there will be some amount of disturbance right and this disturbance will cause will affect the shear strength of the soil greatly so if the soil is very sensitive then this disturbance will be causing significant amount of variation in the soil I mean shear strength. If the soil is not that much sensitive then you will not be getting that much of I mean variation right. So, it depends on the sensitivity of the soil.

That means whatever soil you are collecting so that soil is say undisturbed soil in the field whatever is lying in the in-situ condition that is your undisturbed soil. Now you are collecting the soil. You are collecting the sample and then you are I mean you are collecting the sample for doing the laboratory test to find out the shear strength right. Now how that shear strength will be getting I mean affected or how the variation will be I mean you will be getting in the shear strength parameter whatever you are expecting to get from the field that is from the undisturbed sample and whatever you are getting from the disturbed sample. This is not disturbed remolded sample.

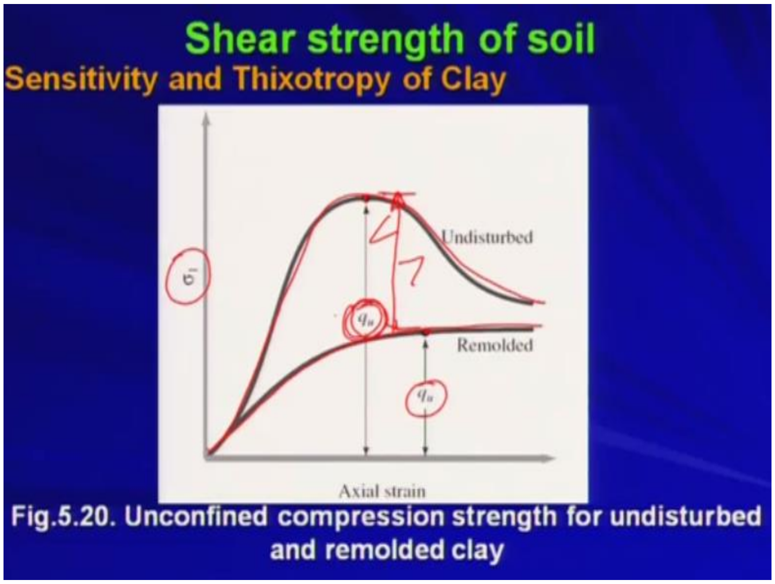
So, that is known as remolded sample that means you are remolding the soil I mean to do the to perform the shear test. So, if the soil is very sensitive then basically you will be you should be very much careful and that will cause the variation significant variation in the strength shear strength parameters right. So, that you must take care. You must take enough care when you are performing the test.

So, first so this property of clay soil is called sensitivity okay. So, if I say my soil, clay soil, is very sensitive then you have to take the utmost care and you should know okay I mean if I say the sensitivity is say 2 or if I say the sensitivity is 4 then you should know that whatever I am getting from the laboratory experiment from the unconfined compression strength test that may not be the same okay whatever is actually lying in the field okay.

So, this sensitivity will define that will talk about that kind of variation. So, the degree of sensitivity so I now we are going to quantify this sensitivity. The degree of sensitivity is given by S t is equal to q u undisturbed that is whatever is actually available in the field or the in situ condition divided by q u remolded so that basically this value you are getting from the laboratory experiment okay.

So, if you know the sensitivity of the soil or how you will get q u undisturbed maybe you can go for vane shear test and you can get for this q u value right this is the way you do and q u remolded that you can go for any triaxial test or maybe unconfined compression strength test and you perform this so to get this q u remolded value okay. So, the ratio of these 2 will be giving you the sensitivity okay.

**(Refer Slide Time: 26:45)**




Now basically if you see the unconfined compression strength for undisturbed and remolded clay with time with axial strength okay. So, this is your sigma 1 say because in unconfined compression strength only you apply sigma 1 so as you go on increasing because you do not have any sigma 3 you do not have any cell pressure so as you go on increasing sigma 1 okay or rather sigma 1 is increasing your axial strain is also increasing right.

So, in case of remolded sample you will be getting the curve like this whereas in case of undisturbed sample you will be getting the curve like this. Now this is the maximum or the peak that is nothing but the q u undisturbed and this is nothing but q u remolded okay this point. So, now you see the difference okay so this is the difference between these two. Now if soil is very sensitive this difference will be greater.

If the soil is not that much sensitive this difference will be coming down or decreasing right. So, it depends on the sensitivity how much sensitive the soil is so when you are collecting the soil sample from the field okay. So, based on this sensitivity you can say okay this I mean say if this q u value or if you know the sensitivity of that particular value of a particular soil then basically you can calculate q u undisturbed from the remolded value of q u okay.

**(Refer Slide Time: 28:26)**


Now S t of most clays ranges from about 1 to 8. So, if it is 1 then this is not at all sensitive that means q u undisturbed is equal to q u remolded so this is not at all sensitive. Now if the value or the S t value is increasing that means the soil is becoming more and more sensitive. So, if I say my soil I mean sensitivity value sensitivity degree of sensitivity of a particular soil is say 7 and if a soil is having degree of sensitivity value of say 2 so that 7 S t value of 7 will be more sensitive and whenever you are collecting the sample whenever you are doing some test on the remolded sample you should be very much careful.

The loss of strength of clay soils from remolding is primarily caused by the destruction of the clay particle structure that was developed during the original process of sedimentation. So, this is I mean why you are getting this variation? Why at all you really need to think about this kind of remolded sample and undisturbed sample? Because the original during original process of sedimentation soil has acquired some structure right as we have discussed like flocculated structure or whatever structure.

So, during the process of sedimentation soil has got some inherent structure. Now when you are collecting the soil though you are not changing the moisture content and all but still you are changing or you are disturbing the structure whatever structure the original soil had okay. Now you are changing the structure and due to the changing or you are destroying the structure and due to this destruction basically you will be getting different I mean lower strength right whatever strength you are supposed to get in the field you will be getting rather lesser value of strength okay shear strength okay in the laboratory.

So, that means if you design with q u remolded basically if the soil is not very much sensitive then if you design any structure based on q u remolded then it is okay but if the soil is very sensitive and if you are still designing with the value of q u remolded then basically you are underestimating the soil strength. So, whatever design value you are considering in the field actually it may be more than that. So, that depends on the sensitivity okay.

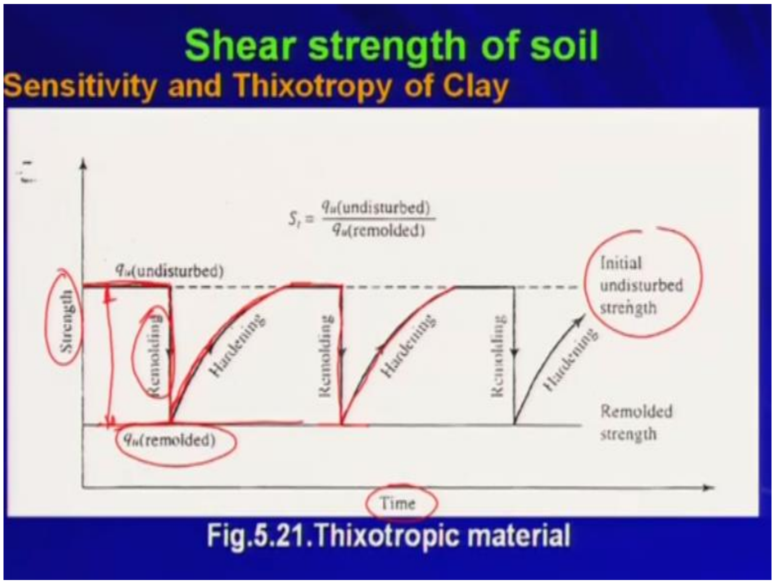
**(Refer Slide Time: 31:03)**

If however after remolding a soil specimen is kept in an undisturbed state that is without any change in the moisture content it will continue to gain strength with time. This is very interesting thing in the soil. What does it say? If however after remolding a soil specimen is kept in an undisturbed state undisturbed state means you are not changing the moisture content okay.

So, you are collecting the soil sample which is now it is remolded sample. In the remolded sample, you are not changing the moisture content that means you are taking enough care so that the moisture is not getting lost from the soil matrix okay. Now you are keeping that thing so with time it will continue to gain the strength.

So, whatever strength it had in the field okay so it will try to approach to q u undisturbed okay. So, this is very interesting thing. So, with time basically soil will gain the strength. So, this phenomena is referred to as thixotropy. So, this is very important parameter and very interesting characteristics of soil. So, with time it will gain the strength and that is known as thixotropy in soil mechanics.

**(Refer Slide Time: 32:28)**




So, now we will explain this thixotropy behaviour or thixotropy cycle for any kind of soil. So, this is for complete thixotropic material. So, what you have so this is along the y axis you have strength. Along the x axis you have time. So, strength versus time you are plotting. So, at the initial this is your initial undisturbed strength. So, this is your initial undisturbed strength okay so q u undisturbed you have.

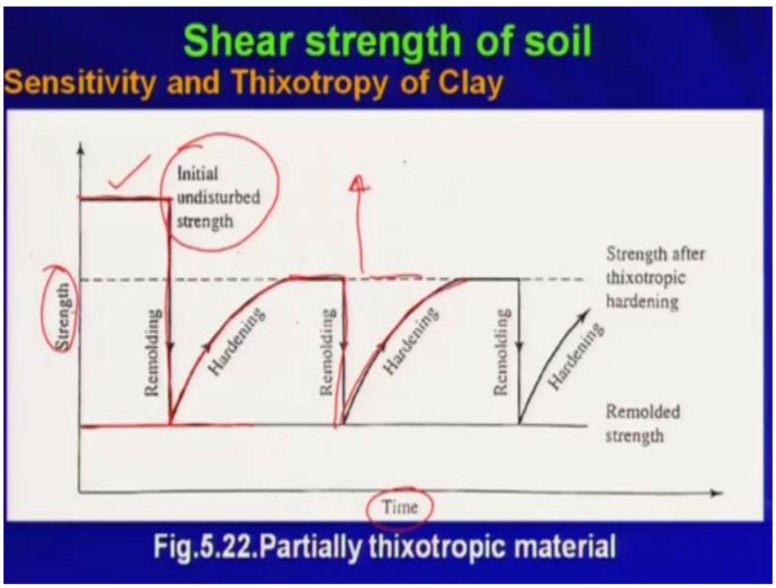
Now basically you are collecting the sample that means you are remolding the sample so you are losing some strength and that is say q u remolded okay. So, this is the difference between q u undisturbed and q u remolded this is the difference okay. So, now it depends on the sensitivity as the soil is becoming more sensitive this difference will be more so anyway. So, this remold after remolding you will be getting this much of reduction in the q u value.

Now if you keep that thing as it is without changing any moisture content as I told you then it will basically harden it will gain the strength with time so that is along this x axis is the time okay with time it will gain the strength and it will try to reach the same magnitude of q u undisturbed.

That means it will regain its own strength whatever it was I mean whatever it lost actually okay. So, whatever it lost so now again it is coming back to the soil. So, this phenomena is known as thixotropy. So, this is known as complete thixotropy. So, after that again if you remold the soil sample it will come down to this. Again, with time it will regain its strength and it will become the same soil whatever you had in the field okay.

So, this is very interesting phenomena I mean very few materials in the world okay which will be showing this kind of characteristics okay. So, and that is why maybe I mean initially if you disturb the soil after certain time the soil will regain its strength. So, that is that happens actually okay anyway. So, this is known as complete thixotropy. That means whatever the soil is losing the same amount of strength it is regaining after certain time.

**(Refer Slide Time: 34:52)**

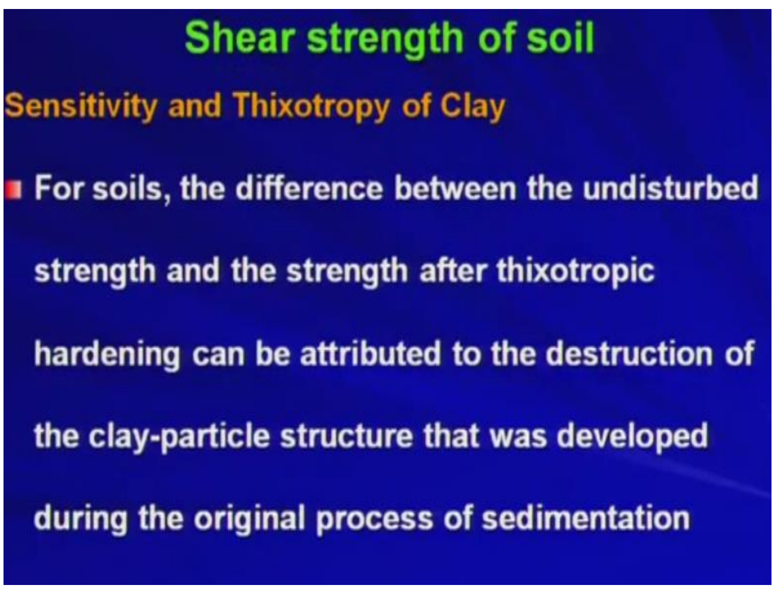


Now sometimes you may get partial thixotropy. That means you started. So, this is along strength versus time again we are plotting. So, this is your initial undisturbed strength okay. Now you are disturbing the sample you are remolding the sample and with remolding you are getting this is your remolded strength okay. Now with time the soil will regain its strength but it will not reach to its original undisturbed strength original or the initial undisturbed strength. Rather it will be regaining but it will be lying here.

So, that is in between your remolding remolded strength and the undisturbed strength. So, but it will regain of course it will regain. So, this is known as partial thixotropy that means it will not it is not going back to its original or the initial undisturbed strength rather it will it is going to some in between higher strength right.

So, after that again if you remold it okay it will come to this point again it will regain and that regain will be same but every time it is regaining the strength at this level. It is not going up to this level. So, that is why it is known as partial thixotropy. So, you will be getting some amount of regaining of strength but that may not be the exactly same whatever the soil had lost during the first collection of soil sample.

**(Refer Slide Time: 36:20)**




Now for soils the difference between the undisturbed strength and the strength after thixotropic hardening can be attributed to the destruction of clay particle structure that was developed during the original process of sedimentation. So, what is the reason behind this partial thixotropy? That means you are not going back to the original position. That means you are destroying the original structure of the soil. So, this destruction will cause that you will not be getting the same regain or the it is not going back to its original position because you have destructed or you have destroyed okay some amount of soil structure okay.

So, I will stop here today. So, in the next class we will talk about the Skempton pore pressure parameter how to find out Skempton pore pressure parameter and how to obtain those parameters whatever parameters you have seen already we have discussed Skempton pore pressure parameter A and B. Now we are going to find out how to obtain the values of A and B. So, in the next class we will take this. So, thank you very much.