NPTEL

NATIONAL PROGRAMME ON TECHNOLOGY ENHANCED LEARNING

CDEEP
IIT BOMBAY

ADVANCED GEOTECHNICAL ENGINEERING

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Lecture No.35

Module-4
On Stress-Strain relationship and Shear strength of soils

Welcome to lecture series on advanced geotechnical engineering being offered by the department of IIT Bombay so BVS Viswanadham.

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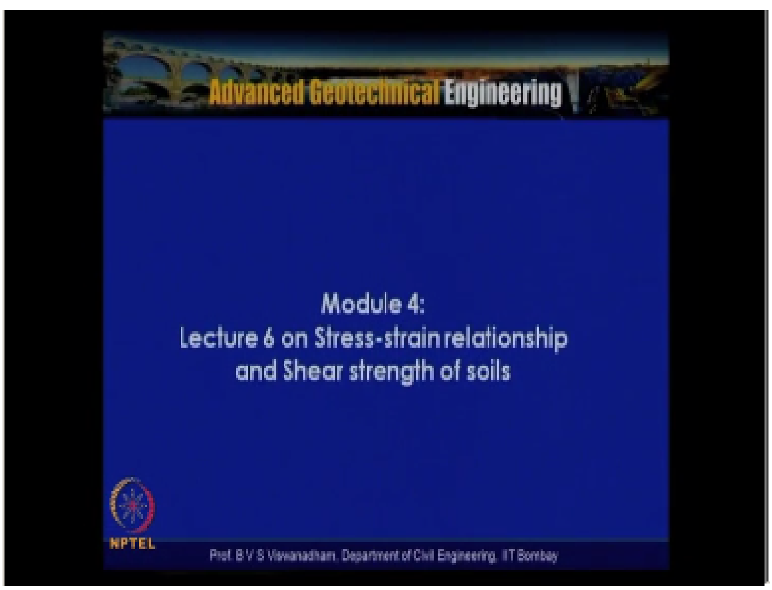

So we are in module 4 and lecture 6 on stress stain relationship and shear strength of soils so in the previous lecture we introduced about Mohr column criterion and then introduced also pq space and in this lecture will try to discuss more about the Mohr column failure criteria and.

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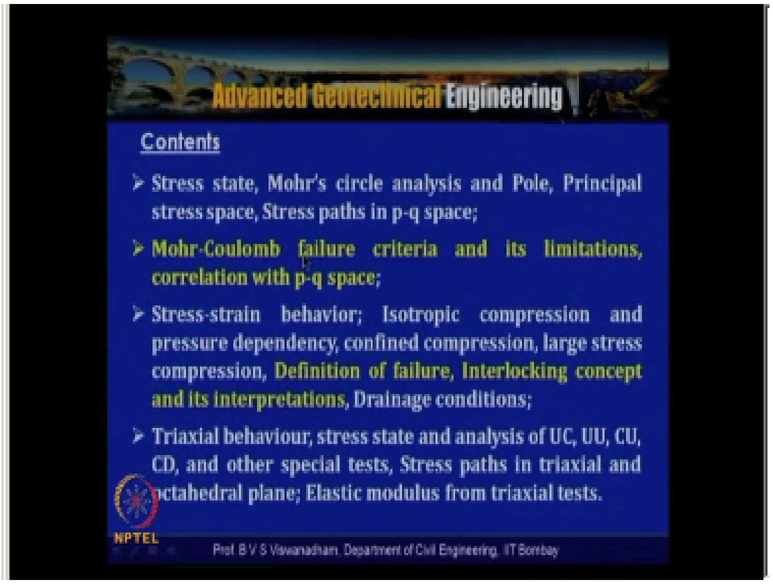

The interpretation and its correlation with the pq space and further will concentrate on definition of failure and inter locking concept in its interpretation that is definition of failure particularly as far as the fiction is consent with the interlocking concept and its interpretation.

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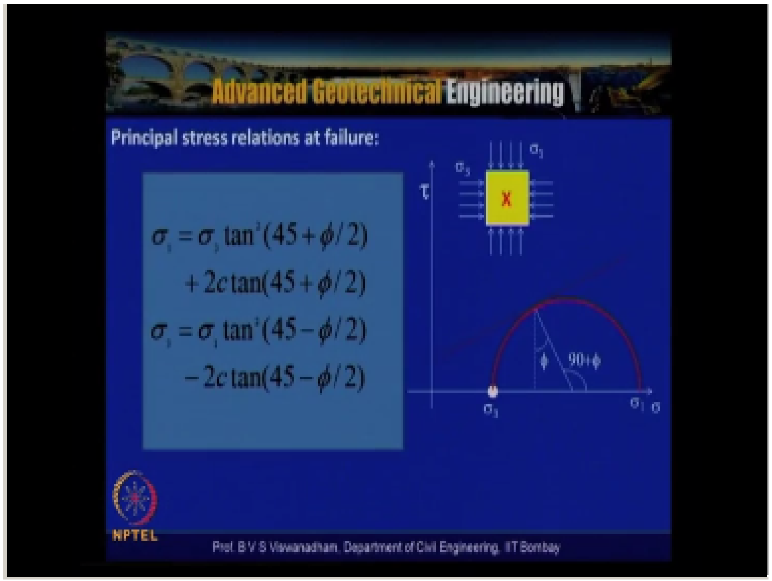

So as we discussed in the previous lecture we can actually express principle stress relationship that failure as follows $\sigma 1=\tan^2\alpha+2ct$ where α =45+5/2 and which is also called as the failure plan inclination and in case if you are having $\sigma 3$=another way has $\sigma 3$ has the major and $\sigma 1$ as the minor let $\sigma 3= \sigma 1\tan^2 45-\pi/2-2c\tan 45-\pi/2$.

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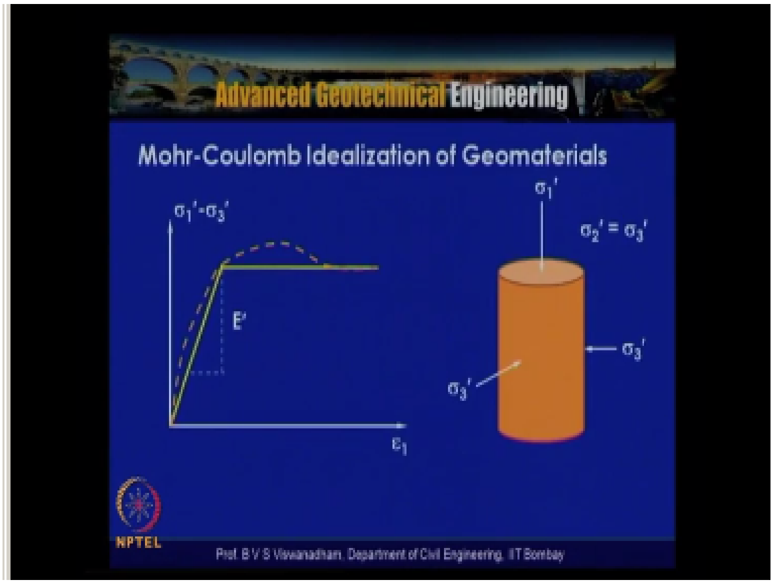

Now the Mohr coulomb idealization of geomaterials if you look into it we have you know a sample a cylindrical sample subjected to principle that stress σ1 and σ2 and σ3 so here as been σ2=σ3 in Mohr column idealization what has been assumed is that σ2=σ3 as σ2=σ3 and this is the stress stain variation stress versus actual strain where actual strain in the direction of whether principle major principle stress so this is the idealization and the slope of this is the elastic models and this is the curve which we make it and this is idealized in this passion it is shown .

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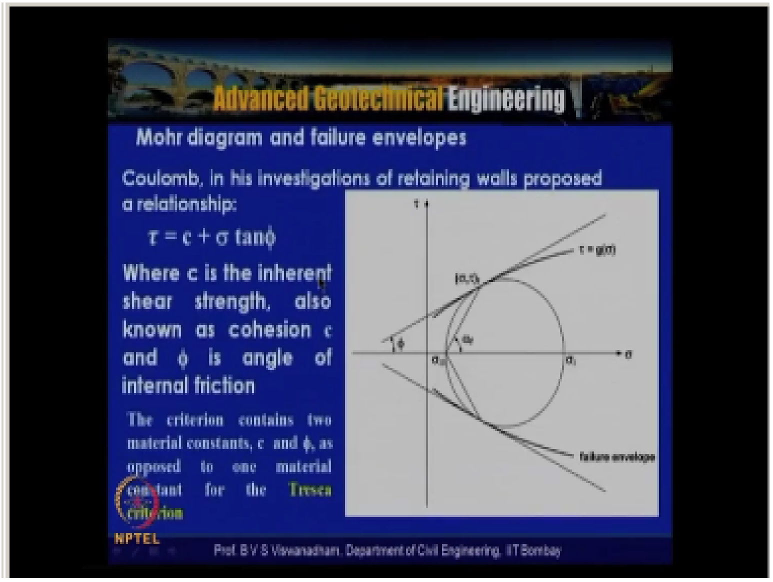

So as we have discussed and coulomb envelope if you look into this coulomb has given you know during the investigations of the returning walls and equation which is actually called as τ=c+σtan5 and Mohr envelope as actually given as τ=function of σ and this non linear envelope this non linear envelope is actually for more coulomb more envelope and this one is for the coulomb equation.

So this actually has been itemized to a straight line and coulomb in its investigation of returning walls proposed relationship τ=c+σan5 where c is the inherent shear strength also known as the cohesive c and ϕ is the angle of internal fiction so the criterion continuous two material constants here c and ϕ and which are actually called as parameters and there are different methods to determine this shear strain parameters in the laboratory.

They are primarily called you know and track status actually has got you know three different 4 different classes you can say and the first category is that where we do a test with no self pressure then you know in that case it is actually called as unconfined you know compressive strength test is called UCS test and when we do this test with you know a self pressure that is unconsolidated and untrained and when we do you know track test by allowing the consolidation during by allowing drainage during consolidation and those drainage during shear.

Then it is called consolidated untrained fraction test when we allow both you know during consolidation as well as the shear it is called consolidated drain fraction compression test so when we do this as we have discussed with that when we do at different self pressures we get the different sets of Mohr circles if you are interpreting terms of total stress will get total stress envelopes if you are actually interpreting in terms of stress effective stress parameter.

Then will get the effective stress envelopes and with that we will be able to get the c and ϕ1 so here in this particular diagram where the more you know envelope is actually shown along with the Mohr envelope and with the slope of inclination is file and αf is that failure plane so the criterion basically consists of b basically consist of two parameters that is c and ϕ as suppose to one material constant for the criteria as far the stress criteria is consist and there is only one material constant.

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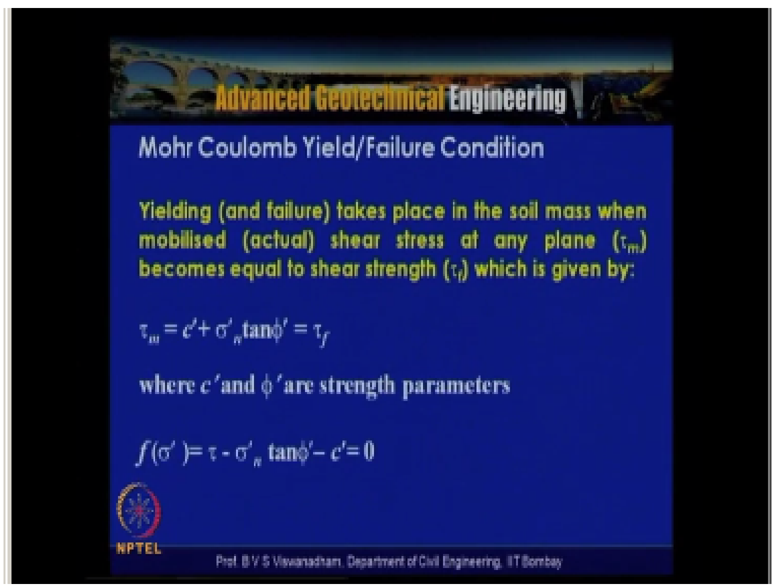

So yielding and failure takes place in the soil mass when mobilized actual shear stress at any plane τm becomes equal to the shear strength τf which is given by so yielding and failure takes place in the soil mass when mobilized actual shear stress at any plane τm becomes equal to when τm becomes equal to the you know the shear strength τf which is actually given by $\tau m=c+\sigma n tan5=\tau f$ where c and ϕ are the strength parameters then we can write this as in terms of function of σ as $\tau-\sigma tan\phi-c=0$ so this we have written in terms of function of σ we have written like $\tau-\sigma n-\sigma tan\phi-c=0$.

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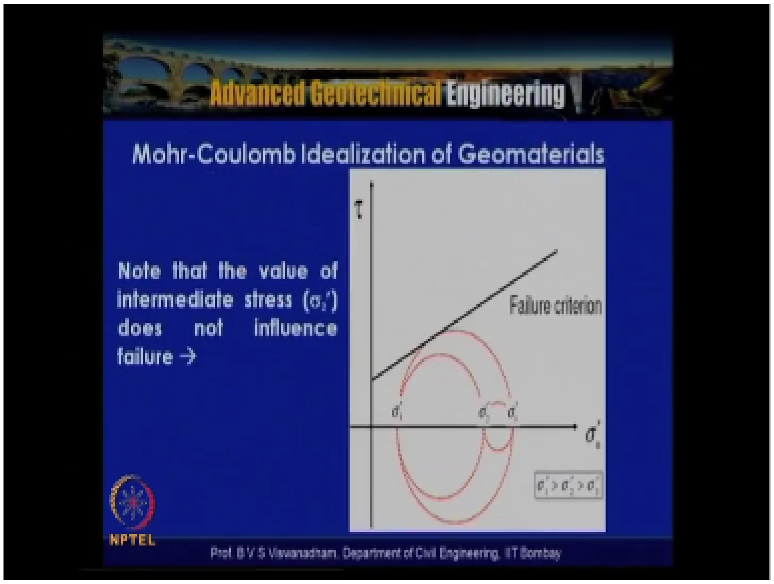

So one point we need to note here in case of the Mohr coulomb idealization we have discussed with that because of the you know non consideration of σ2 as can be seen here when you have σ1 then σ2 and with σ3 with minor principle stress for this Mohr circle is actually you know is contact with failure envelope so where σ1> σ2> σ3 and here note that the value of intermediate principle does not actually influence the failure so this particular you know the value of these σ2 actually does not actually influence the failure so in the case of Mohr coulomb idealization the intermediate you know principle stress σ2 is neglected.

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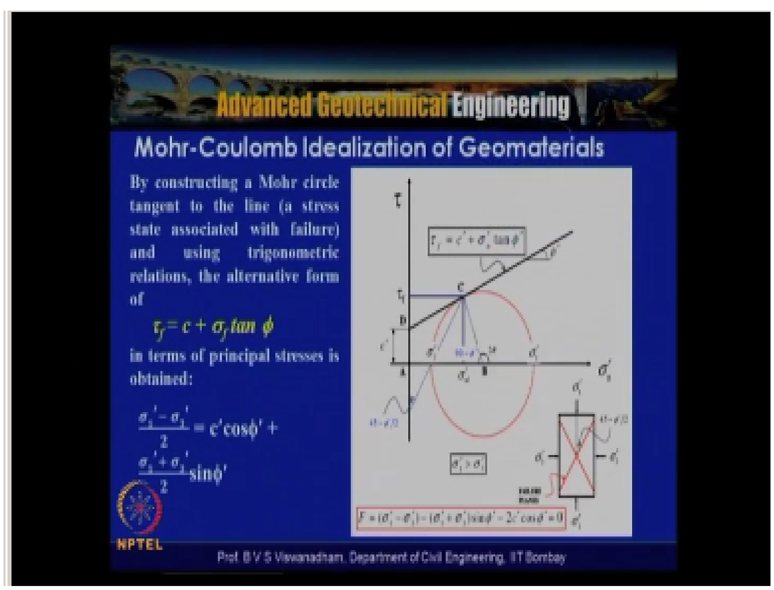

So further to the Mohr column idealization of geometric and in this consider the τ versus σ and where you have got a more circle and you have a sample which actually has got you know if the sample is homogeneous we actually have got the conjugate failure planes in the both direction and you have got failure plan in this direction you can have a failure plan in this direction and with that you know here this is the failure plane this is parallel to this is the failure inclination which is actually shown here.

And so we can write from the geometry of the Mohr circle by consisting a Mohr circle tangent to the line that is the stress state associated with failure that is at this point and using that geometric relationship relations the alternate form of τ=c+ σftan can be obtained so in terms of principle stress it can be written has τf can be seen as τf= σ1+ σ3/2 and σf=which this point is nothing but σ3+ you know σ1- σ3/2 so if you look into this, this will become σ1+ σ3/2.

So this point is σ3 0 to it measure san ordinate of σ3 and this point actually measures you know this distance so that is actually obtained as σ1+ σ2/2 so we can actually write this you know in terms of principles stress σ- σ3/2=ccosπ+ σ1+ σ3/2sinϕ so when we put this in one side and we can actually write f= σ1- σ3- σ1- σ3sinϕ-2ccosϕ=0 so that is what actually to be stated here where f= σ1- σ3- σ1sinϕ-2ccosπ=0 so this you know we actually reduced from the geometric relationship by satisfying the geometric relation and from the geometry of the Mohr.

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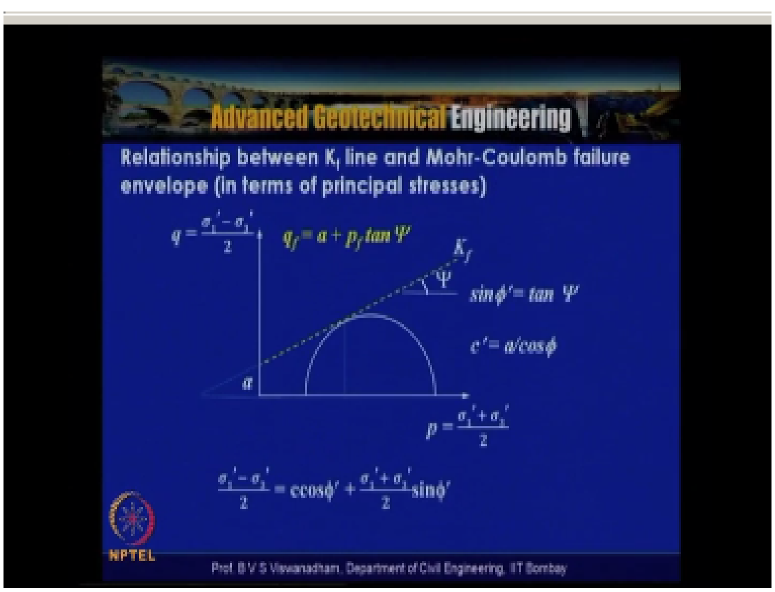

And this was actually earlier we have actually when we have done with relation between the kf line and the Mohr coulomb failure envelope and this also can be expressed in terms of you know principle stresses and when we plot pq plot with $q=\sigma 1-\sigma 3/2$ and $p=\sigma 1+\sigma 3/2$ when we plot so when $q=\sigma 1-\sigma 3/2$ and $p=\sigma 1+\sigma 3/2$ and when you plot this is the kf line and which is actually inclined at an angle ψ so when we compare you know typical Mohr circle and this thing when we said that $\psi\phi=\tan\psi$ and $c=a/\cos\pi$ so by using this also we can get the other form of $\tau=c+\sigma\tan\phi$ as $\sigma 1-\sigma 3/2=c\cos\pi$ so with these also we will able to get expression which we are talking here so $\sigma 1-\sigma 3-\sigma 1+\sigma 3\sin\phi-2c\cos\phi=0$.

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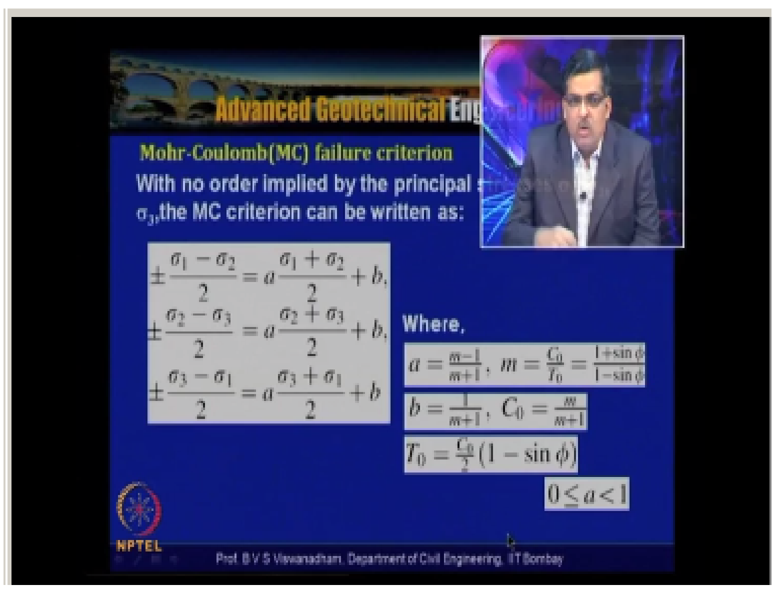

Now with no harder implied by the principle stresses $\sigma 1$, $\sigma 2$, $\sigma 3$ the more coulomb criterion can be written as in the form of this 6 equations and this represent to 2 equation this represent to 2 equations where this is nothing but plus or minus $\sigma 1-\sigma 2/2=a.\sigma 1+\sigma 2/2+b+-\sigma 2-\sigma 3/2=a.\sigma 2+\sigma 3/2+b+-\sigma 3-\sigma 1/2-=a\sigma 3+\sigma$ ½$+b$ where $a=m-1/m+1$ that is $a=m-1/m+1$ and $m=c0/t0$ which is nothing but $1+\sin\phi/1-\sin\phi$ and $b=1/m+1$ and $c0=m/n+1$ where $t0=co/2.1-\sin\phi$ where a is actually within 0 to 1 that is $0<=a$ is within $0>a>1$

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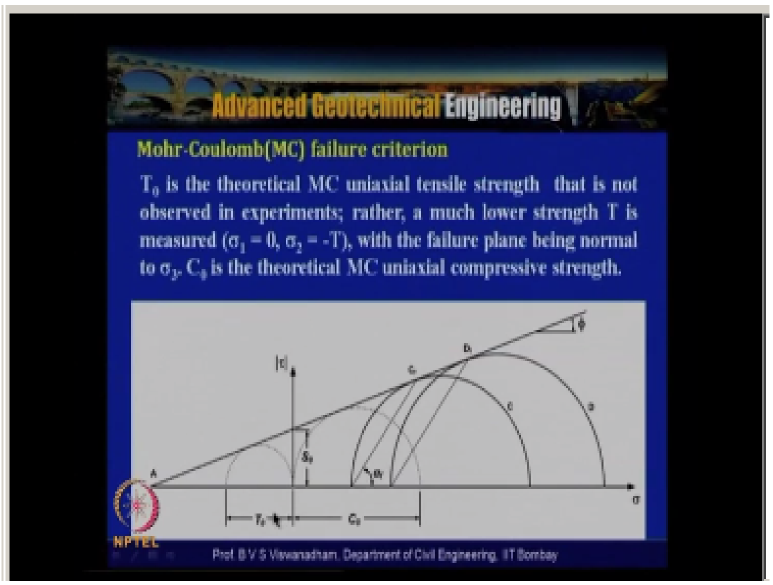

So the c0 and t0 are actually defected here and c0 and t0 are depicted here and which is shown here are the c0/t0 which is nothing but the ratio of these two c0/t0 and this is the you know typical failure envelope with you know the Mohr circle c and Mohr circle d so we have said that there is a 6 equations are there and where in we actually have got a=m-1/n+1 m=c0/t0 and b=1/1+1 where c0=m/m+1 and t0=c0/2.1.sinϕ and where a is in between o to 1.

So this t0 is theoretical Mohr coulomb in action that is on the negative side of the Mohr circle you can see that is τσ plot and that is not observed in experiment rather a much lower strength t is measured and σ1=0 and σ t σ 2=-t that is shown here so with the failure plan being normal to failure plane being normal to σ 3 plane so σ 1 plane is here σ plane being normal to the σ 3 plane so c0 is theoretical Mohr coulomb initial uniaxial tensile so c0 is the theoretical Mohr coulomb uniaxial system c0 is the theoretical Mohr coulomb uniaxial compressive strength.

Now the shape of the failure surface in principle stress say space is dependent upon the form of failure criteria so the shape of the failure surface in principle stress space is dependent upon the form of the failure criterion linear functions map as plans and non linear functions as theoretical surfaces so the shape of the failure surface in principle stress space is dependent on the failure criteria primarily it is linear functions map as planes and non linear functions as curve linear surfaces.

So the following 6 equations the equation which we have said you know just we have discussed or represented by 6 plans that intersect one another along with the 6 edges defining the hexagonal permit so the following 6 equations which are actually discussed just now or represented by the 6 planes that intersect one another along the 6 edges of the defining the hexagonal pyramid.

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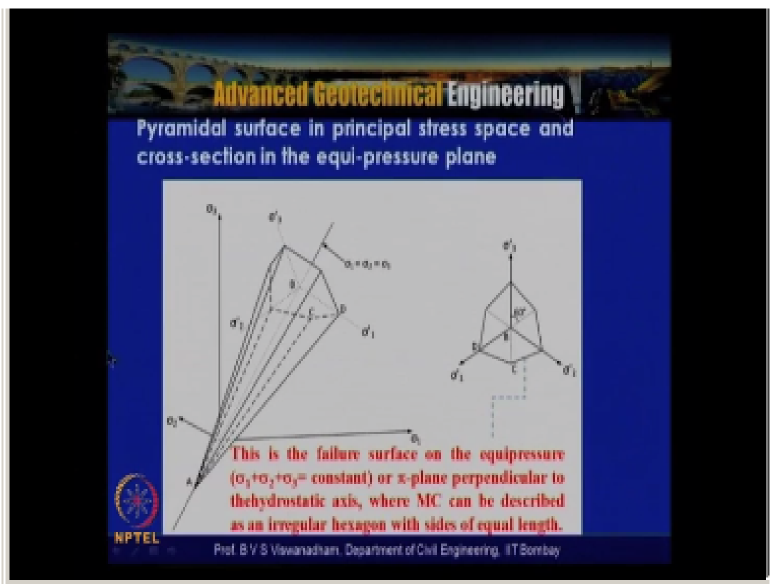

So that is you know these 6 edges which are actually defining this hexagonal pyramid that these equations actually represent this equations represent you know the 6 planes that intersect one another along 6 edges defining the hexagonal pyramid so these is the you know the failure surface that means this is the failure surface and this is the hydrated axis see where σ1- σ2= σ3 and this is the failure surface on equaling pressure on the equal pressure plane σ1+ σ2+ σ3= constant are π plane is also called as the π plane perpendicular to the hydrated axis.

So perpendicular to the hydra tic axis so you know this if you take the projection of this one you will have the this is the pyramid surface which is in a hexagonal pyramid surface and which is also called as the pipe line which is actually perpendicular to the you know perpendicular to the hydra tic axis and where Mohr coulomb criterion can be described as a irregular hexagon with sides of equal where Mohr coulomb criterion can be described as irregular hexagon with sides of equal length.

So here the pyramid surface in principle stress space and cross section equal pressure plane is actually given here and these the equation which you know which are shown here a actually represent the all the 6 edges which are forming the hexagonal pyramids of the surface and the failure surface on the equivalent pressure that is $\sigma1+ \sigma2+ \sigma3$=constant or π plane perpendicular to the hydrostatic plane axis where the Mohr coulomb criterion Mohr Colombo can be described as irregular hexagon with sides of equal length.

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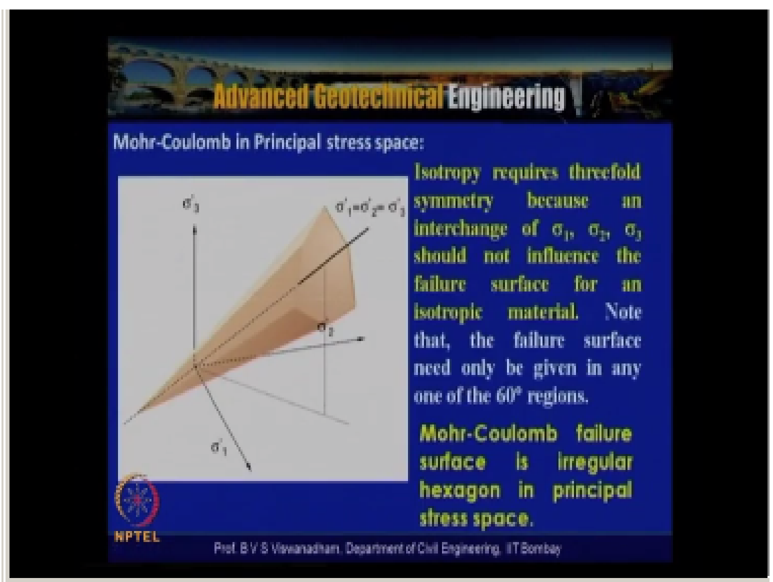

So this is the irregular hexagon with actually shown once second here where this is hydrostatic axis and here is the point the isotropy requires three fold symmetry because an interchange of $\sigma1$, $\sigma2$, $\sigma3$ should be the failure surface an isotropic if you have an isotropic material he requires 3,4 symmetry because of the interchange of $\sigma1$, $\sigma2$, $\sigma3$ failure surface for an isotropic material note that the failure surface need only be given in any one of the 60 degrees that is one of the

60degrees so note that the failures surface will need only be given in any one of the 60 degrees regions and Mohr coulomb failure surface is irregular hexagon in principle stress space.

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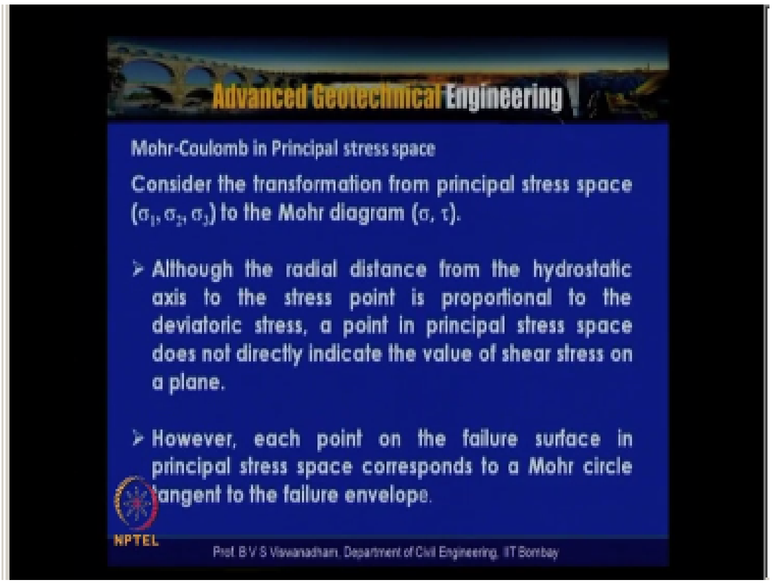

Now consider the transformation from principle stress space σ1, σ1, σ3 so although the radical distance from the hydrostatic axis to the stress point is proportional to the deviate stress space does not directly indicate the value of shear stress on a plane however each point on the failure surface in principal stress space corresponds to a Mohr circle tangent to the failure envelope.

So the radial distance from the hydrated axis to the stress point is proportional to be stress a point in the principle stress space doe not directly indicate the value of stress on the however each point on the failure surface is principal stress corresponds to a Mohr circle tangent to the failure envelope so further you know extending the discussion for the particular case where the σ2 is either intermediate.

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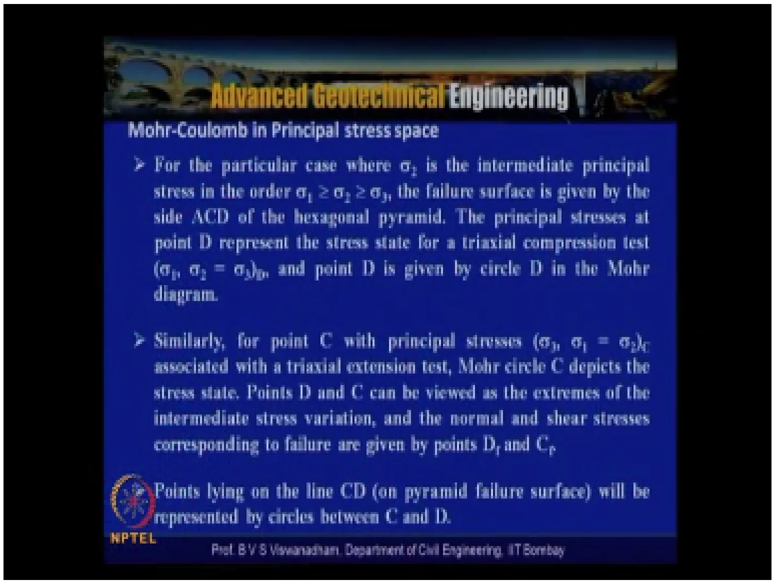

In the order σ1>σ2>σ3 the failure surface is given by the side ACD of the hexagonal pyramid the failure surface is given by the side ACD of the pyramid of that is there side ACD of the pyramid as shown the principle stresses at point D represent the stress state for a rational compression test where σ1 and σ2=σ3 at point d and d is given by circle d in the more circle diagram the point is given by the Mohr circle d which is actually shown here.

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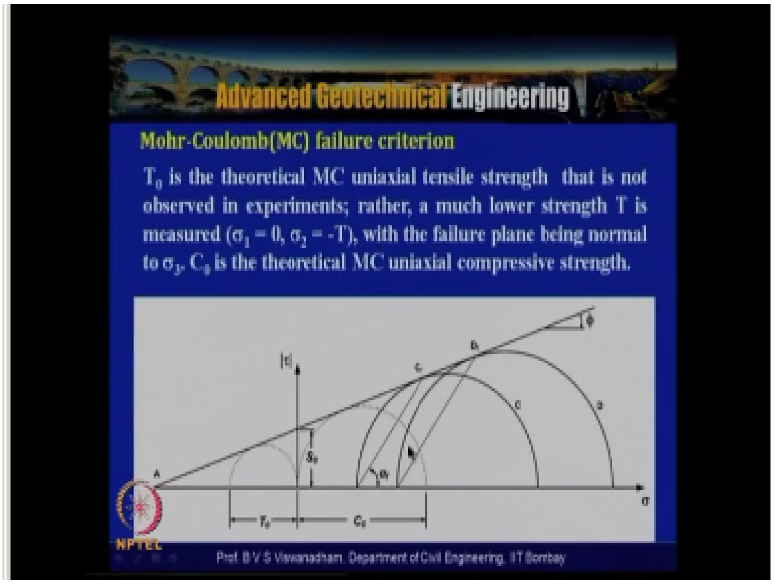

This is the Mohr circle this is actually shown.

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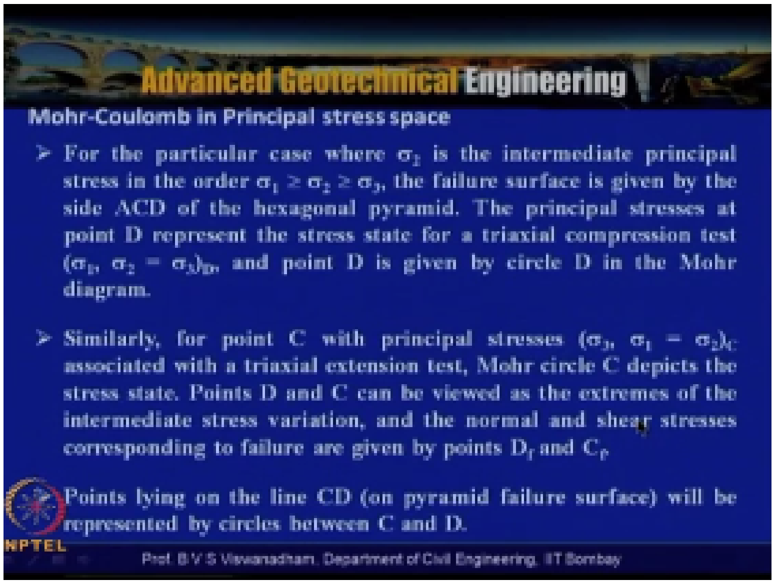

Similarly for point C with persistence σ 3 and σ 1 = σ2 associate with the drag shell extension test, more circle C depicts the stress state, where point D and C can be viewed as the extremes of the intermediate stress variation. So where points D and C can be seen as the extremes of the intermediate stress variation and the normal and shear stresses correspond to failure are given by points DF and CF.

So this indicates the CF and DF indicates the extremes of the intermediate stress variation. So it can be seen that this CF and DF will give the failure points. And so for this is for the drag shell test and where more circles D depicts the stress state and points D and C can be.

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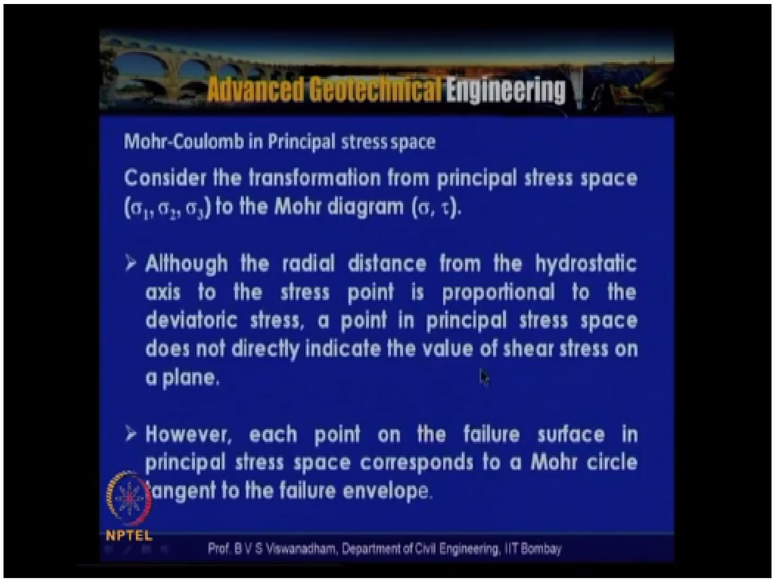

So, this is for the tracheal test and we are most circle P state points C and D can be used as extreme of the intermediate stress variation and the normal and shear stress or correspondent to failure or given by points DFN and CF and points lying on the line CD on the perimeter of the failure surface represented by circle between CND so points lying on the line CD.

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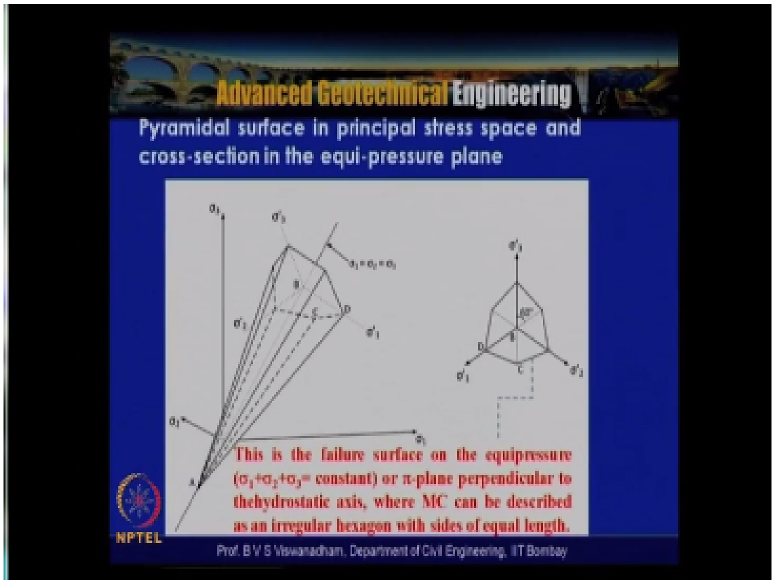

And LS lying on the CD there is this represented by the E.

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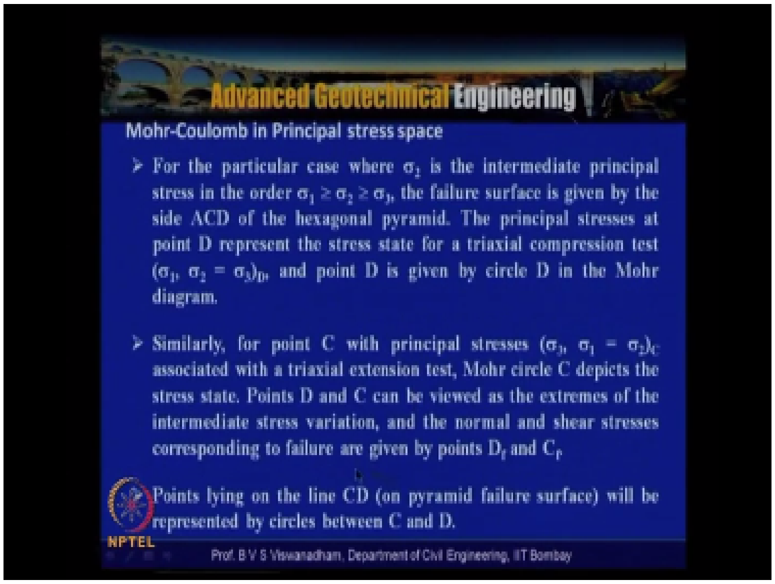

By the represented between circle CND that is.

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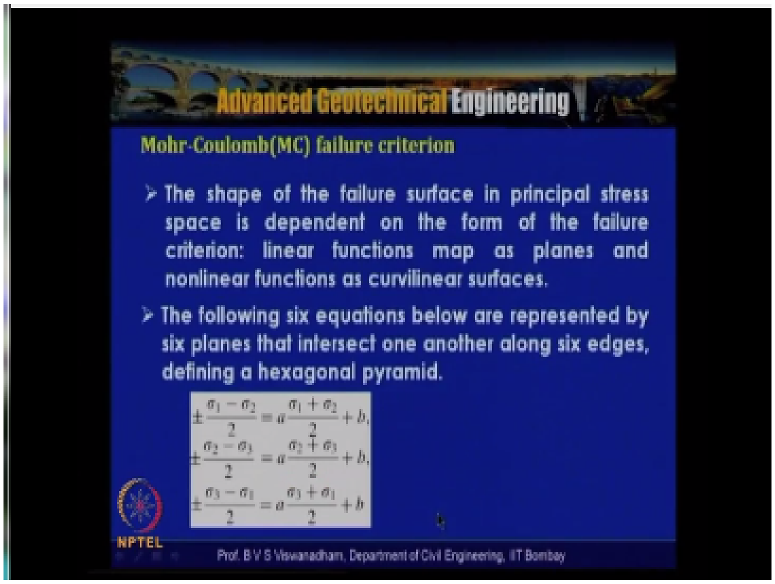

Talking about circles between C and D and has can be seen hexagonal you know per mental surface has the corners that way sometime create problems in computations however this particular difficulties quite easily overcome by introduce single local rounding of the corners according to Griffide,1990.

So, the more column in space which is hexagonal perimeter surface has corners that may be sometimes create problems in computation so, this particular difficulties is quite easily overcome by the introducing the local rounding of the corners overcome by the Griffide,1990.

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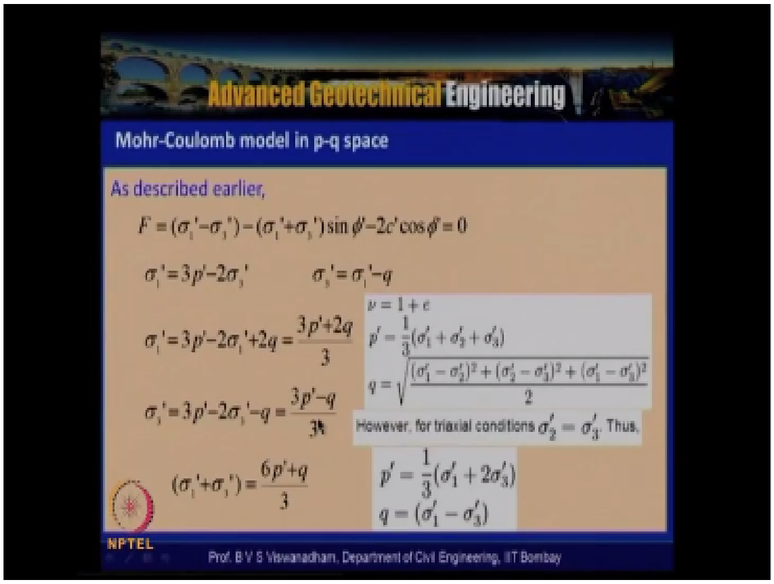

So, as we have discussed in other way of describing $F=\sigma+\tan 5$in the terms of principle stresses as $F=(\sigma_1'-\sigma_3')-(\sigma_1'+\sigma_3')\sin\phi-2c^2\cos\phi=\theta$. So this can be obtained further in order to make attempts to derive a consistently conditions of the more column in space with P'= where specific volume is equal to $_{+}^{=}$+E and P' is equal to $1/3\sigma_1',\sigma_2'+\sigma_3'$and Q=square root of$(\sigma_1'-\sigma_3')^2+(\sigma_2'-\sigma_3')^2+(\sigma 1'-\sigma_2')^2/2$so in the whole divided by 2 and for tracheal conditions as we have set the when you have got the tracheal sample at the $\sigma_2'=\sigma_3'$.When we have this equation when we have got this $P'=1/3(\sigma_1'+2\sigma_2')$and $q=(\sigma_1'-\sigma_2')$.

We have got simplify these here we can write $\sigma_1'=3p'-2\sigma'$ so σ_1'so if you put $P'=1/3(\sigma_1'+2\sigma_2')$and $q=(\sigma_1'-\sigma_2')$ we will get $\sigma 1'=3'-2\sigma'$ and $\sigma_3'=\sigma_1'-q$ is you substitute $q=(\sigma_1'-\sigma_2')$ we will get by using these values with $q=(\sigma_1'-\sigma_2')$ $\sigma_3'=\sigma_1'-q$ we will get q. This particular equation and what we get is that as the $\sigma 1'=3p'-2\sigma'$ when you substitute with $\sigma_3'=\sigma_1'-q$ equation you get $\sigma 1'=3p'_2\sigma_1'+2q=3p'+2q/3$where p' is equal to $P'=1/3(\sigma_1'+2\sigma_2')$ and $q=(\sigma 1'-\sigma 2')$.

So, when you substitute $\sigma 3'=3p'-2\sigma 3'-q$ these with $\sigma 1'=3p'-2\sigma'$ you get $=3p'-q/3$,now when we put these both equations $\sigma 1'=3p'_2\sigma_1'+2q=3p'+2q/3and\sigma 3'=3p'-2\sigma_3'-q$ we get $(\sigma_1'+\sigma_3')=6p'+q/3$and which is you know when we add to this.
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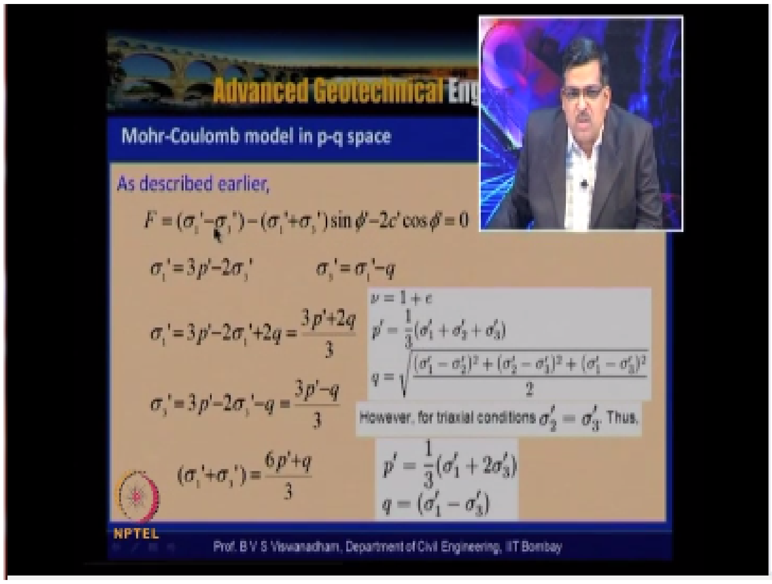

When you substitute in this equation σ3 that is nothing but q=sinn5+6p'+q/32ccos/so by simplifying this we get3q=6p'sin(6p'|+q/3)+2cosϕ so what we get is the at 3q when you do the correspondent relation=6p'sin+qsinϕ+6c cosso the equation actually has got ϕ' and here also ϕ' so q=6sinϕ/3-sin'*p'+6c cosϕ'/3-sinϕ' so this actually indicated as q=nμp'+cϗ where ŋ=6sinϕ'/3-sin and c'=6c cosϕ/3-sinϕ' where this is actually called as formulation for the Mohr-coulomb model in p-q assuming that idle plasticity condition we can write F[p',q]=q-ηp'-c'= so by taking the differentiation with respect to p' ϑF/ϑp'dp'+ϑF/ϑq*dq=0.

So this is actually condition which is called as far as the Mohr coulomb model in concern so what we have done is that from you know the alternative way of expressing F=(σ_1' -σ_3 ') – (σ_1'+ σ_3')sinϕ-2c^2 cosϕ=θ which we have taken from these considerations of by using these in variations P'=1/3(σ_1'+2σ_2') and Q=square root of(σ1'-σ3')^2+(σ_2'-σ_3')^2+(σ_1'-σ_2')^2/2and for tracheal conditions σ_2'=σ_3'we got.

P'=1/3(σ_1'+2σ_2') and q=(σ_1'-σ_2') so what we have written is that we have written (σ_1'+2σ_2') so this is actually expressed. When we have this equation when we have got this P'=1/3(σ_1'+2σ_2')and q=(σ_1'-σ_2')We have got simplify these here we can write σ1'=3p′-2σ' so σ_1'so if you put P'=1/3(σ_1'+2σ_2')and q=(σ_1'-σ_2') we will get σ1'=3′-$_2$σ' and σ_3'=σ_1'-q is you substitute q=(σ_1'-σ_2') we will get by using these values with q=(σ_1'-σ_2') σ_3'=σ_1'-qwewillgetq. This particular equation and what we get is that as the σ1'=3p′-2σ' when you substitute with σ3'=σ_1'-

q equation you get $\sigma 1' = 3p'_2\sigma_1' + 2q = 3p' + 2q/3$where p' is equal to $P' = 1/3(\sigma 1' + 2\sigma_2')$ and $q = (\sigma_1' - \sigma_2')$.

So, when you substitute $\sigma_3' = 3p' - 2\sigma_3' - q$these with $\sigma_1' = 3p' - 2\sigma'$ you get $= 3p' - q/3$,now when we put these both equations $\sigma 1' = 3'' 2\sigma_1' + 2q = 3p' + 2q/3and\sigma_3' = 3p' - 2\sigma_3' - q$ we get $(\sigma_1' + \sigma_3') = 6p' + q/3$ now this particular expression which is you know for q its normal and then the simplification yielded the Mohr coulomb modeling the which is $q = n\mu p' + c\varkappa$ where $\eta = 6\sin\phi'/3 - \sin\phi'$ and $c' = 6c \cos \phi/3 - \sin\phi'$ where particularly $q = 6\sin\phi/3 - \sin\phi' * p' + 6c \cos\phi'/3 - \sin\phi'$ so the Mohr Coulomb Model equation expressed as the result of the above equation causes $F[p', q] = q - \eta p' - c'$ that idle plasticity condition you know which causes the more geometrical in coulomb material function of p' $\vartheta F/\vartheta p' dp' + \vartheta F/\vartheta q * dq = 0$ which is actually called as the consistency condition.

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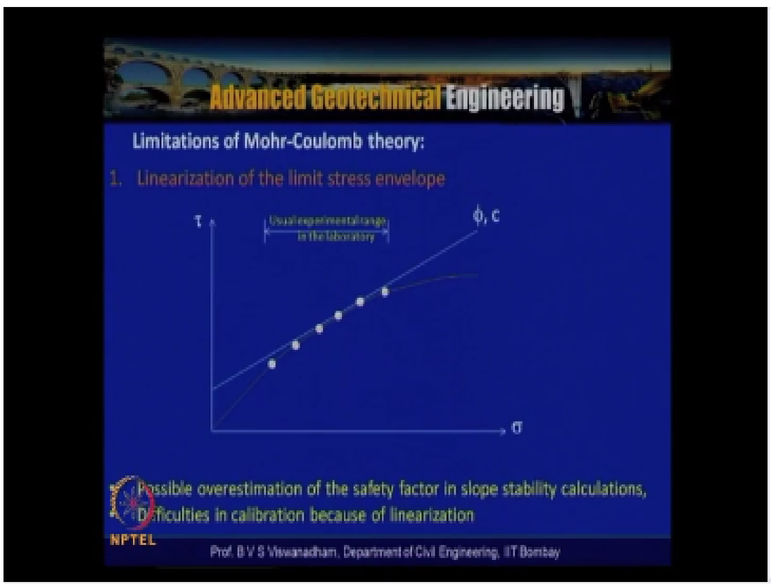

Now some limitations of Mohr coulomb theory this we have discussed but we have again elaborating so one of the prime limitations we actually said is that more envelope you know is a curve the coulomb equation is a straight line so within the usual range of experimental range in the laboratory what has been done is that the it is actually zoomed as circular that is for the within the usual experimental range in the laboratory so possible the geometric calculations can be interpretation calibration because of the linearization.

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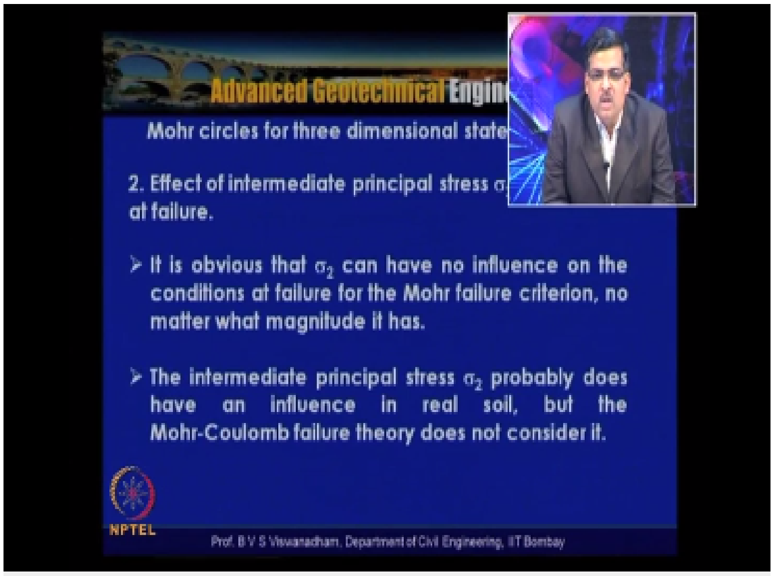

You know calibration and then second is that the effect is that intermediate stressσ_2' in the condition of failure though we actually discussed that it is you know influence in the failure but it is obvious that $\sigma_2$haveno conditions at the failure for more failure and no matter what mature it has so though in the Mohr coulomb criterion which has no limitations but these obvious σ_2 can have no influence on the conditions at the failure and no matter.

What is the magnitude of the σ_2 and the intermediate press σ_2 probably it has having influence in real soil but the Mohr coulomb failure theory does not consideration it. And Mohr coulomb failure material is well approval for most of the geo materials but data for clays is still.

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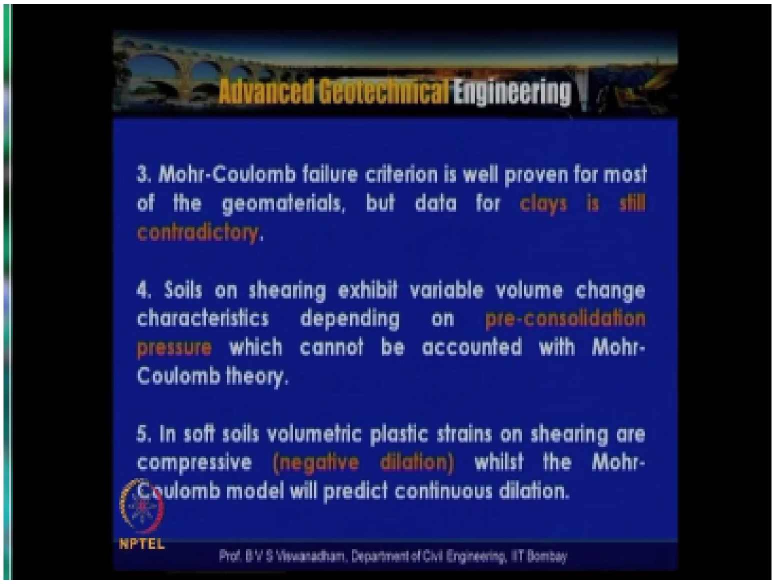

Contradictory that is one of the limitations and the soils on shearing exhibit variable volume change characteristics in difficult upon the pre-constellation pressure and which cannot be accounted with more coulomb theory and soft soils volumetric plastic plains on shearing are compressive native shearing take place while is the Mohr coulomb model predict continues dilation so the in soft soils are lose sands the volumetric plastic strains on shearing compressive in nature that is the unheard of native dilation and while is the Mohr coulomb model will predict the continues dilation. So this is also stated one of the limitations of the Mohr coulomb theory.

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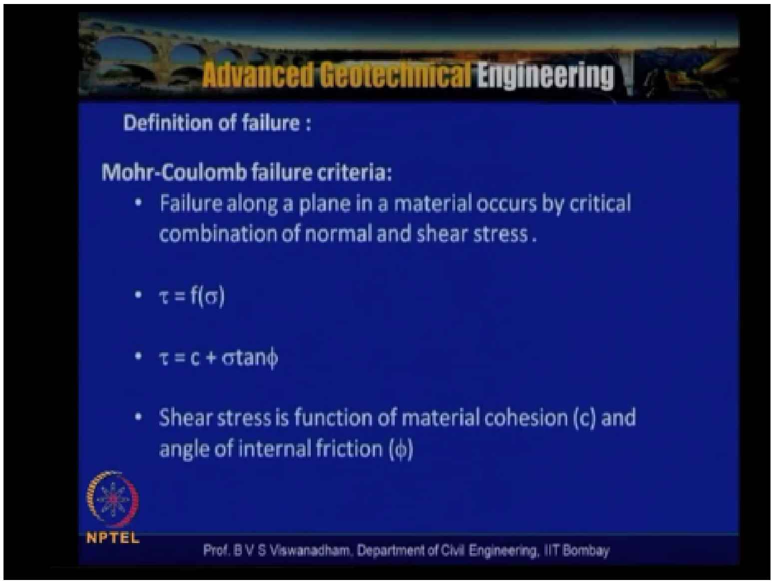

Now the definition of failure when you further you know connect ourselves to friction and interlocking conception order to connect the let us looking to what is the definition of the failure and failure along the plane in a material occurs by critical combination of normal inertia stress that is when we have $=C+\sigma\tan\theta$ so the shear stress is the function of material cognition or soil inherence strength and angle of internal friction.

So this internal friction can be due to you know the sliding friction the sliding which is actually can happens between two particles on also due to interlocking that is you know one particle logged into other particle and then there is depends upon the shape of the particle like an angularity and size of the particles. So the failure along the plain n a geo metrical occurs by critical combination of normal and shear stress $\phi=C+\sigma$ tanЛ so the shear stress is the friction of cogniciency and angle of internal friction.

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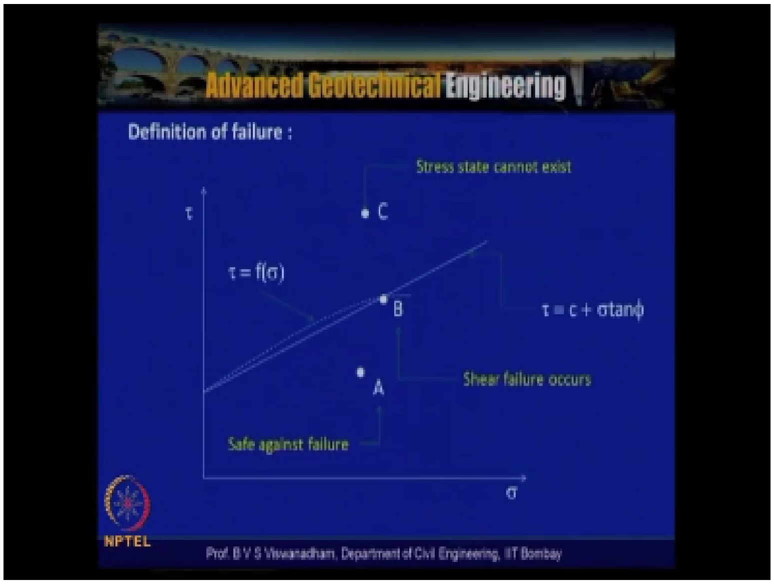

So, if you look into the in the definition of failure when we have an ϕ σ envelope and when we have a point A stress point A and this is actually said that is stable low failure occurs and but when actually the no she failure occurs for A when it is actually I on the failure envelope and when it actually on the failure envelope then it is you know the shear failure occurs and this is the ϕ=[σ] represented here and when it is here that means said you know the stress rate cannot exist above the envelope that is the failure would have already taken place.

Similarly very good draw more circle above the envelope that the implies that failure already taken place so the point C is cannot exist and point B which is act failure and point A is actually stable the safe against the failure.

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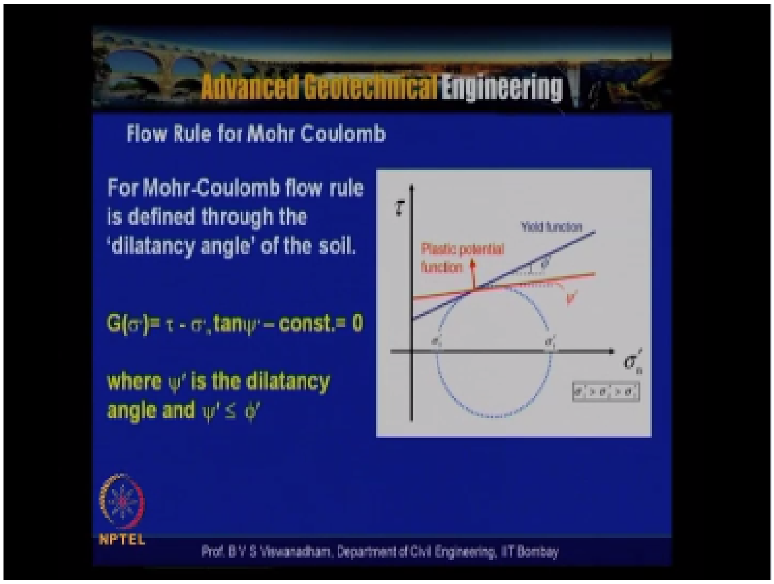

We can also look into the flow rule for Mohr coulomb dilatancy angle and for Mohr coulomb flow rule is define through the dilatancy angle of the soil where G of σ'=ϕ-σ'N tan η' more constant is =0. So this is the plastic potential function so this is the you know for the directness angle so V=σ'=ϕ-σ' N tan η'-constant=0 where η' is the heritance angle and which is actually less than the angle of internal friction and which is the angle of internal friction.

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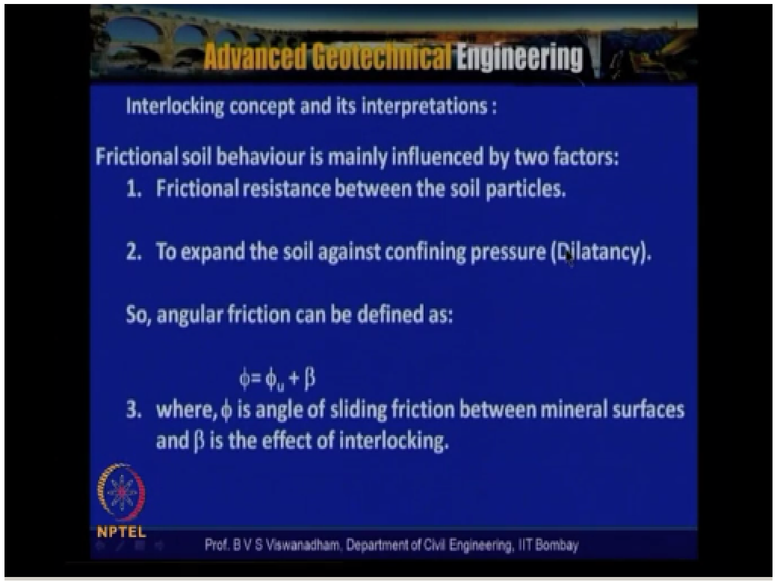

Now the interlocking concept of influence look into it the frictional soil behaviour mai9nly influenced by the two factors one is the you know frictional resistance sliding distance between the you know shear particles upon shearing into expand the soil against the comparing pressure so then the soil which is actually get undergo increase in volume upon the shear under confining pressure so and angular friction can be defined as Л=μ_U+β .where angle of sliding friction between the surface and β is the effect f interlocking.

Where that is also combination which is can be set as because of the angularity of the particles and all so where Лu=Л+βB is the angle of sliding friction between the surfaces and β is the effect of internal locking.

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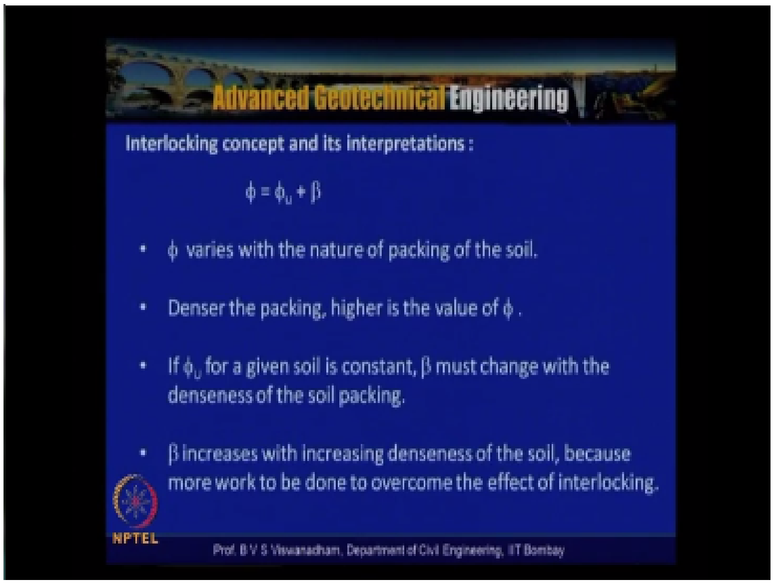

So, the five varies with the nature of the packing of the soil so dense of the packing is the higher of the value is five. Thus density packing that is a tie in given volume if there are more number of particles are there then it is called as denser packing the higher is value of Л. If ϕ is the value of the strength and B must be change in the dense of the particle so if ϕ given of the constant let us say the particular angularity and particular shape and if it is constant B is must change with the dense of the solid particle so,

B increase the density of the soil because of the more work top be done work come the interlocking. so because of the particles are get locked dense of conservation the soil is actually as to work a lot in order to undergo this movement and so β increase the dense thickness of the soil due to shear and because more work to be some overcome the effect of interlocking which is actually arrives due to shear.

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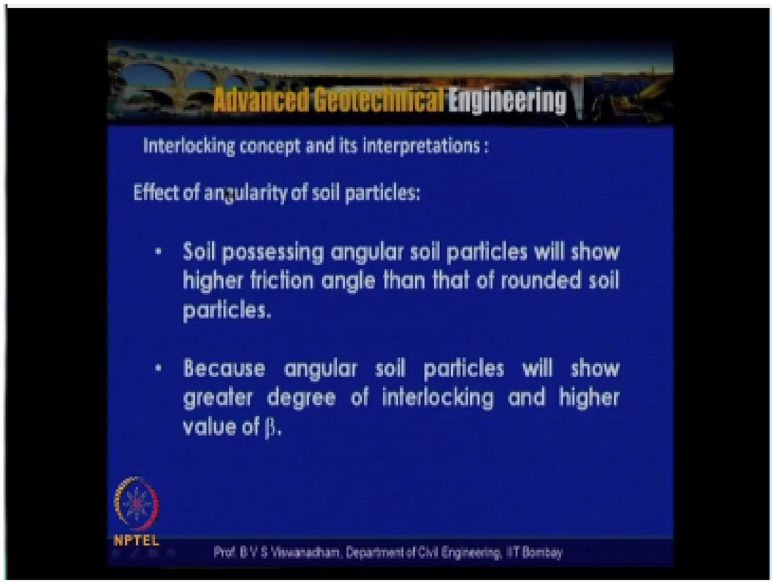

So the effect of the angularity of the soil particles if you looking to it the soil posses angular soil particles will show high friction angle. Effect of angularity of soil particle if you look into it soil possessing angular soil particles will show high friction angles than that of rounded soil particles because angular soil particles will show a greater degree of interlocking and higher value of β the so called this β will be high for you know angular soil particles because of the greater degree of the interlocking the higher value of β.

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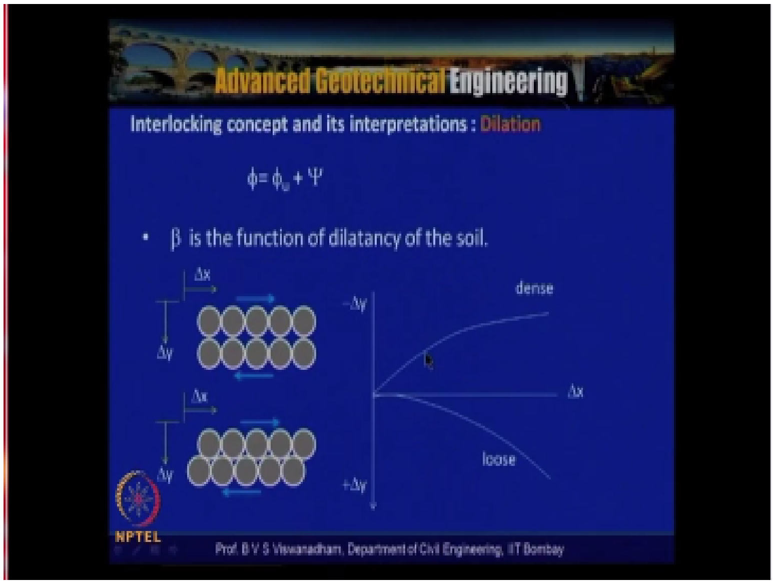

So, further the interlocking concept within the interpretations with dilation so if you look into that here β is the function of the you know the dilation of the soil so if you take loose arrangement of the grains of you take a spherical grains these are the void spaces so when they are subjected to vertical you know vertical stress and they will shear in the horizontal direction and if this is the case the soil actually under goes you know negative dilation in the sense that the soil under goes compression and which actually takes place like this.

So this is the you know called as negative dilation so the volume deceases here. But here when you have soil particles which are actually you know dense then you can see that there is you know the increase in the water volume takes place so, in this interlocking concept interpretations can be interpretive by taking see saw concept analysis when you were in if you take into consideration then we can see that so called direct agency angle in other concept can be success.

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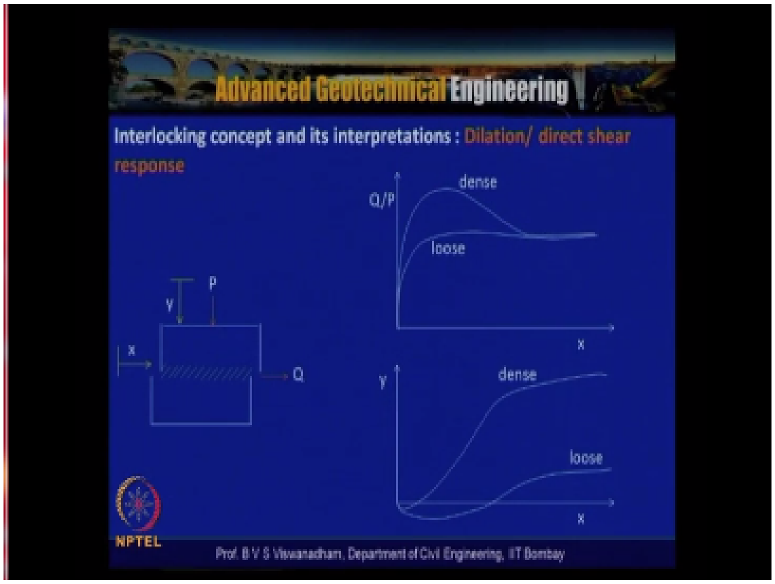

So the interlocking concept and the interpretation with dilation for the loose sand the volume decreases with shearing that is called negative dilation. And for dense sand the volume initially you know very marginally decreases and then there are after it shows actually increase in the, you know the dilation so this is increase in the volume upon shearing so and this is show that in this actually the tendency of this decreases with increase in confining pressure.

So let us consider the interlocking concept and interpretations and the dilation shear response as we said that the one of the if you do by using for determine in the shear time the soil is the direct shear that is that tubes placing A soil mass in the box and then the two boxes and we envelope the box to undergo the movement then you can see that you know the shear is a applied along in the predetermined failure plane which is horizontal.

So here this is for the dense sign where Q/P verses X deflection so the Q is the shear force, and P is the normal force and so this is for dense sand and this is for them loose sand. So loose sand actually has under gone you know there is a compression and then dense sand here where it can be seen that the shear which is actually under goes in the movement with this.

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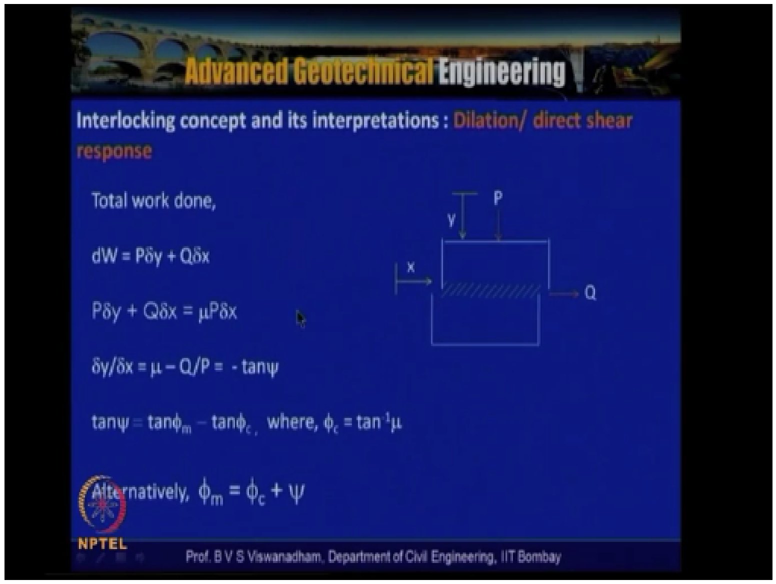

We can actually calculate what is the you know the friction angle with the reference to application of the so called the dilation so here the total work done=DWA which is nothing but P*ΔY that is in the vertical direction and QΔX that is in the horizontal direction so worked done into P*ΔY and Q*ΔX so we can write PΔY+QΔX=counted by μPΔX that is the friction which actually mobilize the along one.

So by dividing ΔX=μ-Q/P simplify this what we get is that Δ/Y=μQ/P and which is nothing but tan Ψ and where tan Ψ=tan ϕn+tan ϕc where ϕm=ϕc+Ψ so this alternatively we can say that ϕm=ϕc+Ψ so what we have done is that in the inherence into interlocking concept of interpretation that the total work done is = PΔY+QΔX and the we divided by the right through by ΔX and that we have Δ/Y=μQ.

And then we simplified further what we have got is that ΔY/ΔX=μ that is the sliding friction by –Q/P=tan ϕ/Ψ is the nothing but the so called inclination of one that is called ΔY/ΔX and which is nothing but you know tan Ψ =tan ϕm that is the due to friction –tan ϕC that is because of the interlocking and so with that ϕC=tan in verse μ ϕC=tan in verse μ and which we have written here. And alternatively we can write ϕm=ϕC+Ψ so that is what actually we have said the deliberation discussed just now.

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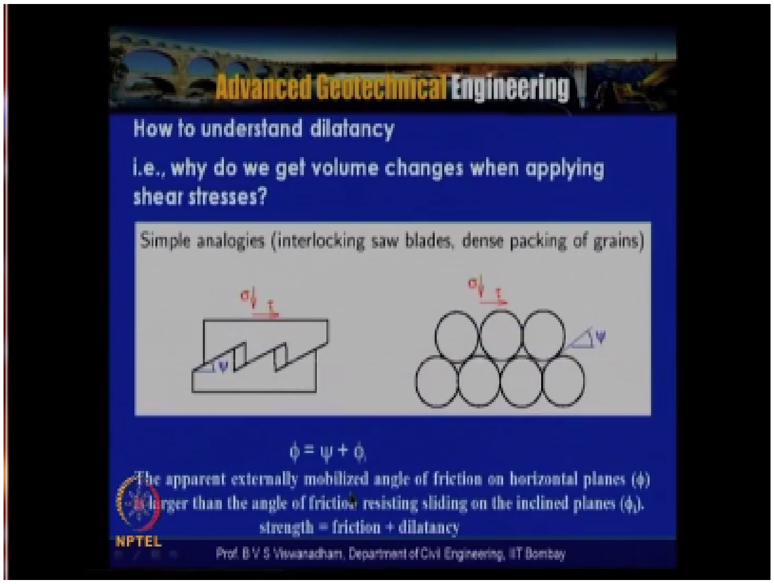

How we understand so called dilatancy so why do we get volume changes when apply the shear stresses and this is can be a explain with a simple analogy which is saw blade you can see that the orientation of these plains they are upward this is the shear directions and this is the normal stress and the similarly what will happen is that when the particles are under dense configuration when it subjected to shear the particles will raid an another particle and we subjected to similar analogical movement.

So the analogy is actually brought between the inter locking blade and dense packing of the grains so the simple analogy which we can actually relate is that interlocking saw blades is that with the dense packing of the grains when its actually acted to shear you know the inclination of the interlocking blades is that the dilation angle and this angle and that angle is actually represented here the .

So which is $\phi=\Psi+\phi m$ that is the due to the friction the angle of friction of horizontal plane ϕ is larger than the angle of friction resisting the sliding on the inclined planes so the strength is= friction +dilations. So it is actually nothing but actual strength of the soil is friction +dilatancy so the when the angle of internal friction is not only that it has actually got only friction and also got component of the dilatancy. Now this further you know can be deceiving two initially dense.

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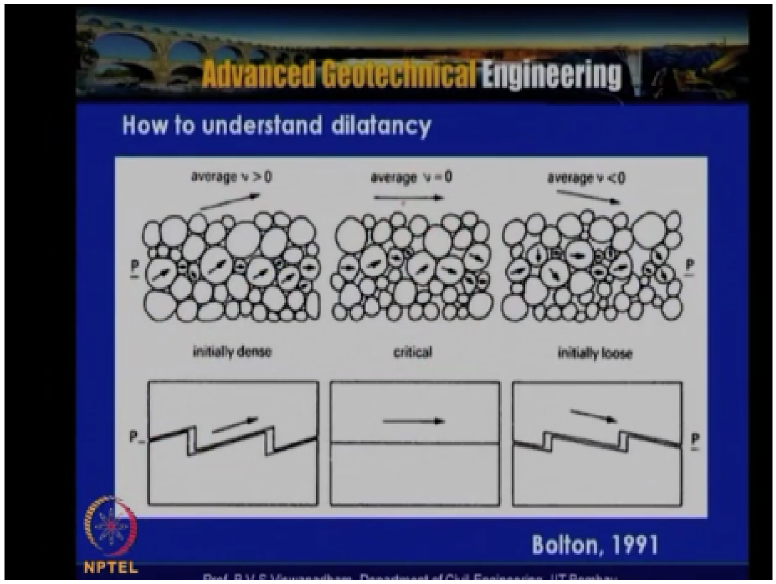

And critical and initial loose conditions so in case of initially dense the particles actually have no way to move except they have to raid on one another. So the raiding of the particles takes place on the one particle raid on other particle so the orientation of the see saw blade can be seen on the upward directions. in case of critical condition where you know can see that the horizontal in case of initially loose soil you can see that inclined down that means its actually go down under pressure.

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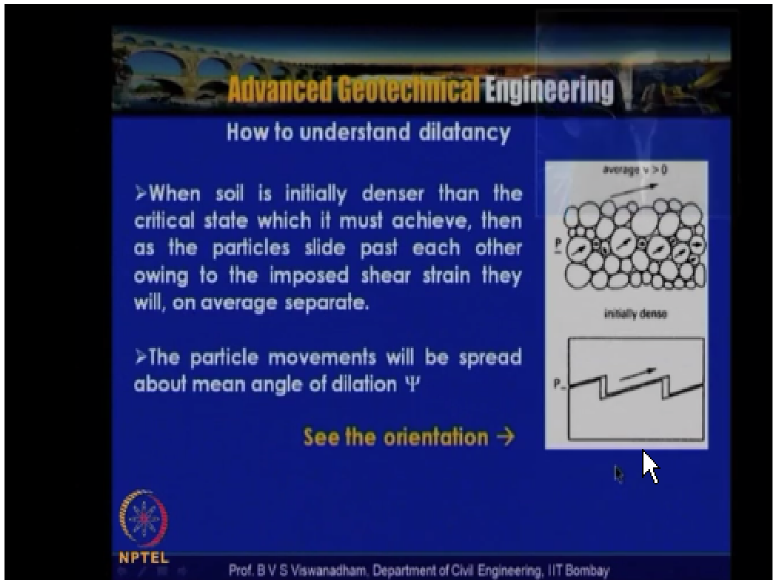

When the soil is initially denser than the critical state it was acute particle slightly dense to the move into the they will have average separate so, the soil is initially denser than the critical state in achieve you know the denser configuration the particles slide each other going into the imposed then they actually got to separate.

The particle movement will spread about an angle and that is actually called as dilation see the orientation sub lead here so this is analogy and this is actually what happen in the real soil. The orientation which is occur in the initially soil, when the soil is initially loose soil then there in the final critical state then it will tend to get looser together as the soil is disturbed, and the average angle dilation will be negative indicating a contraction. So that is why the saw blade you know the inclination or plane of inclination is actually shown below. So this is initially loose soil tend to become you know denser here and.

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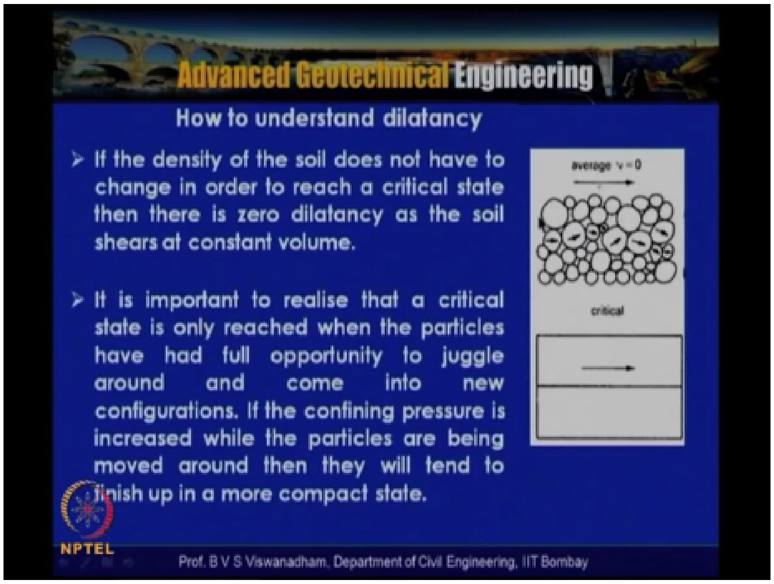

When we have you know have a place where it is constant in sense that critical tense in if the density of soil does not , in critical change there is no volume occurs so the density of soil does not have t change in order to reach a critical state then there is 0 heritance soil shear at constant volume so that the soil shear takes place at a constant volume so it is important to realize that the critical state is only reached when the particles they have full of opportunity to juggle around and then come into new volume formation.

So the confining stress is increase where the particles are being moved around then they will tend to finish up in the more compact state. So we have seen for any initially dense state and initially loose state and also in a critical state and also in a critical state the density of soil does not have to changed in order to reach critical state then there is zero dilatancy on the soil at here in constant volume and it is important to realize that critical state is only when reached the particles had full opportunity to juggle around and coming to new consolations so if the confining stress increased when the particles are moved around then they will tend to finish around more compact state.

So, in this particular lecture we try to understand about Mohr coulomb and the hexagonal surface and also we discussed the consistency conditions as far as the Mohr coulomb condition is concerned, and there after we actually introduce ourselves to interlocking concept and then we also said that introduce to that when the soil is particularly in the dense soil or more dense sand soil when it under goes shearing we said that it is going to experience the phenomenon.

Which is called dilation and the angle is called dilation angle and that is actually is phenomenon is called the angle which is called the Ψ dilatancy angle, and the dilatancy angle you know decreases suppress of the dilatancy or dilation phenomenon can be observed once there is the increase in the normal stress. So we will further discuss in the fourth coming lecture after having introduced about the you know the different methods for the determining shear strength in further will connected with once.

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