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ADVANCED GEOTECHNICAL ENGINEERING

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Lecture No. 26

Module-3
Lecture – 8 on Compressibility and Consolidation

We welcome to lecture series on advanced geotechnical engineering and we are in module 3 lecture 8 on compressibility and consolidation of soils.

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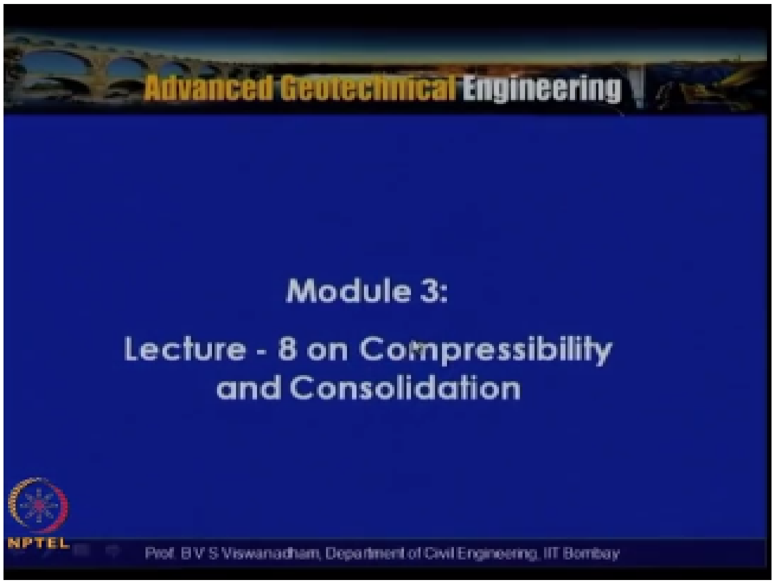

Module 3 lecture 8 on compressibility and consolidation, so in this lecture we are going to discuss about you know the compression curves particularly under different conditions like when it is subject sample is subjected to compression and unloading.

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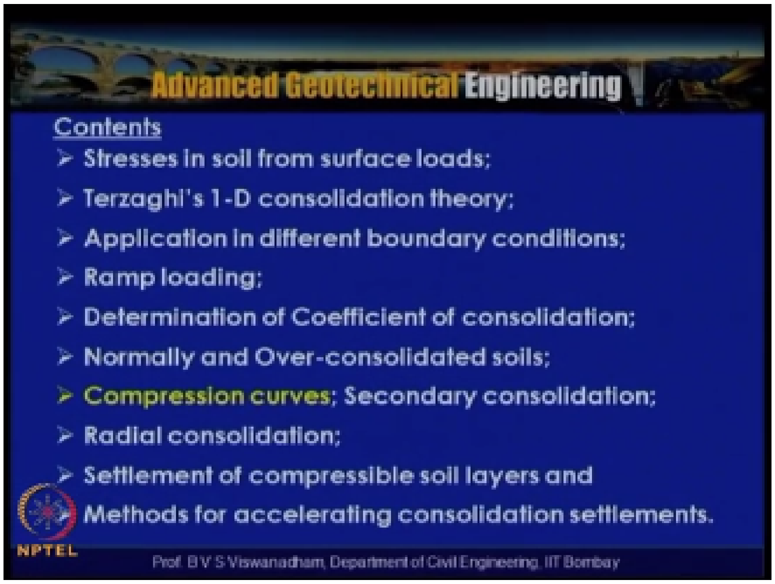

That is recompression and we also discuss about what will happen when the load increment ratios are kept longer or when you have low, low load increment ratios and what will happen if your particular load is kept for long duration that is the effect of the secondary consolidation. And there after we will introduce ourselves to you know the need for the radial consolidation and then in the next lecture we will be discussing about the methods for accelerating consolidation settlements.

So let us before going into the details of whatever we are just discuss, now let us see, now let us look into the effect of sample disturbance on elogσ' curves especially for normally consolidated and war consolidated clays. So first consider normally consolidated clay and in this particular figure.

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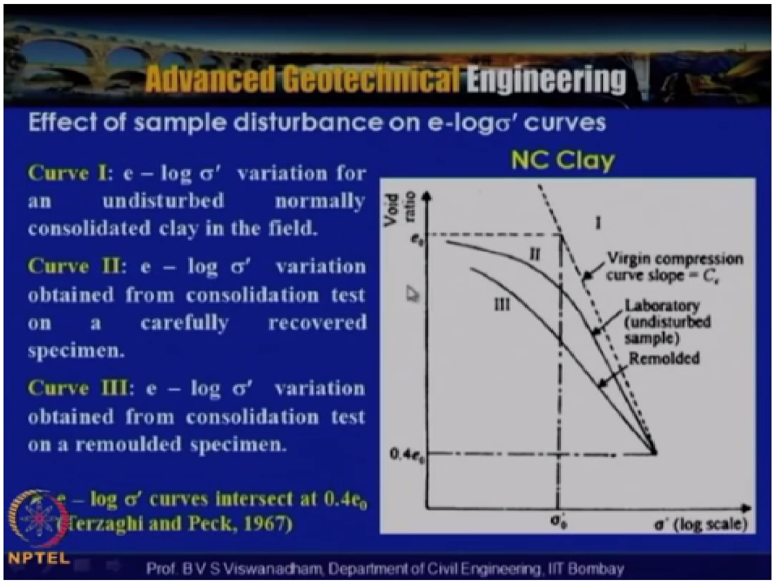

Where void ratio verses σ' on the logarithm scale is shown here and if a normally consolidated soil that is the soil which is actually having higher water content and you know where the you know this pre-consolidation pressure present effect to pressure is only $\sigma 0'$ and that is the maximum pressure whatever the soil has seen then in that case in the field what we actually see is the straight line is the virgin compression curve.

So this is also called as field normally consolidated line or field compression curve, but when we take a sample and if it is subjected to you know generally the sampling is done by is an appropriating by using an appropriate sampler and which actually gives the least disturbance. But if you have a laboratory specimen which is tested which is actually obtained with careful recovery that what we get this elogσ' curve is like this, this is indicated as a curve to in the figure.

But if the same specimen is actually remoulded and reconsolidated then actually what will have is the remoulded specimen will have you know this type of elogσ' curve, so if you look into this all 1,2,3 the field compression line and laboratory undisturbed sample which is you know which is indicated as curve 2 that is the for the consolidate obtained from the consolidation test on a carefully recovered specimen and curve 3 which is obtained from again from consolidation test on a remoulded specimen.

So of you look into this at a certain stress when it actually been subjected then all they will actually meet at a point which is the point 4 e0 where e0 is the initial void ratio at $\sigma 0'$ that is the current war by done pressure. So if you look into this, this the difference the distinguish difference between field compression curve and these laboratory undistributed sample is because of the you know the degree of disturbance what actually enters into the testing.

And the curve 3 which is you know if the same soil which is actually tested in 2 is say remoulded and reconsolidated then what we get is this so called elogσ′ curve which is you know in this form and where actually it appears and one more thing is that if you look into this for remoulded specimen very difficult to distinguish your you know where is the you know the pre-consolidation pressure, so if you look into the as you go away from you know with degree of disturbance it very difficult to distinguish it is correct the tertiary what the sample actually has been subjected.

So in case of a normally consolidated clay what we have is that the field compression curve and you know the elogσ′ curve for the laboratory test specimen can tested with carefully on a carefully recovered specimen and you know the curve 3 which is obtained from the remoulded specimen they actually meet at point which is actually approximated as 0.4 e0 or 0.4 to e0 according to Terzaghi impact 1967.

Now let us see what will happen for a organ consolidated clay, so as you all know that you know the soil actually has seen a pressure which is actually much more than the current present overburden pressure, so you can see that so because of this the initial portion of this curve is actually flatter.

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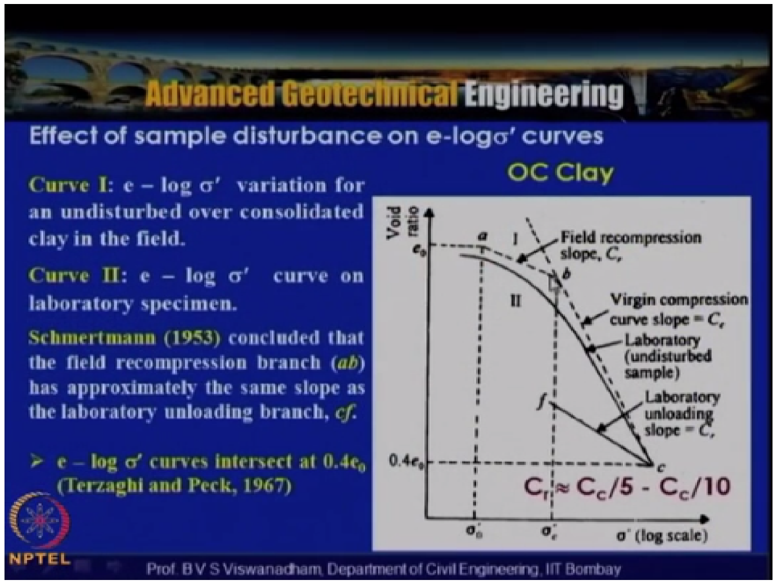

And then once this stress which is actually transferred to the soil is actually more than what it has actually seen then it will change into the you know so called normally consolidated mould again. So you can see that you know the two limbs which are actually there this is actually the portion A, B and portion B,C so this dotted line is the field compression this dotted line BC is the virgin compression curve for the so called you know of the, in the can be obtained for the OC clay in the field.

And AB portion and BC portion these two are the you know two segments which will be there and the slope of this line AB is recompression index and slope of this line BC is the you know the compression index CC. Now if you are actually testing an undistributed sample you can see that the degree of in the initial portion is flatter and then you know again it changes into the normally consolidated mole and again it meets at a point C.

And when the rebound actually happens for that means there once the unloading actually happens here in the laboratory cf segment is actually is the laboratory you know unloading portion. So you can see here that the according to Schnertmann 1953 he concluded that the slope of this line and slope of this line ab are almost identical.
So Schmertmann 1953 he concluded that the field compression branch ab as approximately has the same slope as the laboratory unloading branch cf. So in the, in case of the over consolidated clay and what we have is that you know the two segments ab and bc, so that is the reason why while discussing you know the settlements and you know we have to see the get the pre-consolidation pressure.

After getting the pre-consolidation pressure then you have to, if you are actually having a you know if this is the field compression curve which you are adopting for the design. Suppose this is the stress which is actually has been subjected then you have to calculate for the settlement for this portion and you have to calculate the settlement for this portion, so that is what actually we have discussed in the previous lecture.

So in this the curve 1 is the elogσ' variation for undisturbed over consolidated clay in the field, so this is actually versatile for the field conditions, but we are actually having the sample recovered from the same side, same portion where they actually the with little degree of disturbance then you can see that this how what we get is that laboratory undistributed sample will yield elogσ curve like this, and then you know cf is the unloading branch and the slope of this ab and cf are found to be identical.

And one more thing is that Cr is approximately 1/5th to the 1/10th of Cc, so in the case of absence of data and it can be assumed that the Cr the recompression index is 1/5th to 1/10th of Cc, the Cc is nothing but the compression index the slope of the normally consolidated portion.

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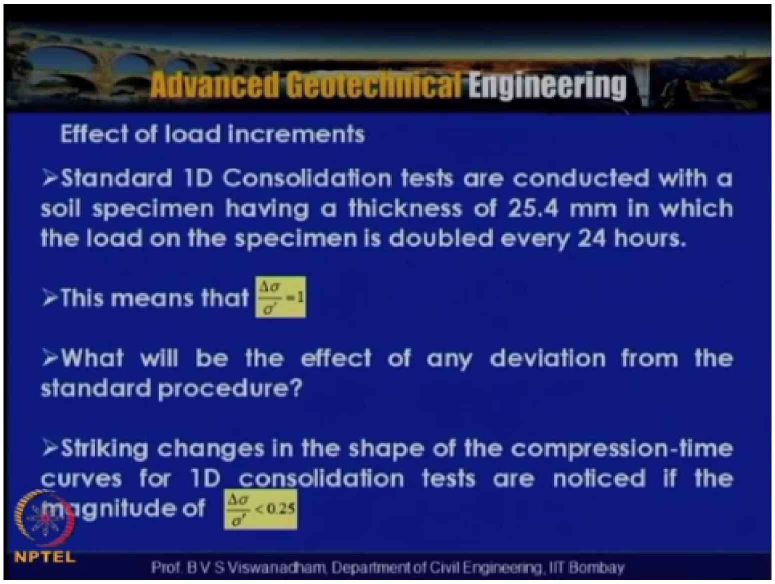

Now let us see what will happen you know if we are actually having deviations from the consolidation test and if the standard consolidation tests are conducted with a soil specimen having a thickness of say 25mm or 25.4mm in which the load on the specimen is doubled every 24 hours this is the standard, the standard consolidation test or aerometer test are conducted with a soils specimen having a thickness of 25.4mm in which the load on the specimen is doubled every 24 hours in the laboratory.

So this means that the $\Delta\sigma/\sigma'=1$, the $\Delta\sigma/\sigma$, $\Delta\sigma$ is nothing but the change in load towards the initial load so $\Delta\sigma/\sigma'=1$ load increment ratio is always maintained as 1, so the coefficient is that what will happen if load increment ratio is greater than 1 what will happen if load increment ratio is less than 1. So what will be the effect of ant deviations from the standard procedure like if you do not keep for 24 hours if you keep for long hours what will happen, if you keep for less than 24 hours what will happen?

So the striking changes in the shape of the compression time curves for one dimension consolidation test are noticed if the magnitude of $\Delta\sigma/\sigma'$ is less than 0.25. So it has been noticed that the several investigates actually have carried out and the striking changes in the shape of the compression time curves for obtain you for the one dimensional consolidation test, if the magnitude of $\Delta\sigma/\sigma'$ is less than 0.25.

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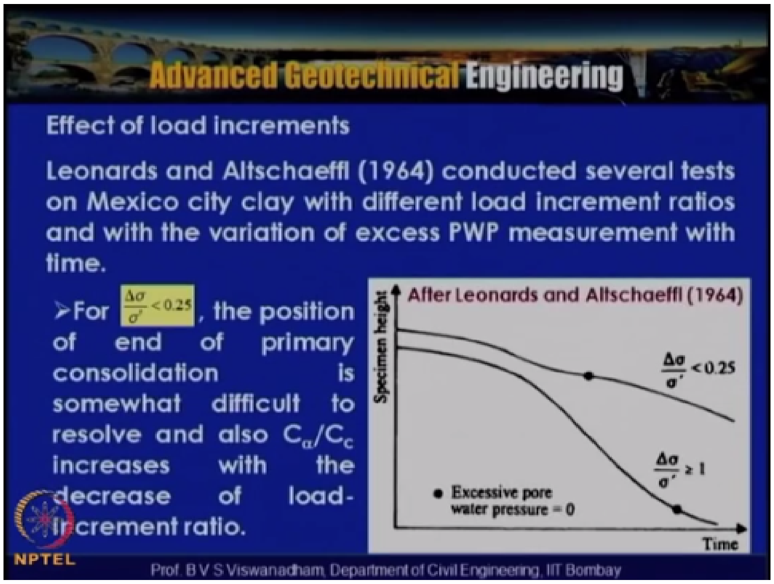

So according to Leonards and Altschaeffl 1964 they conduced several tests on Mexico city clay with different load increment ratios and with variation of excess pore water pressure measurement with time. So conducted this several consolidation test on Mexico city clay with different load increment ratios and variation of excess pore water pressure measurement. So in this particular slide time which is actually shown on the x axis the specimen height is actually shown here.

You can see that this is the $\Delta\sigma/\sigma'$ greater than or equal to 1, and here $\Delta\sigma/\sigma'$ less than 0.25 that means that as the $\Delta\sigma/\sigma'$ so this is equal to are they greater than 1 are found to be you know somewhat you know in this line and when $\Delta\sigma/\sigma'$ is less than 1 it actually migrates in this direction. so for $\Delta\sigma/\sigma'$ less than 0.25 the position of the end of the primary consolidation is somewhat difficult to resolve and also the C_α/C_c the C_α is nothing but the secondary compression index to the you know primary consolidation compression index in the primary consolidation range increases with the decrease of the load increment ratio.
So what we can see is that for $\Delta\sigma/\sigma'<0.25$ the position of the end of the primary consolidation is somewhat difficult to you know resolve will not able to whether you cannot say whether it is here or here or and also it has been noted down that you can see that the distanced difference of excess pore water pressure dispersions which actually happens, excess pore water pressure here is that you know $\Delta\sigma/\sigma'$ is actually happening less than 0.25 it is actually much before and then where as in case of $\Delta\sigma/\sigma'$ greater than equal to 1 is actually happening at much greater.

That can be understood but here you know the reduction and the early you know the passion can be understood because of the low load but here what is actually happening is that here the, if very difficult to distinguish the so called you know the end of the primary consolidation process and another thing is that the ratio of $C\alpha/Cc$ increases with the decrease of the load increment ratio.

So as he go in this direction as we go in this direction you know what will happen is that the ratio of $C\alpha/Cc$ increases, $C\alpha/Cc$ that is ratio of secondary compression index to compression index increases.

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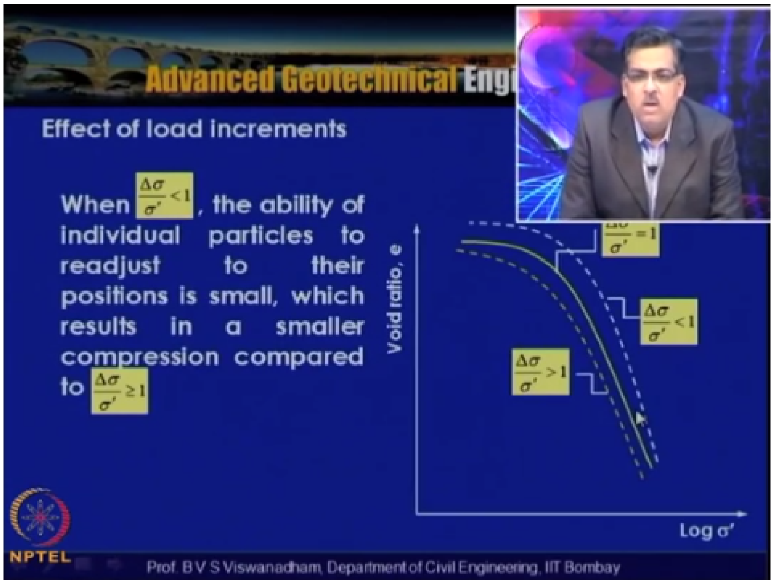

Now when $\Delta\sigma/\sigma'$ is say less than 1 so here void ratio and $\log\sigma'$ are plotted here and this is the case the standard elogp curve for $\Delta\sigma/\sigma'=1$, if it is less than 1 it actually it will be above the you know the conventional oernometer test result if it is greater than 1 it is actually somewhere here, so if you look into this here for a given load and more you know when you have $\Delta\sigma/\sigma'>1$ so the void ratio you know decreases high.

But when you have got $\Delta\sigma/\sigma'<1$ the percentage decrease in void ratio is low, when you relatively when you compared with this tool, so when $\Delta\sigma/\sigma'<1$ the ability of individual soil particles to ranges to the position is small, so when $\Delta\sigma/\sigma'$,1 the ability of soil particles to readjust to their position is very small and which results in a smaller compression compared to $\Delta\sigma/\sigma'$ greater than or equal to 1.

So what we are actually trying to conclude from this slide is that when $\Delta\sigma/\sigma'<1$ the ability of individual soil particles to readjust to their position is small which results in a smaller compression compared to $\Delta\sigma/\sigma'$ greater than or equal to 1, so that is the reason why we actually have a distinct difference when you actually have variation of the $\Delta\sigma/\sigma'$.

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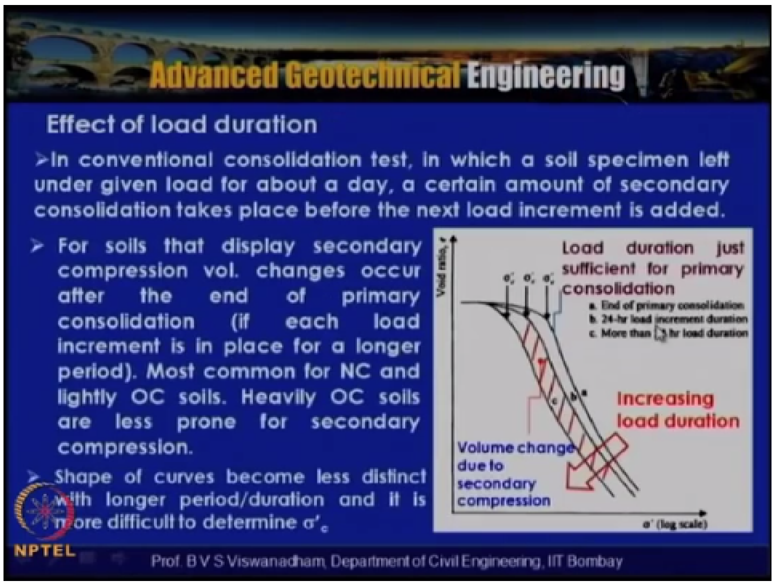

Now what will happen let us see that the load durations suppose if you conventionally we keep 24 each load increment ratio which is actually with $\Delta\sigma/\sigma'=1$ is maintained for 24 hours, so in a conventional consolidation test in which small specimen left under given load for about a day a certain amount of secondary consolidation takes place before the next load increment is added.

So that is possible but so in this particular slide what we have actually seen is that e void ratio and the σ' that is log scale that is you know the log σ' curve this logσ' axis now what we are actually having is that and the curve a, a is the end of the primary consolidation load duration just sufficient for the primary consolidation so load duration is just sufficient for the primary consolidation when you plot and this what is actually referred here in as curve a and curve b is the load duration with 24 hour load increment duration.

That means that this stress actually conducted with 24 hour load duration when you have more than 24 hours load duration you can see that the curve actually shifts towards when increasing load duration elogσ' curve actually shifts towards left side. So what we have is that you know the

$\sigma c'$ the pre-consolidation pressure is also changing previously here it should be this much so there is a shift in the pre-consolidation pressure magnitude and when we actually have you know just actually sufficient for end of pre-consolidation you actually have different pre-con.

So and it can be noted that different values of magnitudes of pre-consolidation pressure so for a soils that display secondary compression volume changes occur after the end of primary consolidation, because not all soils actually express secondary consolidation for soils the displays secondary compression volume changes occur after the end of primary consolidation if each load increment is place for a longer period.

So most common for the or the normally consolidated and likely or normally likely over consolidated soils, up to OCR=2 and they are referred as the likely over consolidated soils so if each load increment is in place for a longer period what will happen is that normally consolidated or likely over consolidated soils they actually subjected to a certain degree of you know secondary compression.

And heavily over consolidated soils are less prone for the secondary compression, so because heavily over consolidated soils are less prone for the secondary compression and the shape of the curves becomes less distinct with longer period of duration, longer period in duration and it is more difficult to $\sigma 0$.

So with shapes of the curves they keep on changing and with longer duration it is difficult to predict it will difficult to you know difficult to determine $\sigma 0c$ that is the pre-consolidation pressure determination is difficult here. so one if you see this actual portion here and this volume change actually occurs due to the secondary compression this volume change because that same load been increment or load duration kept for a longer duration so what will happen is that the secondary compression component is actually attribute to the phenomenon into the picture.

And it actually results in the volume change and it causes the say this is attributed to a secondary compression, so what we understood is that if you are actually keeping the load duration straightly for longer hours then what we actually have seeing is that there is you know certain amount of for Argon consolidated soils you know which is has the negligible influence because they are actually not having much of you know the secondary consolidation component will be very, very low.

But when you have the normally consolidated soils and over consolidated soils likely or consolidate soils we have you know we can see the volume changes due to secondary compression significantly. And also one more thing we have discussed is that the shape of the curves become less distinct with longer period and duration and it is more difficult to determine pre-consolidation pressure $\sigma'c$.

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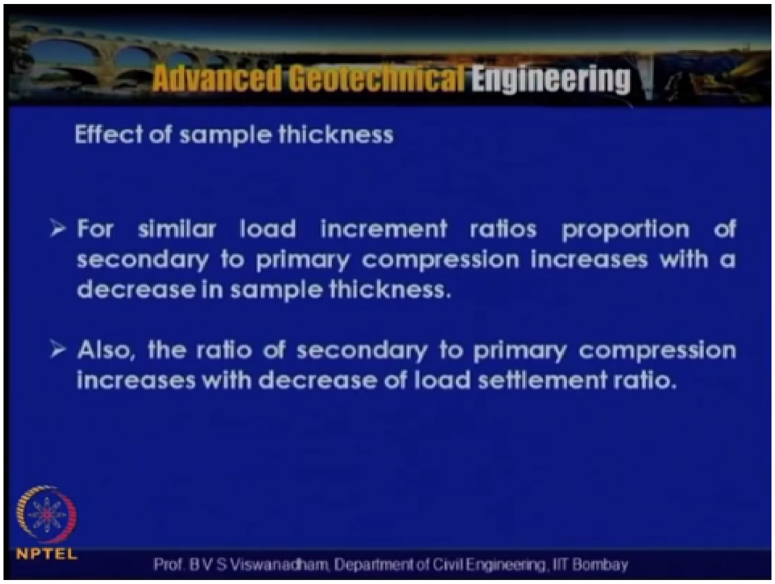

Now what will happen let us say that sample thickness normally the sample thickness to diameter ratio we actually have said that diameter to thickness ratio is actually maintained as 3 basically to reduce the side wall frictions that is one of the reasons for that and the second reason is that you know to have the you know these $\varepsilon r=0$ and also to represent the one dimensional consolidation only.

So for similar load increment ratios proportion of the secondary to primary compression increase as with decrease in the sample thickness so for if you are having for a similar load increment ratios the proportion of secondary to primary compression increases with decreases in sample thickness, and also the ratio of secondary to primary compression increases with the decrease in the load settlement ratio.

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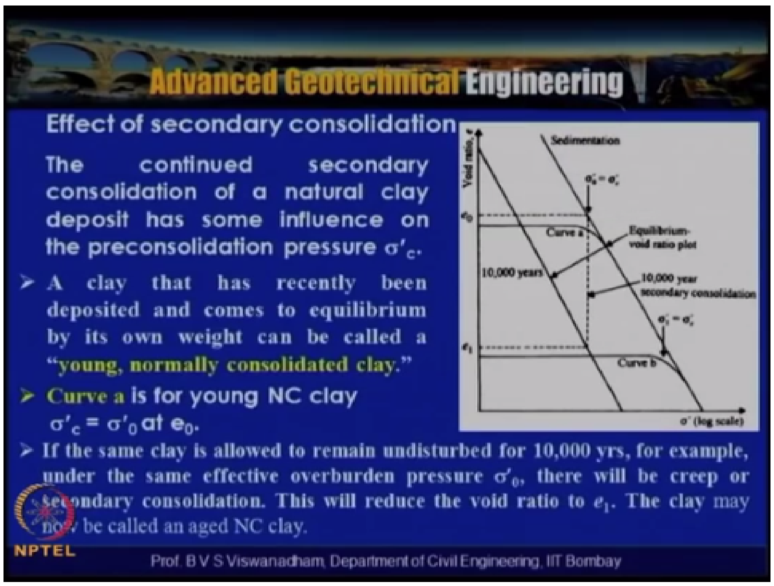

Now let us see the secondary consolidation or creep effect, so in this particular slide where what we see is the elogσ′ curve again, but we have indicated here three curves one is curve a, and curve b and there is one curve which is actually for example after 10000 years of consolidation. So in the curve a what we see is that the sedimentation is actually happening and you know this is the current overburden pressure and then you know further it is undergoing only consolidation.

And the curve b is you know after 10,000 years if the sample is actually subjected to 10,000 years of consolidation when it is actually subjected then the, when it is consolidated and then you know what we get is this variation. So the continued secondary consolidation of a natural clay deposit has some influence on the pre-consolidation pressure, so the continued secondary consolidation of a natural clay has some influence on the pre-consolidation pressure σ′c.

A clay that has recently been deposited and come to equilibrium by it is own weight can be called as young and normally consolidated clay. A clay that has recently been deposited and comes to equilibrium by its own weight can be called as young and normally consolidated clay, and curve a is for young normally consolidated clay and where in σ′c=σ′r and at e0, see that is the at this particular point that is the initial void ratio and this is the curve here.

If the same clay is allowed to remain undisturbed for about 10,000 years and for example under the same effective overburden pressure σ′0 then it will be creep of secondary consolidation this will reduce the void ratio from e0 to e1 because of the creep effect the void ratio reduces from e0 to e1 then here you can see that the constant effective stress the σ′0 which is actually no change let you happen assume that for the 10,000 years then you know if the void ratio changes to e1.

Now so the clay may now be called as so this clay is actually called as aged normally consolidated clay, so previously if there is fresh deposition of clay is happening and the recently deposited and comes in equilibrium by its own weight then it is called young normally consolidated clay and if this you know is subjected to certain amount of secondary creep and then will reduce the void ratio from e0/e1 as shown in the slide and this clay may be now called as the aged normally consolidated clay.

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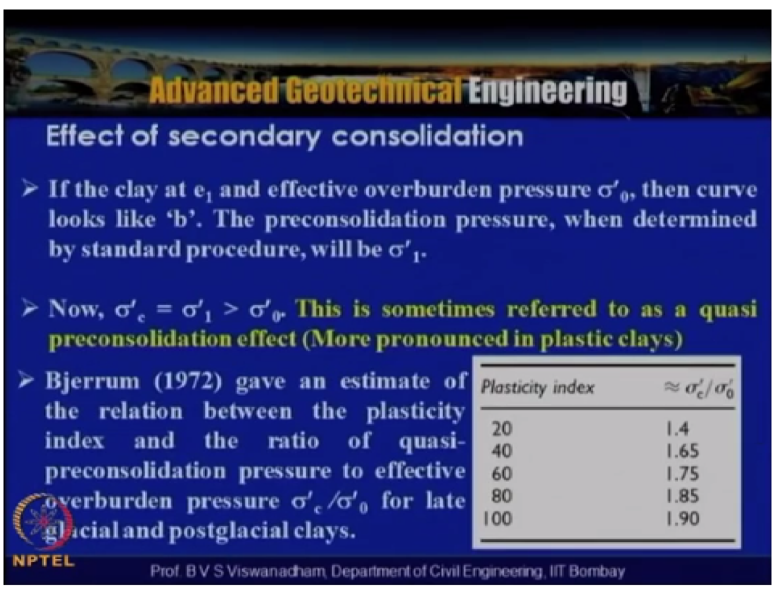

Now if the clay at e1 that is at this particular point clay at e1 now the initial void ratio for this is that e1 which is actually after 10,000 years and the effective overburden pressure is σ′0 that is this pressure σ′0 and the curve looks like b and the pre-consolidation pressure when determined by the standard procedure will be σ′1. So when you do the consolidation test on the sample which is actually collected after 10,000 years with $\sigma'1$ is the $\sigma'0$ has the you know initial overburden pressure what you look like is now that pre-consolidation pressure is actually said nothing but $\sigma'1$, so the quasi pre-consolidation pressure when determined by standard procedure it will be $\sigma'1$. Now $\sigma'c=\sigma'1$ and which is greater than $\sigma'1$ so this is sometimes referred to as the quasi pre-consolidation effect more pronounced in the plastic clays.

So this type of behavior is actually more pronounced in the clays of high compressibility and high plasticity that is ch type of clays that is the more pronounced in the plastic clays. Yoram Bjerrum in 1972 gave an estimate of the relation between the plasticity index and the ratio of the quasi pr-consolidation pressure to effective overburden pressure that is $\sigma'c/\sigma'0$ for the late glacial and post glacial clays.

So for glacial and post glacial clays so you can see that as the plasticity index values increasing there is an increase in you know ratio of quasi pre-consolidation pressure to the effective overburden pressure $\sigma'0$, so with increase in plasticity index then you know this is actually more prominent and it actually increases $\sigma'c/\sigma'0$ which is, which will be high. So the quasi per-consolidation effect will be very, very pronounced or significant in plastic clays so you can see from the table which is given here that increase in the plasticity index value where the $\sigma'c/\sigma'0$.

$\sigma'c$ is nothing but quasi pre-consolidation pressure and $\sigma'0$ is nothing but effective overburden pressure so $\sigma'c$ and $\sigma'0$ which is actually they are for late glacial and post glacial clays.

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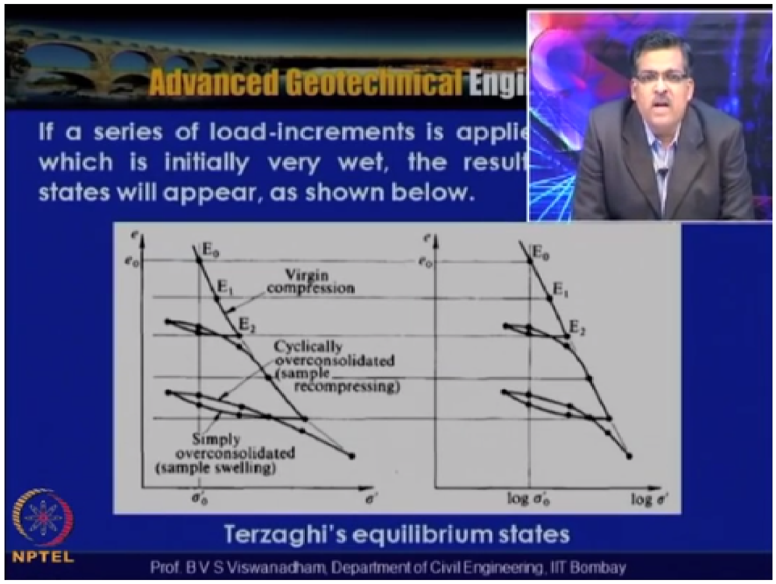

Now after having discussed the effect of load duration and effect of you know the load increment ratios and effect of secondary consolidation and effect of sample thickness now let us look into the compression curves and different forms of representation and particularly for compression and swelling that is in the unloaded zone. So if you serious of load increment is applied to specimen which is initially wet and resulting equilibrium states will appear and are shown below.

So if you look into this here this specimen this is the yield σ′ that is the compression curve eσ′ curve where you can see that the sample as well as been subjected to you know these curve and up to load e0 to e2 then unloaded and then reloaded and then you can see that you know it joints here and then it goes, it get loaded further and then after here unloaded again and reloaded here, so you can see that the cyclic over consolidated sample recompressing.

And cyclic say this is simply over consolidated or the swelling which is also called this limb is actually called as the swelling portion that is the unloading portion that is the soil actually bounds back when the load is actually removed. So this is actually plotted on the elogσ′ curve when it is actually plotted you can see that this all this what are may be the loading unloading cycles we have and this line joining this line this line is actually decades the compression line which is actually obtained and close to the field compression line for normally consolidated soils. So e0, e1, e2 e3 and then unloading and reloading and unloading and reloading so whatever the cycles we have is actually follows that slope.

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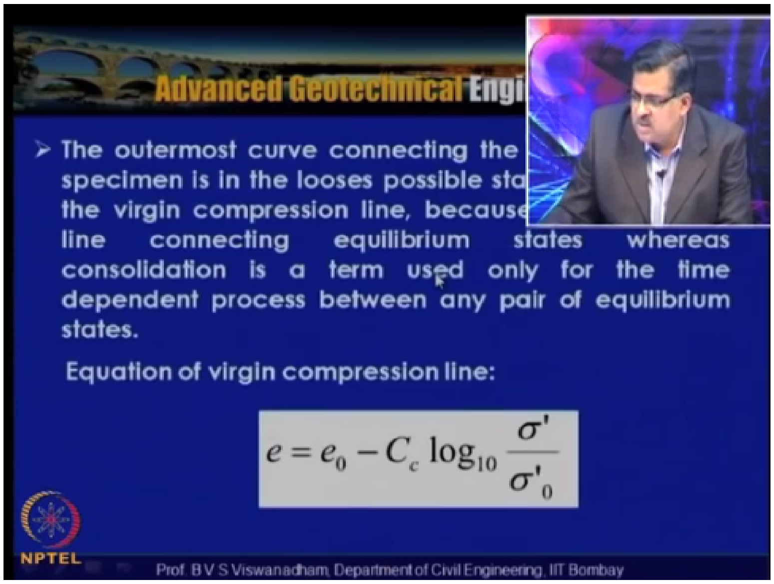

So this is further indicated the outer most curve connecting the points when the specimen is in loose possible states is referred as a virgin compression line that is the this line is actually referred as the virgin compression line e0, e1, e2 is referred as virgin compression line. And because it is strictly the line connect in the equilibrium states where as equilibrium states in the sense that for that type of increment load the consolidation is completed and in the and it is strictly the line connecting equilibrium states whereas the consolidation is a term used only for the time dependent process between any pair of.

So it is also you know this, this is actually called as virgin compression lines because it is strictly the connecting the equilibrium states where as virgin consolidation is something like if the consolidation is have a time dependent process between any pair of equilibrium states. So the equation for the virgin compression line is given by $e=e0-ec/\log_{10} \sigma'/\sigma'0$,so the outermost curve connecting the points when the specimen is in the loose possible states is referred to as the virgin compression line rather than as virgin compression line rather than as virgin consolidation line the reason is due to the fact that the line connecting the equilibrium states where as the consolidation is the term used only for the time dependent process between any pair of equilibrium states.

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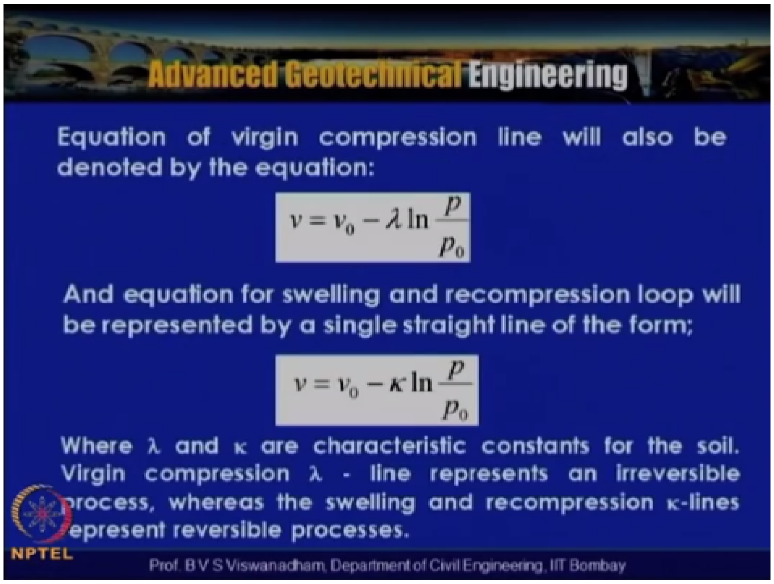

Now this equation of virgin compression line further represented as v in terms of sample volume in terms of specific volume then nothing but $v = v_0 - \lambda \ln p/p_0$ which is nothing but σ/σ_0 and where in the λ is a characteristic constant and the v_0 is the initial specific volume so specific volume is nothing but 1+e and then e is the, you know these are actually related as water contents specific gravity and void ratio they are related is one and there.

And equation of virgin compression line will be denoted as $v = v_0 - \lambda \ln p/p_0$ and equation for swelling and recompression loop will be represented by a single state line of the form that is nothing but $v = v_0 - \kappa$ this κ is the for the you know recompression loop or the swelling loop so which is something analogous to swelling index or recompression index $\ln p/p_0$. Where λ and κ are the characteristics constants for the soil and virgin compression λ line represents the irreversible process.

Whereas the swelling and recompression κ lines represent the reversible process so λ line represents the so this is, this when you plot this line is nothing but the λ line, so the λ line represents the irreversible process because the soil subjected to irreversible changes and it is actually called as irreversible process whereas the swelling and recompression κ lines represents the reversible process.

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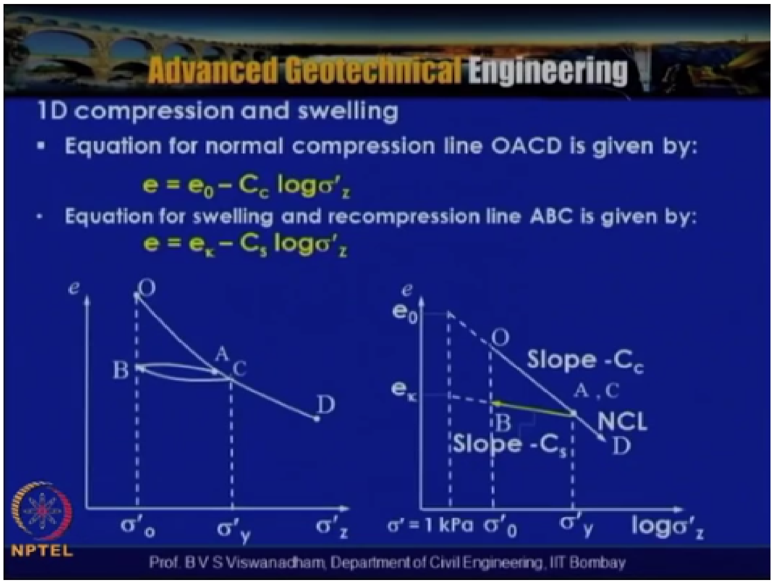

Now this is further indicated where this equation for normal compression line OACD is given by $e=e_0-C_c\log\sigma'_z$, so here you can see that e verses σ'_z for the consolidation compression is actually shown and this is for the one dimensional compression and the swelling so OA and it is actually subjected O into subjected to and effect to overburden pressure of σ'_o, σ' and at point C it actually has been subjected to σ'_y that is the it is called as the yield stress.

And D is again the load was actually terminated here so you can see that at point C you know the load, you know as stopped and then gone unloaded that is called unloading and then that is called also called as the swelling line and this is called recompression line. So BA is the recompression in the path and then it follows and joints to see and then follows further to D, so this is again in the normally consolidated so the same thing is represented in the void ratio verses $\log\sigma'_z$ then what will happen is that, this is the slope of the Cc then this is called as the normal compression line and point from A and C they are at this point and A and C are at this point in the case of normally in case of $\log\sigma'_z$ you will see at this particular point and B is at this point where that at the end of swelling or unloading effect and then you know so you can see that σ'_0 is the overburden pressure here.

σ'_y is the illustrate here and so you can see here that e_κ is this particular one at this particular point where you know these recompression or the swelling was complete. So this equation for the swelling and recompression lines are given as $e=e_\kappa-C_s\log\sigma'_z$ and e=e0.e, $e=e_0-C_c\log\sigma'_z$ is the normal compression line for OACD the equation for line OACD is given by $e=e_0-C_c\log\sigma'_z$

and for swelling and recompression line it is actually given as you know ABC, which is nothing but $e\kappa - C_s \log\sigma'z$.

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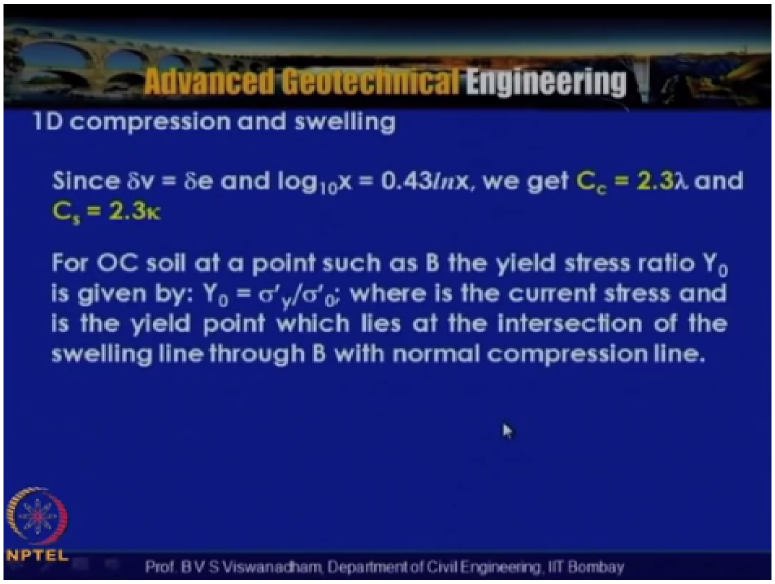

Now since Δv that change in volume is equal to change in void ratio and $\log_{10}x=0.43\ln x$ then we get $C_c=2.3\lambda$ and $C_s=2.3\kappa$,so by using this we can actually you know once you substitute this natural logarithm into this $\ln_{10}$ by using this we actually get into this particular relation they are one and the same. So for over consolidated soil at a point such as B the yield stress ratio y0 is given by $y0=\sigma'0/\sigma'$ this, so for a over consolidation soil that is at a point such as B the yield stress ratio y0 is given by $Y0=\sigma'y/\sigma'0$ where $\sigma'0$ is the current stress and $\sigma'0y$ is the yield point which lies at the intersection of the swelling trough point B and for, with the normal compression line so with the normal compression line that this is so we are actually defining here the yield stress.

The yield stress is nothing but $\sigma'y$ ratio of $\sigma'y$ to $\sigma'0$, $\sigma'y$ is actually obtained at this particular point and where it actually has from the normal compression line where it meets this particular first limb where the unloading which actually meets the normal compression line and that is actually is ranted as $\sigma'v$ and which is $\sigma'y/\sigma'0$, where σ' is the current stress, $\sigma'o$ is the current stress and $\sigma'y$ is the yield point at which it lies at the intersection of the swelling line through B with normal compression line.

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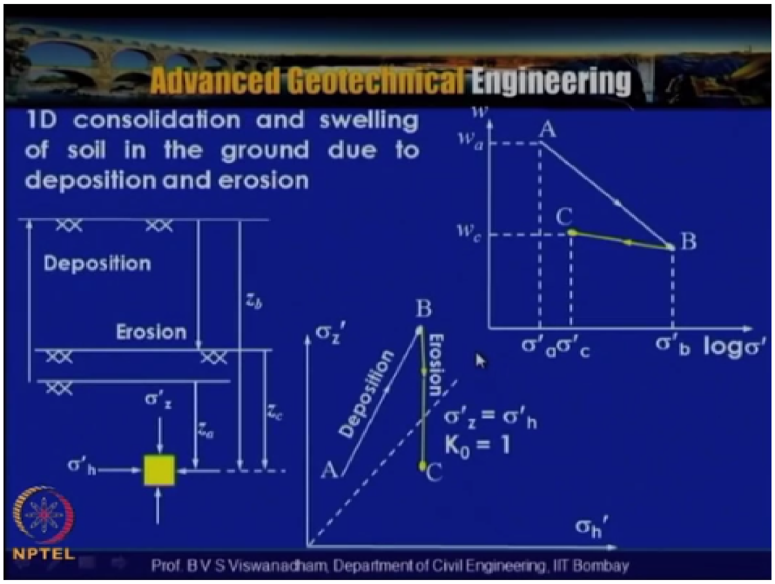

Now let us see the effect of one dimensional consolidation and swelling of soil in the ground due to deposition and erosion, so we know that deposition and erosion they are the continuous process but on the soil layer which is actually proven for you know particularly the normally consolidated and now lightly over consolidated soils they are actually proven for changes because of this actions like deposition and erosion, so considering this particular slide an elements soil element which is actually subjected to vertical stress σʹz and horizontal stress in σʹh and when the erosion actually when the deposition happens what will happen there is an increase in this soil overburden and above this particular point now it is subjected to high stress due to the so you can see the zʹb is increase here.

But when there is erosion takes place the stress on this actually re-decrease for example you can see this is the when the erosion takes place from here to here unloading is actually happening that is σʹc. So this is actually indicated by as e=wgs so from void ratio and now it is actually indicated with water content here and logσʹ here you can see that AB is the, you know recompression line so the water content changes from A to B you can see that the water content decrease and are void ratio decreases so A to B and from B that is σʹb when it is unloaded BC is the path which actually takes and stresses this point as σʹc.

So here what is actually happening is that when you have k0 at pressure at stress is defined as σ horizontal stress by vertical stress when k0=1 when it is actually having elastic equilibrium then σʹz=σʹh so this is that k0 line which actually indicates so this is σʹh on the x axis, σʹz on the y axis so you can see that when the case of deposition is actually happening when the deposition is actually happening you can see that A to B is actually decreases and B to C you can see that here the k0 values are actually you know can actually go more than 1.

Particularly because of this s effect, so the one dimensional consolidation in the swelling of soil ground due to deposition erosion is actually depicted and these actually you know represent the different water contents because of the type of actions which actually have been subjected. So for normally consolidated soil and likely or consolidated soils σ′h is actually less than σ′z.

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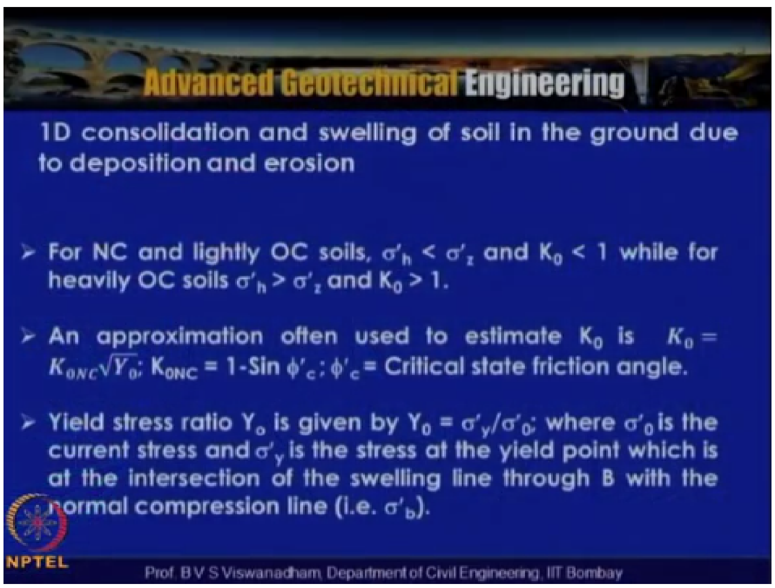

And k0 σ′h is less than σ′z, and k0 less than 1 that for normally consolidated soil where the deposition is actually happening so this is this path which is actually shown AB here. and while as heavy consolidated soils σh>σz and k0>1, so that is because of this here it actually can have k0 values more than 1 can be obtained for some heavily overburden consolidated soils and because of the stress locking which actually can take place because of that you know they exhibit the k0 values very high.

You know sometimes the k0 value can actually go up to k0=3, so here what we are discussing is that got light and for normally consolidated and lightly over consolidated soils σ′h the organ stress is less than vertical stress and k0 value is less than 1, while for heavily over consolidated soils σ′h is greater than σ′z and k0 is actually greater than 1, so an approximation is basically often used to estimate k0 and which k0 is actually nothing but k1c where k0 of a normally consolidate clay is which is nothing but 1-sinϕ′c and ϕ′c is the critical state friction angle and √Y0 and the KONC-√k0NC √Y0.

This Y0 is nothing but the yield stress which yields that ratio which we have defined earlier yield stress ratio is actually nothing but σ′y/σ′0 where σ′0 is the current stress and σ′ is the stress at the point yielding point which is the line or which is the intersection of swelling line through B and with the normal compression line σ′p.

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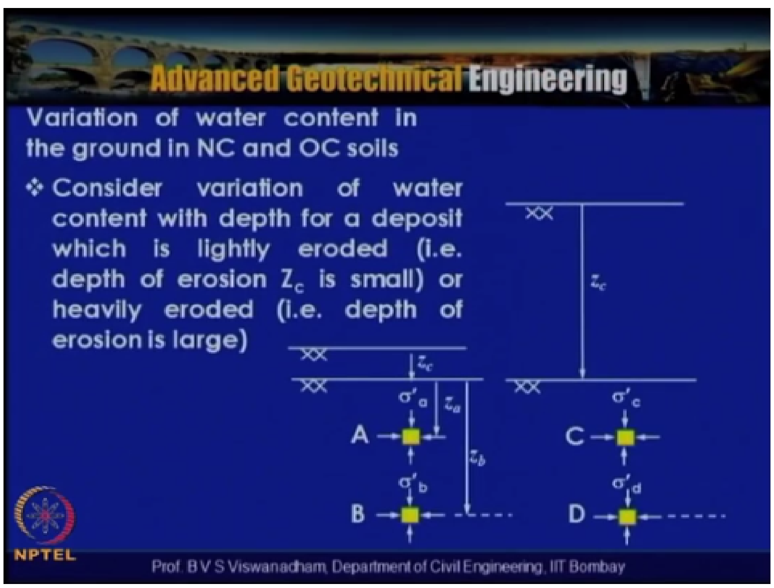

Now let us see variation of water content in normal consolidated and over consolidate soils, we actually have been pointing out that for normally consolidated soils the water content will be very high and over consolidated soils the normal content is less and so consider the variation of water content with depth for different or a deposit which is lightly eroded you can see that eroded that is the depth of erosion which is small or heavily eroded that is the depth of erosion is very large.

So we have two states this is the stress point A and B and stresses at point C and D, so this particular soil state as elements A and B are actually are referring to the way the depth of erosion is relatively small, and in this case the stress elements C and D the depth of erosion is relatively large that means that this the elements C and D is subjected to very high pass pressures, A and B subjected to low pressures low degree of pressures.

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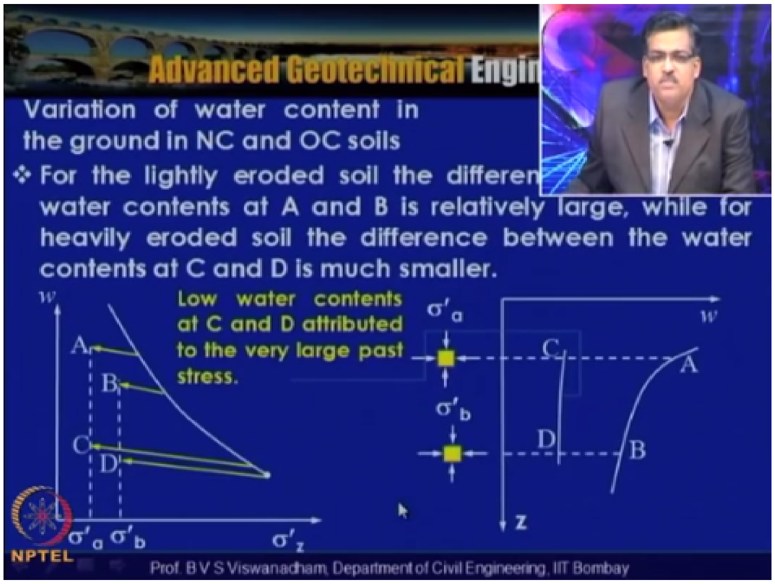

Now what will happen is that for the lightly eroded soil the difference between the water content at point A and B is relatively large while for heavily eroded soil the difference between water content in C and D is much smaller. So here what we have is that water content verses $\sigma'z$ is shown here so you can see that this is the compression line loading and unloading so this first limb actually he is refers to $\sigma'a$ and this is unloading so we have done loading and unloading portion and loading portion we simplified here and this is point B the limb point B.

And you can see here, there is a distinct change in the water content here, here there is marked there is no you know negligible or marginal change in the water content with for the you know in this particular portion. So for the lightly eroded soil the difference between water content A and B is relatively large, while for a heavily eroded soil the difference between the water contents at C and D is smaller, so that is what actually is been indicated here.

So here if you look into this, this is for the normally consolidated soils or heavily, lightly over consolidated soils and these are the heavily over consolidated soils so you can see that the C and D so this is water content verses the depth and the element A σ′a and σ′b low water contents at C and D attributed to the very large passed stresses, so the soil actually has been subjected to pass stresses, so the low water contents here recorded and we can see that you know this is also negligible variation.

But here you can see that the with the depth of course there is decrease in water content but thing is that here there is a large variation but here there is a negligible or marginal variation. So the reason is that actually basically attributed to that the element the soil elements at C and D where actually has been subjected to very large passed stresses.

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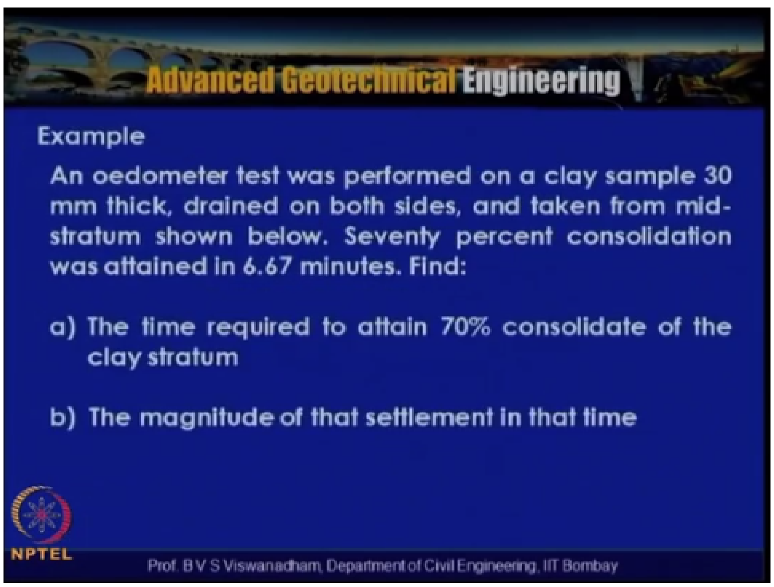

Now let us after having discussed these you know the effects of the load increment ratios and the duration let us look into some example problems and in this example an oedometer test was performed on a clay sample of 30mm thick and drained at both sides that means that we have put kept to for tools at top and bottom and taken from mid stratum at big depth of the clay and 70% of consolidation was attained in 6.67 minutes and what we need to find out is that time required to obtain 70% consolidation of the clay stratum.

And the magnitude of the settlement in that time, so magnitude of the settlement in that time. So in oedometer test was actually preformed on a clay sample of 30mm thick and drained on both sides and taken from mid stratum depth shown and 705 of consolidation was attained in 6.67 minutes, so find the time required to attain 70% consolidation of the clay stratum and magnitude of the settlement in that time.

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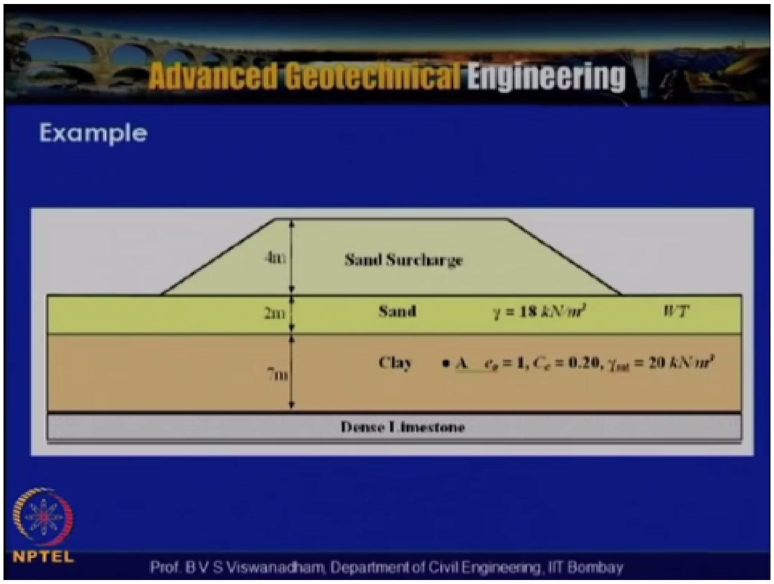

So this is you know a particular cross section here weak cross section where the sand embankment or relay embankment is actually place and this is the clay and we have got you know 2m and 7m is the thickness of the clay and this is the element A which is e0=1 Cc=0.2 and γsat=20kN/m^3 and here is γ 18kN/m^3 water table location is somewhere here.

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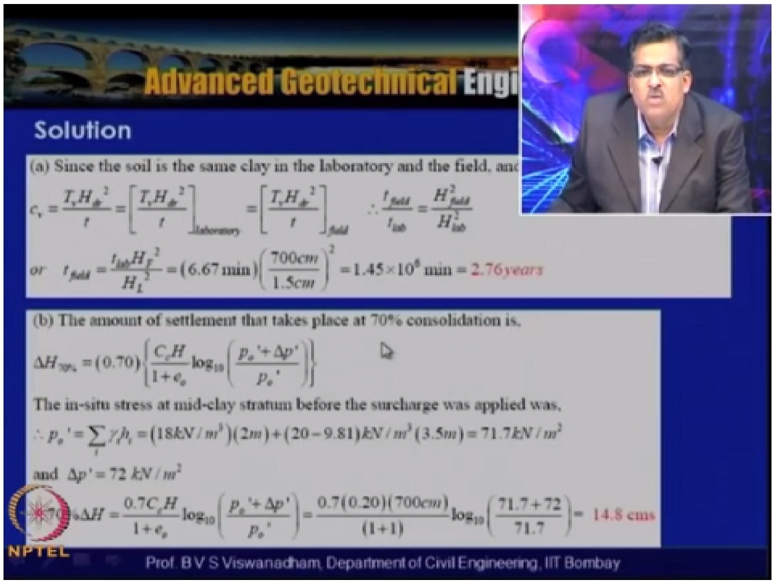

Now the solution works out like this since the soil is the same clay in the laboratory and in the field and both are actually 70% consolidation so first what we can do is that you know we can by the coefficient of consolidation will be same, because what has been done told is that soil is same in the clay in the field since the soil is same, soil is the same clay in the laboratory and in the field and both are actually having 70% consolidation so time factor $Tv=Tc/h^2$ so we can write it as $Cv=Tv/hdr^2/t$ and which is can be related as because Cv in laboratory is equal to Cv in prototype, Cv in field they are same.

So $TvHdr^2/t$ laboratory=$TvHdr^2/t$ field they are same, so with that what we get is that T field by T laboratory=H field square by h laboratory, so T field can be obtained like this T lab into Hf^2/Hl^2 so we actually have measured Tlab as 6.67 minutes into Hf is actually given as 7m thick clay so we actually have said that this clay is actually having a thickness of 7m, so 7 divided by the thickness of the sample is 30mm but it is actually is doubly drainage.

So what we are doing is that 30/2 that is nothing but 1.5cm, so to equalize the units we have taken in centimeter units, and with this what will actually get is that the time which actually takes place in the 70% consolidation is about 2.76 years that is one thing which we have to note down the time in the field is you know about 2.76 years, so this if this state for situation are there in the field there is a possibility that this settlement actually can affect the structure.

And if the settlements are actually occurring say beyond say 30 years or 40 years also and if the design life of the structure is actually small then we need not really worry about that, but if this is the situation there is actually need for understanding and eliminating this settlements otherwise the structure is actually going to be subjected to distress because of the consolidation settlements.

So the amount of the settlement of the takes place for 70% consolidation can be estimated like this which is, we know that degree of consolidation is nothing but 70% consolidation at let us say settlement 70% consolidation to final consolidation settlement, so we know the final consolidation settlement expression so we used this, so Δh 70%=0.7 Cc/h h full thickness 7m we have to take now, 1+e0 logp0 that is σʹ0+Δσʹ/σʹ0.

So the in situ stress at mid clay stratum before the surcharge applied we can calculate that is the effect to stress we can actually calculate, and Δpʹ or Δσʹ is nothing but 72kPa and this can be calculated as this unit weight of this which can be calculated that is the unit weight of the sand surcharge and with that is the increase in the load, so with that what we will get is that the 70% of the settles amount of settlement that takes place at 70% consolidation it can be obtained as 70% of Δh which is nothing but 0.7 times Cc.

Cc is nothing but 0.2 which is actually given into h which is 7m/1+e0 and e0=1 so it becomes 1+1 and $\log_{10}$σʹ0 that is the stress at this particular point is you know effect overburden pressure and that is nothing but 71.7 which is actually completed here +72 is due to this may be which is actually there so because of that what is actually estimates is that so at the center the settlement is actually of the order of 148mm.

And which actually is you know above the tolerable limit of say 50mm so in that case you know the structure is actually going to suffer distress. For example, this is, then this cause the difference settlements for a living and which actually can hamper with the integrity of the system. So the amount of the settlement that takes place at 70% consolidation here what we need to understand is that the degree of consolidation is determined by settlement at any time to final consolidation settlement.

So settlement at 70% consolidation divided by the final consolidation settlement so because of that what we have done is that degree of consolidation is given as 0.7 for that we have taken is that the settlement at 70% consolidation is actually obtained as 0.7 into the expression for the final consolidation settlement we have used here.

So with that what we have got is that at 70% degree of consolidation what is the settlement of the particular Lv at the bit stratum depth, so bit stratum depth the settlement has been computed and this is actually worked out to be around 14.8cm. So here also we can look into that here that if you are having if you take if you divide that clay into number of small increment of thickness let us say 1m, 1m, 1m and each depth each thickness if the settlement is Δ1, Δ2, Δ3 like that Δ7.

Then you know what we need to do is that we have to calculate what is the increase in load due to the so called the trapezium load which is there that is if you do the method of super position I can use for this triangular load this trapezium loading and this trapezium loading then we can actually get the settlement at this particular point with that you know we may actually get the more accurate estimation of the settlement.

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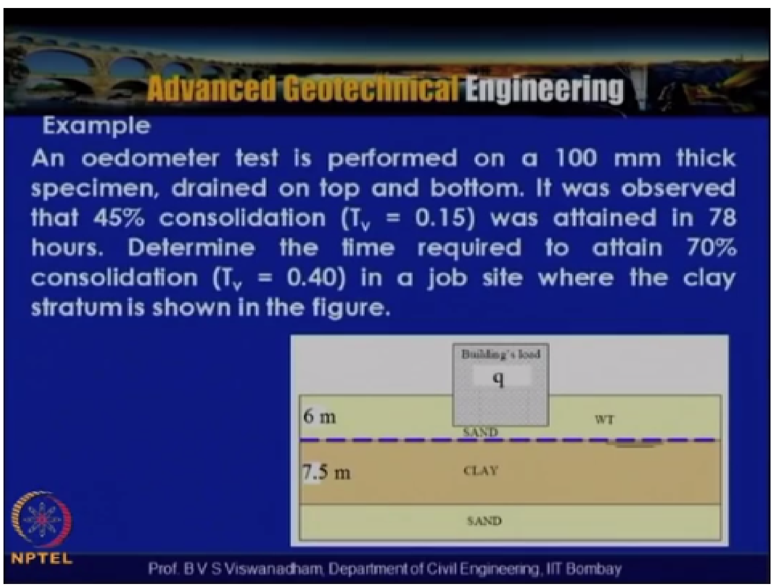

Let us take another example where in odeometer test is actually preformed on a 100m thick specimen drained and top and bottom and it was observed that 45% consolidation the time factor was 0.15 and which was obtained in 78 hours in the laboratory and we need to determine the time required to attain 70% consolidation is Tv is 0.45 in a job site where the clay is stratum is shown in the figure.

So we have got sand layer and sand layer at the top and bottom and clay layer which is at the center here that is you know 7.5m thickness and let us assume that one dimensional consolidation is actually valid here and there is a building load which actually imposes a certain amount of Δσ on the soil, so this is the water table location here, so what we need to find out is that we need to find out.

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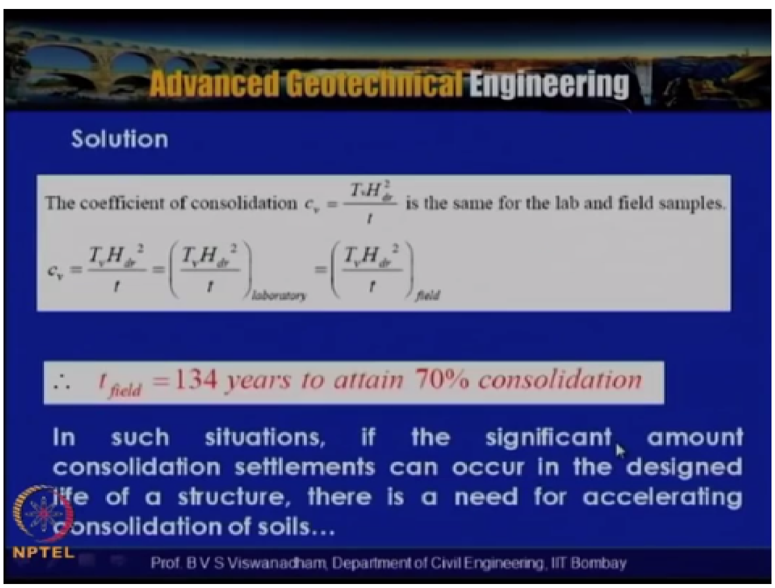

You know what is the time which actually takes in the field, so if it calculate if you see that the coefficient of consolidation is actually same for the lab and field samples again by using the same discussion whatever we had which actually says that $Cv=Tvhdr^2/t$ with that we can actually compute time in field and which actually works out to be the time and field is actually something like 134 years to attain 70% consolidation.

So sometimes actually this appears that for a given type of clay you know that the settlement actually continues for about 134 years of time, so if you are actually constructing an important structure on that and if the clay is actually undergoing the consolidation like this and this is actually is a proof that the for the you know the leaning tower of Pica even after 400 to 500 years actually is undergoing consolidation this is a classical example.

So if you are actually having this type of situations where the settlements are actually coming predominant settlements are coming within the design life of a building then it is actually better to accelerate the consolidation settlements so in such situations if the significant amount of consolidation settlements can occur in the design life of a structure there is a need for the acceleration, accelerating the consolidation of a soil.

So for that there are you couple of methods which actually we will discuss in the next lecture, so with that what will happen is that we will be covering in this particular module the methods for accelerating the consolidation settlements.

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