NPTEL

NATIONAL PROGRAMME ON TECHNOLOGY ENHANCED LEARNING

CDEEP
IIT BOMBAY

ADVANCED GEOTECHNICAL ENGINEERING

Prof. B.V.S. Viswanandham

Department of Civil Engineering
IIT Bombay

Lecture No. 19

Module – 3

Lecture – 1 on Compressibility and Consolidation

Welcome to advanced geotechnical engineering course.

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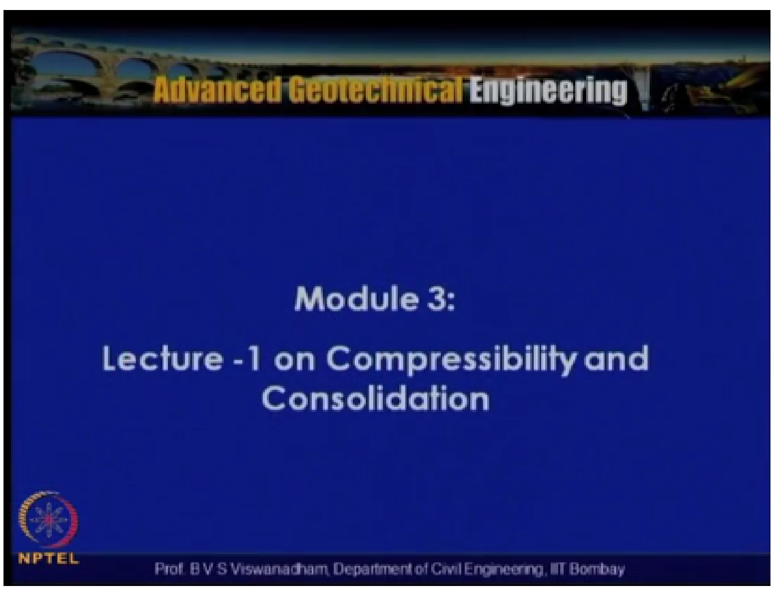

We are going to commence module 3, lecture 1 on compressibility and consolidation. So this is module 3 lecture 1 on compressibility and consolidation.

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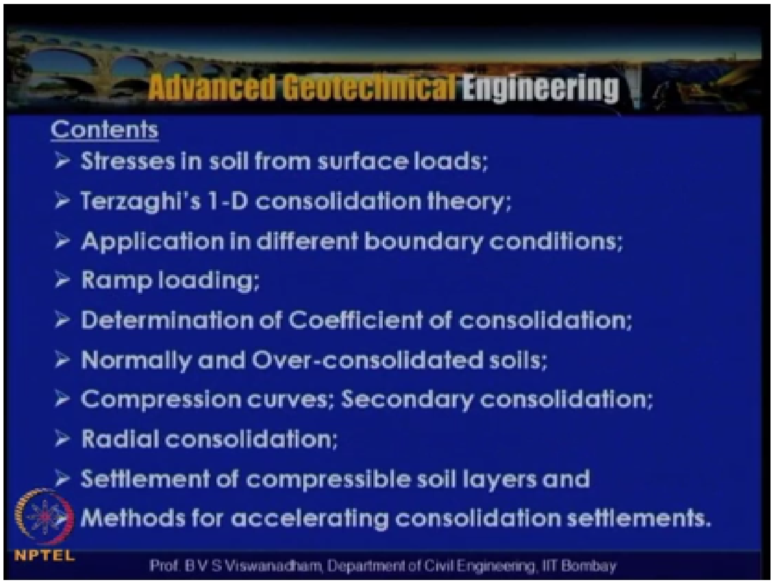

In this module the following contents are outlined, stresses in soil from surface loads due to different types of surface loads, it can be concentrated load, or it can be line loads, it can be strip loads, or it can be distributed loads over a certain area or irregular shaped areas loaded with certain intensity and amendment loading etc.

And then after having looked into the, you know the stresses in soil from surface loads, we will try to introduce ourselves to Terzaghi's one dimensional consolidation theory and application in different conditions and ramp loading condition that is how the amendment constriction on soft soil actually happens.

And methods for determining coefficient of consolidation normally an over consolidated soils, compression curves and secondary consolidation. After having discussed with the one dimensional consolidation, then we will try to look into the balance theory of radial consolidation. And settlement of compressible soil layers and methods for accelerating consolidation settlements.

So how we can actually even accelerate the consolidation settlements, we will try to look into some advanced methods. So in this particular module 3 and lecture 1, we actually commence with the stresses and soil from the surface load. We all know that an important function in the study of the soil mechanics is to predict the stresses and strains imposed at a given point in a soil masses due to certain loading conditions.

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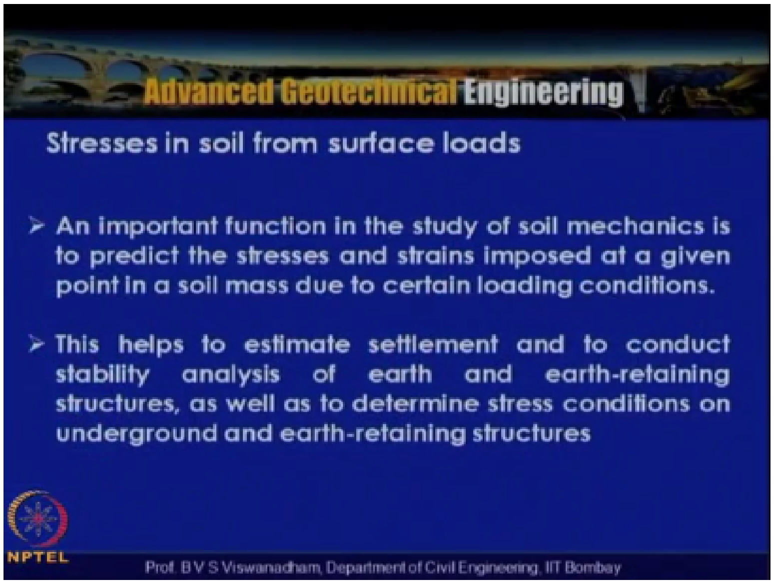

So always the surface is actually subjected to loading, so in that case an important function is the, in the study of soil mechanics is to predict the stresses and strains imposed at a given point in a soil mass due to certain loading conditions. Basically this helps to estimate the settlement and to conduct the stability analysis of earth and earth-retaining structures. As well as to determine the stress conditions on underground and earth-retaining structures.

So once we know the stresses it helps to estimate the settlements and to construct, to conduct the stability analysis of earth and earth-retaining structures, as well as to determine the stress conditions on underground and earth-retaining structures.

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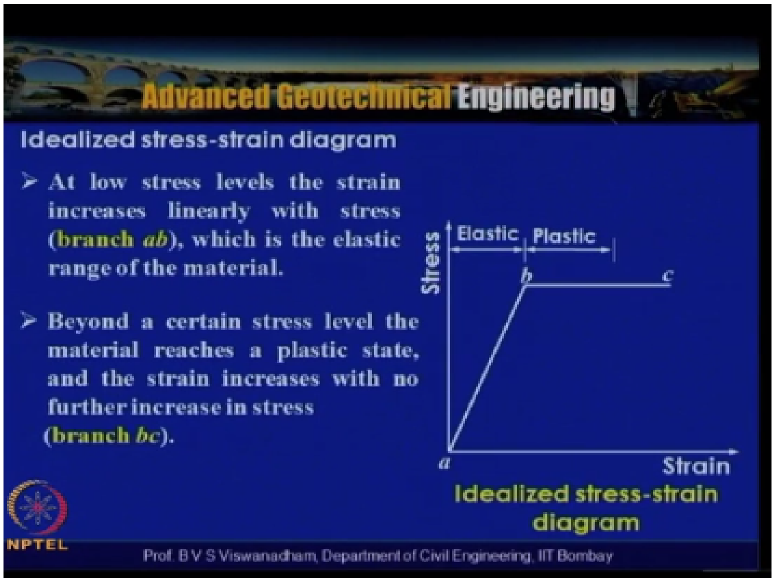

If you look into the idealized the stress-strain diagram, in this particular slide the idealized stress-strain diagram is shown here. The stress is on the vertical axis and strain on the X-axis. And the zone AB is in the elastic range and zone BC is idealized as plastic. So you can see that at low stress levels the strain increases linearly with stress and that is the branch AB, which is elastic range of the material.

Beyond a certain stress level the material reaches a plastic state, and the strain increases with no further increases in the stress. So in the idealized stress-strain diagram whatever we have shown here, that beyond a certain stress level the material reaches a plastic state, and the strain increases with no further increases in the stress. So this is idealized stress-strain diagram wherein, you know in case at low stress levels the strain increases linearly with stress, which is elastic which is within the elastic range of the material.

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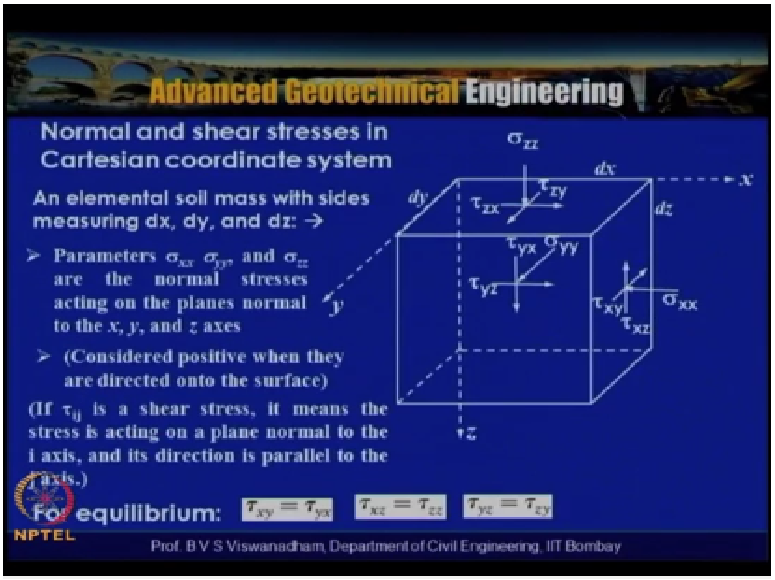

Now let us consider the normal and stress stresses in Cartesian coordinate system. Now an elemental soil mass when you look into it, assume that we are having a small element having sizes of dx in X direction, dy in Y direction and dz in Z direction. And if σ_{xx} and σ_{yy} and σ_{zz}, these are the normal stresses acting on the plane X, Y, Z axis. So here it is shown, σ_{xx} is the stress acting in a YZ plane, YZ plane that is the dy, dz area on this small area this σ_x is acting.

So σ_{xx}(dy, dz) is the force, normal force acting perpendicular to that. Then there are shear stress acting which is shown here τ_{xz}, τ_{xy} and in this case σ_{zz} is shown here, σ_{zz} is acting on dx and dy area. And σ_{yy} is acting over dx and dz area, that is X and Z plane. So here we have the, for convenience only we have shown only three stresses, but in other phases also that is on this phase, on this phase, on this phase all the other remaining phases there these stress are acting.

So parameter σ_{xx}, σ_{yy} and σ_{zz} are the normal stresses acting on plane normal to X and Y and Z axis. So consider positive when they are directed onto the surface. If they are directed away from the surface over which they are acting particularly for normal stress they are treated as intention, or otherwise there will be in decent compression. So if τ_{ij} is a shear stress, it means that the stress is acting on a plane normal to Y axis. And its direction is parallel to J axis.

So if you look into, let us say a τ_{ij}, that means that τ_{ij} is a shear stress and it means that the stress is acting on a plane normal to the I axis and its direction is parallel to J axis. So for equilibrium $\tau_{xy} = \tau_{ix}$ and $\tau_{xz} = \tau_{zx}$ and $\tau_{yz} = \tau_{zy}$, so if you look into the CTL formula for equilibrium $\tau_{xy} = \tau_{yx}$ and $\tau_{xz} = \tau_{zx}$ and $\tau_{yz} = \tau_{zy}$.

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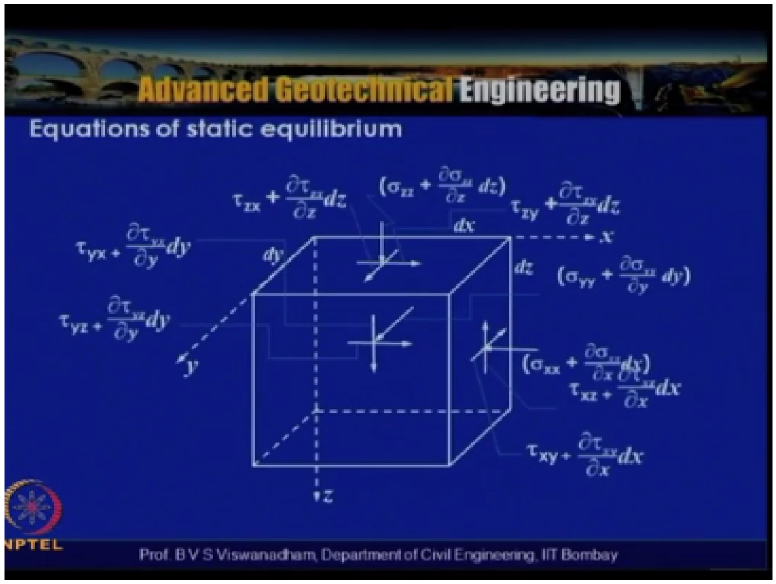

Now let us look into deducing the equation of static equilibrium. So consider the same stresses which are actually acting in X axis and Y axis and Z axis. And we have bought, there is a increase in the stress because of the self weight of the element. So we have on the X axis σxx which is acting and the other phase which is actually having $\sigma xx + \partial x(dx)$ and on the Z axis it is $\sigma zz+ \partial \sigma z/ \partial z$ and dz.

In this phase it is σz so the difference of the stress is nothing but $\partial \sigma z/\partial z(dz)$, so this is the rate of the change of the stress which actually undergoes, because of the self weight and the other reasons. So similarly, the shear stresses are also shown here. For this reason it is $\tau xy+\partial \tau xy/\partial z(dz)$ on this it is actually shown as $\partial zx+\tau zx/\tau z(dz)$ that is $\tau zx+\partial \tau zx/\partial z(dz)$. So now what we do is that we take, you know equilibrium, static equilibrium in X direction for forces acting in X direction and Y direction. And we try to get the so called static equilibrium equations.

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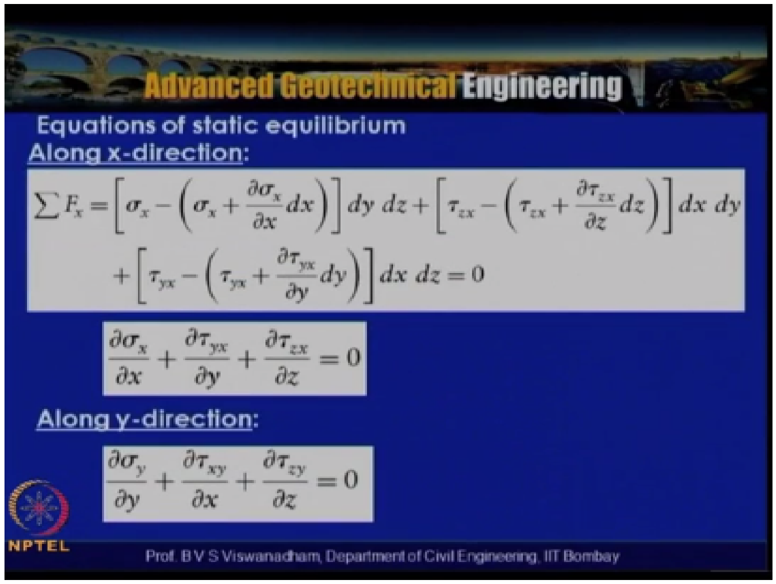

So what we did is that now along the X direction that is that whatever the forces acting. So now we have along the X direction on one phase there is one direction σxx is acting, on other direction it is σx is acting, $\sigma x+\partial\sigma x/\partial x(dx)$. So here it is referred as $\sigma x = \sigma xx$, $\sigma y = \sigma yy$, $\sigma z = \sigma zz$. So $\sigma fx = \sigma xx-\sigma xx+\partial\sigma xx/\partial x(dx)(dy/dz)$, so that is the net force acting in the X direction plus the net shear stress acting along that X direction that is $\tau zx- \tau zx+\partial\tau zx/\partial z(dz)(dx\ dy)$, because it is acting on dx, dy plane plus $\partial\tau yx-\tau yx-\tau yx+\partial\tau yx/\partial y(dy)(dx\ dz)$.

So by simplifying this what we get is that as you also, we know that $\tau yx= \tau xy$, $\tau xz = \tau zx$ by using that we actually get, when we do not use any self weight acting in the X direction, we get an equilibrium equation like this $\partial\tau\ \partial\sigma x/\partial x+\partial\tau yx\partial y(\partial)\tau zx/\partial z=0$. Similarly, by applying and simplifying the forces in the Y direction, we get $\partial\sigma y/\partial y+\partial\tau xy/\partial x+\partial\tau zy/\partial z=0$. So here we have the two equations which we have to be satisfied in the X direction and Y direction.

If you consider the third direction also we get another equation. But here the static equilibrium in two dimensional only we consider for coming this. So the equilibrium in two dimensional case is that $\partial\sigma x/\partial x+\partial\tau xyx/\partial y+\partial\tau zx/\partial z=0$, and $\partial\sigma y/\partial y+\partial\tau xy/\partial x+\partial\tau zy/\partial z=0$.

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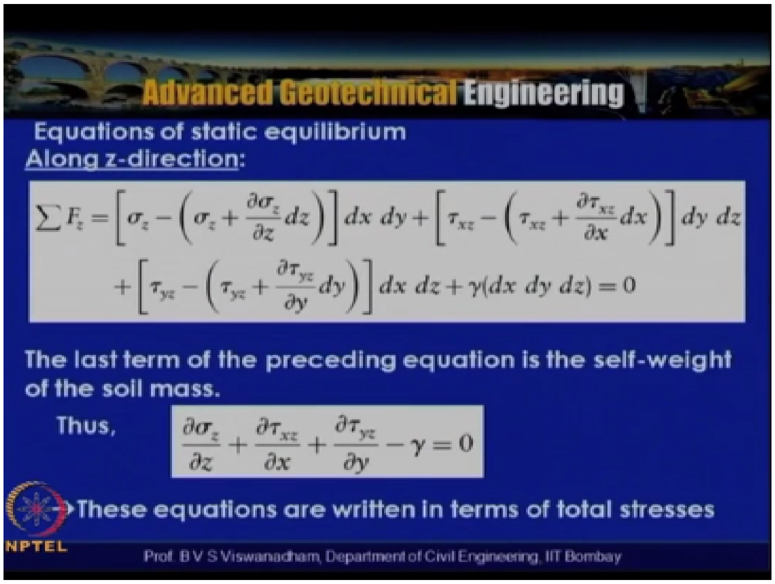

Similarly, in the Z direction also we have taken and with that what we have got is that ∂σz/∂z+∂τxz/∂τx+∂τyz/∂y-γ=0. Here what has been done is that the self weight of the element that is γ, there is a unit weight of the element, the soil in the element into volume, what we have taken is that weight force has been taken. So that is the result why in only in the Z direction it is appearing.

For example, if you are having some initial forces in X direction or some body forces like C+4 which is acting, then also if you are having γx γy and γz, then we may also get this equilibrium equations with γ term as the one of the last terms in the static equilibrium equations. So these equations are written in terms of protest stresses. Whatever the now we have discussed this static equilibrium equations, they are, you know in terms of total stresses.

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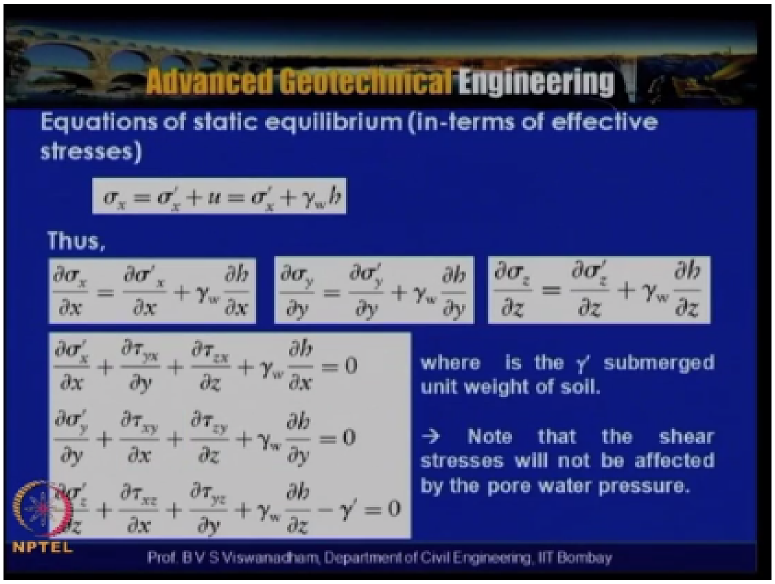

Now let us see equations of static equilibrium in terms of effective stresses. Now we know that $\sigma x = \sigma' x + u$ that can be written as $\sigma' x+\gamma wh$ and now by differentiating this we get this is $\partial\sigma x/\partial x=\partial\sigma' x/\partial x+\gamma w\partial h/\partial x$. Similarly, $\partial\sigma y/\partial y=\partial\sigma'/\partial y+\gamma w(\partial h/\partial y)$ $\partial\sigma z/\partial z=\partial\sigma' z/\partial z+\gamma w\partial h/\partial z$. Now what we do is that we know that in terms of proper stress, now you know we convert that into effective stresses.

So we can write this equilibrium equations as $\partial\sigma' x/\partial x+\partial\tau yx/\partial y+\partial\tau zx/\partial z+\gamma w\partial h/\partial x=0$. Similarly, in the Y axis $\partial\sigma' yy/\partial y+\partial\tau xy/\partial x\partial\tau zy/\partial z+\gamma w\partial h/\partial y=0$. Similarly, in Z axis $\partial\sigma' z/\partial z+\partial\tau xz/\partial x+\partial\tau yz/\partial y+\gamma w\partial h/\partial z-\gamma'=0$. Γ' is the submerged unit weight of the soil. Note that the shear stresses will not be affected by the pore water pressure.

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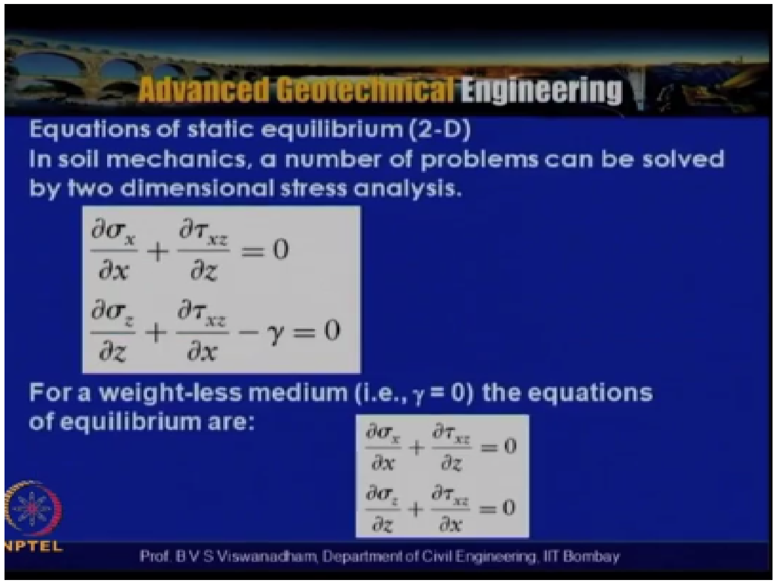

Now for convenience here the equations in two dimensional equilibria or even and soil mechanics, the number of problems can be solved by two dimensional problems. Like returning wall problem or ST footing, for example, they are called plane strain problems. And a tunnel, a long tunnel a load amendment, so all those things are the examples of plane strain problems where two dimensional analysis can be done.

So in the case of two dimensional with plane strain problems, the main in the two equations of static equilibrium required to be satisfied or, if they are X and Y direction, and Z direction is perpendicular to the plane of the along the length of the structure. Then it is $\partial\sigma x/\partial x$, that is Y is perpendicular along with the length of the structure. Then $\partial\sigma x/\partial x+\partial\tau xz/\partial z=0$, that is the Z is the depth axis, X is the horizontal axis, plus $\partial\sigma z/\partial z+\partial\tau xz/\partial x-\gamma=0$.

So for weight-less medium that is that if you are considering a weight-less medium then the equations are reduced to where that γ 10 will get vanished and then we have the static equilibrium equations as $\partial\sigma x/\partial x+\partial\tau xz/\partial z-0$ + $\partial\sigma z/\partial z+\partial\tau xz/\partial x=0$.

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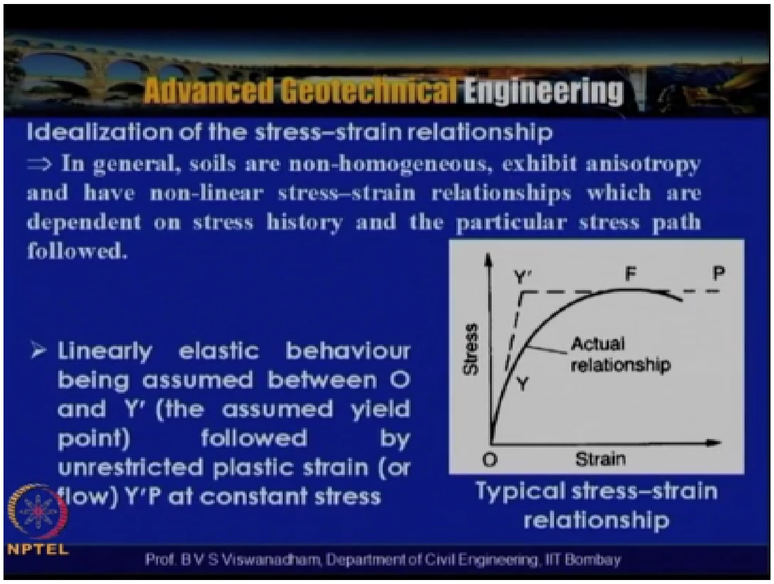

Now let us look into the idealized, you know idealization of the stress strain relationship once again. Some general what we are, you know speaking is that the soils are non-homogeneous, and they exhibit anisotropy and have highly nonlinear stress strain relationships, which are dependent on this stress history and the particular stress path followed. So in general the soils are non-homogenous, and exhibit anisotropy, and have nonlinear stress strain relationship which are dependent on stress history and the particular stress path followed.

So in this particular figure again a typical stress strain relationship is shown here, a stress and strain. And this is the actual nonlinear relationship and this is the idealized relationship that is O and Y’ and Y’P which is, this portion is the linear and this portion is the plastic state. So linearly elastic behavior is assumed, being assumed between O and Y’, and that is the assumed to the yield point.

And followed by unrestricted plastic strain or flow at Y’P. So this is Y’P with unrestricted plastic flow is assumed where no stress increase will be there with an increase in the strain. So this is what actually this particular actual lesson should be idealized to a OY’. So the linear elastic behavior being assumed between O and Y’, and then Y’P is idealized as unrestricted plastic strain.

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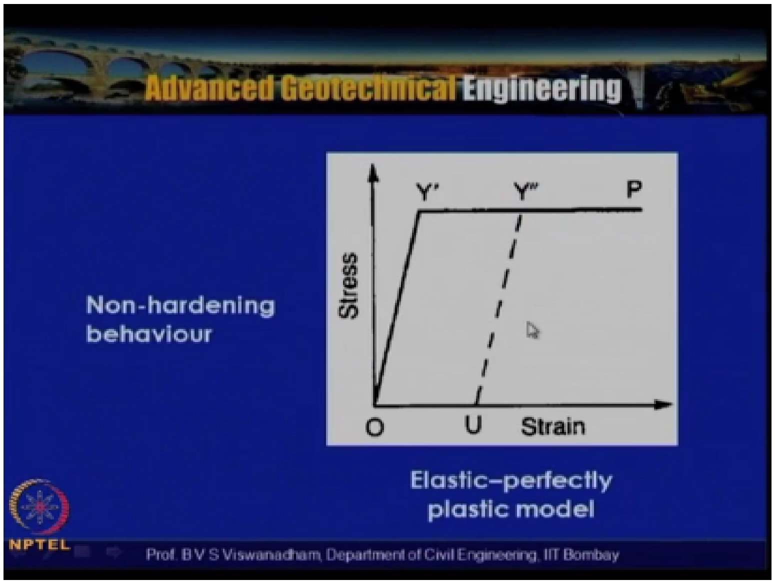

So this is the non-hardening behavior wherein we have got this OY' and Y'P.

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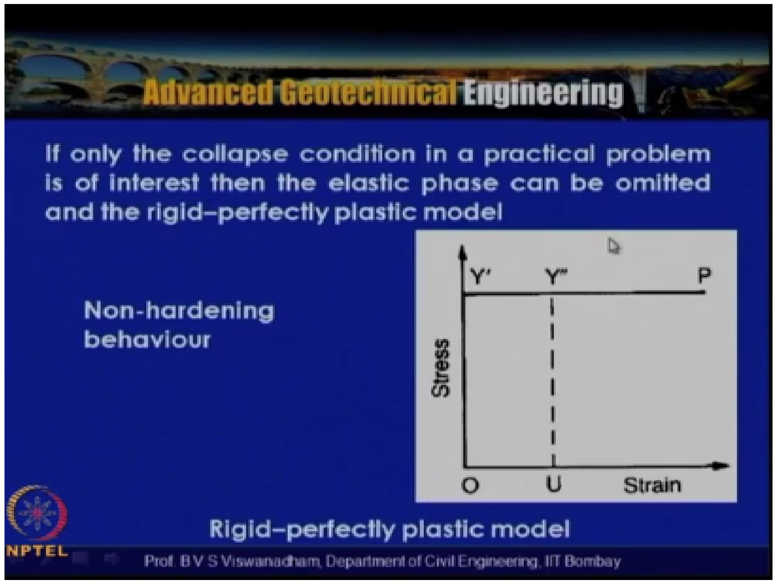

If only collapse condition in a practical problem is of interest, then the elastic phase can be omitted and rigid-plastic model, rigid-perfectly plastic model can be assumed. So that means that the linear elastic segment is ignored, then directly we have taken the OY' and Y'P. So this is nothing, but a non-hardening behavior and rigid-perfectly plastic, this is this trusted relationship is indicated as rigid-perfectly plastic, that is OY' and Y'P.

So this is only, if only the collapse condition in a practical problem is of interest, then the elastic phase can be omitted and rigid-plastic model, rigid-perfectly plastic model can be considered.

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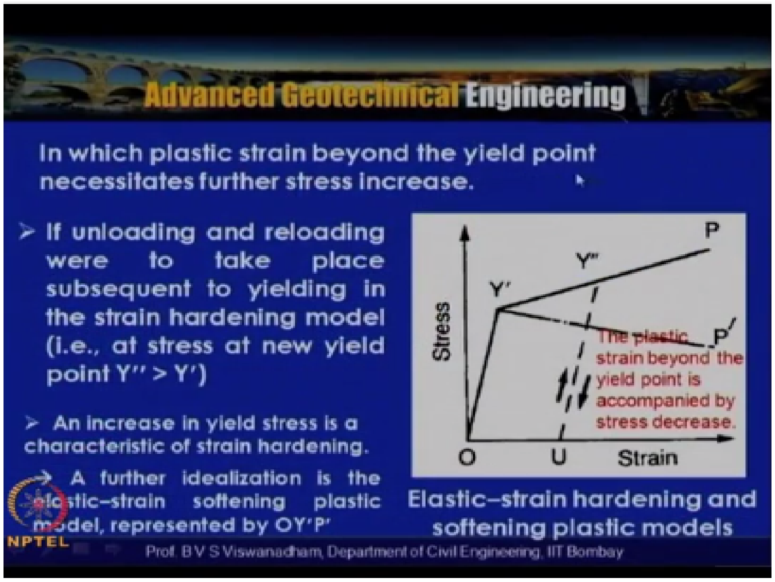

Now then, in which the plastic strain beyond the yield point and this is yet the further stress increase. So if unloading and this is particularly elastic strain hardening and softening plastic models. That means that sometimes beyond, you know the yield point there can be hardening or there can be softening, you can see that in increase in the stress or decrease in the stress.

If unloading and reloading were to take place subsequently, subsequent yielding in the strain hardening model, then the stress at the new yield point is Y'' which is greater than Y'. Suppose if unloading and reloading were to take place subsequent leading in the strain hardening model, that is at stress at new yield point Y'' is greater than Y', so an increase in the yield stress is a characteristic of strain hardening.

A further idealization is the elastic strain softening the plastic model is represented by OY'P'. So this is, you know softening model, elastic strain softening model. And this is elastic strain hardening model where the stress increase will happen beyond the point and here the plastic strain beyond the eyelid point is accompanied by a stress increase, stress decrease. The plastic strain beyond the yield point is accompanied by the stress decrease.

That in this case, this model is actually called as the elastic strain softening plastic model. In this case this is actually called as the elastic strain hardening model.

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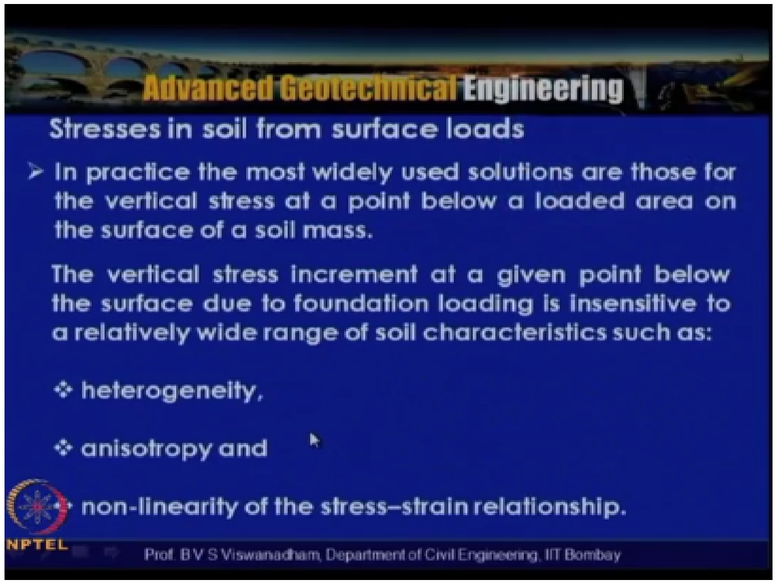

So after having seen different, you know the elastic perfectly plastic and rigid plastic models, you know we try to look in to analysis of the stresses in soil from surface loads, and further we will actually use this knowledge in, when we discuss about the shear strength. So the stresses in soil from surface loads in practice the most widely used solutions are those for the vertical stress at the point below the loaded area on the surface of a soil mass.

So whenever the different types of surface loads of different shapes and different, because of different structures the stresses are actually transferred to the soil. So in fact the most widely used solutions are those for the vertical stress at a point below the loaded area on the surface of a soil mass. Basically for vertical stress, but you can also get as we said in a element when it is subjected to loading we can also get the shear stresses in acceleration X direction, XY direction, Z direction, XZ direction and all. And the planes on which this shear stresses are acting.

So the vertical stress increment at a given point below the surface due to foundation loading is insensitive to a relatively wide range of soil characteristics such as heterogeneity, anisotropy and nonlinearity of the stress strain relationship, that is what we just discussed, the vertical stress increment at a given point below the surface due to foundation loading is insensitive to a relatively wide range of soil characteristics such as heterogeneity, anisotropy and nonlinearity of the stress strain relationship.

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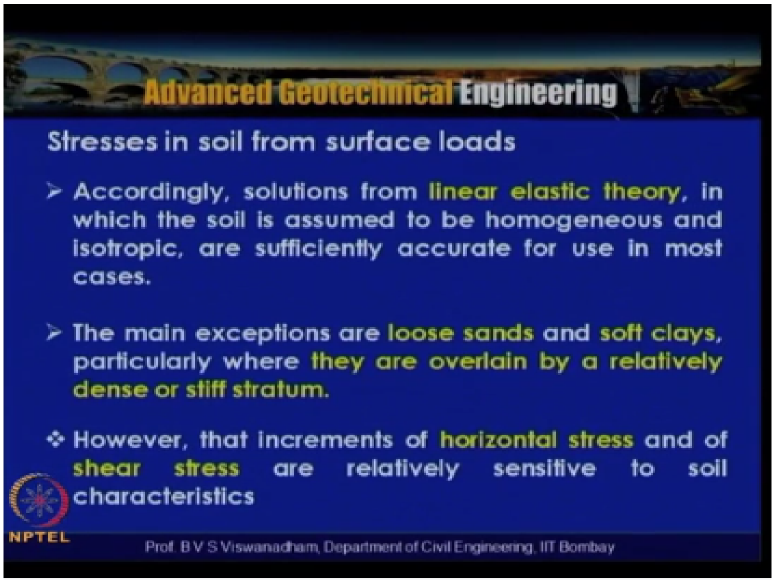

So accordingly the solutions from linear elastic theory in which the soil is assumed to be homogenous and isotropic, and are sufficiently accurate for use in most cases. And the main exceptions are loose sands and soft clays, particularly where they are overlain by a relatively dense or stiff stratum. Then, you know this is some of the exceptions which are followed. However, that increments of horizontal stress and of shear stress are relatively sensitive to soil characteristics.

So the increments of horizontal stress and of shear stress are relatively sensitive to soil characteristics. So mainly we try to determine the increase in the vertical stresses due to these surface loads.

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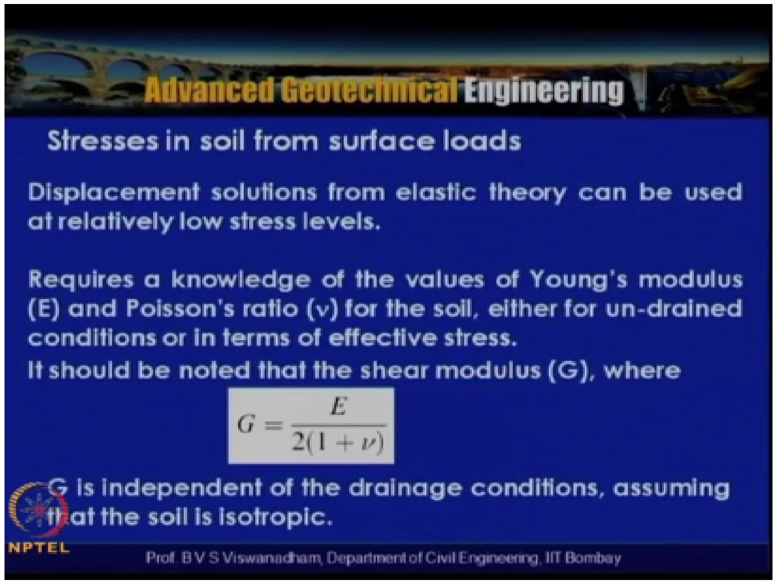

So displacement solutions from elastic theory can be used at relatively low stress levels. Requires a knowledge of the values of Young's modulus E and Poisson's ratio ν for the soil, either for un-drained conditions or in terms of effective stress. It should be noted that shear modulus G, where G=E/2(1+ ν), G is independent of the drainage conditions, assuming that the soil is isotropic.

If you assume that the soil is isotropy then G is independent of the drainage condition, and assuming that the soil is isotropic. The stresses in soil from surface loads we are discussing.

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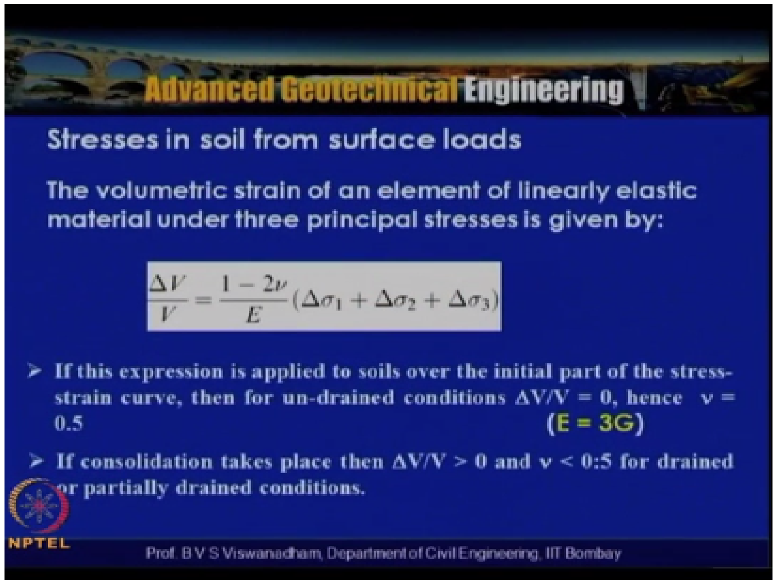

And particularly we are now talking about the volumetric strain of an element of linearly elastic material under three principle stresses is given by $\Delta v/v=1-2\ \nu/E(\Delta\sigma1+\Delta\sigma2+\Delta\sigma3)$. If this expression is applied to soil is for the initial part of the stress strain curve, then for un-drained conditions the $\Delta v/v=0$, and once you put $\Delta v/v=0$ with $\nu=0.5$ then for un-drained conditions E=3 times G that is the G is nothing but E/3.

And if consolidation takes place then $\Delta v/v$ greater than 0, then ν will be less than 0.5 for drained or partially drained conditions. If consolidation takes place then $\Delta v/v$ greater than 0 that means that there is some volume change occurs. And the Poisson's ratio will be less than 0.5, and for drained or partially drained conditions.

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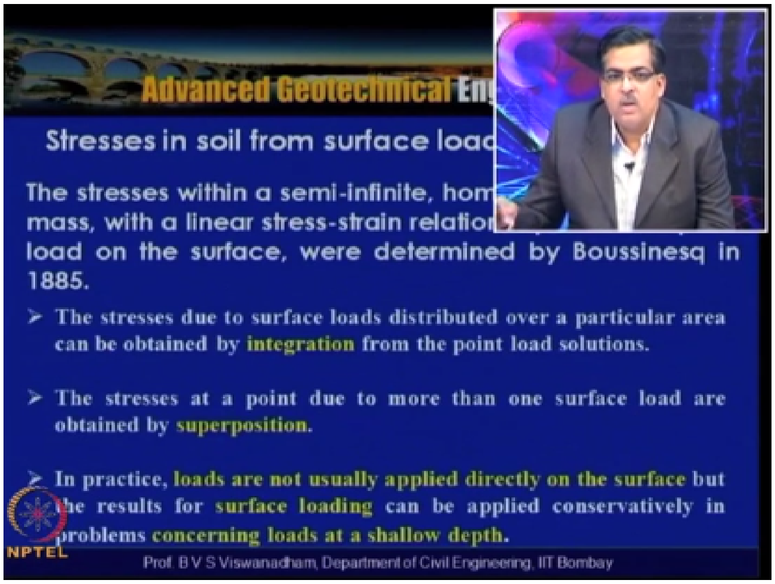

So the stresses within a semi-infinite, homogenous, isotropic mass, with a linear stress strain relationship, due to a point load on the surface, were determined by Boussinesq in 1885. The stresses due to surface loads distributed over a particular area can be obtained by integration from the point load solutions. And the stresses at point due to more than one surface load are obtained by superposition.

In practice loads are not usually applied directly on the surface but the results of surface loading can be applied conservatively in problems concerning loads at the shallow depth. So we compute, we assume that the loads are applied on the surface, but in practice the loads are not applied directly on the surface, but the results for this surface loading can be applied conservatively in problems concerning loads at the shallow depth.

If you're actually having, you know one or two loads, then the superposition principle will be used, and if you wanted to get the effect due to stresses or certain depth, the integration principle is used. The stresses due to surface loads is distributed over a particular area, can be obtained by integration from the point load solutions.

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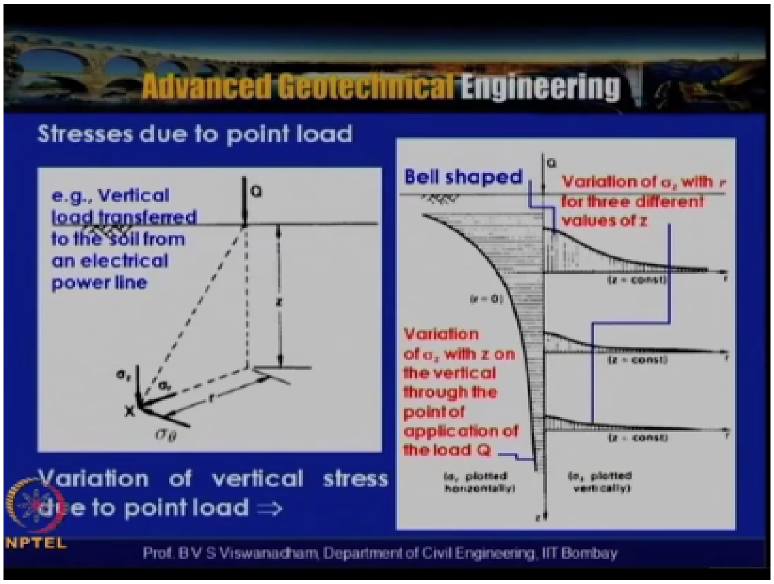

Now let us consider the stresses due to point load. So point load are concentrated load, vertically, vertical load transfer to the soil from an electrical power line. So one of the practical examples is that for the point load is the vertical load transferred to the soil, from an electrical power line or electrical pool. So Q is the concentrated load, and we are interested in determining the stress at a depth Z and the vertical stress and σr is the stress in the radial direction, σ θ in this direction.

Now the distribution of vertical stress σz with depth is given here which is actually here like a curve which takes the shape like this. And it is high close to the surface, and as you go deeper the vertical stress effect decreases. So variation of σz with z on the vertical through a vertical, through the point of application of the load Q. And at any depth Z1, Z2, Z3, where Z3 greater than Z2, Z2 greater than Z1.

If you look into it, and this is something like the distribution as you go away from the load, the stress decreases. So this is something like a bell shaped curve will come on both sides. And as we go down the magnitude of the increase in vertical stress due to the load at the surface keeps on decreasing. Now you see the theory behind this, the variation of the vertical stress due to point load, which is given in this.

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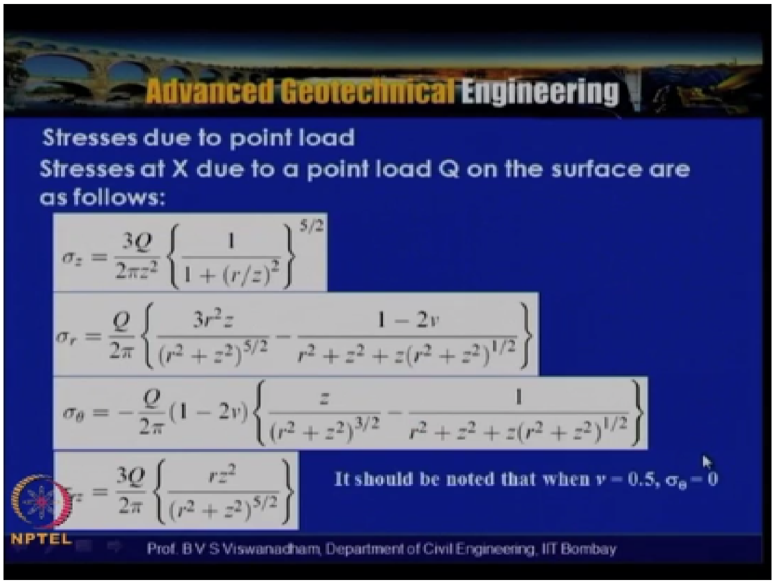

So the stresses at the X due to point load Q on the surface are as follows. And these are actually obtained by, you know taking the equilibrium in the vertical direction let us say for the vertical stress. So $(\sigma z=3Q/2\Pi z^2(1/1+r/z)^2)^{5/2}$. Similarly σr is given here and the σ θ that is the stress in the radial direction and the stress along this direction. Now $rz=3Q/2\Pi((rz^2(r^2+z^2))^{5/2}$, it should be noted that when $\nu=0.5$ σ $\theta=0$, when $\nu=0.5$ σ θ the stress will be 0.

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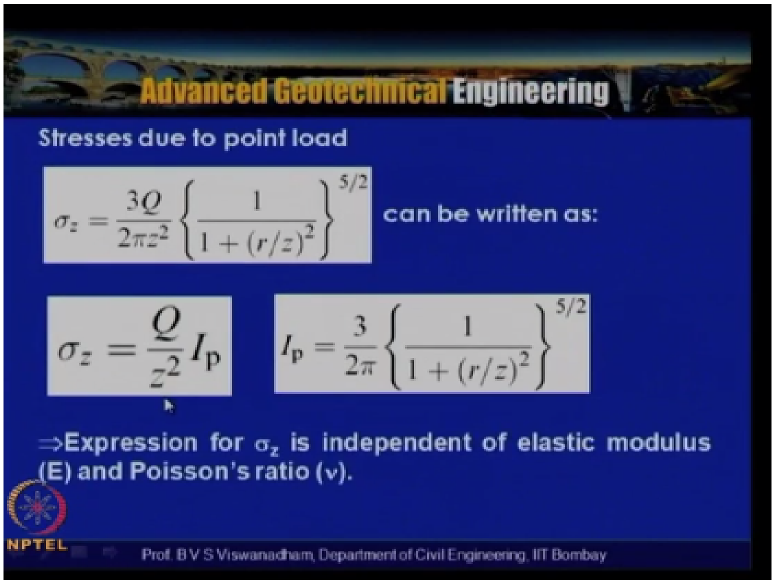

Now stress due to point load, that importantly vertical stress we can write it as $\sigma z=3Q/2\Pi z^2((1/1+r/z)^2)^{5/2}$ and this can be written as $\sigma z=Q/z^2(IP)$ where $IP=3/2\Pi((1/1+r/z)^2)^{5/2}$. So this is the expression for σz which is independent of elastic modulus and Poisson's ratio. You can look into it, the expression for σz is independent of elastic modulus and the Poisson's ratio. Now influence factors for the vertical stress due to point load can be given like this.

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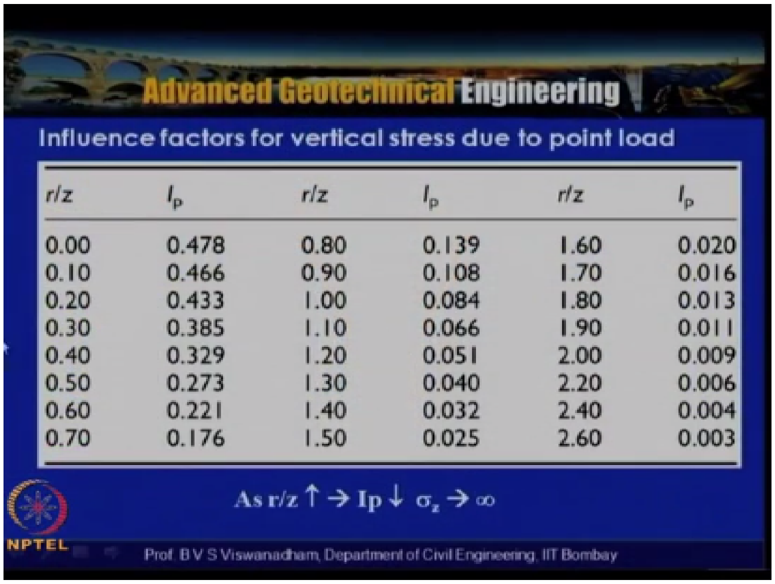

And this table is actually shows for different values of r/z and IP values. IP are is also called as I with suffix P, that is I Boussinesq, and r/z. When r/z=0, so this is for different r/z values we can look into it, this is one set of r/z, this is another set of r/z, this is another set of r/z. When r/z=0 IP will be 0.4775 which is actually simplified as, you can say that 0.478. So you can look into it, so this is r/z=0 to 0.7, r/z=0.8 to 1.5, and r/z=1/6 to 2.6.

So as we go deeper and deeper you can see that the IP value is decreasing. So as r/z increases IP decreases and σz, you know tends to be ∞. So influence factors for the vertical stress due to point load, that means close to the, you know load the stresses are, you know close to the ∞ σz this thing. But at a certain depth, you know they also diminish.

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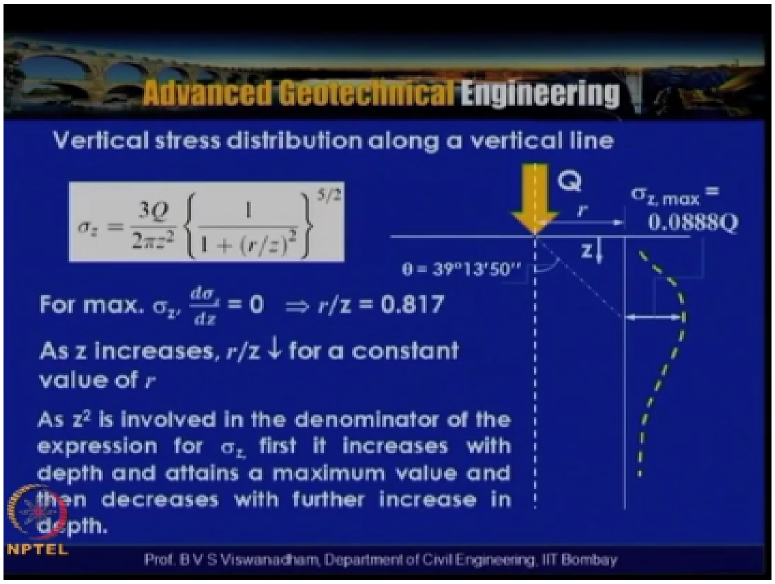

So vertical stress distribution along with the vertical line, this can be obtained by $\sigma z=3Q/2\Pi z^2((1/1+r/z)^2)^{5/2}$, one for maximum σz if you differentiate this and equate it to 0, then by simplification we get r/z=0.817. When r/z=0.817 then the σ, the distribution of the vertical stress follows this type of curve, where we have, there is an increase and it reaches to the maximum value, and that maximum value at, you know this particular depth is σz max = 0.0888Q.

And this is the stress, maximum stress σzmax, and then this has again decreases for a certain depth. So here you can just see that in this expression as z^2 is involved in the denominator of the expression for σz, first it increases, then with the depth and attain a maximum value, and then decreases further with an increase in the depth. So this all be the vertical distribution along a vertical line, not at the center, but at a distance away from the r, from this thing that is how the stress variation, the distribution of the clear stress will be like this.

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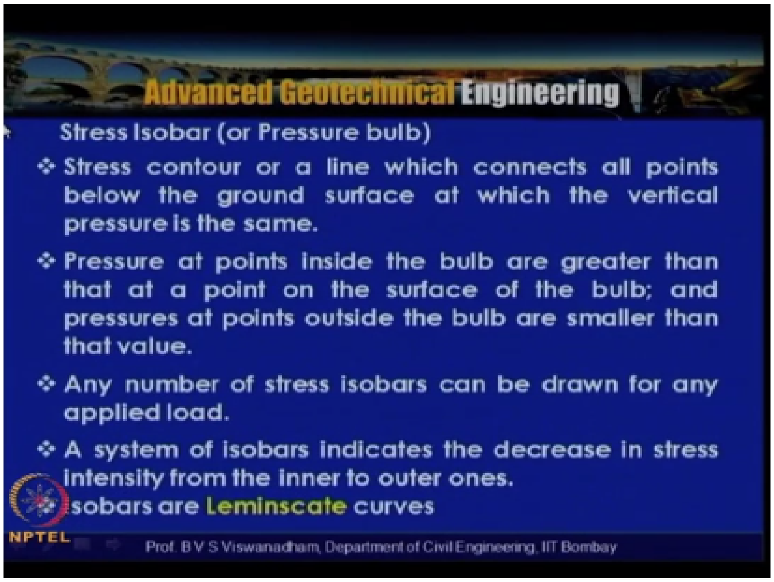

Now as we said that we have understood that, you know the stresses, you know they have, whenever the surface is actually loaded with certain type of a loading, then there is certain influence zone. So this is defined by stress isobar or a pressure bulb. So this stress contour or a line which connects all points below the ground surface at which the vertical stresses is the same, is called as a isobar, stress isobar, stress the pressure bulb.

So pressure at points inside the bulb are greater than that at a point on the surface of the bulb, and the pressure at points outside the bulb are smaller than that value. So any number of stress isobars can be drawn for any applied load, so innumerable number of stress isobars can be drawn, you know for the applied load. And the system of isobars basically indicate the decrease in the stress intensity from the inner to outer ones.

So that means that as we are actually coming, this is the stress bulb or a pressure bulb resembles like a onion, like from the inner side, inner layers will have the higher stresses, and as you're traversing towards outside, the stress intensity keeps on decreasing. So mostly the stress isobars are not circular curves, and they are actually classified and categorized as Leminscale curves. The stress isobars are the Lemniscates curves. Now let us see how we can actually get the, you know plot the isobar.

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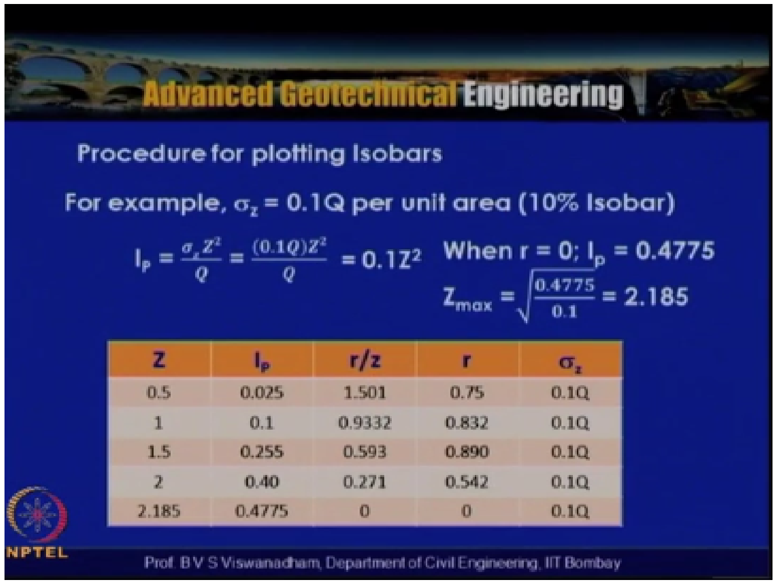

Say for example, let us say that we wanted to plot σz=isobar for 0.1 times Q for unit area. That is 10% isobar we wanted to plot. So now we know that σz =Q(IP/z^2) so we write IP=σzz^2/Q, by substituting for σz=0.1Q we can write 0.1Q(z^2/Q), so we get 0.1z^2. So when r=0, IP=0.4 sense of 5 we said. So the depth of the pressure bulb or depth of the isobar can be obtained by zmax= √0.4775/0.1=2.185 units is the depth.

Now we can actually take Z and IP and r/z, r and σz, so with that what we can do is that, once you substitute say z=0.5, then we can calculate what is IP and r/z and r. So by knowing r and z we can actually plot, and then the stress intensity along that particular Leminscale curve portion is 0.1Q. Similarly, the last point that is being Zmax = 2.15 and at the center where r=0, IP is 0.4775 and r/z=0, and r=0, that is also intensity is 0.Q. So like this by using this procedure we can actually determine the stress isobar.

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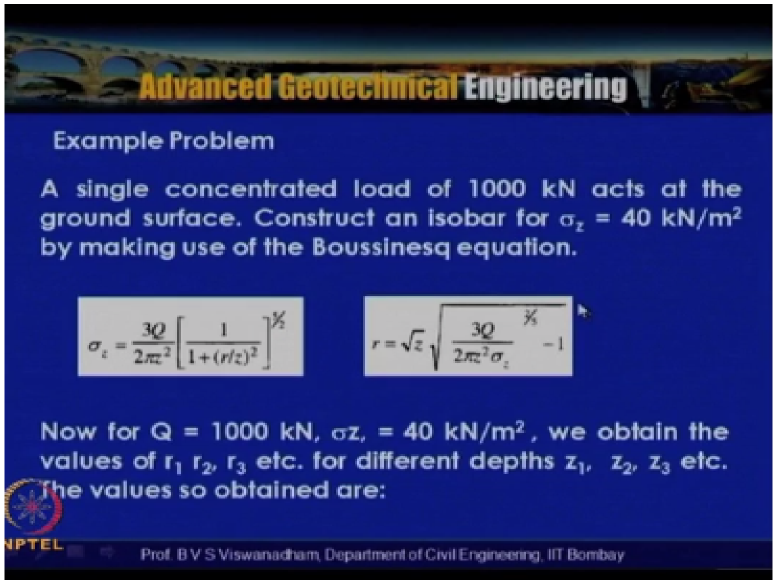

So example problem let us consider, a single concentrated load of 1000KN, acts at the ground surface. So we need to construct an isobar for σz=40 KN/m^2 by making use of the Boussinesq solution. So let us consider$\sigma z=3Q/2\Pi z^2(1/1+(r/z)^2)^{5/2}$. Now we can simplify this by taking r out, r= $\sqrt{z}(\sqrt{3Q/2\Pi z^2(\sigma z)})^{2/5-1}$. So now for Q=1000 KN, σz = 40 kilo pascals, we obtain the different values of r1, r2, r3 for different depths, different depths z1, z2, z3. So the values can be obtained.

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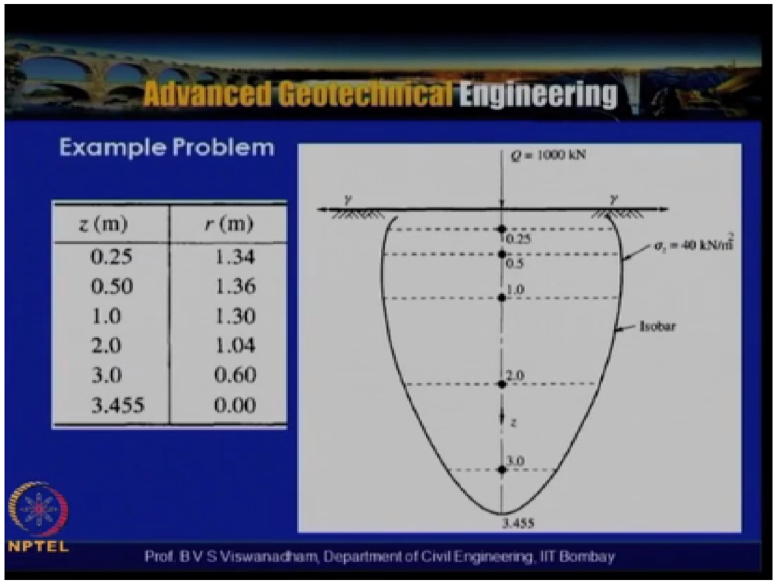

z (m)	r (m)
0.25	1.34
0.50	1.36
1.0	1.30
2.0	1.04
3.0	0.60
3.455	0.00

So similarly by, otherwise by using now the example which we have done earlier, so by putting different values, we can actually calculate and this is how the isobar are influenced zone. So this is very much important sometimes if you are having say, isolated fooding, and you know, if you are having the load, trying to see what is the depth of extent of the influence of the zone. Suppose, if you having some week zones, then these zones can actually undergo the settlements.

So these, you know the predictions of these, the extent of the influence is actually helps here. The stress isobars are pressure bulb indicates the zone of influence. So you can see that, this is the Zmax that is 3.445, which is actually indicated here. So this is for 1000 KN load, this is how the, you know this isobar for a σz=40 kilo Pascal's is given. Suppose, it will be 20 here, somewhere here will be there.

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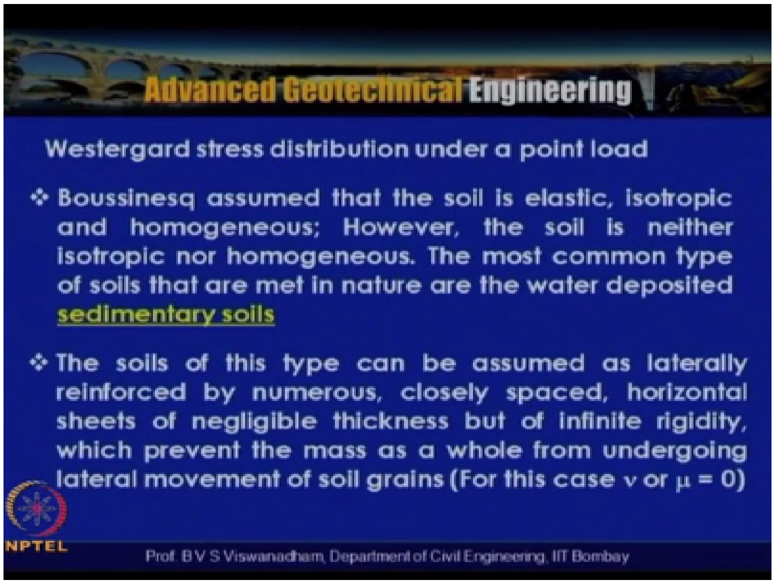

So, and mostly, you know the two solutions are actually popular, one is, you know Boussinesq solution, and Westergard solution. We also compare in the Westergard stress distribution under the point load let us say. So Boussinesq assumed that the soil is elastic and isotropic and homogeneous. But however the soil is neither isotropic nor homogeneous. The most common type of soils are met in nature are the water deposited in sedimentary soils.

That means that we have ordinary layers of clay and truly compressible layers and laterally incompressible layers like sand. So we have like say in alluvial soils where clay and sand, clay and sand deposits are there. So the sedimentary soils where we actually have got, you know the most common type of soils or this stratified soils. So soils of this type can be assumed as laterally reinforced by numerous, closely spaced, horizontal sheets of negligible thickness.

But infinite rigidity, which provide the mass as a whole from undergoing lateral movement of the soil grains. So for this case ν or $\mu = 0$, so here, you know what Westergard has actually assumed is that the soils of these type can be assumed as laterally reinforced by numerous, closely spaced, horizontal sheets of negligible thickness, but infinite rigidity, which prevent the mass as a whole from undergoing lateral movement of soil grains. So with that the theory if you look into the solution proposed by Westergard σz is given by.

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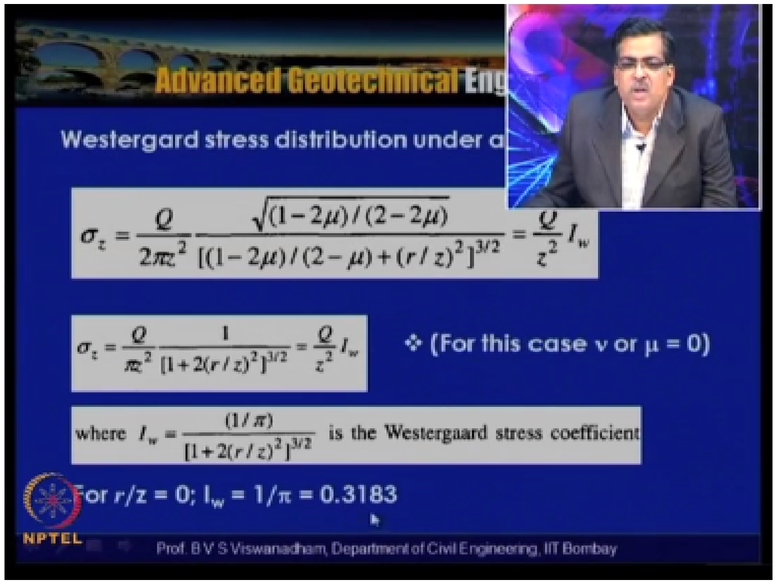

Q / 2πz2 in the √ of 1 – 2 μ / 2 – 2 μ / within square brackets of 1 - 2 μ / 2- μ + R / z whole square to the raise 3 / 2 which is indicated by Q / z2 into I and w iw is impressed factor for the westergard stressed machine for point load and for the case where μ = 0 the westergard equation for stressed machine for vertical low practical stress is reduced to σz = Q / πz2 into 1 / 1 + 2 x R/z2 / 3/2 so that Q/ z2 into iw so iw is inference factor as far as the westergard is also called as westergard task question and which is iw = 1/ π/ 1 + 2 are proved R/z2 to the raise 3/ 2 for R/z = 0 iw = 1 / π which is nothing but 0.3183 so you can see that this is actually you know 0.3183.

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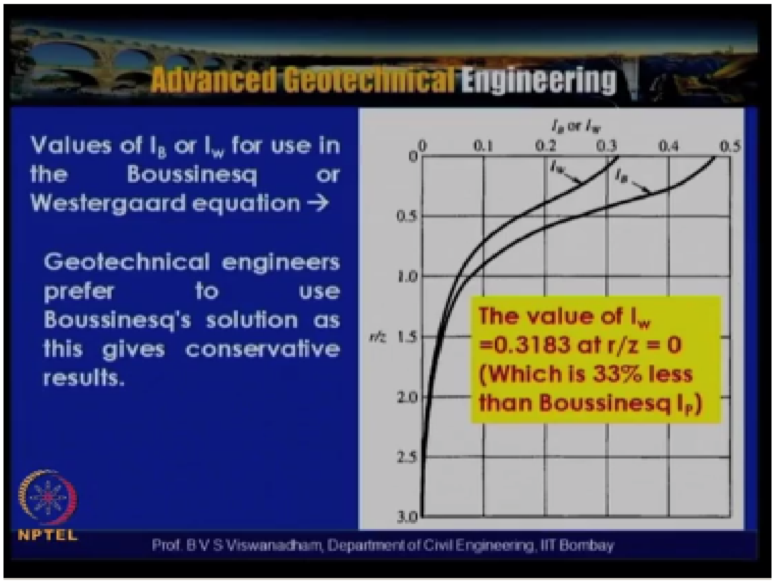

So now here if you look into the plot this is the Bosussinesq and which is influence factor of due to Boussinesq theory and this is the influence factor due to westergard theory, so values of you know iw are ib or iw for used in the Boussinesq and westergard equation and this is the depth axis r/ z so you can see that at up to 1.5 up to r/z = 1 there is a distinct variations is there and the value of iw which is = 0.3183 at r/ z = 0 which is 33% > the Boussinesq influence factor which is 0.478 or 4.4775 so because of these by joule technical engineers actually preferred to you is the Boussinesq solution.

As that this gives the conservative results but these westergard series also used in a determining the stress particularly for the payments when we are actually having two layers system in trail layer system and this series is actually extended in determination of the stress in the pavement layers now after having considered you know the you know different types of theories where two different theories for point logs, now what we do is that we would try to use the whatever the knowledge we gained from the Boussinesq solution for the point load we extended to the word types of loadings now you assume that we have series of you know line loads a line load which is actually.

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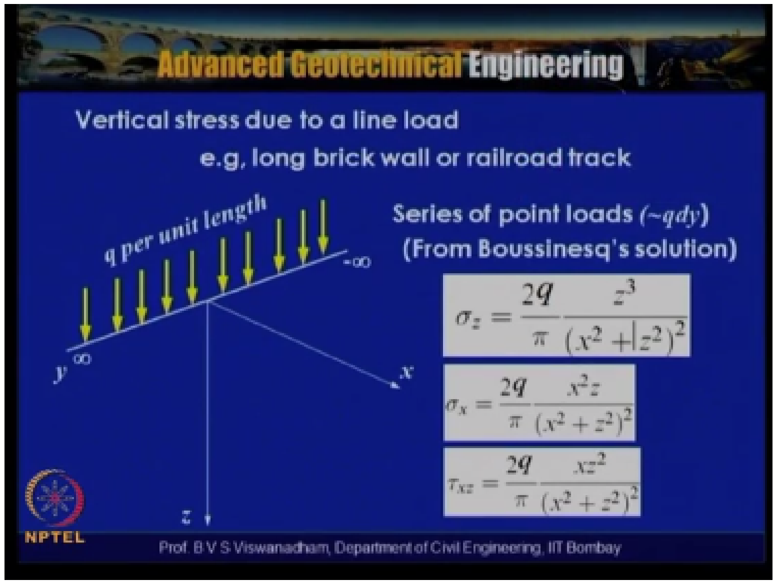

Giving so example of the for the line load in the real practical problem is that a long brick wall are a rail road track if you are having a two tracks two rails then that is actually that is actually two for a broad cage that as says 1.65m they separated by two lines is separated by separate distance, so a long brick wall are a rail road track is example for the vertical stress due to a line load, so the series of point loads which is actually given so what we do is that along the length y you take a load intensity q per unit length into dy.

So assume that there are series of point load which are actually there so by using that Boussinesq solution we can get stress depth z in terms of the Cartesian code nets x and x along the other axis and depth along the depth axis is z σz = 2q/π x z3/x2 + z2 to the raise 2 and σx is nothing but in the σx is nothing but 23 / π x x2 z x x2 +z2 to raise and τxz = 23 / π into xz2 into x2 + z2)2 so here by knowing the σx so this is you know when we have a line load let us say if we are got a returning structure.

So we actually calculated the certain depth what is the increasing the horizontal stress due to a presence of a line load or if you are having a returning wall and you know there is say two rail tracks are actually going parallel to the length of the road, then you know we can actually true mean what is increase in the stress long the length of the wall that is by the σx, so σz here is obtained from the Boussinesq solution here what we have done is that we actually have taken qdy as the point low and integrated what this length between - ∞ into + ∞ then with that we have got σz these 2q/π into z3 by x2 + z2)2 so vertical stress should stress would line load.

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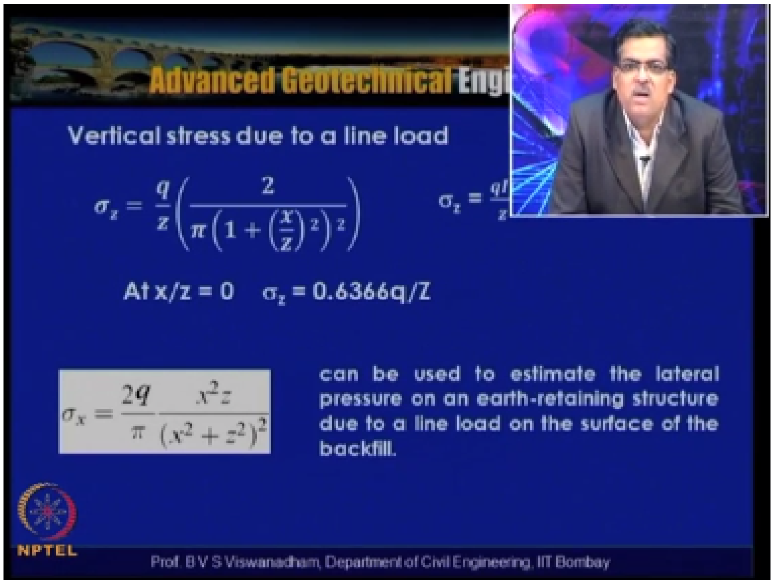

Can be given by signification like σz = q / z 2/1 π into 1 + x /z whole to the raise two so this is gain indicated by a in terms of σz = q il/z il is then influence factor for the line load and at the xyz = 0 that il = 0.6366 into q/z so σz = 0.6366q /z that xyz = 0 so σx now as I said 2q/π into x2z into x2 + z2 to the raise two this a be used to estimate the laterals pressure and lateral pressure on earth-retuning structure due to the line load on the surface of the back fill, how it can be done that is looking do it.

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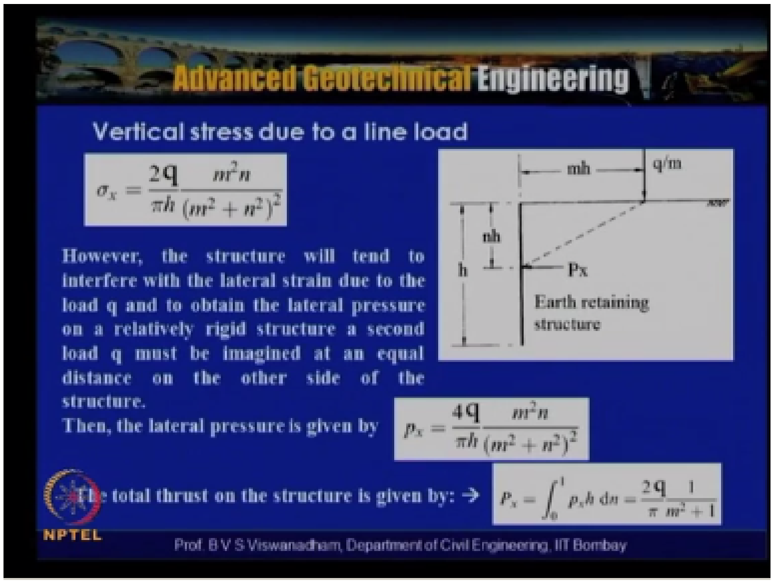

So if you assume that there is a retaining structure and in the dimension form here let us assume that it is in the m times h and n times h let us say the h is the height of the retaining structure and at a distance from the top of the returning one the del density is actually acting at m times h away from the that is q per unit length is actually acting what is assume that there is a brick wall or a boundary wall is actually just in here, when you will see that what is the influence of this boundary wall on the lateral thirst existed on the wall.

So the basic by using the expression which is given for the horizontal stress obtained from the Boussinesq solution we can write $\sigma x = 2q/\pi h$ into m2n / m2 + n2 whole square, so however the structure will turn to interfere with the lateral strain due to the load q and to obtained the lateral pressure on relatively rigid structure the second lay out q must be imagine when an equal distance on the other side of the structure, so for the two you know two line looks two you know line loads.

The lateral pressure is actually given by $px = 4^3/\pi h$ so this is multiplied simply by 2 $4^3/\pi h$ into m^2n the m2 = n2 the whole square, so we can actually get the total thrust on the structure is given by P suffixes 0 to n there is P_xh into dn which is nothing but $2^3/\pi$ into / 1 / $m^2 + 1$, so this is the total thrust exited on the so, by union by knowing m which is the coefficient which is multiplied and so many times the height h and by knowing the load intensity per unit length and we can actually calculate what is the lateral thrust of the sector in depth, so vertical stress due to the strip load if you look into to it.

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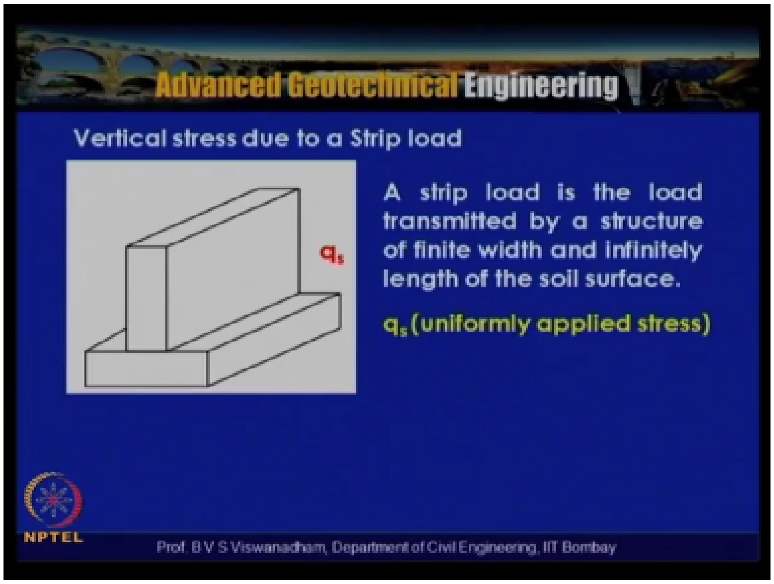

A here strip load is the load transmitted by a structure a finite with of infinite length of the soil surface, so before looking into this let us try to look into the problem with one second with how to construct a stress isobar for you know if the point load is about 2000KN so let us look into this particular problem.

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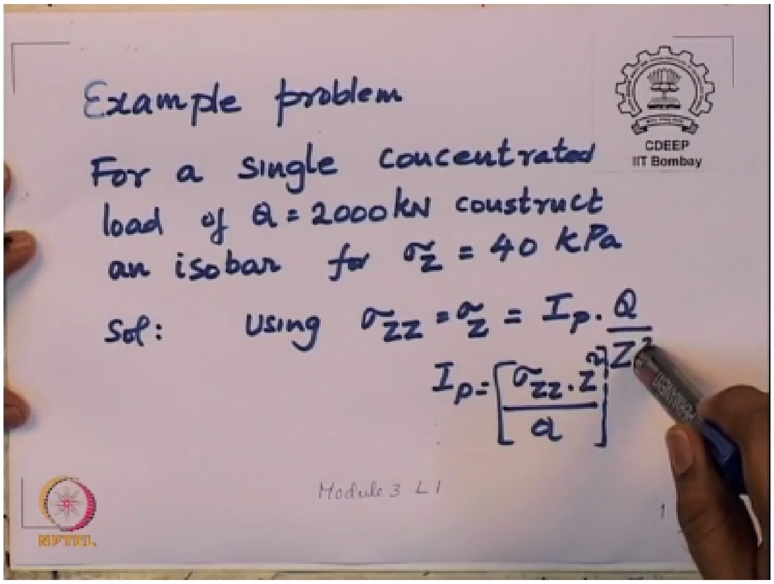

Where in we have the example problem for a single concentrated load of Q 2000KN and construct and isobar for σ = 40KP so here the solution runs like this σzz = σz = T_p into Q/Z2 that is what actually we have discussed in this lecture now IP = σzz into Z2 / Q which is nothing IP = σzz into Z2 / Q so what we have done is that we have rewritten this expression is IP in terms of IP = Z2 into σz / Q now what we do is that we know the σz the for which intensity we wanted to determine.

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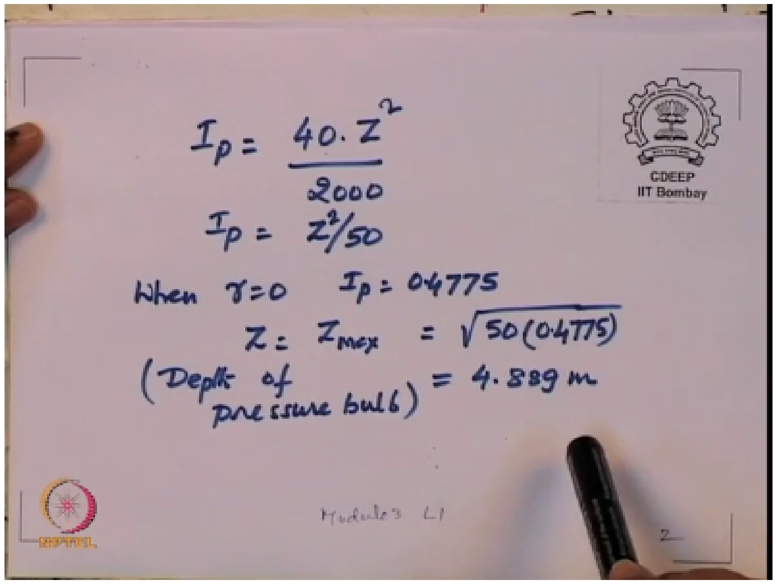

So for to get that what we do is that IP = 40 into Z2 / 2000 so here what we have done is that by putting the intensity magnitude of the point load and by putting this stress intensity for which actually we interested in trying the isobar we can actually that the IP in terms of z, so IP = Z2 / 5, so when r = 0 IP = 0.4775 by using this we can actually calculate what is the depth of the pressure bulb that is Z = Zmax at r = 0 so with that we can actually get Zmax = √ of 50 into 0.47775 with that we can actually gt as 4.89m as the depth of the pressure bulb then after having obtain this like the procedure which we have discussed what we can do is that.

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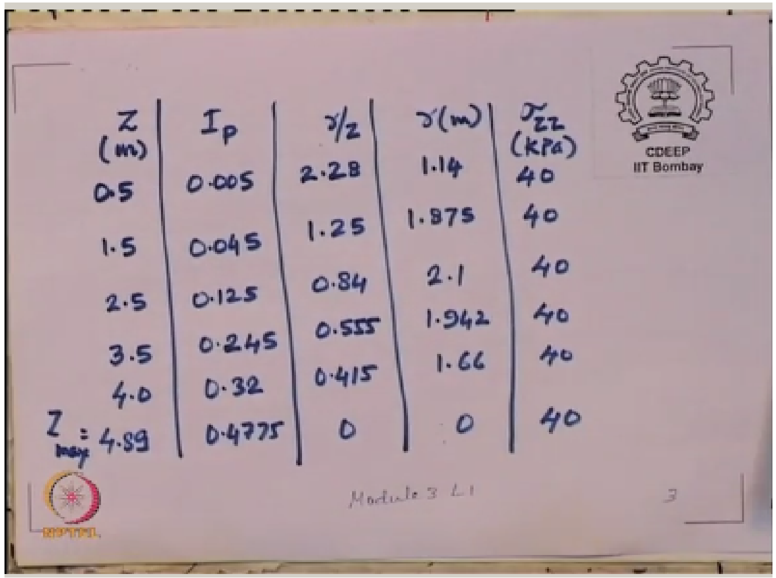

Z (m)	I_P	r/z	r (m)	σ_{zz} (kPa)
0.5	0.005	2.28	1.14	40
1.5	0.045	1.25	1.875	40
2.5	0.125	0.84	2.1	40
3.5	0.245	0.555	1.942	40
4.0	0.32	0.415	1.66	40
Z_{max} = 4.89	0.4775	0	0	40

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We actually take Z on the you take Z = 0.5 1.5 2.5 3.5 so and Z_{max} = 4.89 and for using IP = Z2 / 50 we can actually determine what is the you know values of a IP so that r = 0 which is 0.4775 and r/z = 0 r/r = 0 the stress is again 40KP so by knowing r and z we can actually again plot the here by plotting this unit and on the radius axis radial axis and 0.5m t will be something like a you know in landscape curve portion where we can see that the r is actually increasing that is 2.1 again is dropping down.

So this curve which actually takes the shape is actually you know takes the form a latent state curve and the this will be you know stressing density for a particular Pascal's stress industry suppose if you need isobar for 80KP it will be inside and if it is 20KP it will be outside that particular line, now after discuss into the example problem we continue with the vertical stress due to a strip load so here strip load is the load transmitted by a structure of finite with so here assume that we are having you know we.

We have a boundary wall where it is connected with you know that the foundation for that can be a strip foundation or if you are having a closely spaced columns along the length of the building and all the foundations are corrected along the length that is actually found so like a strip load with the finite width here and the width can be 2a a strip load is the load transmitted by a structure finite with or infinite length along this thing so this is again the you know two dimensional you know two dimensional analysis.

Because of these are called again plane strain structure so qs is nothing but the applied uniformly applied stress over this area, so what we do is that you know for the solution for this we use again extension of Boussinesq solution.

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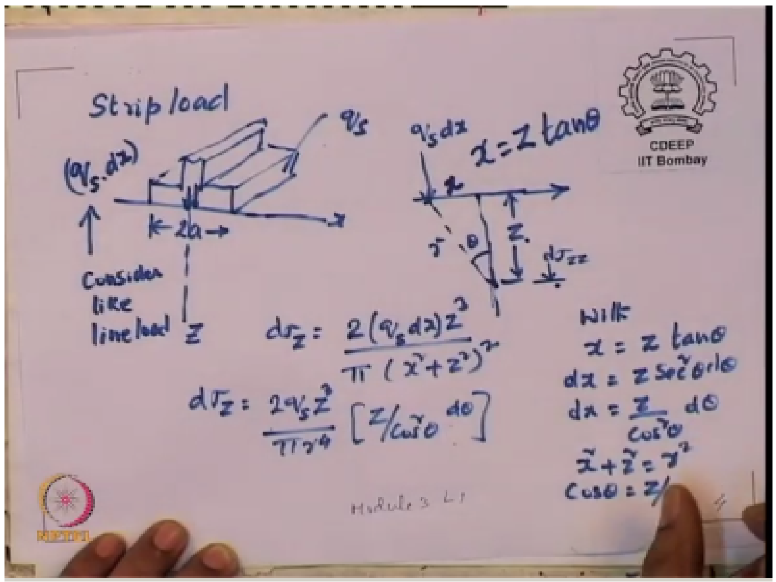

And we have in the define that this is the putting which is actually running and the width is 2a and we have the loading density qs by what we do is that along this is the x axis and this is the depth axis and this width is 2a that is the a this side and a reach this side and a root that side like what we do is that we along this x axis we assume that the qs which is actually again qs into dx so we consider this like a one line load along this length and assume that line load is actually at distance x from here.

And the depth z and so this is the thing that x and this is the depth z x2 + z2 = r2 and Cos θ = z /r and x = this distance is nothing but x = z Tan θ, so dx = z sequence square θ d θ dx = z / Cos^2 θ d θ so by using now the Boussinesq solution which we have obtained for line load what we can write is that small increase in the stress at a depth d σzz = by using the line load expression for the you know vertical stress we can write this σz = 2 but instead of q now we write qs dx that we are considered that as the line load.

This is the intensity but into multiplied by a small r distance d 2qs dx into Z3 / π into x2 + z2 to the raise two, so these σz = 2, 2q was z3 / πr4 z / Cos^2 θ d θ now what we have done is that for dx we substituted $z / Cos2\ \theta\ d\ \theta$ and with that what we have what is that where you simplify further we have got $d\ \sigma z = 2$.

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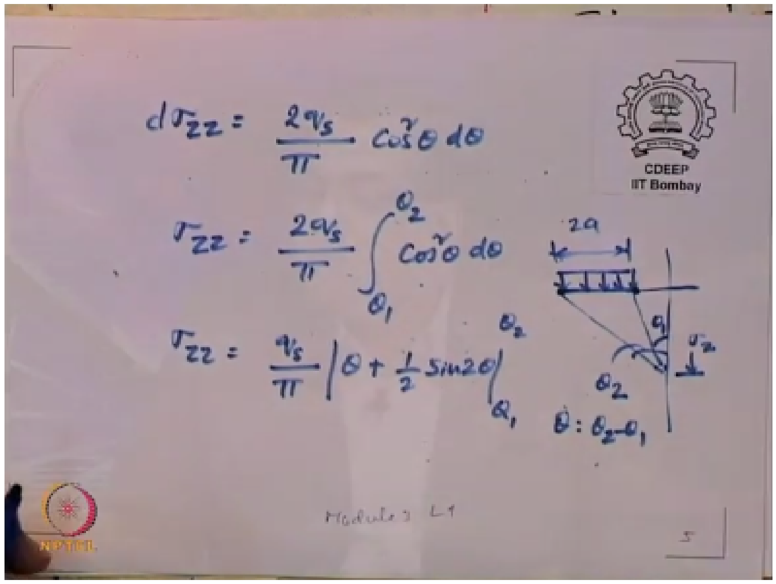

$2qs / \pi Cos2\ \theta\ d\ \theta$ with that $\sigma z = 2qs / \pi\ \theta 1$ to $\theta 2\ Cos2\ \theta\ d\ \theta$ so $\theta 1$ and $\theta 2$ are nothing but where we have the this is the extent of this load and this is another extent of this load this is the strip load so $\sigma zz = qs / \pi$ once after signification we can get in terms of θ, $\theta + \frac{1}{2}$ Sin into θ that is $\theta 1$ to $\theta 2$ so $\theta = \theta - \theta 1$ so what we have got is that if you are having a strip load this is the expression which actually we will get if you are actually having a the so called you know the increase in the stress due to a strip having.

Width which is actually defined by deflect geometry having definite depth of 2a that is the breath of the foundations indicated by b = 2b so in this lecture we have actually try to understudy about the stresses caused by in the soil due to some surface load and this is as a pre you know request for the understanding from the compressibility and consolidation theory in soils.

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NPTEL
Principal Investigator
IIT Bombay
Prof. R. K. Shevgaonkar
Prof. A. N. Chandorkar

Head CDEEP
Prof. V.M. Gadre

Producer
Arun Kalwankar

Project Manager
Sangeeta Shrivastava

Online Editor/Digital Video Editor
Tushwar Deshpande

Digital Vodeo Cameraman
Amin Shaikh

Jr. Technical Assistant
Vijay Kedare

Project Attendant
Ravi Paswan
Vinayak Raut