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**NATIONAL PROGRAMME ON
TECHNOLOGY ENHANCED LEARNING**

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ADVANCED GEOTECHNICAL ENGINEERING

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Lecture No. 49

Module – 6

Lecture – 3: Buried Structures

Welcome to course on geotechnical engineering module 6 in on Buried Structures lecture.

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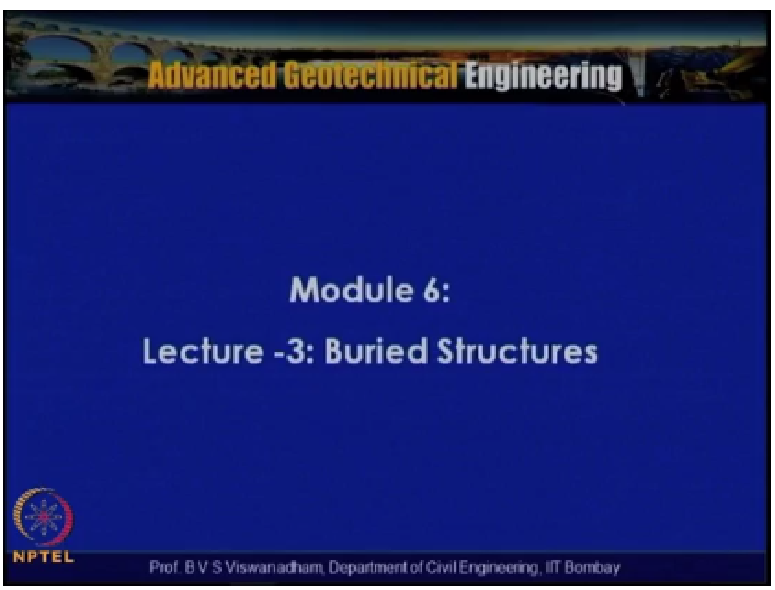

So in the previous lectures we have discussed about Marston's load theory.

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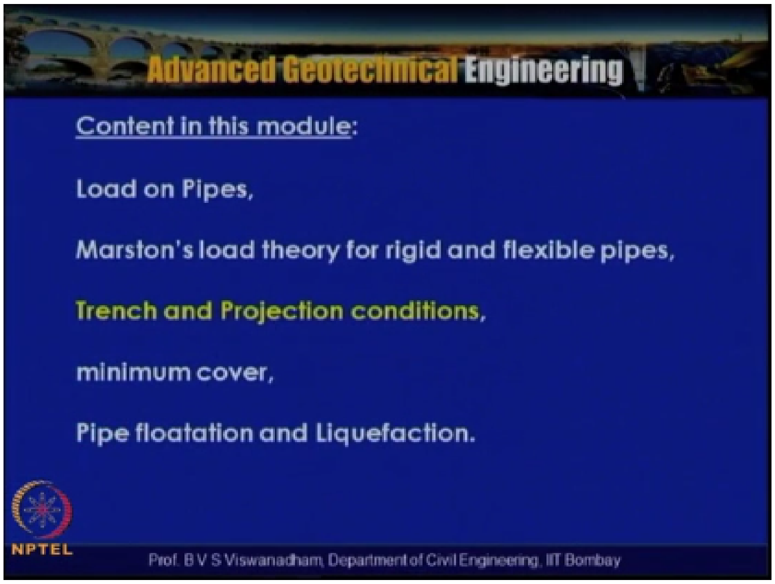

For residual flexible pipes and different trench and projection conditions now let us looking to what are the requirements for the minimum cover and foliation and liquefaction effects on the buried pipes, so in this lecture we are going to discuss about the what are the generally loading conditions which are required and then minimum cover which is required and flotation and liquefaction effects on buried pipes so as the these pipes are subjected to different types of loads.

One such load is live load if it is under installed below a railway amendment or high way amendment is subjected to wheel loads.

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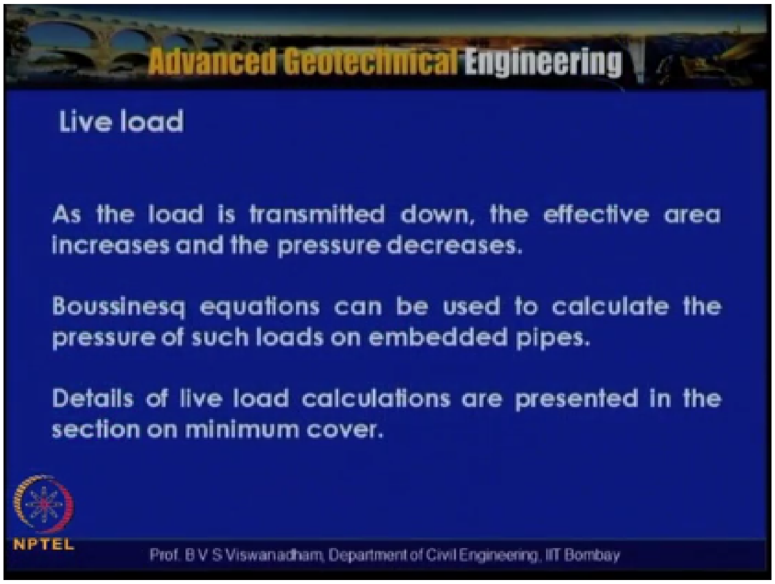

So as the load is transmitted down the effective are increases and the pressures decreases so naturally what happen is that as the load which is applied at the surface takes diminished once you know the reaches to the top of the pipe where the pressure decreases so Boussinesq theory can be used to calculate the pressures and the different types of loads and the embedded pipes and details of live load calculations are actually connected with minimum cover requirement.

So like we can assume that wheel load is actually you know happening on the light on the top of the pipe or at happening at a certain distance away from the pipe so one of the predominant loads which can affect the integrity of the pipes is that the live loads so as the live load is actually transmitted down the effective area increases and the pressure basically the transmitted to the pipes will decrease but whoever the intensity of load transmit to the pipe due to a particular load can be calculated by using Boussinesq theory which is actually there in the stress distribution component of geotechnical engineering.

The another you know effect which is need to be considered if these pipes lines are installed in the seismically prone areas that the seismic loads needs to be considered.

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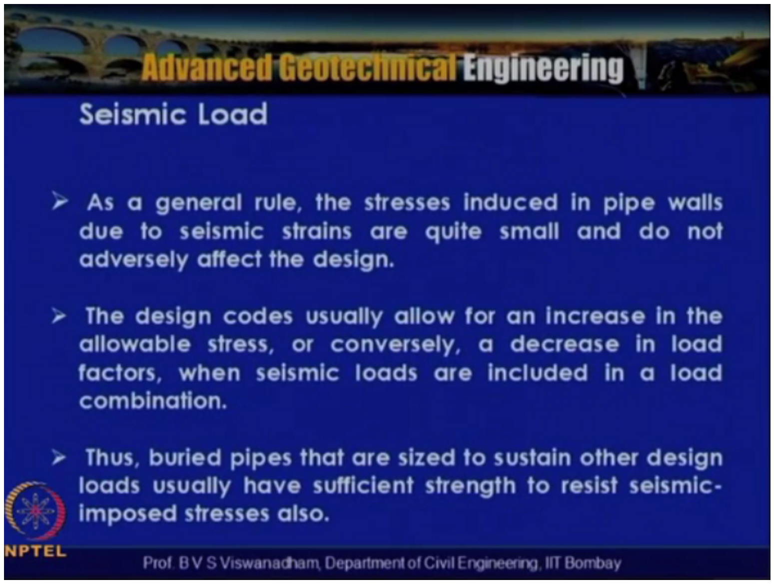

So a general the stress induced in pipe walls due to seismic strains are quite small and do not adversely affect the design but the design codes usually allow for an increase in the allowable stress or conversely decrease in the load factors when seismic loads are induced included in a load combination so the buried pipes that are sized to sustain other design loads usually have sufficient strength to resist seismic imposed stresses.

But other that there can be some effects like effects due to liquefaction and because of the or flotation of the pipes those issues need to address but as such the seismic loads if it is a if the pipe lines are passing through seismically prone areas the adequate consider should be made to have the seismic loads.

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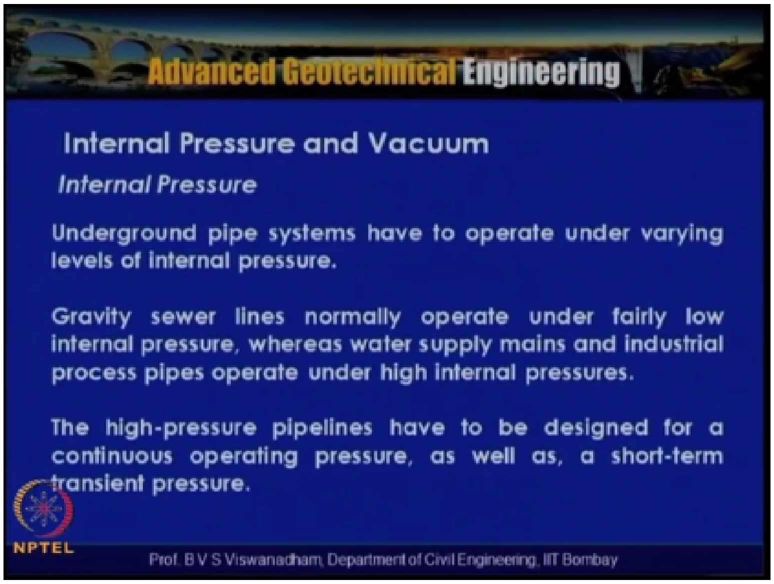

Then another you important loading consideration which lead to looking to 80's internal pressure basically these underground pipes are they operate under basically the two categories one is called high pressure pipes and low pressure pipes the underneath pipe systems have to operate under varying levels of internal pressure gravity sewer lines normally operated very fairly low internal pressures that is the pressures in sewer lines are very low.

So they can be sewer lines are can be classified a low pressure pipes where as the water supply mains and industrial process pipes operate under high internal pressures. That means that these pipe lines for say cool water cooling water running pipe lines in say in power plants an all they operate when very high pressure pressures the high pressure pipe lines have to be designed for a continuous operating pressure as well as you know the short term transient pressure.

And these pressures also some times because of the rapid closure of the wall are something like that there can be possibility that you know the surges can actually happen or it is also called as a water hamper effect, so in a short pulse of time there can be possibility that the pressures can actually increase beyond the operating pressures so the high pressure pipelines have to designed the high pressure pipe lines have to be designed for a continuous operating pressure as well as the short term transient pressures. And the short term transient pressures in the mean that can arise because of a water hammer or water such which can actually increase the pressure in the pipe in a short duration of a time.

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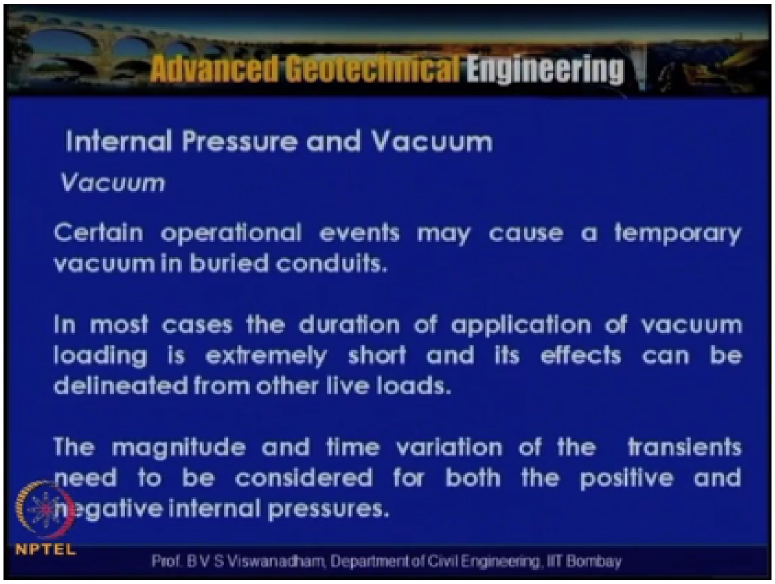

And the internal pressure another issue that vacuum this vacuum can actually arise because of the you know the closure of the walls of an empty pipe so some times what will happen with the certain operations events we cause a temperature vacuum in the buried pipe conduits so one need to really concern about this particular issue, in most cases that duration of application of vacuum loading is extremely short and it is effects on can be deviated from other live loads.

The magnitude and the time variation of the transients need to be considered for positive and negative internal pressures so the one need to look into the magnitude and the time variation of the transients basically for both the positive and the negative internal pressures.

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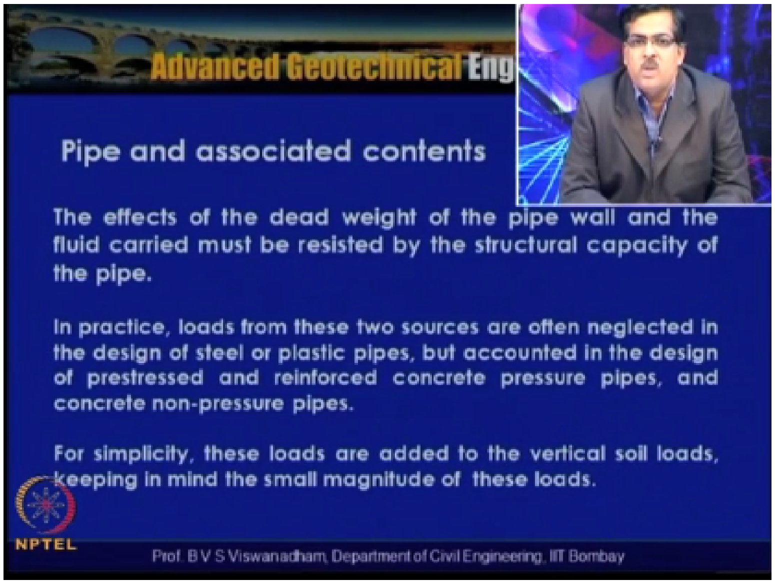

Then another issue is that the pipe and associated contents the effects of the death weight of the pipe wall and the fluid carried out fluid carried must be resisted by the structural capacity of the pipe so the effects of the death weight of the pipe wall and the fluid carried must be resisted with the structural capacity of the pipe in practice load from these 2 sources are often neglected in design of steel or plastic pipes, but accounted in the design of pre stressed and reinforced concrete pressure pipes and concrete non pressure pipes.

So for simplicity these leads are these loads are to be added to the vertical soil loads keeping in mind that small magnitude of these loads, so these loads are actually added to the vertical soil loads keeping in mind of the you know as they are actually they are small in the magnitude of this load is actually small compared to the soil loads so the effect of the dead weight of the pipe wall and the fluid carried out must be resided by the structural capacity of the pipe.

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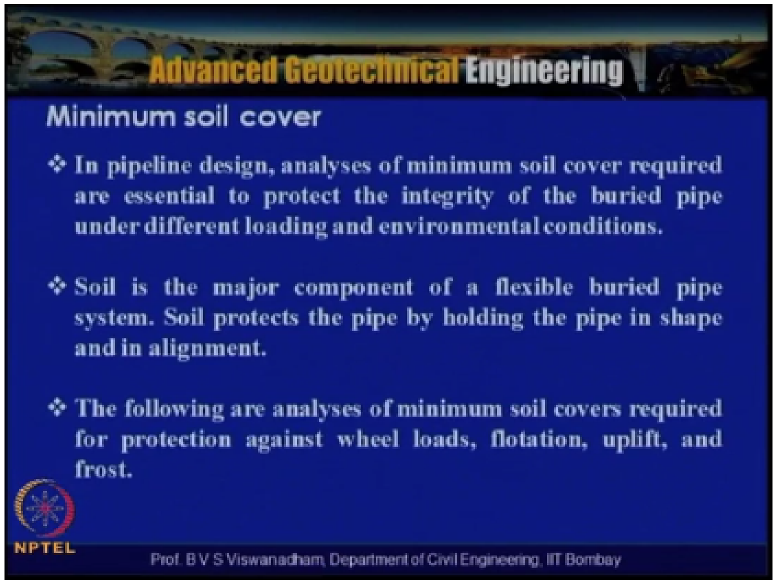

So now having discussed about the different loading consideration like live loads and then we also have discussed in the previous lectures how you know the different conditions how the soil loads can be you know calculated by using Marston's load theory so in addition to that you know these loads due to external loads due to wheel load traffic or seismic loads are due to consider so the minimum soil cover which is very important as for as buried conduits functioning is concern.

So in the pipe line design analysis of the minimum soil cover required are essential to protect the integrity of the buried pipe and that different loading and environmental conditions in pipe line design analysis minimum soil cover required basically are essential to protect the integrity of the buried pipe under different loading in environmental considerations so soil is a major component of the flexible buried pipe as the soil protects the pipe by holding the pipe in shape and alignment.

So soil basically you know helps to hold the pipe in shape and in the alignment so the following are the analysis of the minimum soil covers are required for the protection against wheel loads flotation, uplift and some issues of frost are there but which are not discussed in this lecture so first what we do is that we will try to look into wheel loads that is due to live load traffic in case if the buried conduit pipe lines are there which are embedded in a location where there is no wheel load traffic then in that case this particular live load issue will not arise so in the pipeline design the analysis of minimum soil cover required are essential to protect the integrity of the buried pipe under different loading and environmental conditions and we will try to look about the analysis of the minimum soil covers which are required for protection against the wheel loads and due to of the pipe due to the high water table areas that is flotation and floatation and uplift and due to action.

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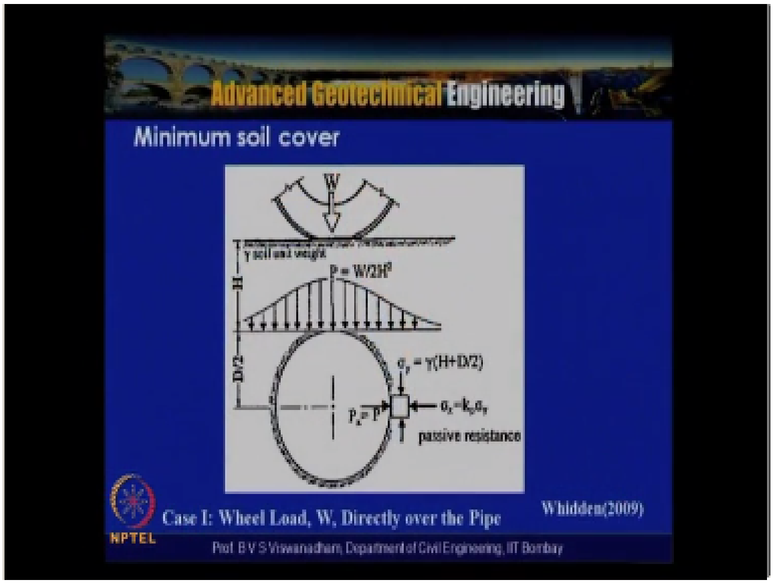

So in this particular slide case 1 where you know the minimum soil cover computation is actually shown here where v load w directly were top of the pipe so here the stress distribution which is actually is on the pipe right at the center of the pipe where and which would pressure is $p=w/2h^2$ and which is actually decreases you know as the you know going away from the you know the centre of the wheel door.

And γ is soil into it h is the embedded depth that is the cover above the pipe and d/2 is the mid height so h+d/2 is the mid height so you can see that σv is the vertical stress which is $\gamma.h+d/2$ that is actually acting at the side of the pipe and the lateral stress the resistance offered is nothing but $\gamma x=kp.\gamma y$

So this passive resistance is provided by the soil and internal pressure that is px=p is actually excepted and which is counted by this positive resistance that is σx so σy is the vertical stress that is $\gamma.h+d/2$ so the passive resistance is nothing but $kp.\gamma.h+dy$ so that is the passive resistance which is passive this stress in the σy σx in the xf so this is the minimum soil cover requirement of computation for a case where the load is actually dusting right on top of the pipe.

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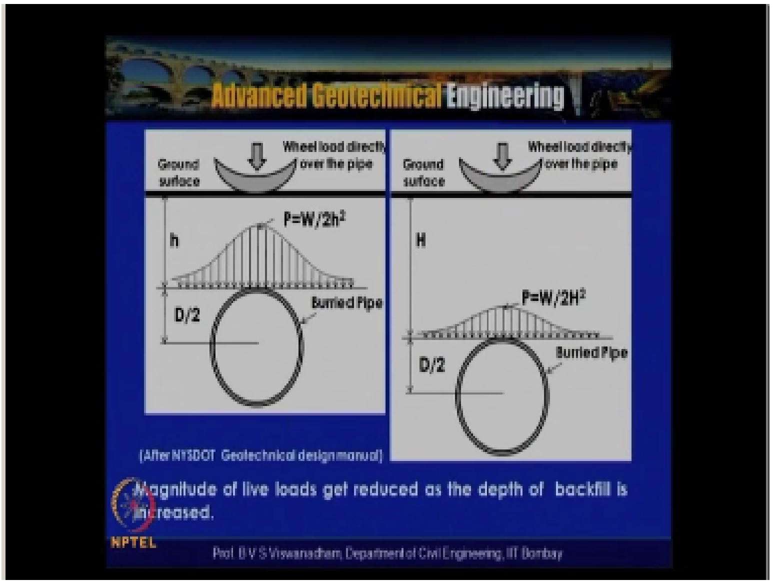

We can also see that as the you know the depth increases the stress magnitude keeps on decreasing because let us say that in this particular figure h and capital H where H >h in this equation the magnitude of the life loads get reduced at the depth of the as the depth of the back wheels is increased as the depth of back wheel is increased the magnitude of the life load gets decrease.

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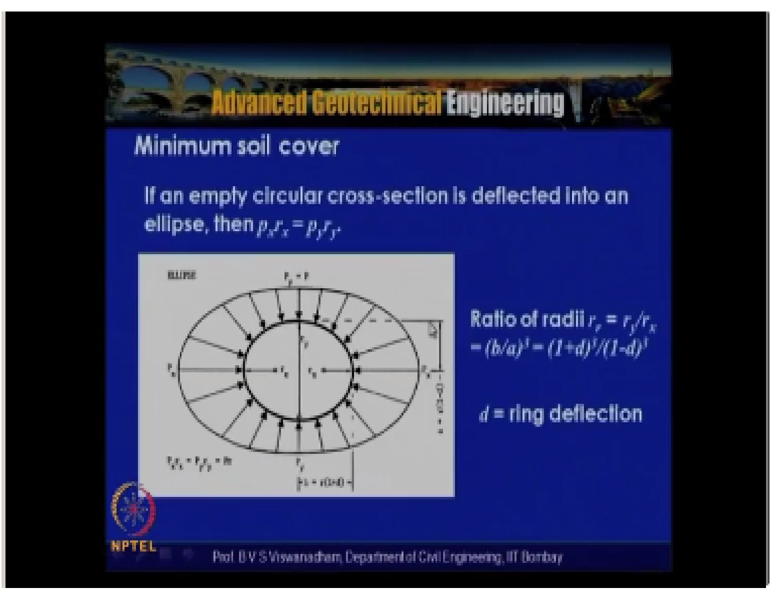

So in order to in the computation of this minimum soil cover and if you are actually having an empty circular cross section of let us say of having diameter d capital D and if it is deflected into a ellipse so here elliptical pattern of deformation is actually shown here so here which actually rx and ry are the radii in x and y direction and the ratio of the radii r_r=ry/rx so ratio of radii of the deformed you know cross section in the elliptical fashion it is ratio of radii r_r=ry/rx which this ordinate=B=r.1+d and this a=r.1-d

So we can actually write ratio of r radii as b/a3 as b=r.1+d so we can write you know this is something 1+d^3 /1-d^3 where d is nothing but the ring deflection that is di s nothing but the ring deflection by how much actually this has actually has undergone changes so if an empty circular cross section is described into ellipse and px rx=pyry

So pxry=pyry px is the pressure in x direction py is the pressure in the y direction so pxrx=pyry=pr and this is you know this is the you know for a empty circular cross section if it actually undergoes deflection in the form of an ellipse then you know this is used actually this valid.

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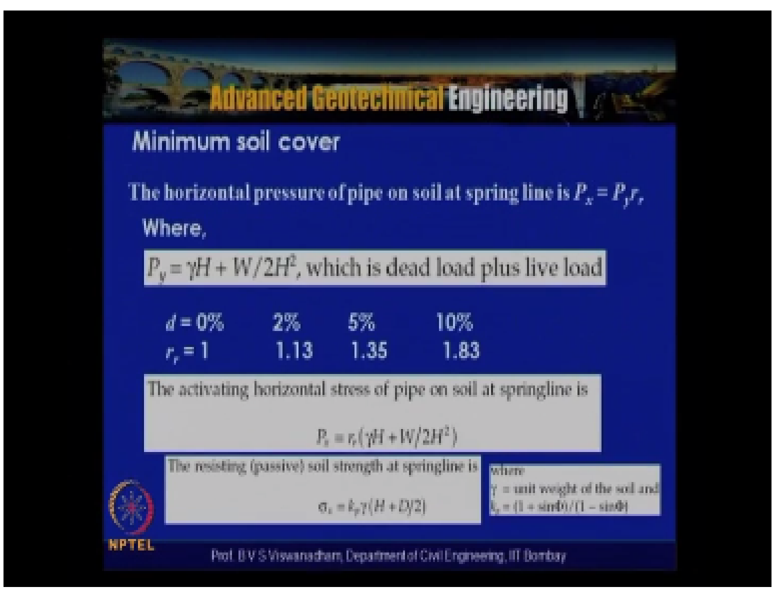

Now what we need to do is that in o0redr to calculate the minimum soil cover the horizontal pressure of the pipe on soil at spring line is nothing but px is the spring line is nothing but that wind height=px=pyrr where py=γh.γh+w/2h^2 that is due to dead load plus live load so b=o percent by using this one where d=0 then pya=1 that ratio0 of radii=1 and for 2% deflection 5% ring deflection 10% ring deflection we can say that r_r the ratio of radii=1.13, 1.35 and 1.83 this ratio of radii is 1.83 for ring deflection of 10%

So the loading is py=γh+w/2h^2 that is due to the red light that is sulphate of the soil and plus live load and the activated activating horizontal stress on the pipe on soil at spring line is px=rr.γh+w/2h^2 now the resisting force for this soil strength and spring line is nothing but σx=kp.γ.h+d/2 where γ is the soil.

And kp is nothing but the passive earth pressure quotient which is actually 1+sinϕ 1-sinϕ that is the rankings earth pressure quotient we have taken so here the resisting stress is actually nothing but σx=kp.γ.h+d/2 activating horizontal stress on the pipe at soil spring line is nothing but px=rr.γh+w/2h^2

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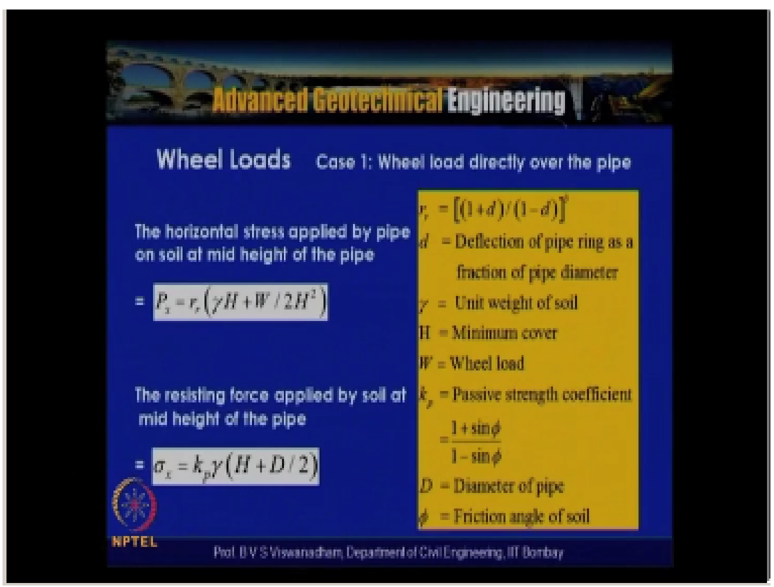

By what we do this again the same issue is actually described here the case 1 v load directly on the pipe where the horizontal stress applied by the pipe on the soil at mid height of the pipe is given here that is the spring line and then the resisting force applied by the soil on the mid height of the pipe is σx=kp.γ.x+d/2 where d is the diameter of the pipe.

And ϕ is the fiction angle of the soil and kp is the passive you know the passive quotient passive earth pressure quotient w is the wheel load and h is the minimum cover and γ is unit weight of the soil d is the deflection of pipe ring as a fraction of the pipe diameter and where r_r is nothing but $1+d/1-d^3$

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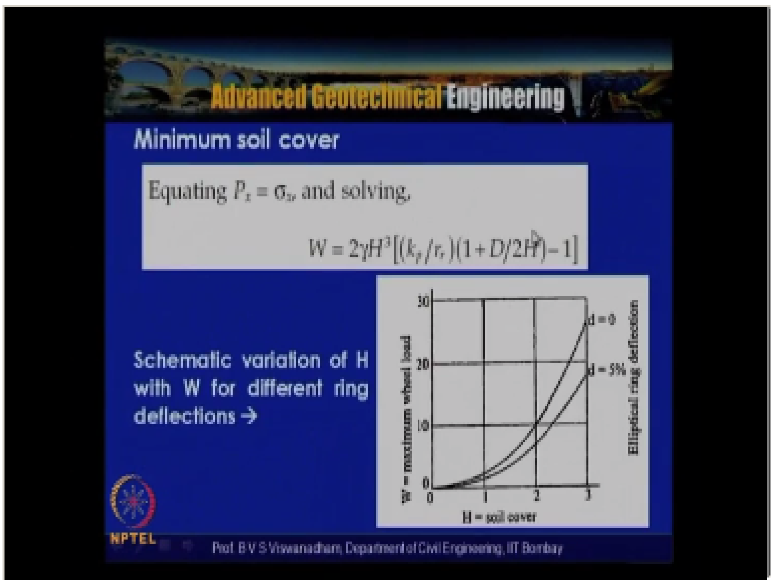

Now by equating this pressure applied by the you know the px which is nothing but by equating this pressure which is applied by the you know the px and the resistance by the kx where pressure applied you know the px and then resisted by the passive pressure coefficient –offered by the soil by equating the horizontal stress supplied by pipe on soil and resisting force applied by the soil at mid height of the pipe by equating them what we get is that you know we get the expression for $w=2\gamma h^3.kp/rr.1+d/2h-1$

So if you look into this for different for value of ϕ and for a value of atypical wheel load and different ring deflections and we can actually get typical schematic variation of h soil cover and with the increase in soil cover can actually allow us to have accommodate higher wheel loads and let us say that we know for ring deflection of say 0% that means that the soil cover of this much two units is required and where the maximum wheel load is allow is about 10 units of the maximum wheel load so by equating the you know px=σx we have got $w=2\gamma h^3.kp/rr.1+d/2h-1$ so this symmetric variations of h with w for different ring deflection actually is given in this slide.

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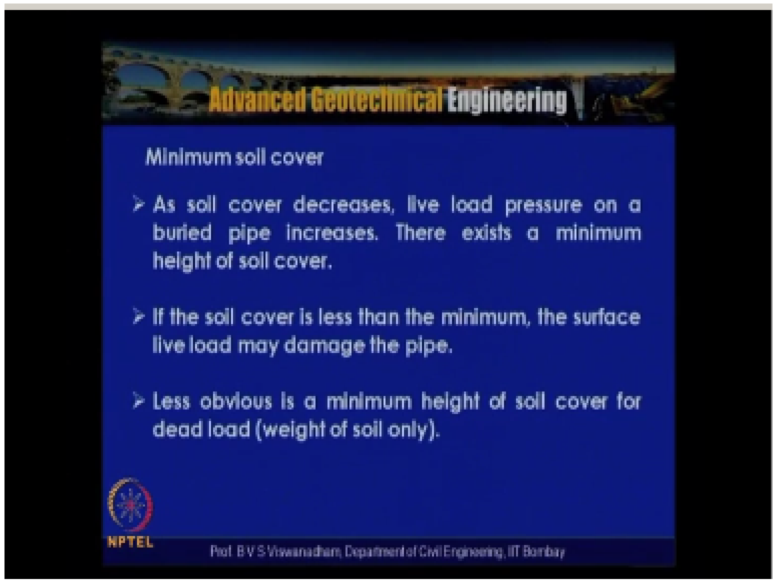

Now as the soil cover decrease the live load pressure on a buried pipe increase. So look into that as the soil cover decreases the liv load pressure on the buried pipe increases, so the pressure transmitted the pipe will keep on getting enhanced, so there exist minimum height of soil cover we have to see that the minimum soil the minimum height of soil cover ensured by all means with the soil cover is less than minimum the surface load you know damage the pipe and less obvious is that is a minimum height of soil cover for dead load and the weight of soil only so this minimum height of soil cover for dead load that is weight of soil only.

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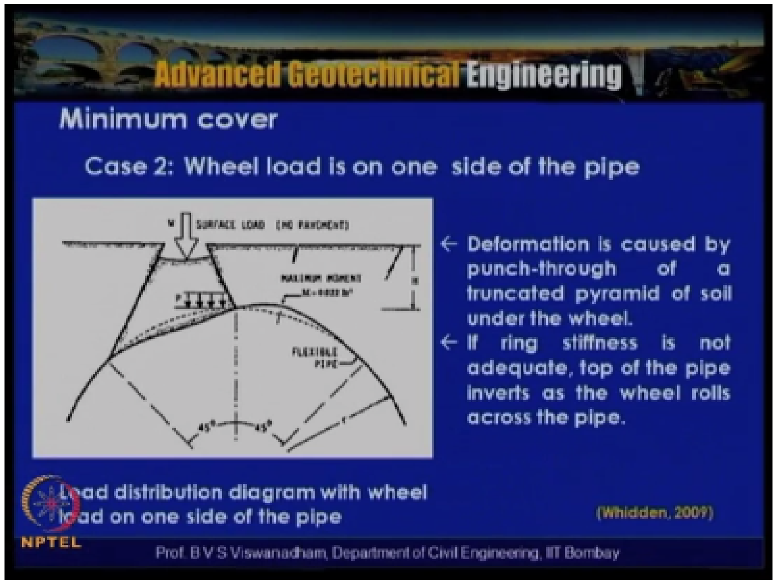

So now while considering now we have taken you know the wheel load right of the typw now the wheel load is one of the and one of th sides of the pipe, so that we assume that we are actually having a fix though pipe and the wheel load is on the towards the the left hnd side which actually shown and it actually has got load is exited on like a trapezium and then it is actually transferred to the type of the pipe like this.

So now the deformation is caused by the punch through of truncated pyramid of soil under the wheel so the deformation is actually caused because of the punch through which actually happens truncated pyramid of soil under the wheel, if the ring stiffness is not required if the ring stiffness non required the top of the pip inwards and as a wheel rolls across the pipe, so the top of the pipe will get inverted and as the wheel rolls on the pipe so you can see that the maximum moment exited is nothing but $M = 0.022Pr^2$.

So this deformation is actually caused by the punching mod of failure and through it is like a truncated pyramid of soil under the wheel.

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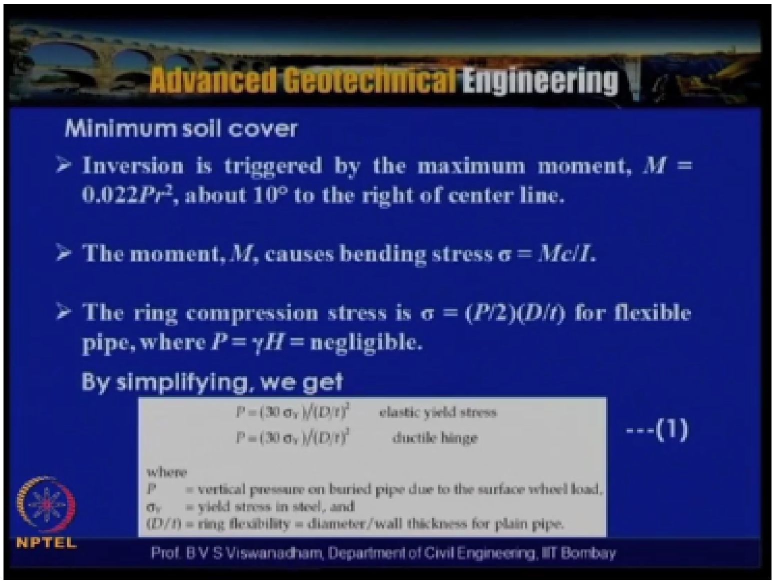

So the inversion is triggered by the maximum amount which is given as $M = 0.022Pr^2$ at above 10^0 to the right of the center line so when the load is on the left hand side the maximum it actually gets you know mobilized on the right hand side of the pipe and this moment causes the bending stress where $\sigma = Mc/I$ so the axial this thing axial stress axial component is neglected here because of its magnitude, so the maximum the moment M causes the bending stress $\sigma = Mc/I$.

So the ring compressions compressive stress is nothing but $\sigma = P/2$ into D/t PD/2t for flexible pipe where $P = \gamma H$ is actually negligible, so by simplifying what we get is that P = you know P is nothing but the vertical pressure on buried pipe due to the surface wheel load which is actually 30 / σr where 30 x σy where σy is nothing but the yield stress in if it is a steel pipe, if it is a plastic pipe the yield stress in plastic respect to plastic pipe need to be use into D/t^2 so this is for within the elastic range in the ductile hinge.

Range then it is $P = 30 \times \sigma y \times D/t^2$ so here where σy is nothing but the yield stress in steel and so D/t is nothing but the ring flexibility which is actually defined as you know diameter as well as the wall thickness of the plane pipe so for example f you are having about 3.8 you know 3.8m of pipe having the thickness of about you know something like about 20mm of thickness then the D/t ratio is about 190 also that indicates that you know the pipe is actually having very high you know ring flexibility and pipe is set be a flexible in nature.

Test as the you know very flexible pipe so where D/t = ring flexibility which is nothing but the ratio of diameter of the wall thickness fro plane pipes, so sometimes for cooling water pipe lengths and all where the flexibility ring flexibility would be of the order of 192 180 to 200.

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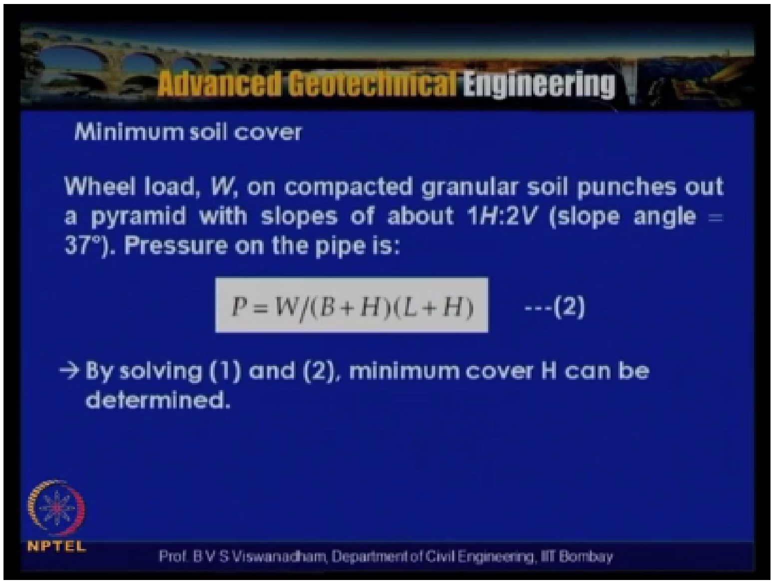

And the minimum soil cover for considerations now we are actually trying to look when the wheel load is actually on the you know line load on towards the left over the pipe, so what we have done is that we actually have got with you know this particular P = 30 x σy x D/t^2 and with that after having obtained now we can actually calculate the wheel w on the compacted granular soil punches out pyramid this slopes are about 1H horizontal to 2 vertical with slope angle is equal to about 37^0.

But pressure on the pipe is approximately can be approximated as P = W/B + into L + H this is nothing but where H is the cover you know minimum cover, so by solving one and two so this is 1 where by solving 1 and 2 what we get is that the minimum cover H can be calculated, so whenever the wheel load is actually on the you know not on the write on top of the pipe then you know we need to use this particular expression and by using the equations which are actually given in 1 and 2 by solving 1 and 2 the minimum soil cover H can be determined.

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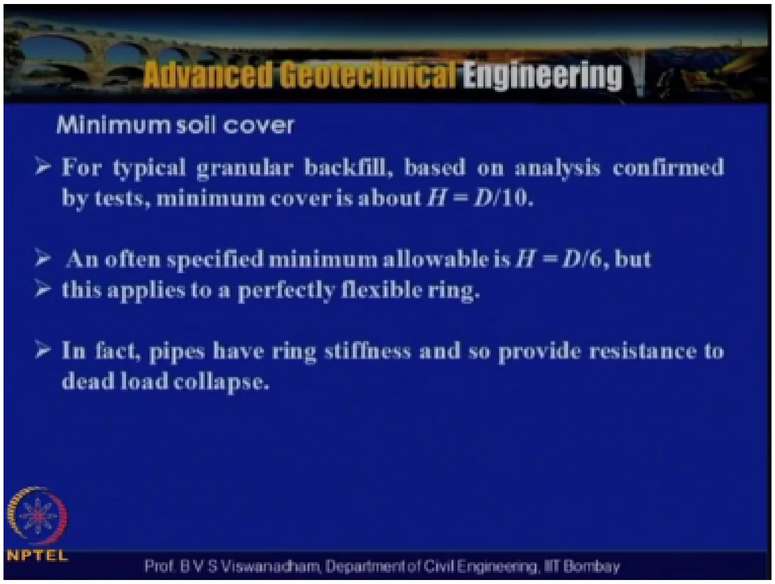

Now for typical granular back fill based on the analysis come forward by the test we do not cover is about H that minimum cover need to be ensure that D/10 that means that if you are having a D = about 4m then minimum cover about 4/10 about 4m cover has to be ensured that is 4/10 that is about 0.4m is cover and often specified minimum allowable is nothing about H = D/6 but this implies for ferry perfectly flexible ring so if you are having a flexible ring like you know we disused about D/t = bout 190.

Or 200 so for that actually the minimum cover which is actually to this nothing but H = D/6 in fact the pipes have ring stiffness and so provide the resistance to dead load collapse.

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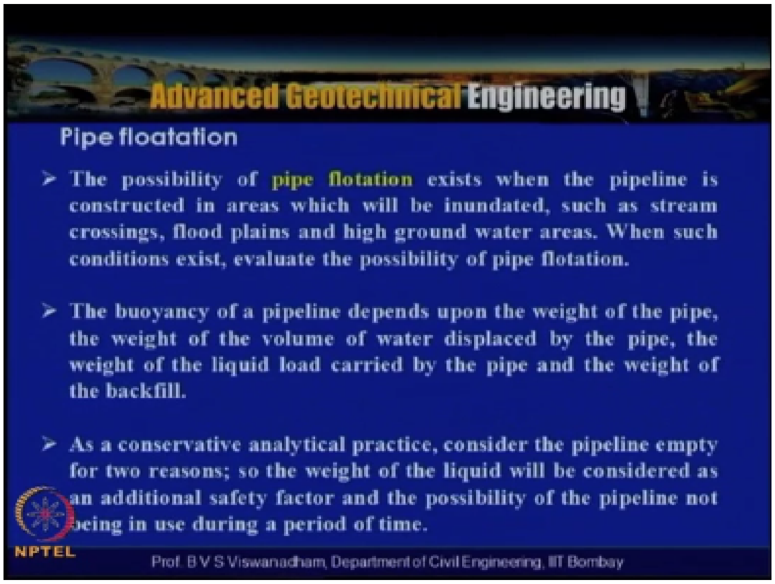

Now after discussed about the minimum cover requirement from the live load consideration point of view where in we actually have discussed of wheel load right on top of the pipe and wheel load location on the left of the pipe when the wheel load is located left on the pipe we said that the inversion of the pipe takes for the moment is actually mobilized on the towards the right set of the pipe and with that actually we have calculated what is the minimum soil requirement so for flexible pipes we said that.

That minimum cover is nothing about D/6 need to be ensure the, so the next issue we need to think about is the pipe floatation see the possibility of the pipes flotation exists when the pipe line is constructed in areas it should be in an dated and such as this stream crossings and flood plains and high ground water areas, when such conditions exists evaluate the possibility of the pipe flotation, so whenever also we need to consider the effect of the you know the filled pressure on the pipe due to.

Let us say if it is in a rainfall areas in a rainfall area if rainfall prone areas if the pipes are actually installed when we need to even consider the effect of the filed pressure on the you know on the integrated of the pipe, so the possibility of the pipe floatation exist when the pipe line is constructed in areas which will be an dated such as this stream classics and flood plains and high ground water table or it can be elaborated due to the derivation of rainfall water into the trench which actually was used for installed on the pipes.

When such conditions exists to the possible pipe flotation need to be over late, so the buoyancy of the pipe line depends upon the weight of the pipe, weight of the volume of the water displaced for the pipe and the weight of the liquid load carried by the pipe and weight of the back fill, so the buoyancy of the pipe line depends upon the weight of the pipe and weight of the volume of water displaced by the pipe and the weight of liquid load carried by the pipe and the weight of the back fill.

So as a conservative analytical practice what one does is that the pipe line empty will be considered this is for two reasons one is that so that the weight of the liquid will be considered as additional safety factor, and positive to the pipe line is not being in used during the period of time it also accounts for that, so as a conservative analytical practice like we consider that pipe line empty for two reasons on is that the weight of the liquid will be considered as an additional safety factor.

So and the possibility of the pipe line not being in used during the period of time of maintenance will also be taking care.

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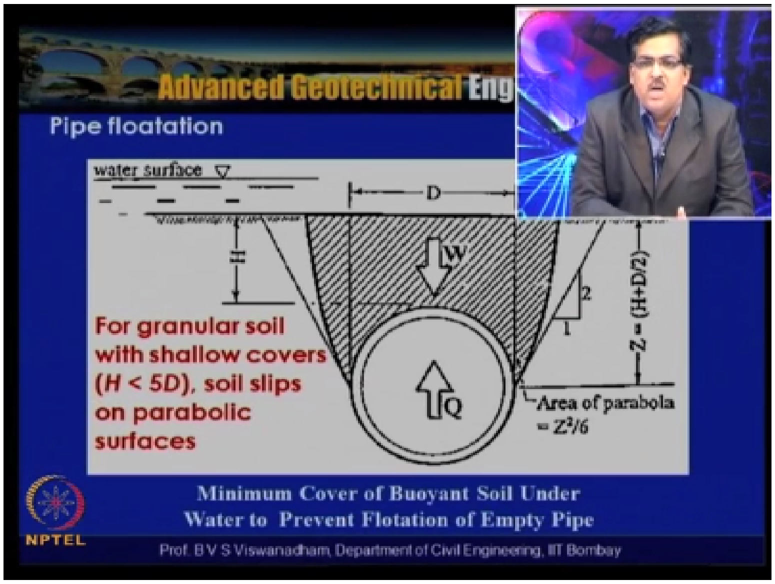

So in this particular slid a typical you know which failure which is actually shown and this is obtained based on the model test and if you are actually having a satiation of water surface at this level and H is the embedded depth and this is the diameter of the pip and this is the wall thickness and for granular soil with shallow covers H less than 5D soils snips like a parabolic surface, so this is actually obtained from the model test data and this z have to mid depth of the pip which is nothing but $z = H + D/2$.

So z is nothing but this is H and this is D so $H + D / 2$ and at this edge is actually having a two vertical and 1 horizontal this is the you know the wedge which actually undergoes you know if this q is actually more than W when the pipe actually subjected to flotation, so we need to ensure that the W / Q is actually having a twist the factor safety of two so that the flotation issues can be headdress then B is the you know this diameter and $Z / 4$ is the extent of the, the parabolic wedge so this area of parabola.

Is about $Z^2/6$ so this is the you know minimum soil cover computation for buoyant soil under water to prevent flotation of an empty pips, so here the pipe is actually considered as the empty in empty condition.

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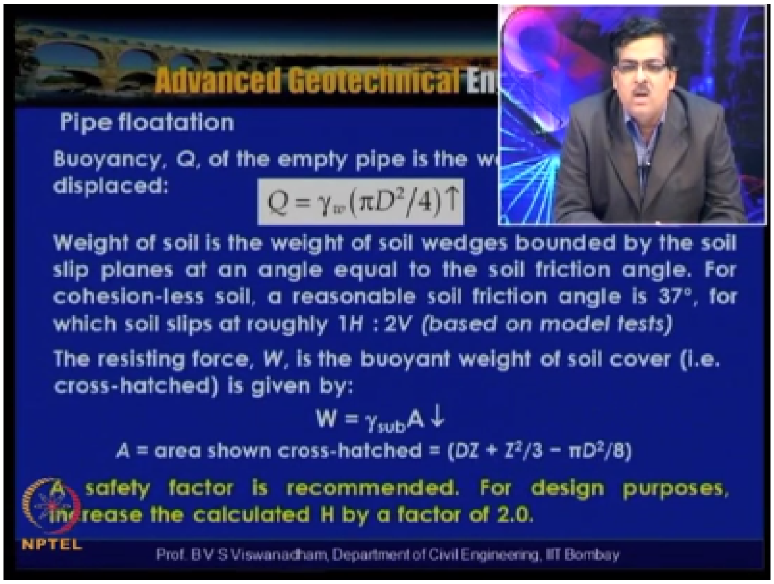

So the buoyancy Q on the empty pipe is the weight of th water displaced so which is nothing but $Q = \gamma W \times \pi D^2 / 4$ and D is the diameter which actually acts and weight of soil is the weight of the soil which bounded by the soils slip planes at an angle = to the soil friction angle for quotient less soil reasonable soil friction angle assumed as 37^0 are which soils slips are roughly 1He vertical this is actually based on the model, that is actually this inclination is assumed to be about 370 which is also assumed to be equivalent to the friction angle.

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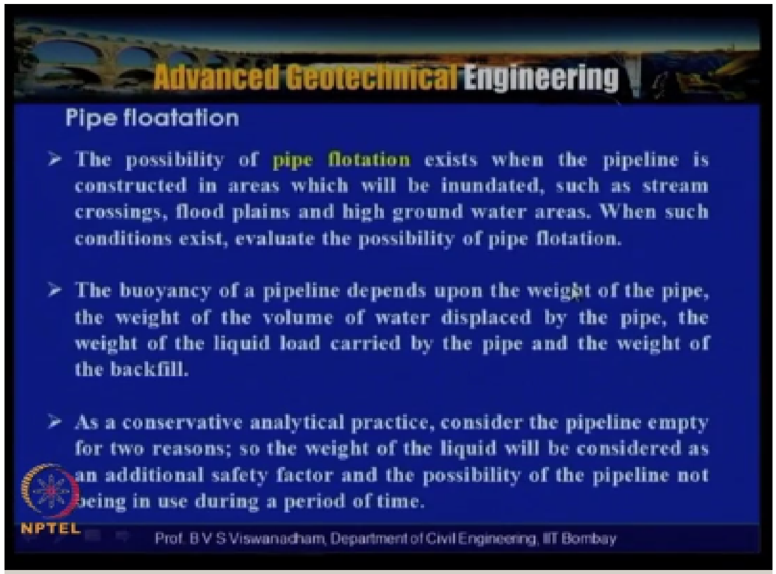

So the resting force W is nothing but the buoyant weight of the soil cover that is hatched Cos hatched which is actually given by, so the resting force is taken in this particular zone so this rectangular portion and this small portions which are shown in the actual way and this is this parabolas here and this parabolas, so the resting force W is the buoyant weight of soil cover that is the cross hatched is actually given by W = γsub, sub merged into area, so where A is the area of the cross hatched area.

Where D that area is given as DX D is the diameter and Z that is the total rectangular area plus $Z^2/3 - \pi D^2/8$.

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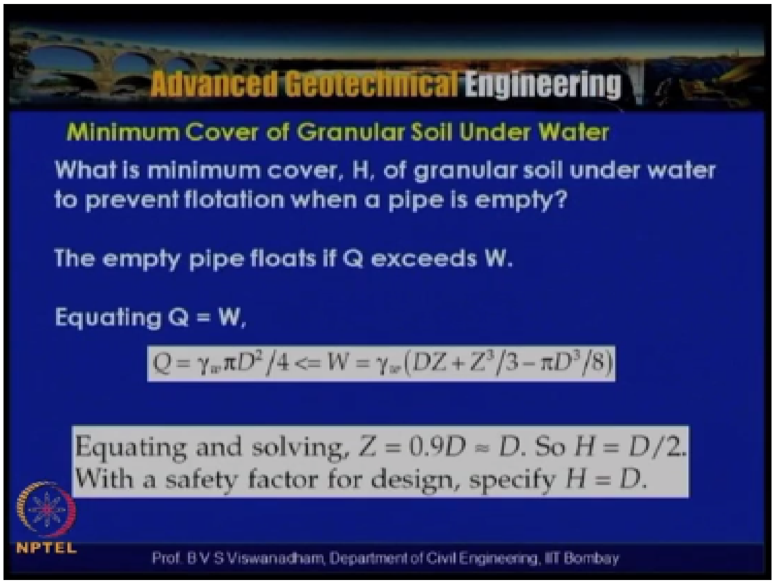

So that is these two areas what we have consider is that this rectangular area the Z and DZ we have considered and then we have to take out this area, so we have taken out this area and then we added this area and we added we have taken entire area and then we have taken this area we subtracted and added these two areas, so with that what we have got is that $DZ + Z^2/3 - \pi D^2/8$, so because of that area shown in the crossed hatched portion is we considered and with that multiplying with γ submerged unit weight.

That is let us say that if the soil is actually having 20KN.m3 – 10 so about 10KN/m3 is the unit weight of the submerged soil into area, so your safety factor is recommended generally factor safety of 2, so designs purposes increase the calculated H / a factor of 2, suppose if you have got 1m then we have to provide about 2m with the factor of safety of 2, so minimum cover of granular soil under water so this is what is the minimum cover H of granular soil under water to prevent the floatation.

When pipe is empty so the empty pipe floats if Q exceeds y so Q exceeds W the empty flight empty pipe floats if Q exists W, so equating Q = W what we have got at equilibrium $Q = \gamma W \times \pi D^2/4 = W \times \gamma W \times DZ \times Z^3/3 - \pi DQ/8$ by equating them and simplifying to get Z = 0.9D so Z = 0.9D which implies that you approximated as D so this is approximated as when Z = H+D/2 when you substitute that we get H = D/2 so with the factor of safety of 2 we provide that H = D so when you provide H = D then the you know that is the minimum soil cover required from floatation consideration point of view.

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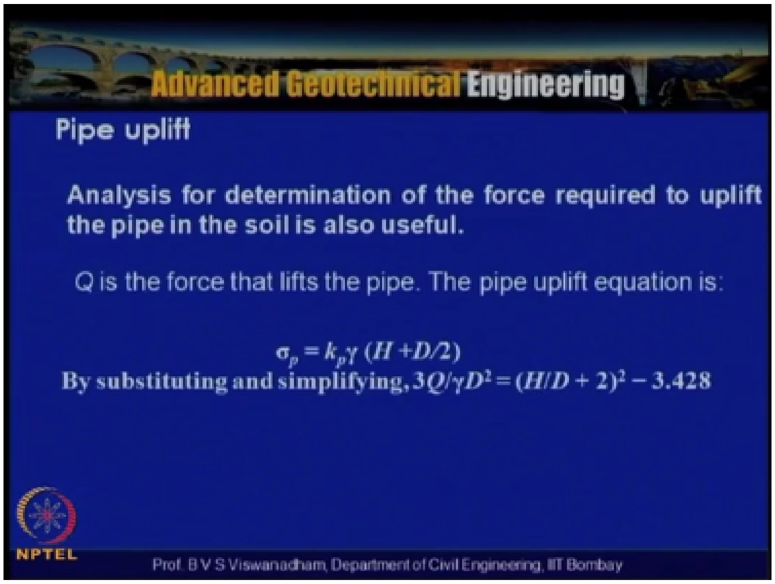

Now pipe of lift what is the uplift force which experienced by the pipe se analysis for determination of the force required to uplift the pipe in the soil is also useful, so Q is the force that lifts the pipe so the pipe of uplift equation s given by σp = kp γ into H + D/2 so which is nothing but by σp the pipe uplift equation is nothing but which is lifted by the soil σp = kp γ into H + D/2 and with that we can actually write by substituting and simplifying we can write that you know $3Q/\ \gamma D^2$ = H/D + 2 whole square – 3.428 so with that what we get is that we get the.

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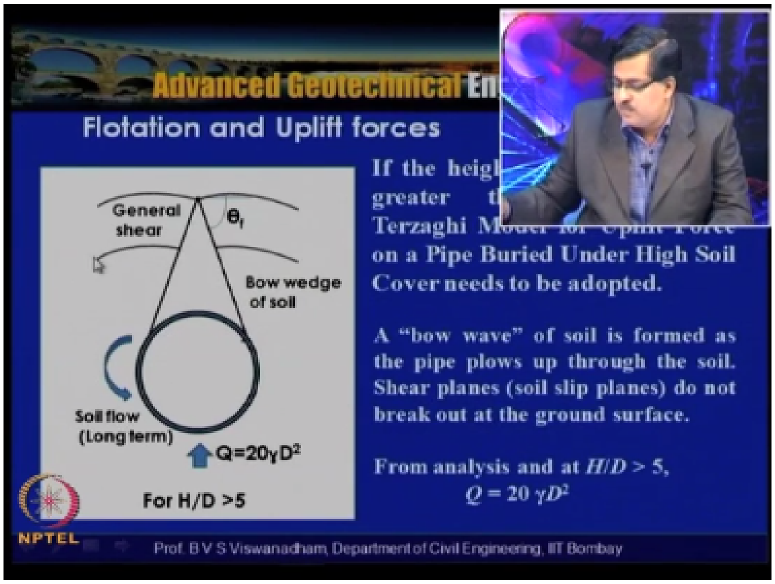

Pipe of lift equation and if they are actually having you know the height of soil cover H is greater than 5 times D that is or H/D >D then you know the Terzaghi model need to be adopted and with the height of soil cover is H and > 5D inverted Terzaghi model for uplift force on force on pipe buried under high soil called heads need to be adopted, so here in this Terzaghi an inverted Terzaghi model a bow way of soil is formed as the pipe falls up to this soil, but shear planes that means soil thick planes do not break out and thick round surface.

So the shape lines we actually do not break out the long surface, so from the analysis at H /D = >5 w can actually obtained Q= 20 xγD^2 so for you know for the pipes which are actually embedded with embedded depths >5 H/D>5 the bow way of soil is formed as the pip flows through the soil and the shear plains basically did not break out at the ground surface, so from analysis point of view when H/D>5 and Q = 20γD2 is the computed, so here in this particular figure which is actually shown here.

Or the high H/D ratios that is H/D>5 the inverted Terzaghi model is valid so in that case the uplift for is actually calculated by using the expression given by given here is nothing but Q = 20γD2 and where γ is the unit weight of soil and here as this is something like a bow way of the soil is formed as the pipe force plows through the soil in the shape lengths do not break out at the ground surface.

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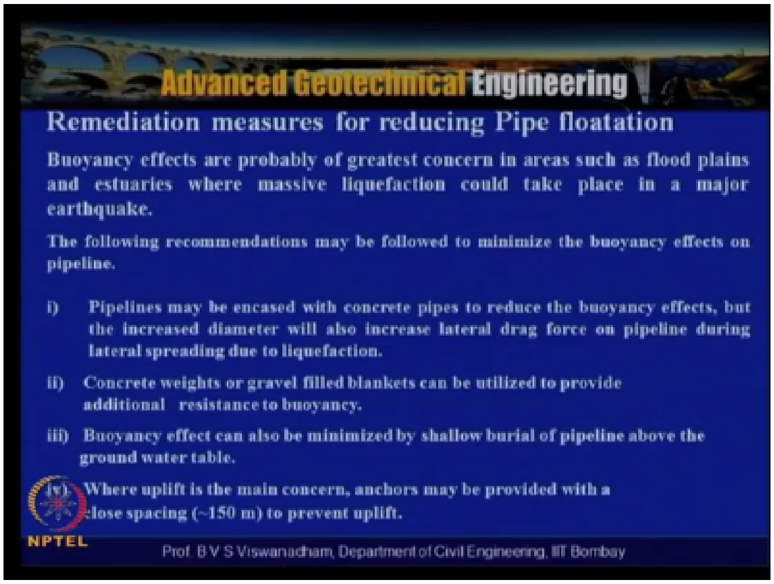

So what are the you know remediation measures for you know preventing are mitigating pipe flotation the buoyancy effects and probably the greatest concern in area such as flood planes and estuaries where the mass will liquefaction could take place in nature earthquake also, so the falling recommendations may be considered to minimize the buoyancy effects pipe lengths may be en case with concrete pipes to reduce the buoyancy effects but the increase in diameter will also increase the internal lateral drag force on pipe lin.

During the lateral spreading due to liquid action so pipe lines may be encased with concrete pipes to reduce the buoyancy effects but they increase in diameter will also increase the lateral drag force on the pipe line during lateral spreading during liquid of action the concrete weights are gravel filled blankets can be utilized to provide additional race to buoyancy concrete weights or concrete blocks or gravel filled blankets can be used to provide additional resistance to buoyancy, so buoyancy effective can also be minimized.

By shallow barrier of pipe line above the ground water table, so instead of taking below the ground water table in the pipe lines can be kept above ground water table and way the uplifting is the main concerned anchors may be provided with a close question or about 150m grow and uplift, so in a appropriate anchoring system need to be design and where in you know this you know the flotation of the pipe line can be straight, so the two popular issues one is that anchors use of anchors.

The other one is that to keep the pipe lines at shallow level itself and you know the other one is that encasement with concrete pipes these are the issued you know can be used the recommendations can be used for minimize the buoyancy effects on the pipe line, the another issue which w have said that when you have got the pipe line shear actually embedded in a trench narrow trenches are in the embankment conditions and we said that.

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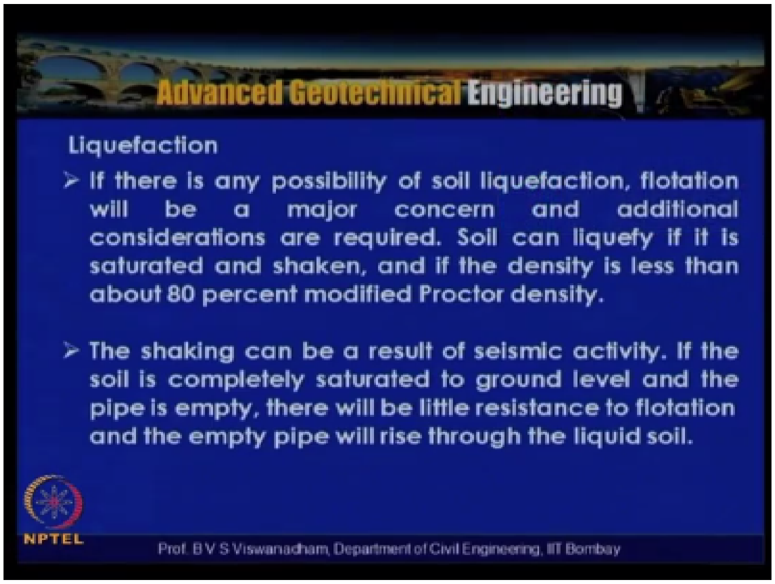

They when we are actually having the you know this fills there is a possibility that below the water table that can be subjected into liquefaction because of this size of pertabances, so if there is any possibility of soil liquefaction the flotation will be a major concern and additional concentrations are required, so soil can cab be liquefy and if it is saturated and shake and if the density is less than about 805 of the modified proctor density, so the soil can be liquefy and you know then you know once the soil liquefies.

The resistance to all these uplift and all those things cannot be expected because the liquefied mass will lose its strength, so the shaking can be result of you know any size we get activity and if the soil is completely saturated to be ground level and the pipe is empty so there will b little resistance to flotation and the empty pipe will raise through the liquid soil, so that the un set of liquefaction what will happen is that because of the you know any size of activity and the soil is completely saturated.

To the ground level and the pipe is empty and then it will b little resistance to preventing the pipe from floating and then the empty pipe will raise through the liquid soil, so this actually lead to you know the failure of the pipe lines are many case study is actually have been reported in the failure of pipe lines and man whole covers due to liquefaction particularly when they ar actually embedded below the ground level and particularly the sandy type of soils and with when they subjected to this in high water level areas.

In the subject to the sort of very high magnitude of this earthquake forces the damages have been reported, so here in this particular slide.

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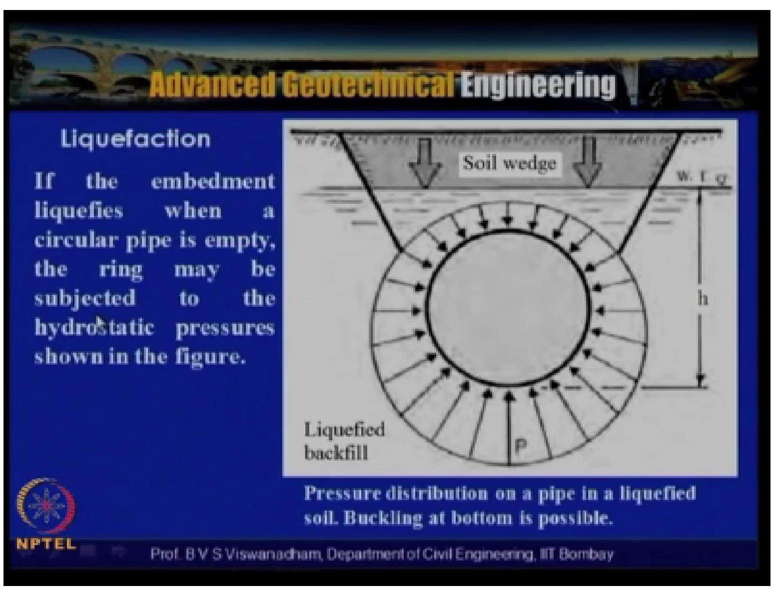

Where the a typical pipe line which is actually subjected to you know the so called you know the liquefaction in has been shown here, so here the pipe line and this is the liquefy backfill which is actually shown and H is the you know from the water table that is this is the below the water table and this portion is actually above the water table, so this is the soil which actually offers the resistance and pressure distribution on pipe in liquefied soil so buckling at the bottom is actually possible.

So the distribution of the pressure at the answer tough liquefaction is estimated like this which is actually shown vertically here the maximum what the base and minimum at the top and thy compared to base the side magnitude is less, so if the embedment liquefies when a circular pipe is empty the ring may be subjected to the hydrostatic pressure shown in this, so this is the you know the so called hydrostatic pressures momentum in the subject and that can lead to the damage of the pipe.

So in this particular slid what we have seen is that you know this is the countering resistance and this is the hydrostatic pressure distribution and the unset of liquefaction due to some size pick perturbance.
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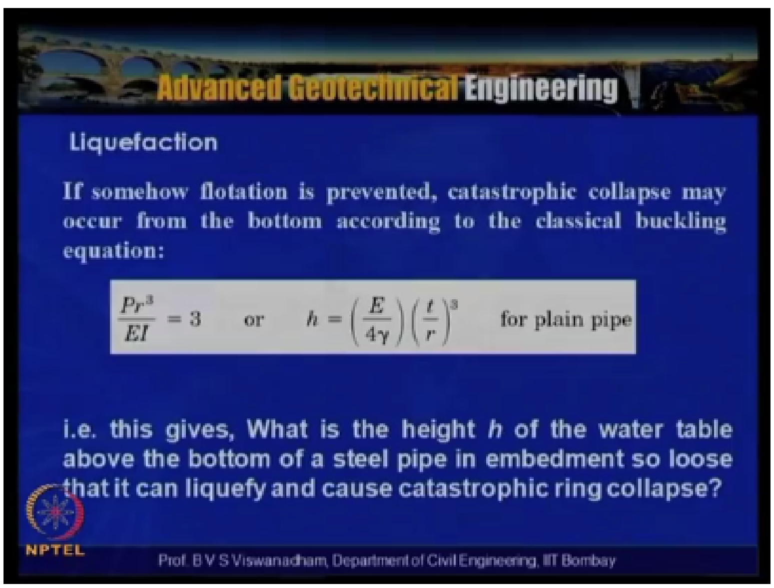

Now if somehow the flotation is prevented the catastrophic collapse may occur when the from the bottom according to the classical buckling equation, so if somehow the flotation is prevented the catastrophic collapse may due to the buckling and this is given by $Pr/^3$ $Pr^3/I = 3$ which is nothing but $H = E / 4\gamma$ into t/r to the raise 3 this is for plane pipe that means this gives what is the height H of the water table above the bottom of the steel pipe in embedded embedment so lose that it can liquefy and cause the catastrophic ring collapse.

So this gives touch with the height you know of water table about the bottom of the steel pipe in embedment so that so that is the soil so lose that it can liquefy and cause catastrophic ring collapse, so we can actually calculate from the combining with buckling equation so with that if that is you know if this depth is calculated and if we can sure liquid factor safety then you can actually say that the pipe can be prevented from liquefaction, some appropriate preventing division you know the remediation.

Measure need to be design if it is actually prompt for you know effect due to flotation effect due to liquefaction, so if somehow the floatation is prevented by catastrophic collapse may occur from the bottom according to the buckling equation which w have given, so that depth is nothing but is actually calculated is height of water table above the bottom for a steel pipe embedded in los sand and that can liquefied and cause catastrophic ring collapse.

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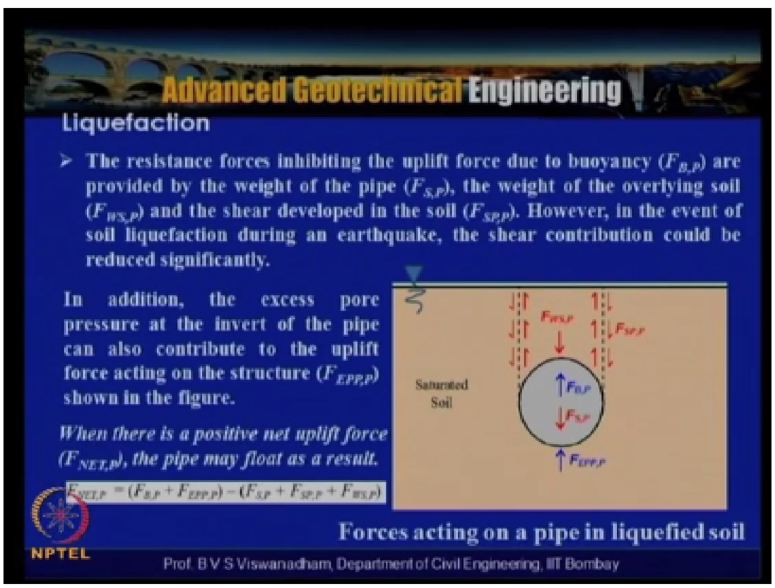

So here for the liquefaction so here what you in this particular slide a typical force is acting in a pipe in a liquefied soil shown here, so this is the saturated soil and this is the you know pipe and we have this is the FSP is nothing but the self rate of the pipe and FBP which is nothing but the force due to buoyancy and FEP that is the you know the force acting on the structure and this is weight of the soil, so what will happen is that when we at onset of liquefaction the forces acting or actually shown here.

Where in the shear stress is acting downwards here and upwards here and then resistance offered by this prism in this download direction, so this tends to go up and then this is these all forces will get mobilized so the resistance force is actually inhabiting the uplift force due to buoyancy that is FBP or provided by the weight of soil weight of the pipe the sulphate of the pipe itself that is FSP which is acting downwards and weight of the over line soil that is WSP which is acting downwards.

And at the shear developed in the soil that is FSPP that is here the shear developed in the soil however in the case so all downward forces are shear developed in the soil and weight of the soil above the pipe and the sulphate of the pipe the rest or actually in the direction of buoyancy is the pressure up light and the buoyancy steel, so the however in the event of soil liquefaction during in earthquake the shear contribution could be reduced significantly so the FSPC this FSPP component will be very marginal.

So the resistance force is uniting the uplift force due to buoyancy are basically provided by the weight of the pipe and weight of or line soil in the shear developed in this soil and however in the event of soil liquefaction during in a earthquake the shear contribution could be reduced significantly so in addition the access pore water pressure at the invert of the pipe can also contribute to the uplift force acting on the structure that is FEPP showed in the figure.

So which is you know the excess pore water pressure which is actually the excess pore water pressure the invert to the pipe can also continued to the uplift force and which actually can lead to you know flotation of the pipe so when there is a positive net uplift force the pipe may flost as a result, so when there is a net positive you know uplift force acting in this direction so then there is a in the pipe can result in the flotation, so F net is nothing but FBP that is FBP which is nothing but the buoyancy in force acting in this direction FEPP.

Minus so FEPP + FBP – FSP that is this surface of the pipe and FSPP + F δSP so F net pressure when it is positive then the pipe will be subjected to uplift force and the pip may float as a result, so this case study is actually have reported that this issues are weight quire common then when we are actually install this buried pipes in liquefaction prone areas, so in this particular slide what we have understood is that at the unset of liquefaction if the you know if there is a positive net uplift force.

The pipe may float as a result so the for the, the two contributing forces for you know causing the pipe to lift are the one is the buoyant weight of the pipe that is the F or BP that is the uplift force due to buoyancy that is due to because water table is here, the uplift force due to buoyancy and second thing is that the excess pore water pressure at the invert of the pipe cal also contribute, so this excess pore water pressure at the answer to liquefaction moment it will be very high and then the dissipation actually takes place.

But at that point of attenuation of this you know the liquefaction the excess pore water pressure is so high and then the positive net effect of uplift force will be very high and will lead to the pipe flotation.

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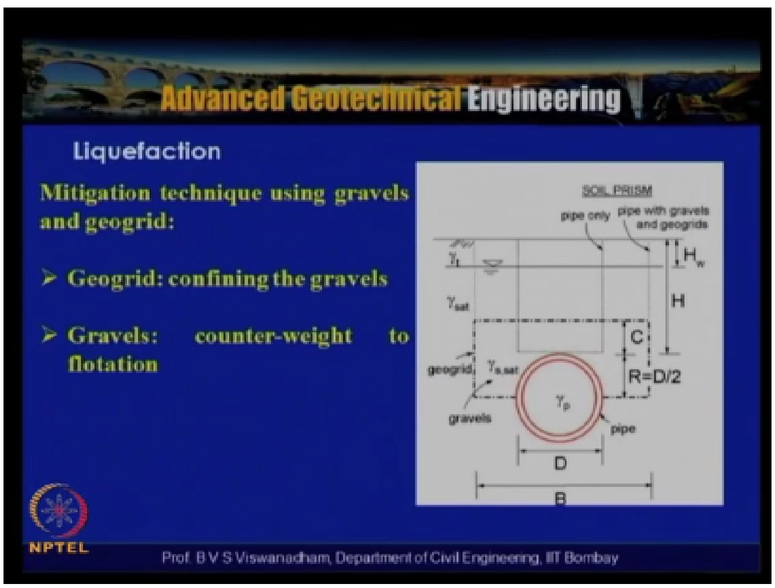

So there are many methods to restrain this liquefaction the liquefaction effect on the buried pipes so for this actually some investigators like link that all they are actually working on you know revolving at the use of geogrids for as a confinement the confining the gravel that means that a placement of gravel around the pipe and it is actually confined with you know at geogrid, so if some means some resistant is also considering the analysis by the geogrid which is actually offer and there are also some.

You know techniques which are actually try to the literature like using this synthetic materials like geogrid as a straps at intermediate certain spacing and in preventing the you know pipe flotation issues and all, so in this particular slide a typical mitigation technique using gravels and geogrid where a gravel can find gravel contribute can find as geogrid is used to counter the flotation at unset of liquefaction, so how these things are actually tested is that we actually have discussed the physical modeling.

So these you know these situations are actually have to be modeled and then you know once by understanding the phenomenon you know the design methods can be evolved and then we can lead to the design in the field so after having discussed about these issues now another important is that if you are actually having this steel pipes the corrosion is another issue the corrosion of the buried pipes so three environmental agents.

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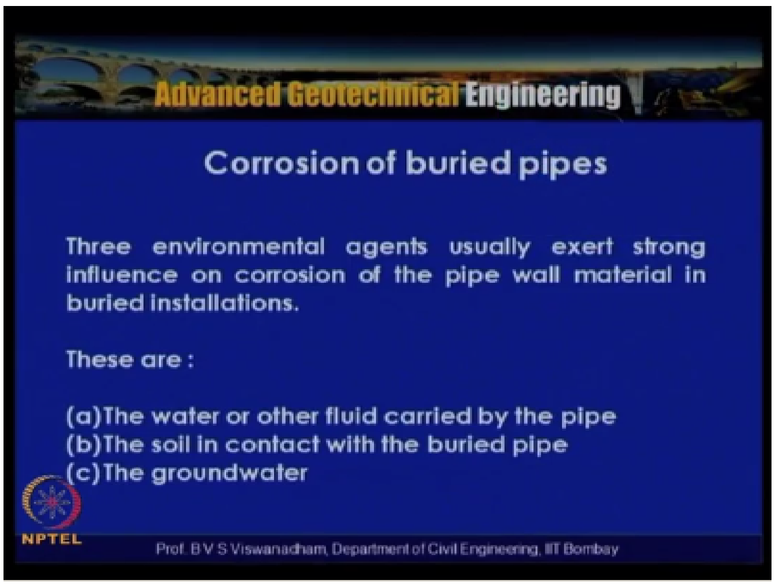

Usually exert string influence on corrosion of the pipe wall material in buried installations particularly the water or other fluid carried by the pipe and the soil in contact with buried pipe if it is in saline in nature then you know it can lead to the extensive corrosion and the ground water, if the ground water is actually having high chlorides and sulphates then it also can cause a cause of concerned for the corrosion so the three environmental agents that are actually usually exerts stress strong influence of corrosion.

Which we have discussed one is water or other fluid which is carried by the pipe so these corrosions of the buried pipes which are actually shown here.

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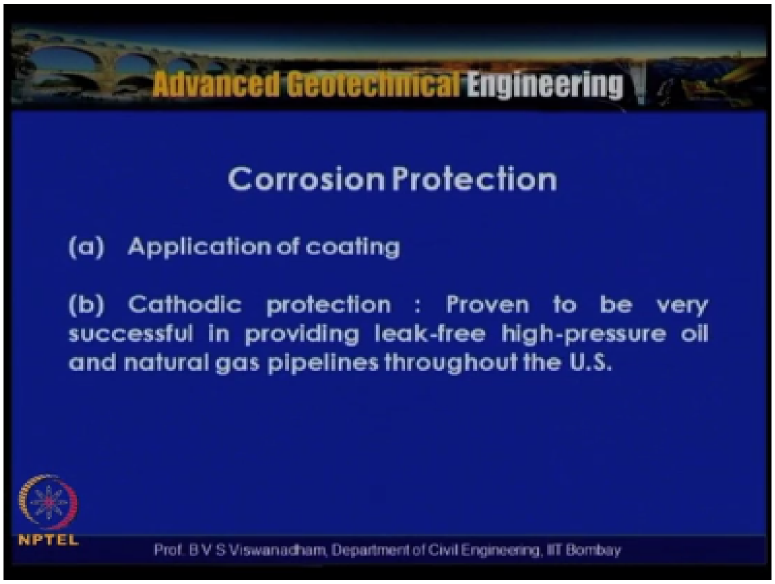

And the protections are basically done by application coating and cathodic protections are basically done by application coating and the cathodic protection and cathodic protection s basically proven to be very successful in providing leak-free high pressure oil in natural gas pipe lines throughout the U.S.

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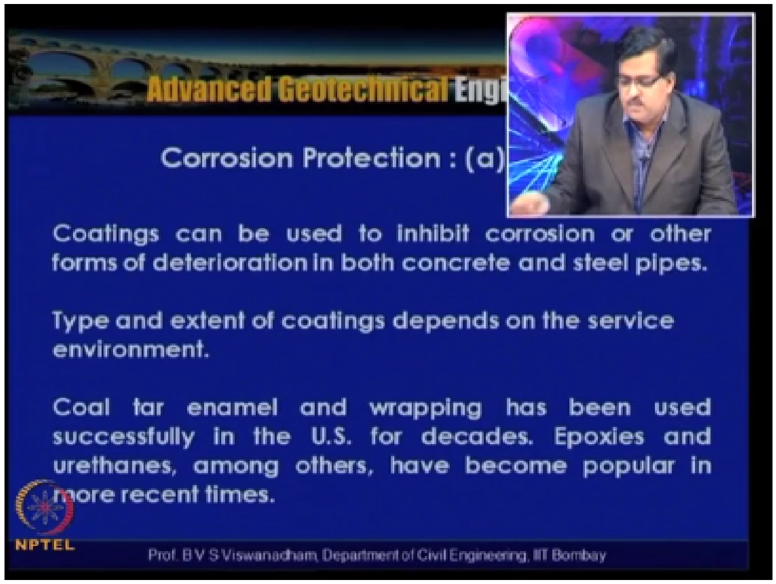

And the other one is that coatings can be used to limit inhibit corrosion or other forms of deterioration in both concrete and steel pipes and type and extent of coatings depends on the service environment and coat tar enamel and wrapping has been used successfully in the U.S for several decades a proxies and urethanes among others have become popular in more recent times, so recently also in India this urethane coated you know corrosion protection systems are actually replaced.

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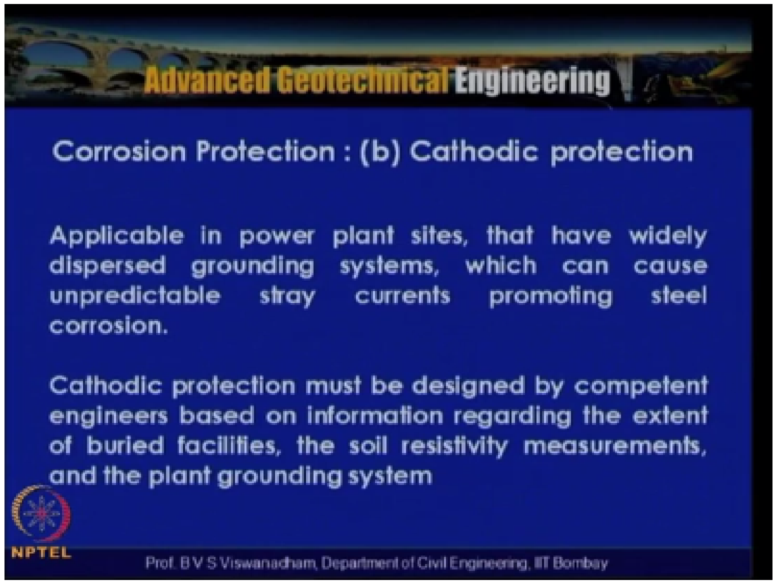

Then this is the cathodic protection which is actually shown in this particular slide.

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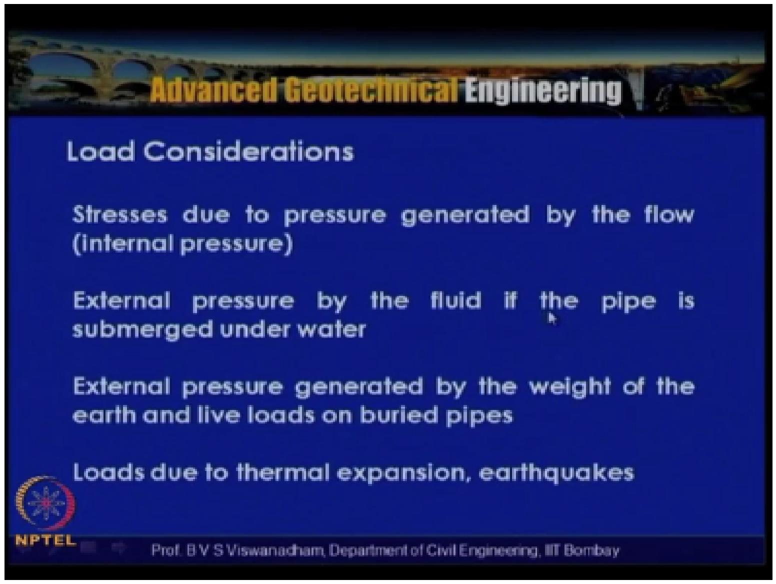

So now we actually look into a case study where a particular buried pipe is about you know 3.8m diameter embedded in soil cover at a with soil cover over 1.5m that is about D/2 and this time so the loading considerations is one need to construct what we have understood is that the load due to pressure generated with the flow next 2 pressure by the flow in the pipe is submerged in the water and action pressure generated by the weight of the earth and live loads on buried pipes and load due to thermal expansion earthquake.

So load due to thermal expansion earthquakes and action pressure by the fluid with the pipe is submerged in water in the virtual of a in this particular case study we will try to look into what will be the effective of the axial pressure which is actually arise and because of the unset of rainfall.

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So this is you know typical installation of a flexible pipe at the side where the trench is actually made and this is the natural ground water table and the pipe is actually made with dispense here which are actually prevented these are used for you know retaining the shape temporarily but once they are actually commission then the these will be removed, so this typical stata you can see that having certain amount of fines and question need but the ground water table is actually here, so this is one of the pipes like this there are amount for number of pipes which are actually shown here.

So this is you know the other amount of pipes so you can see that these how important in the soil support so the event of changes in the you know deformations in the pipe so the gaps can actually arise so these gaps actually can also lead to so these are actually due to some increasing pressures are deflections which actually takes place, so the rain deflections which actually takes place , so the ring deflections are valuable are evident actually here in this particular figure, so this is the same figure which is actually modified here.

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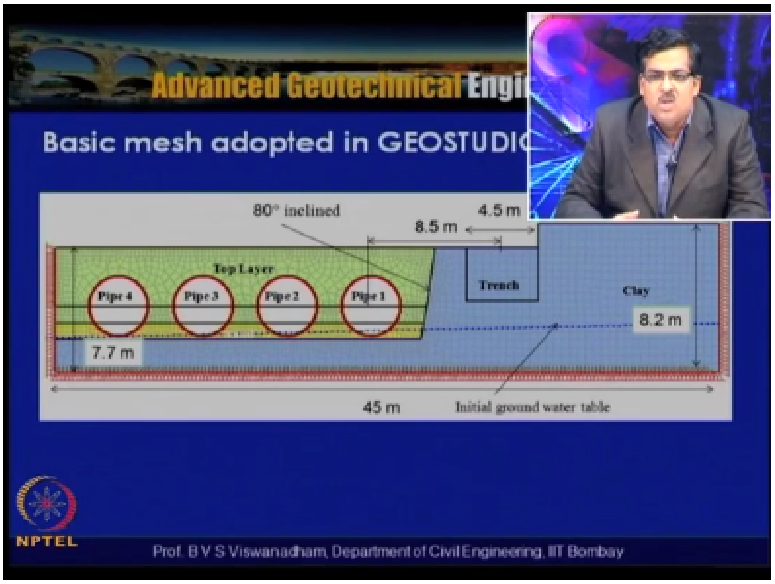

So this is a typical case here pipe1 pipe2 pipe3 pipe4 where in this area what has been done is that the rainfall actually has been stimulated and then the water actually has you know has been water flows been stimulated when this has been done what actually happen is that pipe1 and pipe2 are found to actual under submerged water and pipe 2 is actually already with internal pressure about for handed KNm3 but the pipe1 was actually found to experienced distance due to high external pressure so that we will see how that actually you know can be seen through a video.

So here in this particular issue the rainfall density which actually happened at the sight is actually simulated then it can be seen that as the rainfall is actually happening or a duration the water table actually reaches up to this level, so you can see that the both the pips are actually under submergence then we will see the other case this is again with the trench in this case also you can see that the pipe line actually submerged with water table as we go down we can see that the water table.

Diminishes as the rainfall is simulated we can see that the water table reaches and stands about the pipe1 and pipe 2 now we will see the third case.
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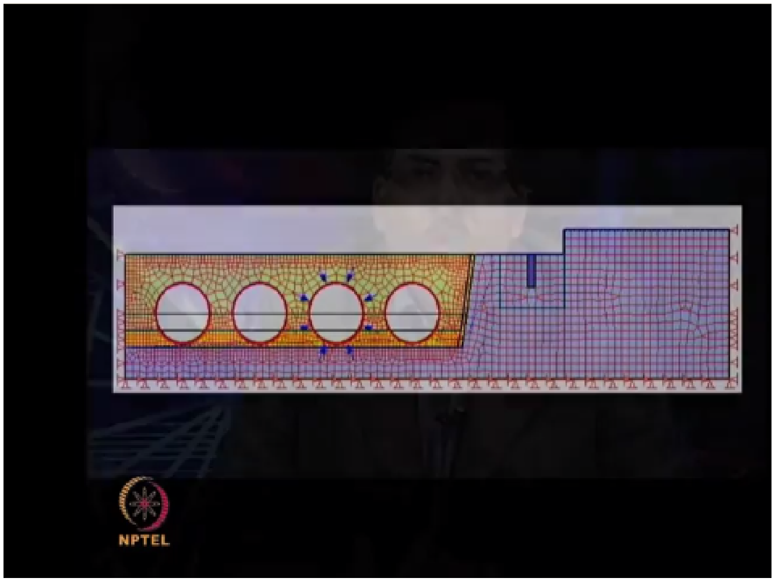

So in this case remedial measures as in place with were in a filter layer actually has been placed at this level, so is the you know the application of soil mechanics where in like in earth and dams a filter layer actually and if it is induced what will happen is that it actually prevents the water table and maintains a water table write you know the bottom of the pipe and which actually prevents you know reduces the extension pressure and it will prevent the pipe from losing this support from the soil.

So in that case what will actually happen is that stresses are become where in high and it left to very high amount of you know non inform stresses and which actually has led to the failures so this is you know the situation where the water table is drained directed with you know the so called a drainage layer which is actually placed suit in the sight condition, so the typical failure which actually as actually happened at the sight here is actually shown here.

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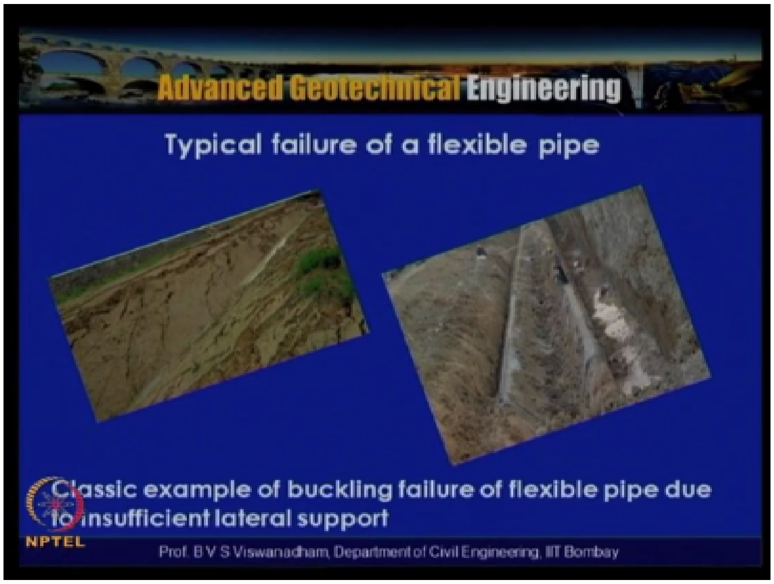

So here this particular pip after excavation is actually found like this so this is berceuse of the, the onset of you know rainfall in an we can see that the pipe actually is undergone in buckling failure and 3.3m diameter 8m which is actually undergoing distress, so this issues of loading on the buying conduits is very, very similar partcilaulry this flexible pipes with flexible ratios about D/t of the order of 12 they have to be required adequate here has to be taken the design by taking these you know appropriate loading considerations.

So in this particular module what we have understood is that what are the different types of pipes there are two types where two pipes and rigid pipes and then also we discuss in the loading theories masters loading theory for different considerations and then what are the different types of loads and what are different types of loading conditions then we also discussed with minimum soil cover requirement and pipe floatation particularly due to buoyancy alone and due to the liquefaction effects.

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