Port and Harbor Structures
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Module-04 Lecture-25
Load Combinations and Design

In this class, we will see these load combinations. So we have discussed about various loads, so we will see how to combine the various loads. And there is the two different types of design, we will see how to do the design using these two methods.

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So these are the various loads to be considered: one is the dead load, vertical live load, impact or dynamic effect of live load, cranes, shiploader, unloader, material handling equipment loads, centrifugal forces of vehicles moving on curve, earth pressure, berthing, mooring and seismic forces. In addition we have the temperature stresses also, it is not listed here, so we have to discuss about the temperature effect also.

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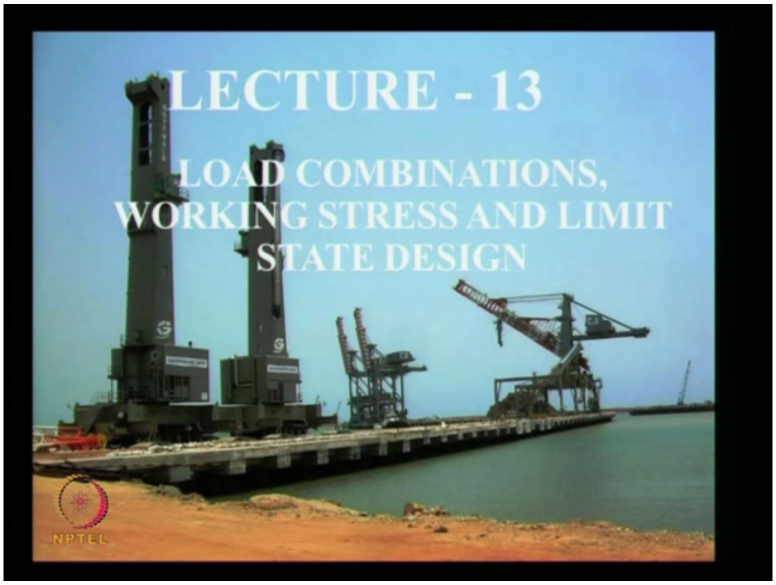

So these are the various equipments, mechanical handling equipments on the structure. So when these equipments are moving you will have some impact as well the dynamic loads.

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That is what we have written that impact or dynamic effect of live load. These are the things to be considered.

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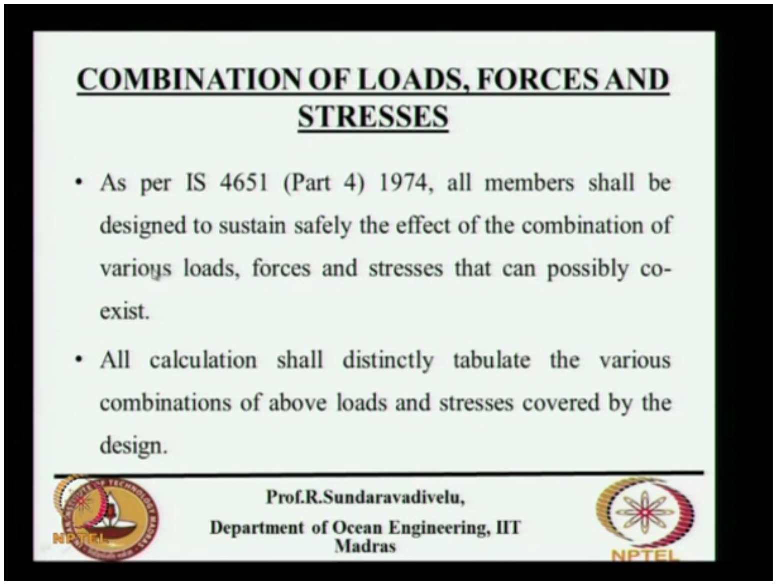

So as per this code, all the members shall be designed to sustain safety, safely the effect of the combination of various loads, forces and stresses that can possibly coexist. So what we are trying to say is when there is loads, different loads are acting, there is only certain combination which is possible, possibly coexist. That is what it means.

“Professor-student conversation starts.”

Professor: Berthing and mooring, can it coexist? Yes or no? When the ship is hitting the structure, you will get berthing. When the ship is moving away from the structure, moorings will take place. So berthing and mooring will not coexist. Can you tell any other two forces which cannon coexist? Civil engineering practice, we consider one type of….?

Student: (())(02:05)

Professor: Why? Earthquake and wind cannot coexist, why? What is it?

Student: (())(02:15)

Professor: Probability of occurrence of earthquake and wind is very low. That is why we say it has not occurred, in the study so far the earthquake and the storm or cyclone has not occurred together. That is why we do not consider it together.

“Professor-student conversation ends.”

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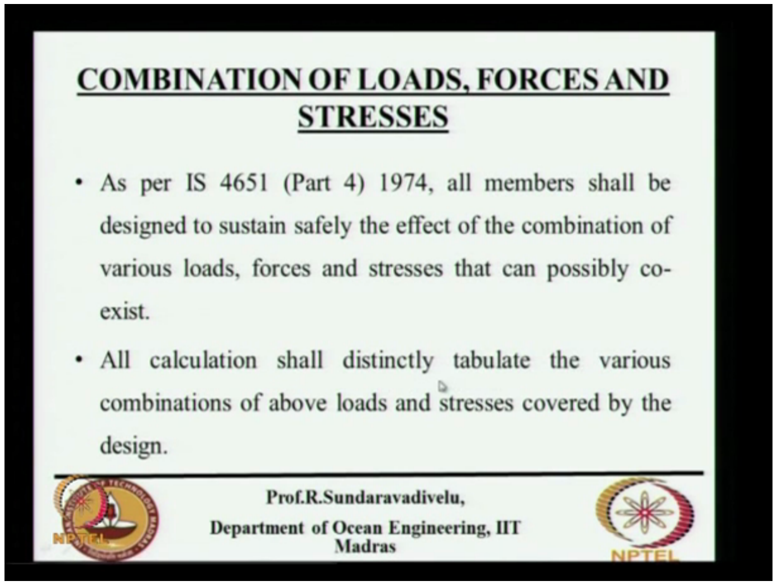

So when you do the calculation, you should distinctly tabulate the various combinations and then carry out the design, that is what it means. This is very important.

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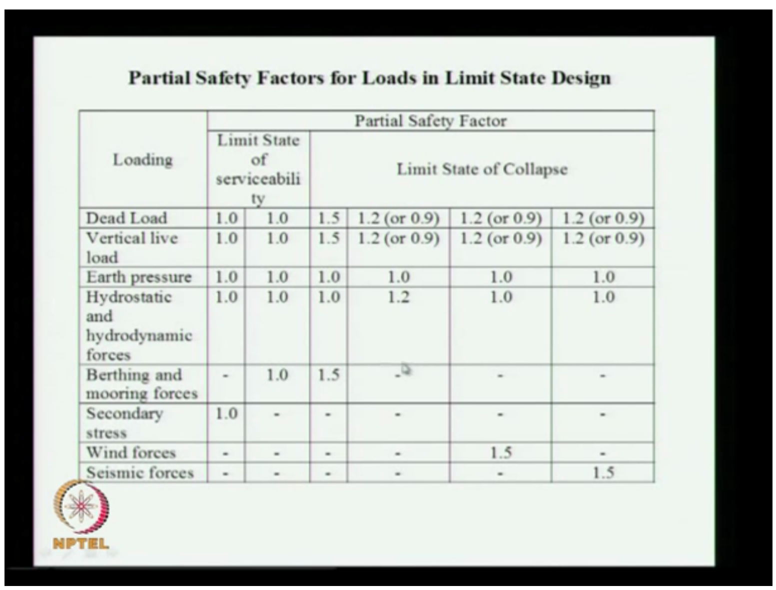

Partial Safety Factors for Loads in Limit State Design

Loading	Partial Safety Factor					
	Limit State of serviceability		Limit State of Collapse			
Dead Load	1.0	1.0	1.5	1.2 (or 0.9)	1.2 (or 0.9)	1.2 (or 0.9)
Vertical live load	1.0	1.0	1.5	1.2 (or 0.9)	1.2 (or 0.9)	1.2 (or 0.9)
Earth pressure	1.0	1.0	1.0	1.0	1.0	1.0
Hydrostatic and hydrodynamic forces	1.0	1.0	1.0	1.2	1.0	1.0
Berthing and mooring forces	-	1.0	1.5	-	-	-
Secondary stress	1.0	-	-	-	-	-
Wind forces	-	-	-	-	1.5	-
Seismic forces	-	-	-	-	-	1.5

So this figure shows there are two combinations, two sets of combination. One set is limit state of serviceability, another is limit state of collapse. Okay, limit state of collapse is due to stresses in the member. Suppose I want to find out what is the strength of this. I can apply it and send force like this. I am not able to break.

“Professor-student conversation starts.”

Professor: What else can we apply to break it? Say let me break it, it is breaking. What is a force here?

Student: Shear.

Professor: Shear or bending? Might be shear or bending. And the fact it is the brittle fracture.

“Professor-student conversation ends.”

Okay, there are three forces and three moments by which the structure will collapse. The three forces are axial force, shear force in two directions, bending moment in two direction and (()) (03:44) moment. Right, these are the three stresses due to axial forces, three stresses due to bending moment. If it reaches the yield, it may fell. That is what is given by limit state of collapse. What is limit state of serviceability? Limit state of serviceability, there are two components. One is the deflection, another is a crack width.

So deflection should be within permissible level. The deflection should be span by 250, suppose span is about 25 meters and span by 250 will be 100 millimeters. So we can allow 100 millimeter of deflection.

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Okay, 100 millimeter means this will be the 100 millimeter deflection.

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Hydrostatic and hydrodynamic forces	1.0	1.0	1.0	1.2	1.0	1.0
Berthing and mooring forces	-	1.0	1.5	-	-	-
Secondary stress	1.0	-	-	-	-	-
Wind forces	-	-	-	-	1.5	-
Seismic forces	-	-	-	-	-	1.5

The crack width is 0.3 mm or 0.2 mm or 0.1 mm. Normally the serviceability criteria is for a load factor of 1. What is a service load? Service load mean actual load that is likely to occur. Whereas limit state of collapse is considering the probability variation of the loads that can occur, we will increase the load factor. In some cases we will reduce the load factor also and find out what happens in limit state of collapse.

So in limit state of collapse we check against the yield stress. Whereas in limit state of serviceability we check against the deflection and crack width. The crack width is a function of stresses whereas deflection is a function of Young's modulus and moment of inertia of the structure.

So let us take this combination. This combination is 1.5 dead load, 1.5 live load, 1 earth pressure, 1 hydrostatic pressure and 1.5, there is a mistake here, it should be either berthing or mooring forces, this one combination. The other combination is the wind and seismic will not coexist together. So we have this as a wind and this as the seismic. So we have dead load, live load, earth pressure, hydrostatic pressure and then wind force or dead load, live load, earth pressure, hydrostatic pressure and seismic force.

So we do not check for seismic force and wind force serviceability, so these two cases are not there. The secondary stresses are due to temperature. Then we have berthing or mooring forces per second. So we have, what are the forces which will always act? This dead load will always be on the structure. Then what else will be there? Active air pressure will always be there. Then the differential water pressure also will always be there. So there will be hydrodynamic force maybe due to wave and current, that can be there or cannot be there.

Whereas this dead load, earth pressure and differential water pressure should be always present in all the load combination. This point is clear to you. Whenever you do your load combination, you should have dead load, live load, I am sorry, dead load, earth pressure and differential water pressure in all the combinations. The vertical line is a combination, one combination. This is another combination. This is a third combination, fourth, fifth and sixth combination.

But there are much more combinations. Typically around 30 to 40 combinations will be there. But this is what is given here, so we do not give differential water pressure and earth pressure, higher load factor in this limit state of collapse because the limit state earth pressure will become active earth pressure coefficient only. That is why in case of higher forces coming onto the structure due to dead load, live load or mooring force or berthing force, the earth pressure will reduce from earth pressure at rest to active earth pressure and remain constant. That is why we do not increase the load factor for this.

And differential water pressure we can estimate exactly, so we do not do that also. But in case only these three combinations are done, we will give this. Dead load we are reducing because in some cases there is a tension in the pile, then we have to use a lower load factor. So this when we do example, I will explain why 0.9 is required. Dead load means if you are providing a thickness of let us say 400 millimeter as a deck thickness, sometimes you may increase the thickness also while construction. Sometimes it may be less also. That is why we give a lesser load factor.

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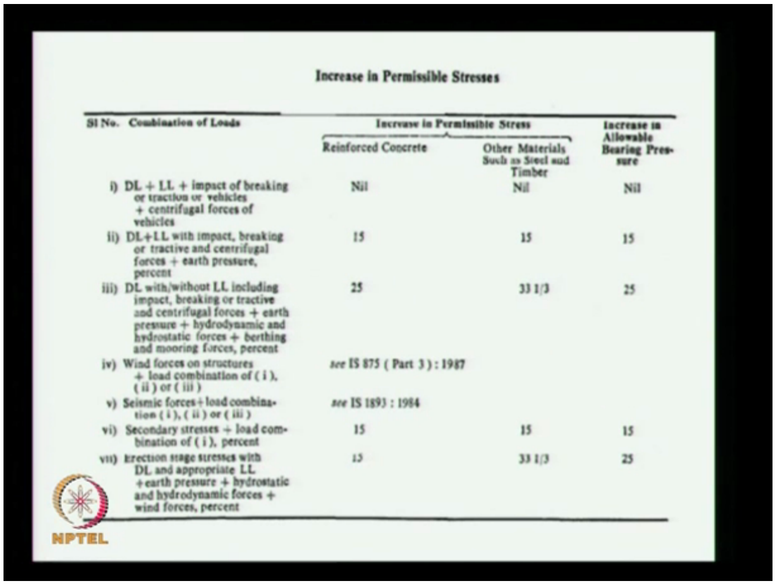

Increase in Permissible Stresses

Sl No.	Combination of Loads	Increase in Permissible Stress		Increase in Allowable Bearing Pressure
		Reinforced Concrete	Other Materials Such as Steel and Timber	
i)	DL + LL + impact of breaking or traction or vehicles + centrifugal forces of vehicles	Nil	Nil	Nil
ii)	DL+LL with impact, breaking or tractive and centrifugal forces + earth pressure, percent	15	15	15
iii)	DL with/without LL including impact, breaking or tractive and centrifugal forces + earth pressure + hydrodynamic and hydrostatic forces + berthing and mooring forces, percent	25	33 1/3	25
iv)	Wind forces on structures + load combination of (i), (ii) or (iii)	*see* IS 875 (Part 3) : 1987		
v)	Seismic forces + load combination (i), (ii) or (iii)	*see* IS 1893 : 1984		
vi)	Secondary stresses + load combination of (i), percent	15	15	15
vii)	Erection stage stresses with DL and appropriate LL + earth pressure + hydrostatic and hydrodynamic forces + wind forces, percent	15	33 1/3	25

This is increase in permissible stresses for working stress design. This is permissible bearing pressure in the soil medium. So what is a permissible increase? 15 percent in concrete and 15 percent in steel and timber or some combinations. Sometimes the berthing, mooring force is present, it is 33 1 by 3 percent. And in case of wind force or seismic force, we can increase the permissible stresses and working stress by 33 1 by 3.

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So when you use the crane and machine operating loads along with dead load, combined with wind load, we have to by the manufacturer or normal wheel load with maximum wind load as specified in IS 875, whichever is more severe should be taken for design purposes. So there are two cases for wind load. One is specified by the manufacturer, another is as per IS 875, whichever is maximum that you have to do.

So when you do the wind loads which will be given by the manufacturer, that is based on the operating wind load condition. Another is as per IS 875 which gives the wind speed at a particular location. So whichever is maximum that you should consider. So when you consider the berthing force, you do not need to consider the crane or machine operating load. So this condition is when the vessel is coming and berthing now, that time the crane will not operate. What it will operate? You press just near it, so crane will not operate. So you do not consider the crane operation load along with the berthing load. So when the berthing is not there, you consider the crane or operating load.

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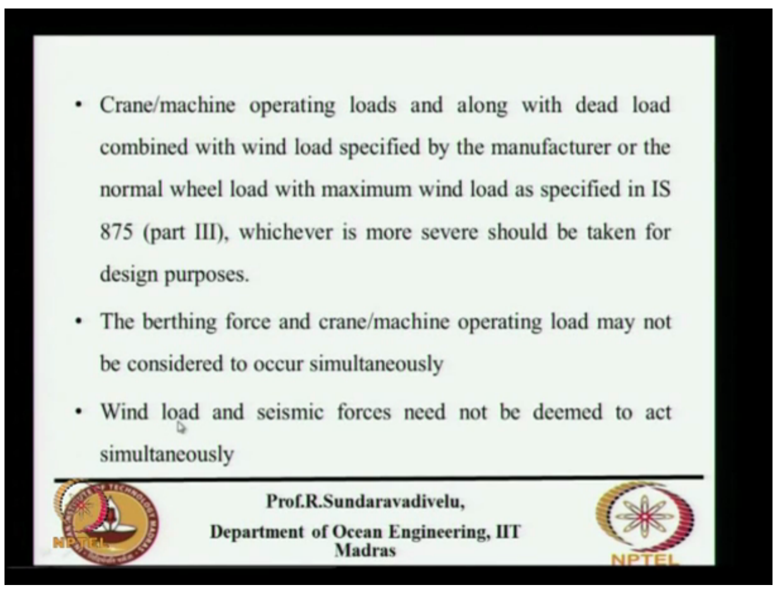

So this all of you answered the wind load and seismic force need not be deemed to act simultaneously. The wind load, there are two cases, one is operating load, another is extreme load, that is a cyclonic load, I will discuss later about this.

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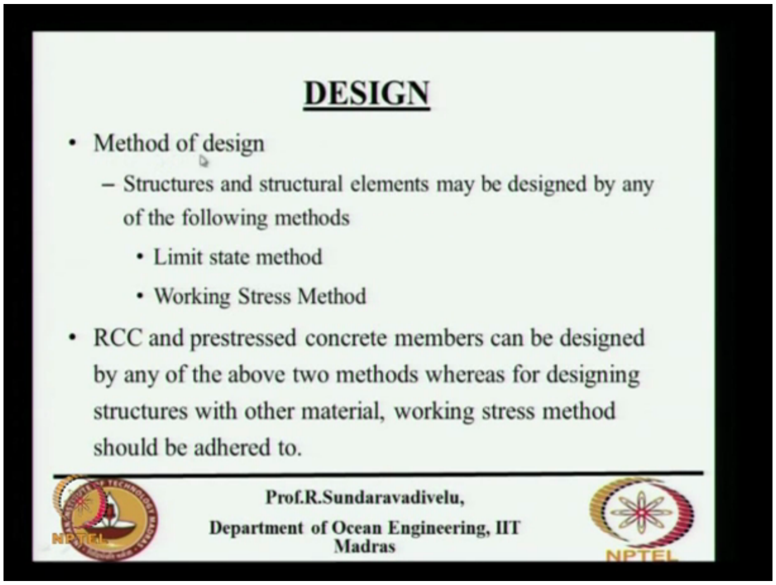

There are two types of design. Most of you maybe knowing only the limit state method but the older method is called as a working stress method. So we have to study about these two methods, I will give a brief introduction of these two methods. So we can design by using any of the two methods. So RCC or prestressed concrete whereas for designing structures with other material, working stress methods should be adhered to. This is old specification because for steel and timber we normally use the working stress method. That is what is given here. We do not use the limit state method.

Whereas for concrete as per today's criteria even if you design by working stress method, you have to check for limit state method. That is the present scenario. So concrete, even if you want to adopt working stress, you can adopt but you have to check for limit state also.

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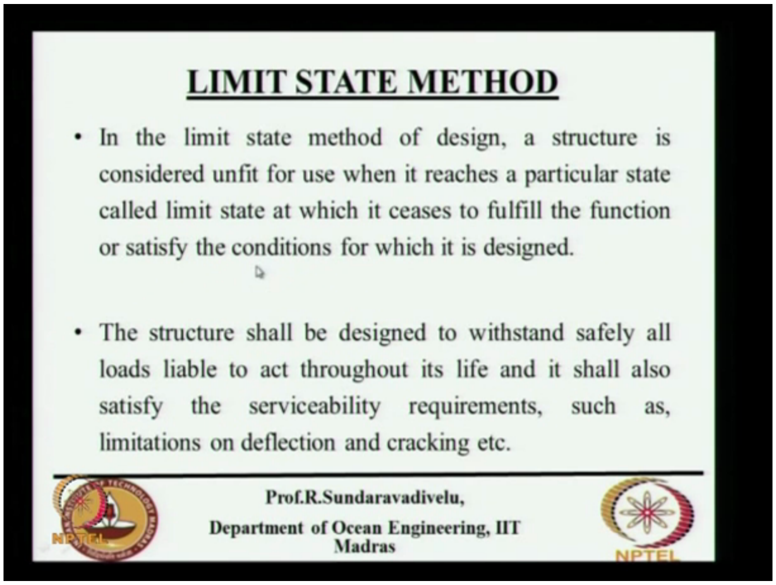

What is limit state method? In the limit state method, we assume that the structure is unfit when it reaches a particular state called limit state at which it ceases to fulfill the function or satisfy the condition for which it is designed. So that is what the philosophy for a limit state method. The structure shall be designed to withstand safely all loads liable to act throughout its life and it shall also satisfy the serviceability requirement such as limitations on deflection and cracking. The first one is for collapse. Second one is for deflection and cracking. That is what it implies.

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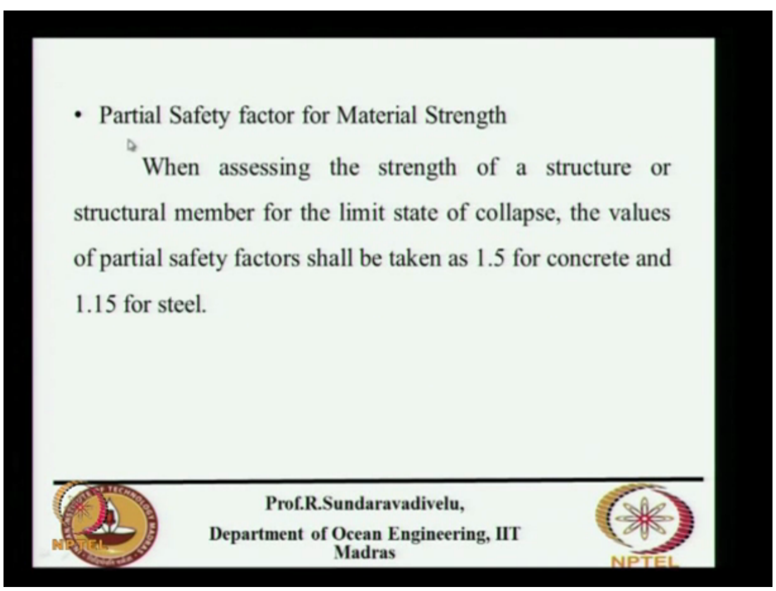

So we use what is known as partial safety factor for material strength. I will be asking this question, I am already telling all the questions, already answer is there.

“Professor-student conversation starts.”

Professor: What is a partial safety factor for concrete?

Student: Steel.

Professor: Why? Why concrete is having higher partial safety factor and steel is having lesser partial safety factor? Steel is made in….

Student: Industry.

Professor: Factory. So quality control is there and it is more ductile compared to concrete.

“Professor-student conversation ends.”

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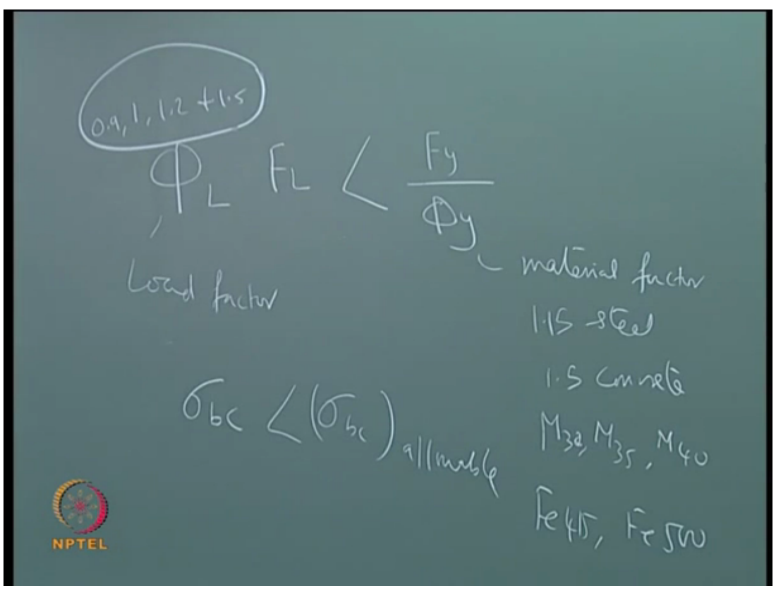

So your stresses happening due to the load should be less than the stresses which will be coming with the material. This is a simple way of expressing. That is a stresses appearing due to the load combinations, various loads. This FL can be dead load, live load, seismic force, wind force. You attach that with a load combination, load factor. This is called as a load factor. This is material factor. So this material factor is 1.5 for steel, 1.15 for steel and 1.5 for concrete.

So whatever is the yield stress of the member, we are reducing the stress because of probability nature of stresses that can have yield strength. So we are reducing the stresses and increasing the load. The load can be increased, the load factor can be 1, 0.9, can be 1.2 and 1.5. These are the various load factors. Sometimes 1.35 also will be there. So we are increasing the load. 0.9, I will explain later why we are doing that.

So the load is increased probabilistic nature, the strength is reduced. So whatever stress you are getting due to this after doing the analysis, you find out the stress. Suppose there is a stress, bending stress in the member, let us say sigma bc, bending compression stress, this should be less than sigma bc allowable. So this is a stress coming in the member due to the actual load, that should be less than allowable stress. The allowable stress depends on the material what you are using.

If you are using M grade of concrete, M30, M35 or M40, it depends on this. If you are using Fe415, Fe500, depends on the stress. It is nothing to do with the loads acting on the structure, depends on the material what you are using, the allowable stress. So whereas this bending compression stress in a member, a circular pile or beam member, it depends on the load which is acting on the member, based on that you have to do.

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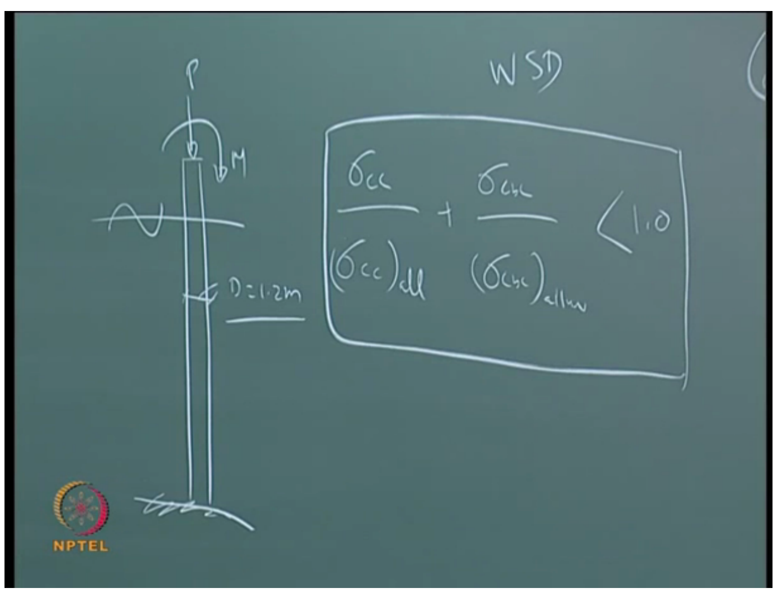

Then we may have a combination of stresses, so sigma cc divided by sigma cc allowable plus sigma cbc divided by sigma cbc allowable should be less than or equal to 1.0. This is another criteria. This is normally we use it for working stress design. The sigma cc, it is a stress acting on the member divided by sigma cc allowable. This is compressive strength in concrete. This is bending compression in concrete. This allowable stress, when you have the interaction, you will have a bending compression and direct compression.

Suppose you have a pile, this is not level. You have a load and bending moment. So this diameter is about 1.2 meter. This is here P, this is M. Due to this you will calculate the bending moment and force at any section.

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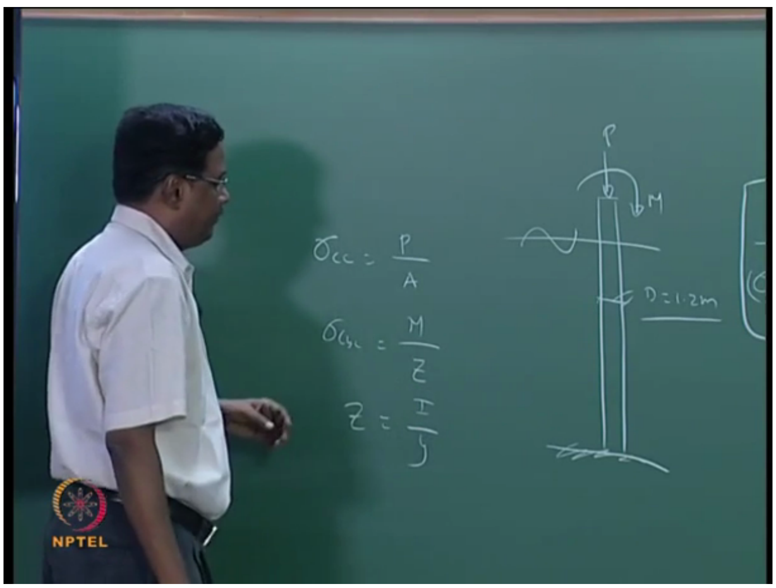

Sigma cc will be P by A. Sigma cbc will be M by Z. Z is equal to I by Y. So this is how we calculate sigma cc and sigma cbc.

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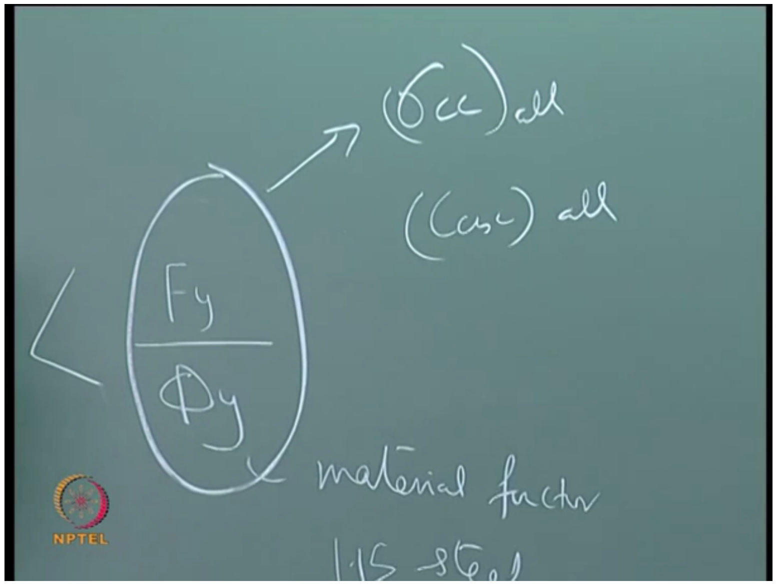

Sigma cc allowable and sigma cbc allowable based on this, this Fy by phi y will give sigma cc allowable or sigma cbc allowable.

“Professor-student conversation starts.”

Professor: So when you talk about this column, this column can be short column or it can be a long column. What is a difference between short column and long column? What is it? Yeah, (()) (17:28) is greater than what value you get?

Student: Greater than 12 means long column.

Professor: 12 means long column.

“Professor-student conversation ends.”

So the permissible stress level we have to multiply by a reduction factor depending on long column or short column. That depends on the length of the member which is L. So you have to calculate KL by r ratio. This is called as slenderness ratio. So K is factor. For a cantilever what is a value of K? 2, that is effective length factor. L, r is equal to radius of gyration, that is equal to root of I by A. So all these things you know, you have to reduce the allowable stress by a reduction factor. There is a formula for CR, if you see the working stress we can do it.

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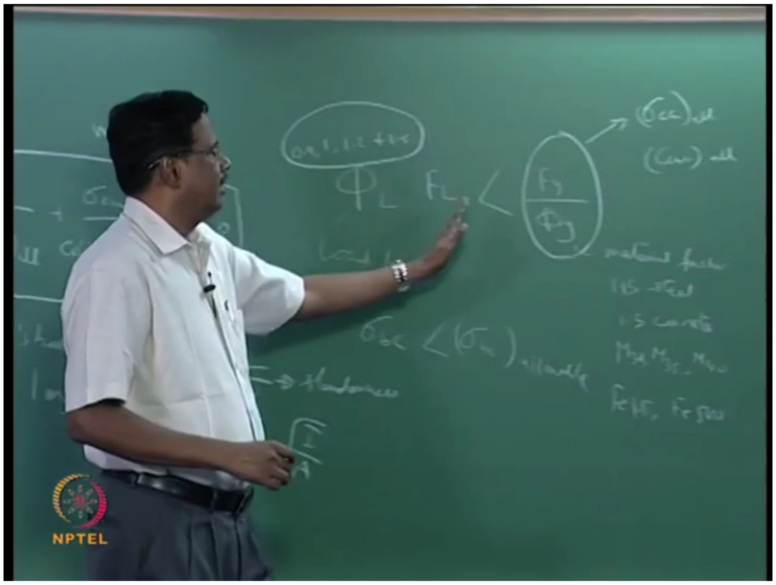

So this is a limit state.

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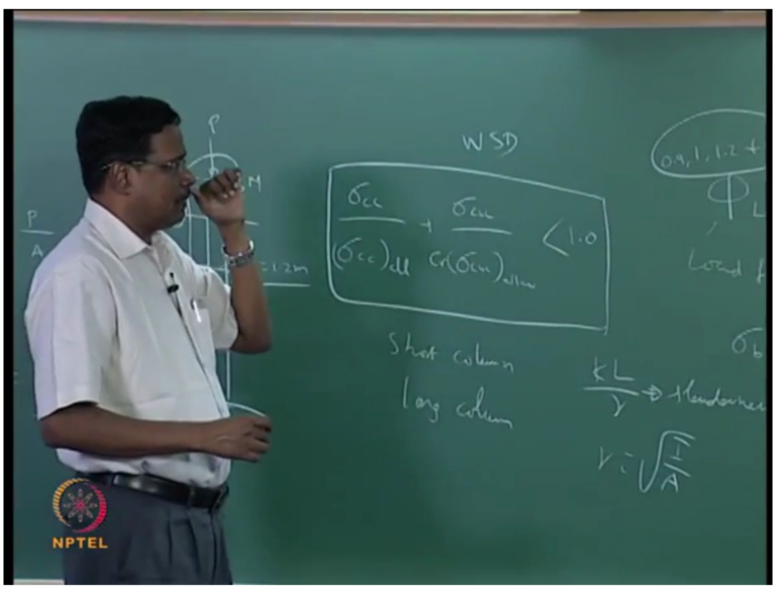

This is working stress for combination. Limit state also there is a formula for combination.

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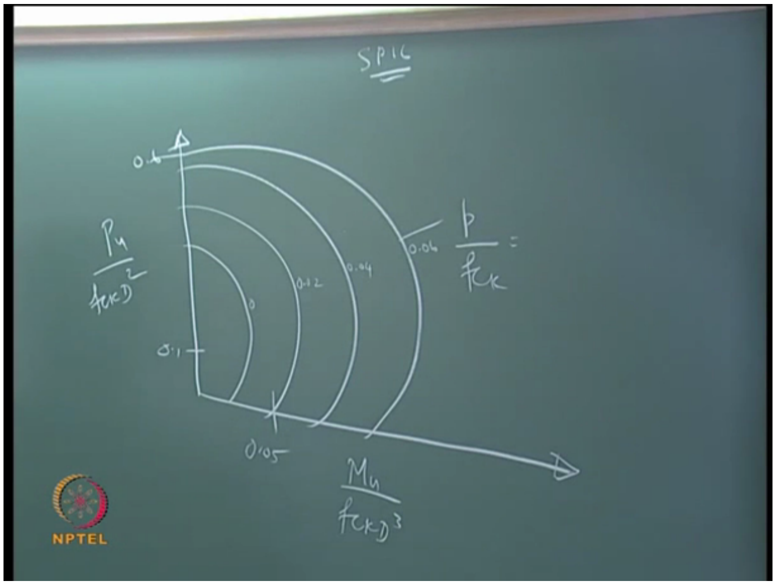

In a limit state method what we will do is we use this curve. This is given in code called as SP16. So here we have Pu by fck D square. Here we will have Mu by fck D cube. So we have the curves here like this. So here we write P by fck is equal to 0, 0.02, 0.04, 0.06 in this case. This was a 0.05. The value is 0.1, 0.6 like this.

So when you do the phi L and FL combination, phi L and FL, you will get the axial force in the member, that is called as Pu. You will get Mu that is a bending moment.

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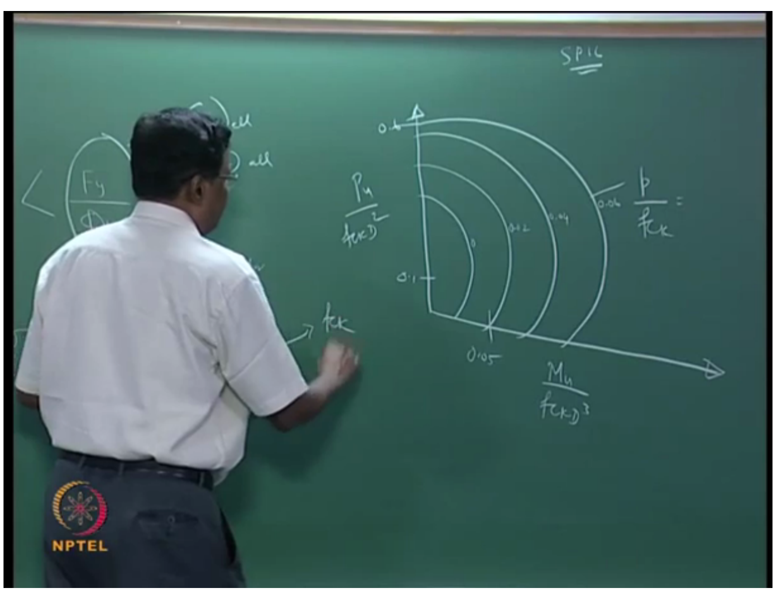

fck is the grade of concrete, is here fck.

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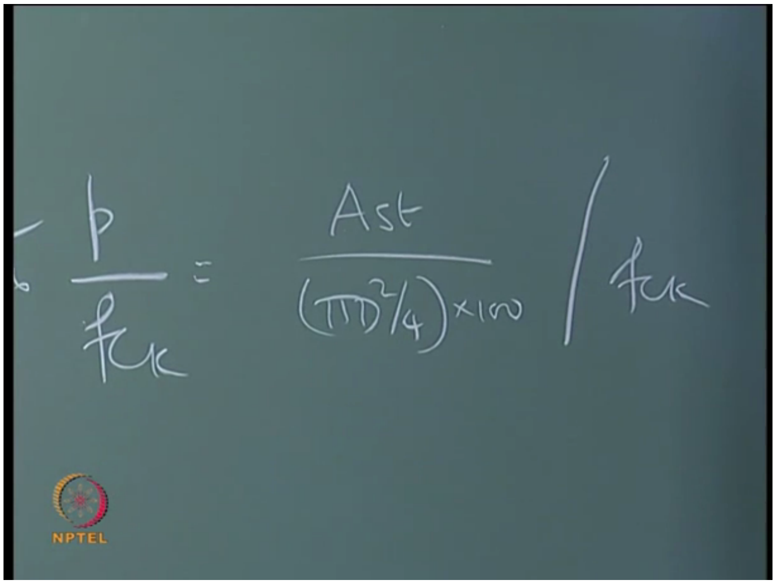

This P by fck is nothing but percentage of steel, Ast by pi D square by 4 into 100 divided by fck.

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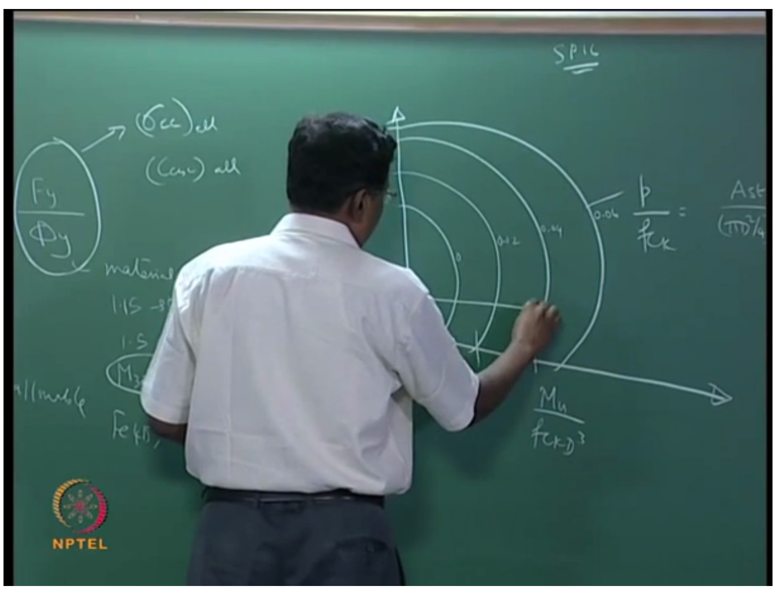

Suppose your value comes somewhere here let us say.

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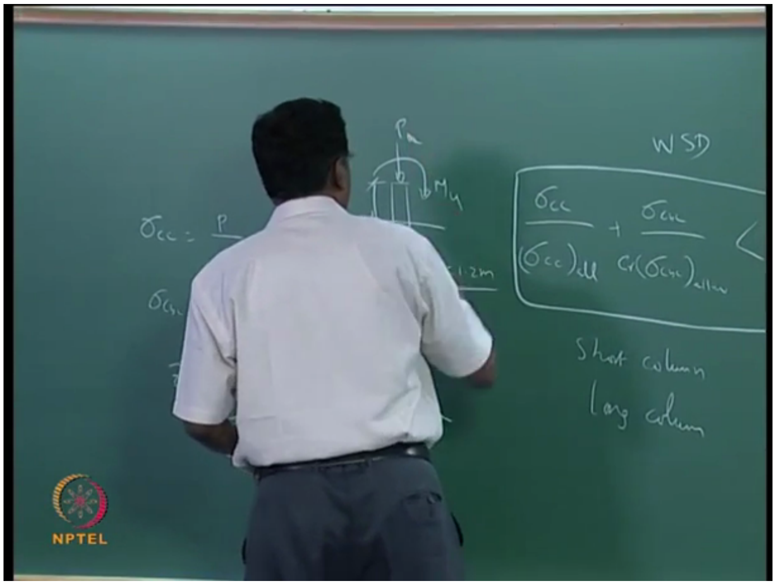

You calculate the Pu, it is a member acting on this. You calculate the Mu acting on the member.

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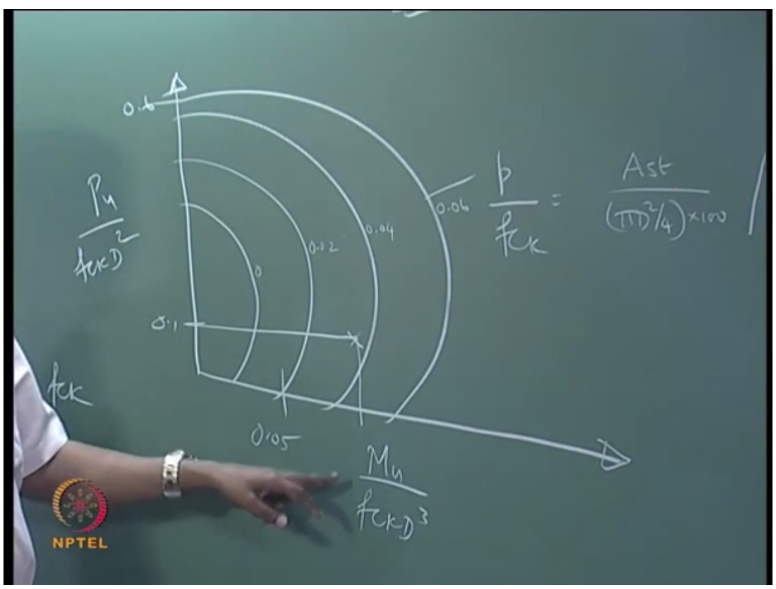

Then you find out Pu by, you know the diameter what you assume, you know fck, you can calculate Pu by fck D square, it comes 0.1. You get Mu by fck D cube, you get this point.

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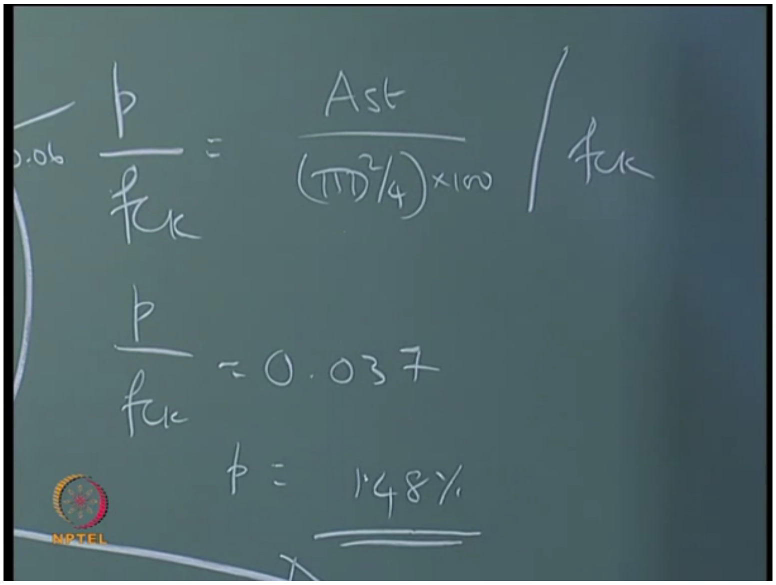

Then this P by fck comes equal to let us say 0.037. If you use fck as 40, so P will be 1.48 percent. So when you do the analysis, you will have the pile.

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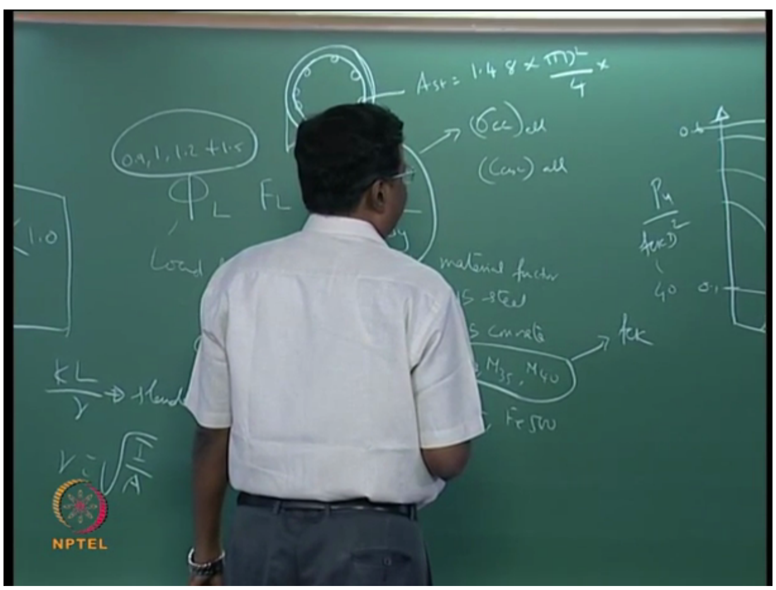

Let us assume diameter of pile is taken as 1.2 meter. There is what is known as enforcement here. Then we will have the steel here. So this percentage you can calculate. This is your Ast, area of steel. It is equal to 1.48 into pi D square by 4 into, is it correct or not correct?

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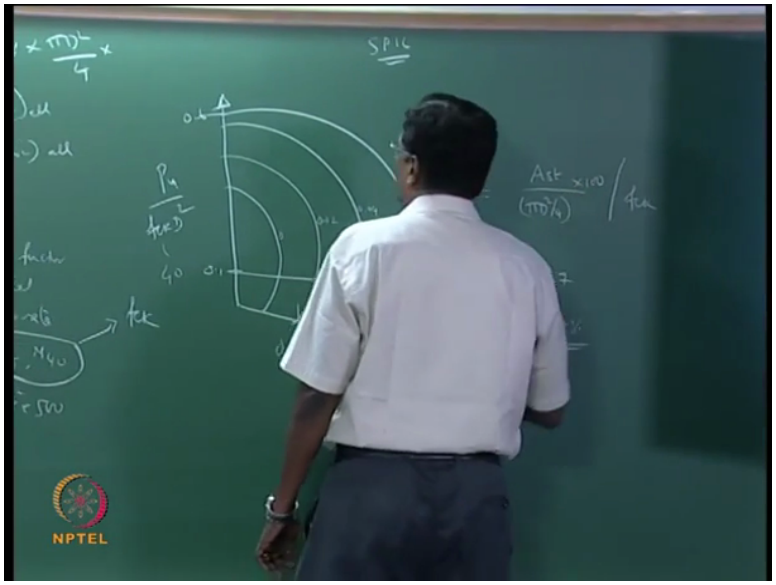

Into 100 here.

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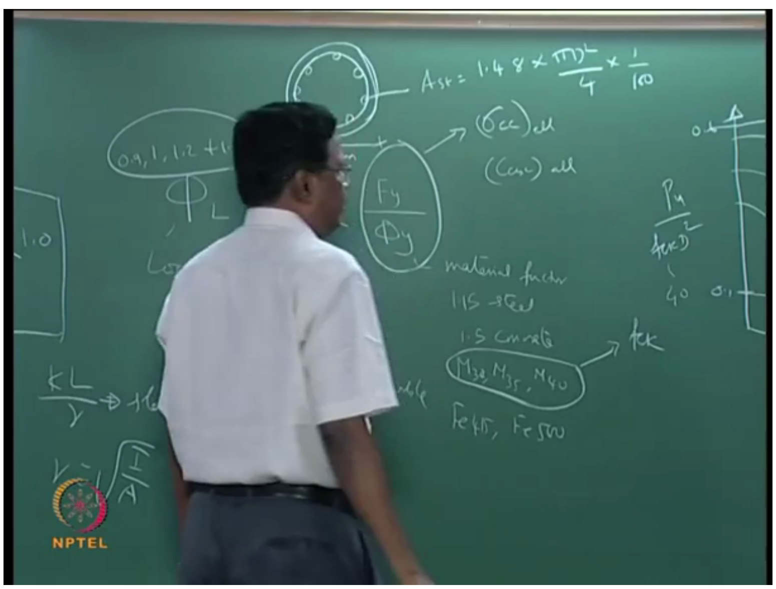

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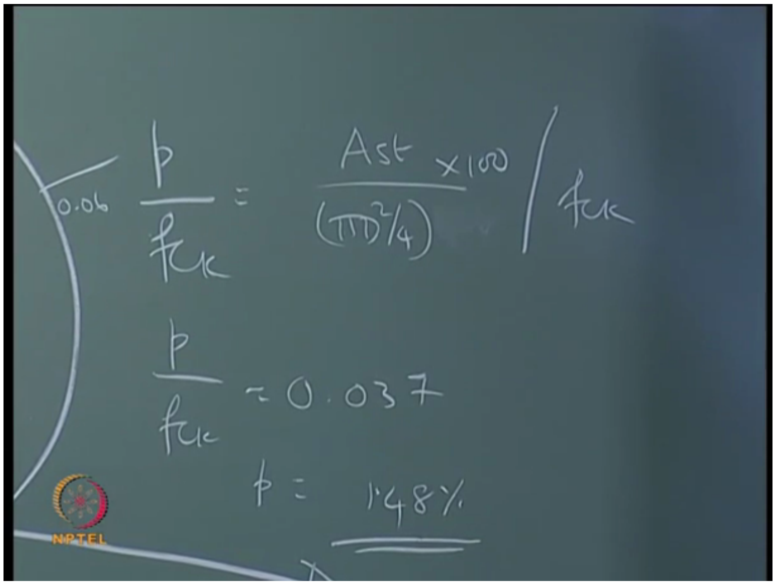

So you will get area of steel. Please write down all these things.

So in the design what we are doing is all of you know we are doing analysis with a particular diameter of the pile. What is to be found out is what is area of steel which you have to provide. How to find out the area of steel? You do the analysis for the load combination, find out what is the axial force and bending moment. Then you go to SP16, this interaction chart is given. This interaction chart is given for different grades of steel. It is given for Fe250, FE415 and FE500.

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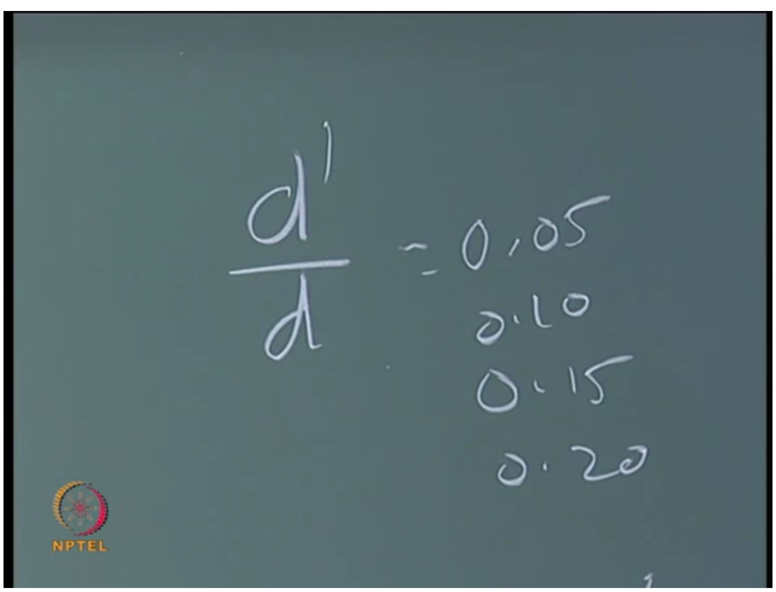

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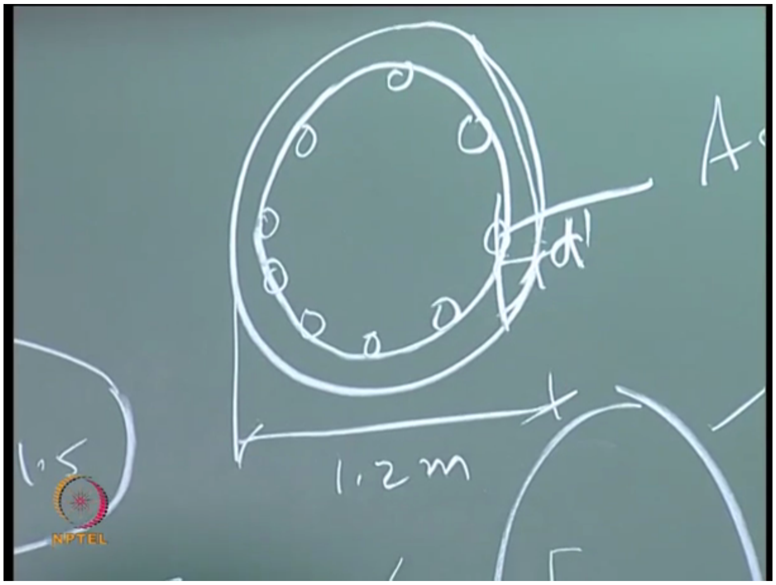

It is also given for different d dash by d ratio which is 0.05, 0.10 and 0.15 and 0.20. Where d dash is the cover and d is the diameter of the pile. SP16 if you check the (())(23:34) are given for different grades of steel, for different ratio of effective cover to the diameter of the pile. You go to the corresponding chart, you know what is Pu and Mu, this is coming from the analysis and go to this chart.

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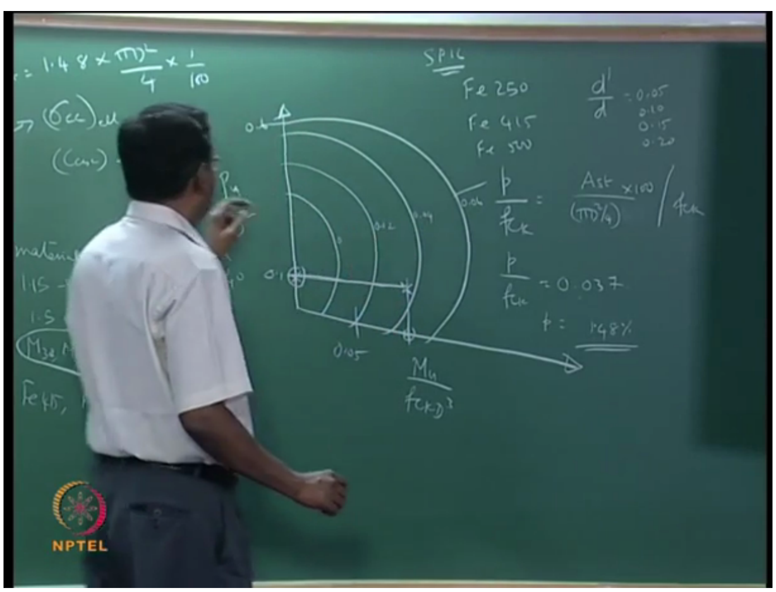

If you have used the M40 grade, you find out Pu by fck D square. You find out Mu by fck D cube. You are getting it at two points, do your horizontal line and do a vertical line, it gets here.

So this P by fck, this is 0.01, 0.04, so somewhere here it may be 0.037. 0.037 into 40, that will give you the 1.48 percent.

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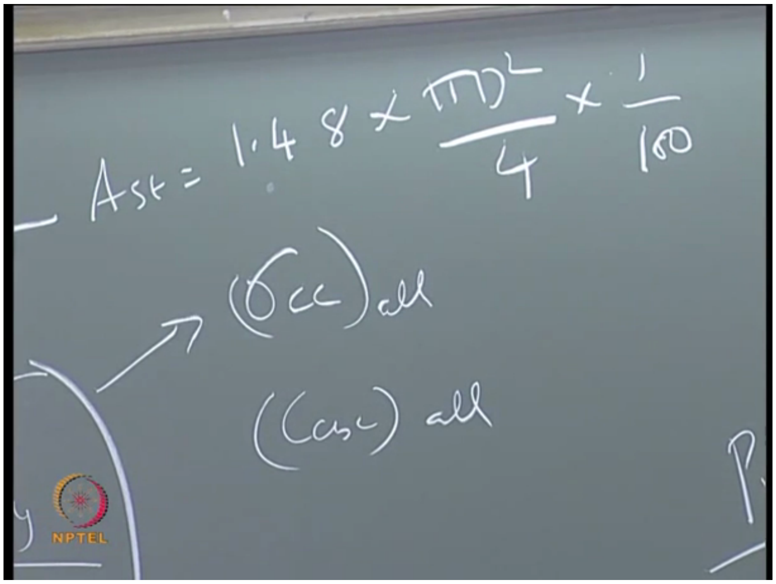

Once you get the 1.48 percent, you calculate what is the area of steel required. Then you provide the area of steel. Suppose to your calculation of Pu by fck D square and Mu by fck D cube does not fall within the chart, then you have to go back and revise the diameter.

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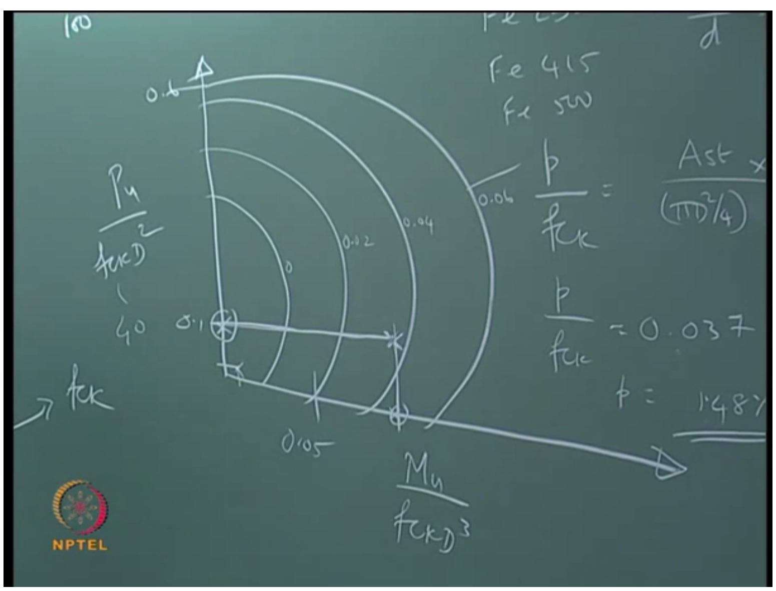

Suppose you get the values very close to this, 0 percent steel is coming, then you can reduce the diameter 1.2 meter. So you have to do the design.

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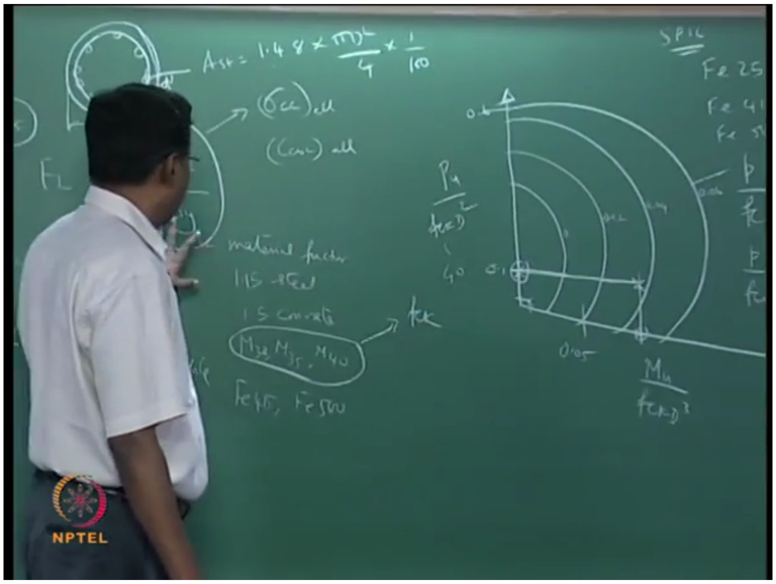

This interaction chart when they have developed, they have included already this 1.15 and 1.5 in the preparation of the chart.

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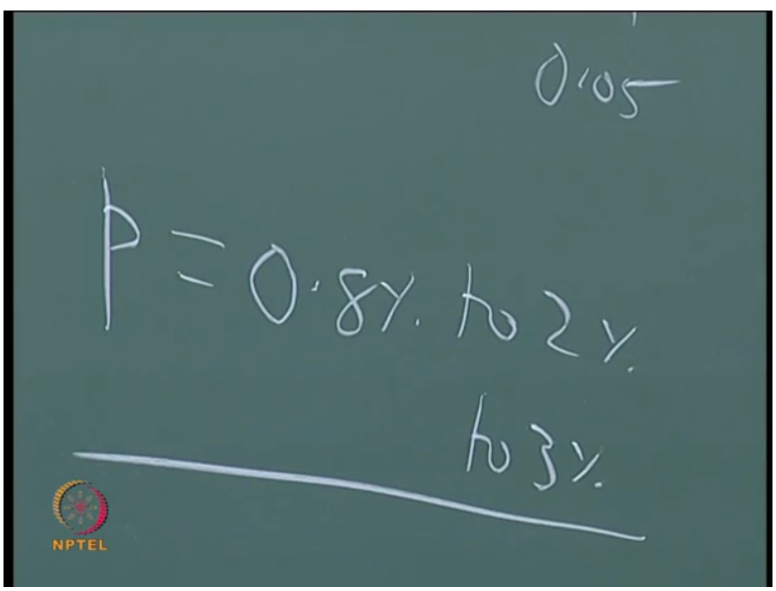

This percentage of steel what you are providing, generally it is should be in the range of 0.8 percent to 2 percent. Sometimes they may allow up to 3 percent, is very difficult to provide more than 3 percent steel.

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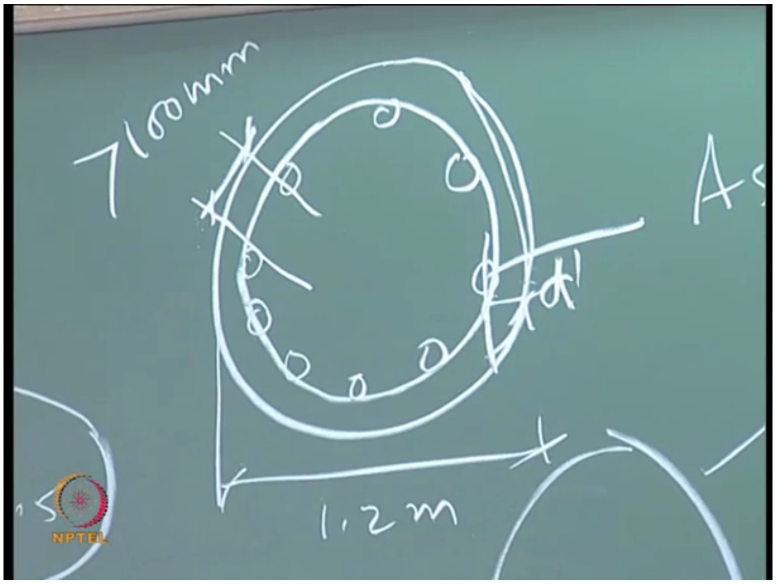

Because this clear gap between the reinforcement should be greater than 100 millimeters, then only the concrete will flow through this. It is another consideration. The minimum percentage of steel is 0.8. Even if it comes 0 percent, do not put 0 percent. Minimum steel requirement is 0.8, why minimum steel is required?

“Professor-student conversation starts.”

Professor: Why we are providing minimum percentage of steel in RCC? To take care of thermal stresses, shrinkage. Okay. Do not put plain concrete, you have to provide minimum.

“Professor-student conversation ends.”

The minimum reinforcement is different for different type of structures. For beam, it is different. Slab, it is different. Column, it is different. Just like here we have taken the reduction factor in the case of limit state design. It is a long column or window, you have to calculate slenderness moment. So whatever moment you are coming, you have to add one more moment which is called as slenderness moment and do it. Otherwise there is an analysis called P-delta analysis. If you do a P-delta analysis, we do not have to add the slenderness moment.

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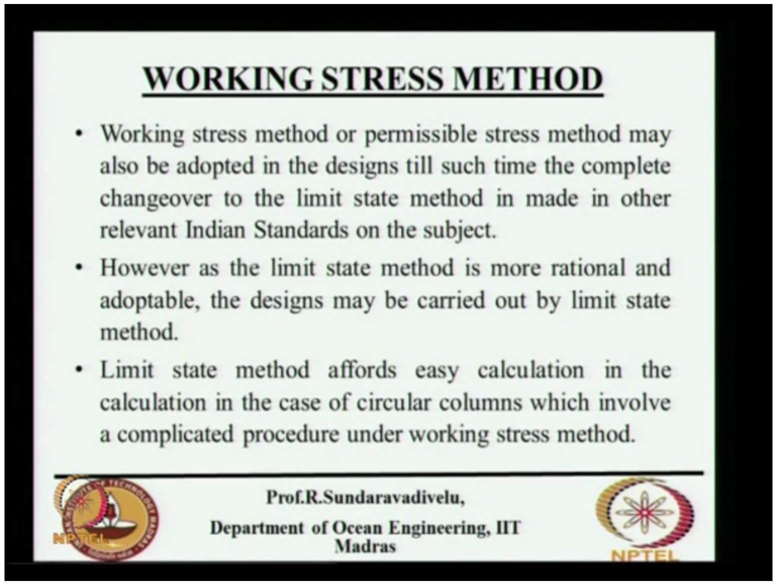

So working stress method or permissible stress method may also be adopted in the design till such time the complete changeover to the limit state method is made in other relevant Indian standards on the subject. So when this code was developed, IS 800 which is a steel code, they have not implemented the limit state.

"Professor-student conversation starts."

Professor: I think in 2000, when did the IS 800 limit state has come?

Student: 2007.

Professor: 2007. Now we can do that.

"Professor-student conversation ends."

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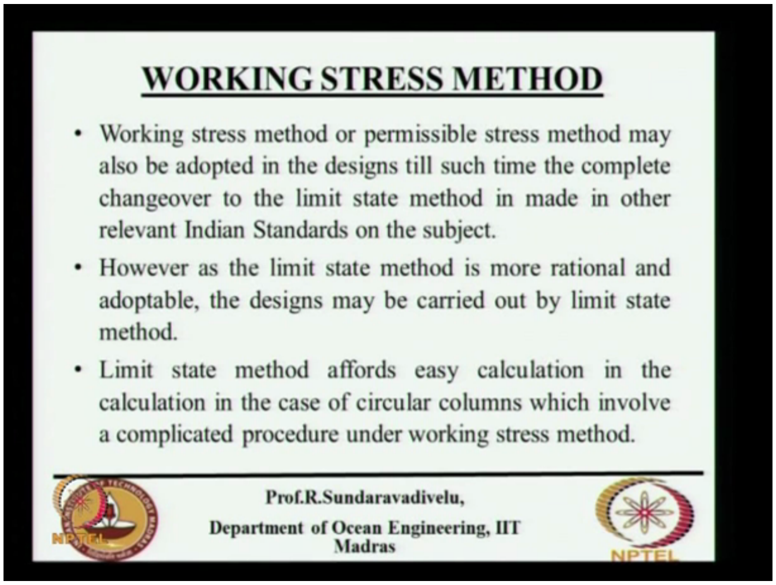

However as the limit state method is more rational and adoptable, the designs may be carried out by limit state method. So we recommend to use it, limit state method. So limit state method, the calculation is simpler for circular columns compared to a working stress method.

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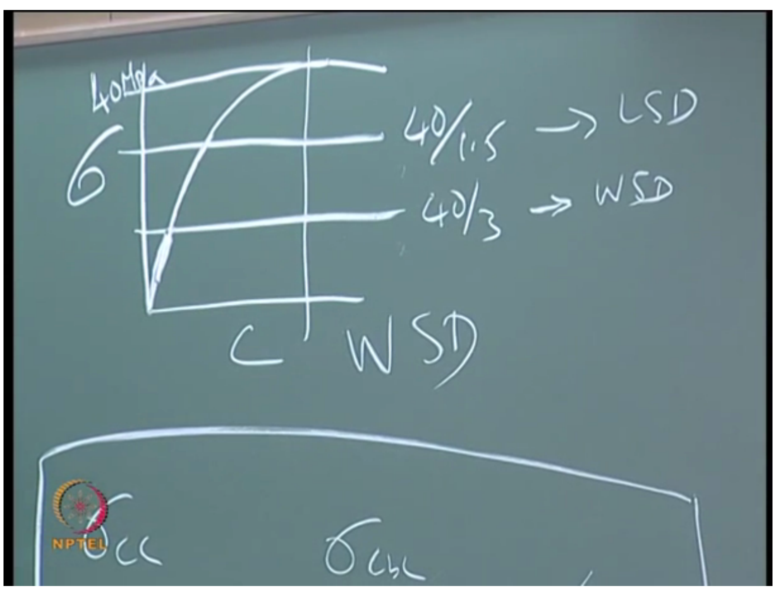

So this basically limit state method and working stress method, what we do is, suppose this is the stress-time curve for concrete. This is your maximum stress M40 mean this is 40 megapascal. What we do is we go to the stress level which is equal to 40 by 1.5, this is for limit state method. This 40 by 3 is we do it for working stress method. 40 megapascal is the compressive capacity of the member, M40 grade. 40 by 1.5, we use this in the limit state method. 40 by 3, we use it for working stress design.

That means we are still in the linear range, our stress levels are lower. Whereas in working stress, limit state it goes into the other, non-linear portal, okay. Actually this line may be slightly higher also. That is what we are doing. Whereas this stress what you are calculating, is for increased load, 1.5 times. Whereas here the stress is calculated for the service loads. Okay.