Design of offshore structures
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Lecture - 03
Steel Tubular Member Design 3

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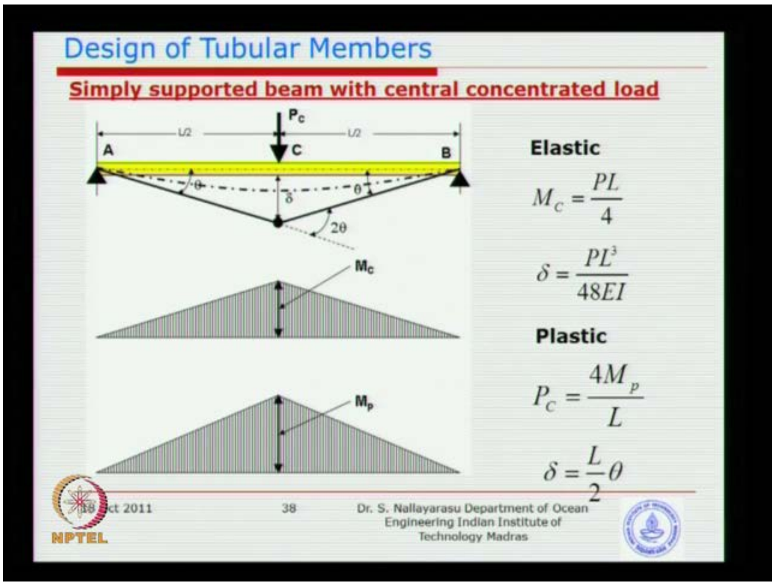

The other day we were looking at this effect of geometry of the cross section.

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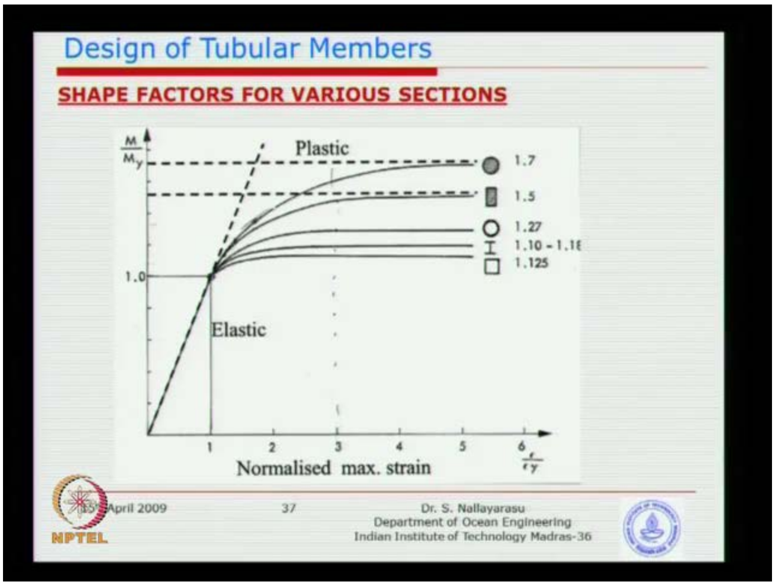

Now, what we are going to just quickly look at few slides showing the effect of the boundary conditions and the location and this type of loading. So, if you look at this simply supported beam with a centrally loaded point load. You could see that I think most of you remember the bending moment diagram will be a triangular shape, with a maximum bending moment is P L by 4 or W L by 4, which you will remember from your basic mechanics.

Now, if you keep loading this or increase the load magnitude until such time the stress diagram linear triangular distribution to a rectangular elasto plastic stage. You will see that the bending moment will become maximum. That means at that point of loading the plastic hinge at the centre will form, which basically means substantial section of the beam was yielded for full depth.

At that instant of time the beam will start rotating about this point starts collapsing, which is called collapse state, which is what we are interested. When the beam will actually collapse, basically from a linear stress strain diagram to a rectangular stress strain diagram. That point of time the load is called collapse load. So, that means when we are designing a simple beam like this, the beam is not going to collapse. Until, such time the redistribution across the cross section from a rectangular from a triangular stress diagram. Like this to a rectangular stress diagram at that particular point of loading.

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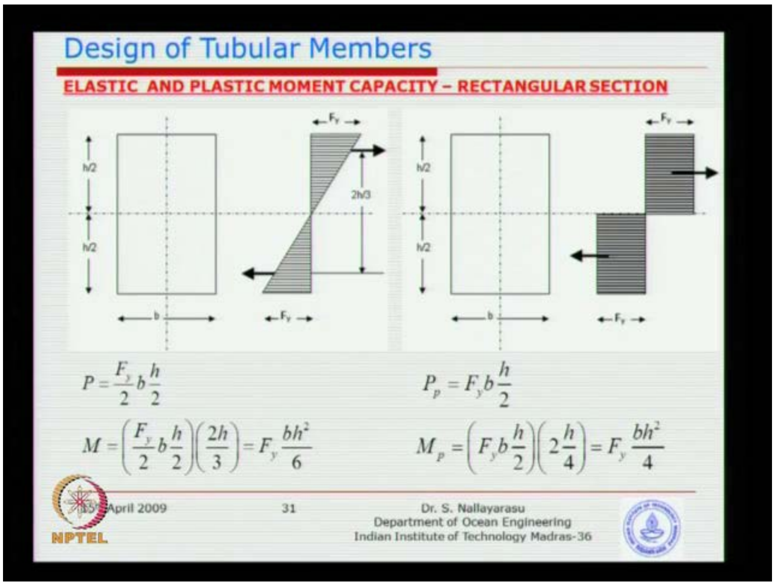

The reason why the plastic hinge is going to form at that centre location is, we know very well that that is the place, where the bending moment is maximum, elsewhere the bending moment is definitely smaller. So, the first point of hinge formation or so called yielding will happen at the centre under the loading. That means the load at which such a state of stress that means the uniform stress, along the section for a reasonable distance from the centre. It is not going to the beam going to collapse, when only point on the one top surface becomes yielded. You need the full depth to be yielded also little bit depth or at the distance from the centre. That means a reasonable length along the member axis needs to be yielded.

So, basically that point of state is called collapse state the beam will not be able to sustain any further load. Because, this end and the other left end both of them are simply supported have no moment capacity beam is unable to stand and it will start rotating now. This is the state that we are interested. When a structure is designed for so many methods, which we have to discuss today. Particularly, we are looking at a state of stress at the working load versus the state of stress. When the structure is collapsing that margin is larger and larger it is good. So, that we have extra margin to satisfy.

So, this particular concept of simple bending moment diagram. We know all of you might have studied in applied mechanics W L by 4 also the deflection at the centre. I think if you use any one of the method you have learned, slope deflection method or moment distribution method or other integration methods. You could find the displacement at the centre will be definitely maximum for sure. At the time of the beam is collapsing or the stress diagram becomes rectangular. I can denote the load is corresponding to P collapse instead of conventional P, I am calling it P c. Basically, when I substitute in this moment diagram the moment becomes plastic collapse moment.

So, I just rewrite the equation in terms of the collapse load is equal to four times the collapse capacity. That M p is nothing but the capacity that you have already calculated using the various principles, we discussed in the last class. For example, if we go to rectangular section the M p is calculated as F y times b h square by 4. So, you substitute that in this formula you will get the amount of load. The beam will take before collapsing. So, that is the idea behind you have a cross section, which is capable of taking M p. The load at which this the beam will fail, because of the support conditions are simply supported and basically four M p times l.

Now, this is just by inspection we have been looking at this. Can we derive this by basic principle? Yes, we can do that in the next slide. Basically, before that we also can calculate the deflection at the centre by simply using a simple small angle principle. I think you might have seen from this delta equal to L by 2 theta for small angle tan theta becomes theta. So, you can just use this L by 2 theta, which means that the beam cannot keep on deflecting infinitely, because the beam will get separated.

For example, you have a delta of large number, by the time what will happen the beam should have broken into two pieces cannot satisfy the climatic condition. So, basically this is the principle behind the collapse load of any structural system you can derive. Now, let us go back to the next slide how do we derive, because this slide I just showed only by inspection like looking at a bending moment diagram. Then just equalise, but you can also do by energy principle or work done.

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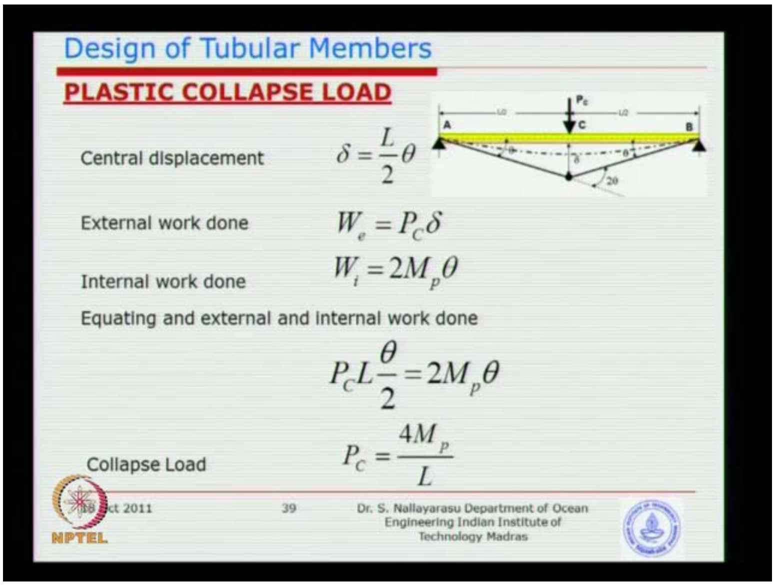

So, you look at this diagram the central displacement. As I was explaining can be calculated by L by 2 theta assuming that the length extension of half the beam due to bending is too small. So, del L by 2 actually if you look at it carefully, L by 2 plus delta L will be there. Because, of the strain in the beam, which I am ignoring smaller, because it could be considered to be small, because delta itself is small. So, when I do that I have L by 2 theta is a approximated displacement at the centre.

Now, if I look at the external work done is basically at the time of collapse. It is basically P c times delta. I think most of you remember your physics work done is force multiplied by the distance moved. So, P c by delta and the internal work done is nothing but the rotation of the beam, at the centre multiplied by the capacity of the section, which is the moment capacity. So, two rotations is happening, because there is one rotation at the end. This sum together at the centre is two times theta. So, when I multiply 2 theta times M p I will get the amount of work done on the beam, because of the applied load at the top.

Now, when I equate the internal work done to external work done for equilibrium condition I can get the same P c of 4 M p by, all of you understand this simple idea. Basically, we are equating the external work done to the internal work done. This is the principle normally adopted for almost all collapse analysis of complicated structures. You can go for from a simply supported to a fixed beam portal frame multi frame structures. You could do this exercise only problem is the solution term becomes larger. So, you may actually use a computer to solve this, which is not a problem.

So, basically you look at this what we are achieving just because, of the stress distribution from triangle to a rectangular at the centre for a smaller portion, we increase the load from M y. This is the normal moment bending moment to a plastic moment, which is similar. Because, the diagram of bending moment does not change, whether it is in the elastic stage or in the plastic change, but what is changing is the stress diagram across the section from a triangular to rectangular? Now, let us just quickly look at how the boundary condition is going to affect if. You look at simply supported is this 4 M p by L.

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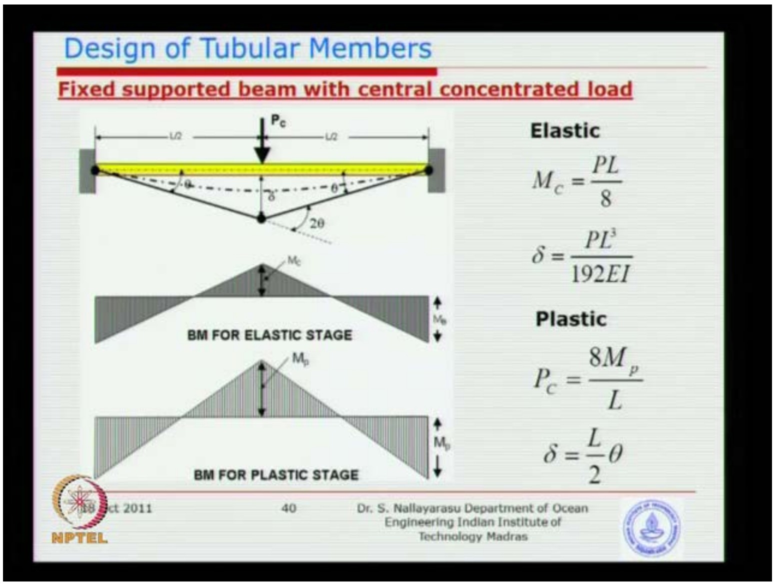

When I just change to a fix at both ends I can see here it becomes 8 M p by L, you could read the slides yourself simply. Because, you know the bending moment diagram. Basically, the collapse load or the load at which the beams are going to collapse becomes double just because, we have a boundary condition at the extreme ends, with a restrained condition, where the rotations are prevented. Basically, you can see the boundary condition influences the capacity of the beam by almost double. So, you could apply actually double the load to a fixed beam corresponding to a simply supported beam.

So, that is the idea behind the boundary conditions to influence quite a bit on the capacity at which the beams are going to fail. So, that is why when you have a redundant system. If you have a fix condition substantial amount of load can be increased before the structure becomes unusable, same thing we could derive exactly the same principle the idea behind is 2 theta is happening at the centre.

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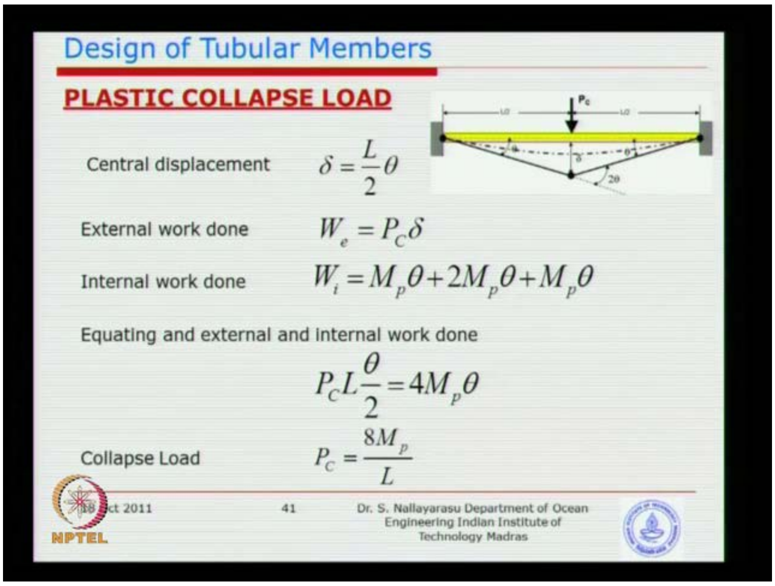

Also, the end has got M p, because in the previous case we do not have a bending moment at that point. So, moment capacity is not there, whereas here moment capacity at this the fixed end is also there. So, you can have theta times M p and the other end is theta times M p. You could equate the internal to external work done. You could arrive at the plastic capacity or the collapse capacity of a fixed beam. So, the idea why wanted to show this picture was to make sure that you understand the cross section. As well as the boundary conditions influence the ultimate load.

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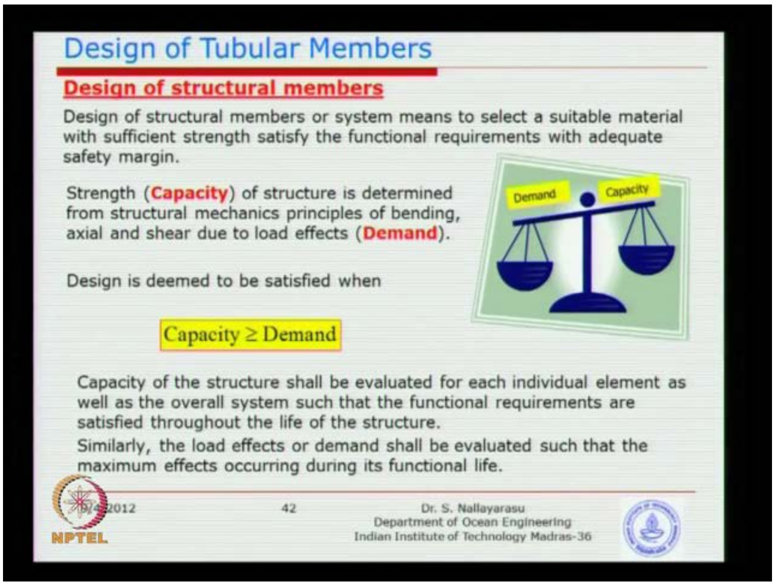

So, I think in summary what we have discussed over the last few classes we were looking at four things in total one is the fabrication methods tolerances. Then we were looking at the cross sections. Then the boundary conditions and the loading diagrams or loading pattern. These are going to affect the strength of any section. Now, let us look at today we will just introduce what is design. Then we will just look at probably the two types of design methods available. So, that we could solve some problem over the next few days.

So, the design means what exactly we mean is to make sure that the structure has sufficient strength to carry the service loads. So, that means we are just going to go for a reverse problem. We know what is the service loads and their effects and look for the response. The response must be within the resistance of the structure provided by or proposed by us.

We will propose a section, we will propose a geometry, we will propose boundary conditions, we will propose material. All of them together it is going to satisfy what exactly is called the demand from the system. That you are actually building for you can actually build a building bridge offshore platform, whichever you try to design the demand has to be satisfied. That means the capacity of the system should be such that always capacity is on a higher side.

Now, how do we satisfy there are various methods proposed in the past. So, we have got basically two system of design, which I think by easy understanding is allowable stress method or sometime we call it permissible stress method. Whatever it is we are going for the oldest method, which was actually started back in nineteen forties. Trying to design within the parameters, which was defined earlier time. We were not even knowing about the ultimate strength like nineteen fifties and forties. Nobody was bothered about beyond yield, you know post yielding behaviour was not known for many materials.

So, that was the reason why the allowable stress method was considerable use in classical structures machines for quite some time. In the recent days like last thirty years I think things have started slowly changing from the old methods to the probability based design methods, where you could utilise the material to a maximum extent. So, allowable stress design is nothing but we have a design load we have a design resistance.

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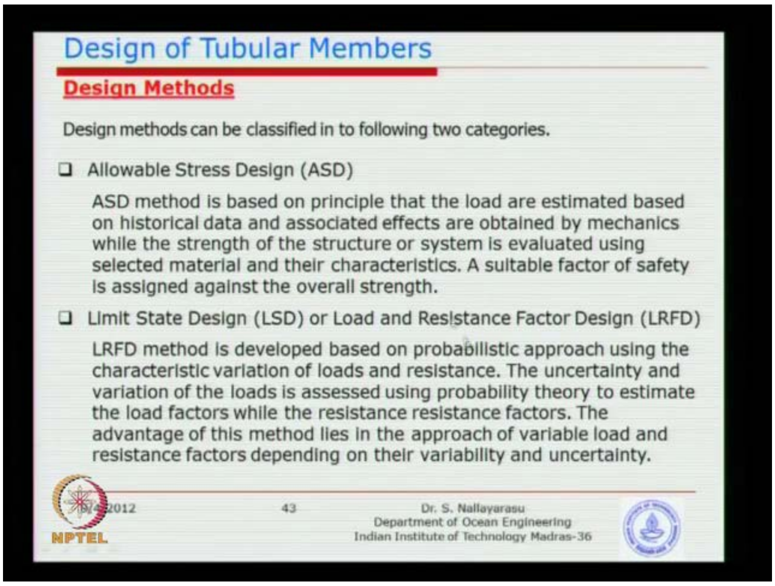

Both of them are arrived by historical experience based on certain testing not complete, but we do not evaluate scientifically, the resistance as well as the load pattern. That means there is still a uncertainty of evaluation of either the strength or the loads. So, that uncertainty is removed by looking at the parameters like for example, if you look at strength of system or loading pattern.

Possibly, you could look at slightly closer over the last say several years what was the pattern of loading? You look at the probability distribution, what could be the potential risk of exceedance? So, once you evaluate and then look for particular parameter to be multiplied, because this a variable loading or if it is a non variable load like. It is not going to change for sure, but how sure whether it is 100 percent or 99 percent. Now, if you say 99 percent there is a risk of 1 percent exceedance.

So, should we design for that one percent risk or should we design for a 100 percent? So, that means no risk. So, depending on the risk that you would like to take you could possibly adapt a slightly increased load factors. Whereas, the allowable stress method we do not look at that way. We design for a load, which we do not know, whether it will exceed or will not exceed. So, that is exactly the difference between so called allowable stress design and the limit state or L R F D. We will just quickly look at some of the factors used in the allowable stress method.

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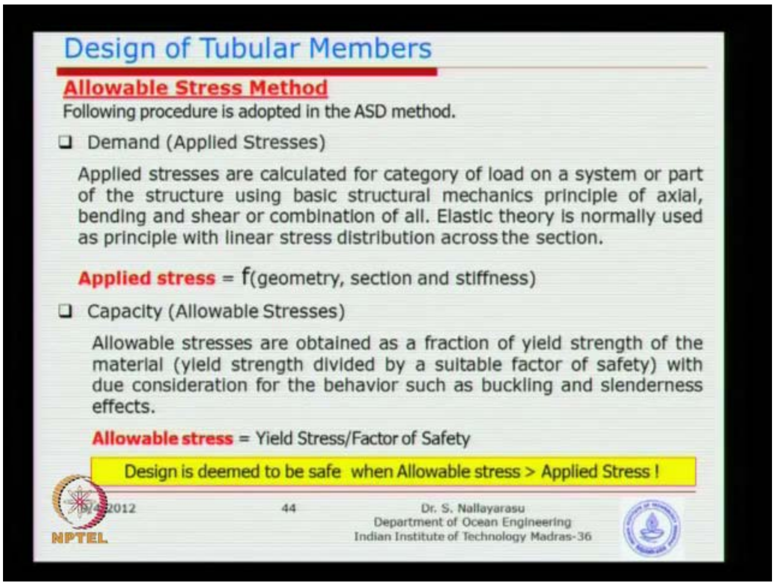

Basically, allowable stress design the applied stresses are calculated on the system, basically are of individual system using simple mechanics principle for axial loading, bending moment, shear and other components of loading if you have. Basically, elastic theory is used I think most of you might have studied, what is elastic theory. Simple beam bending axial loads and non-linear stress distribution is not taken into account. Probably, we try to limit all our stresses to less than linear or the yield limit. The applied stress is a function of what we discussed for the last three days.

One is geometry, the other one is the section property and then the stiffness system what material you are using. Whereas, the capacity depends on purely on the yield of the material. Like, if most of the structures for offshore we are designing for steel using material. So, basically the yield stress divided by a factor of safety is taken as the allowable stress.

So, when you compare applied stress versus the allowable stress always the allowable stress is higher the design seems to be safe. So, that is the principle adopted under the allowable stress method, where the allowable stress is taken as a percentage of yield stress. Like for example, if you have a factor of safety of two what will happen? It will become 50 percent of yield. If you have a factor safety of 1.5 it will become slightly higher. So, lesser the factor of safety higher the percentage of the yield will become allowable stress. Now, how much is better we need to decide this number so called the factor of safety, that number needs to be decided by the designer or the particular codal practice, which you are using.

Now, what will be the allowable stress for different load conditions? For example, you have axial loads, you may have bending loads, you may have shear. You will have stress, because we have tubular structures you have external pressure. So, each one will have different behaviour and different factor of safety for different loading conditions can be adopted. That is how historically all the loads are applying. For example, you apply a 0.6 for bending axial and bending. You may use 0.66 or you may 0.75, depending on what is the section. So, basically here the allowable stress calculation become quite simple, that you take a fraction of yield as your allowable stress.

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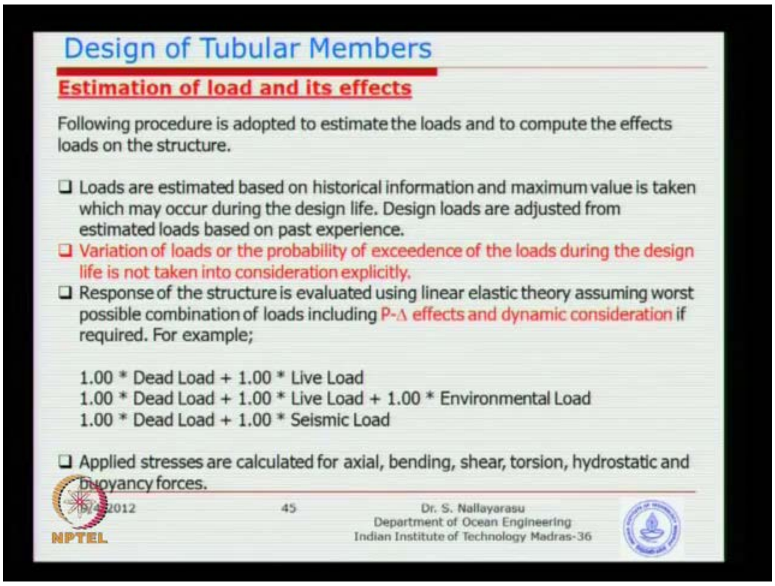

Now, if you look at the load effects how do we normally evaluate for allowable stress method is basically look at what was done in the past from the history. Like, few examples residential building you design for 500 kilogram per square meter. You design offshore platform probably past several examples of design will be available. So, based on that information you look at the loads and estimate using past experience.

There was no historical or basically mathematical study to prove that, particular 500 k g per square meter, which was used for one particular residential building will not be exceeded. For example, you have two particular residential buildings. One may not actually exceed the other one maybe exceeded, but what we do not know is how often that is exceeded.

So, that percentage or so called the probability is not known. That is where the problem occurs. You may see that know that one building is very safe designed exactly in the accordance with the same code. Whereas, in another building you do not know how many times that is exceeded. How much risk it has posed for the building safety, but of course, the building still remains little bit safe. Because, the safety that we apply here we still use only a fraction of yield.

Also, after yield we have so called post elastic capacity. That is why even if these norms are violated you will see that none of the building actually collapse. Just because somebody have load at slightly higher, but of course, in the recent times you will see several places instead of two storeys, you build four storeys. Then definitely the building is going to collapse.

So, basic idea is the estimation of load is a crude method, if I put it that way. Basically, based on past experience without looking at the scientific variation. The combination of load you will see that most of the time you just simply combine maximum of everything. For example, maximum dead load, because we are all worried about the safety. So, you take the maximum dead load plus maximum live load irrespective of, when they are going to coexist. For example, in this particular case of a typical example taken from a code.

You take dead load plus live load plus environmental load all of them are taken hundred percent, thinking that hundred percent live load may occur. Actually, at the hundred percent of storm loading, which may or may not exist the coexistence or so called the probability of coexistence has not been investigated. If it is investigated you may actually see that during the high storm nobody is going to have say.

For example, high live load you can actually reduce it, which is not done in this particular allowable stress method. Because, we are not very sure we are not actually evaluating that side of the load affects. So, that is one of the disadvantage that actually we see in using the allowable stress method. We simply accumulate the loads to the maximum possible extent. Because, we have only one factor of safety, which takes into account all the uncertainties, that we have left behind. Whatever, we have not investigated we simply put it in a bigger basket.

That we will give a factor of safety, which will take care of everything, but what we do not know is whether that factor of safety is adequate or not adequate, which is not very sure. So, that is one of the drawback that we have left behind, but so far I think doing well so much. So, many structures have been designed.

So, basically that gives you an understanding of how the allowable stress method is working. Of course, if we require additional effects due to p delta deformations could also be included. Nobody is going to argue that allowable stress design cannot have non-linear stress distribution, allowable stress cannot be implementing the p delta effect or the dynamic. For example, in offshore structures we have a dynamic loading, which always causes a trouble. So, you could all include that only problem is how we implement the system is the major issue there.

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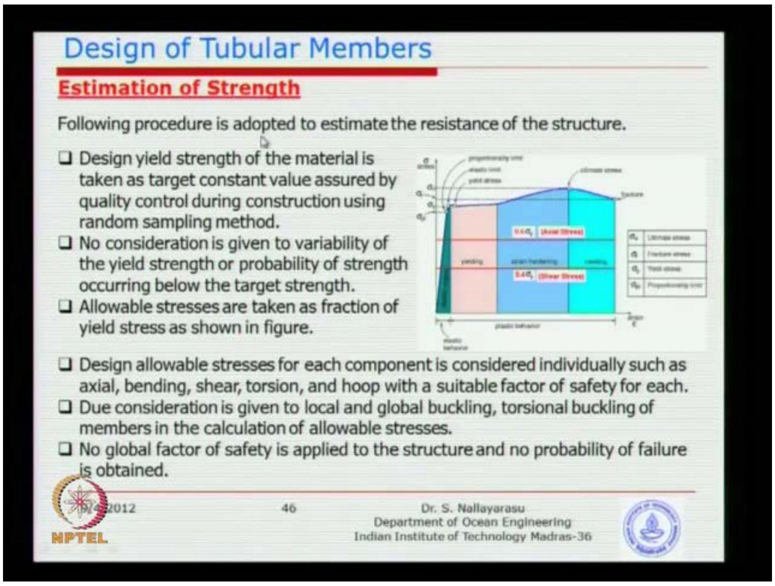

Estimation of strength similar issues are actually going to be there. For example, you take a concrete when you build a structure with a concrete. We do know that concrete everywhere is not same. You have a concrete with ingredients going to vary considerably from place to place, but fortunately concrete is made everywhere using cement aggregate and sand. Nobody is making a concrete with different material. So, you will have a characteristic variation, but not out of bound.

So, basically this how much is the variation depends on basically the workability of the concrete or how the concrete is made. That means there is a basically a influence of the characteristics of the concrete strength could be by the human interference. Basically, how you make the concrete? How you pour the concrete? How you vibrate and compact? How you cure could actually change the strength from certain percentage to certain percentage? That means the variability of concrete in the same structure from one location to other location could considerably vary. That is why when you do a building structures normally you have so called sampling. Take a cube and go to the laboratory and do the testing.

That sampling, normally if you remember in civil engineering you might have studied basically take sampling at random every hundred cubic meter. You will take one sample and you do the testing you come up with the results. When you prove that all of them are beyond your expectation. For example, your design strength is 30 mega Pascal. If everyone of them passes 30 mega Pascal you will be happy. Because, the target strength is 30, but you got everyone of them beyond, but if what happens if fifty percent of them is below your expectation. Because, you are doing construction first sampling and testing next. So, either you have to degrade the structure isn't it? You either degrade the structure or you do not use the structure.

So, there is a risk of such practices. That is what is one of the potential problem in current or today's practice is your construction is going on. At the same time you are doing a quality control and randomly not hundred percent, but you do not know whether hundred percent of the structure is safe or even one percent of the column is unsafe. It makes the system to be unsafe, which is not evaluated in the today's practice. Because, we have only one factor of safety, which is taking into account all these parameters.

Of course, in concrete strength testing if any of the test results fall below 95 percent of your expected value you actually discard that. That does not mean that you are going and actually demolishing the structure. Basically, you do accept a 5 percent failure rate, what if the failure rate is more than 5 percent? That is why we call it concrete strength is 95 percentile strength. Basically, when you are doing your if you take hundred cubes 5 percent of the cubes can actually have the strength less than your target value, which is 30 mega Pascal or 20 mega Pascal.

Now, one of the problem with this method is we are not sure the design strength is met everywhere. For example, you when you build a offshore platform. You might have several thousand tonnes of steel coming from various places. You are not going to test every piece of steel coming to your area coming to your particular fabrication place. Unless, you have tested you are not sure, which part of the component or the structure is going to fail prematurely before it achieves the design loading. Now, if you evaluate and characterise the steel that there is a potential chance of steel, coming from this particular mill will not satisfy this percentage of exceedance. Then probably you could include that in your design calculation, that I will multiply with a higher factor. So, that the design steel will be safe.

Even, if 10 percent of the steel is going to have the yield strength less than the target yield. So, such idea is to be included in the design, but there is no provision in the allowable stress design to do that simply. We take the target strength design it. Then we feel safe because applied stress is always less than the allowable stress. So, that is one of the weakness that we see here in the allowable stress design.

So, you see this diagram you can see here there are two red colour marks drawn. There one is having a shear strength or shear stress is 40 percent of the yield. The other one is actual stress of 60 percent. Now, if you ask why we have got this disparity between shear and the axial. Basically, shear has no distribution, whereas at least the axial can have some distribution depending on the combination with bending, but bending has larger distribution, like we saw that bending moment diagram. We could actually possibly increase the load double just because of the triangular distribution one and half from triangular to rectangular and basically that is.

So, shear if you look at most of you might have studied shear stress distribution across the cross section. There is no way shear can redistribute across the section, because the maximum is at the centre and cannot go to the extreme ends, because it is unsupported. So, that is one of the reason that shear failure should be prevented at any cost. So, you should keep the allowable stress at lower percentage of the yield.

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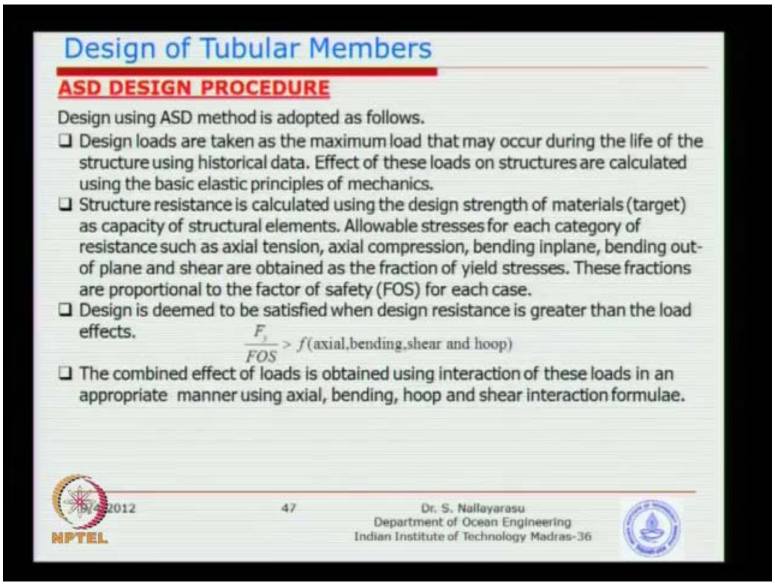

So, the next one is a simple procedure I think I have just combined how we do the design using allowable stress loads are taken. I explained in using the historical methods structural resistance is calculated using simple mechanics linear principles, with a factor of safety adopted for each of the stress states design is safe. As long as the applied stress is smaller than the allowable stress combined effects could possibly be taken. For example, you have a column subjected to axial versus bending. You could combine them in a proper manner linear or non-linear.

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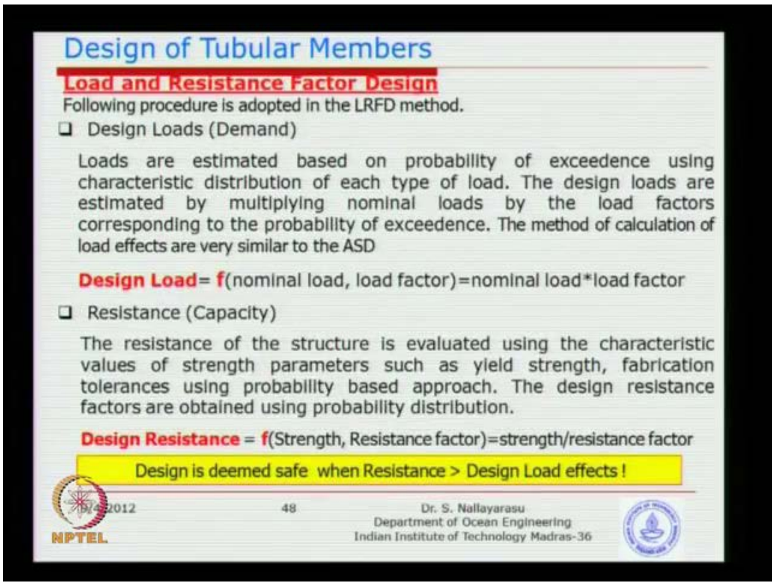

Let's move onto the load and resistance factor design or so called limit state design. In this method we do exactly the same procedure, except that the loads are evaluated scientifically. We do a probability distribution of each of the loads. For example, you have dead loads live loads environmental loads and then seismic loads. So, four category of loads you could easily understand dead loads are not going to vary too much, unless you keep changing the structure. Normally, when you have a designed structure built for particular purpose I do not think the beam size is going to change every day. The built beam is going to be same.

When you look at the live loads typically superimposed loads for a particular class of structure. If it is a residential building probably the variability is very low, but if it is a industrial building you could see that the superimposed loads could vary considerably for offshore platforms. Probably, variability is could be there, but not too much. Because, I do not think you will transport every time too much of the loading or the loads to the offshore platforms.

Environmental loads highly variable, because the potentially estimation itself is very much uncertain. So, you could see that the design loads the variability has to be accounted for. That means we need to study the parameters involved establish the frequency distribution versus the characteristics. Then find out if I want to take one percent risk of exceedance, should I allow what load factor. So, you reverse calculate risk versus reward, if I do not want to take any risk 100 percent. Then you ultimately ended up at the allowable stress design. So, the maximum load that may occur during the design life, but that maximum you only guess you do not know, whether realistically that is the maximum or there is another maximum, which you do not know.

So, basically in this method of L R F D you try to assess scientifically using probability distributions and find out what could be potentially maximum. Then arrive at what is the risk of exceedance of a particular value. For example, live loads you take a live load you design for a residential building versus public building. Typically, you take a case of a table or a chair when you design for a residential building. You could use a lesser value, because potential variation of loads could be very small, but of the same particular table or chair. If you are designing for a public building, it could have a higher variation. Because, of change in loads the characteristic loading could easily change.

Of course, it cannot go from 50 k g to 500 k g. Because, the chair is used for what purpose, it is only for occupation by humans. You are sure that there is a particular range live load by humans could only vary between 50 to 100. So, that is the definition of a characteristic of a particular variable, that you may not actually get a surprise from 50 to 500 for sure, it is not going to happen. So, even though we call it variability is there, but within a band of values. So, that is exactly we are looking at, for example, you take a environmental loading wave loads at particular location cold be 10 meter wave loads at another location can be 20 meter, but not going to be 200 meters.

So, if you look at the probability distribution of wave heights. You could see a pattern that you can arrive at. So, if you look for exceedance 99 percent non exceedance. Maybe, you will get 15 meter, 16 meter. If I want 100 percent non exceedance, then I take 20 meter and design it. If I want to take 90 percent probability of excedance, then I can design for say lesser values.

So, that is where the estimation of load becomes more scientific. That means we need to study each variable take a look at the characteristics. So, you can go to the site measure the wave heights for a period of six months one year two years. Look at the distribution over a time look at the variations. Then you try to extrapolate and predict this could be the characteristics over a next hundred years.

So,. you can come up with the probability distribution functions for a particular location. That is where I think when you look at your hydrodynamics course. I think hopefully they will teach you how to define a spectra for a sea state conditions, which I think I will leave it there just now. Basically, probability distribution function for each variable could be defined, whether it is a dead load, live load, environmental loads. Similarly, for resistance for example, you take a concrete or steel. You could potentially derive the probability distribution for the exceedance or non exceedance. Use that functions to derive the probability of exceedance or probability of non exceedance.

So, basically the methodology of calculation of demand or method of calculation of capacity, there is absolutely no change. What we are trying to do is implement the characteristic variable in the process. Still the design is deemed to be safe as long as the resistance is greater than the demand. So, there is no other change in...

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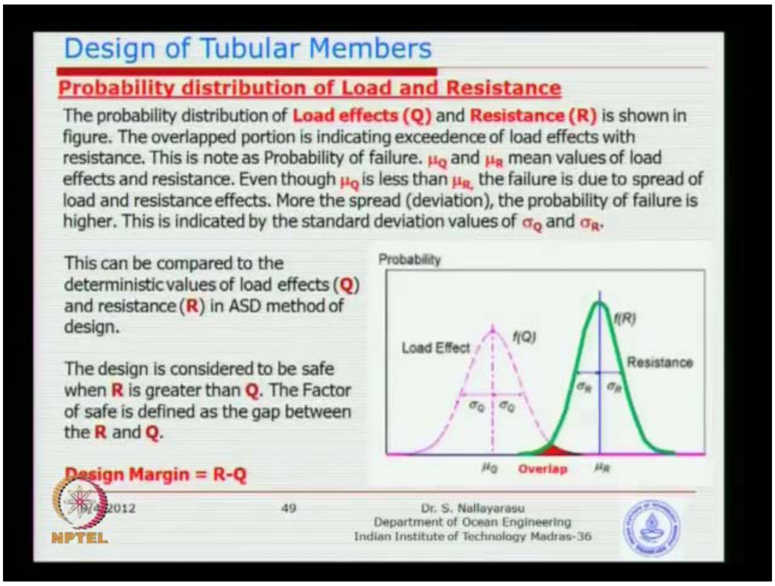

So, if you look at this particular diagram this is very important diagram. that you should understand the first paragraph describes the idea about the L R F D method. Whereas, the next two paragraphs will touch up on first. For example, you take a beam, which we have shown a simply supported beam central point load, you apply the load. You calculate the stress say 100 mega Pascal is the applied stress bending stress. All of you know how to calculate bending stress, right? So, simply moment divided by your modulus of the section.

Now, you calculate the allowable stress maybe using point six times the yield. So, you get 200 mega Pascal. Now, the design is safe by factor of safety of twice even though allowable stress is 200 applied stress is 100. We got a gap of 100 mega Pascal between the demand and the capacity. Now, how did we get this numbers 100 and 200, we got the number 100. We got basically using simple mechanics and you have taken the load as x value, that x value has been defined by somebody take that load and design it.

Now, if you look at that load and look at the probability distribution you could actually have something like this. It could be having a peak value at certain times. It could be less at certain times, it could be high at certain times, we do not know. So, if you look at the probability distribution the picture could be or the basically the variation could be, something like this. You might have heard of several distributions normal distribution in your mathematics course log normal distribution beta distribution. Or you can have

Weeble distribution Rayleigh distribution. Each variable has naturally have a certain variations.

Now, if you look at this diagram the load effect it includes geometry boundary conditions sections none of them are going to change. Because, when we design a beam with 10 meter span. Tomorrow, it is not going to become 11 meter for sure it is going to be 10 meter every day. So, what is going to change in the load effect is the load is primary concern. So, if you look at the whole load effect the diagram could be described as a load effect.

Now, if the load is constant you would have got the result of 100 mega Pascal, but if the load is varying, you will see that the load effects have spread value of it. Could be 10 mega Pascal yesterday. Today it is 100 mega Pascal because, the load has increased today. So, you could actually develop a diagram of load effect something like this. Also, can do a similar diagram for the resistance. Basically, because strength effects could vary, because of the yield strength of the material. Now, the 200 mega Pascal is the mean value that you got simply, because you have taken the yield strength of 300 mega Pascal. Now, if that value also has a spread you could actually develop a resistance graph, something like this frequency versus the strength.

Now, you see here a smaller portion of a overlap the strength is below the demand. Now, when we concluded the design using allowable stress, we concluded that 100 mega Pascal is always less than the 200 mega Pascal. The design was very well safe with a large margin. Whereas, when you look at the probability distribution of the same load. The same resistance you could see that there is a potential chance of probably a smaller percentage of failure because, there is certain locations where the load is always going to be higher than the resistance.

So, this overlap is the potential problem, because if one component in the structure or system fails the whole structure may collapse. If there is no redundancy and that is exactly what we are trying to picturise in the L R of the here. Because, when you design the L R F D you will always be able to define what is the probability of failure. Whereas, when you design by allowable stress design possibly you cannot define whether the structure is safe or unsafe. You will only conclude the structure is safe without a qualification how safe cannot be quantified. So, that is one of the drawbacks of the allowable stress design comparatively to the L R F D. L R F D could be quantifying the safety of the system or a structure.

So, the design margin in allowable stress has been defined earlier is always the difference between the allowable stress to applied stress. Whereas, in here the design margin in L R F D is always the percentage or the probability of failure, is the design margin. If you have 2 percent margin, basically you are designing for 0.98 probability of non failure. That means you know already quantified the 2 percent risk you would like to take and 98 percent definitely. Now, if you do not want to take 2 percent I want to take only 0.001percent. Well, we can actually implement that in our system. Basically, calculate back the loads and resistance, according to the lower risk you would like to take.

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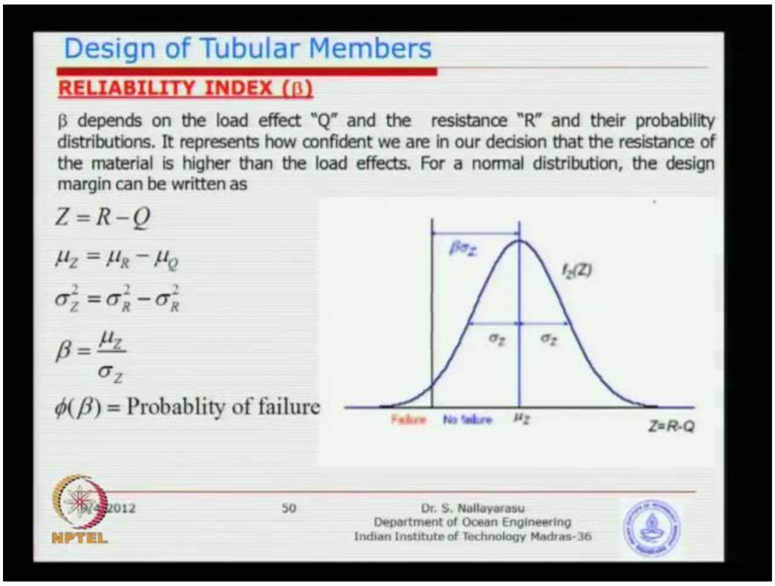

So, typically we call it factor called reliability index. This what we have is the function of loading function of resistance could be actually combined with the net function. Like, what we did here earlier is the net function is nothing but the resistance minus the load effects, which can be written as R minus Q. So, R will be your 0.6 times F y you are bending. For example, a typical beam Q will be your W L square by or W L by 4 divided by section modulus. So, R minus Q will be your the Z function, which is basically the net effect. You could actually use a normal distribution this is basically a normal distribution.

You might have learnt and the beta value will be for example, in our for allowable stress design. What we used? We used of allowable stress divided by applied stress is basically, that is what we are trying to do mu Z versus the sigma Z is the standard deviation mu Z is your the mean value of the net effect. If you look at most of the available textbooks, now for normal distribution you can get the table, for reading the probability of failure for a given reliability index. When you next time take the advanced mechanics course, we will go in depth into how you actually can calculate the probability of failure.

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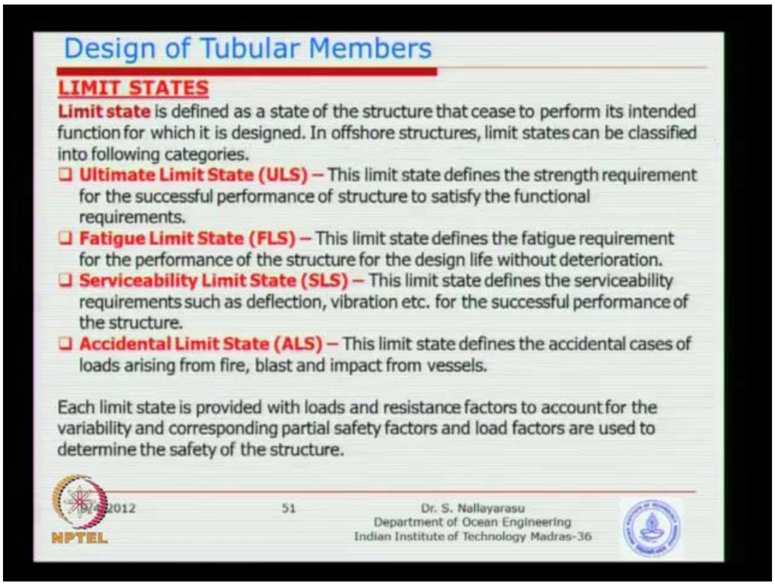

In this L R F D or limit state design we got to define several limit states, what is the meaning of limit state? Limit state is nothing but a state of the structure or a system unable to perform the intended function. For example, you design a beam for carrying a load by bending is unable to be satisfying the bending strength. Then that state is called a limit state a state at which the function is unable to perform.

Of course, other functions may actually perform. For example, you take a beam, it may be very safe in strength, but it is unsafe in deflection. That means it is limit state of deflection has reached. So, that is why you have got several limit states you got ultimate limit state. That means it is going to collapse or fail by deformation limit state of fatigue, which I think we will be looking at in more detail in the next few classes, basically failure by cyclic loads.

Then the serviceability limit state is basically, because of the deformation effects. The last one is deformation like deflection vibration could also potentially cause, unable to serve the purpose for which it was built. For example, you design a structure to support a compressor or a power generating machine. If the vibration is too much probably the machine will fail structure may not fail, but the function for which it was designed is unable to operate.

You will end up switching of the machines. So, basically the serviceability is more of a concern in this kind of structures. Then the last one is the accidental limit state, typically designed for basically accidental cases like fire, blast. Then basically a ship impact, these effects we will look at in the last module. I think we have design for accidental loads, we will look at it later.

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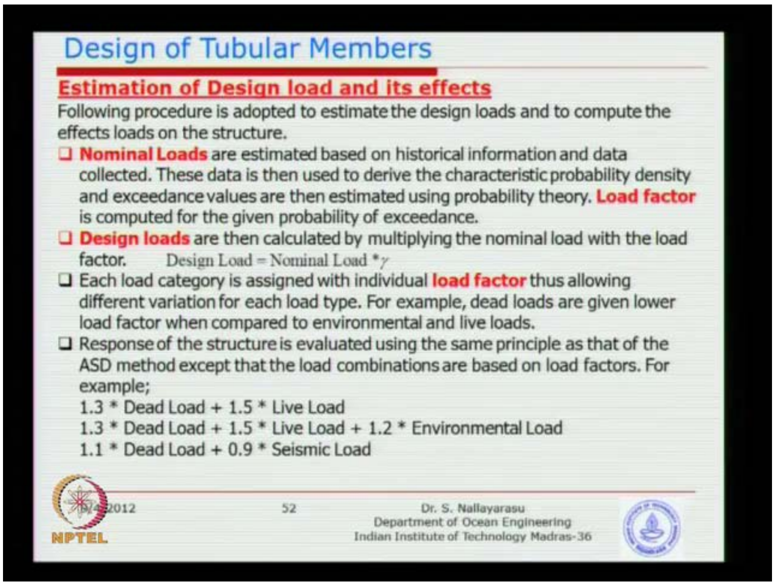

Similarly, in the L R F D method, basically what we are looking at is the nominal load arrive at historical basis, but then you will develop a system. Wherein, you will take into account the probability of exceedance, by developing a characteristic probability distribution for each of the for each of the variables. Then determine a factor called partial load factor or a load factor, which will be proportional to the risk. That you would like to take. For example, 1 percent risk or 2 percent risk or 10 percent risk will carry a different factors, that you can derive using the probability theory. That will be called the design load the design load is taken as the nominal load. Whatever, the method you derive multiply by a load factor, which will carry the risk or the assumptions that you have made. That will be a better idea than the earlier methods.

Other than that the combination of them also will be associated by the coexistence of the loads. For example, you have load one load two you will evaluate joint probability instead of a individual probability. To obtain the load factor you could actually look at the probability of occurrence of two loads together joint probability. Then you can find out what is the corresponding factors. For example, in here joint probability of live load and environmental loads the factors are different. So, you could you have a chance of instead of multiplying 1.5, here we have reduced to 1.2, so slightly greater of.

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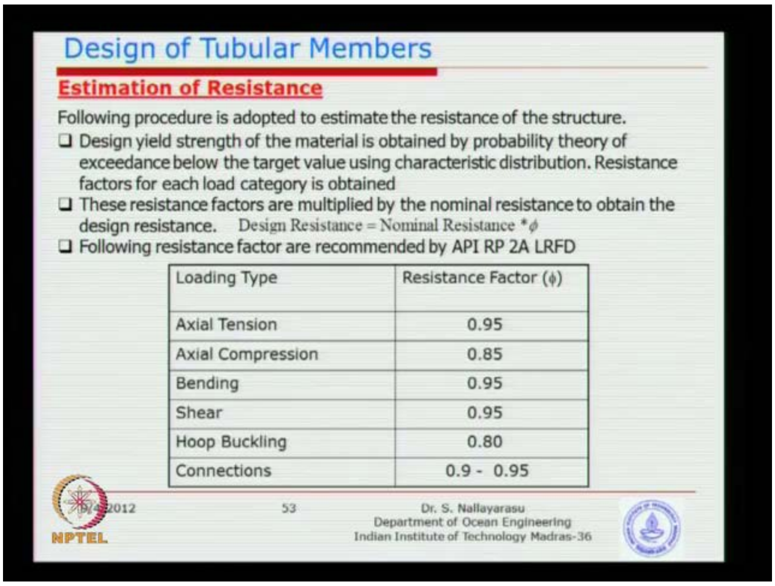

Similarly, estimation of resistance we have the design resistance is equal to nominal resistance applied or calculated as normal multiplied by a resistance factor, which is to be calculated based on the variation of the resistance parameter. In this resistance parameter you can have your yield strength. You can have your fabrication tolerances. You can have other parameters included in here for particular case here, only for yield strength, the factors given by A P I I have just taken from A P I R P 2. A L R F D method you could see that for different loading pattern, like tension compression bending each one carries a slightly different factor. So, you do not see a factor of safety here, but what we have is the loads are slightly increased by load factors. The resistance are reduced by resistance factors. Then finally we look at the demand versus capacity.

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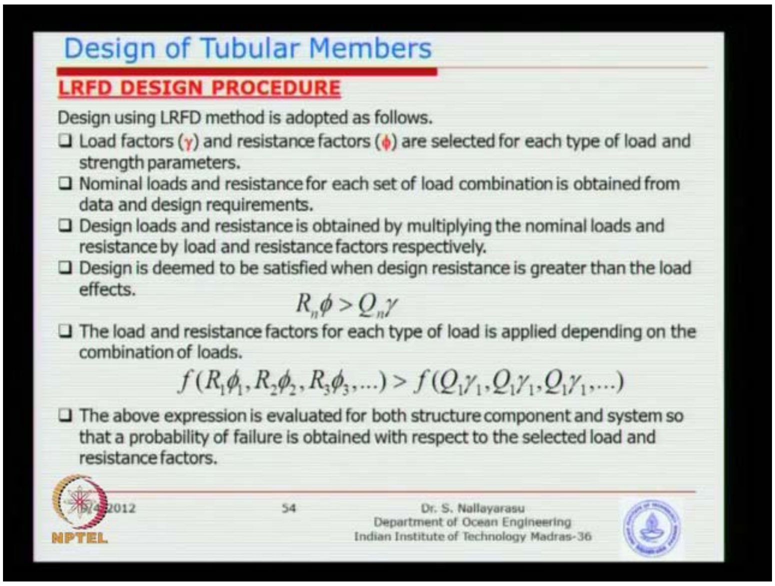

Basically, the demand is the load effects and resistance is the strength factors. Fortunately, we can have a variable factors for each one of them number one. Also, the factor of safety is not one global factor of safety. Basically, you can have individual partial factors. That is why sometimes we call it partial load and resistance factors or sometime we call it partial safety factors. Either way what we have is the multiplication factors for both resistance as well as the load effects.

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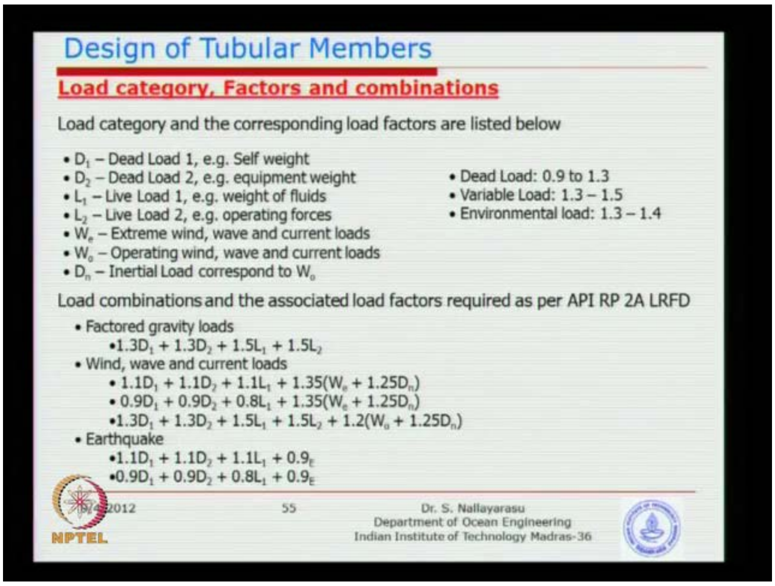

Some of the numbers, which I have just taken from A P I R P 2 A for dead loads. It varies from 0.9 to 1.3 depending on, which load you are combining with. For example, if you combine with live load you may say 1.2. When you combine with variable loads, you may have a different factors typical example will be the three cases, which I have displayed here. The first one gravity loads are given 1.3 combining with the live load. Whereas, when you combine with environmental loads you have only a reduced dead load. So, the joint occurrence of the extreme sea state with the dead load. You do not need to increase so much.

So, basically that is why instead of 1.3 you have a 1.1 here. Similarly, for earthquake condition the reduced factor of 1.1 rather than 1.3. so, that is the advantage of giving a variable load factors for different scenarios not only for different loads, but different scenarios of loading. I mean here you can see here there are two types of dead loads. One is the fixed dead load, basically self weight or structure weight.

Then you have got a super imposed dead load. Normally, defined by the facility loads in terms of whatever the functional loads. Then you have live loads and then live loads variable. Then you have got extreme and operating environmental loads as we defined one year hundred year storms. Then you have the inertial loads from motion it could be a rotational loads or it could be other forms. So, these are some of the ingredients of idea behind L R F D. So, by this time I think you should have a clear picture how the allowable stress design works, the L R F D design works.

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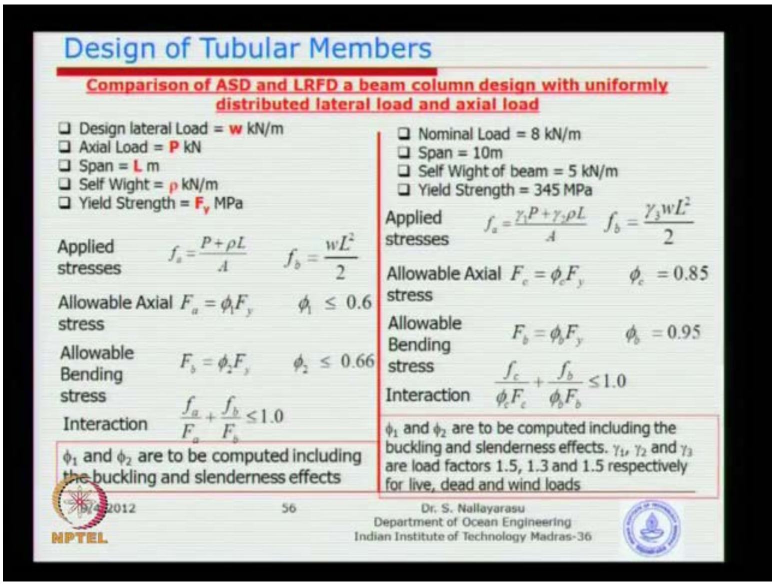

So, simple comparison I have given you a simple example summary of both the methods. I think you can you can easily understand what we have is a load and a span. Basically, the strength the normal procedure, what you follow, when you are looking at the allowable stress design, when you are looking at the L R F D. We just simply have two differences the loads are, multiplied by load factors and resistance is multiplied by resistance factors. Ultimately, you see the interaction between the axial and bending is simply a linear proposition in the allowable stress. The same linear proposition is also used in the L R F D, except that you got the factors for combinations. This is the only difference.

You see here 5 c is taken there. So, I think in summary the design method does not change mechanics, does not change the only the treatment of variables like loading or the resistance are treated in a better way. So, in my opinion you cannot get a different result when you design by allowable stress method or L R F D method. The variation of design result could only be a very small magnitude. So, you cannot get wonders, when I design by whether L R F D or the allowable stress method. You could only fine tune the design, but not find a new design, probably we will stop here.