Design of offshore structures

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Lecture - 4
Steel tubular member design 4

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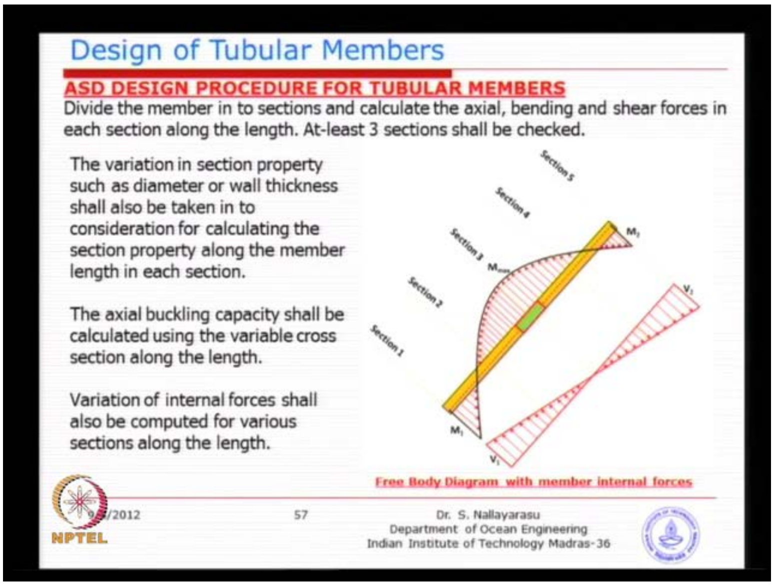

For, this course, we are going, to follow only allowable stress design, for the whole of the remainder design activities. We will not discuss any further on LRFD. So, basically looking at the picture, I think, we did discuss about, this few classes back, when you design a structural element, means it is not just one simple calculation. You should look at the whole of a member and divide the member into several sub segments. Look at the composition of forces, on each section, so you look at a simple, infact quite a simple diagram of bending moment distribution, along the length and the shear forces and you might also have axial force variation, not considerably, actual force, normally uniform in most of the sections.

But what you might actually have variation is, the section properties. You see this picture, at the centre we have a different colour, means you have a slightly increased thickness because there may be a member coming and connecting, somewhere in that location. So, you may have a variable cross sections, changing moment of inertia, changing cross sectional area and changing bending moment diagram and shear force diagram. So, all your design calculations needs to be verified, at every section that has got the critical combination of, section property lower, higher moment and the forces.

So, that means, if there is no change in cross section, for example, bending moment diagram is uniform like this or maybe even better than this, like a simply supported diagram. Only maximum bending moment is at the centre, we know very well. Then, you do not need to check at so many sections, you may say, check at only one section about the middle and forget about it, because you know very well established, that section is not changing moment is maximum there. There is no axial force, shear force is maximum at the extreme ends. I will check the shear at this extreme end, bending moment at the middle.

Whereas, if you are not very sure of the variation of the distribution of the forces and the section property, changes from location to location, you might divide the whole member into several sub segments. Normally, in offshore, we may divide more than 3, 4. Sometimes, if you have variable cross sections, you can divide into 10 sections. You have to remember, the calculations what we are going to learn from now, have to be repeated at every cross section and find out, which one is the maximum unity check or maximum stresses and that will be the governing case.

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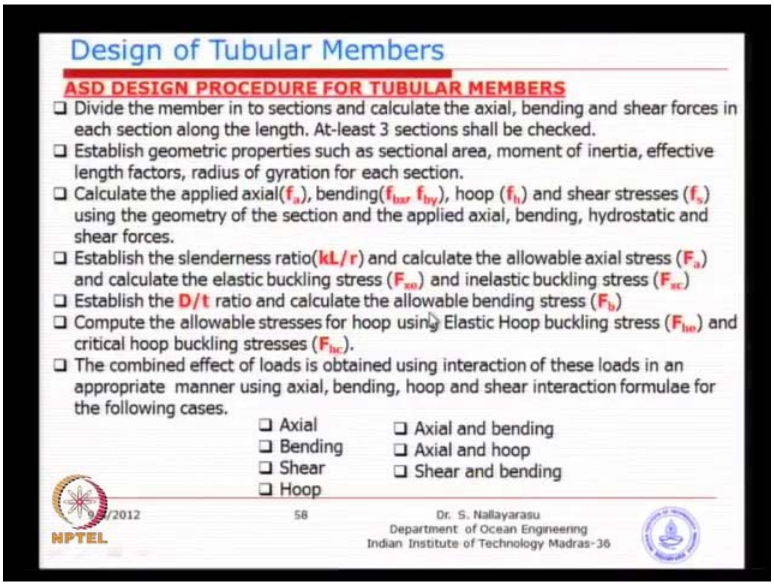

Now, the procedure is very clear. What we are looking at is the, divide the member into several sections. Establish the member forces, establish the section properties like moment of inertia, sectional area, effective length factors, radius of gyr[ation], everything you calculate for each section. Calculate the applied stresses, axial bending in the x direction, bending in y direction maybe and then bending, associated with the hoop stress due to hydrostatic pressure and then, shear stresses at every section. Establish the KL by r ratio, for the whole of the number because even at each section, KL by r ratio will not change. KL by r is for the whole of the member and then, find out what is the allowable axial stress, which is what we learned. The whole of allowable stress design is applied stress, calculate the allowable stress, find out the ratio.

Now, when you are calculating the allowable stress, for axial direction or axial effect, you need to make sure that, the buckling is taken into account, that is what we learnt earlier. Whether the yielding is governing or buckling is governing. As long as you have the slender member, buckling may actually make the structure to fail, before the yielding starts. So, basically allowable buckling stress, needs to be found out, in terms of reduction in the applied, allowable stress for axial direction.

So, what we normally do is, we calculate the allowable stress using the normal yield stress and then, try and evaluate whether yielding is going to happen or buckling is going to happen, even before that. That means, the limit the yield stress to the buckling stress. So, the limiting yielding stress is nothing but, the maximum stress at which buckling. In here, we got 2 types of buckling- one is the local buckling, the other one is the global buckling. Global buckling is taken care, in terms of Euler buckling length, which is the K factor. But the local buckling has not been taken into account, so that is what, we are going to look at, we calculate the local buckling, in terms of elastic buckling stress and inelastic buckling stress. Basically, instead of going to elastic, we also go slightly higher than elastic. The reason why, we go for inelastic because the local buckling, if you limit to elastic only it will be very high. So, we try to go for reduced and basically, that formula is empirical. We will try to do that.

Then, establish the D by t ratio, which already you have, diameter is known, wall thickness is assumed by you only. So, you know the D by t ratio, find out the allowable bending stress. Basically, that is the only governing case, for bending stress and finally, you come to hoop stress, due to external pressure and basically, due to external pressure again, the local buckling will happen .The first one here, the local buckling is due to axial stress, whereas the fourth one, the buckling stress is due to the hydrostatic pressure applied, on the outside of the cylinder. And that is why, you see the 2 symbols, the buckling stress due to axial stress is F x e, whereas hoop stress is called F h e.

So, in, you please note down the symbol change. If it is axial stress or axial load, corresponding buckling is F x e. Whereas, if it is a hoop or basically, due to hydrostatic pressure, then it is F h e, elastic part. The inelastic part is F x e and basically, that is name is changed to critical, basically it is called F h e. So, there are 4 sets of buckling stresses, one for axial loading, the other one is for hydrostatic elastic part and inelastic part. That means, elasto plastic, inelastic is nothing but, beyond the yield part, that you are looking at.

Then, what we need to establish is, the combined effect of all this axial bending, shear and hoop. Now, you will see that, you will also need to make sure that every single component is also lower than the allowable and also the combined effect is lower than the allowable. In terms of axial allowable, you just simply compare the axial stress applied, with axial stress allowable. Similarly, each component. Then, we need to do an interaction because you may have the axial load, at the same time, when the bending is applied. So, you need to combine them together and see whether the combined effect is within the acceptable.

Similarly, the axial stress with hoop stress, basically you need to make sure, that is also within the limits. Finally, the shear and bending, if you look at a simply supported beam, shear is 0, where the bending moment is maximum. Shear is maximum, when the bending moment is 0. But elsewhere, somewhere else, you may also have a bending moment, you may also have a shear force, which may combined effect could create problem. So, you have to look at the shear and bending. So, all this combinations, is to make sure that, in no situation, the structure is stressed beyond the limits supposed to be allowable stress. So, that is the idea behind.

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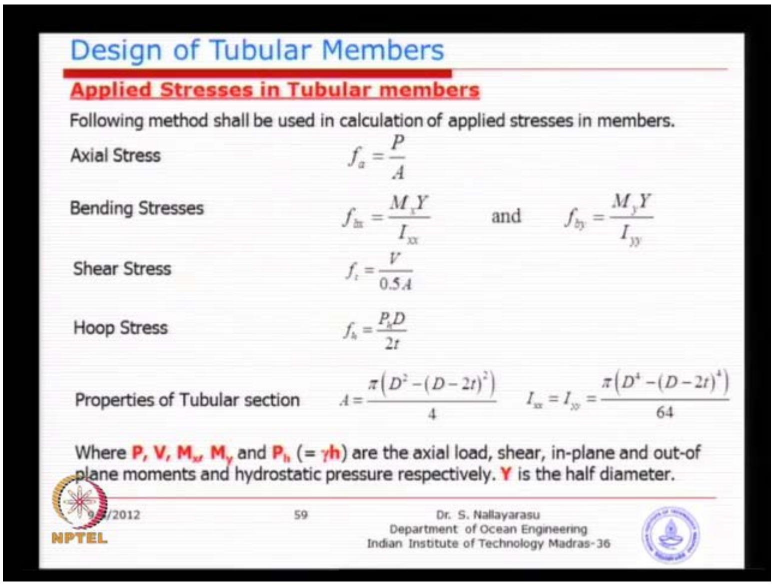

So, if you look at, how do we calculate the applied stress? I think, most of you must, I just repeated here, because many times, in the last semester several of them, did not know how to calculate applied stress. So, for that purpose, I have just listed down, the basic mechanics, you might have studied in your bachelor’s degree, second year. And you must remember, this for this full course because you will be repeatedly using this, many times and do not ask for, can you tell me the formula for applied axial stress. So, just make sure, refresh this, just for completeness I have given you, so that you can keep it for your records.

So, basically the P is the axial load, M x and M y are the bending moments associated with the axis of bending x and y and shear stress, basically your V is the shear force. And in this particular case, we have taken the half the area of the circular section. You should ask why? You know basically, the direction of shear is, you know you have to find out the effective area. For example, you take the i section, for vertical shear force, you only take the web. I think most of you might have studied in your applied mechanics. For horizontal shear, you take the area of the flinch. So, when you actually make a circle, change into a square section, for example. Just take the same circular section, hollow section, change into equivalent square hollow section. So, what will happen? Same 50 percent area will be on the web side, 50 percent area will be on the flanch side. But that is only the crude way of explanation, you actually need to integrate the circular section, like what we did in few slides back.

You need to integrate, the 1 quarter of the circle for shear stress distribution, you will get actually 50 percent of the area is effective in vertical shear, 50 percent of the area is effective in horizontal shear. And then, you have the hoop stress, I think, most of you will know, how to calculate the hoop stress. Pressure times, the diameter is the projected area, divided by 2 wall thicknesses. If you draw the free body diagram of a pipe, cut into 2 pieces, 2 wall thickness is effective at any cross section. So, basically that is why, we have a hoop stress is P D by 2 t and I think, the area and the moment of inertia is well known to all of you. So, basically we need to make sure that, you remember this basic principles of calculations of applied stresses, very easy. As long as, if you are given the loads like axial shear bending, you should be able to calculate the applied stress.

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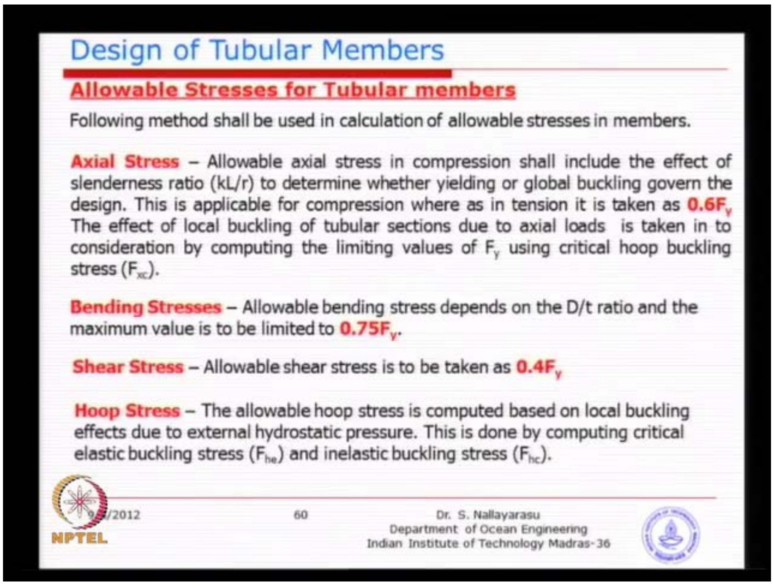

The allowable stress is a matter of looking at the member behaviour, both in terms of cross section and in terms of the length itself. So, basically three things- yielding, local buckling, global buckling. Now, if you look at the axial stress, mostly global buckling is taken into account, by means of a so called parameter slenderness ratio. Where it comes from? It comes from, back in euler buckling, we had a simply supported beam, this is the reference number, the length is L. Euler buckling is say, some amount of load it starts giving global buckling.

Now, when you compare that with other members, like fix fix condition or a cantilever, the load capacity is different. Compared to a simply supported fix fix will carry more load, cantilever will carry less load. So, we actually prorate the effective length, for fix fix it will be half length, for cantilever, we have double the length because of lesser load, which to carry the same load, so that is how the K factor was determined

So, the global buckling is taken into account, by means of a multiplication factor indirectly, it is called effective length factor. But the local buckling needs to be taken into account, by means of computing a local buckling stress, find out whether local buckling is going to happen, then you substitute the value of F x e instead of F y. Because, it is not going to yield, it is going to buckle. So, basically the limiting yielding stress, we call it, the limit yield because, buckling is governing the design. So, instead of a global buckling, local buckling is going to govern the design. So, that means we will replace the F y with F x e. So, we need to find out F x e first and check whether, buckling is happening, if that, then you replace this F y in the equation, to calculate the allowable axial stress. So, there are three steps.

As long as the member is subjected to axial tension load, there is no question of either local buckling or global buckling. So, very simple, allowable stress is a constant which is taken as 60 percent of the yield stress. Very, very straight forward, so tension means, no tension, easy. But whereas, compression, you have got a problem. You have to step by step, three steps you have to calculate and then, find out the allowable axial stress.

Bending also similar, only it is governed by the slenderness of the tube. Basically, the diameter to the wall thickness. The more slender, not in terms of length, in terms of its local effect, the cross section is too slender. Then, it might actually bend, easier than the other. So, the maximum is limited to 75 percent of the yield, but we will prorate according to the D by t ratio. The larger the D by t ratio, lesser the allowable stress. Smaller the D by t ratio, higher the allowable stress. So, very simple idea, there is no complication there.

Shear stress, very straight forward, irrespective of whatever the D by t ratio or l, KL by r ratio is taken as 40 percent, also very easy. The last one is the hoop stress, is going to be governed by local buckling. Basically, the buckling due to slender D by t ratio. So, that is going to be calculated and we will use the F h c as the representative allowable stress, basically the inelastic allowable stress.

Now, among this, I think, if you look at it, the first one seems to be little bit complicated. The second, third, fourth also little bit. So, we will just go through, quickly today, to try to make understand, we know how to calculate allowable stress, applied stress. If you know allowable stress, then the design can be concluded because the our design equation is, applied stress is less than allowable stress or the allowable stress is greater than applied stress. So, basically if you know these 2 components, the design can be. So, how do we calculate a allowable axial stress. There are 2 components, one is the tension stress or tensile stress, 60 percent very straight forward.

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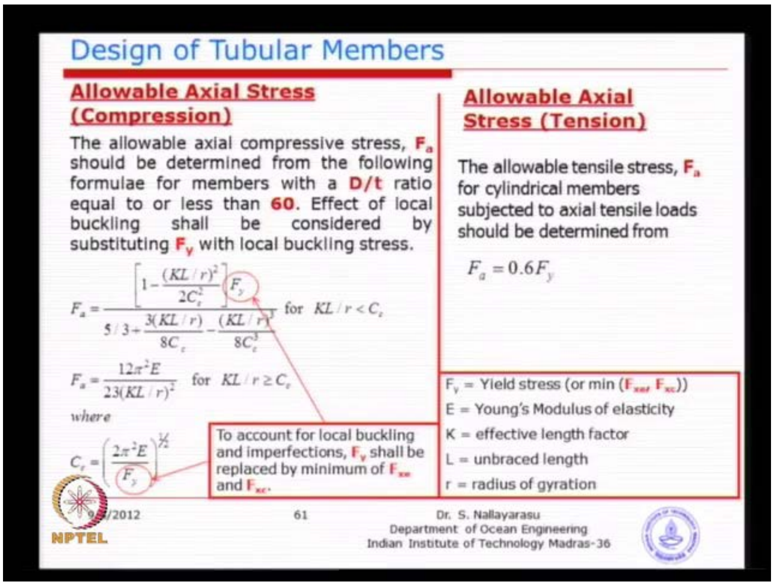

Whereas, the compressive stress, we got a interaction formula, very simple formula. How it comes is, basically based on experiments. As early as 1940's, there is a organisation called column research council, in U.K. They have done lot of studies, experimental studies, come up with relationship between member aspect ratio. Those days, we use to call it aspect ratio, length versus the size or the lateral dimension like column, you have x dimension, y dimension and you have length.

So, the aspect ratio matters a lot, the aspect ratio is larger is no good. The smaller is better, so basically based on that, they have done quite a number of experiments on circular hollow sections. So, that means you fabricate a pipe, apply the load, load at which it fails, it is noted down. Like this, you develop several experimental points and come up with a plot, something like this.

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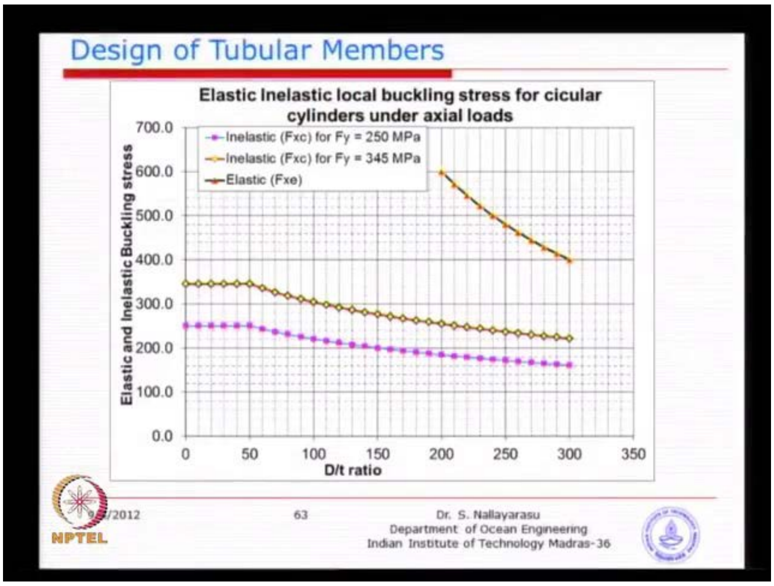

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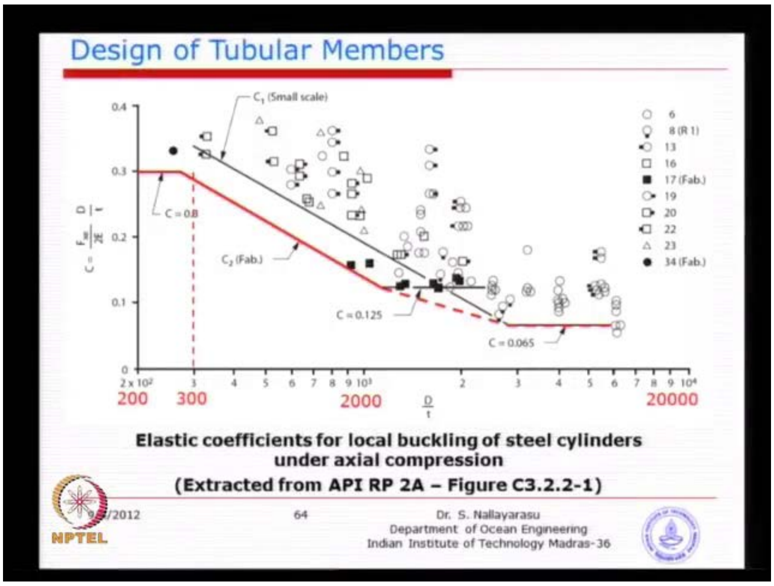

When you look at this picture, you know basically, you have got several points. This is not the chart, for the actual stress. But basically, typically, you come up with so many experiments and then try to understand, the pattern of failures, you know and then draw a line with a regression analysis, that will be the equation for your future design.

So, that is how, this formula what you see here is not derived from somewhere. It is basically, a regression line defined by the experimental points, to take into account the parameters of interest. In this particular case, the parameter of interest is 2 things, one is the slenderness. which is going to lead to buckling or the yield stress, which is going to allow the member to yield. So, this 2 parameters, we just have two equations, the equation one is basically, the yielding side, whereas, the second one, is the buckling side. You can distinguishingly note down these equations, one of them is very very easy to understand.

The second equation have no relationship with the yield strength of the material, you can see there. There is no relationship, that means it is a pure buckling. So, that means, irrespective of your strength of the material, you can have high strength, you can have mild steel, you can have any, because the member is so slender, that buckling is going to govern the design. You see here, there is no F y whereas, the first one, you have both the f y value as well as the slenderness. Now, you carefully note down this, If I make the KL by r ratio, very very large big number. So just, substitute here, what will happen. If you make KL by r ratio, very large, you are going to definitely, the deduction factor, this is basically here, one minus something, isn't it. So, that means KL by r ratio larger means, you will have larger number to deduct, that means it might be the F y will be multiplied by a smaller fraction, isn't it.

Now, the vice versa. You make the KL by r ratio, very very small. When you make it very small, that the nominated becomes close to 1, isn't it and what will become at the bottom, you see here this also is KL by r, this is also KL by r. So, this becomes a smaller number, this is also become. So, you can knock down this, this ,this. So, ultimately what will happen? You will have only bottom 5 by 3, which will become 3 by 5 multiplied by F y. So, what is 3 by 5, 0.6. So, basically we end up, when the KL by r ratio is very small, means the member is too big, too small the size is so large, but the length is too small, that means it is stocky member, it may not be governed by buckling at all. So, basically, it will reach the value of 0.6 F y. So, that is the understanding you need to get. So, if I plot this graph, basically somewhere here.

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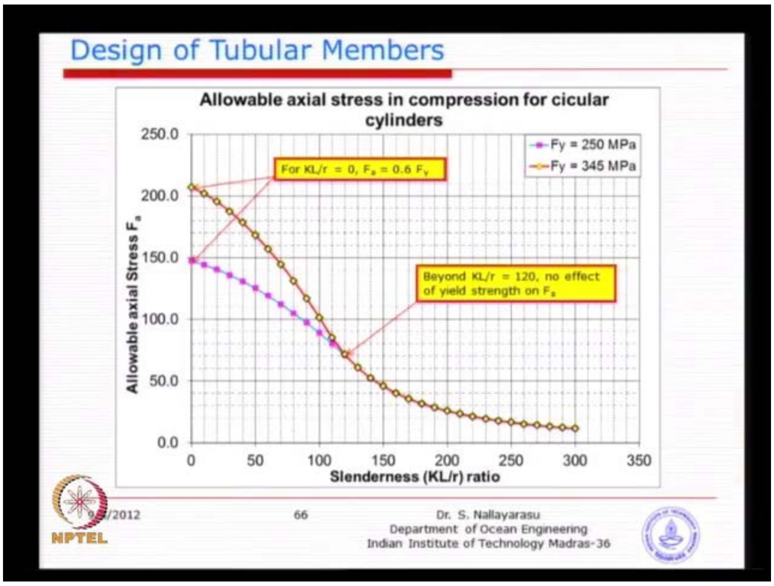

Yes, allowable axial stress, in compression for circular cylinders. Basically, you see here there are 2 charts I have made, using the same graph, what the equations ,what you have seen, for a different yield strength of material. So, after KL by r ratio of 120, the yield stress has no effect on the , allowable stress is not effect on yield stress because both are same. Basically, buckling is almost governed, so anything less than 120, you can see a deviation for a lower strength and a higher strength. Ultimately, this KL by r ratio is 0, then the yield stress the allowable stress becomes 0 point. So, the lower the KL by r ratio, you are going to get the higher allowable stress.

So, what we are trying to understand here is slenderness, play a major role, in trying to allow, whether you want to allow higher stress or lower stress. As long as you keep this member length quite small, then you can straightaway take 60 percent of yield and then do your computations. Then you make the member longer or keep the length same and make the member too small, then it is not going to be, you might think, I am doing a very economic design, by making the size smaller. That might work, but ultimately it might fail because your slenderness effects have to be taken into account

So, basically going back to this page of this formula, there are 3 things, you need to remember. Calculate KL by r ratio, that is basically effective length factor multiplied by length divided by radius of gyration. How do you calculate the radius of gyration? Square root of i by a, so you can see easily calculate that. i is the moment of inertia in the direction of interest, remember allowable axial stress, you have to calculate very carefully taking into account the weakest KL by r ratio.

So, for circular section we do not have any worry, any direction is same property. But if you have a un symmetric sections, probably high sections or channel sections, angle sections or any built up sections, which has got the moment of inertia in one axis, is not as same as the other axis. So, what we need to see is, we need to look at the weaker one, means the larger slenderness ratio needs to be taken into account. So, that you need to remember, though it is not specifically mentioned here.

So, once you calculate the slenderness ratio, find out the limiting slenderness ratio, beyond which the member will definitely go by buckling. So, you see, KL by r ratio greater than a particular value, it goes into buckling. Whereas, KL by r ratio less than that particular value, it goes into yielding. Now, in here thus, the limiting slenderness ratio value is very much to similar to our Euler buckling, 2 pi square e by f y. So, you calculate the limiting value and substitute, look at which one is governing and basically either, you go for this or go for this. So, note down here, this is very similar to our Euler buckling load. Euler buckling load, for a simply supporting beam is Pi square d by l square.

So, basically that is exactly the same, exact that you got a factor of 12 by 23, which is nothing but, a factor of safety of 2 approximately, isn’t it. So, that is exactly we are trying to do here. So, this Euler buckling stress, divided by a factor of 2 is given as your allowable stress, as long as buckling govern the design. It is, it is not just coming from nowhere, basically, coming from our mechanics.

Only thing, it is the first formula is derived as from the experiments, using a regression, basically just a curfity, if you, if you remember, if you go and do during your M.Tech thesis, if you do experimental studies on some aspects, you will also do a regression analysis, to come up with a polynomial. For example, to fit a curve against the experimental points, is exactly done the same way.

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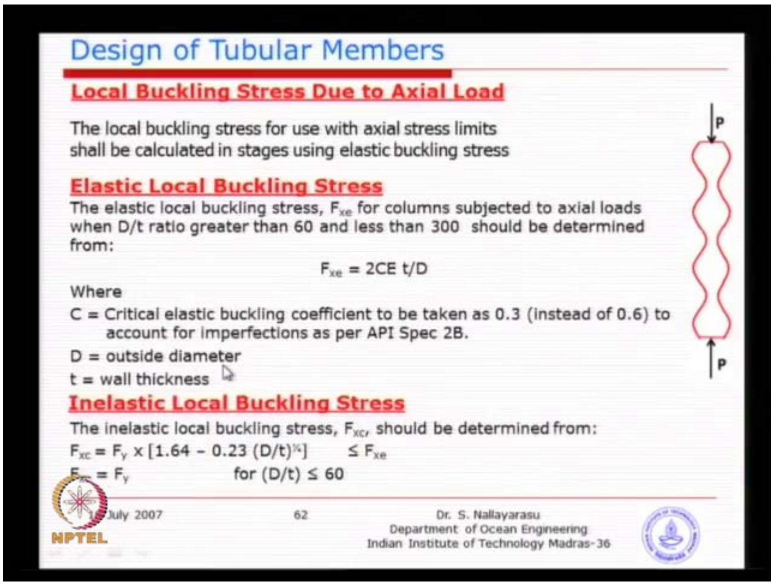

Now, one important thing to note is, you need to substitute this F y value with the calculated value of x, F x e or F x e, whichever minimum, if the local buckling govern the design. So, what you are going to do is, look at the D by t ratio, calculate it and then go to this particular formula, to evaluate the local buckling and basically, local buckling is due to axial load. Here we have axial load and the elastic buckling stress is calculated using this formula, which is basically 2 CE, the reverse of D by t ratio and then, the inelastic buckling stress is calculated using this formula and you have to find out, whichever is smaller and substitute these values, back into F y. So, we have taken into account the global buckling by KL by r, local buckling by the D by t ratio and if I plot this graph, I think you will get something like this.

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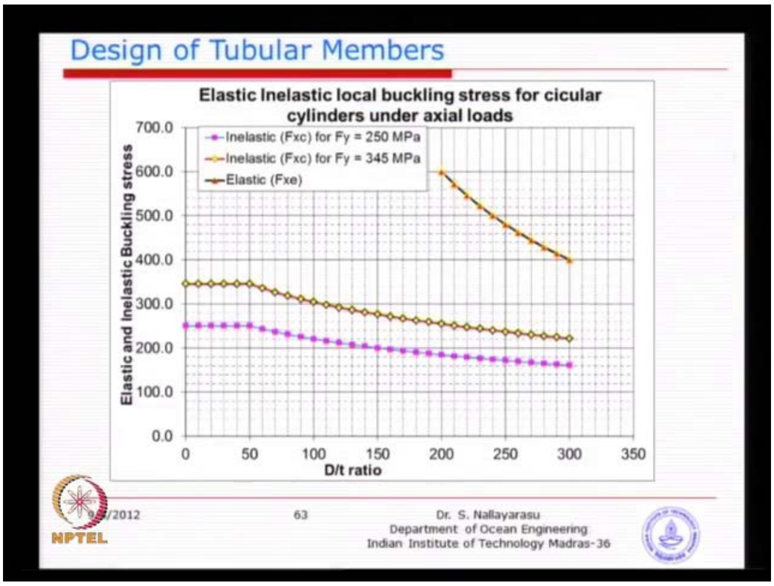

Basically, most of the time, the elastic buckling stress, is going to be very large, so the inelastic part, we have got 2 starts given for 250 mega Pascal steel and 345 mega Pascal steel. So, you will see that most of the time, this is not going to be governing. So, you will take the inelastic part and supply to F y value.

Now, you see here, the D by t ratio less than 500, you get almost constant value, after that it starts degrading because if you look at the equation, it is 1.64 minus 0.23 into D by t to the power 1 by 4.So, basically using such a simple formula, only thing is, you will be using this F x e value in here, as long as it is less than F x e, it is fine. If it is going greater, then you will assign the value of F y itself, that means if the D by t ratio is smaller then, automatically you will not be, you will not required to substitute here, automatically Fy will be the value coming there. So, D by t ratio, larger means local buckling is going to reduce the yield strength, which you will supply to the axial stress. Hope you understand this idea behind. So, global buckling and the local buckling limits.

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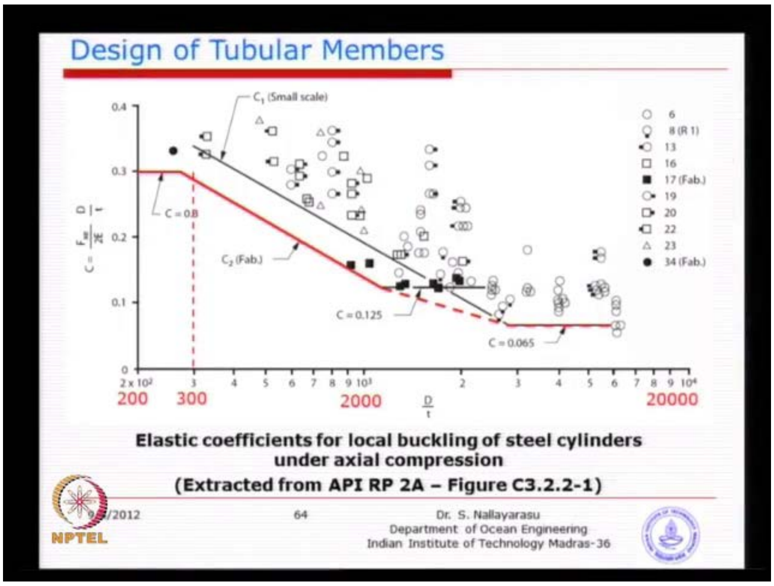

The next thing, what we want to look at is, all this charts, I extracted from basically, the API, based on which some of these equations were derived. So, if you look at this basically, D by t ratio versus the coefficient c. This coefficient 0.3 I have taken. Though it is showing a variation like this, most of our D by t ratio, you see here, D by t ratio is 200, 300, we have a D by t ratio is far less than 100. You know, normally most of the jacket structures, we have D by t ratio not acceptable, if it is exceeding 60.

Always, we keep the D by t ratio less than 60. So, these all are applicable, the values less than 0.3 or something like this, is only for large diameter cylinders, especially for floating structures, like what we have seen in the few classes earlier. We were talking about spar type of platforms, where the cylindrical diameter is 20 meter, 30 meter, 50 meter and the thickness could be smaller, whereas for structural cylinders, you may not be so much useful.

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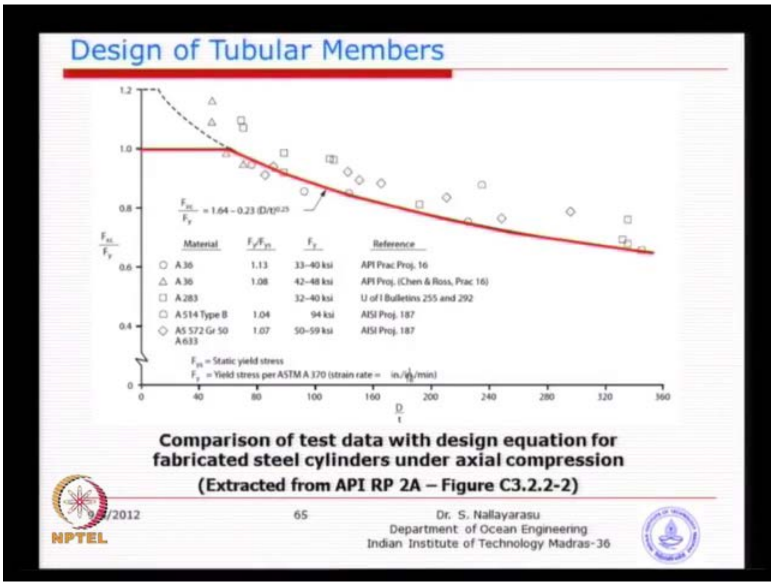

Similarly, this is basically the variation of F h x e, which we saw in a equation know, the equation is 1.64 minus some empirical formula. So, basically a chart, how did they come up with this equation? This equation was arrived, this equation is arrived based on the experiments conducted by, so many people and finally, they draw one line. This could be a potential trend. So, I just write down the formula that, 1.64 minus 0.23 times D by t. So, horizontal axis is D by t and vertical axis is the ratio between F x e multiplied by Fy. So, basically you read this and multiply by F y will give you the value of F x e, instead of using the equation. But, the equation is convenient, so you can calculate accurately instead of reading from here.

So, but we need to know, how the equation came. The equation is just simply, a reproduction of, so many experiments, that they have done. So, fabricated a cylinder, tested it and then failed, note down the value of load at which it failed and then repeat the experiment several times quite, a number of steel different, different steel and different, different projects. These are all research projects sponsored by various government organisations, oil companies ultimately, to produce a usable relationship between D by t and the allowable stress.

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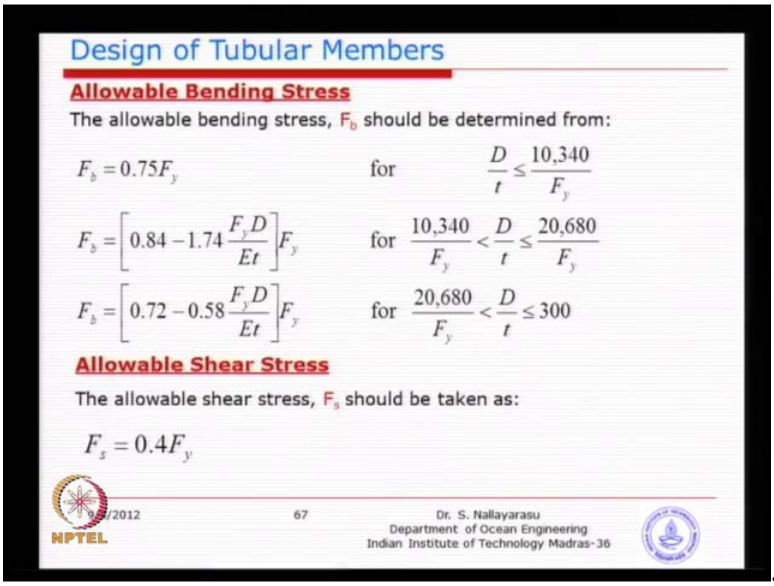

Similarly, you will see this, we have seen the allowable bending stress. Again, you see this formula is highly empirical, related only to diameter to wall thickness ratio.

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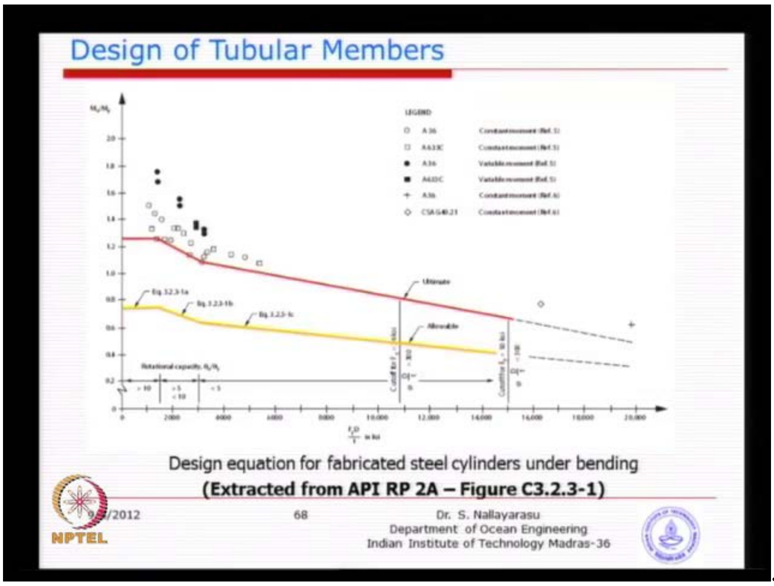

And how these equations are arrived, basically again by experiments. Unfortunately, we have got experimental results only on the lower range of D by t ratios. The larger range of D by t ratios, we really do not have experiments because nobody got the money and time to fabricate big cylinder and test it. So, you see here, we have got the ratio around 4000 of course, here F y is multiplied. So, D by t multiplied by F y, please note down it is given in KSI units. So, you have to be a little bit careful. So, basically the lower range, quite a number of experiments were done and the curve fitting is done like this. So, using this curve fit, the red line is the ultimate strength, at failure. The yellow line or orange colour line is the allowable, so just a division by a factor of safety.

So, you see here the equations are arrived basically, based on that experimental studies. So, how do we get allowable bending stress is 75 percent of yield, as long as the D by t ratio is less than this. Now, what is this? This is a limit 10340 divided by F y. So, if you do this, you will get a number of somewhere around, if you take a F y value of 30, 50 kg's material. In terms of 345 or 350, you will get somewhere around 30. This is from 30 to 60, this is from 60 to 300. So, D by t ratio is starting from 30 up to 300, we have got the relationship given here. So, if it is less than 30, you can understand, if you take 1000 m m diameter, what will be the thickness, if you want to keep it less than 30. It is 30 millimetre, isn't it.

So basically, if you want to keep it a 100, if 1000 divided by 30, will give you, how much? If you want to keep it at, 30 then, you have to have the corresponding thickness. So, if that D by t ratio is less than 30 means maximum allowable stress of 75 percent whereas, if you keep it between 30 and 50 and 60 and 300, considerable reduction is given there isn't it. So basically, it is a quite straightforward, calculation of allowable bending stress. So, you take this 0.84 minus this, as long as the D by t ratio increasing, the deduction factor will increase.

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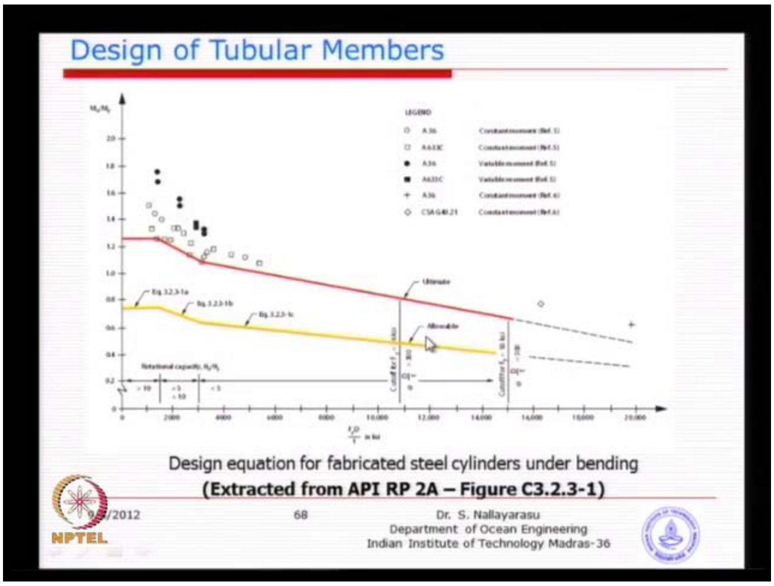

So, that means the net factor will come, lower multiplied by F y. Similarly, here the next range because if you see this graph, there are 3 linear parts. One is this part, second is this part, third is the last part and that is why, you see here first, second and third. Allowable shear stress, straight forward 40 percent of yield, no issues.

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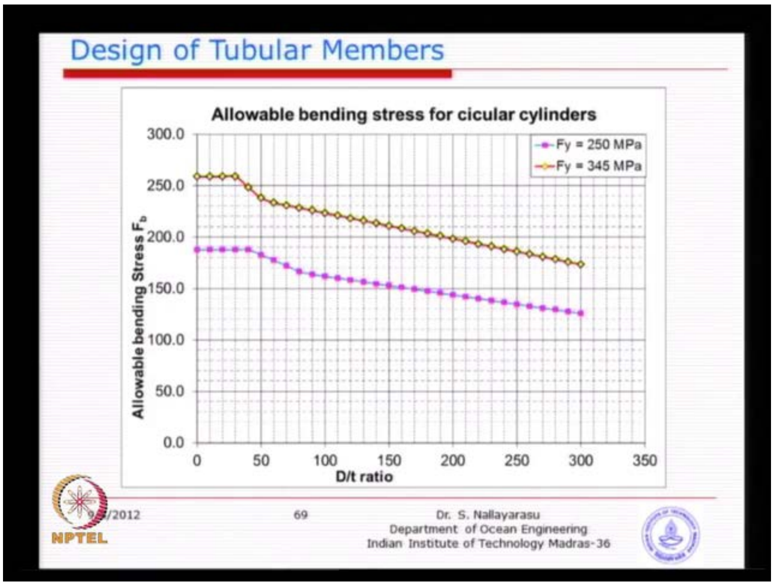

The same thing is plotted, whatever you see here, in terms of D by t ratio, I directly plotted instead of so. You can see here, this is 0.75 times F y, first reduction and second reduction, as long as the D by t ratios keep on increasing, for 2 different steels- mild steel and the high strength steel. And basically, most of the times, we do not permit D by t ratio beyond 60 for offshore structures, we keep the D by t ratios, less than 60 mandatory. It is by API because the larger the diameter and wall thickness smaller, you may actually govern by the local buckling which is no good. So, that is why, we keep the D by t ratios less than 60.

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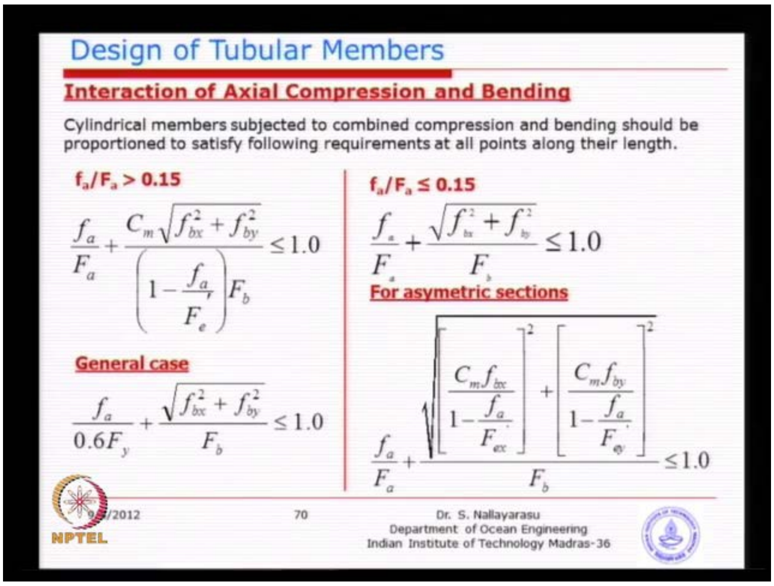

Now, finally comes, we have done the allowable axial stress, allowable bending stress, allowable shear stress and then, allowable hoop stress. Now, what we need to look at is, how do we combine this, all of them together. Straight forward, is the first look at the general case. We have a applied stress and allowable stress, we will be happy and we can conclude, if the allowable stress is always greater than applied stress. A linear super position, so you look at this.

This particular, general case here, if this is applied stress, allowable stress, basically taken as maximum, that means there is no buckling happening here, that is the first case, where we take tension or there is no buckling happening, plus you look at the second one added, it is the bending stress divided by allowable bending stress. But what we have got, here is a 2 component bending stress, you got a x bending, you got a y bending. Suppose, if you have only one bending, then what will happen. One of them will disappear, automatically it will become F b divided by F b.

So, what we have done is, you have we have got the axial component acting, plus the bending component, but remember, axial and bending, the stresses are in the same direction. If you have understood, axial stress is along the member length, bending stress also, along the member axis only. Only thing is, one portion will be subjected to compressive, the other portion will be subjected to tension. But the stress direction is along the longitudinal axis of the member. So, there is every opportunity that, we should actually combine the stresses.

So, you can actually do this way. F a plus F b, you can add them together, as long as you can find a combined allowable stress. Can we find a combined allowable stress? Because axial stress is governed by the buckling, local, global and slenderness, whereas, the bending stress is governed by, the diameter to wall thickness ratio. Nobody have developed a equation, for a combined allowable stress, so far. That is why, we compute the applied stress, separately for axial allowable stress separately for axial and then, applied stress for bending, applied stress allowable stress for bending separately.

Then, we find out the ratios and then combine them, because we do not have a facility or a equation or a experimental studies done, for a combined allowable stress. You understand the idea behind know, why we are doing this business? Basically, we compute the component, for example, if you have a bending stress is 0, then the ratio here can go as much as to 1. Now, if you have axial stress ratio, so called the F a, by F a by 0.6 F y is the fraction is coming to be say, 0.7. So, what can you, have it for bending Only 30 percent you can so, 0.7 plus 0.3.

Now, you can see here basically, a summation of effects of axial plus bending. So, that is basically called the interaction between axial and bending. So, we are just cumulatively adding and linearly super positioning. Remember, we will talk about this non-linear business later on, because here we are doing only just a linear superposition, axial effect and then, bending effect.

Now, this is basically, a general case, needs to be verified for almost whether it is tension case or compression case. Whereas, if you look at the first 2 formulas, basically on the left side and right side, if it is a predominantly axial case. For example, you take a column, more axial load, but small bending, whereas in this second case here, the axial is smaller very small axial load, predominantly bending. So, we have a 2 situations, either axial load is taking too much of stress or bending load is taking too much of stress.

What is really happening, when the axial load is less, we have got a less problem. Because, for example, you have a bending load, the beam is trying to bend or a beam column is trying to bend. Actually beam means, typically a horizontal member, subjected to transverse loading, whereas, column means predominantly subjected to axial load. When you have a combined effect, you should call it beam column. So, when a beam column is subjected to a smaller axial load, it is better because buckling may not happen. Remember, when we talk about buckling, global buckling especially, you need to have larger axial load so, global buckling may happen. So in that case, you can see here, this formula and this formula is same, isn't it.

Only thing is the allowable axial stress is considered with respect to the slenderness, instead of taking maximum allowable stress, we take the allowable stress calculated by, whatever be the allowable stress, as per the axial. Otherwise, this formula and this formula is same, as long as the applied axial stress to the allowable axial stress, the ratio is less than 15 percent. That means, a smaller axial load.

Whenever the axial load is larger, you come to the left side, then there is a potential problem, have going to happen because of interaction between the axial load and the bending load, which we call it p delta effect. I think, some of you might have studied, you remember, you take a cantilever column, apply a horizontal force at the top, what happens? The column tries to bend horizontally, producing a deflection of some amount. It can be, so many millimetres.

Now, if you have axial load on the same column, what happens is additional bending moment is produced because of that deflection. You understand the idea know. But in a realistic beam column analysis by elastic theory, you normally do not take into account, you assume that the column is still in the original position when you are trying to calculate the axial stress. That delta effect is not taken, presence of the bending moment, on a column with axial load, the magnitude larger, you produce additional bending moment, in addition to the bending moment produced by the horizontal load. For example, if you have the height of the column is h, bending moment for the column is taken as the horizontal load multiplied by h. whereas in this case, you will take the delta times, the vertical load also produces additional moment.

So, basically we call it moment magnification, because of, so called the larger axial load. Of course, why we are ignoring here because, we say that 15 percent is too small to cause larger moment. So, that is why, in this case, we just ignore whereas, in here we take it here. So, you look at the bottom part, especially the allowable bending stress, everything else is same, except here we got a 1 minus something. As long as your applied stress is larger, especially the axial stress, the deduction factor for allowable bending stress is coming down. The reason is the magnification of the moment becomes larger and larger because of this bending and we need to reduce the allowable bending stress. This we call it, the moment magnification factor, which is lying at the bottom. Then, there is one more factor coming here at the top is called moment reduction factor, which we will be discussing in the next page.

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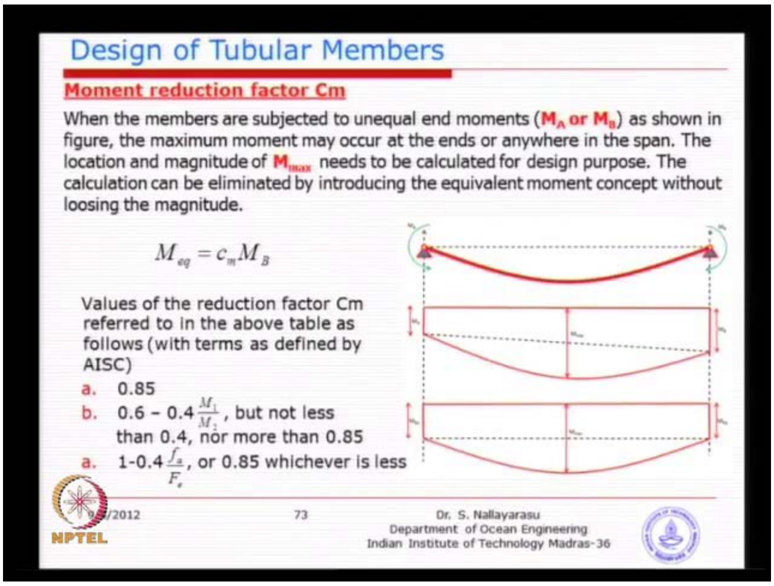

What is moment reduction factor? So, if you look at this diagram, it is a single curvature bending and mostly, you have bending moment here, bending moment here, probably a different magnitudes. But we all know that, if there is a span loading, you have a point load, you may have a load or you may have other forms of loading, bending moment may be maximum somewhere in the span, we do not know, where it is. Now, you see here, this is the un symmetric bending moment diagram, can be symmetric symmetrically drawn like this, with the equivalent moment at the ends, but still not losing the maximum moment at the centre. We just rearrange the diagram, but still the maximum is at this, but the end moments are not going to govern the design in any case. So, when you are having such a situation, it may not be exactly the same every time.

We have got several scenarios, I have just drawn only one scenario, how we calculate the equivalent moment, for a particular design aspect. So, this we call it single curvature bending. You may have double curvature bending and for each case, API gives you a recommendation of a reduction factor, instead of taking the full maximum, you fund out the equivalent maximum, multiplying by the end values and reduction factor of c m equal to 0.85 or the ratio between the end moments or the other factors. So, the 3 cases given, most of the time for primary structures, we apply a reduction factor of 0.85. This is given by the codes.

So, if you look at this formula, everything else is same, except you have a moment magnification factor and you have a moment reduction factor, due to equivalent moment. For asymmetric sections, you see here, the difference is very simple, you split into, this formula is split into 2 components, that is all. Basically, effects bending moment F y bending moment, otherwise, it is same. So, all the formulas are arriving from, basically a simple formula of F a by F a plus F b by F b, combined effect must be less than 1. So, all of them are basic principle is very simple, linear superposition of the stress ratios, should be less than 1.

So, this is basically called axial compression and bending. If it is tension, then there is no worry about anything. Straightaway, you can use, this formula because this inter interaction, all will not be there. This, the term appearing here, so called F e prime, it is nothing but, our Euler buckling stress the formula is given here.

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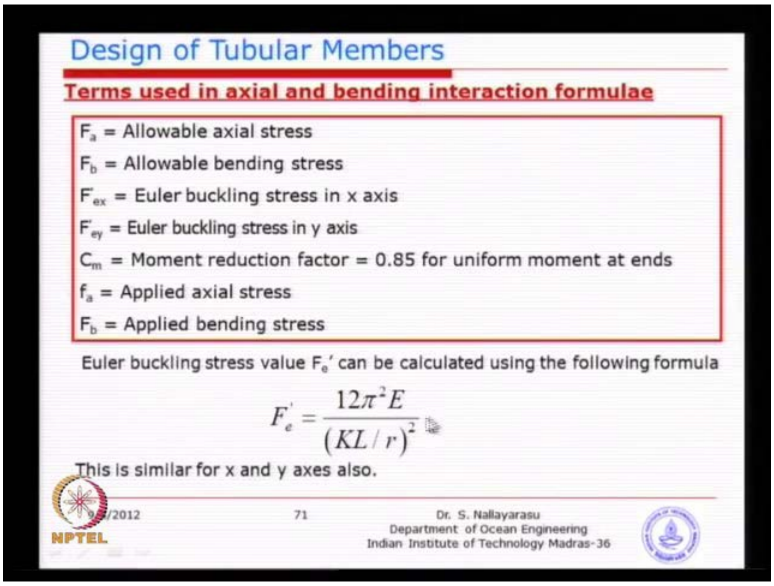

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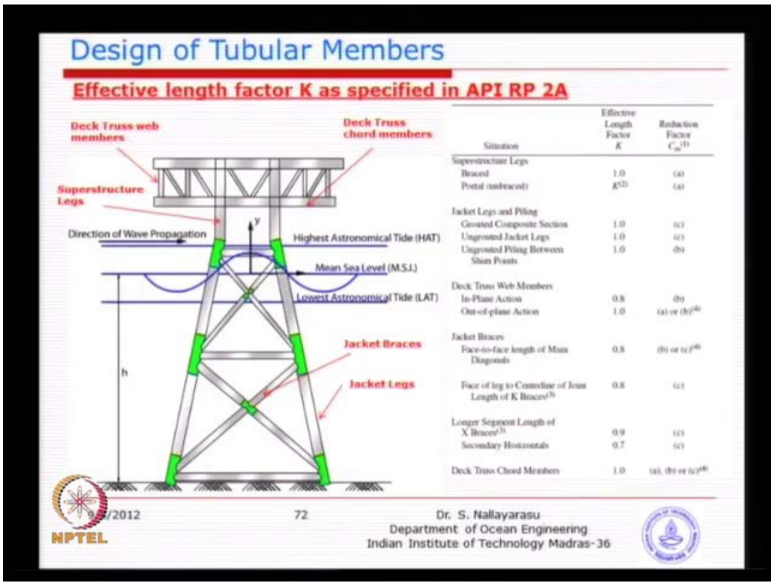

Now, the effective length factors given by API, I have just taken that API table, this table, what you see in the right hand side, is a table extracted from API, for different scenarios of, I do not know, whether you are able to read. You can see in the notes, basically for structure columns, super structure columns, effective factor is 1, jacket legs also 1. That means, 1 means, the distance from the point, this point to this point, you should take it as, full length and for various other scenarios, like braces say, 80 percent and 90 percent.

Basically, the effective length for 100 percent fix fix members, you can take it 50 percent, isn't it. Because the effective length factor is half, whereas in this particular case, you see here, we have not gone to 50 percent. For example, you take a brace, this brace anyone of the brace, they are not going for 100 percent fixity, because this connection is not producing, the sure fixity there. Because you have got a hollow section at the end. So, you may actually have a deformation and rotation. So, that is why, it is less than 1, but not necessary that, it is 0.5. Only theoretically, you will have effective length factor of 0.5. Whereas, most of the practical designs, you may have 0.6, 0.7. 0.8 depending on how much rotational restrain, you are able to achieve. Whereas, in tubular construction achieving 100 percent rotational restrain, is very difficult.

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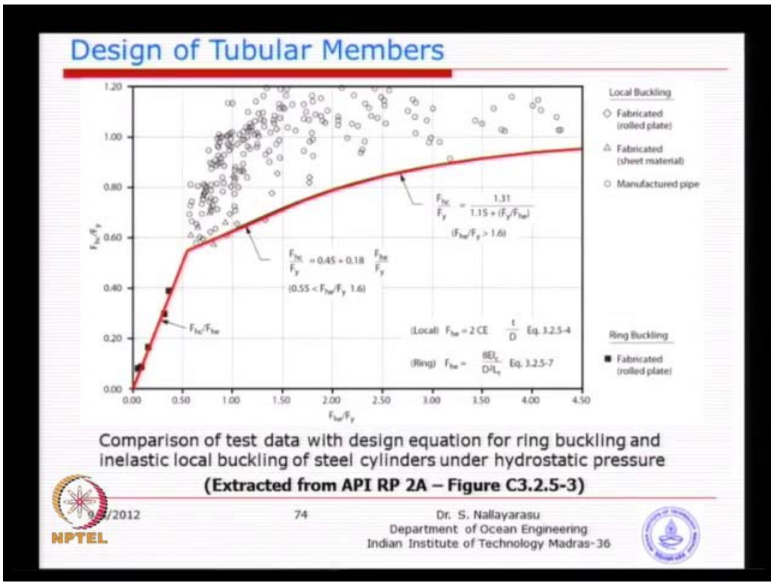

Some of the graphs extracted for, you know basically, the F h c and F h e, so we just saw earlier, all those are API graphs, that equations what we discussed.

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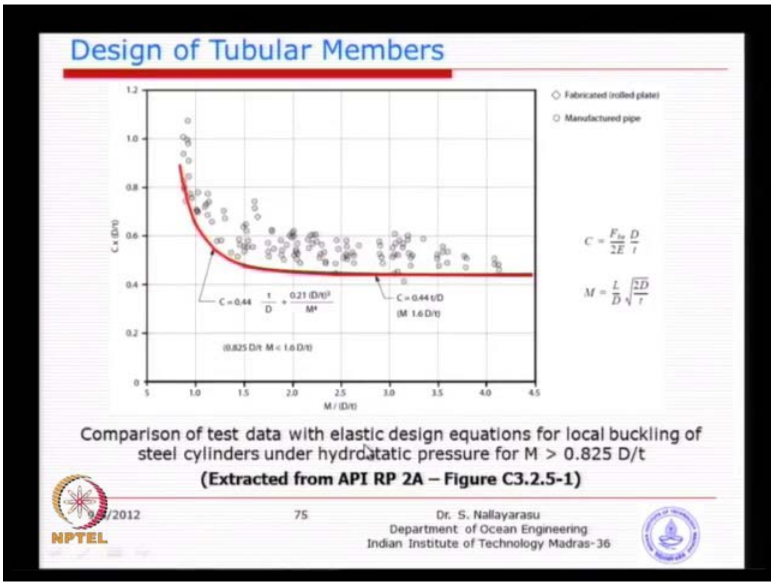

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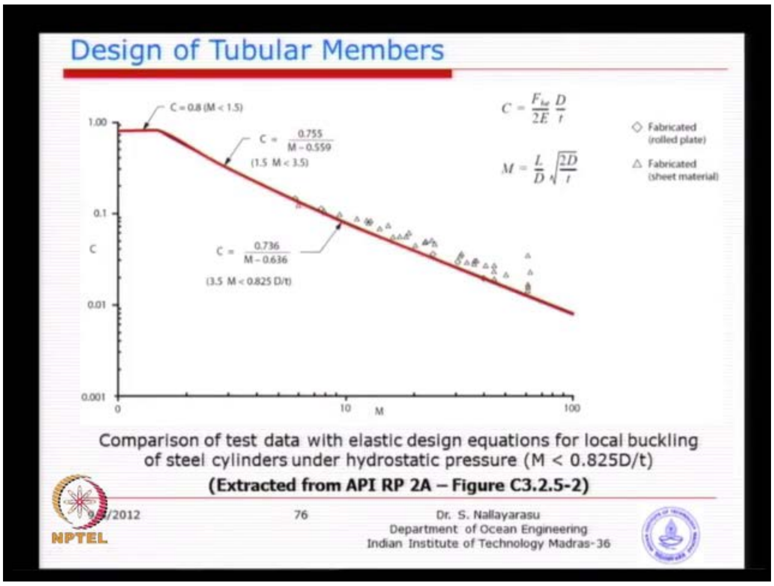

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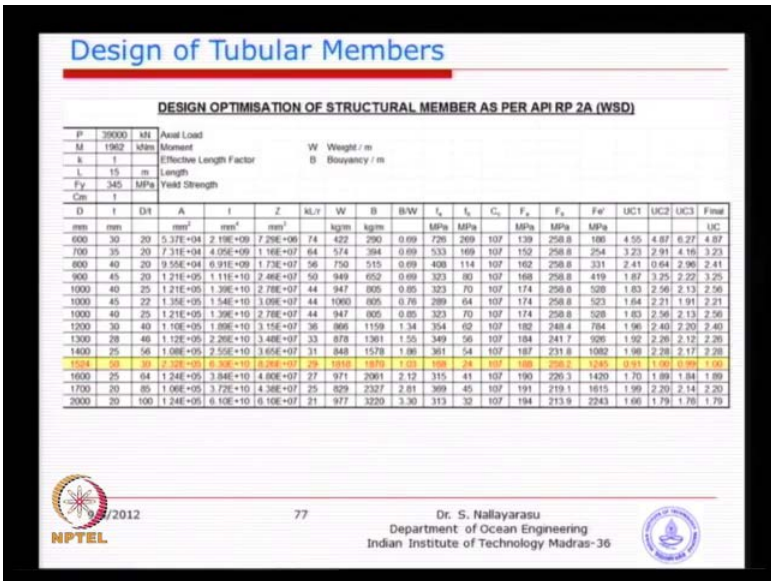

P	39000	kN	Axial Load
M	1962	kNm	Moment
k	1		Effective Length Factor
L	15	m	Length
Fy	345	MPa	Yield Strength
Cm	1		

D	t	D/t	A	I	Z	kL/r	W	B	B/W	f_a	f_h	C_c	F_a	F_b	Fe'	UC1	UC2	UC3	Final
mm	mm		mm^2	mm^4	mm^3		kg/m	kg/m		MPa	MPa		MPa	MPa	MPa				UC
600	30	20	5.37E+04	2.19E+09	7.29E+06	74	422	290	0.69	726	269	107	139	258.8	186	4.55	4.87	6.27	4.87
700	35	20	7.31E+04	4.05E+09	1.16E+07	64	574	394	0.69	533	169	107	152	258.8	254	3.23	2.91	4.16	3.23
800	40	20	9.55E+04	6.91E+09	1.73E+07	56	750	515	0.69	408	114	107	162	258.8	331	2.41	0.64	2.96	2.41
900	45	20	1.21E+05	1.11E+10	2.46E+07	50	949	652	0.69	323	80	107	168	258.8	419	1.87	3.25	2.22	3.25
1000	40	25	1.21E+05	1.39E+10	2.78E+07	44	947	805	0.85	323	70	107	174	258.8	528	1.83	2.56	2.13	2.56
1000	45	22	1.35E+05	1.54E+10	3.09E+07	44	1060	805	0.76	289	64	107	174	258.8	523	1.64	2.21	1.91	2.21
1000	40	25	1.21E+05	1.39E+10	2.78E+07	44	947	805	0.85	323	70	107	174	258.8	528	1.83	2.56	2.13	2.56
1200	30	40	1.10E+05	1.89E+10	3.15E+07	36	866	1159	1.34	354	62	107	182	248.4	784	1.96	2.40	2.20	2.40
1300	28	46	1.12E+05	2.26E+10	3.48E+07	33	878	1361	1.55	349	56	107	184	241.7	926	1.92	2.26	2.12	2.26
1400	25	56	1.08E+05	2.55E+10	3.65E+07	31	848	1578	1.86	361	54	107	187	231.8	1082	1.98	2.28	2.17	2.28
1524	50	30	2.32E+05	6.30E+10	8.26E+07	29	1818	1870	1.03	168	24	107	188	258.2	1245	0.91	1.00	0.99	1.00
1600	25	64	1.24E+05	3.84E+10	4.80E+07	27	971	2061	2.12	315	41	107	190	226.3	1420	1.70	1.89	1.84	1.89
1700	20	85	1.06E+05	3.72E+10	4.38E+07	25	829	2327	2.81	369	45	107	191	219.1	1615	1.99	2.20	2.14	2.20
2000	20	100	1.24E+05	6.10E+10	6.10E+07	21	977	3220	3.30	313	32	107	194	213.9	2243	1.66	1.79	1.76	1.79

Now, what we are going to look at is the hoop stress, allowable hoop stress.

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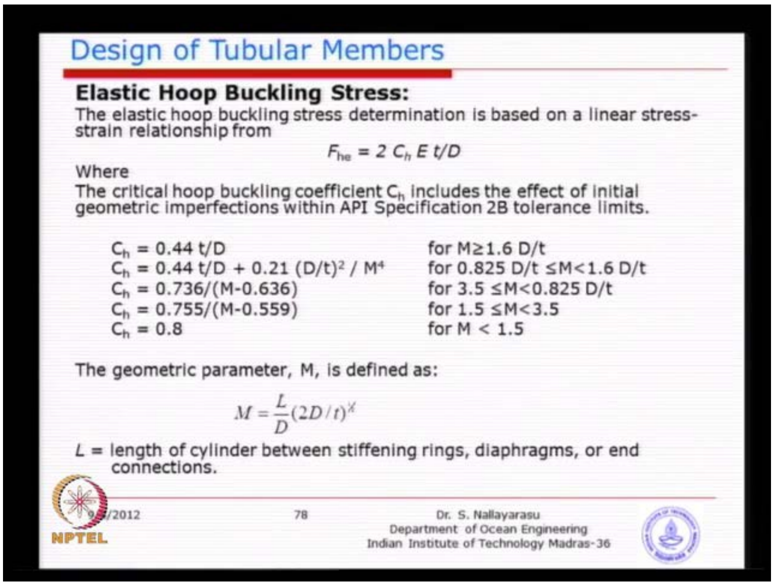

Basically, what we need to do is, we apply the hydrostatic pressure, externally. This formula is very similar, what we have seen earlier. The hoop stress due to applied actual stress, similar only thing is the coefficient c, instead of 0.3, what we have taken earlier, it will be calculated based on D by t ratio. Basically, how we calculate is a parameter called M, is the length to diameter, is very simple. The larger the diameter, lesser the M. Lesser the M, larger the coefficient. So, you see here, the if the m value is less than 1.5, you have a, C h coefficient of 0.8, compared to what we have used 0.3 for axial buckling. So here, if you keep the M value is less, for sure, you are going to get the higher elastic buckling stress. Basically you see here, L by D of course, you got D by t inside, with a square root.

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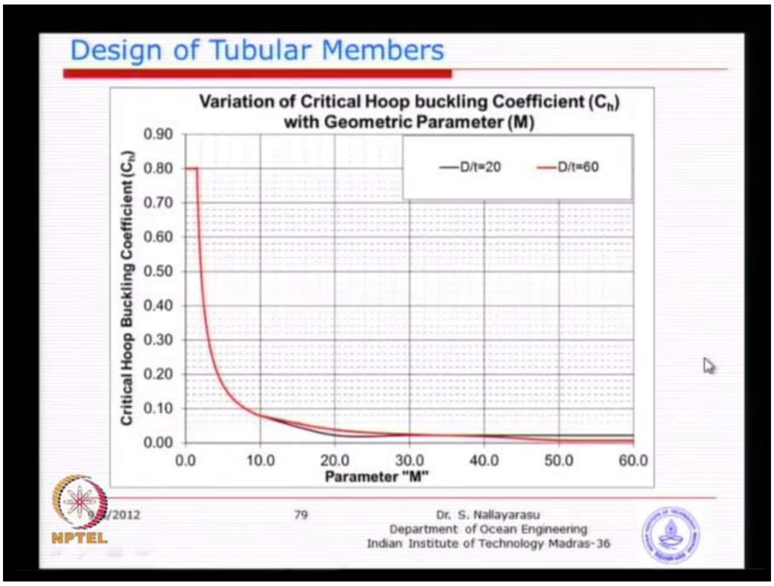

Now, you see this, there are 4 segments or 5 segments given here. If you plot this one in a graphical manner, supplying D by t ratio as one of the parameter, with a parameter M here, you could see here, the buckling coefficient is 0.8, maximum when the parameter M is, we call it geometric parameter. This M is geometric parameter basically, length versus diameter. So, the buckling coefficient, reduces to almost 10 percent, when the M value is around 8. So, you can see here, length to diameter, if you keep it smaller, then you have the larger buckling coefficient. After that, it becomes almost less than 5 percent. That means, local buckling is going to govern the design, we should never ever do that.

The idea behind is, first you calculate the L by D ratio, length is the length of the member. Suppose, if you fail to do that, for example, you go to this diagram, so the original length of the member is like this.

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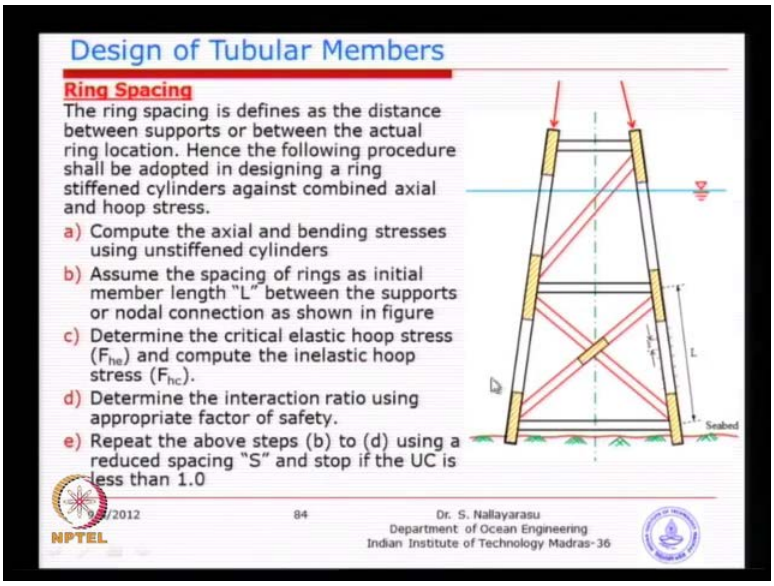

But then, what actually can prevent this member, from local buckling. You provide, rings like this, you see here in tiny dots, basically we have a circular rings, preventing the pipe from becoming this way, that waveform. Where it is? Something like this, so as long as you will provide a ring, in this location, for example, in this location, you provide a circular ring, the pipe will not be able to buckle because the rings will hold it, by taking as a shear force.

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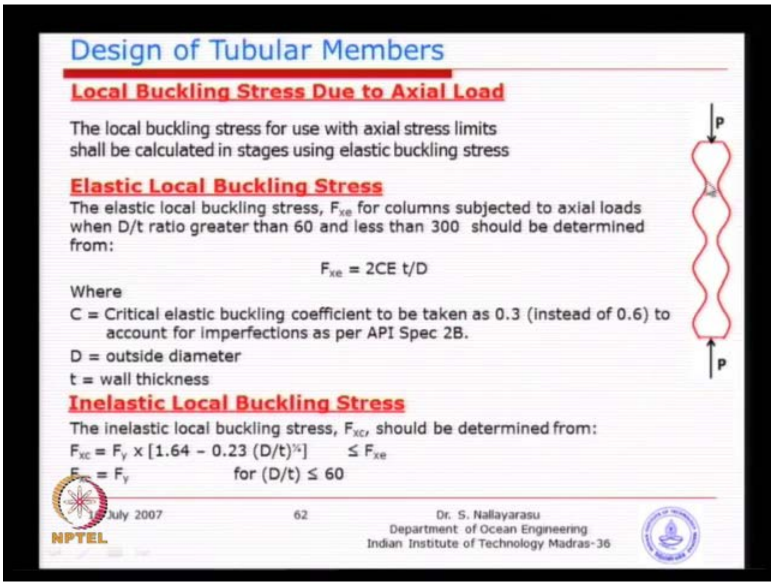

So, the idea behind is, if you provide rings, you could get additional stress. So, in this equation, either you take the initial length or the length of rings spacing. Basically, one ring to another ring. So, the M parameter can be controlled, by means of introducing additional rings, not necessary only to introduce a structure to be attached to, because it is only a local. It is not a global buckling.

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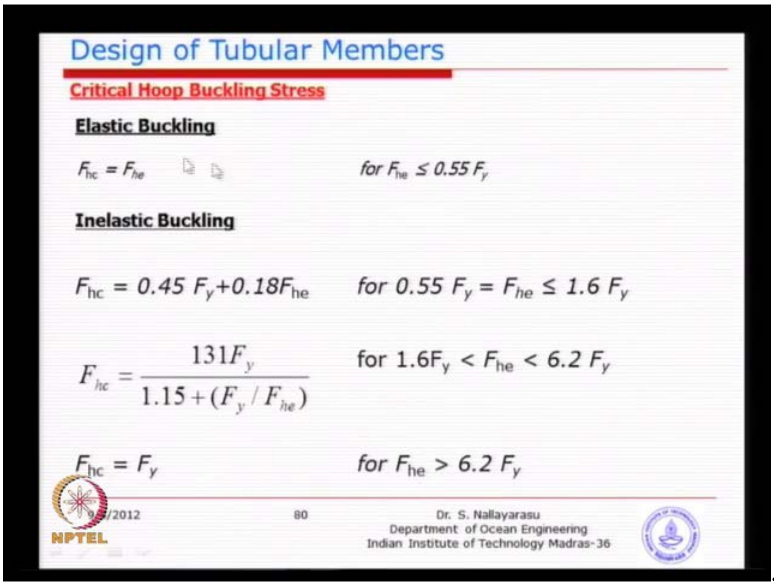

So, when the critical hoop buckling stress is relation to the elastic buckling stress, basically, as long as it is less than 55 percent, you take the elastic stress, as the buckling stress and there are 2 more ratios given, in the range of basically, 55 percent to 160 percent, F h e, you use this empirical formula. These are empirical formulas, for which the charts are given here, I think.

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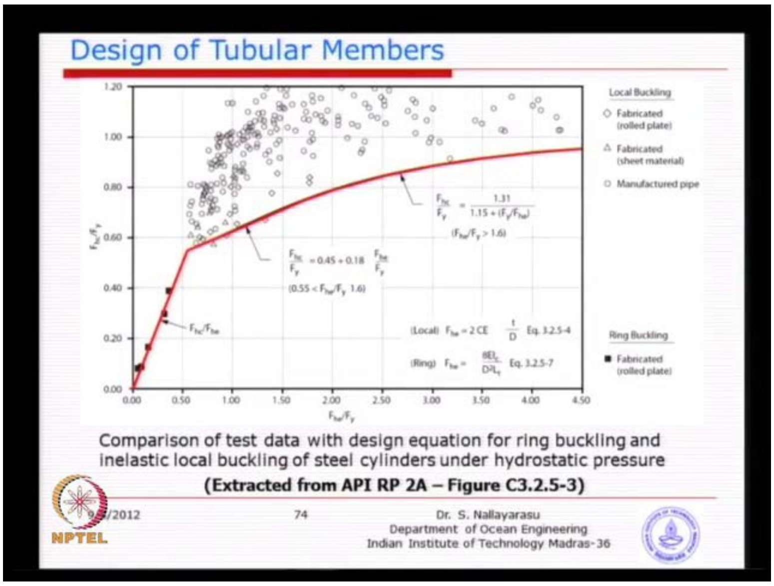

This charts, basically developed, those equations are derived from this chart and large range of experimental points, you can see here, how many experiments have been done for this kind of, you fabricate a cylinder, apply external force until failure.

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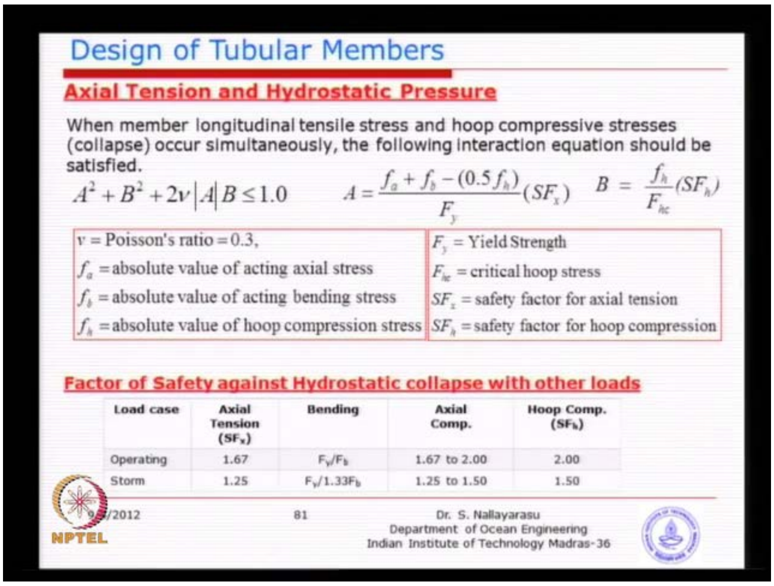

Note down the failure load and basically, develop this chart, based on that type of principle. So basically, that 3 lines, what you see here, these lines were coming from that particular experimental points. So, once you achieve this, then we can do the interaction. I think, we will discuss this one tomorrow.