Design of offshore structures
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Lecture - 02
Steel Tubular Member Design 2

So, let us continue the residual stresses during manufacturing of pipes I think what we need to look at is what are the process, how we can actually reduce the residual stresses we had a look at the seamless manufacturing.

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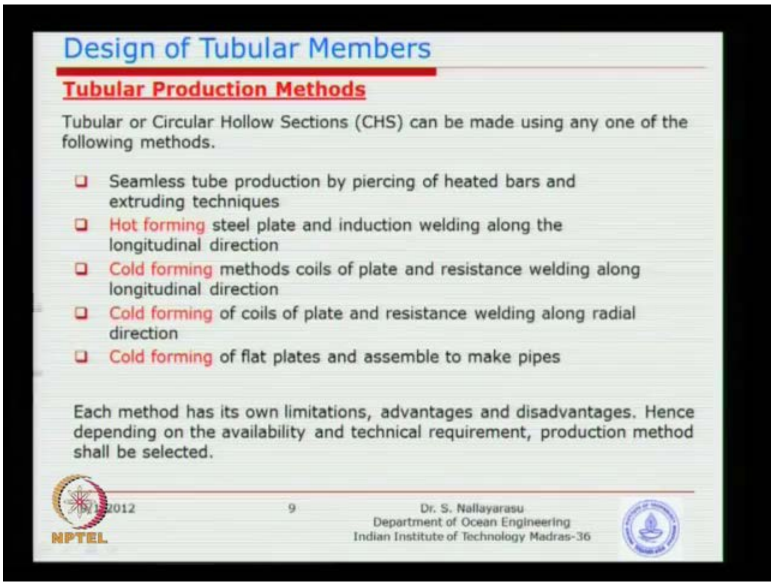

Then hot and cold forming in the previous class so basically we will just to go back one step backwards to see.

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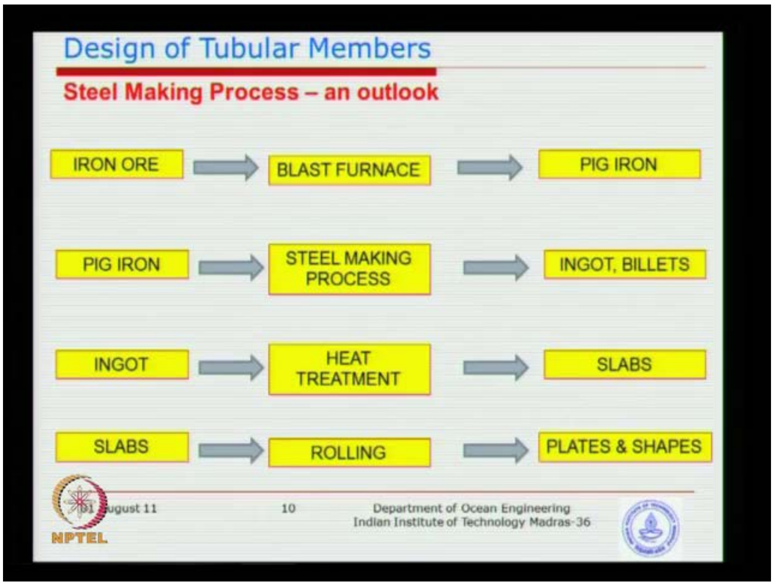

What is the manufacturing process of steel because there also you will see that the process affects the produced quality of steel starting from iron ore all the way up to the produced shapes? So, you can see here several subgroups of activities happening starting from collection of iron ore blast furnace I am not going to go into the details of this because it will be taking more time. So, we will just quickly look at the methods used and what exactly is happening at the stage where the prig iron comes and then you make the removal on unwanted impurities you will get ingots and billets.

This is the stage where you take the large piece of steel can go for producing seamless pipes after that you may have actually changing from ingots and billets which is very large size could be potentially bigger in section. Then you can form into slabs and plates by rolling and that is during that process you may actually have a heat treatment to remove the residual stresses built up in case if it is there.

Basically, finally you will do shapes and plates to the required thicknesses required cross sections mostly if you see there we call it rolled shapes of I beams channels might be coming from mills without welding. So, they basically instead of rolling into a circular section like what I was talking about you may get sections which are of most interest.

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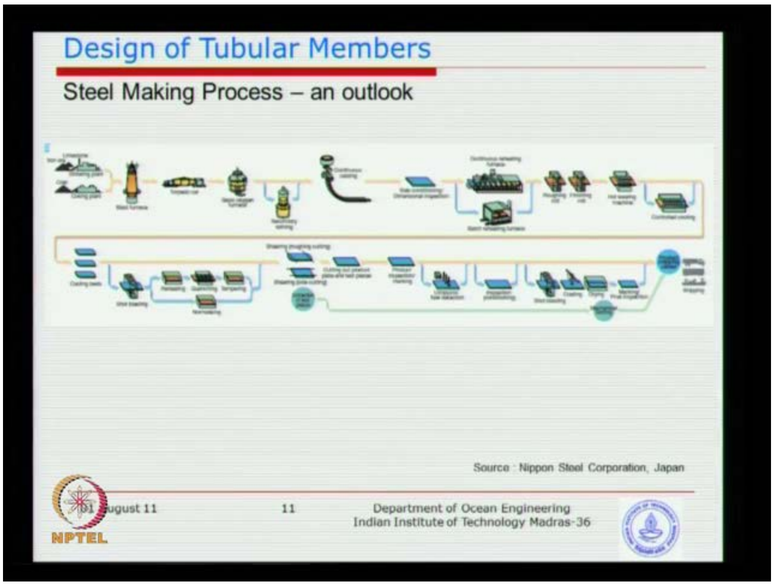

So, the whole process could be described into a graphical way I think the next few slides.

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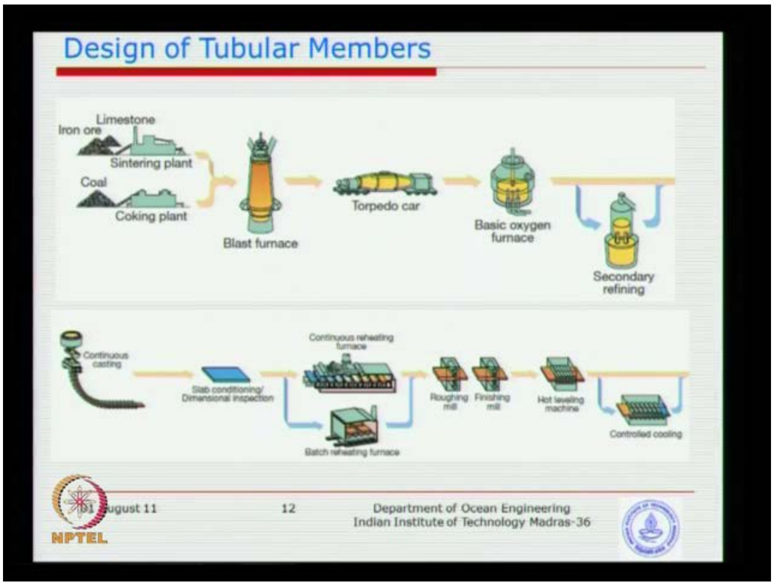

I have just collected photographs from a particular mill which produces this way just to give you an idea of what is really happening, so what is the meaning of blast furnace. Basically, you have a burning material where in the excess materials of chemicals or the unwanted chemicals will actually burn away come as a gas. The solid material of steel will go and deposit at the bottom as a fluid which is basically a large furnace and this open heart furnace is one of the oldest method starting from 1940s.

Now, if you look at the new technology you may not even have this idea, but then over the period of time that basically the improvements in the production process keep improving. Then while going through the whole process you know basically you see here hot and you know the controlled cooling the reason why we do this. Basically, we want to change the characteristics of plates you actually make a temperature increase in the steel slabs and then do a rolling on top by pressure loading and then the temperature needs to be reduced in a controlled manner which we call it the heat treatment process.

In that process if you are not leaving the temperature the inherent temperature inside the steel might actually create additional stresses which we do not know across the cross section at least because the other edges are free can expand, but across the thickness it might create problem.

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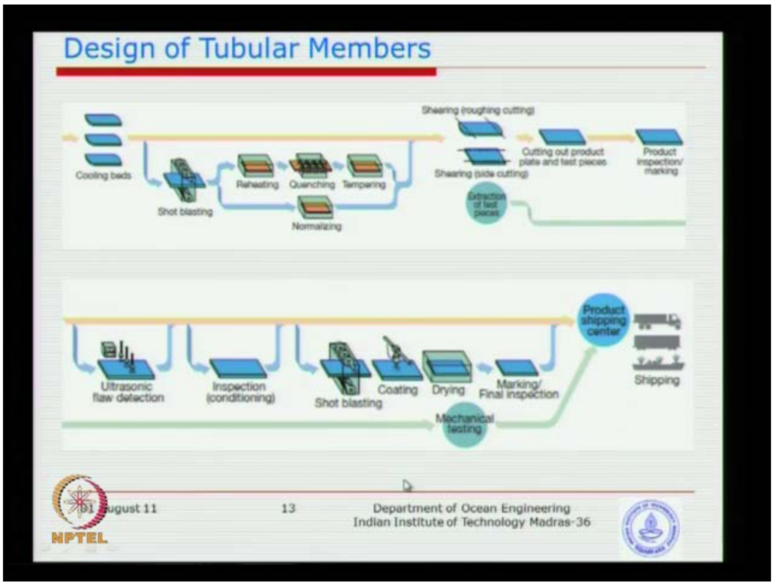

Similarly, there are several other activities which we are not much of interest in this course, but if you take the materials course next semester each of the activity we could spend few hours trying to go about what the process all. Then you know what is the result of this and how we actually make it work for us, so each of the activity we can describe into a particular area like impurities removal heat treatment rolling into shapes and mechanical properties and the treatment. So, basically each stage we try to do something of our interest ultimately we need the products of our requirement.

So, during the process if the treatment process is not done properly you will end up what the message we want to get is production process itself we need to start looking into the characteristic of steel not just after buying the steel. Then look at what we have bought because you can actually control the residual stresses and the properties back in the production itself or in fact you can control the properties at this stage by selecting right iron ore better quality steel will come out. So, that is the idea behind that means when you design a structure it is not the structure design in paper, but actually you need to look at what material we are going to use have the say in the design.

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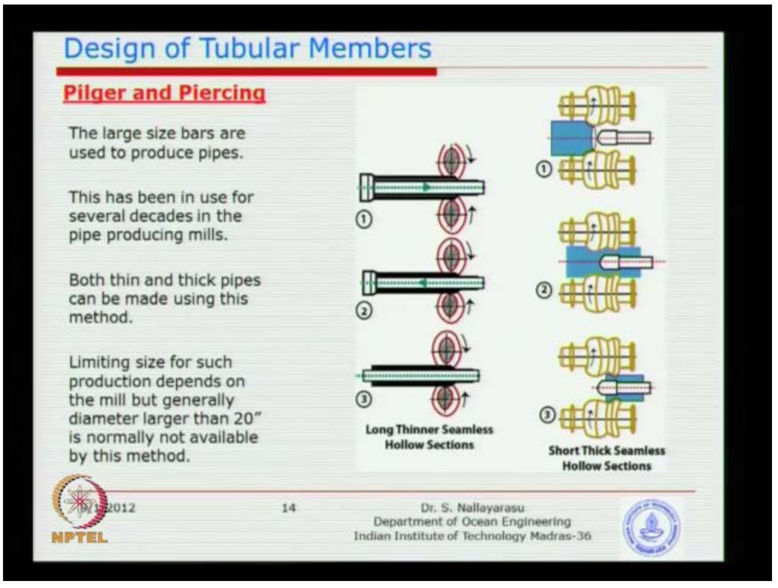

I think we did look at this, so called pilger and piercing pipes which is quite simple.

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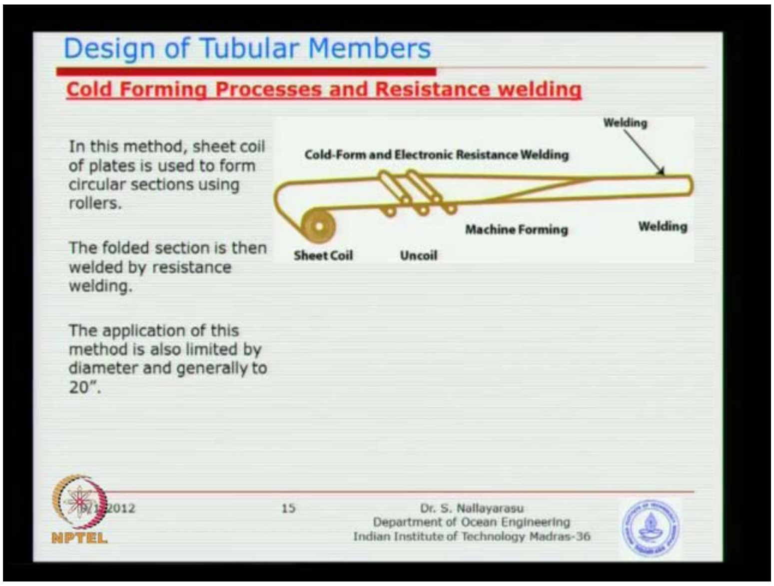

Second one is a role of sheets made into circular shapes by single welding.

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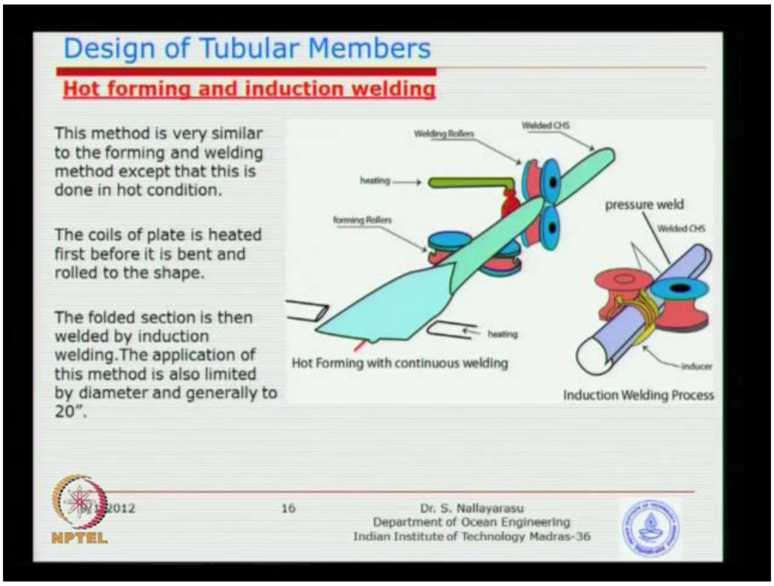

Third one only the welding process changes, but otherwise the rolling and the welding is very similar.

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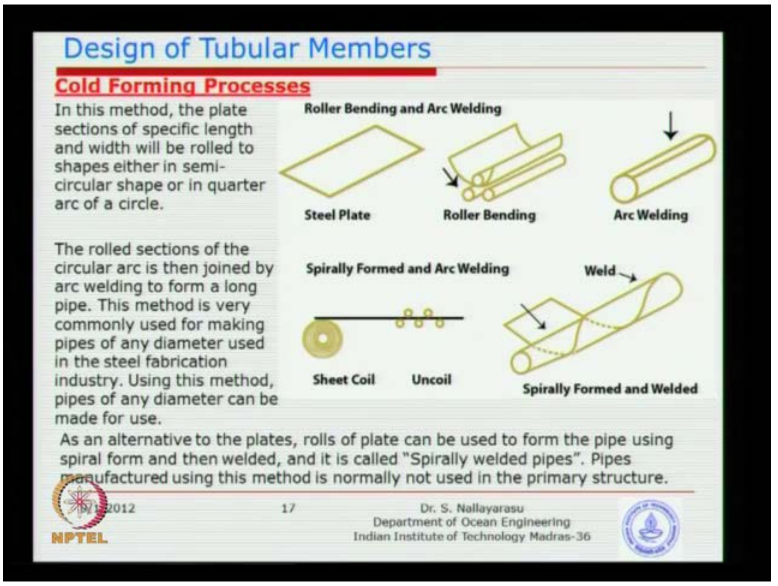

Commonly used method is the cold process which I think you can see from the picture that the sheets of plates are folded to form either single fold or multiple folds I think that is what we were explaining in the other class may be not feasible by this. For larger diameters, smaller diameters yes you can take one plate and fold it to single fold and do a stitch welding at one line whereas if the diameter is 1 meter 2 meter. Then you may have multiple folds you may actually form quarter of an arc you know basically 4 quarters will form the pipes that means you will have 4 longitudinal wells or 2 longitudinal wells depending on what is the segments that you take.

Sometime we have this kind of spirally welded you take a piece of plate just roll it in the spiral form and do the welding accordingly. Basically, for many reasons of uncertainties in the weld quality normally for structural purposes we do not use this type of spirally welded, but in some cases some of the times we do have allowed for secondary structures spirally welded pipes.

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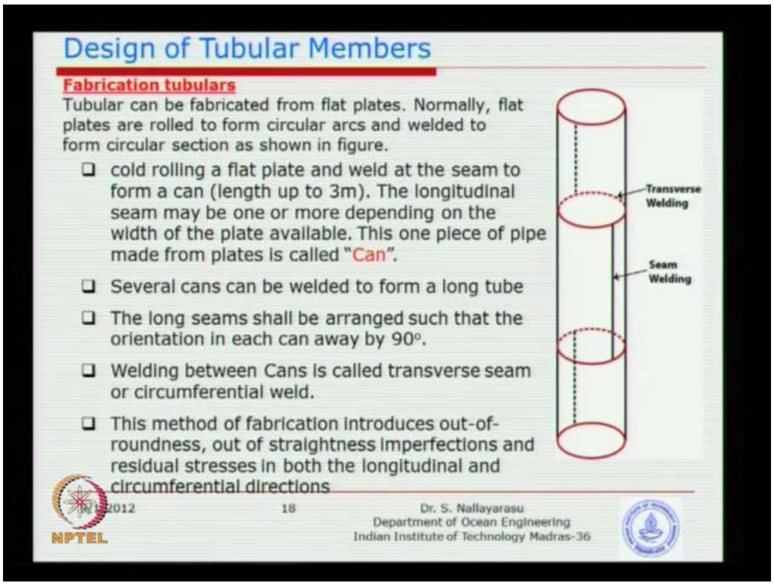

The last one basically is the one that we commonly use for offshore structures because mostly you will you will see from onshore structures to offshore structures the shift in size of the pipes used. For example if you go around in many of the steel structures on land like if you go to airports if you go to some industrial structures you will see the diameters few 100 millimetre like 200, 300, 400. You would not see big pipes because of the scale of the structures number 1 and also the type of loading, but if you look at offshore structures you will see the diameters straightaway start from 600, 700, 1 meter.

So, the diameters are slightly bigger and in such cases you basically need to make it from the plates of several sizes and then assemble them like this you get. So, imagine you will have one welding vertically down and another horizontal welding along the diameter of the tube. Now, every time when you do welding what will happen is the stresses developed due to heating of this material because you are not heating the material throughout same temperature.

Only along the welding locations you do the temperature increase elsewhere the temperature is, so the material will try to expand wherever there is an expansion possible stresses may not develop. But, otherwise there will be a built up stresses because expansion could not happen you take a piece of pipe for example you heat the whole pipe throughout and both ends are restrained what will happen. Basically, the pipe will induce actual stress on the support where it is not allowed to expand exactly the same, here the circular section when one section is heated the other sections are not heated the axial and the circumferential directions you may induce additional stresses.

So, this is called that means whenever you want to do design you need to go back to selection of material and then the method of manufacturing because they have inherent say in the process when you are doing this normally. You have got this length of the each of the segment not more than few meters like 3 meters, 4 meters mostly about standard is about 3.2 meters which is the size that you get. So, that means you will invariably end up doing this circumferential welding or called transferors welding you will see many of them if you take a 10 meter pipe you will see 3 joints. So, that means every time you do this before you take and fit up this into the structure for example you have 2 jacket legs, by this time I think you know what is jacket.

So, basically you have 2 legs you have 1 member joining one of the legs to another leg and when you take it and fit it there when you start welding this end and that end you will see that the member is trying to expand and because of the large size the expansion is not also allowed. Two things can happen either the member can just bend laterally because of the large temperature forces that means it can go out of plane or buckle or it can actually expand and just try to produce reaction forces on the legs on either side. So, you could see that substantial amount of force can come if the dimensions are exactly matching the dimension of the leg, so that is basically needs to look at it how much that can actually cause how do we remove this.

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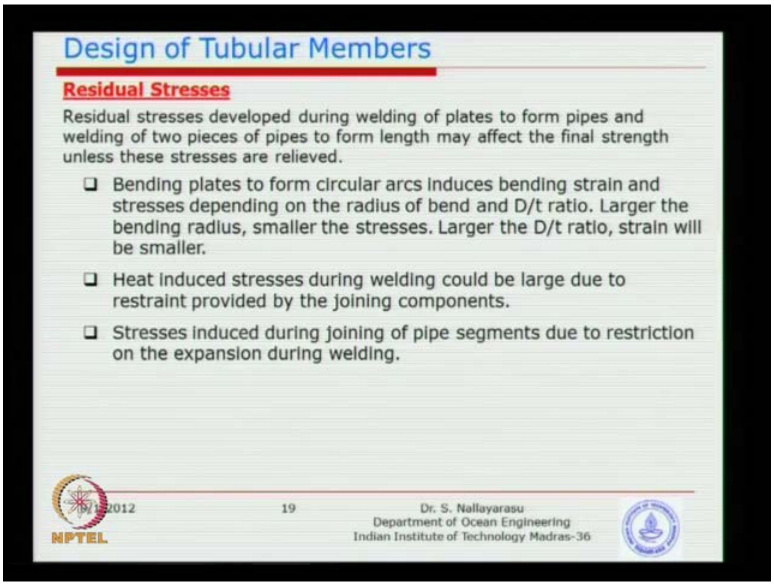

So, the residual stresses is basically a cause of worry because you have no control during the process of design you do not have as a designer you do not have a control. So, what we need to do is create a procedure in such a way that you do not do this you do this as part of the design process make a specification give it to the fabricator that you should only follow this, this, this steps. So, that my design becomes valid because if you do something else the design becomes violated because the residual stresses created are higher than what I have permitted you cannot go and stand in the fabrication yard.

That I will, I will watch every activity that is going to happen which is not at all feasible, so we will assume certain percentage of the strength of the material as the residual stress built up and we need to make sure that during the process of fabrication that activity is controlled so that is the idea behind why do we need to know this as a designer. So, there are three forms bending plates you take a flat plate bend it which is a simple beam bending theory you can calculate what the stress could be caused.

If we take 2 meter plate simply bend it to a radius of whatever required find out what is the stress and heat induced stresses basically a temperature effect I think most of you have studied the thermal coefficient of steel and the expansion related to length and the thickness. So, as long as the expansion is allowed no stresses will be built if the expansion is not allowed corresponding stresses corresponding actual force or bending force will come.

You can find out depending on the size and depending on the flexibilities allowed and stresses induced during joining pipe with the main structure. Basically, like what I was trying to explain you have two ends restrained you take the piece of pipe fix it there, do the welding at both ends. You will see that the stresses will be induced both on the parent structure as well as on the structure being welded.

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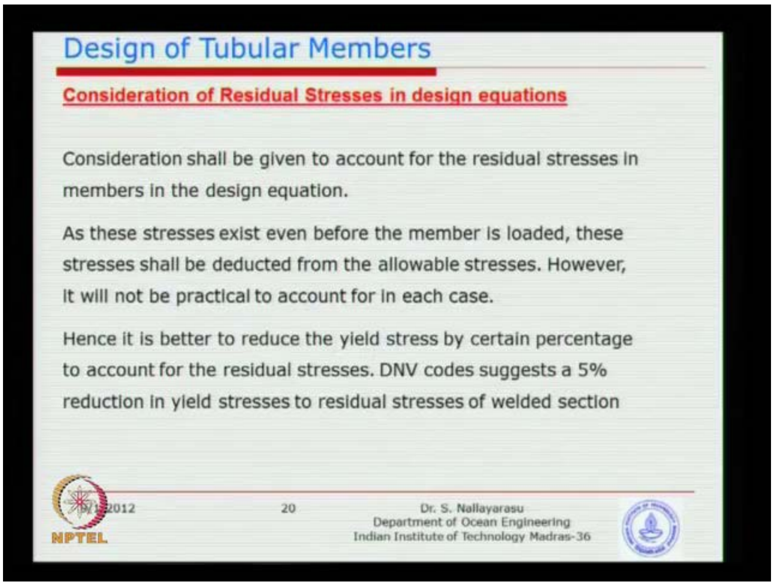

So, the how do we take into account typically if you look at A P I have not given any guidance it is up to the designer to fix, but if you look at D N V codes. They suggest if you have 350 mega Pascal as the design strength given to you as a target strength to be used in the design you simply reduce 5 percent which is good because then you do not need to really worry too much except that the fabrication process. They should have a specification there that the residual stresses should be kept less than 5 percent, but then how do you control this you are not going to put the strain gauge in the fabrication and measure the stresses it is very difficult.

So, what we need to do is come up with the fabrication process such that the residual stresses will be less than 5 percent because practically going to the site and making every measurement at the site. Where my residual stresses will become a new project which will not be possible to do it, so that means we need to have a systems and procedures in the fabrication. That the residual stresses will be less than 5 percent then you do not really need to worry because you can reduce your requirement.

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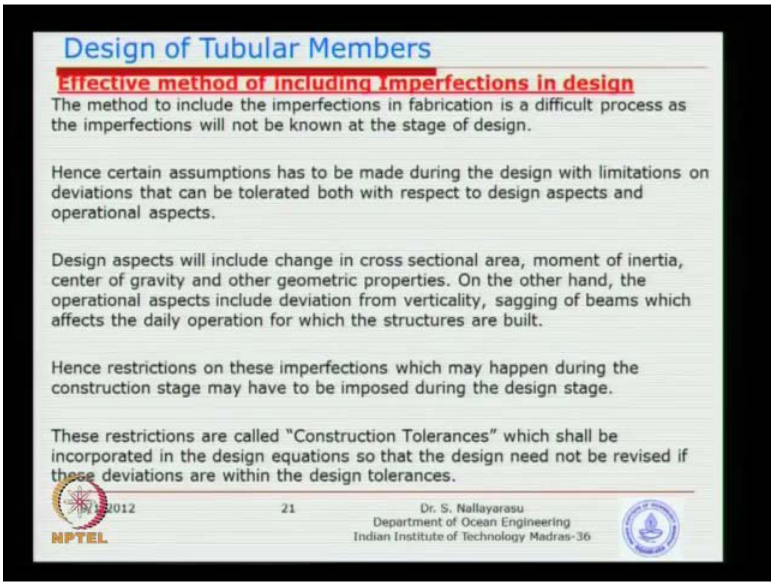

So, effective method of including imperfections is another cause of worry I think imperfections can be caused by several inefficiencies in construction and fabrication for example I wanted a pipe circular section 100 percent no deviation in diameter. So, what can happen it can actually not possible to fabricate at all I need a 100 percent circle every time you make one circular section you may have a deviation of something you throw and take a another piece of plate fabricate it.

So, what will happen is the quality control becomes quite difficult because you will not be able to find a contractor who can make 100 percent error free all the time and all sections to be produced. So, you need to give a tolerance how much can I agree that he can make a small mistakes how small is the small needs to be defined. So, that is where we need to find out a system in procedure that you give it to the fabricator you do this my design is if you do this your fabrication is rejected.

So, basically in no time you will go and accept a deviated project construction for design purpose unless the deviation is slightly higher than the acceptable deviations sometimes we do accept or recheck the design to make sure that we do not throw out too much of material. So, basically again quality control under fabrication is all other thing that we need to look at, so if you look at some of the pictures.

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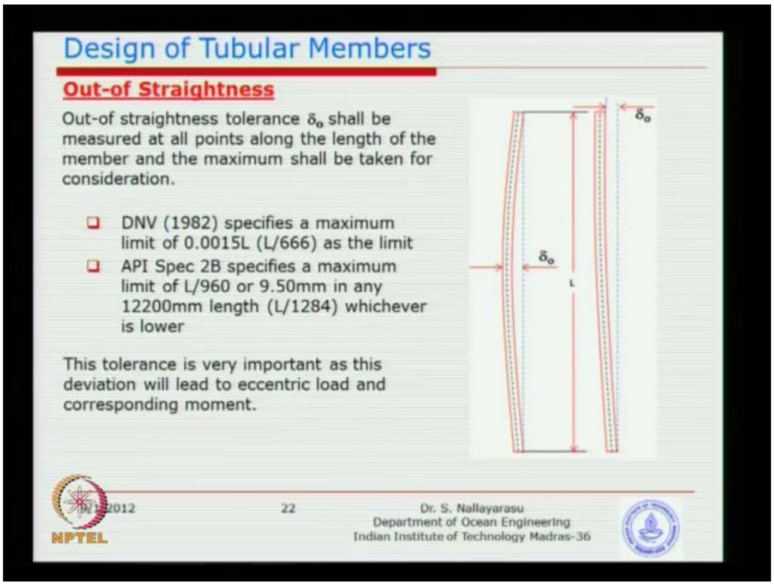

Something like this a column is being built perfectly 100 percent verticality is required, but then if you have a deviation how much you can accept because this is going to have undue effect on actual capacity of the column initially crude, initially supposed to be vertical. You have an axial load you calculate your actual stresses and then actual allowable stress we are going to see a few of them when you do this initially this much of deflection horizontally it is supposed to be taking some load.

But, it may not take the same load because this is initially some deflection is there which is going to induce additional bending. That means your load capacity comes down this is very straightforward as long as you have deviation in the construction the final capacity is supposed to be taken cannot be taken because you have reduction because of the imperfection in the structure. So, this is one area where even the mason who is doing the construction he will be worried if the if the pillar is going inclined he will do a correction that is why every time you do a verticality check.

So, what actually goes here the D N V is earlier the out of verticality is acceptable as long as is less than l by 6, 6, 6 is a typical number like 15 percent you know 0.0015. So, basic idea is the A P I said to be this is the one that we normally use. For offshore structure, it is actually a fabrication specification the one that I am describing here most of the data is taken from to be which is nothing but a specification to be given to the fabricator. He will have it, he will read that specification, he will start fabrication based on this specification looking at the tolerances looking at the limitations he has got even before talking to the engineers if he has made a big blender he will throw and make an another one.

So, basically they talk about l by 960 or 9 and half millimetre which is maximum over a 10 meter span you can see that how much mistakes he can make or 12.2 meters is about 9 millimetres which is quite long. Which is reasonable because if you say 0 millimetre over 12 millimetre long span probably quite difficult to make you can make in fact some of the class of structures like aircraft structures. If you look at the specification they may not even agree this because there it is more important to have the shapes and size correct. So, in offshore structures we say 9.5 if you come to onshore structures you may actually have slightly less stringent depending on the criticality you fix up this number and then make sure that the contractor follows.

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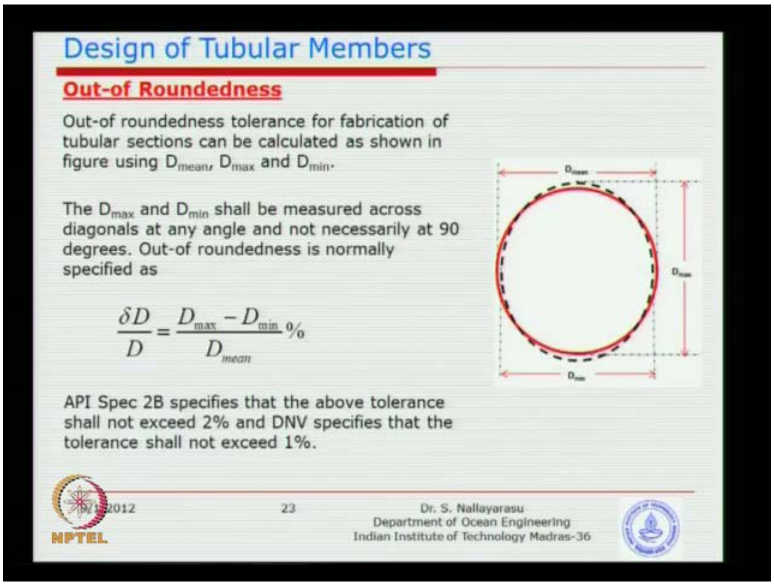

So, this is on the length the second thing is on the shape itself the cross section instead of making circle if you make an ellipse what will happen your section properties changes your calculations become completely devoid. So, that is why we can allow certain percentages, but not more than that, so typically if you look at A P I allows 2 percent deviation.

The deviation is defined as the change in diameter over the original nominal diameter can be calculated by the D max and the D mean, it looks exactly like ellipse I think probably and then you look at the nominal diameter and then calculate this ratio. If you express in terms of percentage you can go for 2 percent deviation in A P I and one percent deviation by D N V so just you could see that such type of deviations are also allowed we call it out of roundedness you wanted a circular section.

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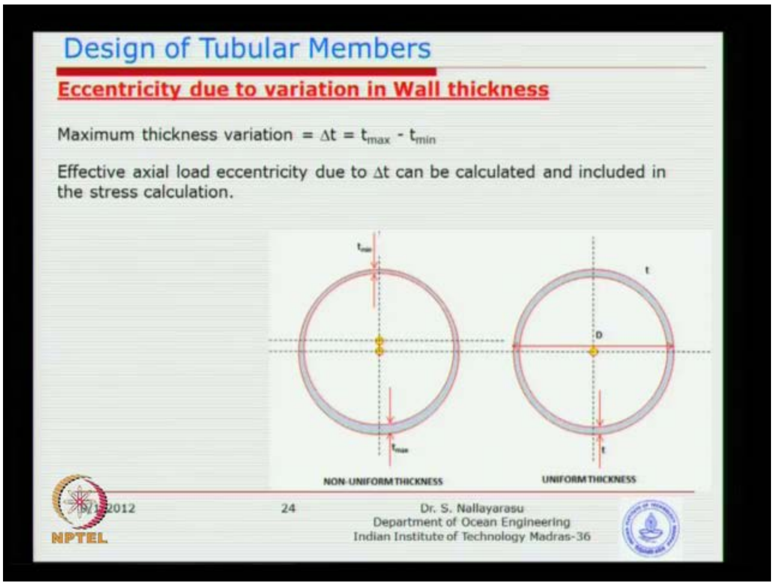

But, then slightly deviated and also variation in thickness you see, here this is another cause of worry because when the plates are received from the mill you expected the plate thickness to be very uniform throughout the length and width. So, when you roll into shapes of this kind we expected something like this, now what really happens when the thickness becomes one side is slightly bigger, one side is slightly smaller. There will be cross section centre of gravity changes to one side, so when that happens you will see that your additional moment will generate.

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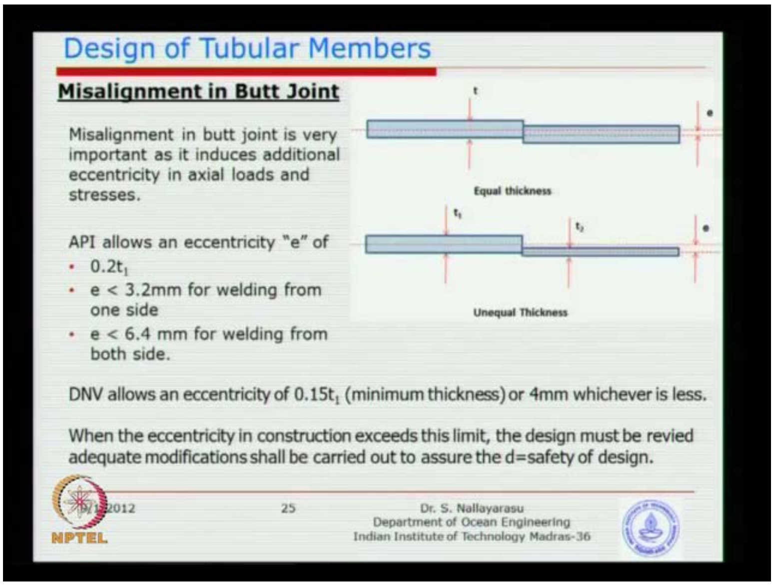

Also when you try to join 2 or 3 plates together of different thicknesses you wanted a concentric welding, but you may actually see that the welder made a mistake assembling has been done in an incorrect manner. But, this could actually look like a exaggerated sketch you may not do this if you do this actually you throw, but then there could be mismatch of 1 millimetre, 2 millimetre, 3 millimetre depending on the constructability.

So, there you can allow also certain percentages certain numbers, so you see here A P I allows point 2 times 20 percent of the smaller thickness which if you have a 10 millimetre you have a 2 millimetre tolerance or 4 millimetre tolerance. Which is not very small I would say and should be less than 3.2 millimetre from welding, from one side for example you make a pressure vessel or a tube you weld from top the mismatch could be only less than 3 millimetre if you weld from both sides you have double. So, that you can have a the weld metal helping us, so all that what we are trying to conclude inherent built up stresses even before it receives the actual design stresses, so you allocate some portion for your residual stresses and the mistakes.

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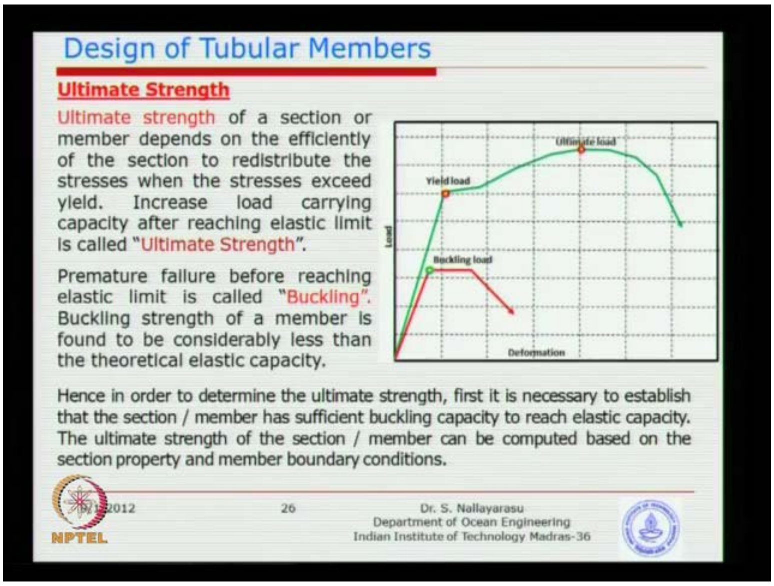

So, let us quickly move on to the next activity because if you look at this whole factor is affecting strength we had several parameters the last one is the ultimate strength because what we are looking at when the structure will fail. If you know the structure failure condition then you can fix up what is the acceptable design condition by giving a factor of safety. So, that we know the ultimate failure point then we divide by the factor of safety to convince our self that the structure will never fail because I have a factor of 2, factor of 5.

So, that before it reaches the failure equilibrium or failure condition the structure is very safe, so that is the idea behind that means not only just looking at the lower stresses we need to look at when the structure is subjected to higher stresses than the actual stresses. That they are going to get in cases of accident in cases of extreme conditions what really happens, so that is where we need to just quickly look at.

So, called ultimate strength is the strength of the structure at complete collapse or failure, now if you look at this graph there are 2 lines shown there one is the yield line the other one is the buckling line you take a piece of a column you try to apply axial load. So, what really is going to happen if the column is sufficiently shorter enough that the yielding will govern because the length is too small compared to the dimensions and the load it carries? Now, if that length of the column is too long you will easily see that it becomes slender the word slender is actually relative there is no absolute term called this is slender or this is not slender it is related to the dimensions of the structure both in terms of length and the geometry.

Now, if you look at this green line because the column is probably too stocky too small it never ever goes into the buckling mode that means keep on carrying larger load until it get compressed. So, that is where we call it the yield is governing the design whereas if you take the same column apply a same load, but make the cross section smaller it becomes too slender. Even before it achieves the full yield yielding means the F y it goes there just the column starts buckling laterally or buckling locally and starts failure earlier.

Now, we can decide what we want to do you might have thought that by reducing the size of the structure I have economised that is what everybody thinks you know just simply make this size of the column smaller. But, then unfortunately what happen we have selected a high strength steel very good steel three 50 mega Pascal but the size was made so small we are not able to utilise the full yield strength of the material. You have only used up to may be 100 mega Pascal, so what is the purpose of buying a high strength steel and then not using the strength.

But, we allow the structure to fail earlier because we made it too slender, so we need we just need to see where do we if I make the column slightly bigger I will spend more cross section because more money needs to be spend on the material. But, then I am going to use the available inherent characteristics called a material yield full yield is used so that i am not wasting money. So, that means the proportioning of the member sizes it is as important as selecting right material so basically that is what we need to see that the premature failure by buckling is not a very good idea.

We need to make the sizes sufficient enough that we never govern the design by buckling we could say that, but sometimes we do that because of constraints you know many times you will not be freely allowed to go and make the sizes bigger. For example when you design a multi column structure you will not be given free hand to make the columns as big as you want because if you have too many columns you would not be able to use the particular the particular property for which it was built. You have so many columns that the whole space is occupied, so there will be restrictions and you may have to follow.

In such cases some of the design will become governing by buckling, but then you have no choice, so what we are looking at is beyond yield what really happens whether the structure collapses immediately or it is able to take sufficient load beyond yielding is the characteristics called ultimate strength. So, what we want actually a additional strength before collapse so imagine if this line is just basically horizontal line after yielding it just goes straight horizontal what happens once one of the place or few of the places have yielding the structure collapses which is not very good.

So, you can see here this is the type of failure the ductile failure we are looking at that means both in terms of material selection and also in terms of cross section selection. We need to look at whether the structure behaviour is going to be ductile or going to be brittle or immediate failure that process involves two things selection of cross section selection of the structure system or boundary conditions, so we have two things to investigate.

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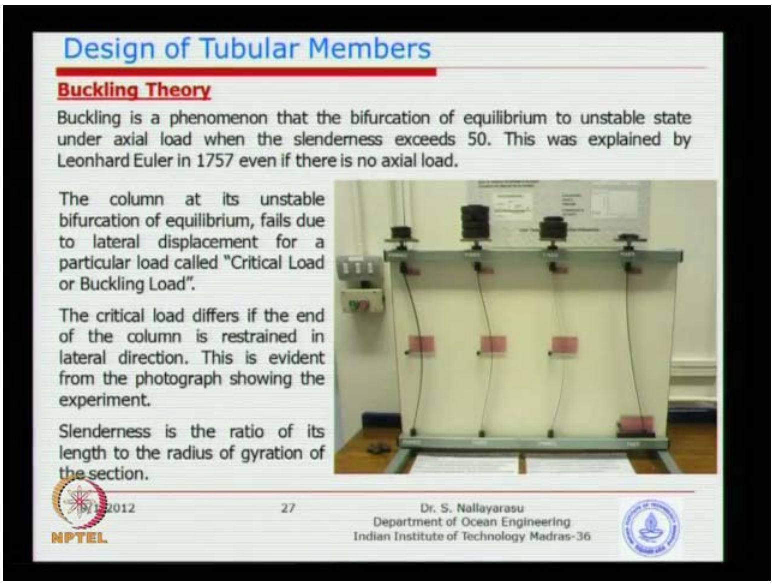

One is the, let us investigate the cross section and we will go just to the length I think we have the length first, so you might have studied in your buckling theory in your applied mechanics most of you might have learnt. So, the support systems make the carrying capacity of columns basically Euler theory is one such for a global buckling. So, you can see this experiment what they have done with different boundary conditions they carry a different loads of a simple column you could easily visualize that if it is a free end. At the one end fixed at the other end it carries lesser load then both ends are fixed and the vice versa.

We call it the effective length basically if you look at all four sets of diagrams or the experiment you could see one of them carries very heavy load for a typical lateral deflection of some amount whereas if you look at this fixed free it carries only very small amount. So, that means if the effective length is the reflection of what is the loading carrying capacity depending on the boundary conditions, so you see here it might be taking three or three time four times the load. Whereas, the other one carries only one-fourth, so vice versa we express the capability of the columns in terms of effective length because if one carries higher load the other one carries lesser load.

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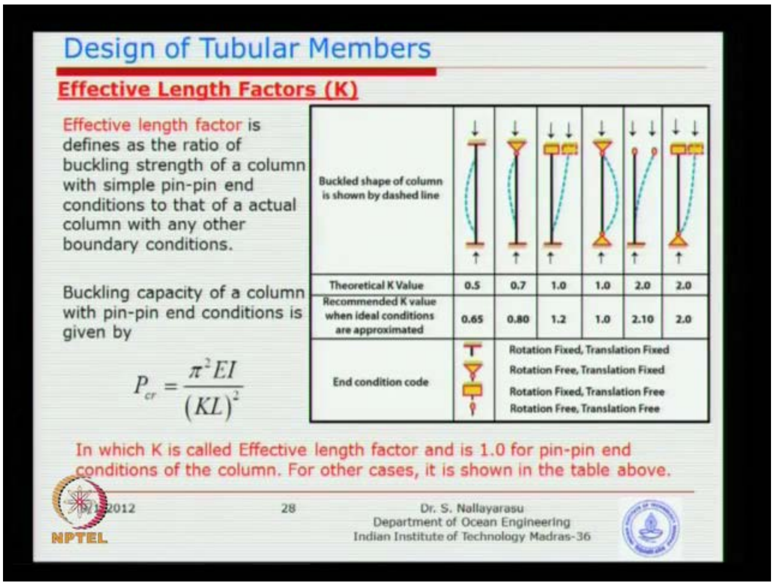

The same thing is expressed in terms of a typical picture here which could easily be understood for a fix fix column the effective length factor is 0.5 compared to a pin pin column. Always remember pin pin column is taken as the base which carries say 1 kilo gram or 100 kilo gram a fixed column can carry twice the load, so that is basically relative. But, one thing is the theoretically derived values are given in this table and also recommended values by the codes and the practice mostly we use the values shown in the second row and the capacity of the column could be evaluated depending on what is the boundary condition. So, that is called buckling load i think most of you should remember this formula because it is used in many of the structural mechanics calculations.

So, what is defined here is the K value which is nothing but the effective length factor which is exactly pro writing the load carrying capacity the boundary conditions are reflected by the so called boundary condition factor Euler buckling length, buckling factor. So, whatever you call it is the means of treating the edge conditions to transfer higher load or lower load, so you can see here the pin pin condition is nothing but rotation is allowed translations are not allowed. Whereas, if you go to fix fix conditions 100 percent restraint on rotations as well as the translations you know very well if you have a beam vertically supported for sure translation is restrained.

But, when you apply a load if the beam is rotating at the ends because it is only an edge support not encased into support itself then the rotation is going to happen. But, at the same time if you hold the beam for a sufficient length by a clamp or by an encasement the rotations are not going to happen it is called fixed support. So, it is all how the construction is done you have to reflect them in the design so you need to just plan for it if you have a pin pin condition assumed in your design you simply can allow the constructor or fabricator to place the beam do nothing.

Whereas, if you have assumed a fix fix condition you must make sure that you actually reflect your design condition to be reflected in the construction. That means they have to encase the complete beam inside a wall inside a support so that the rotation does not happen otherwise your design becomes invalid. So, basically this is quite important for any civil engineering construction, but fortunately most of the jacket structures we have welded construction number 1. That means if there is any beam or column is welded to another beam or column mostly you will get fixity close to partial fixity that means you will get somewhere here.

That is the conditions that we normally assume in the design because over a period of time it has been established the tubular to tubular construction you will go close to fixed condition. So, that means the influence of the boundary conditions on the ultimate capacity you see here you are going to increase the capacity not allowing the system to buckle because you make the system quite strong at the ends fix it. So, you may reach slightly higher for example instead of pin pin condition if I do a fix fix, it carries higher load then what it is supposed to be carrying pin pin that is the idea behind improving capacity by means of boundary conditions.

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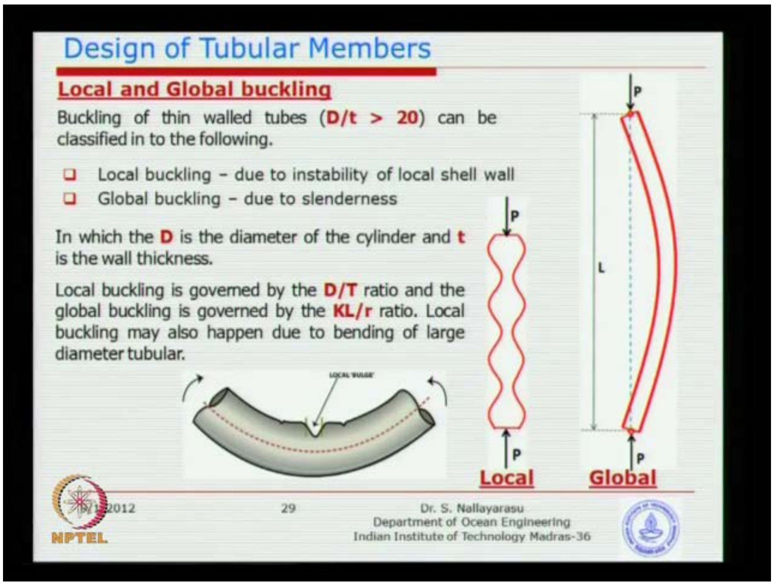

The next thing what we want to do is just look at will it go for global buckling or local buckling you can have a column you can have a length of well. But, unfortunately if you have made the wall or cell wall too thin then what happens before the global buckling happens, you can even see the wobbliness of the tube itself. It can do a waveform which is called local buckling because the instability caused by the actual stress locally the tubes get deviated in the cross section which is called local buckling.

Sometime if you have bending large you may see that the local buckling becomes problem at particular location because of this kind of local bulge failure which is potentially possible. You take a piece of paper roll into a small tube you try to bend you will see that you would not be able to bend even few millimetre because the wall thickness of the paper is so thin that the centre portion will be able to bulge out and bent failure. So, basically this phenomena needs to be understood before we reach the global buckling because this is not a problem for open section.

For example, you take I section you do not need to worry about this because this is specifically for hollow circular sections that means you need to think about improving the D by T ratios you make it very thick you would not be able to even bend. But, if we make very thick your design is not good because it is too heavy number one too much steel is being used and buoyancy is not there more money needs to be spent. So, we need to find a balance to avoid local buckling what we need to do, so basically avoid the region of D by T ratios go beyond it that means D by T ratios cannot exceed certain limit.

If you go by D by T of 100 for a 1 meter, 10 millimetres is it good you look at the limitations given by the experiments a lot of experiments have been done on this. We will see the results probably in the next class because you can see quite a number of experiments have been done on both beams and columns of the tubular sections have proved that after certain D by T ratios. The behaviour becomes more local than global so not even think about going here not even think about going to buckling load it will even fail somewhere here the local buckling govern the design.

So, after buying a high strength steel making the column one meter diameter we are not even achieving ten percent of the capacity which is above after all no good. So, we need to proportionate in such a way that slowly you march into avoid local buckling avoid global buckling then go into yielding but, at the same time you do not make so big that is good. But, it becomes too big too heavy because too big is a problem for offshore structures because it carries too much of wave load is not it too heavy no buoyancy is available. You cannot install the jacket, so you need to find a very fine balance where do we put it put at the right place.

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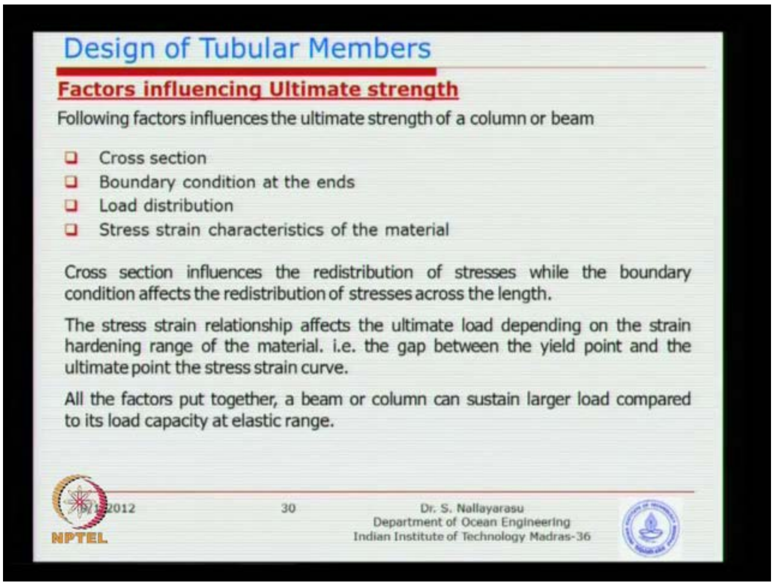

The next one basically the summary of what we have discussed we have looked at the boundary conditions I think the slides would be in the first. The second what we are going to look at is the cross section and then later we look at the load distribution these are all going to affect that for the same beam. If you put the load at the centre it may carry some load if you put the load at somewhere else it may carry slightly different. We will try to do at least that cross section today and then stress strain characteristics we will see it in the next class.

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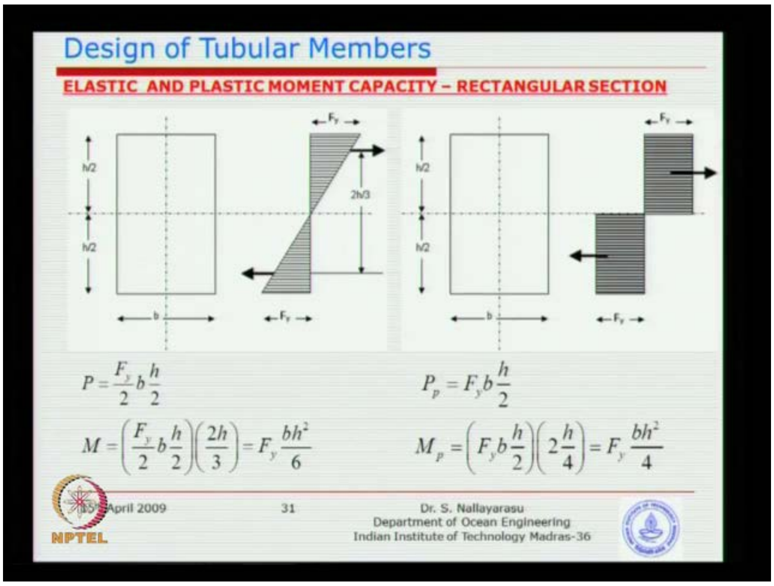

So, if you look at the rectangular section I think most of you must be familiar with this we are just looking at how this cross section of a beam column is going to affect the ultimate strength. How do we compare it is very simple evaluate the elastic strength within this area basically the green line is the elastic strength and beyond the green line after the yield point is called elastoplastic or probably the ultimate collapse capacity. So, what exactly is the difference whether the elastic capacity is giving us say 100 kilo Newton to carry and the plastic capacity is say 150 kilo Newton to carry?

Then we have a 50 percent difference before it failure even after reaching 100 it is not going to fail, it will only fail at 150 that is what we want to find out. If another column 100 kilo Newton is elastic, 110 is the ultimate failure then the margin reduces considerably not a very good section. So, we want to evaluate which section offers us the best or the highest margin of safety between elastic to plastic, so quickly we will just look at the rectangular section I think most of you must be familiar with this.

So, called the elastic theory as elastic beam bending theory for a rectangular cross section the stress strain diagram will be linear and basically going across the neutral axis you might have studied in your applied mechanics course. Then this section or the extreme fibres of the beam reaches yield point and basically that is the situation we are evaluating and if you look at this force on the top and bottom half section of the beam you can see.

Here, this is F y by 2 because you can take an average of F y plus 0 divided by 2 multiply it by width of the section. Multiply it by half depth of the section which will give you the force on the compression part or on the tension part they have to be equal for the beam to be in equilibrium this is just a beam subjected to bending something like this if you look at the beam.

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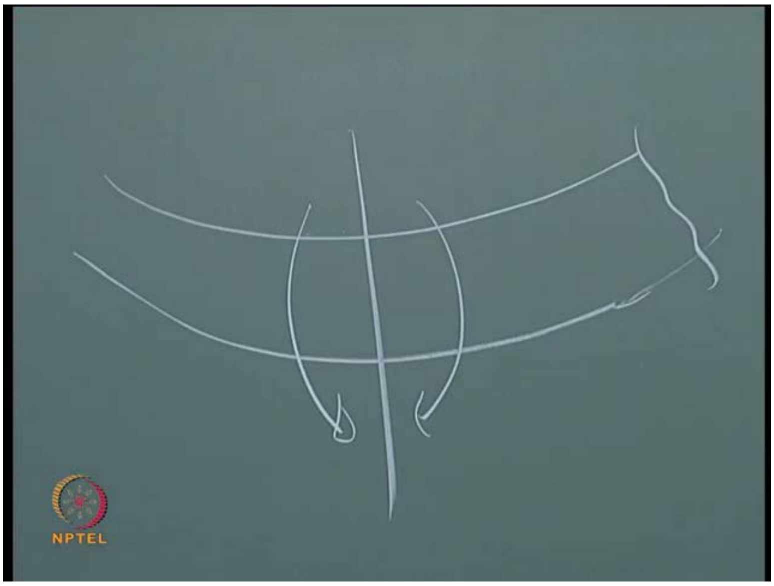

You have a long beam bending like this you take one cross section at this place your bending movements have to be in equilibrium and the beam subjected to a simple bending I have just taken one cross section. So, if you look at the movement produced by the beam internally it is the force multiplied by the lever arm between the compression forces to the tension force. So, I exactly I reproduce I have the P, here multiply it by the distance between the compression and the tension basically will give you the moment capacity at equilibrium.

So, you see there what we get here F y multiplied by b h square b d square whatever you are talking about same procedure can be repeated when the beam reaches the plastic capacity. So, what you mean by the plastic capacity basically when one particular section of the top fibre is reaching yield does not mean that the beam is not going to collapse because the next fibre or the material just below still under the yield. So, what will happen is the redistribution will start happening because the extreme fellow is unable to take what will happen this fellow is trying to give.

Thus, the load or the stress to the next fibre and vice versa progressively transfer from external thus the material to invert because we know very well that the inner material is underutilised. So, we will start transferring the load from external fibre to inner fibres, so ultimately the stress distribution becomes uniform like this. So, when you do the same integration for this is called sectional redistribution I think some of you might have studied. So, this redistribution is the one that we are looking for this is the additional strength available in the section beyond this location the yield load means a particular location of a cross section or a length of the beam is yielded.

But, not the whole beam is yielded you must remember so that means we want to look at how much additional capacity this can carry because of redistributions on the section. So, once it becomes like this same procedure you can repeat what I have done here integrate the forces on the half section take a moment you see here F y b h square by 4, so which one is better the right hand side is definitely better because the division is less. Here, it is 6, here it is 4, so this is what we call it section modulus I think most of you might be familiar called moment of inertia divided by the section depth by two so you have b h square by 6 you have b h square by 4.

So, this is elastic section modulus this is plastic section modulus the section modulus or the time of collapse basically the section is fully yielded. Whereas, this is section is partly yielded only 2, 2 locations at the top and bottom has yielded elsewhere you see the stresses are far below the yield point all of you understand this, the ratio is called the safe factor. Basically, because of this particular shape I have the elastic capacity to plastic capacity is 1 and half, so plastic capacity is 50 percent higher, so I am happy, now let us look at you have understand this.

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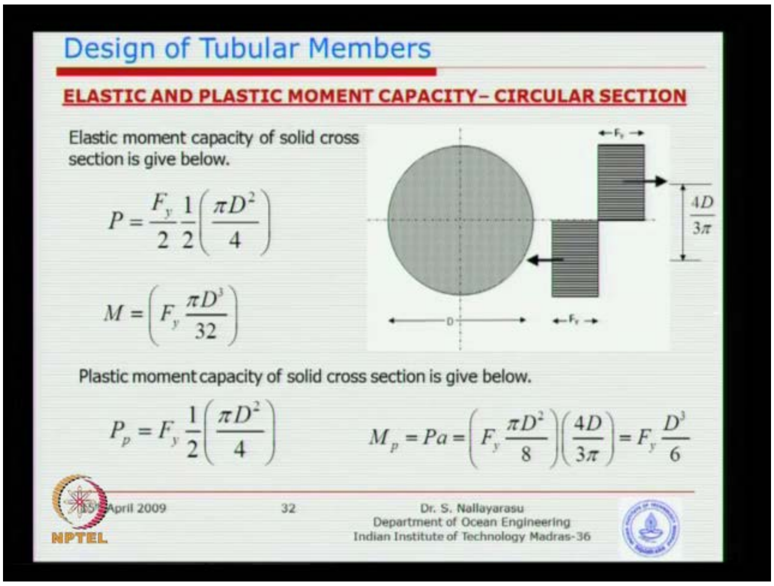

Now, we will quickly move on to a circular solid section which could yield some result procedure is same divide into 2 half of course for elastic section I have not put the stress diagram. But, you can easily derive it, so the moment capacity is given by pi D cube by 32 just for a triangular distribution whereas if you take a rectangular distribution you get F y D cube by 6. If we do the ratio you will get something slightly different from 1.5, so for rectangular you got 1.5 for circular.

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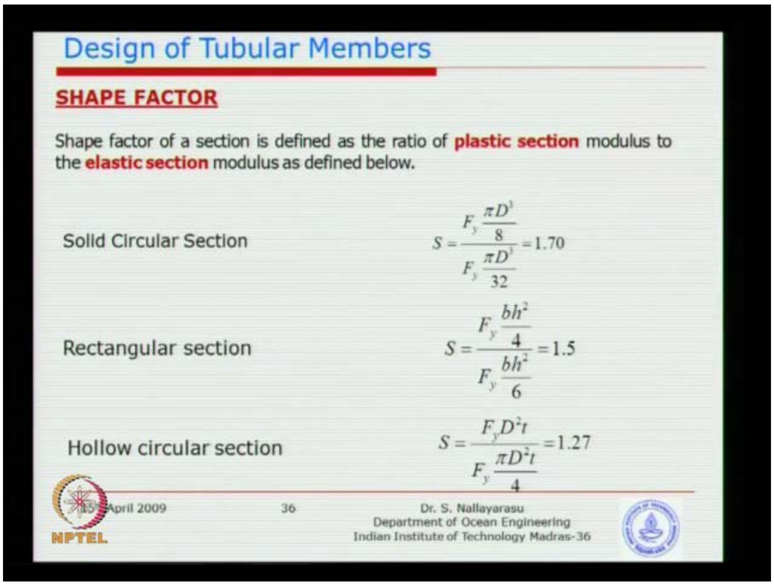

I think if you look at solid circular section is 1.7, it is for sure it is good, so you got 70 percent increase, but unfortunately if you use this type of sections you have too much material inside too heavy and basically may not be suitable for our applications. But, solid sections are used in machineries elsewhere in industrial applications sometimes, but not in offshore structures. So, but what we want to highlight here is you could improve the failure load considerably if you make the cross section better the last one before we finish the class today.

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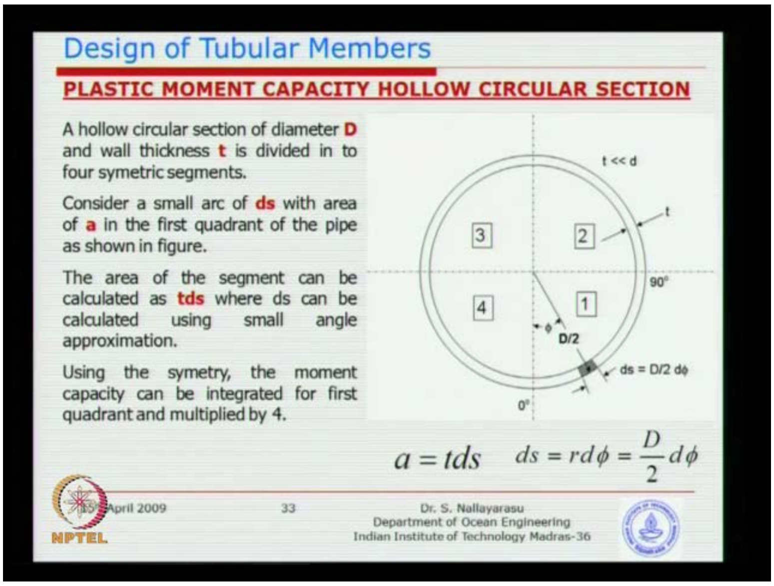

The hollow circular section which is of our interest you could, so exactly the same principle only thing is little bit complicated because of the hollow sections what I am showing here is take this whole pipe divide into 4 segments of 0 to 90 degree. Do a integration of because remember the area is changing because we are going to integrate from bottom to top and the stress distribution is continuously changing because of the pipe section. So, we cannot simply do a simple calculation like what we have done here we have to do an integration.

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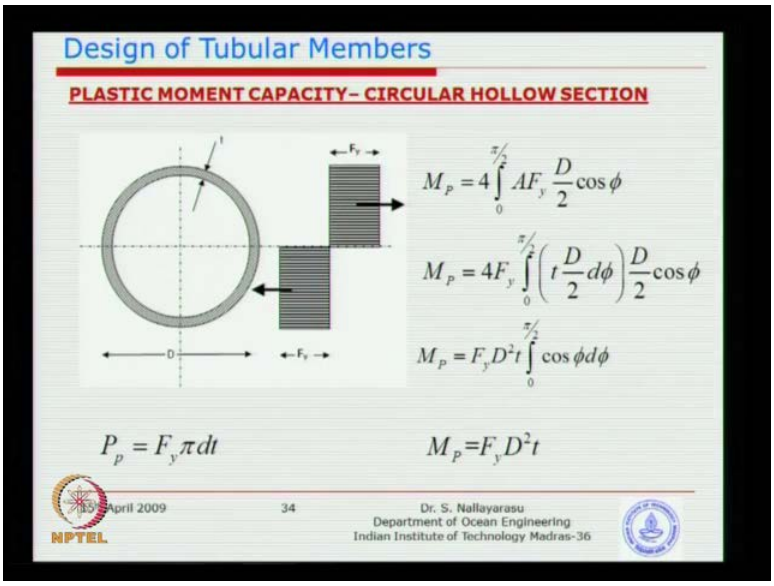

So, basically that is what I have shown here the force is basically F y times area which is pi times D times t or you can calculate accurately using your inner diameter and outer diameter. So, you see here the division of the pipe into 4 segments 1, 2, 3, 4 and only do the calculation for 0 to 90 and just multiply and mirror image by 4 you will get the full capacity, the area of the small segment is basically thickness times the arc length.

Basically, the arc length or the segment length can be computed using small angle principle using R theta I think most of you might have studied in your mechanics and the angle is smaller you do not need to apply Pythagoras theorem. You can simply multiply by R times the angle you will get D s and basically D by 2 d phi and then just do an integration of area of the segment multiplied by the force at. That segment into F y because everywhere F y very easy and multiply by 4 integrate from 0 to phi by 2 and then you will get a formula something like this.

Now, what is the difference between this and the elastic the elastic one we can calculate because we already have the property know what is the moment of inertia of the circular hollow section pi by 64 D power 4 so you know the formula beam and then multiply by F y divide by I by y. You will get the section modulus and you can multiply by F y you can get the plastic elastic moment capacity how we do it because we want to see in the similar form.

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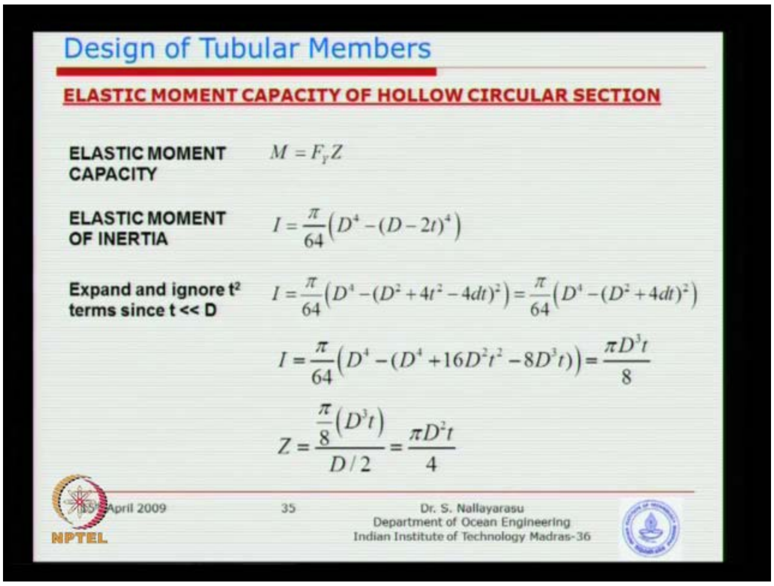

What I am doing here the elastic moment capacity is F y times z and I value is known to us you simply reduce this formula by simplifying it by assuming the thickness is too small basically the thickness is quite small compared to diameter. So, you will get a formula something like this when you ignore the second order terms, so you compare pi D square t by 4 with D square t. So, you can see d square t d square t get cancelled what you have is pi by 4 as a additional term there, so basically that gives you an idea of the ratio so this notation for elastic modulus i have used just to make sure that you do not get any confusion.

So if you look at a hollow circular section you do the ratio is 27 percent not very bad as well not very good because you see here rectangular solid sections giving 1.5 solid circular sections is 1.7 Whereas, the hollow sections is slightly lower, but of course you see the construction in concrete most of the time you have 90 percent you have solid cross sections. So, they are either circular or rectangular square they offer very good failure capacity compared to the hollow sections, but for obvious reasons we do not want to use the solid sections neither rectangle nor circular because it is becoming too heavy and not necessary.

The second reason is we do not really want to go to ultimate we want to use even less than yield capacity so though they offer higher ultimate capacity. We may not go to this much of failure capacity because most of our allowable stress design historically will limit our design capacities less than sixty percent of the even the yield capacity. So, basically that is the reason that most of the design then we use hollow circular sections and also most of the cases they offer alternative ideas like circular hollow sections. Fabrication becomes easy less heavily, more buoyancy, good hydrodynamic properties, so using that we try to optimise the design.

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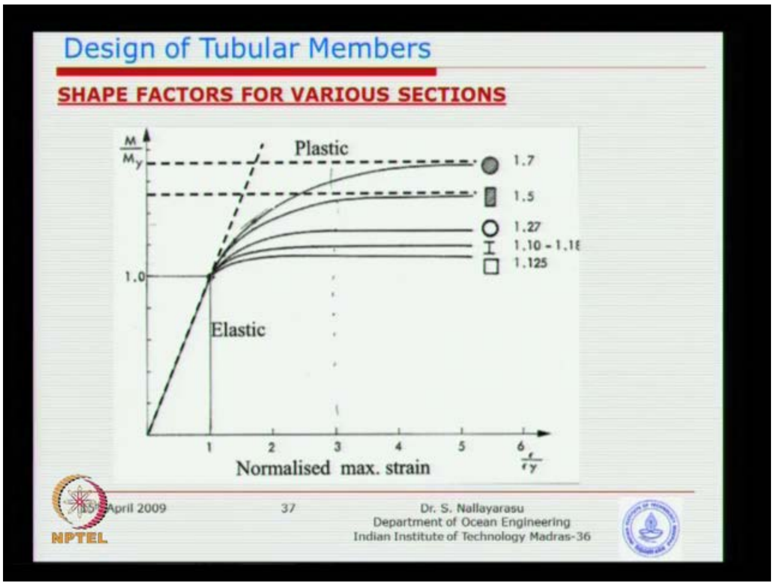

What is the next this is the comparison that you can see basically giving us the moment capacity, so mostly if you are having a design somewhere here within the elastic limit we may not be worried unduly whether it is circular or whatever? So, basically whenever you have a situation where you need to look at the ultimate capacity before you decide the allowable capacity many cases.

Most of the allowable stress design will equate the yield capacity divide by a factor of safety and that is you design. But, if you look at some of the designs like L, R, F, D design or maybe design against accidental loads we do not look at the elastic capacity we look at the ultimate capacity divide by a larger factor of safety. You understand the differences no if we take the yield capacity divide by a smaller factor of safety or you take ultimate capacity divide it by slightly larger capacity.

But, the difference is the second one at least you know when it will fail the first one you do not know when the structure is going to collapse or fail. So, at least you know the real truth before you make the structure usable that is why the ultimate strength based design becomes more and more familiar and in fact the L, R, F, D uses such type of concepts we will do it Monday.