Design of Offshore Structures
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Module - 4
Lecture - 2
Offshore Structures – Tubular Connections

So, today we will continue to look at the tubular join design. You can see from the picture left side.

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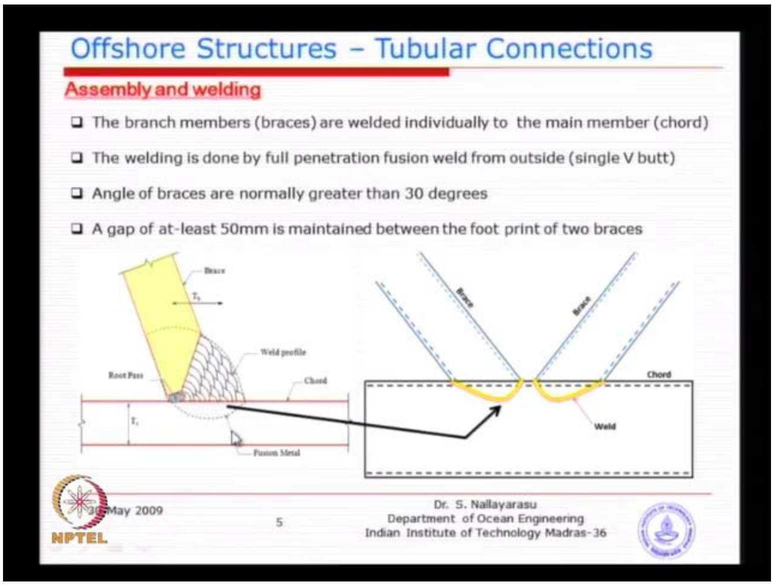

You see here the welding is in made in multiple passes. You know it might look so small in this diagram, but actually this width depends on the thickness of the plate, whatever the thickness of the plate. So, it is 50mm. You will see that basically from here to here, it may be 70mm and another 70mm also is a quiet large size area where you need to do the welding. When you try to do this, you normally do it using multi pass. This means that every time use a 6mm or an 8mm welding rod, you weld around first pass, second pass, and third pass. So, you will see that several passes have to go through in order to make sure that you get the complete fully and the reason why we need to know this the particular purpose is the profile of the welding is here the surface.

If you actually have, I might show in one of the class. You have real photo graph of welder surfaces. You will see a lot of changes in the curvature. So, when it is getting at join to this connection between the base metal and the weld, you may not get a very nice clean surface. That is where most of the time we see the stresses increasing because of the notch effect. We will see from one of the finite element picture later on I think might see here.

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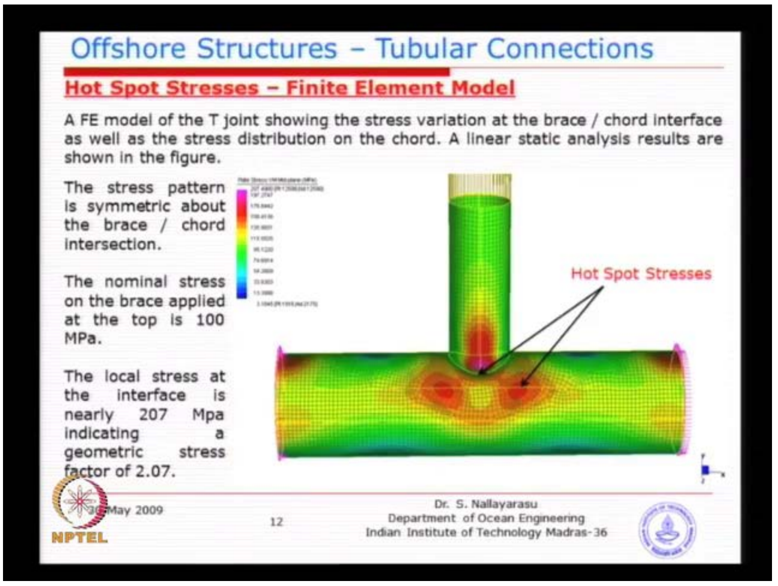

You can see that the change in stress or that location could be substantially larger. That is the reason why we need to know. So, we will come back to this picture later. Basically, the reason why we need to know how it is welded is just to understand how the distribution of stresses or the location of the welding. That makes a difference because that stress is larger than stresses applied at the plate elsewhere. You know basically that is the reason why we want to know.

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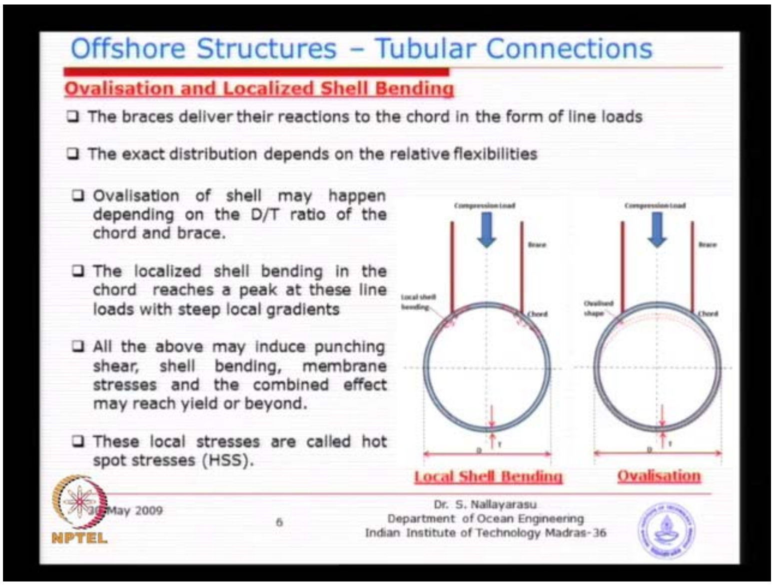

Now, if you look at total process of application of load from brace to chord, you could see here in these two diagrams that any one of them can happen. So, the first point is basically local bending of a cell. Imagine if you have the brace wall thickness as substantially larger, good, strong and you apply the load. What will happen is basically just poking at a thin shell, you know if that chord diameter is large, wall thickness is smaller, what will happen is just going to go down. This is something very similar to local bending of plate. Probably, if the shear capacity is not adequate, what will happen?

Simply, the shear through and the brace can enter into the chord member. So, that is basically a starting with the local cell bending. It may actually end up punching through, piercing through the chord if the chord thickness is very small. So, now you can see one parameter. We have identified the thickness of the chord is going to play a major role whether it will fail or not fail, isn’t it and association with the diameter. See, you cannot isolate a thickness and see whether it is too small or too big. All depends on what is the slenderness of the section itself.

So, larger the diameter, this bigger thickness also becomes lender. Smaller the diameter, smaller thickness also can become very stiff. So, that D by T ratio is an important parameter rather than just a wall thickness, the diameter to the thickness. We look at the right side because we made the wall thickness may be better thicker. We can see instead of locally failing over all pipe is getting ovalised, something similar to ellipse. So, that also can happen depending on a relative stiffness s of the brace and a chord. So, what we need to understand now is the total problem may be not isolated only to the chord or only to the brace. It depends on the relative stiffness of the brace member and the chord member.

That is what we are going to just look at one by one. When you do this kind of bending, for example, you have a load here. You have a bending like this. So, you will see that the bending moment will develop locally. You may have a local bending stress, which can actually substantially be larger than the actual stress produced by this load itself. This is because we made the plate thickness so small, so it is basically bending here. That is the kind of information we are actually looking at.

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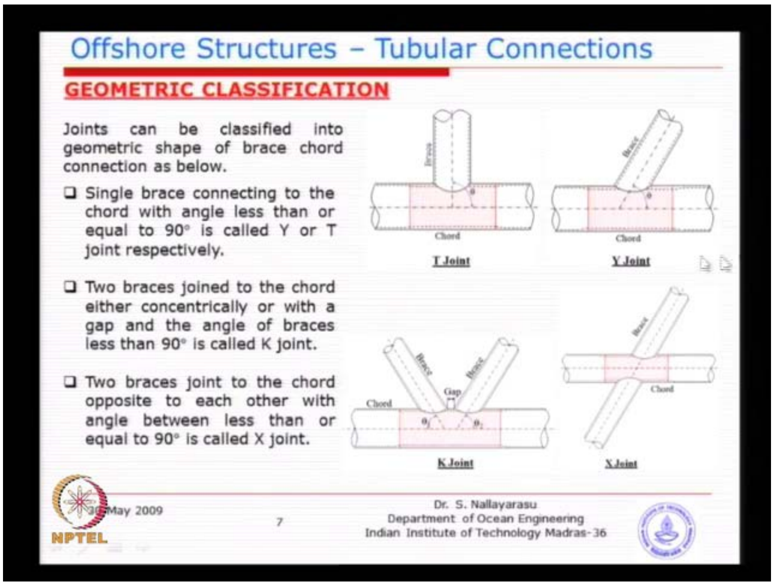

Now, if you look at this, yesterday we discussed about we know the design approach is from three dimensions to planer information. We are trying to for plane by plane. In each plane, we can look at any connection. They will fall any one of these characteristics. Either it can look like T junction. It can look like a T junction. It can look like a Y junction or it can look like a Y junction in opposite direction or can be direction which is perpendicular to each other, at can be any angle between them which is similar like an X joint. So, what we are trying to understand? Anyone of this will be fitting into your actual design. The only thing is that the parameter may change. For example, when it is ninety degrees, we call it a T junction.

When it is less than 90 degrees, it can be from any angle from lowermost as like see 30 degree, 40 degrees to 90 degrees. So, if it is within this, you will call it Y junction because it looks almost like a shape of a Y, whereas when it became 90 degrees, it is T junction. If you have two or three members coming in, for example, in this case, I have drawn only a two, two members coming in, which we call it double Y or we can call it K junction.

Now, there is a primary K, rightly of a K junction, which we will see little later. This is just a look at it. We are just classifying based on geometry, whereas it is not going to behave similar like a K. K means what is only shape, but the behavior. We have to look at the load transfer. So, you can see here. You go and do your design or anybody does the design, almost every one of them will fall into any one of this category, which we will see one by one.

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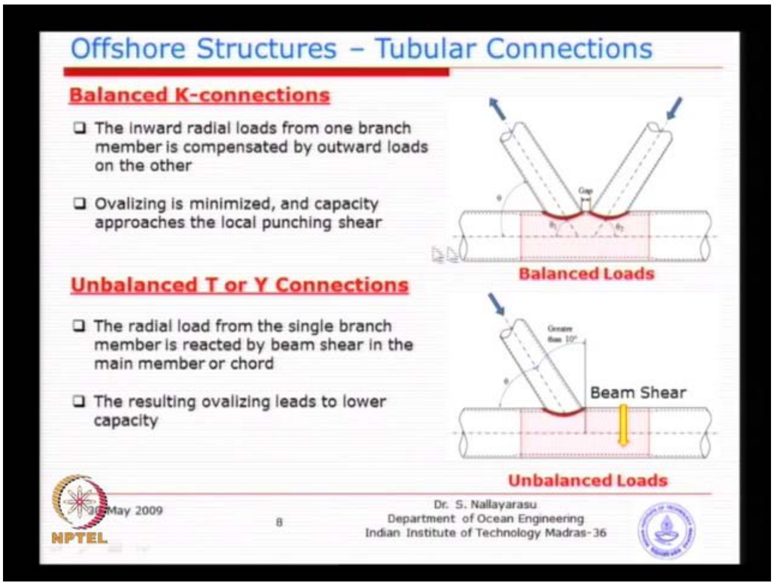

Now, what is called a K junction or K connection? What is defined as is basically a balancing of loads for any join to be equilibrium like this. Then, you have two members. One member is having a tensile load. Another member is compression load. Then, it is called a balanced K junction. So, as long as you have this balancing, if whatever the load comes here and takes in by the other brace angle of this and angle of this is same, then there is no load applied on the chord across the section. So, there is no shear load because member load is coming in, member load goes out. So, that means it is balanced.

So, this balanced junction is always better because the local stresses will be counterbalanced. One is compressive and the other one is tensile. So, that is why, we have a special case where the loads are balanced. Then, it is called balanced K junction and you have T or Y. There is no balancing here. Whatever the load is coming from the brace, it is to be taken as a beam shear by the chord member. So, here there will be substantial increase in stresses compared to the K junction. So, we do practice reaching design. We will compare, use the case of balanced K equation and use the Y junction and find out the result. It will be more for this compared to K.

So, that is the idea that we want to show. When you are trying to classify, you need to see not only the shape, but also whether the load is balancing or not. For example, you have both equal loads. You can classify as a K joint, but if one of them is getting more load and another one is getting lesser load, so you can see that there will be fraction of K joint plus fraction of unbalanced Y joint. So, that is what the classification, we call it load path dependent classification. Not only the geometry how it looks, but also, we should look at whether the load is balanced or unbalanced.

So, for classifying into K junction, we need to have the loads are balanced for T and Y. You do not need to have the load balancing X connection. Anyway, you can have any type of combination, but of course, you can have both braces carrying compression or both carrying tension which you will have to have two different design equations. Many of the times, we have these types of connections.

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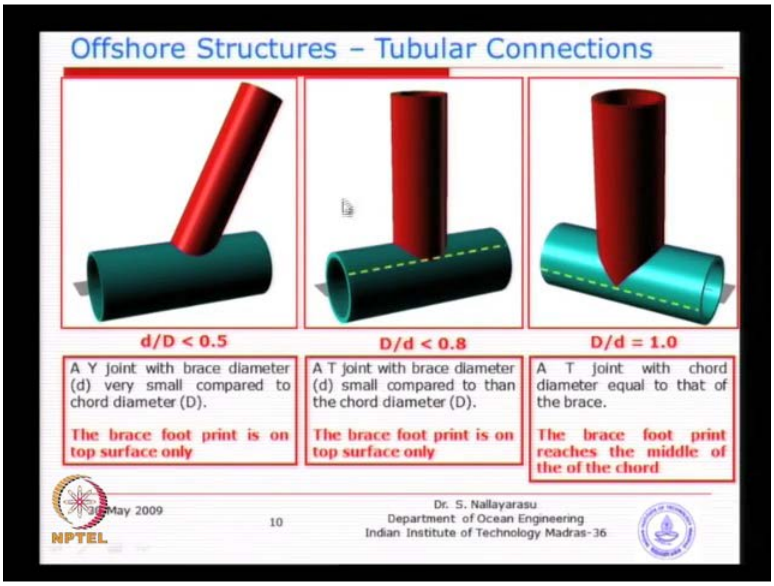

So, now you can see. You just carefully watch these three diagrams. The first diagram is the diameter of the braces smaller, quite smaller comparative will be smaller to the chord diameter. I think most of you understand know the chord and the brace now. So, basically there is seeming member versus the member transferring the load. So, the blue color is the chord member receiving load from this brace member. Now, you see the diameters. I perfectly made it to just indicate how things will go wrong or how complicated things could be; you could see here is smaller.

So, basically the ratio becomes less than half or equal to half or whatever. When you make the brace bigger and bigger, see here, the D by d ratio is, this must be the other way, basically D by d and this also. So, when you have the D by d ratio close to 0.8, you can see almost the, look almost similar, listen it. When you come to the right side, when they become equal, you can see the brace correction is coming all the way up to the middle of the chord member.

So, you need to realize how this will be done because this will be a similar point. Both diameters are same and welding here becomes actually impossible. That is why we do not want to have any brace member as big as the chord member. Try to limit less than 0.9, 0.8. When you have such a situation, you will actually have the stress concentration here. It will be very large because of the behavior welding singularity. So, you need to understand the configuration when before designing whether you should go this way or the other way, the results could be different just to indicate what the increase the stress order junction is.

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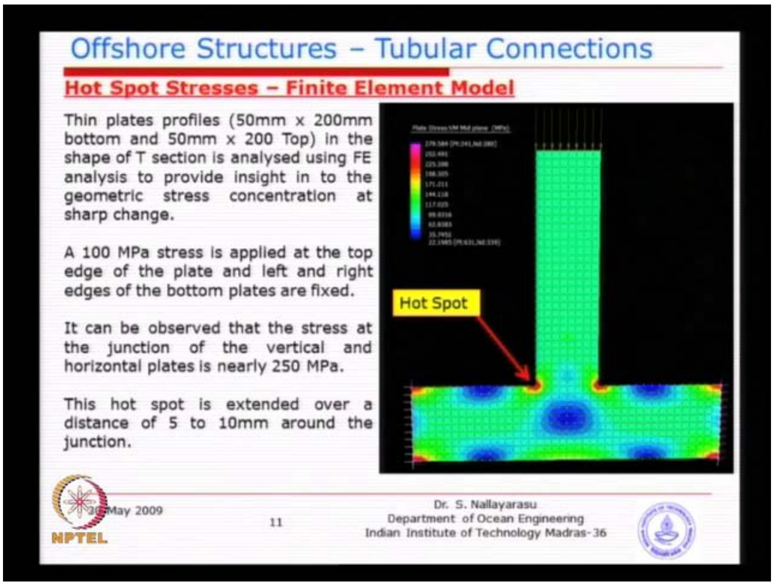

I just wanted to show you basically just a flat plate 50mm by 200mm welded to another 50mm. Just a plane plate is not a plate. So, load it applied in terms of pressure at the top above 100 mega Pascal. So, all the plates around all the way up to this point, you can see stressed equally because there is no change in direction. There is no change in dimension. There is no change in any local pattern.

So, you can see uniformly applied actual stress on the plate from top all the appeared, but when it comes to a junction, you can see here the local change in direction from vertical plate to horizontal plate. You can see it not stressed. Basically, we call it a norch effect and that becomes a highly stressed point. Now, if you look at the stress difference between this, I applied a 100 mega Pascal and when you apply to dislocation, you could see almost 250 something around. So, you should have one location here. The mention of this area is about, it is may be 5 mm maximum to 10mm in that vicinity. You can see the stresses to 52 and half time applied stress, but can we conclude based on this?

This assembly will fail definitely. It will not fail because only if you see everywhere the whole area throughout the next section here, if it is 250 mega Pascal, probably we can conclude the section is highly stressed trying to the overstress and failed. But, fortunately only to junctions, left side junction and the right side junction is only a local 10 mm plus

10 mm, but still substantial cross-section is under stressed. This is because you see here the stress at this location, this is around probably 110 and 112 and because this blue and green are mixed, so still it will take larger stress before the failure takes place.

That is what we need to understand this local hotpot stresses or local stresses or only isolated for one location, not throughout. If you understand that concept, that means this junction or this connection is not going to fail right now until you increase this stress in such a way that the whole neck will become 250 or 300 mega Pascal. So, yielding will start. That is the idea behind we need to worry about hot spot, but actually, we should not unduly worry because the hot spot is not going to be or throughout the section. That is why it is called at what is a basically isolated point on the connection.

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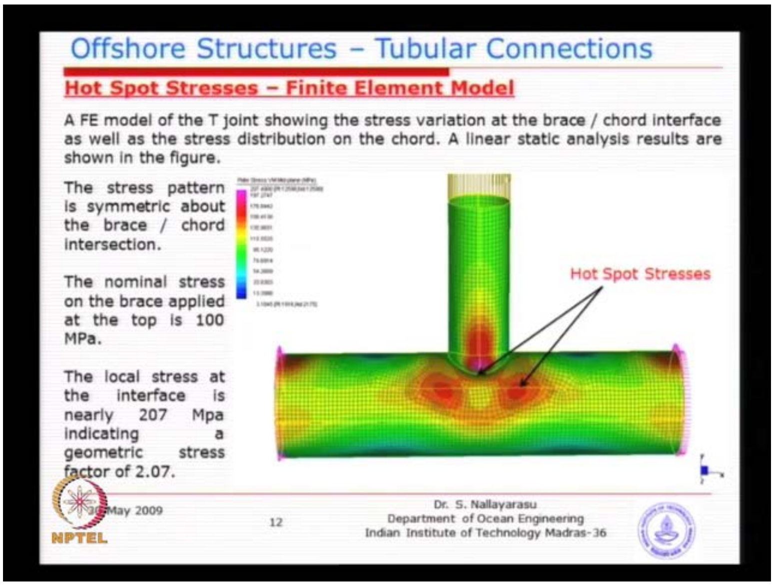

A similar exercise can be looked at on a pipe to pipe connection by just looking at it. You can see a typical pattern because in this case, it is not a flat plate is a hollow circular fiction welded with another hollow circuit fiction. So, you could see here on that particular location is very high stress of 200 plus, but same 100 mega Pascal only; I have applied at the top most part of it. It is green. Basically, there is no change, no deviation in the load, no change in the cross-section and it comes. But, when it comes to the connection at this point, it is reflected on two sides, reflected on the brace and reflected on the chord.

So, if you go back to this picture also, you can see here this junction, some portion of the vertical plate is stress, some portion of the horizontal plate also stress, so it has got effect on both sides. That is why; we need to know what the pattern of stress in the chord side is and what a pattern of that is. So, if you go actually, if you zoom this area, very large zoom, you will find that there is that plate horizontal and plate vertical coming and joining. You will see that the stress on the vertical and the stress on the horizontal, there will be different magnitude, but there will be matching at the intersection. If it is not matching, it has probably failed. That means that they have separated.

So, in order to see that you need to go to the software, I perfectly could not put it here, but you can see that there will be a connected plate is stressed in a different manner. So, what we understand from here? When I apply 100 mega Pascal at the top of the brace which is basically nothing, but load divided by your area because you know the load and remember that you divided by the area, you got 100 mega Pascal which has become 200 something mega Pascal at the junction. This is purely because of the change in geometry for a vertical pipe. It becomes a horizontal pipe carrying the load.

So, that is called a hotspot stress or stress concentration. Several terms, we can use. It is basically nothing, but the stress produced here which is 207 is not uniform throughout. It is going to be maximum at one place and lesser elsewhere. This is what we were discussing about the methodology.

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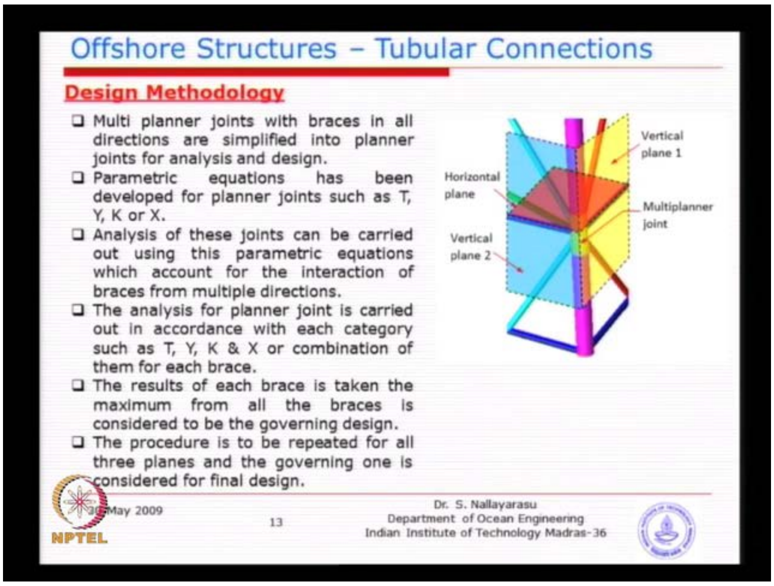

I think the idea is clear. We could not do the design in three-dimensional multi planer designs. So, what we are going to see is develop a parametric equation empirical method for each of the plane frame and basically looking similar to either T, Y, K or X. Analyses will be done plane by plane. Of course, the three-dimensional effect is taken into account in terms of empirical multiplications. So, you do the design of one side, but that effect of other side is already taken into account. So, that is the idea behind all those empirical equations. Basically, you repeat the procedure for all frames in one junction and look at whichever is producing maximum requirement. That will be the design. For example, if I have one jacket leg.

One member is coming in this direction and another member is coming in the perpendicular direction. You will do the design of one member and first find out what is the thickness required. Keep it one side, go to the next frame plane, do the design, find out thickness whichever is asking for highest thickness. That will be the design requirement. It is not that you will take thickness from here and thickness from other. Adding together, it is not like this. The cross-reference effect is taken into the design itself. So, you do not need to worry which is going to be. So, that is that methodology adopted in the tubular joint design. Now, you see here. This is what we were trying to discuss earlier also. If you look at this picture, the first yield is the most important.

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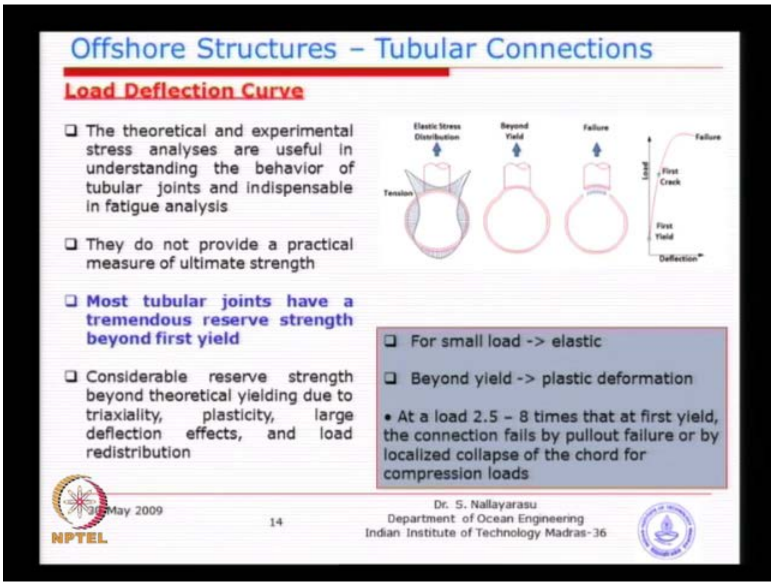

If you look at the load deflection diagram of a typical tubular joint, either T junction of Y junction the first time, when you keep on increasing the load, when you see hotspot; that hotspot is one location. Maybe two locations joint is not going to fail. You further increase the load until such time cracks develops at one point, very similar to the discussion we had on the plastic collapse analysis. Basically, you keep on increasing the load until such time. The hotpots will start increasing from one location to multiple locations.

Basically, one location, yielding load is transferred to the next point and next point, next point. So, you will see that basically, cracking will happen of the sufficient amount of load have been applied, but one small crack does not fail. So, you need for a failure to happen. You need to have dislocation of the brace and chord for a sufficient length. One millimeter is not going to fail. So, if it is 20, 30, 50, all around the circumference, so that means the failure will occur when the load is substantially larger. So, from the time that we saw first yield also called the hot spot at one location to a failure, you will see that the amount of load that you have to increase to fail that junction is typically six to eight times or even ten times.

Sometimes that means that if you have one coded clone applied on this, it will only fail at 800 kilometers. That means that the redundancy exists in this type of connections. Now, we have to decide whether we want to do the design as per 0.6 or 60 percent of yield like normally, we have designed the members no 0.6 as our allowable stress factors, which I think most of you remember for bending actual and shear and so on. We need a design whether you want to use that kind of concept or we want to go beyond.

Now, nobody will accept a design when the design itself is I will have a crack. Isn’t it? I think no one will accept. So, you can actually have a condition not acceptable. It is that is there a crack in the design calculation? So, what we are trying to find out whether we want to go below yield or slightly higher than yield the concept adopted by a p i is basically between the yield and the crack because the first crack may happen at say 500 kilo Newton instead of first yield at 100 kilo Newton. So, there is a substantial margin between 100 and 500. So, let me use 200. Maybe still crack is not there, but other points have yielding which is acceptable, but still a lot of redundancy is there.

So, the idea behind the tubular joint design is that we are not using the elastic concept. We are going to use the elastic plastic so called ultimate strength concept, the ultimate strength basically just below first crack. We do not want to have crack, but we want to have higher strength than the first yield. So, that is the idea behind divided by factor of 50. Basically, that is the idea of almost all the codes behind tubular connections. So, we need to find out what is that ultimate strength. You look at this picture here in this picture under the elastic stress.

What is the meaning of elastic stress? If you remove the load, what will happen? The shape should come back to original circular shape. You look at just beyond yield. There may be a permanent deformation could be larger, could be smaller depending on where you are. If you are very close to the yield, maybe you would not see these distorted shapes, but if you are close to somewhere here, you will see that this distorted shape will become permanently which is also not good. But, if you go beyond a first crack, you may see that the connection becomes disjoint. That means the brace will come separately and the ford will become damaged.

So, basically we want to go between this and this and a proper factor safety we want too. We do not want to have permanent deformation. We do not want to have a crack, but we also do not want to design below yield limit because the capacities very small. That is exactly the idea we go beyond yield. Yield means one location hotspot, not yield everywhere, whereas if you actually take a piece of plate like this, you apply tensile stress, then the yielding will be uniform across it. Isn’t it? This is because when you apply 300 mega Pascal on either side, this stress along the section everywhere will be 300.

So, basically that is not permitted, whereas why we are permitting here beyond yield is because only one location is gilded. We have so many other connections less than the yield point. That you must remember because you cannot get an idea that we will allow yielding in joint design, but not allow in member design. The reason why we are allowing is because of non-uniform state of stress along the ferry, ferry of the connection and one point is higher. The other points are very low stress. So, you want to utilize the reserved strength available so that we can optimize the connections.

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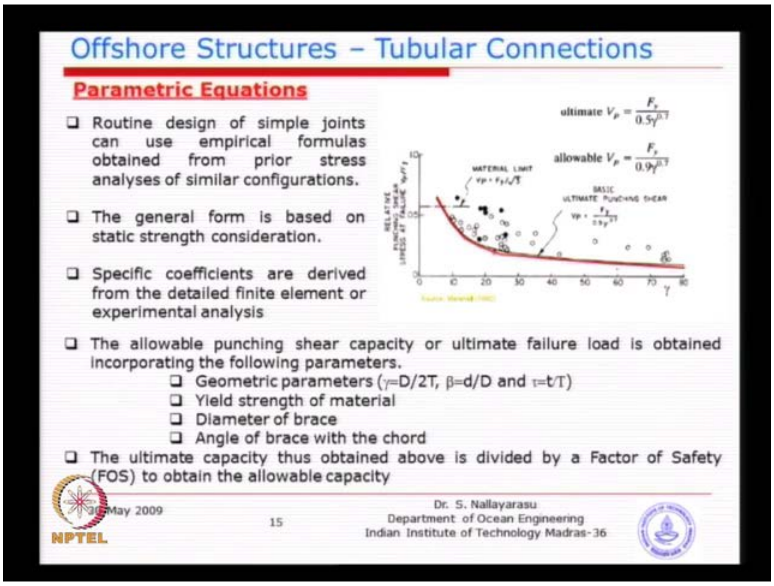

Typically back in 1990s, early 80s or 90s, many researches were carried out on these types of joints by doing experimental tests. So, you fabricate a T joint testing machine. I think most of you might have seen the universal testing machine. So, you can put it there, apply load, keep increasing in implement and just find out what is the load at which the junction has failed, either by collapse or by pullout. So, both tests you can carry out and basically you see this diagram. What you see here is a horizontal axis is gamma. See gamma is a ratio of D by T of the chord, very important parameter set to cylinder you make is going to fail definitely. The vertical axis is the failure of the relative punching shear stress at which the failure occurs. So, quite a lot of experiment will be done as usual.

You can see that they have driven. They have drawn a line just at the bottom of the whole experiments and described by this curve. Basically, you can write the equation using a regression analysis and find out what will be the equations for future use. So, this is how almost until 90s, quite a number of experiments were done, but after 90s, what happened? The experiments have become quite expensive. So, what was done during 90s to 2005, quite a lot of finite element studies are like what we have seen in this kind of analysis was provided and your tool is validated.

That means you will do one experiment, compare with your finite element analysis, make sure your parameters are right and then you go for several finite element analysis instead of spending lot of money and time on doing experiment. So, that is the idea behind over a period of time. Lots and lots of such publications have come. So, a p i had a committee in 2001 to 2004. A committee of researchers was put together and collected all the study work from 1970s until 2000. They came up with a new design code.

It is actually old design code, which I am not going to speak about it because it is becoming obsolete. Until 2002, we were using this method, but they found that this is not really conservative. So, that is why the committee was set up to make sure that they collect all the information from the reason pass and they come up with new design equations. That is what we are going to see, basically parametric equations. We should understand nothing but the equations are simple polynomials.

I think most of you also can do experiment in our laboratory. You can fit a polynomial equation to describe the behavior between the result and a parent variable. The parent variable could be diameter, wall thickness, angle length, and any more than one or one itself. So, basically the result will be your response of the structure in terms of deflection, in terms of capacity to failure. So, that will be your goal.

So, if you relate the response versus the parent variable by some means, some relationship, then it is not necessary that you should derive it. Basically, you know in mechanics, you normally derive. For example, a bending capacity of beam, you do not write yourself. You actually derive from first principle of simple bending theory. If it is actually loaded, you derive, whereas in this particular case, we cannot derive because the behavior is so complex.

So, it is purely based on experimental studies. The relationship between the capacity and the parent variable is by I would say simple interpolation, you do two experiments. So, in between, maybe it might behave in a similar manner. So, that is called a parametric equation which is nothing but a semi empirical idea.

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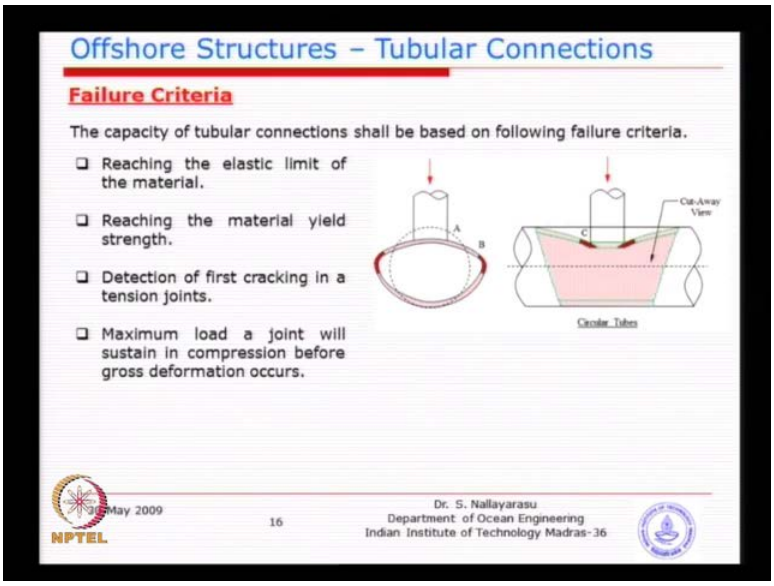

So, what will be the failure criteria? We do not want to have a situation where you have a local chord failure, something like this. You see here this chord is not just a limited length. It is continuous, connected to other parts of the structure. So, you could actually have a failure like this because the chord is having sufficient stiffness, but locally is failing something. It is similar like a beam. You can see here. It is actually both a supported and the middle is going down just like a small spam beam. So, reaching elastic limit of the material is one of the goals that we want to see, but we want to go slightly higher than that and material yield and then the first cracking and the load at which is what we saw in that.

So, we need to have test or simulated until this. So, you cannot do finite element analysis in an elastic state and take the result and use it, which is not correct. We need to do a finite element analysis until the failure occurs and then note down the capacity until first crack. So, you shall substantial, you know computational power required normally. If you do a static analysis, it may be faster, but when you want to do this kind of elastic plastic stage analysis, it may take a longer time. So, what are the failure modes we are expecting?

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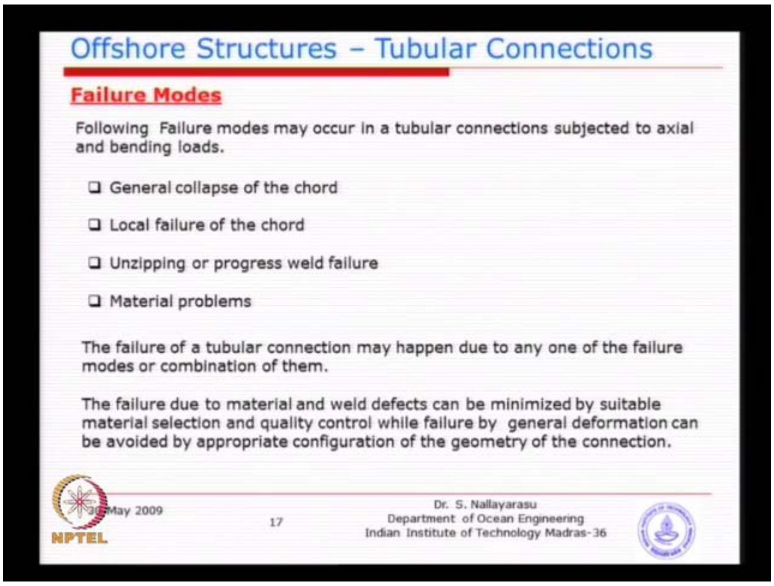

We think it may be happening in this way. There is of course a probability that any one of them will be cracking the problem. One is the general collapse. Second one is the local failure which we saw earlier. Then, the third one is unzipping. Basically, one location is failing and at that location, there is no contact. The load is going to the next two locations around and that locations get over stressed and start opening up. So, we have a one location opening or a crack or a separation. The load from that part will go to the next part. Subsequently, the opening becomes larger and larger and becomes you know disconnected or disjointed.

The last one is the material problem which we discussed about it during the earlier few days. You know, basically during welding, you heat the material and you make a fusion bonding. That may actually give up because of the irregularity is there. So, we need to see what exactly is the remedy that we can make because this, we can prevent definitely by selecting suitable material, whereas for the first three, we have to design for them in such a way that that does not happen.

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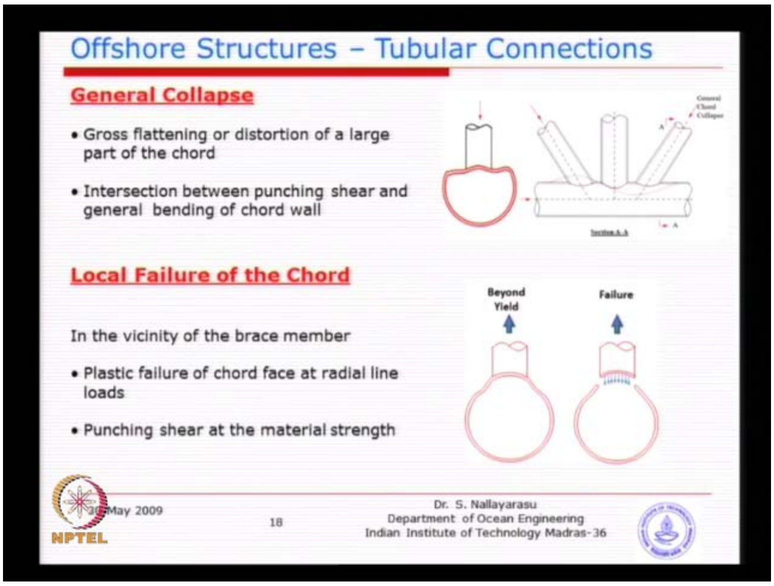

So, general collapse is something like this. One of the members is getting compression load. The other member is getting tension load. You can see here rotational behavior about the common point, which actually can ovalize as well bulge. The buckling effect at the location there to local failure of the chord is basically because of the flow out because the d by t is so small that when it is just coming out, it is actually taking part of the chord itself. It is actually a punching flow out.

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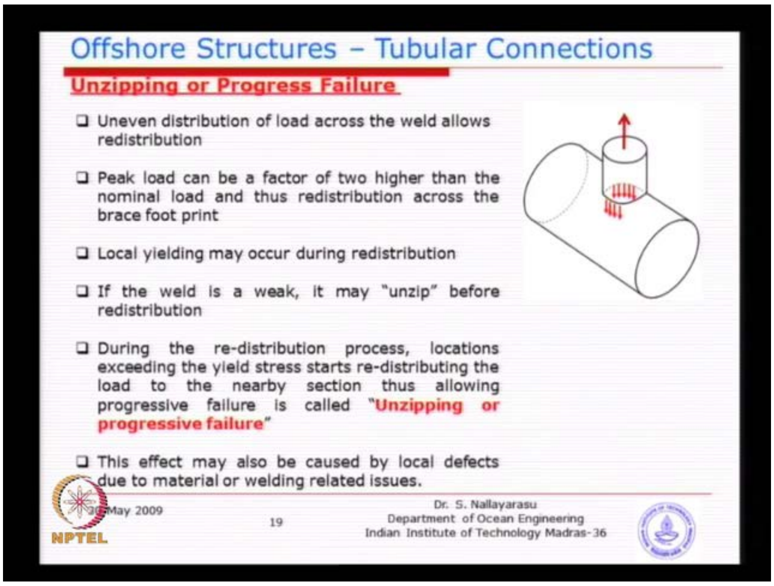

The third one is the unzipping is nothing but a very simple idea, smaller yielding, smaller cracks. The crack portion load is transferred to the next point and continuously progressive unzipping happens. This may happen if you have one particular location not welded properly or defective welding. That is a location the load cannot take, whereas you have actually taken full area for your load calculation, whereas actually some locations are not possible to transfer. This progressive failure can easily happen in any type of connection.

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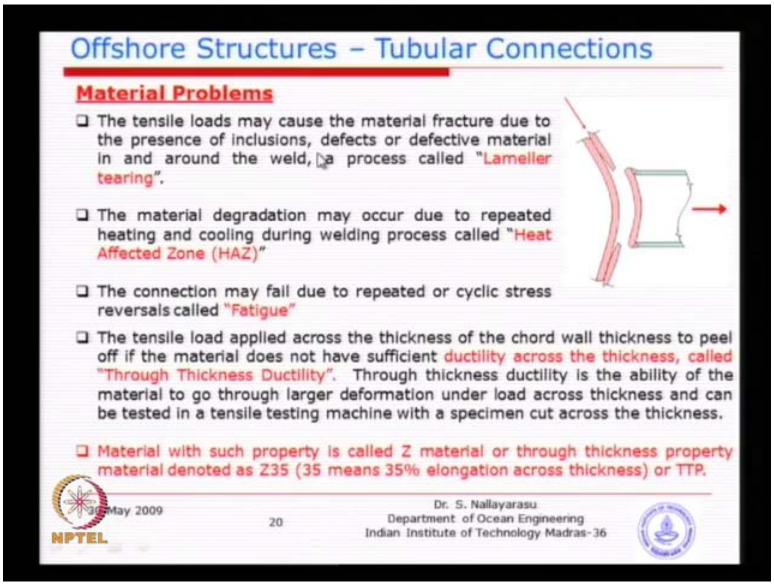

Last one is basically the material problem. Now, the material is one important aspect we have to see in this connection. Always remember that when you try to weld plate perpendicular to the plate surface, when you try to pull out, what will happen? You know across the thickness, the load is applied normally. The plate is very strong. When the load is applied along the length of width direction, the plate has got grind direction aligned in the plate length or width. Now, you applied load across that means the skin is trying to come out. That means the plate characteristics should be such that you should have enough strength in your crystalline structure that they are not going to come out.

So, that means we have to go back to the parent material whether the material characteristics are able to transfer the load across the thickness or not otherwise what will happen is something similar to your plywood. It will start coming out. You imagine that you take one plywood layers of material and try to apply the loading across a thickness. It will, straightaway the first layer will come out. Listen it. So, that is the exact bonding required between the grind structures. This can actually happen in any material specifically. For steel, it may actually happen when the thickness is larger and larger.

For example, 10mm is less susceptibility to come out. For a 50mm, the chance of pilling up is more and that we call it lamellar tearing. Basically, the plate comes out instead of coming out together, something similar. If it comes out like this, then this is not any more a material problem. It is actually a local wall thickness problem, not enough. So, it is coming out, whereas here, you see this picture. The thickness is still adequate, but unfortunately, the material is degraded for several reasons. One of the reasons could be the heat affected zone.

Basically, at that location, when you are welding, you are increasing the temperature to 1000 degrees. So, that time, material characteristics deform and get weaken and basically cooling it faster than what the necessity. For example, whenever you are doing welding at 1000 degrees and you should not cool it very quick. It should be slow cooling. Then, you will have a brittleness form and can actually crack even immediately of the welding. So, the heat affected zone is one of the potential problems where we have a worry about and also the failure may happen due to fatigue. I think that is what we normally want. To break something, you apply the load or you apply the similar thing several times repeatedly.

So, it may come out or break. So, in order to avoid this, we need to select a suitable material. Number one is that it should be homogenous across the thickness. I think you understand the word homogeneous. That means there is no impurity or widens or crack within the thickness across. So, when the load is applied, it should not come out so that we special material. We need to buy because only for that location, not for everywhere because at the connection, we will buy a special material which we call it through thickness property. That means the property across the thickness is same.

When the loading is applied, then the grind bonding is such that the lamellar tearing will not happen. So, that material sometime is noted as Z35 or we call it Z property because across the thickness, it is called Z property length and width direction anyway you will have. That means the notation what we normally give is that 35 that means 35 percent of elongation across thickness. So, how do we do it actually? Most of we might have seen a time mission. You have seen or not seen. So, you might have seen the tensile testing specimen. It will be a small rod with the attachment pieces. You just do a tensile testing.

So, you take the same tensile specimen testing and cut the specimen into a half at the middle. You cut a plate. For example, this is the plate. You cut one circular plate of mm diameter. Basically, in the tensile specimen, you fit it in between and again pull it. So, you are pulling actually across the thickness. When you pull it before failure, if 35 percent elongation happens, for example, I took only 10mm thick plate. So, it should become 135 percent or basically 13.5mm, it is elongated. Then, it has got 35 percent elongation before the neck form and failure because you keep on pulling. Then, there will be a neck formation and just breakout.

So, that means the more percentage like this is better because if it failed in a 5 percent deformation, then that means this is not very good. So, we need to see that when you apply the loading across it, it should take ductile failure rather than brittle failure. Suppose if you have some kind of voids inside the thickness, when you pull it, it may actually come out straightaway. There is no deformation and that is what we were trying to prevent. So, that notation is called jet material because it got a jet property thickness property, which makes the load transfer without failure. You will see that in that this kind of picture, I have given you some kind of, you see here that there is a special color, green color there. Basically, only at the junctions, we provide such material so that the connections become safe.

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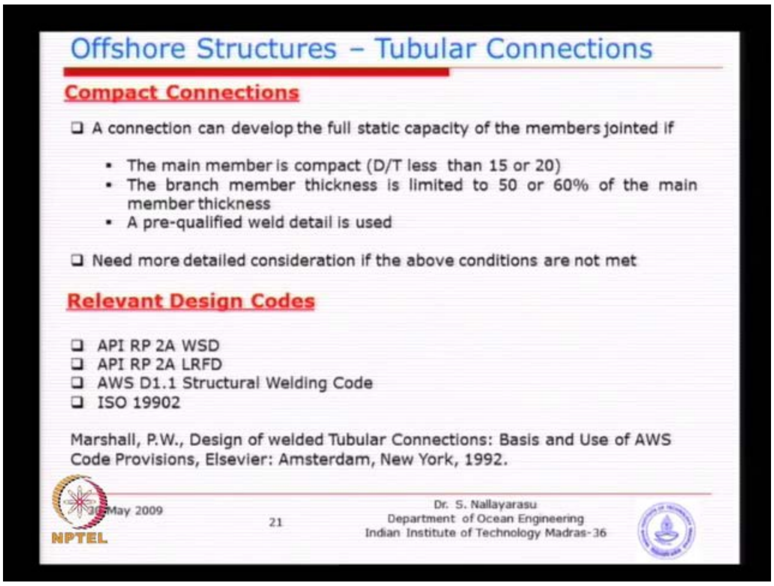

So, what are the codes available? Basically, about this compact connection, we will discuss later what the codes available are. Basically, nowadays it is API and also DNV codes, but the originator of this whole business is actually coming from American welding society. Actually, even before API was set up, this American welding society has come up with the design requirements in an informal way because that society is not meant for offshore business, but they have been using noncircular tubes. For example, like box sections, rectangular box sections, hallow sections are used for various building industries.

That is why; they wanted to develop such a connection. Basically, that from there, it originated and subsequent editions of AWS, they have introduced circular. In some places, you can see in many of the airports, circular hallow sections are also used. Then, later it was adopted by, this was adopted by the API codes and copied and modified. Almost all the work is coming from this PW marshal's one of the pioneer. He has done extensive work on tubular connections. He is still alive and has been doing some more and more and more publications.

He is the member of the API subcommittee for structures. Most of his work was adopted in the earlier revision, but what happened is, unfortunately, his work was based on the early part of some small-scale experiment plus some finite element analysis proved to be not conservative and rather right. Now, we are not using his proposals or his equations because they were found to be not very good. Over a period of time, more and more data was collected, more and more experiments were conducted and the new equations will be not looking like what he proposed earlier. So, basically he has done some work.

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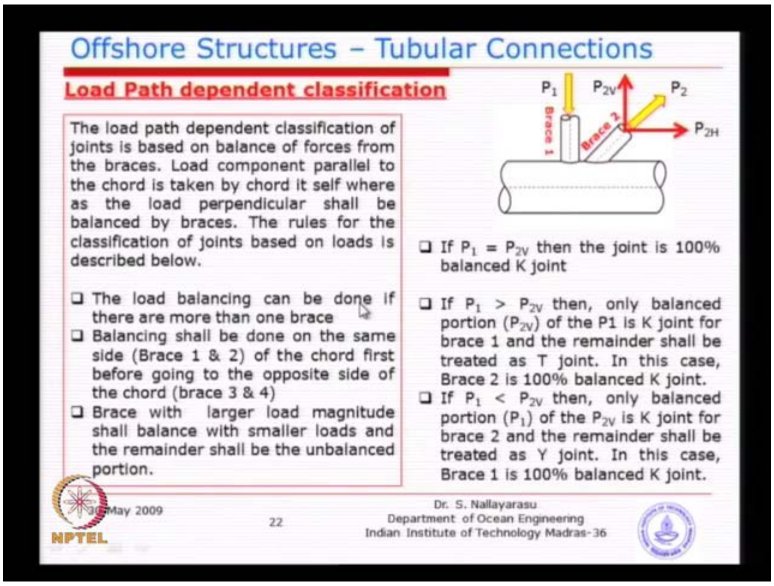

Now, we will just look at the classification of joints based on loads. I think this is very interesting. We should understand that it may become Y joint or it may become K joint depending on whether the load is coming balanced or not balanced. So, if you look at that, we call it load path dependent classification. So, you should not just believe that the joint looks like a Y joint, I will go for Y. It should not be that way. We look at geometry plus the load coming in.

The only simple idea is if it is balanced, then it will automatically go to K joint. If it is unbalanced, it will either go to T or Y joint. So, simple classification idea is here that I have got a brace one and brace two. One is carrying compression load, brace one. The other one is carrying tension load of different magnitudes, but then, we just find out what is a vertical component or component normal to the brace chord. We should not call it vertical or horizontal normal to the chord.

So, this is basically 90 degrees. So, it is normal to the chord and this is basically an angle. I will find out what is the normal component. Now, if this P1 and P2V are equal, then I can call it k joint because this load is balanced even though they do not look like. They do not look like K geometry because there is one member which is vertical. The other member is slightly inclined. So, you may not classify as K joint, but fortunately, the loads are balanced.

Now, you may not get exactly the same load. Nobody is able to control the loads. So, you make it different magnitude. So, if you look at this vertical component or normal component equal to P1, then members, this member and this member will come under the classification of K joint. Now, if they are unequal, that is way the problem if because even after finding out the normal component, if P2V is larger or P1may be larger. So, we have got two classes. The first one P1 is greater than P2V. P1 is larger. P2V is smaller. So, what we will do is we will find out what is the amount, which is balanced.

For example, if this is 200 kilometer, this is 300 kilo Newton, this is 300 kilo Newton, and 200 kilo Newton is balanced. Only the reminder 100 kilo Newton is not balanced or unbalanced. So, we would say out of 300, 200 is balanced. That means we can find out 200 by the 166 percent behavior as K joint for both the braces, but for P1 because it is slightly larger that is 100 kilo Newton. So, 33 percent is T joint. You understand the idea no? So, we just simply split the problem into two different ideas. So, this can happen vice versa also. You see here that P1 is less than P2V. So, automatically what will happen is that whichever is satisfying, that much portion is balanced. The reminder portion is unbalanced.

So, this is how the joints have to be classified depending on whether the loads are balanced or not balanced. We will have some few cases if you have understood. If you have not understood, then let us stop now because you will have to classify a joint and design yourself in the example. Basically, first idea normal components of braces, if they are balanced each other, and then it is called a balanced. If anyone of them is larger, the larger one, you take it split in to two halves, balancing part and non-balancing part. For the balancing part, the ratio is so many percentage of balanced K joint.

The reminder part divided by the overall load or bigger load will be unbalanced part. It can be T or it can be Y. In this first case, it became balanced part is T joint. The second one balanced part is Y joint. So, you should do this one before going and designing. So, you cannot get just pulled by how the joint looks like. It can be looking not like K, but we will classify into K joint. So, you need to do some practice. Probably, I will give you one of the examples of one of the days.

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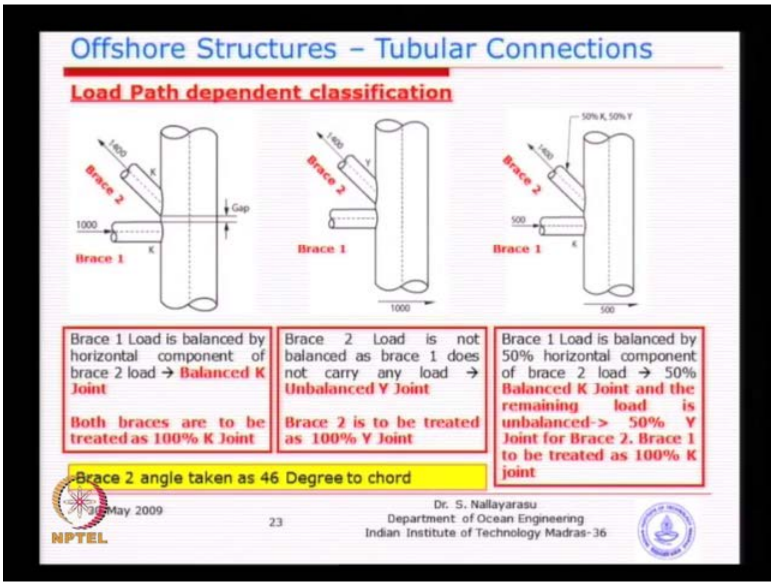

So, we have got some nine cases just to illustrate how things are done. So, I will just explain one or two. Then, you can just follow the notes. So, if you look at the first one, very similar to what we described just now, then the brace one is carrying 1000 kilo Newton. The brace two is carrying 1400 opposite. So, basically in this one, if you just look at it, I have just taken as 46 degrees, which will be basically 1400. If you find out the normal component, what will happen? You will get around 1002, 1003. So, 1000 and 1000 get cancelled each other.

So, this can be classified as 100 percent K. You understand the idea now. If I have this angle instead of 40, 46 degrees, I have 25 degrees or 30 degrees, and then you would not get 100 percent K joint. You need to find out what is the load amount here and that amount only will be K joint. The reminder here is there will be a T joint of certain percentage.

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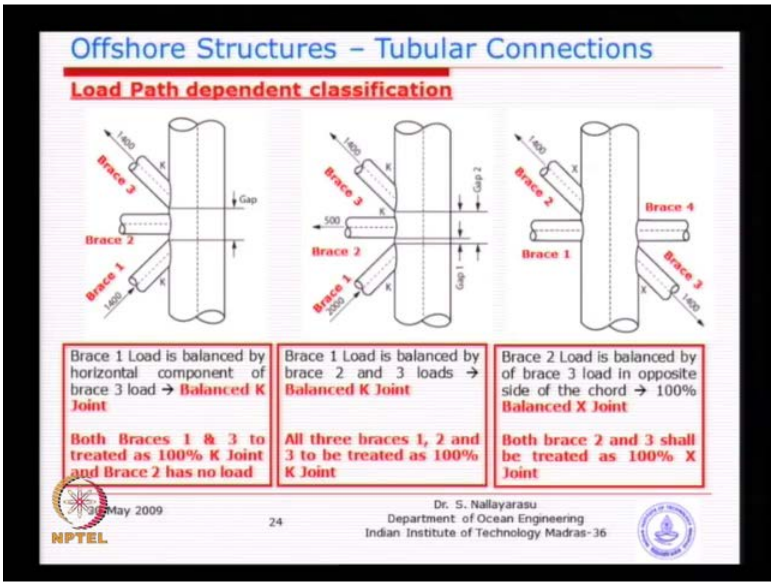

So, you should know how to calculate. So, same thing here, if you come to the second day, I have 1400 applied only on this brace. This brace does not carry any load. So, here I do not have a balancing load is the unbalancing load fully. So, this will be 100 percent Y joint. There is no K behavior because there is this number is carrying no-load. So, that means that I cannot go to K. Coming to the last one, you see here exactly. We were trying to talk about 500 there, but I will get 1000 from there.

So, we get basically 50 percent K joint for this because that is the one higher. Isn't it? This is because that 1000 is going out, 500 will be balanced by this. So, this is 50 percent K, whereas the Y joint, additional 50 percent will come because that is carrying more load. So, this is a very simple algebraic comparison. So, like this, there are quite a few examples. I was just given from API. So, you should understand, try to do. I will ask the girl to give that notes today. Try to practice.

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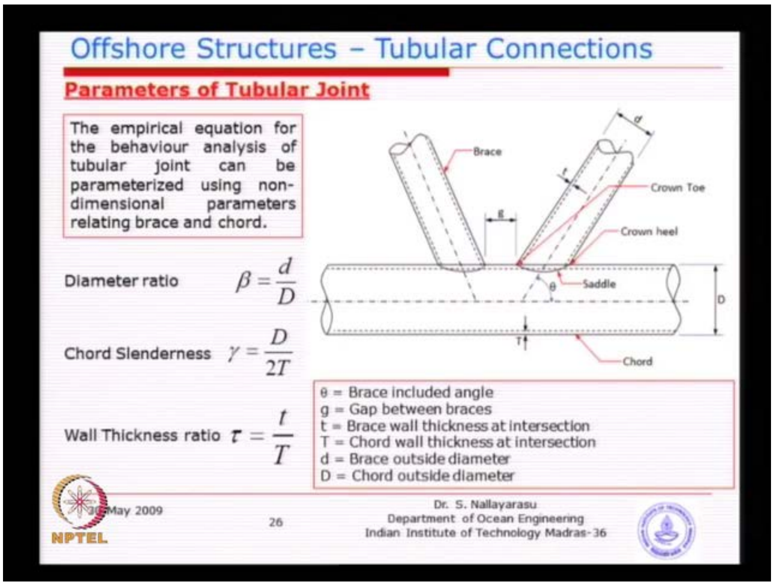

So, the next one, I do not think we need to go through because you can easily read it. Just to get an idea, the next one is the parametric equations. They are developed based on three parameters. One is the diameter ratio. I think I have explained to you the importance of diameter ratio. The diameter is very close to 1. You see a problem there. Similarly, this is slenderness ratio of the chord diameter to wall thickness.

The third one is the wall thickness ratio of brace and a chord. These three parameters plus you will have the angle as one of the major parameter to differentiate between K, Y and a T joint. Basically, with these parameters, if somebody can come up with the equation to describe the capacity, then that will be the best.

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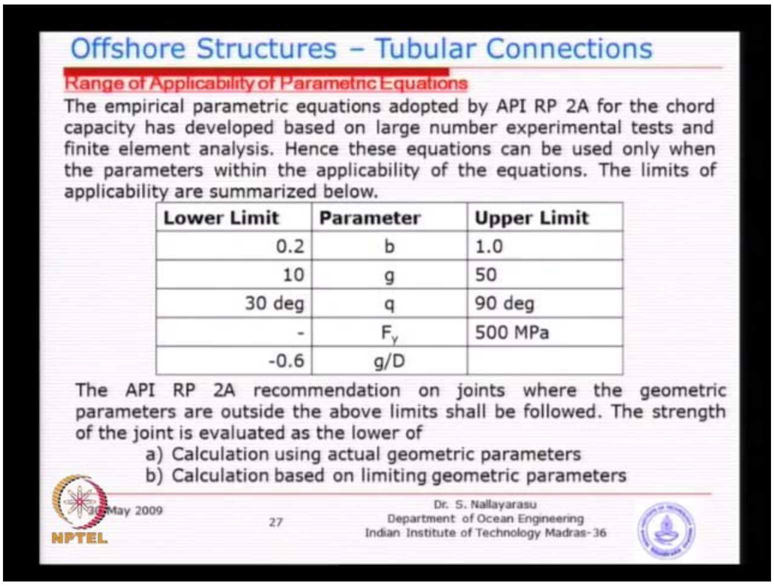

So, the basic idea is what are the parameters, the range is permitted, I just summarized. I mentioned it in the last class. You cannot go beyond this limit. Basically, if it is going beyond that, the equations are not valid. This is because most of the tests and finite elements studies are done within these ranges.

For example, beta, beta is basically between 0.2 and 1. Gamma is between 10 and 50. Theta is between 30 and 90. The yield stress would be less than 500. The gap basically should be greater than minus 0.6. That means you do not have over lap. So, these are the parameters they have used to study the experiments and the finite elements and come up with the empirical equation. So, you should clear outside here. There are some guidelines given here, calculation using actual geometric parameters. Do that exercise, calculate based on the limiting.

For example, if the angle is 28 degrees, you have to do two calculations. You to do the calculation using 30 degrees and do the calculation using 28 degrees and whichever gives you the lowest capacity, you use that capacity as the design capacity so that you practice. It is not that if you go outside, you will not be able to design. You will be able to design, but with the lower capacity.

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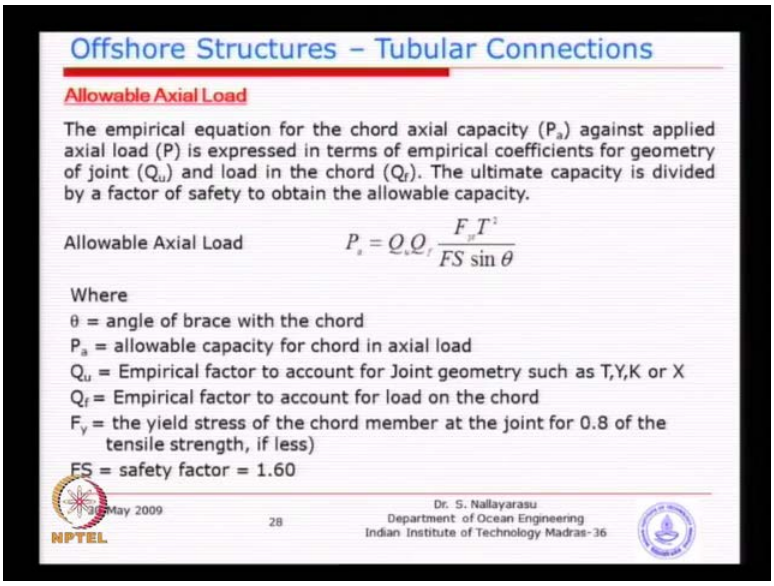

I think we will see this tomorrow.