Design of Offshore Structures
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Module - 4
Lecture - 1
Tubuler Joint Design for Cyclic loads -1

So today, we are going to see the design of tubular connections. I think so far you might have understood little bit ah clarity on tubular member behavior, I think we have spent about three four sessions. The circular shape helps in transmitting several loads in better way compared to other shapes, doesn't have torsional buckling which is one of the greatest advantage and shape gives you as advantage of uniform sectional property in any bending direction.

So quite a few with I think we start of in the, we starting of tubular members. Same thing also have a similar advantage on the connection itself, which you remember or if you seen connection elsewhere. For example, if you have a concrete beam-to-beam connections, beam to column connections like a if you see here in a any building, we don't have a special as such, you actually cast it monolithic. You know simply have a mold, the column is coming and the beam is coming and you have a concrete board in a monolithic casting methods.

Whereas, in steel structures, it is not going to be exactly there, if it is I beam to I beam connection, you may have several ideas, how you want to actually transmit the loads, we have to decide it. And if you look back, we have a plate, and if you want to connect as another plate, you can do a penetration weld you know basically weld from both side or weld from single side depending on the design. And you also can do a bolted connection by simply having a cleats bolt onto the receiving member, bolt onto the connecting member. So similar ideas, once you do that then you need to make sure that the connected parts transmit the load successfully. For example, if it is a welded connection, the weld should have sufficient strength to transmit the loads from the receiving member the vice versa.

Basically similar idea, when you talk about pipe to pipe connection, how do we achieve that, that's what we are going to discuss. This is going to be little crucial ah in a sense most of them are empirical very similar to structural member tubular design what we did. Every one them is empirical, we start from axial allowable stress, bending stress, buckling, hook buckling, actual buckling every one of them is derived from experiments. Because the analytical method of response characterization is not feasible because of quite complex number one, number two it's we are using elasto plastic characteristic, so mostly we will we will actually find out the ultimate strength by means of experimental study and then from their we derive the allowable strength by dividing by factor of safety.

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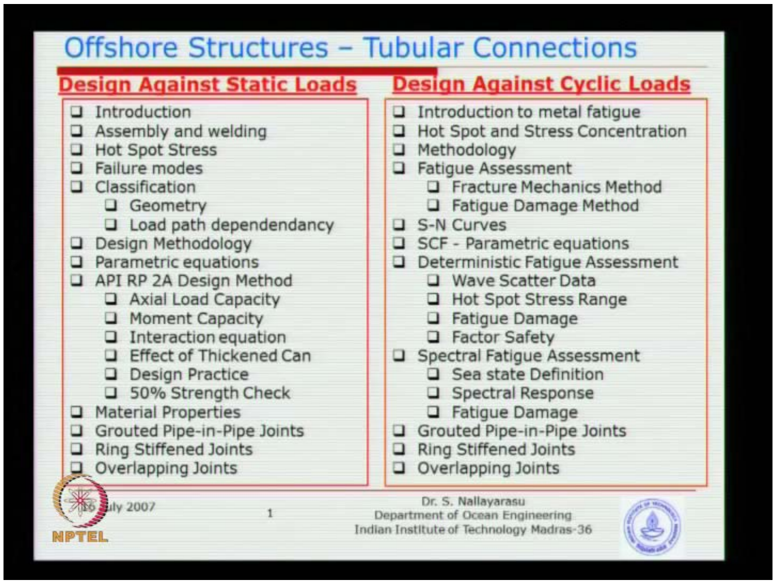

So in here in tubular design, so similar principle every one of them is to be highly empirical means we rely on what was done in the past by experiments and take that results extrapolate that result to our situation. And that is where we need to be little bit careful, because they may not have done testing to your scenario, what you are doing just now previously nobody would have expected that you will do this.

So basically limited amount of experiments were available from where researchers have developed some useful method of design that means you should design within the perimeters of restriction given by them. You cannot simply come up with the design, which is falling outside the parameters that they have defined. So that's where you have to employ your ah you know ideas to play within the range that the the design is permitted.

Of course, if you go outside then you may end up on a case-by-case basis to your own studies, means you can do a experiment, you can do a ah finite element analysis or otherwise. Like what we are doing in our laboratory wave plume, if you have gone to our wave basic.You know whenever the situation is complex, and unable to describe by the theoretical methods of responses, we always conduct laboratory wave plume test. Just to make sure that our assumptions are valid, the responses are in line with what we are assumed so that you feel comfortable.

And if there is a difference then you correct your theory, the experiment are not conducted to not correct the experiments , you understand the idea know. The experiments in any wave plume or in structural mechanics labs used to verify that you are proposed a theory is reasonable to predict the response that is the idea behind the experiments, otherwise some people may be thinking we keep on do experiments for what purpose.

So basically in here, there are two things we need to worry about, one is design against the static loads, the other one is design against cyclic loads, so I have just listed down the things that we are going to look at these are very large subject, probably will spend about ten hours I think. Because it is one of the most important subject in this full subject, as I mentioned earlier on the day one, if the structural connection fails before the member fail the whole structures collapses.

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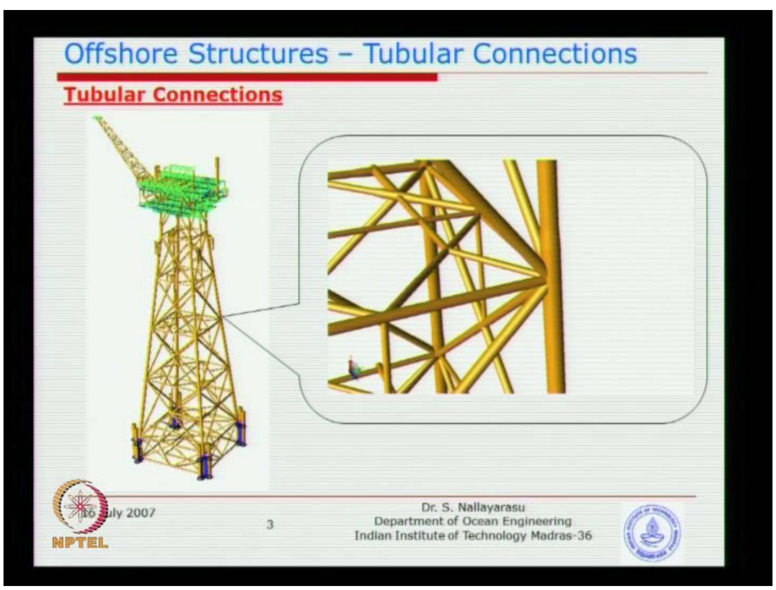

You might have seen one of the pictures I think you may also see here. If you look at this particular ah connection here what is shown here something like this. At that junction you can see, nearly nine members if you count I think about nine or ten members are connected together. So if the joint give away, because of instabilities, because of local failure, you will see that all the nine members will get disengaged and the structure will become unstable. So, you need to design the joint in such a way that, it will never ever fail until all the members become plastic are near collapsing, you understand the idea. So that means the factor of safety or the design constrains on the joint should be such that that should be the last one to fail. So that's why we should give ah reasonable important to the design criteria understanding and then application of parameters within the limits of what is being done in the past.

Now if you look at the whole things, I just given a list of things that we should know as similar to our design of members. You know we need to know what is the history of that join prior to loading. So that means you need to know how it was assemble, how it was welded, because they are going to affect little bit of influence on the ah strength. And how they may fail, failure modes, which is where it is more complexity is induced there, because the failure of tubular connection is not that easy to predict.

So basically, you will see several forms of failure and it may happen or may not happen depending on parameters involved. So we just learn that and then try to do a simple classification patent, what kind of shapes are once we go the one by one you will know. And then we will look at the design methodology adopted by the current codes. You may see that there may be not logically correct, but we still use that method, because that is the only possible way its now, because the alternate methods proved to be impossible at this stage, because the practical design becomes difficult.

Then we will look at the empirical equations, sometime I call it parametric or empirical both are same. Parametric means the empirical equation in terms of a certain parameters of the system, so for example, if you take a column, last time we were looking at allowable axial stress is highly dependent on one parameter is K l by r ratio, so that is one parameter. Now if you if you look at any other parameter, which is influencing is a modulus of elasticity, which is governing the buckling. And the third one is the yield stress, so three parameters are involved in that equation, is not it? So that is three parameter equation for a allowable axial stress. So, this is parametric equation is nothing but defining a particular response characteristic by means of one or more parameters; it can be linear, it can be non-linear depending on what was the regression analysis you have done.

So basically, parametric equation can be written for any type of behavior as long as you have sufficient information either by FE or by experiments. Now we are going just quickly look at what API is as we as to do, because most of the design offshore structures either in India or elsewhere is adapting API, universally because it is well established for long time. It is not that we are addicted to it, but there is no other choice, because we do not have a design code in-house, like you have design codes from European, Indian standards - several codes for concrete structures, industrial steels structures or other mechanical components.

Whereas for offshore structure we do not have a code, so we tend to use which was established earlier, so that we can use it. But in the recent times, things are slightly changing, you can actually using ISO codes which are international accepted codes or you can use European codes or British codes, but historically I think for the last thirty-forty years, people have been using API for simple reason that was the first one was established. And they have actually done very good job, so that it continue to use it.

And then we will also look at what particular material is susceptible to failure in the connections. If you go back to this picture, you know if you look at this one important thing you will realize, each of the members is going to get loads from any directions. You just contradict depending on the waves and the gravity load, some of them can be pulling away, some of them can be going towards the joint. When you are pulling away what happens, imagine if you have a steel material, try to pull out, if the material is not hundred percent you know solid or without any pores or voids, what will happen, the material can come out.

So you need to have a material, selected material should have sufficient strength across the thickness. Normally, if you look at it, you know if you look at a steel plate subjected to axial stress, it is going along length of the plate, not across mostly, so that is one of the problem that we are going to face that material selection in the joint which has special attention to be given. We’ll spend sometimes on that and then we have few special areas of joints stiffened with rings, joints stiffened with grout, joints overlapped one on each, which you may find that funny. But then there are some situation where you will encounter that.

So basically, this might take about three, fours hours of lectures and then we go to fatigue which is may another three, four hours. We'll go little slow, because very important area of subject. So as you can see here, I think most of you now familiar with design of tubular members, which one is carrying may be axial, bending, shear, torsion and hydrostatic. So all these loads are resisted by members and we have decided to check the member from one end to other at various close intervals, is not it? Because the design process, what we discussed in the previous classes is basically design means every section along the length must be safe enough to transmit the load to this end and transmit the load to the other end. Once the loads are transmitted to this place, for example so what happens is, the receiving member so called the legs, you see here, this is very easy to understand where the loads are going, ultimately, the loads have to go, go where?

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It has go to the foundation, it is not going to the sky, is not it? So the loads are not going to go upwards. Every member receive the loads from gravity or from wind or from wave, and they have to transmit and then they have to go downwards to the foundation, so that means if a brace member is like this, you can't expect the loads to go upwards and then go to sky, it is not possible. So basically, these loads are going to be going to leg only, because the legs are predominantly larger in size. As you can see, more the stiffness, the attraction of loads will be more. You can imagine, you see this one member here, for example, there is member here that member is supported on one smaller member on left side and a big leg on the right side.

So you can see the stiffness of the leg is more than the left side member. So by relative stiffness, you will see that most of the loads is trying to attract down to the leg and that's where you will see the design of joints here becomes, so the distribution of end moments or end loads will be going towards the supports. Basically the stiffness, wherever the stiffness is more, the loads will get transmitted. In this particular structure, if you look at the whole thing, the whole structure where is the stiffness, stiffness is higher at the foundation only, because it is very simple cantilever is not it. So basically that's why, you can see here the more and more members, loads as there go down will be subjected to higher loads.

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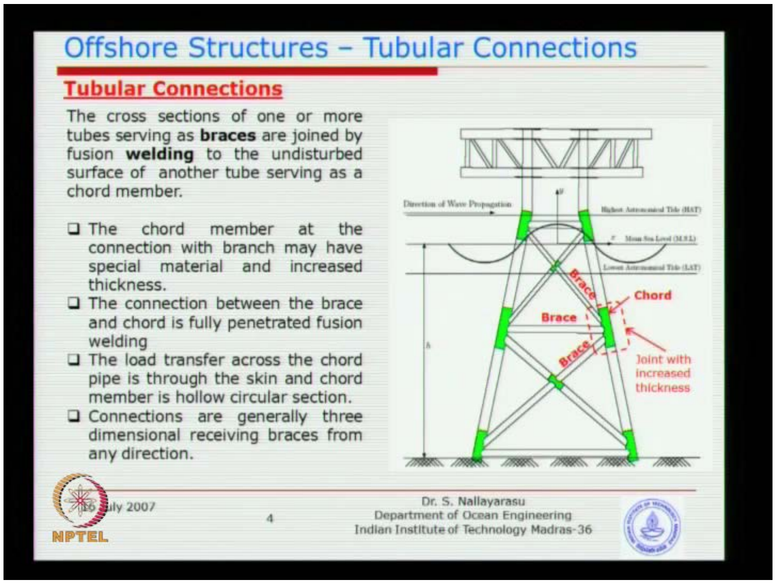

So in this particular case, if you look at ah particular connection for example, I just taken one frame, one elevation from a three-dimensional structure, I just drawn one section in a simplified manner, so what is so called joint or tubular connection means ah receiving members is called chord. It is a just technical name used by researchers and literature. And the member transferring load from elsewhere towards the joint is called a brace.

So basically those members are all transmitting the loads to the joint and the total assembly is called the tubular connection, like if you look at the concrete structure, you have a column and a beam also a junction. You basically, a junction of beam and column is called a connection, or if you look at a industrial structure, I-beam column or a channel or an angle bar also have a connection. So here we have got tube and another tube connecting and basically that is called tubular connection and always remember in offshore construction, we do not permit bolter connections, we all cannot sustain because of the nature of environment we are in.

If you have a bolter connection, if the bolt fails because of corrosion, because of movements, so the structure will fails. So always we need to have hundred percent fusion welded that means is not even fillet weld, you need to have penetration weld, which actually make the welded connection stronger than parent plates that is the idea behind. You have two plates ten mm, ten mm, the connection should fail only because of material not because of the weld. So go for a higher strength of the weld during the welding process. So, basically fusion welding is only permitted; in some cases, very minor cases like secondary structures or above water top sides, you may permit others form of welding, but not bolting. So, this the terminology used in this design is basically chord and brace join together in many of the forms which we will discuss later are called tubular connections.

Now you see here, the difference between this picture and the picture that you are seen just now is three-dimensional, so if you go into this junction here, you can see here you take one plane, you got one, two, three members coming and joining. And if you take another plane perpendicular or on the other side, you will see another three and if you look at horizontal plane, you may see another one member or two member or three member coming and connecting.

Now one by one, you just slice off and see how the loads are transferred, but it is not that you can go and control the structure, you do not transmit the load one together, you can't control. So all the braces are going to deliver the forces simultaneously at given instant of time. Whereas the design process, what we are going to plan is possibly designing a three-dimensional joint is not feasible, because the design procedure develop to ((Refer Time: 16:13)) doesn't have provision to take into account, all loads coming from all ah members in space.

So the design procedure adopted here in this last twenty-thirty years, we are going to design plane-by-plane, but then the interaction between plane one, plane two and plane three, you actually have a multiplication factor, the effect. For example, I have one brace in this plane, another brace is in the perpendicular plane, and another one in the diagonal plane, basically three are going to deliver the forces simultaneously, but I don't have a design tool to do design by three together. So what I am going to do is I will take the the first plane design it, design means find out the what is the thickness required.

And go to the second plane, and do the same thing, third plane I will do the same thing. So three thickness I have, but none of them is correct is not it, because I have taken only load from one direction and come up with the thickness of ten mm, load from another direction come up with the distance of twelve mm and the third one I might have say fifteen mm, but each one is designed for only individual loading. What I apply three together, what will be thickness required, it will neither be anyone of them nor you don't know the answer.

So what we need to do is, you need to multiply some factors such that I'll get a one thickness which will satisfy as if all the loads are supplied together. So that is why the design procedure today what we have is treat individual planes, and then automatically the design is satisfied if you follow the procedure given by the course, because the course have built in empirical factors which will take into account three-dimensional effects. So that is the design principle adopted, so you must remember nobody could come up with the design equation for such a joint. In future, somebody is going to design how many braces nobody is able to come up. Of course, there are some recent research papers thinking about three-dimensional joints but then implementation by designer code still not it done.

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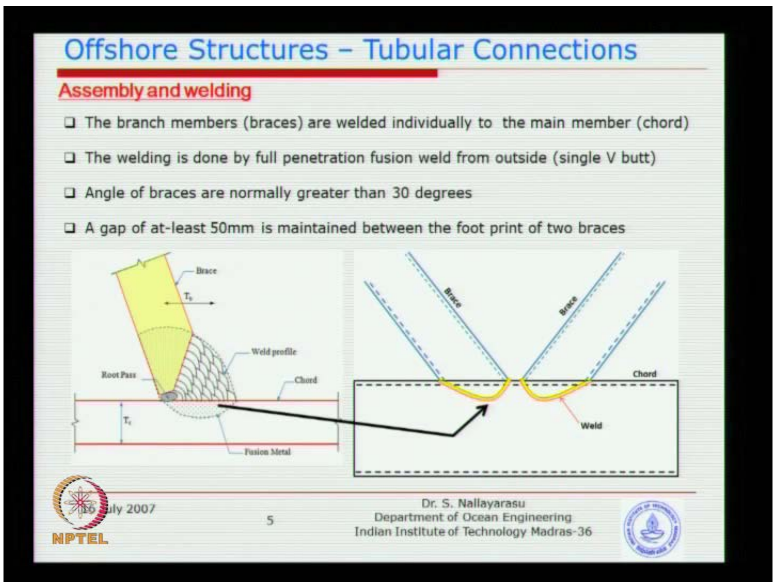

So basically as I mentioned earlier assembly is simply cutting the pipe into the shape that is going to be received by the car member. Imagine, if I have one plate something like this, so flat plate or this is not a flat plate, if I have a flat plate, if I take one pipe and connect it. I will have a circular shape simple circular shape cut, so I can just weld it like this.

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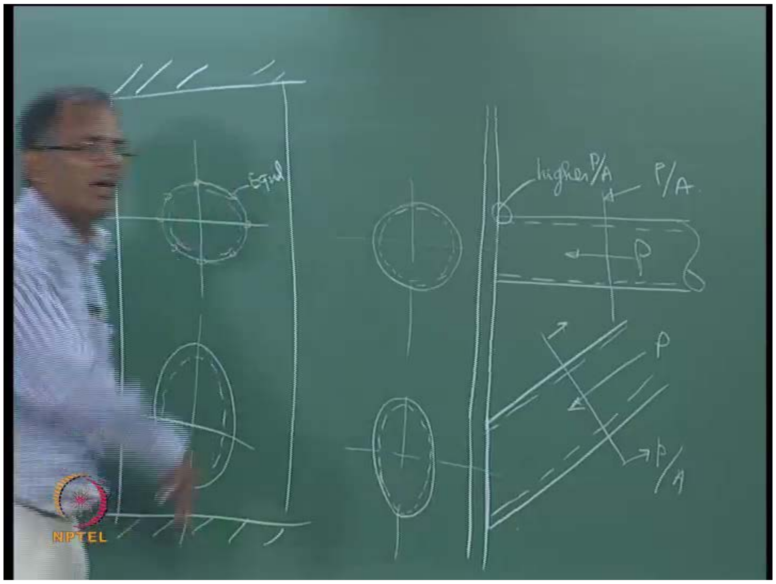

So if I draw it in the board will be very simple, if I have a flat plate, something like this and pipe, so this is going to deliver the load here, now if I cut the cross -sectional at this junction, so what will be same, possibly something like this, basically you will see this. But if I make the pipe to be joint in a inclined manner, what will happen, what will be the shape of the plate, ah the shape of this section at the intersection. So I will see a what will happen, I will see an ellipse. All of you can understand know, so basically this is the inclined member received by a flat plate, ah perpendicular member received by a flat plate.

Now imagine, I don't have such a situation like nice plate like this; I have another member, this member is actually circular in shape. So you can imagine the cut section at that interface is going to be a continuously changing profile. If you look at this yellow color zone there is going to be a continuously changing all the time, because it is not a flat surface. It is the surface, which is circular in shape, every time you will change. So you have a very complex connection, that's why the design of tubular connection are quite interesting because the behavior if you see there, you know the stress variation is very large.

So if you could imagine this, I think then you can imagine right now how the connection is done. Remember, we are not going to remove the material here, this material will be there, don't think that the intersection at this point purposely I have made a doted line here, because the material is not removed. Something people might think, it is like making a pipe flow, you actually remove that, normally if you want to make a drainage pipe, so you remove that. It is not like this, that plate is not removed, so basically that is why you can see that doted line is there means the material is available there to transmit the loads.

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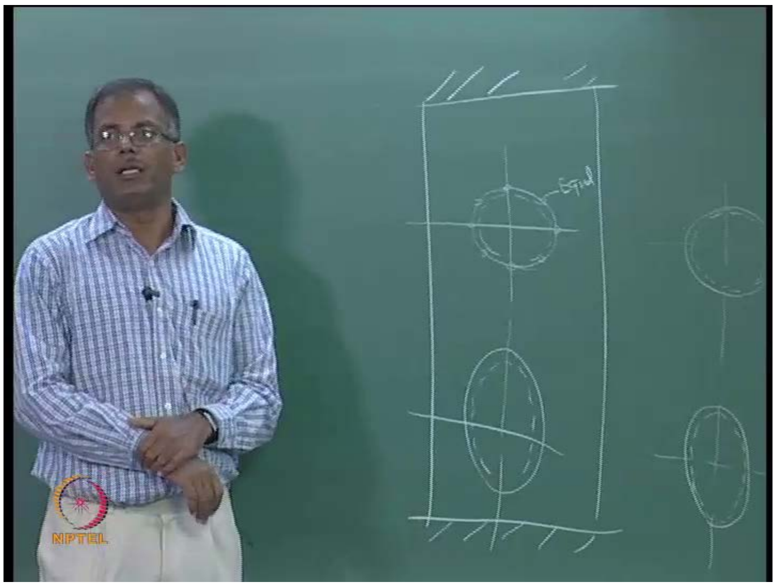

So basically that particular shape makes more complex, because evaluation of stresses at this point, for example, if I just draw one plane view of I just have one view from this direction, I will just super imposed something like this, the plate may be fixed here, does not matter, something like this. If I look at the periphery of this point, four points or six points, if I apply a load of p, the stresses all around will be same or different, it will be equal every point will get exactly same stress.

But what stress we don’t know. If you cut a cross section here, the stress in this point will be is not it P by A, simple actual stress calculation. But when you come to the intersection nearby, there is a ninety degree change in the geometry of the load transfer, you may see that this may be slightly higher than P by A, local notch effect, geometric effect, because it is trying to transfer the load by changing low direction. So the understanding here, the loads the load is same, area of the cross section is same, only thing is because of the ninety degree transfer, I have a same stress.

When I come here, what will happen, will I have the same, I will apply P here, if I do a perpendicular cross section, I will see that P by A little bit away, but when I come to the junction, I would not see that the stresses are equal. I will see some higher stresses here, lower stresses here, different stress here, different stress because I have an inclination and pattern will be symmetric.

If I look at this, this is the center line, if I see the pattern here and pattern here, it will be similar, but what I will not have is, it is not going to be anymore uniform stress. Now if you understand this, if you go back to that picture, it is continuously changing surface and you will see that the stress are not going to be same. Even though the load is only one load, you will find that, and that is basically the complexity introduced by the continuously changing profile of the surface of the pipe, wherein the tube is coming connected.

So basic idea is assembly and welding is part of the fabrication, basically what we don’t want to adopt or avoid is the gap is to be kept smaller, we will later, but not too large according to the standard practice, we give the gap of 50 mm, just for welding access; otherwise you will weld on the second weld. Then the brace angle should not be smaller than 30 degree because you can imagine here, if I go here, if I make this angle ten degrees, what will happen, I would not be able to axis for welding it is placed.

So that is why minimum angle is 30 degree. If it is thirty degree, it not going to help transmitting the forces, and then the weld is always done from outside, do not expect to somebody jump inside the pipe and weld, is not it. You will creating ((Refer Time: 25:08)) ground, that is you cannot come out, is not it. So always a welding is done from outside. Some cases, if you have large diameter pipe, but not for the braces but for the main pipes, you may actually see people go inside and weld, and not for the braces, so basically, mostly we have a single V butt weld that means only weld from outside.