Risk and Reliability of Offshore Structures
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Module – 03
Risk assessment and Reliability applications
Lecture – 06
Tubular joints – experimental studies on T joints

Friends, welcome to the sixth lecture in module 3, where we are going to extend the studies on Tubular joints based on experimental and numerical investigations.

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So, we say experimental studies and of course, numerical as well on T joints. Let us focus on T joints in this lecture. This is lecture 6 on module 3, the online course on risk and reliability of offshore structures. In the last lecture, we discussed about general behavioral phenomena of a tubular joint here, irrespective of its geometry may be KYT, etcetera. We also said there are various parameters which actually affects the behavior of tubular joints.

Under the cyclic stress behavior, one can always use stress concentration factors obtained from the parametric equations to obtain or to determine the fatigue life of tubular joints, but there are many factors that influence the estimate of stress concentration parameters or factors in hotspot areas because hotspot stresses are not only seen in the vicinity of saddle and crown, but also nearby the juncture, which can also improve the understanding of the behavior.

So, we decided to pick up the specific case of load study of a tubular joint before we look into the experimental setup and the definitions and derivations or the conclusion summary, what we get from the investigations made by Rohit; one of our master student under the user inter program of L&T sponsored program in department of ocean engineering. It is very interesting that let us try to summarize what could be the reasons of failure of a tubular joint.

So, based on the literature one can infer, the tubular joint generally fails, if any 1 of the following conditions is satisfied. Let say, stress in material reaches elastic limit, stress in material reaches yield strength, first crack is detected in the tension joint, maximum load carrying capacity of the joint is reached in compression which can cause large deformation. So, these are some of the important factors which will intuit the failure of the tubular joint as seen from Chandrashekaran and Bhattacharya in specific term T joints under axial loads fail by two reasons.

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As stated by graph, 1981 what are these 2 reasons; ovalisation. Second, it could be punching shear. Now, 1 can also divide this explicitly by a specific value for tubular connections, or for tubular joints with b less than 0.3, failure generally occurs by punching shear which can be caused or results in punching in or pulling out of the plug from the side of the chord for b exceeds 0.8 chord generally fails by collapse. So, for a geometric parametric b, which lies between the ranges of 0.3 to 0.8, 1 should actually estimate the interaction of punching shear and the general chord collapse.

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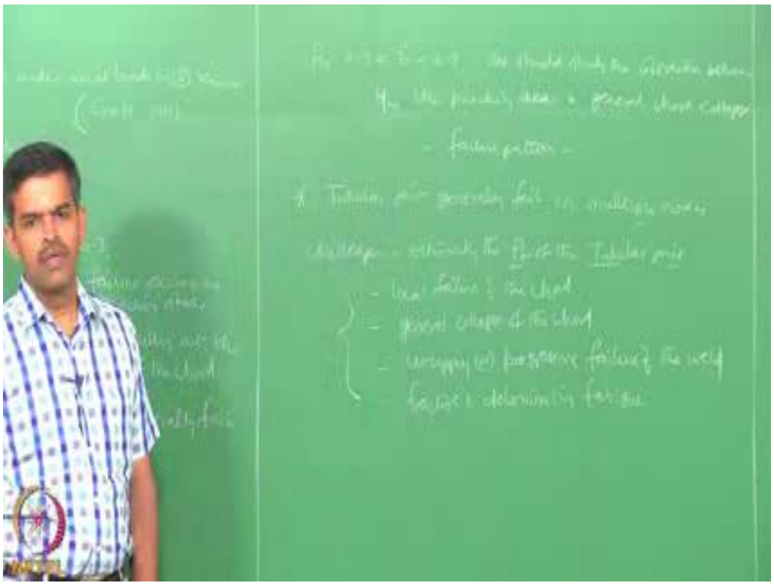

So, for 0.3 to 0.8 ranges one should actually study the interaction behavior between the punching shear and general chord collapse that is what the literature advised. So, this will give me the failure pattern based on which I will be like it to estimate the fatigue life of the joint. So, therefore, it is necessary to know when the geometric parameter is between the ranges of 0.3 and 0.8. I should have to study the interaction between the punching shear failure and the general chord collapse. There is another critical issue which is very important in tubular joints, please note the tubular joints generally fail in multiple modes. So, there is no guarantee that what mode of failure will prelude the other one it fails in multiple modes. So, one has to examine this joint behavior very carefully using experimental investigations.

So, such statements impose challenging nature in estimating the probability of value. So, that challenges in estimating the probability of failure of the tubular joint could be the local failure of the chord. We have to check for this the general collapse of the chord further unzipping or progressive failure of the weld and fracture and delaminating fatigue. So, these are some of the major challenges one need to understand before estimating the probability of failure of a tubular joint now, based on the finite element analysis using shell elements.

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Various researchers have actually developed parametric equations to estimate the joint life in the reliability perspective rather than the design perspective. So, it is more in reliability perspective and not in design perspective, please understand is a very important statement, which we are making examples can be seen from the studies reported by 1985, 1975 Rajashankar et al 2007.

So, the parametric equations suggested by the researchers are essentially on the reliability perspective, please understand this though people use them for estimating the fatigue life or estimating the design parameter, but essentially the purpose of this were not for designing the tubular joints, they are only to estimate the fatigue life in terms of reliability perspective.

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So, coming to the experimental and numerical investigations of the present study, T joints are fabricated and investigated under two combinations; one is the axial load and the other is out of plain bending. The geometric parameters of the tubular joints especially, T joints are very important to really assess the behavior under this combination. So, the geometric parameters of the T joint used in the study are as follows; beta ranging from 0.2 to 1, T ranging from 0.2 to 1, mu lying between 8 and 32, alpha between 4 and 40, theta between 20 and 90 and the gap which we call as is taken between 0.6 beta by sine theta to 1.

Of course, these are guidelines given by PRP 2; a 2000 based on which the specimens are fabricated and experiment investigated. Kindly pay attention to the photograph shown on the screen now.

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Which is the T join fabricated for the study. We can see here, the chord and brace which is 90 degree at each other, which will investigate currently for the study. Kindly pay attention to the geometric details of the T-joints, which will be used for the study the diameter of the brace is 234.3

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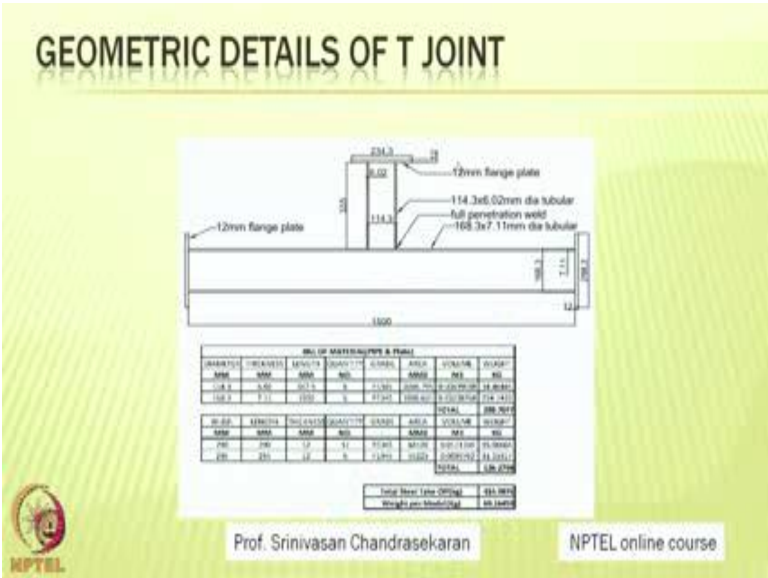

At this end the diameter is about 114.3 at the connecting end and a flange plates is about 234.3 millimeter. The brace extended by 335 millimeters from the chord surface, thickness of the brace is 6.02 millimeters. One can also see that the chord is having 2 flange plates of 12, among the chord length is about 1500 millimeters, whereas a brace length is about 335 millimeters, the chord diameter is about 168.3 millimeters against the brace diameter 114.3 and 0.1 millimeters whereas, it is about 6.02 for the brace and so on and so forth. One can also see the bill of materials prepared for fabricating it and 1 can see what is a total model in terms of kg, the weight of the model which has been used for the study welding of the joint is done is done as per API recommendation.

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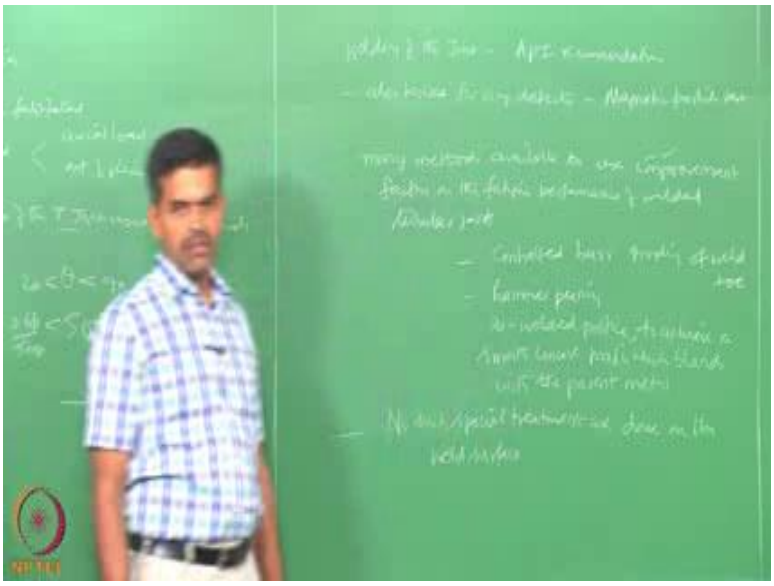

They also tested for any defects using magnetic particle test, if we really wanted to apply an improving factor on the fatigue performances of welded joints. There are many methods available, use improvement factors on the fatigue performances of welded tubular joints; one can look for controlled burr grinding. If you are using controlled burr grinding done on the welded surface of the weld toe, then one can always use the improvement factor on the fatigue performance if done hammer preening, then also 1 can add the improvement factor. If we can also say using it as welded profile then the performance factor is different because as welded profile, if are able to obtain a smooth concave profile which blends with an pairing metal nicely then one can also again use improvement factor for fatigue performance.

But in the current study no such specials treatments are done on the weld surface. So, that no improving factor is actually foreseen in the given study. Kindly pay attention to the axial load setup, which being used for investigating the T joint under the axial load.

The left hand side is actually the assembly which is housing the T joint, which is connected to the loading.

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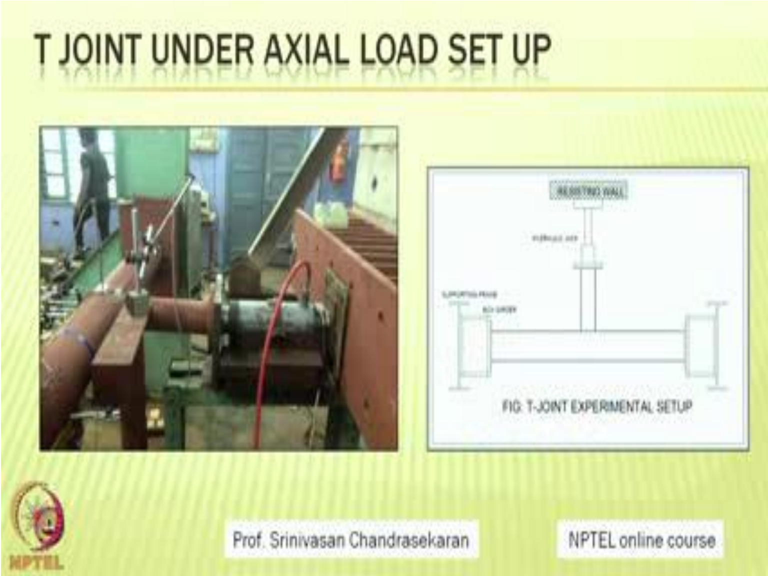

Loading jack which then facing the reaction wall on the right side, the schematic view of this is shown on the right hand side picture, where the T joint is assembled between the box girders and the supporting frame, and the brace is now connected through the hydraulic jack to the resisting wall or the reaction wall is going to offer me the load through which the loads will transferred to the entire setup. Please pay attention to the photograph shown on the screen now.

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It shows me the experimental setup with various components. The test sample is what you see here from a different view. There is the reaction of the resisting wall; there is box girder and a frame. A frame is actually locked to the floor, so that the frame does not allow the flange plates of the chord to get twisted when the loading is applied. The other view shows how the hydraulic jack is actually giving the axial force to the brace. This is the picture which shows clearly LVGT located which can also be seen in 2 different pictures. The test setup what we saw in the photograph is actually custom design.

We sincerely thank the structural engineering people of civil department, the faculty and the staff of the structural engineering group of civil department of IIT, Madras, who has dedicatedly prepared this setup exclusively for asserting the requirements as suggested by myself and my students who can conduct the experiment on this.

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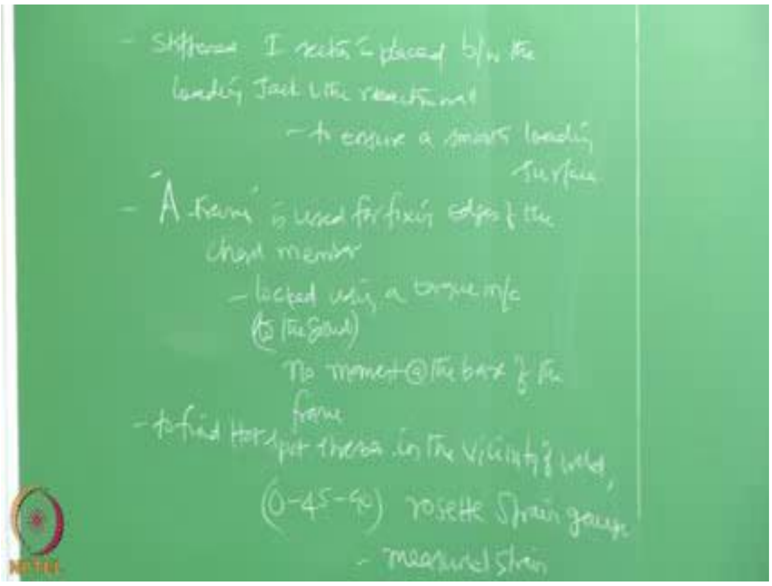

An existing reaction wall is used, the reaction wall has a capacity of about 200 tons is used to apply the load. The stiffened I section is placed between the loading jack and the reaction wall. This will ensure smooth loading surface, a frame is used for fixing the edges of the chord member which is custom design for the setup. The frame is locked using a torque machine, so that torque of course, is locked to the ground using a torque machine. So, that no movement at the base of the frame is created to find the hotspot stresses in the vicinity of the weld strain rosette is placed at 0, 45, 90 degree. They are used to measure the reflection. Please pay attention to the photograph shown on the screen now.

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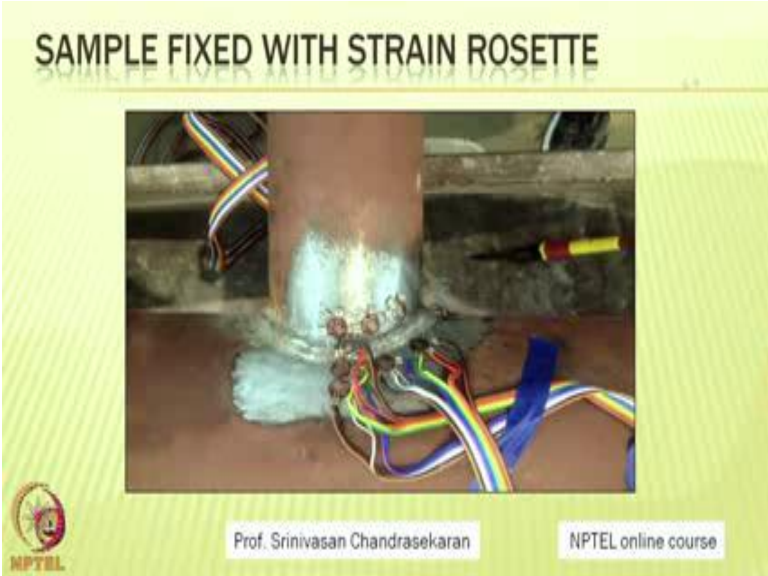

The strain rosette with samples fixed on the sample is shown on the photograph, 1 can see here, there are three strain rosette at 0, 45 and 90 degrees which are placed respectively on the sample to understand the strain at three different directions based on which the stress concentration on the hotspot stresses are going to be computed LVDT; linear variable differential transformer is used to measure the deformation or the displacement of the brace with the specific chord. Strains are measured in the physical model using the strain gauge rosette as we just now saw in the photograph the maximum principle stresses are given.

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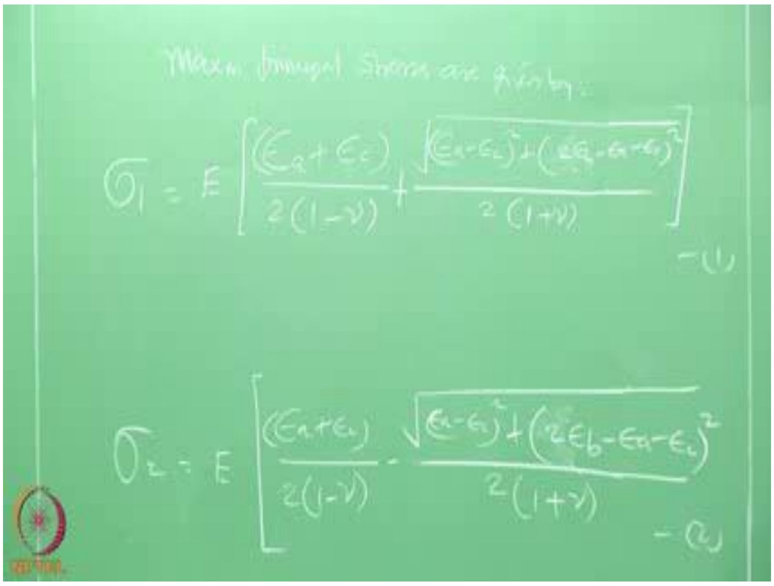

Let us say sigma 1, sigma 2, strain a and c by 2 of 1 plus 1 minus mu plus root of a minus c plus 2 b a c divided by twice of 1 plus mu, whereas strain a, b, c are respectively from the strain gauges at 0, 45, 90 degrees strain a and c twice of 1 minus mu there is sigma 2. So, minus root of a minus c square plus 2 b a c, this is 2 whole square divided by twice of 1 plus mu. So, let us call the equation number 1 and 2.

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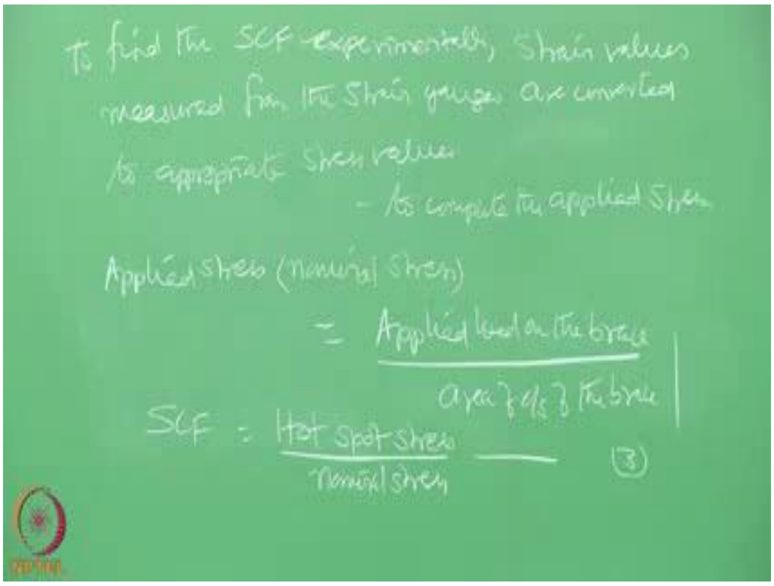

So, sigma 1 and sigma 2 are the maximum and minimum principle stresses, epsilon a, b, c are the strain values measured at 0, 45, 90 degrees respectively, capital e is the Young’s modulus of the material and mu is the Poisson’s ratio during the conduct of experiment extra stiffening is provided between the frames to actually avoid any unwanted damage to the frames as well as to the specimen. These also are equate ensure fix it the conditions at both the ends because the chord both end should be fixed thoroughly and the brace should be able to apply the axial force from the reaction wall.

So, to whole this chord thoroughly at a fixed boundary condition while the load is applied, which generally have a tendency that these chords or the brackets of the chords may get warped of extra stiffeners are provided between the frame to ensure that unwanted damage to the frame or the loading frame does not occur as well as to the model. Interestingly, the stress concentration factor to obtain the hotspot stresses essentially depends also on various parameters of the chord and brace which has been chosen for the study. So, kindly pay attention to the details of parameters of T joints and the axial load is shown on the screen now.

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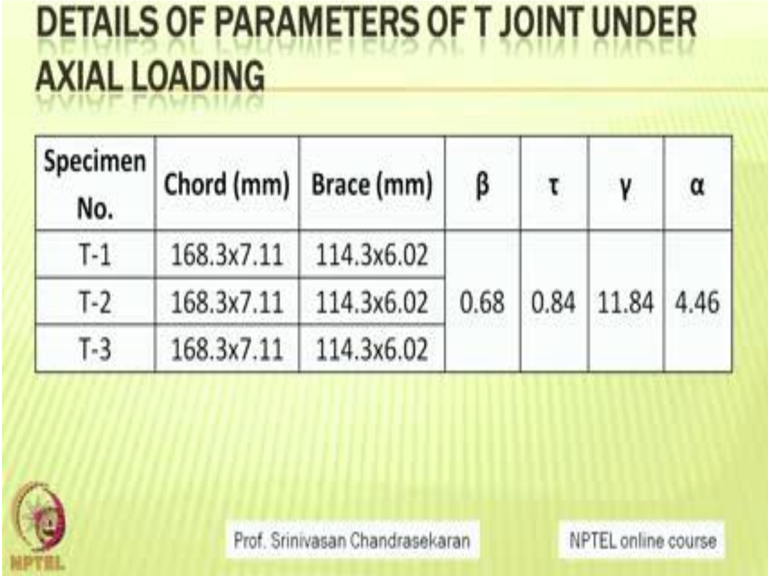

DETAILS OF PARAMETERS OF T JOINT UNDER AXIAL LOADING

Specimen No.	Chord (mm)	Brace (mm)	β	τ	γ	α
T-1	168.3x7.11	114.3x6.02	0.68	0.84	11.84	4.46
T-2	168.3x7.11	114.3x6.02				
T-3	168.3x7.11	114.3x6.02				

We have taken three specimens designated as T 1, T 2 and T 3 as shown in the table. The dimensions of the chord with its diameter and thickness and the dimensions of the brace with its diameter and thickness is shown on the table based on which the parameters beta tau mu and alpha are calculated which is seen in the screen. Now, in addition to the experimental investigation numerical analysis also carried out on the T joints under the axial load to compare the behavioral obtained to really check, which is super seeding the other stress concentration factors or also obtained from the numerical analysis directly frequently the results of the numeric analysis.

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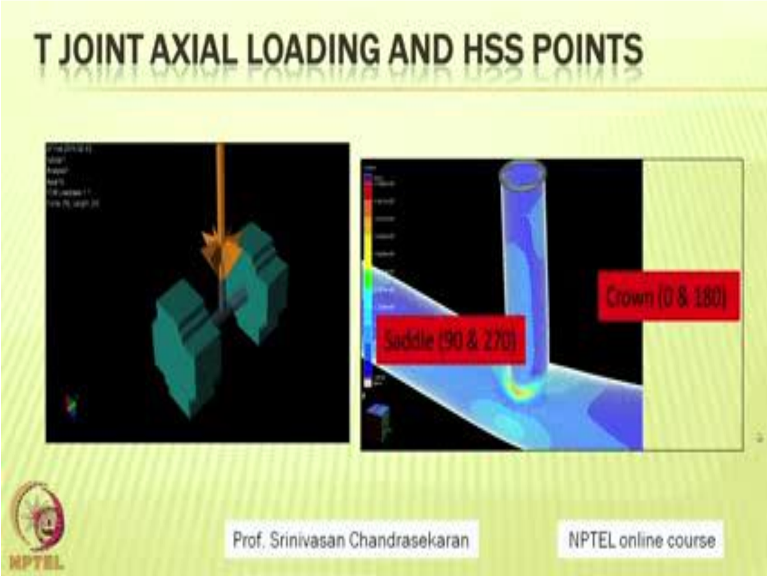

Please pay attention to the figures shown on the screen. Now, which shows the axial loading condition and the hotspot stress points generate in terms of contour in the saddle and in the crown as shown in the picture here.

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SCF EQUATION AND PARAMETER VALIDATION FOR T JOINT UNDER AXIAL LOADING

Location	Equation	Short chord correction
Chord saddle	$\gamma\tau^{1.1}(1.11-3(\beta-0.52)^2)(\sin\theta)^{1.6}$	F1
Chord crown	$\gamma^{0.2}\tau(2.65-5(\beta-0.65)^2)+\tau\beta(0.25\alpha-3)\sin\theta$	None
Brace saddle	$1.3+\gamma\tau^{0.52}\alpha^{0.1}(0.187-1.25\beta^{1.1}(\beta-0.96))(\sin\theta)^{2.7-0.01\alpha}$	F1
Brace crown	$3+\gamma^{1.2}(0.12\exp(-4\beta)+0.011\beta^2-0.045)+\beta\tau(0.1\alpha-1.2)$	None

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Now, let us compare the results obtained from the experimental and then let us see what will be the parametric equation applicable for the specific case. Kindly pay attention to the table shown on the screen. Now, which is giving me the stress concentration factor parametric equation and the parametric validation used for the T joint under the axial loading, we look at the chord saddle and chord crown and the brace saddle and brace crown based on the equation, the short chord connection is estimated and qualified as to be seen on the table now.

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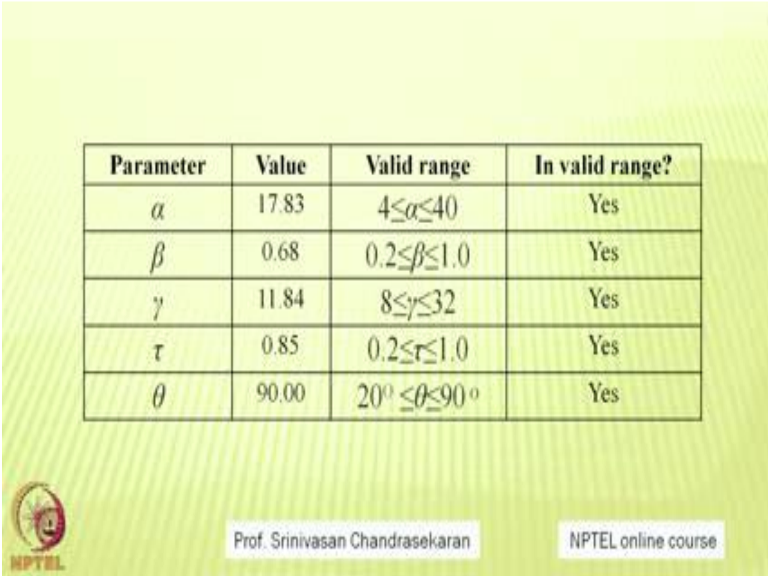

Parameter	Value	Valid range	In valid range?
α	17.83	$4 \leq \alpha \leq 40$	Yes
β	0.68	$0.2 \leq \beta \leq 1.0$	Yes
γ	11.84	$8 \leq \gamma \leq 32$	Yes
τ	0.85	$0.2 \leq \tau \leq 1.0$	Yes
θ	90.00	$20^0 \leq \theta \leq 90^0$	Yes

Based on which the parameters alpha, beta, mu, tau and theta as shown on the screen. Now, in the table are estimated and the values for each one of them are listed the validity is also shown as explain earlier and it is confirm that these values do lie within the range of the study as recommended by international course for a tube joint for T joint under axial load.

Now, to find the stress concentration factor experimentally strain values measured from the strain rosette are converted to appropriate stress values. To compute the applied stress which in this case is also called as nominal stress is given by the applied load on the brace by the area of the brace resisting this low, then the stress concentration factor can be simply said as the hotspot stress divided by the nominal stress. Let us call equation number three, in order to understand the validation or variations on stress concentration factor values which influences the fatigue life estimate of the tubular joint T joint under the axial load the fatigue assessment of the T joint is also done using s n curve approach.

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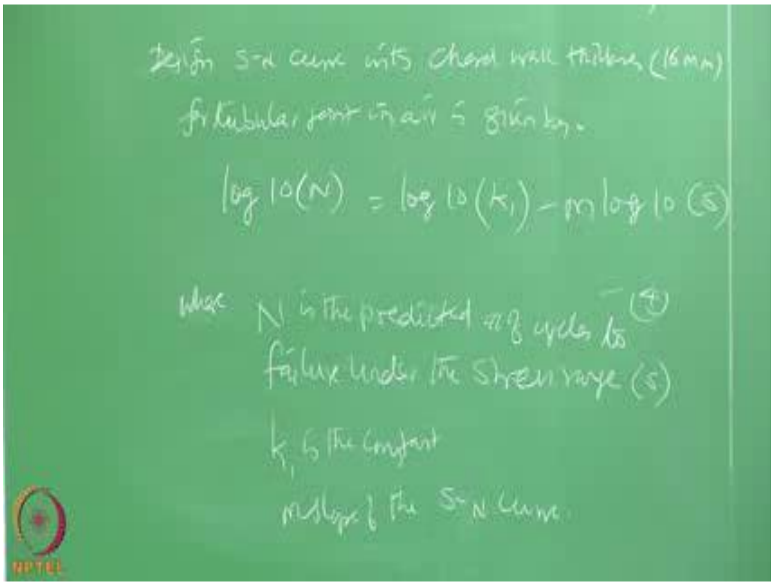

So, the fatigue assessment is also done using the conventional s n curve approach. It is only to understand the variations in stress concentration factor obtained experimentally. Interestingly, design s n curve and tubular joints in air with the chord wall thickness of 16 millimeter is given by a specific equation. Let us say, the design s n curve with chord wall thickness of 16 millimeter for tubular joint in air is given by log 10 m is log 10 k 1 minus m log 10 s, where equation number 4, where n is the predicted number of cycles to failure under the stress ranges k 1 is a constant and m is the slope of the s n curve.

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So, the constant k 1 for the welded joint for our specific case that is log 10 k 1 for s in mega pascal is obtained in 2 cases, one is taken as 12.48 for m 3 for the number of cycles to failure is less than 10 power 7 is taken as 16.13 and the slope of the curve remains 5 for n greater than 10 power 7. Kindly pay attention to the allowable number of cycles for T joint for different stress concentration values as obtain from experimental and computed for the parametric equations for both the chord and the brace saddles.

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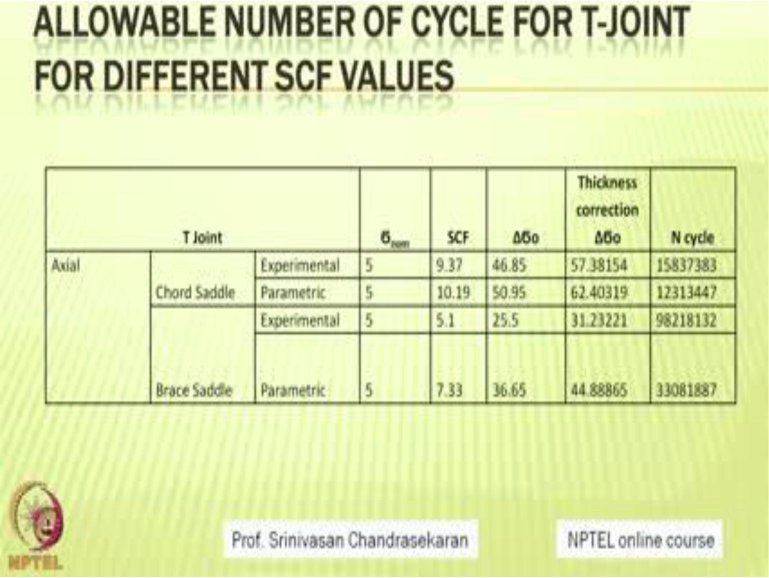

T Joint			σ_{nom}	SCF	$\Delta\sigma o$	Thickness correction $\Delta\sigma o$	N cycle
Axial	Chord Saddle	Experimental	5	9.37	46.85	57.38154	15837383
		Parametric	5	10.19	50.95	62.40319	12313447
	Brace Saddle	Experimental	5	5.1	25.5	31.23221	98218132
		Parametric	5	7.33	36.65	44.88865	33081887

If you look at the chord saddle, the experimental and parametric values of the stress concentration factors are seen based on which n-cycle is computed. For the brace saddle again the experimental and parametric values, the stress concentration factors are worked out based on which n-cycles are estimated. One can see from this table that the stress concentration factors obtained experimentally for both the chord saddle and the brace saddle for the T joint is lower compared to that obtain from the parametric equations, as a result of which the stress cycles or the number of cycles to failure in the stress range is higher experimentally compared to parametric equation for both cases of chord saddle and brace saddle as seen from the table.

So, from the above comparison one can easily observe that the fatigue life of the joint significantly increases because there is a significant in reduction the stress concentration factor, which has been obtained experimentally. When you compare this with other parametric equation and uncertainties with respect to life prediction of offshore structures can easily be seen through this particular comparison. One is also interested in estimating the fatigue life of the T joints under axial loading.

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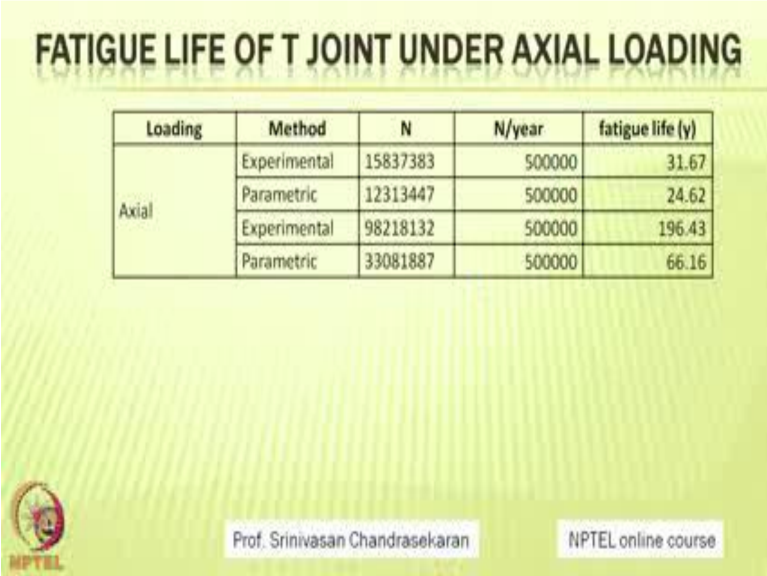

Loading	Method	N	N/year	fatigue life (y)
Axial	Experimental	15837383	500000	31.67
	Parametric	12313447	500000	24.62
	Experimental	98218132	500000	196.43
	Parametric	33081887	500000	66.16

Please pay attention to the tabular values given in the screen now, for the axial loading both, for the chord and for the brace comparing experimental and parametric. So, these values practically are taken from the previous table of the n-cycles. For the values computed n-cycles based on the stress concentration factor determine experimentally are from parametric equations the n per year is taken as 500,000 for the specific kind of joint under axial loading then based on which the fatigue life in terms of number of years is estimated, one can see very easily that for the chord the fatigue life is comparatively 31.67 against 24.62 which is computed or is recommended from the parametric equation. Similarly, for the brace the experimental study show that the fatigue life is very high compared to the parametric estimates.

So, if we consider 550,000 cycles per year has a base increase in life of a joint is considered to be 24.62 years which is increased. Now, to 31.68 years which is fairly about 40 percent increase, the experimental studies conducted on T joints under the axial loading and out of plain bending shows very clearly that the fatigue life estimates done based on experimental investigations or higher compared to the parametric equations for all the three joints T 1, T 2 and T 3 considered for the study the failure observe is actually punching failure mode with the weld intact. As I said in the beginning overly session of chord is observed till the chord member yielded after which passive deformation occur near the weld area which resulted in sudden punching of the joint.

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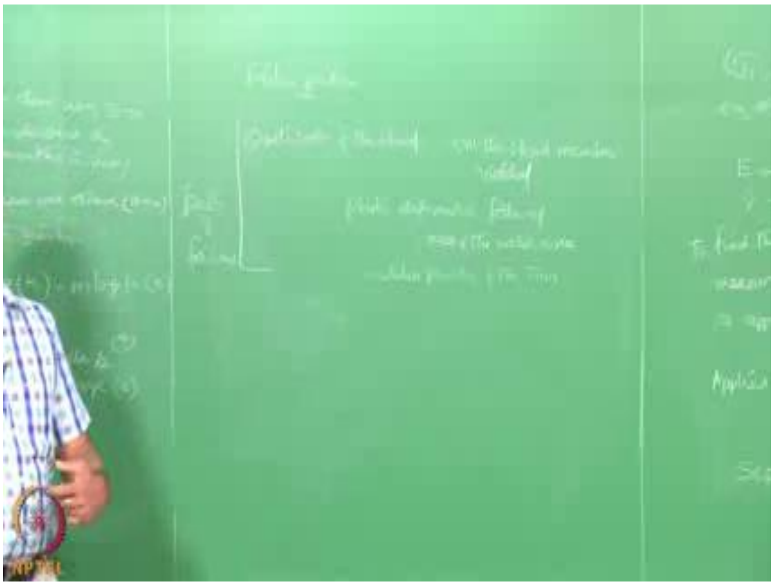

So, the failure phenomena, lets us say the failure pattern or the failure behavior is actually ovalisation of the chord, till the chord member yielded after which passive deformation occur near the weld area which resulted in sudden punching of a joint. So, one can see the path of failure which has been traced based upon the experimental investigations and observations, it is also plotted interestingly and the figure can show this which shows both in punching mode, and shear mode there is bulging of join indicating there is a plastic inch formation.

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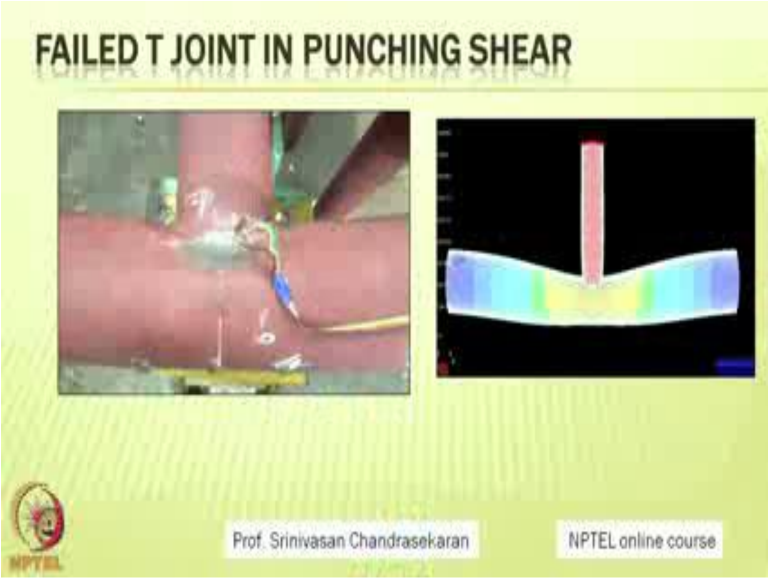

We pay attention to the photograph shown on the fail, the T joint in punching shear one can see that experimentally and numerically both, shows the bulging of the joint. It can be seen from the figures very easily that influence of the axial load on the chord is extended beyond the brace diameter region. Please pay attention to the figure shown. There has been influence of this failure beyond the brace region which is actually shown both experimentally, there is a bulging here, and there is a bulging here as well. This is important information to account for uncertainties in reliability parameters.

The region of influence is also plotted the maximum hotspot stresses are observed at the saddle point and minimum at the crown point of the weld as can be seen from the failed T joint showing bulging of the joint again.

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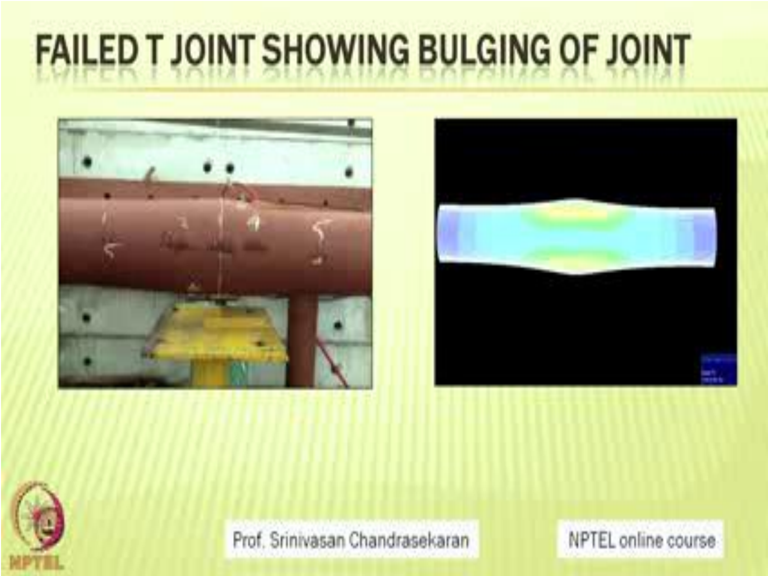

So, one can see here that the saddled at the crown points showed bulging as you see which is also verified from the numerical investigation.

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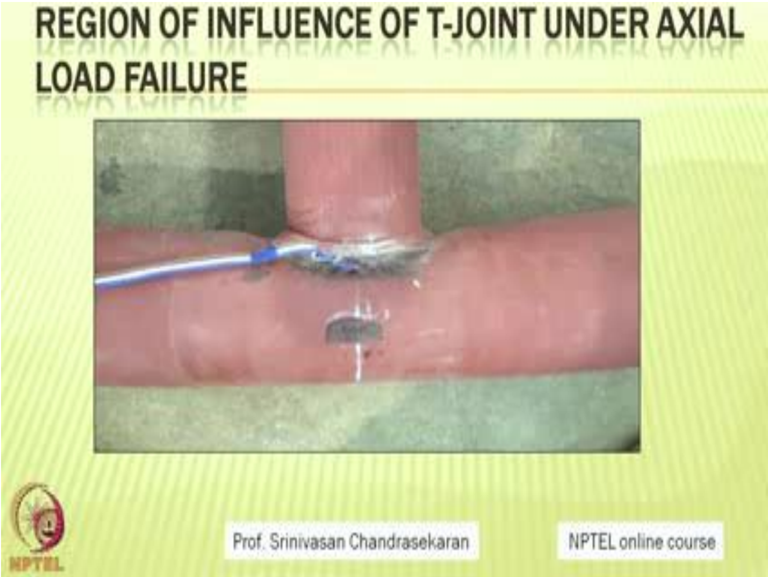

Please pay attention to the picture shown on the screen now, which shows the region of influence of the T joint under axial load failure. It is not only the brace region, but beyond the brace region even the edges in circumferential area is also affected. So, these are the reasons why the stress concentration factor or the fatigue life estimated from the experimental investigations are higher compared to that of the parametric equation. So, one can see that the stress concentration factors computed from the experimental investigations are lesser in comparison to the parametric equations indicating there is a necessity for reliability estimates through experimental investigations, fatigue life of the T joints under axial load increase significantly by about 40 percent when you examine them experimentally compared to that of parametric equations which increase from 24.622 of the chord to that of 31.68 years.

So, friends this application example showed interestingly, how uncertainties in estimating the stress concentration factor, which is one of the capital issue in estimating the fatigue life of the T joint or the tubular joint in general are very importantly highlighted. One can understand physically the factors which are very important that are contributing for this kind of enhanced fatigue life assessments. So, even if you are using the parametric equations which give me a conservative estimate of fatigue life, but one should really know, why there is a difference between the fatigue life estimated from the experimental studies in comparison to that of parametric equations which is one of the important issue in understanding the reliability of the behavior of tubular joints.

So, as I said in the beginning the focus is on reliability perspective not on design perspective. So, it is important to know that uncertainties do exist in estimating the fatigue life of reliability estimates of tubular joints, and as an example illustrated through this presentation one can easily appreciate that these factors can contribute significantly to the understanding of the failure behavioral because we also discussed about the so called path of failure based on which actually a T joint under axial force fails from the experimental investigations. So, this study as an example could be very valuable for reliability estimates. We thank the structural engineering group of civil department of IIT, Madras and L&T, which sponsored this particular study in financial aspect through the user inter program running at IIT, Madras in the department of ocean engineering by L&T.

Thank you very much and bye.