

Design of Offshore Structures
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Module - 4
Lecture - 8
Tubular Joint Design for Static and Cyclic Loads VIII

So, yesterday we were looking at the stress concentration factor calculation for three of the points.

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Hot Spot Stress Range (HSSR or S)

The hot spot stress range (S) shall be evaluated at 8 points on the chord and 8 points on the brace as shown in figure. The following equation can be used to determine the HSSR for both chord and brace.

$$S_{sa} = SCF_{AX}^{sa} f_{AX} \pm SCF_{OPB} f_{OPB}$$

$$S_{qr} = SCF_{AX}^{qr} f_{AX} \pm SCF_{IPB} f_{IPB} \pm SCF_{OPB} f_{OPB}$$

$$S_{cr} = SCF_{AX}^{cr} f_{AX} \pm SCF_{IPB} f_{IPB} + CE$$

Where

sa – saddle points (L and R position)

cr – saddle points (B and T position)

qr – quarter points (BL, BT, BR and TR positions)

ip – interpolated from saddle and crown points

CE – effect of stresses in the chord applicable for chord crown only

AX – Axial,
IPB – inplane bending
OPB – out-of plane bending

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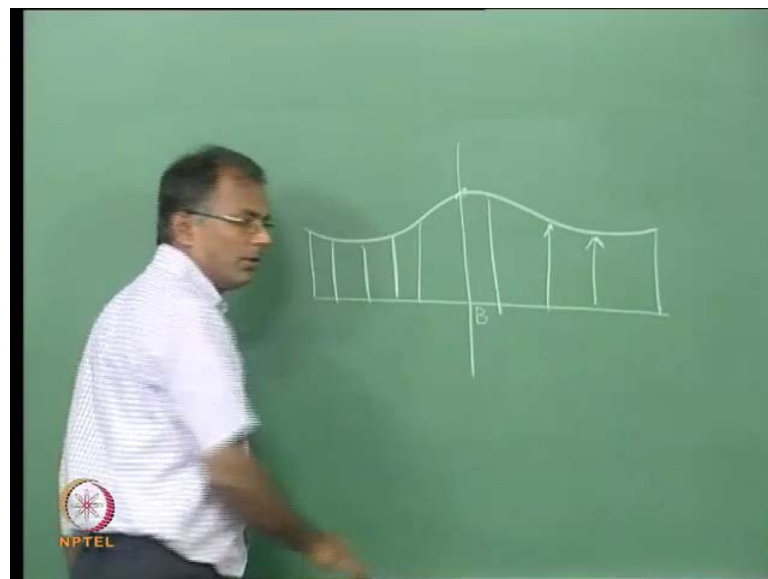
They are basically the saddle point quarter point and the ground point and the combination. Basically, at the quarter point, you will be combining by linearly interpolating between the points and there are in the vicinity, simple idea is if you do not have equations either you can develop within analysis yourself. You find out what is the SCF or you existing empirical equation given by others to interpolate this the concentration factor for this quarter points is a combination. So, basically this is an idea, only thing is we are not trying to find out the SCF value interpolated, trying to find out the stress range by multiplying the SCF with the corresponding stress or reach of these three locations.

So, you will find the stress at this point, this point and this point and ultimately you are trying to find out the quarter point by simply adding. This is only an example were all of

them will be combined together, but your little bit care full because there is a plus minus sign depending on the direction and move on to you know the sign. You will see that this may be minus or plus for example, if you want to write equation for all eight points you will have to rewrite this one for the quarter points in four forms minus plus and minus plus, whereas the left and right.

Basically the Crown Point we were only change the enplane moment, for example you have actual stress on the left side in the binding moment is clock wise. You will see the right side is compressed stress, there is a left side is tensile stress that is why I have put the plus minus here. So, you have to little bit care full in main platy, so there may be you may be ask to you may be ask to basically plot the stress concentration factor or the stress range across one full card interface. For example, something like this, this could here bottom point.

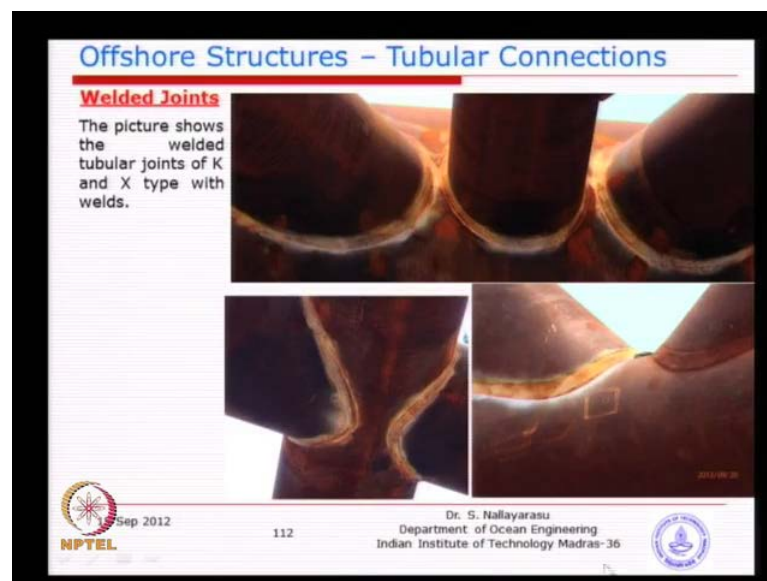
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Then, something like this you may ask spot at eight point, so that is your point, where you know this bottom point. You go all the way on the left side and right side you can plot the variation of stress concentration factor or overall stress range. So, for a given problem, you should be able to calculate nominal stress which I think most of your very familiar. If I give applied actual load applied binding moment in plane applied binding moment out of plane and you should be able to calculate f actual f in plane F out of plane.

Then, it comes back to the interface, you should be able to calculate the SCF values build on estimate equations which is available and I will give you printout. So, you can calculate, but you must remember the SCF values are given only for the 4 points left, right, top and bottom. So, you should able to calculate by inter pollution and calculate the stress and make a plot like what I have drawn in the black board this is the idea to understand how you will do it.

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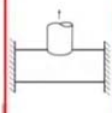
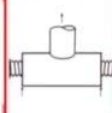




This typical joint you can see fabricated, then of course little blare here because of this whatever was clearly indicating multi pass building and gap available. So, you can see here in this particular location though you have given three in this particular project to end of actually having very small after the welding because the weld has taken most part of the space available. That is one of the area where you do not want to have weld overlap or weld on weld.

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Effthymiou equations

Load Type and Fixity Conditions	SCF Equations	Equation No.	Short Circuit Correction
Axial Load – Chord ends fixed 	Chord saddle $\tau^{1.5} [1.11 - 3(\beta - 0.52)^2] \sin^{1.5} \theta$	T1	F1
	Chord crown $\tau^{1.5} [2.65 - 5(\beta - 0.65)^2] + \tau \beta (0.25\alpha - 3) \sin \theta$	T2	None
	Brace saddle $1.3 + \tau^{1.5} \alpha^{0.1} [0.187 - 1.25\beta^{0.1} (\beta - 0.96)] \sin^{1.7-0.08\alpha} \theta$	T3	F1
	Brace crown $3 + \tau^{1.5} [0.12 \exp(-4\beta) + 0.011\beta^2 - 0.045] + \beta \tau (0.1\alpha - 1.2)$	T4	None
Axial Load – General fixity conditions 	Chord saddle $[T1] + C_1 (0.8\alpha - 6) \tau \beta (1 - \beta^{0.1}) \sin^{1.2} \theta$	T5	F2
	Chord crown $\tau^{1.5} [2.65 - 5(\beta - 0.65)^2] + \tau \beta (C_2 \alpha - 3) \sin \theta$	T6	None
	Brace saddle Eqn. T3		
	Brace crown $3 + \tau^{1.5} [0.12 \exp(-4\beta) + 0.011\beta^2 - 0.045] + \beta \tau (C_3 \alpha - 1.2)$	T7	None

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This is the typical equation which I have just taken from actually we produced in in the appendix shop vi p i. So, you can see here on the left side actually loaded card n 60, so you see here you were yesterday we were drawing one typical joint with boundary condition. So, instead of taking so large card from one support to other support and middle loaded, just they have considered a small card length which is probably there only with joint location and n sort assume determine fixed and basically loaded only by actual load.

The equation is given here for card saddle, remember card side and brave side, saddle point and Crown Point. So, that is given here, so in if you go back to this picture, we have left side card left side crown right side crown and then bottom saddle and top saddle. Basically, there will be two saddle point and two crown points, both are going to be having same values only thing is when we combine with your actual and binding stress. You will see that you have to increase or decrease, so you could depending on the binding moment.

So, basically you see here card side and brave side I have explained yesterday why there will be a different SCF. I think you have seen stress variation from nominal stress to put print out the weld, I think you can go back to few pictures before some way here. So, for the brave side we take the stress at the put print of the weld here for card side, you take the put print of the weld to at the card connection. So, there will be local area were which

we have not simulated weld, but the stress will be there. For example, if you go here, if you go inside here the intersection between the vertical plate and the pipe there will be a junction you should not take the stress there.



We have not stimulated the weld effect and that is what the meaning we were to see here is basically stress concentration factor for card is taken as the weld to of the card side and for the brace is taken at the weld at the brace side. So, in between stress, you should not take, so that is why you see a different, so you can see here the first letter look at the card saddle the SCF depends on gamma value which is basically there. The cylinder less of the card d by t value, basically the thickness ratio and then the next parameter is beta which is your d by D .


The ratio of the diameter of the brace two called and then you have the angle which is theta, basically this are four parameter we discussed even for static capacity only the static capacity. They may not have tau value there, but otherwise this the well known this four parameters or going to influence the stress concentration factor. So, you can see all the four of them or geometric parameters, you know how they joint looks on right hand side. You see here the saddle card correction factor in a basically and the notation the equation number is given just to identified equation number t_1 joint first equation.

On the right hand side, you see here the correction factor f_1 which we discussed yesterday the longer the card may actually see. So, you may have to calculate the stress concentration due to factor from this equation multiply this by this f_1 the f_1 equation for f_1 is given at the end on the second page, so you can see here you do the minimum one and can increase.

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In-Plane Bending 	Chord crown $1.45\beta t^{0.82} \gamma^{1.1-0.88\beta} \sin^{0.7}\theta$	T8	None
	Brace crown $1 + 0.65\beta t^{0.24} \gamma^{1.08-0.77\beta} \sin^{0.08\beta+1.02}\theta$	T9	None
Out-of-Plane Bending 	Chord saddle $\gamma t \beta (1.7 - 1.05\beta^3) \sin^{1.6}\theta$	T10	F3
	Brace saddle $t^{-0.34} \gamma^{-0.87} (0.99 - 0.47\beta + 0.08\beta^4) \cdot [T10]$	T11	F3
Short Chord Correction Factors ($a < 12$) $F1 = 1 - (0.83\beta - 0.56\beta^2 - 0.02\gamma)^{0.23} \exp[-0.21\gamma^{-1.18} a^{2.1}]$ $F2 = 1 - (1.43\beta - 0.97\beta^2 - 0.03\gamma)^{0.34} \exp[-0.71\gamma^{-1.18} a^{2.1}]$ $F3 = 1 - 0.55\beta^{1.3} \gamma^{0.38} \exp[-0.49\gamma^{-0.88} a^{1.8}]$ where $\exp(x) = e^x$		Chord-end Fixity Parameter C $0.5 \leq C \leq 1.0$. Typically $C = 0.7$ $C_1 = 2(C - 0.5)$ $C_2 = C^2$ $C_3 = C^5$	

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So, basically we can decrease depending on the geometric values, so you can calculate the correction factor and use that after completing here you multiply it. So, like this, the whole set of four types of joints, eight types of loading, so see here actual load and then the same t joint instead of fixed both the ends have a spring supported you. Basically, that means this is going to be the realistic you look at the jacket, yesterday we were trying to draw one picture you will never get 100 percent like this.

So, there are also connected to another member, so you may have stiffness which may prevent from rotation and translation, but it is not absolutely rigid. You may have flexibility, so you may have to consider that flexibility in here and basically repeated for card side crown and saddle brace side saddle and crown also same equations modified and for different boundary conditions. So, if you go to the next you will have in plane binding out of plane binding, now you see here you saw one simplified a SCF table very simple alpha times a two-third of a and three by fourth of a is as simple empirical to the calculated.

So, that was the equation originally proposed several years back for simple points, now after so much of studies the equation for SCF is when the elaborated so much in act. If you look, there was no differentiation between card and saddle, let us go back to the table if I just so that one minute, so simplified you look.


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Offshore Structures – Tubular Connections


SCF Formulas for Simple Joints

	Joint Type	λ	Axial load	In-plane bending	Out-of plane bending
	Chord SCF	K	1.0	λA	$2/3A$
T & Y		1.7			
X $\beta < 0.98$		2.4			
X $\beta \geq 0.98$		1.7			
Brace SCF's			$1.0 + 0.375(1 + \sqrt{r/\beta} SCF_{chord}) \geq 1.8$		

r and β are as defined earlier and $A = 1.8\sqrt{r} \sin \theta$


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Here, there was only a difference between chord and brace, but there was no difference between saddle point and the Crown Point, the stress concentration factor what was shown here it just taken as one single value for brace side. Of course, at least there was a differentiation between the load type actual load in plane out of it, but there was no difference between the saddle point and a Crown Point, which you could have seen from this picture. If you look at this picture obviously you can see from this f e analysis the saddle point is going to be higher stress higher stress concentration compare to the Crown Point.

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FE Analysis of T Joint

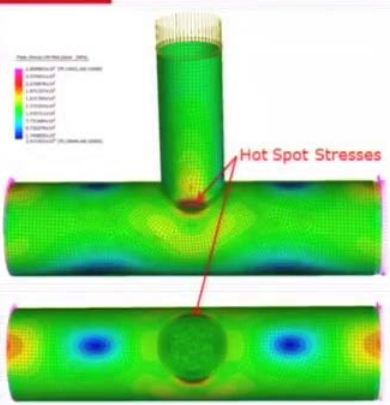
A FE analysis of the T joint has been carried out. The details of the Joint are as below.


Length of Chord : 3000mm
 Chord Size : 762 x 25 mm
 Brace Size : 508 x 20
 Brace Stress : 100Mpa (comp)

Hot Spot stress is around 260 MPa near the Saddle point.


This indicates the SCF to be 2.6.

The stress in most part of the brace (green) is nearly 100 MPa except near the connection. On the chord side, away from the brace location, the stresses are around 125 to 150 Mpa.




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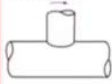




So, that is happened over the years more and more studies have been done and differentiation at the taking place. That is the idea beyond why we do not want to use those old equations which are simple looking very initial to you, but then there are not reflecting the real picture. That is why many more researchers have been involved in a SCF can calculations experiments and if the analysis finally come up with this one of the equation. Now, after very long deliberation in fact ten years of deliberation by research comity appointed by API since 1995 to 2005.

They found that they the equations given by still stand very good even after quite or large number of stress large number of studies the equation given by estimates still conservative compare to others. So, that is why we continuity use this and it has been now part of API, so you have to use it mandatorily. So, the first set of equation is for is joins actually loaded fully fixed condition, second one is spring, the next one is the in plane and out of plane.

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 <p style="text-align: center;"><i>In-Plane Bending</i></p>	<p><i>Chord crown</i></p> $1.45\beta t^{0.85} \gamma^{(1-0.85\beta)} \sin^{0.75}\theta$ <p><i>Brace crown</i></p> $1 + 0.65\beta t^{0.85} \gamma^{(1.09-0.75\beta)} \sin^{(0.86-1.16)\theta}$	TB	None
 <p style="text-align: center;"><i>Out-of-Plane Bending</i></p>	<p><i>Chord saddle</i></p> $\gamma t \beta (1.7 - 1.05\beta^2) \sin^{1.5}\theta$ <p><i>Brace saddle</i></p> $t^{-0.18} \gamma^{-0.85} (0.99 - 0.47\beta + 0.08\beta^2) - [T10]$	T10	F3
<p><i>Short Chord Correction Factors (a = 12)</i></p> <p>F1 = $1 - (0.83\beta - 0.56\beta^2 - 0.02)\gamma^{0.22} \exp[-0.21\gamma^{-1.18}\alpha^{2.1}]$</p> <p>F2 = $1 - (1.43\beta - 0.97\beta^2 - 0.03)\gamma^{0.88} \exp[-0.71\gamma^{-1.18}\alpha^{2.1}]$</p> <p>F3 = $1 - 0.55\beta^{1.1} \gamma^{1.8} \exp[-0.49\gamma^{0.88}\alpha^{1.8}]$</p> <p>where $\exp(x) = e^x$</p>		<p><i>Chord-end Fixity Parameter C</i></p> <p>$0.5 \leq C \leq 1.0$, Typically $C = 0.7$</p> <p>C₁ = 2(C - 0.5)</p> <p>C₂ = C/2</p> <p>C₃ = C/5</p>	



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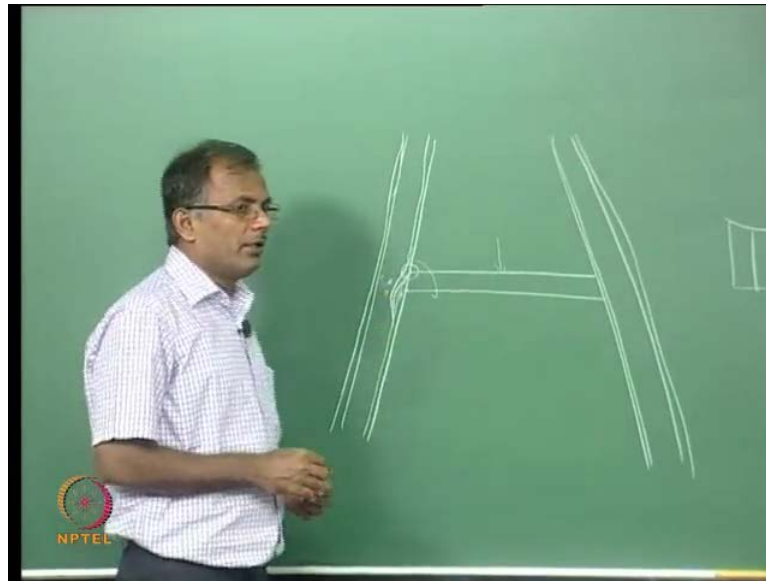
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Of course, the boundary condition does not really influence two grades because the flexibility on the correction factors and corresponding coefficients available required for the calculation of n 60 parameter. Basically, it will be 0.7 means partially fixed most of the time; you might remember it will be tubular connections. If you have one cube, one left side and right side in a connective press tube because of the flexibility I think I try to explain the other way.

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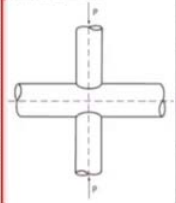



For example, if you take one jacket line going a member design, you have one member connected this way when you apply a loading. You can see here this wall thickness this is a allow section, now if this is solid, actually you can see here this rotation may not happen, but because this is not solid and there could be local deformation which allows the rotation of this end. It is not 100 percent rotation like a simply supported because this having own thickness.

So, that is why we most of the time the tabulated tubular end connections, you will either can connect consider as 100 percent fishery or 100 percent simply supported, it will be in between, you may rotate may not allow the full rotation. So, that is why this partial fixity, so this parameter is to be calculated according to where accommodation.

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Load Type	SCF Equation	Equation No.
	Chord saddle $3.87\tau\beta(1.10 - \beta^{1.8})\sin^{1.7}\theta$	X1
	Chord crown $\gamma^{0.2}[2.65 + 5(\beta - 0.65)^2] + 3\tau\beta\sin\theta$	X2
	Brace saddle $1 + 1.9\gamma\tau^{0.2}\beta^{1.8}(1.09 - \beta^{1.7})\sin^{2.2}\theta$	X3
	Brace crown $3 + \gamma^{1.2}[0.22\exp(-4\beta) + 0.011\beta^2 - 0.045]$	X4
In joints with short chords ($\alpha < 12$) and closed ends, the saddle SCFs can be reduced by the short chord factors F1 or F2 where $F1 = 1 - (0.83\beta - 0.56\beta^2 - 0.02\gamma)^{0.22} \exp[-0.21\gamma^{-1.18}\alpha^{2.1}]$ $F2 = 1 - (1.43\beta - 0.97\beta^2 - 0.03\gamma)^{0.68} \exp[-0.71\gamma^{-1.18}\alpha^{2.1}]$		



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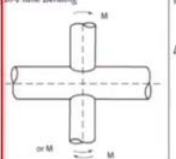
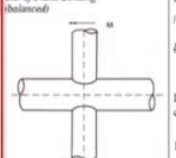
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So, 0.7 means typically it is about 70 percent fixed, it will go further known you have actually loaded balanced x joints and similar equations for in plane bending and out plane bending. Of course, some time you will see the equation are just repeated that is why the numbers there given the purpose for which the numbers in this order is given because there will be a duplicated use.

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	Chord crown: Eq. T8 Brace crown: Eq. T9	
	Chord saddle $\tau\beta(1.56 - 1.34\beta^2)\sin^{1.9}\theta$	X5
	Brace saddle $\tau^{0.2}\gamma^{0.2}(0.99 - 0.47\beta + 0.08\beta^2) - [X5]$	X6
In joints with short chords ($\alpha < 12$) and closed ends, Equations X5 and X6 can be reduced by the short chord factor F3 where $F3 = 1 - 0.55\beta^{1.2}\gamma^{0.18} \exp[-0.49\gamma^{-0.89}\alpha^{1.8}]$		



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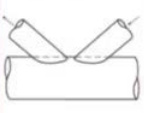
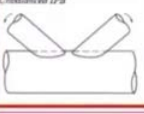
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So, instead of rewriting, you to this provided idea of repeating.

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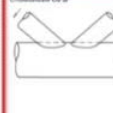
Load Type	SCF Equations	Equation No.	Short Chord Correction
Balanced Axial Load 	Chord SCF $\tau^{1.5} \beta^2 (0.67 - \beta^2 + 1.16\beta) \sin \theta \left[\frac{\sin \theta_{max}}{\sin \theta} \right]^{0.25} \left[\frac{\sigma_{max}}{\beta \sigma_{nom}} \right]^{0.25} =$ $[1.64 + 0.29\beta^{0.34} ATAN(\theta)]$	K1	None
	Brace SCF $1 + [K1](1.97 - 1.57\beta^{0.25}) \tau^{0.14} \sin^2 \theta +$ $C\beta^{1.5} \tau^{1.25} \sin^{1.5} (\theta_{max} + \theta_{min}) = [0.131 - 0.084 ATAN(14\zeta + 4.2\beta)]$ <p style="font-size: small;">where C = 0 for gap joints, C = 1 for the through brace, C = 0.5 for the overlapping brace.</p> <p style="font-size: x-small;">Note that τ, β, θ and the nominal stress relate to the brace under consideration. ATAN is arctangent evaluated in radians.</p>	K2	None
Unbalanced IPB 	Chord crown SCF , Eqn. T8 (For overlaps exceeding 30% of contact length use $1.2 \times [T8]$)		None
	Gap joint-brace crown SCF , Eqn. T9		
	Overlap joint-brace crown SCF , [T9] $\times (0.9 + 0.4\beta)$	K3	None

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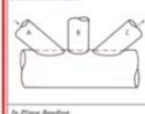
Then, finally you will have k joints for actual load for unbalanced in plane binding unbalanced out of plane binding.

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Unbalanced OPB 	Chord saddle SCF adjacent to brace A $\frac{[T10]_A}{\sigma_{nom}} [1 - 0.08\beta_{max} \tau^{0.25} \exp(-0.8\tau)] =$ $\frac{[T10]_B}{\sigma_{nom}} [1 - 0.08\beta_{max} \tau^{0.25} \exp(-0.8\tau)] [2.05\beta_{max} \exp(-1.1\tau)]$ <p style="font-size: x-small;">where $\tau = 1 + \frac{\zeta \sin \theta}{\beta}$</p>	K4	F4
	Brace A saddle SCF $\tau^{0.75} \gamma^{0.25} (0.99 - 0.47\beta - 0.08\beta^2) - [K4]$	K5	F4

$F4 = 1 - 1.07\beta^{0.25} \exp[-0.16\tau^{0.25} \sin^2 \theta]$
 Note that $[T10]_A$ is the chord SCF adjacent to brace A as estimated from Eqn. T10. The designation of braces A and B is not necessarily dependent. It is indicated by the text.


Load Type and Finity Conditions	SCF Equations	Equation No.	
Balanced Axial Load 	Chord SCF , Eqn. K1 Brace SCF , Eqn. K2 For the diagonal braces, A and C use $\zeta = \zeta_{AB} + \zeta_{BC} + \beta$ For the central brace, B use $\zeta = \text{maximum of } \zeta_{AB}, \zeta_{BC}$		
	In-Plane Bending Chord crown SCF , Eqn. T8 Brace crown SCF , Eqn. T9		

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Then, basically balanced actual also several cases here some of with after along study some of with this equation.

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	<p>Chord and/or SCF adjacent to diagonal brace A:</p> $[F10]_A [1 - 0.08(\beta_{sc})^{1.2} \exp(-0.3\beta_{sc})] \cdot [1 - 0.08(\beta_{sc})^{1.2} \exp(-0.3\beta_{sc})]$ $+ [F10]_B [1 - 0.08(\beta_{sc})^{1.2} \exp(-0.3\beta_{sc})] \cdot [2.05\beta_{sc}^{0.2} \exp(-1.3\beta_{sc})]$ $+ [F10]_C [1 - 0.08(\beta_{sc})^{1.2} \exp(-0.3\beta_{sc})] \cdot [2.05\beta_{sc}^{0.2} \exp(-1.3\beta_{sc})]$ <p>where</p> $x_{adj} = 1 + \frac{2.42 \sin^2 \theta}{\beta_{sc}} \quad \text{and} \quad x_{di} = 1 + \frac{(2.42 \sin^2 \theta + \beta_{sc}) \sin^2 \theta}{\beta_{sc}}$	KT1
	<p>Chord and/or SCF adjacent to central brace A:</p> $[F10]_A \cdot [1 - 0.08(\beta_{sc})^{1.2} \exp(-0.3\beta_{sc})]^{2x_{di} x_{adj}^2}$ $\cdot [1 - 0.08(\beta_{sc})^{1.2} \exp(-0.3\beta_{sc})]^{2x_{di} x_{adj}^2}$ $+ [F10]_B \cdot [1 - 0.08(\beta_{sc})^{1.2} \exp(-0.3\beta_{sc})] \cdot [2.05\beta_{sc}^{0.2} \exp(-1.3\beta_{sc})]$ $+ [F10]_C \cdot [1 - 0.08(\beta_{sc})^{1.2} \exp(-0.3\beta_{sc})] \cdot [2.05\beta_{sc}^{0.2} \exp(-1.3\beta_{sc})]$ <p>where</p> $x_{adj} = 1 + \frac{2.42 \sin^2 \theta}{\beta_{sc}} \quad \text{and} \quad x_{di} = 1 + \frac{2.42 \sin^2 \theta}{\beta_{sc}}$	KT2
	<p>Brace and/or SCF under CPB: Obtained from the adjacent chord SCFs using</p> $x^{0.25} \exp(-0.14x^{0.25}) \cdot (0.99 - 0.47\beta) + 0.03\beta^2 \cdot SCF_{max}$ <p>where $SCF_{max} = KT1$ or $KT2$</p>	KT3

In joints with short chords ($\alpha = 123$ Eqn. KT1, KT2, KT3) can be reduced by the short chord factor F4 where $F4 = 1 - 1.07\beta^{0.08} \exp(-0.14\beta^{0.25})$

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This balanced out of plane binding that means both the moments are similar are equal. So, you can see here this equations quite complicated there is a potential of making mistakes. So, you have to little bit careful I will give you the better printout this is very hard to read in this slide because of reduction in size probability. Tomorrow, I will bring the printout, so you have to keep it in your hand throughout the course in the exam in keep it. So, I think I have the original print, so you can just bring few copies to all of you, give you the soft copy, you can one print, the next grannies basically there SN curve. So, what we have done is, we have the nominal stress calculated from an analysis of the structure.

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S-N Curves

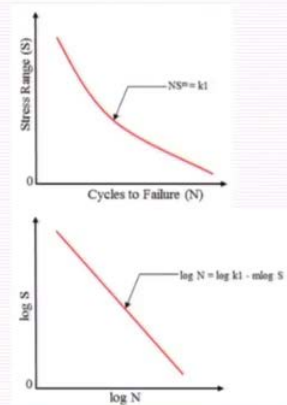
S-N curves are the material characteristics relating the number of cycles (N) to failure for a given magnitude of stress (S)

$$NS^m = k_1$$

In which m is the slope of the S-N curve and k_1 is the constant this can be written in log form as follows

$$\text{Log}_{10}(N) = \text{Log}_{10}(k_1) - m\text{Log}_{10}(S)$$

Also, for easy computation of number of cycles to failure, this can be expressed as

$$N = 10^{\log_{10}(k_1) - m \log_{10}(s)}$$


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Here, applying a wave write and wave period well and we have calculated the stress concentration factor. So, it is stress concentration factor multiplied by the nominal stress gives you the hotspot stress and the stress ranges defined as either twined or the difference between the maximum or minimum. Now, you have the stress range applied, we also know what the number of cycles that stress ranges applied is. So, we have the loading side demand side is known; now the capacity side we need to establish the relationship between numbers of cycles to failure at a particular stress range.

So, that is needs to be established, so basically that is relationship is called, so is basically again remanded capacity. So, demand is establishes, so for and the capacity side is the allowable number of cycles which is typically known as stress number of cycles relationship for a given type of joint. Depending on the material connection geometry and well profiling and the characteristics of material, so basically this has been done to a great extent, I would say in fact many of this connections have been established what they are looking at just they are tubular connection.

So, the SN curve is going too defined for each type of connections if it is a tubular connections something like this there is SN curve. If it is a plated connections there is a different SN curve if it is a plate are tubular, if will be another type of SN curve because the relationship is going to be influenced by the type of connection type of conditions that are being applied there. So, here few classes that we derived one relationship

between the initial crack growth the final crack growth with the material constant, which is basically k_1 .

If you plot this relationship, the horizontal axis the number of cycles the vertical axis is the range of stress applied very similar to problem off a paperclip be no way we were try to do is simple experiment. Basically, the opening the large angle is the island stress in this at the junction, so the larger angle where less number of cycles we need to break it up, so we see here horizontal axis. Basically, you are number of cycles applied, then larger the number of cycles that you applied that the smaller the stress range you requires to break the connections. If you go for the launch of the stress or the effort, then you may break in the smaller number of cycles.

That means any number of combinations can actually fails the same joint different combination of number of cycles and the stress range that needs his statement. Here, it is correct basically you may have numerous number of combination of number of cycles to stress range applied to produce the effect of same. For example, I want to produced 3 mm crack in a particular joint, I can have x number of factors, y number of or y amount of stress range or another combination that can exist like modification to the stress and the number of cycles.

So, that means this constant depends on the material type, their connection type and also their welding profiles around the connections. So, that is why you see here, but of course is not almost linear and is non linear curve something like this. Typically, you will see now when you plot the same data in log axis or log plot papers, I think you made a seen here a mathematics course normally you have a log paper just for convenience. Basically, if you plot you might get, so there characteristics become 0. So, when you plot the SN curve will be log graph becomes linear, so we can write this in terms of log equation. Basically, that is why we can do, so you can see here the n is the number of cycles to failure s is the stress amount.

The magnitude there is range applied to the joint and m is the slope of the there is linear or the stifling given their and k_1 is a constant depending on the type of joint geometry and associated. If it is, remember yesterday we talked about SN curve, includes undercut well profiling and at the location at the well ditto. So, this affects what we already included in here, so depending on the type of joint, the k value or the k_1 value the reason

why we do not want to use k because k normally used for other variables. So, that is why most of the references, we use a just k_1 , there is no great point, some of the course the use k_2 , some depends on you know not a very is a constant.

That is what we wanted to use that, Sharif can actually rewrite this whole thing in terms of this will be very handy because when you are solving problem, we need to calculate the number of cycles given the stress range. This is calculated from your previous analysis by applying loads calculate the loads and stresses can be calculated multiply by stress concentration factors you get the stress range. So, you bring the stress range here, so you know what the k_1 for a particular type of joint and the slope is known. So, you can find out what is the number of cycles to failure, so once you this know this than the particular problem is resolved.

So, basically a typical SN curve, so you need to remember everyone of the SN curve developed by so many course could be American code and it could be gain v code all of them will be this kind of only. What will differ is the coefficients which is k_1 will differ m will differ sometimes you have a tips know these keepers a slope. This is not very good because stress range comes down flatter the slope is good because you stress range comes down flatter.

The slope is very good because it will take a longer number of cycle before failure, so that is the only difference some time you will see that instead of the single slope like this some of the SN curves are having double slope something like different. So, different ranges you will see that tips slope and some of the materials exhibit double slope SN curve. So, again I earlier revision for API code, in fact we were having single slope something like this in the recent time class five years, they have changed to double slope because based on additional experimental studies.

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Thickness Correction to Stress Range

The S-N curves were generated using models made of steel plates of certain maximum thickness (in API case it is $T_{ref}=16\text{mm}$). However, the actual thickness used in the fabrication of prototype structures may vary beyond 16mm. Hence the correction shall be applied on the stress range. The reduction in stress range can be calculated using the following relationship.

$$S = S_0 \left(\frac{T_{ref}}{T} \right)^{0.25}$$

In which S_0 is the stress range without thickness effect (Original S-N curve). The correction factor shall be less than 1.0 for thickness larger than 16mm.

Effect of thickness on Stress Range

T_{ref}/T	S/S_0
0.0	0.0
0.2	0.6
0.4	0.75
0.6	0.85
0.8	0.92
1.0	1.0
1.2	1.0

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So, we will just see some of the examples, so if we see here another correction factor given to before go to basically their various types of SN curves. So, what is the correction factor regarding, basically this correction factor is to incorporate the effect of the typical fabrication going to happen in future. During the testing, they have taken as certain amount of thickness and carried out the experiments for SN curve generation. Now, in future somebody use in higher thickness or lower thickness, it may actually not exactly reflect what was done in the experiments to generate this graph.

So, that is called thickness correction factor scale effect factors because in the real practice people are using in the different thicknesses whereas, the tests were carried out for the reference thickness of 16 millimeter. Now, if I have a 25 millimeter, thickness is their failure or the crack growth different when a 16 millimeter thickness of a. So, you not at a account for the correction factor needs to be applied, so the correction factor is very simple where reference thickness is very small is 16 and you are your tickets is also 16.

Then, it becomes 1, there is no correction requires, these long as the thickness required our signals used in your actual design is higher than this thickness in the correction factor will always be higher than 1. So, basically here you need to make sure as longer as you have ratio is 1 and basically the values of multiplication will come lower, but what we are actually you are going to get you are going to actually use this one. So, that is why I

have plotted if you go to the next graph, I have plotted just as the rivers is because you will be using this in your reading of the SN curve, not the other way.

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Thickness Correction to S-N Curves

To obtain corrected "N" value from the S-N curve, the calculation needs to be reversed. The actual calculated stress range is S_c and the stress range (S) to be used to read "N" from S-N curve shall be calculated using the following formula.

$$S = S_c \left(\frac{T}{T_{ref}} \right)^{0.25}$$

For example, if the thickness of the chord is 50mm, then T_{ref}/T becomes 0.32. The value of S/S_c is 1.35.


The increased stress range S due to increased thickness T is then calculated using

$$S = S_c * 1.32$$

This "S" value will need to be used for reading corresponding "N" value from the S-N curve.

Effect of thickness on Stress Range


T_{ref}/T	S/S_c
1.0	1.0
0.5	1.32
0.32	1.35
0.2	1.5
0.1	1.8



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Basically, this is the calculated stress from your actual analysis and this is a stress range, you are looking that basically t by t all your values as longer you are there in there ratio it is 1, the multiplication factor is 1. If there ratio is less than 1, then you will see the values as much as the 101.8, so the thickness suppose you have 16, you have 13 mm or 32 mm and you will have the effect of that scale.

So, that is why these stress range that they are going to use in your SN curve basically multiplied by 1.3 depending on what thickness you are using. So, this correction can increase the stress concentration factor, basically that is not included in stress concentration factors. So, it is included in the SN curve, so whenever you reading the SN curve before we go and apply you are s value you correct the s value by using this. That will be always greater than 1, if your thickness is higher on where this types SN curve available, you can see here four organizations, I have just listed out all of them almost have all four joint types American code.

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S-N CURVES

The S-N curves for welded tubular joints from various codes and standards are summarized.

Organization	Connection Type	S-N Category
American Petroleum Institute API RP 2A WSD (21 st Edition)	T, K, Y and X type tubular connections	X' – Welded Joint X - Improved for profiled joints
American Petroleum Institute API RP 2A WSD (21 st Edition Supplement 3)	T, K, Y and X type tubular connections	WJ – Welded Joint WJ - improved for profiled joints
Det Norske VERITAS DNV-RP-C203	T, K, Y and X type tubular connections	T – welded tubular joints
ISO 19902	T, K, Y and X type tubular connections	TJ – welded tubular Joints

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If you look at the recent ones, almost the curves are similar that earlier version of the API as a single slope curve which you have use to call it x and x prime, whereas now they call it W and W j W j improve and basically DNV is they call it t. Basically, welded tubular and the ISO, they exists notation is t j does not matter almost there reflect every similar idea only the notation is given.

So, slightly different if you look at other connections instead of tubular is there is AT plated connection, they will have p as a SN curves, just a notation what we are interested is these values.

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S-N Curves for Tubular Joints

The S-N curves can be generated using the following relationship, if the values of k_1 and m are known.

$$\text{Log}_{10}(N) = \text{Log}_{10}(k_1) - m\text{Log}_{10}(S)$$

The values of k_1 and m for various S-N curves from API RP 2A and DNV codes applicable to tubular joints are summarized.

Code	S-N Curve Designation	$\text{Log}_{10}(k_1)$	m
API RP 2A (21 st Ed)	X' (Welded Joints)	13.39	3.74
	X (Improved Profile)	15.06	4.38
API RP 2A (21 st Ed) Supplement 3	WJ (Welded Joints)	12.48 16.13	3 for $N < 10^7$ 5 for $N > 10^7$
	Improved WJ (Weld Improvement)	12.17 16.50	3 for $N < 10^7$ 5 for $N > 10^7$
DNV-RP-C203	T (Welded Joints)	11.76 15.60	3 for $N < 10^7$ 5 for $N > 10^7$

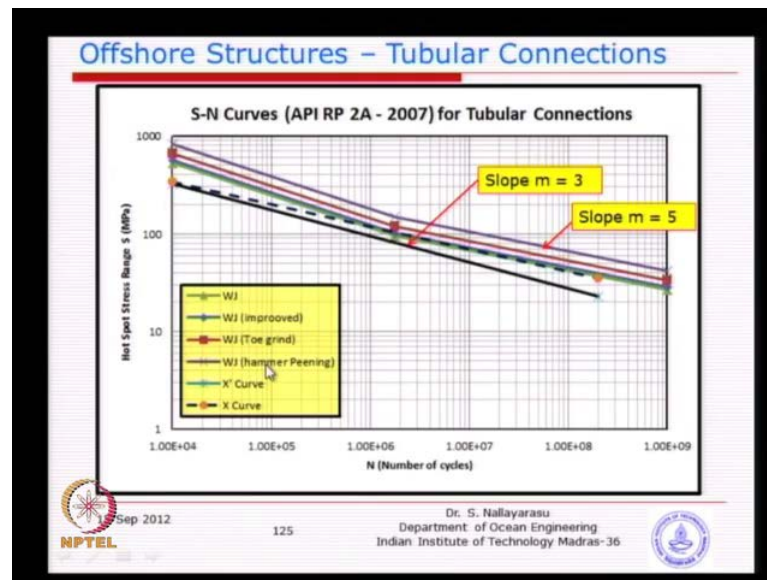
The S values shall be in MPa

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You know basically the values of $\log k_1$ or k_1 , sometime you will find instead of giving $\log k_1$, you will be directly giving k_1 value. So, you have to find out what is the $\log k_1$ value depending on which code almost all the DNV codes are giving directly the values of k_1 , whereas the API there is just give $\log k_1$. So, you have to be a little bit careful in using it and out of the earlier version of API, you can see here 13 and 15 slope is 3.74, 4.38. In the new version you can see here slide change 12.48, 14 and the slope has been differentiated between the steep slope to your known gentle slope for a demarcation between $n = 10$ to the power 7 cycles.

So, basically you will see in the graph and then the DNV curve not a major difference, you will see that if you compare this is these 12.48 versus 11.76 and 16 versus 15 slightly conservative. You know the DNV curve is slightly conservative you see the comparison between all the just get an idea what exactly happening there is for example, if you look at this pink color this basically the improved member feeling.

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That means you have merit all weld, I think we did discuss maybe we will be discussing in to improve one techniques. Basically, we improve the welded joint which tried to remove the rough material number one profile, lot of activities can be performed under weld so that the stress concentration can bring down, so that is idea. So, if you see here there are four, three of the methods to improve you can see the higher you go, the stress range it can take higher the stress range it can take means Patrick life will be higher, so that is the idea behind.

So, if you compared the previous revision of x, x prime curve versus the w j, w j is the green color somewhere year's kid, then there and the x curve, x prime curve is just above. So, you can see here the blue line little bit about here and the new one is basically this little green almost coinciding everywhere except that extended little bit. You can see the new curve is slightly lower, of course slightly difficult to see here, but when you actually enlarge it could produced reasonably a and through the results. So, that is why that is 1 and there was no double line the word original, one was single line versus the double line. Probably, I think usually to enlarge it.

So, basically for competition purpose you will be given this values, you do not need to memorize v, you will be given the short like this. For example, the examination point by give you the chart you will able to read the chart because you know what is the stress range that you have. So, you go to the graph, we go to this point and then straightaway

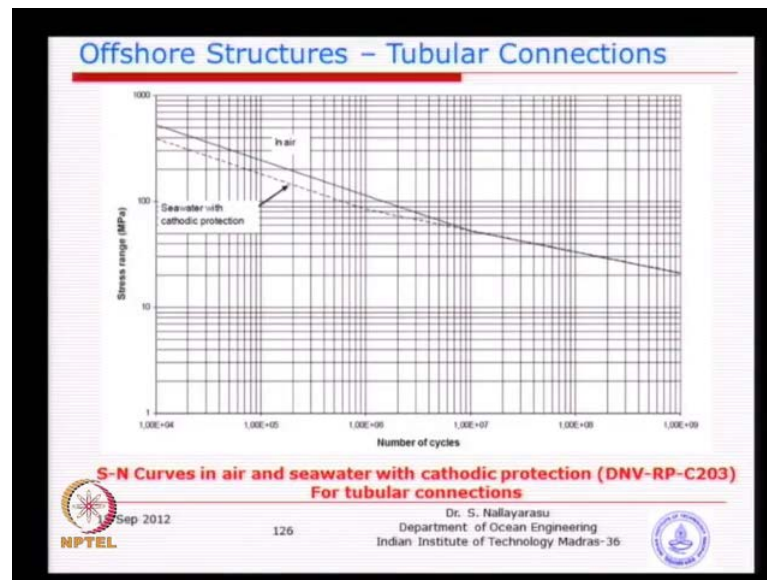
come down, you will be able to read what is the number of cycles that the joint will fail. So, basically to read it all, if you are given the this type of numbers the type of SN curve will be given and the table will be given at the all the SN curve $k-1$ values are $\log k-1$ values and you should be able to calculate using this equation.

A generic equation like this will be given, you can convert that yourself into typically just on the long. So, the purpose of SN curve has to be clearly understood is to get the relationship between the stress range and the cycle to failure and different type of joint different type of SN curve is exists. You have to keep in mind there are several type of joints I have not introduced here and I have just introduced only the tubular connections. So, if you go to DNV curve, you will have twenty different SN curves called different types of plated connection. If you go to shift construction, you will see plenty of different joints there, you will have to select the suitable SN curve applicable to your joint.

If you desire like welded different SN curve presentation weld with a stiffener is a different SN curve. So, you have to selecting suitably fortunately for tubular connections. It is so generalized, any type of connection does not matter whether is a t connection, y connection, x connection does not matter is only a single SN curve. Life has become little bit easier to select, only thing is you will find slide difference between the previous revision of API and the present division of API.

So, you have to use only the present revision which is just basically the twenty fifth additions with a correction supplement which is called a W_j and improved W_j . So, what is improved, W_j basically the weld is smooth end, I think other day we were trying to discuss about probably be have a bit more discussion, how you will be able to improve a profile of weld by simply doing emmer work. You may actually grind it so that the joining of the weld with the apparent material is very smooth means the stress concentration is reduced.

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This is another example taken from DNV 203 which is basically recommended practice for static analysis of these structures of basically tubular connections. I just quit it up, one of the graph you can see almost similar, we just over plot this and you will see that is almost both are them or copied except where is small difference.

There is actually two lines shown here, seawater with crows and protection the tubular joints under water also protected against corrosion as a slide lower stress range comparison to the same joint. If it is not API that means above water, so basically that these is idea behind, so how do we get the calculation for this.

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PALMGREN - MINERS' RULE

The cumulative fatigue damage shall be calculated at the brace chord interface using the following formula as proposed by Palmgren-Miner.

Cumulative Fatigue Damage at a particular location in the connection for design period $D_{cd} = \sum_{j=1}^8 \sum_{i=1}^k \frac{n_i}{N_i}$

n_i = Number of occurrences in each sea-state and a minimum of 8 directions shall be included in the fatigue sea state for $j=1$ to 8 and $i=1$ to k is for all the waves in a particular direction.

N_i = Allowable number of cycles for hot spot stress range (S) corresponding to n_i number of cycles of i^{th} sea state

The fatigue damage for each joint shall be evaluated at a minimum of 8 points on the brace side and 8 points on the chord side as shown in figure. The maximum value among the 8 points shall be taken as the design fatigue damage representing the joint.

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So, we have come up with a steps, now last for classes, we have been discussing about fatigue starting with crack propagation theory, and basically Paris law of crack growth relationship between crack growth. The material constants or material toughness and then we have learned about so called stress concentration factors which typically equation from a was sold to you calculation at a eight points. So, stress concentration factor multiplied by nominal stress is giving would a stress range.

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n - Number of cycles applied stress (S_2)

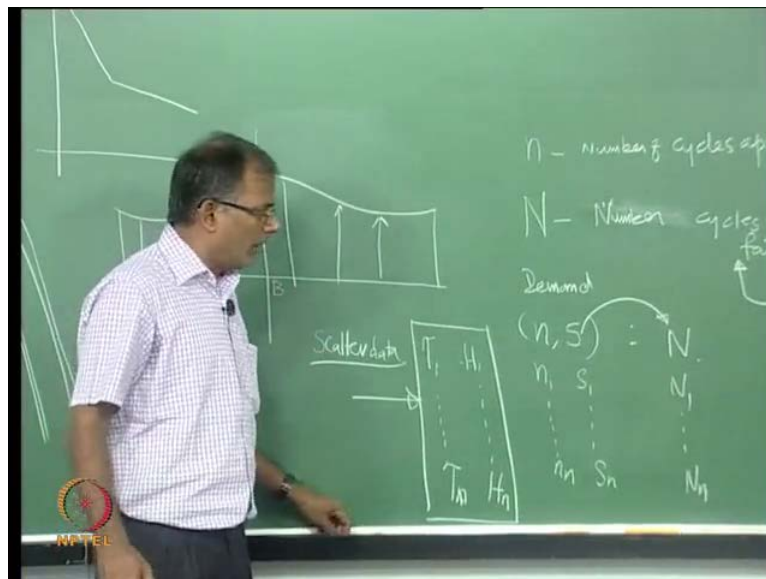
N - Number of cycles to failure

Analysis SCF

Then, you have gone to SN curve to read the number of cycles failure, prior to that it is also at the idea of the number of cycles applied due to external waves on the structures. So, what we know is four variables, you have number of cycles applied is not stress which is basically this, you can call it stress range hotspots stress range. So, these two values this is coming from your analysis, SCF value analysis is done by you, SCF is given by SCF equations parametric equations from in the code number of cycles.

Allowable cycles to failure are you can say a number of cycles to failure that will be better number of cycles to failure. Now, we have number of cycles applied number of cycles that the joint will fail corresponding to that stress, so basically four parameters defined the demand in the capacity demand side.

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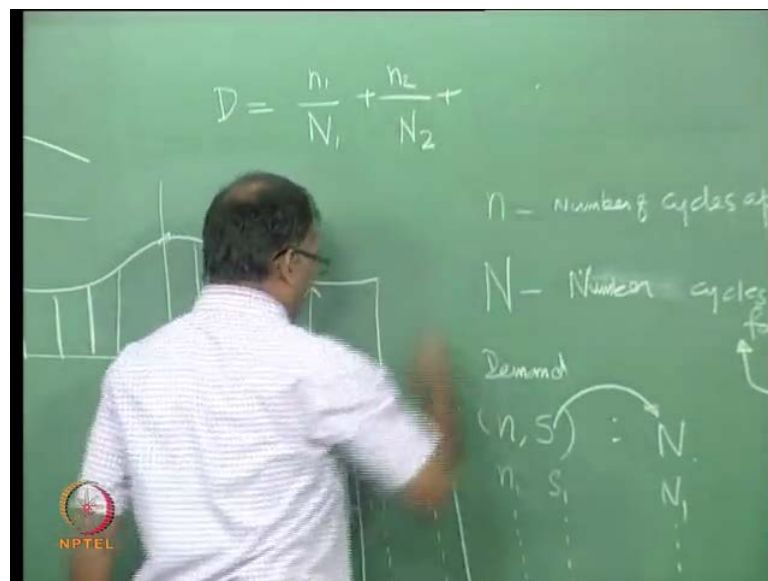


The number of cycles and basically the stress applied bases and the demand side and basically on the capacity side number of cycles that the joint may fail and you have this, but of course is related to this one, the slide is applied. So, remember in the whole picture of the tubular sign for a design life of 25 years, you are not going to have only one value of s , one value of n . You may have several combinations of s values and n values corresponding n values, so basically what will happen is you may have $n_1 s_1$ and n_1 corresponding. So, you may actually repeat and correspondingly because that many waves, so basically t_1 and correspondingly, you will have this.

Here, it is defined SFC state which you have it from your scattered data measured are stimulated or somehow you have got the data from the site at each wide wave period corresponding number of cycles from these to three values. You have calculated the s value because you have done the analysis and you have calculate the SCF that you have gone to number of cycles to failure.

So, once you have this information, now we can just sit back and see what exactly is going to happen every time particular stress value is applied on the structural joint and a damages is done. The damage is hypothetically given as the ratio of number of cycles supplied to number of cycles that the joint may fail so that ratio, for example if I joined sale at 1 million cycle and cycle is also 1 million, then the damage is one. Basically, cumulatively have because of we know very well the flighty gives the phenomena which can start from x and propagate over the period of time. Basically, that is why we have to keep on at the effect and nothing but there is equation describing earlier.

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The fatigue damages is nothing but n_1 divided by N_1 plus n_2 divided by N_2 until all the cycles, where the data are all the waves in that particular field is added together. This is called Tom Gran minus 2 because she proposed to this several years back cannot remember that date, but 30, 40 years back proposed this idea and seems to be well working.

This is because 100 percent you use this idea to design the offshore structures for fatigue and one difference what I have done here. You know typically API requires minimum eight directions. So, that means for a given structure, whether it is supporting structure are fixed structure, so you look at eight directions for the sea state conditions for a fact tangle structures, eight directions means four orthogonal, four diagonal, simply for us ship. Similarly, you will have to end all to be inside and then four quiet drink see, so basically you have to look at the those conditions and get information each directions.

You have find out what could be the potential wave period, where wide and then basically the number of cycles and then carry out the analysis. So, that means this 1 to n 1 to k is nothing but as much as a many number of ways that you may have in that directions. You saw once waves scattering table, you know one big table you have got certain combination of waves and waves period to waves and waves period. Each one will become one case and as long as you have fully filled, then you have more number of cases to remember this calculation is to be done at eight points on the interface.

Remember, we have left right bottom top and then 4, quiet drink point, so quite a lot of competition is to be carried out. So, only differences you are not going to add cumulatively the results of eight points, each point will be monitored separately. You understand the idea know, whereas you will be adding the cumulatively all the sea states will be adding it, whereas each point on that peripheral interface between the brace on the card. Each one is one problem, do not go and add all the damages in the all eight points, there are individual hotspot location.

So, you have to look at them, so do not have to add it, but if you are intelligent enough you do not want to do add eight point, you can figure out which point may actually create more problems fatigue calculation. So, you can only do calculation for that particular point, suppose if you know, but if you do not know what we not and do is you need to repeat this calculation for all the eight points whichever gives you the highest damage. That will be the representative design for that joint, you understand the idea know, whereas for each joint, you have to do the calculations for all the sea state or a directions at them cumulatively.

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Factor of Safety
The fatigue calculation involves several assumptions and to account for uncertainty of parameters in the calculation, suitable factor of safety shall be included.

Failure Critical	Inspectable	Not Inspectable
No	2	5
Yes	5	10

Failure Critical : Primary structure joints failure of which makes the structure unstable

Inspectable : Joints within the reach of manual /ROV inspection. Certain depth can be specified in some cases.

Not Inspectable : Joints that cannot be inspected due to reach or to obstruction such as overlapped portion of the joint.

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Now, many things we have discussed deal, we have discussed from the state scattered data deterministic wave spectral wave. So, you could see that direction number of cycles, there is potentially large amount of uncertainty in the world because of the data is not available and it is going to be actually used by the designers for switcher purpose. That availability is only look at the past and it could be longer term data or it could be shorter term data. So, what we are going to use a lot of assumptions made for a extra violation purpose for next 20 years, next 30 years next 50 years.

So, there is a reasonable amount of uncertainty or be demand side, means there could be it could exceed or it could load than that. It could be lower than that nobody is very because joint is not going to fat for sure it may be overdesigned, but then we can be happy. If you can exceed the joint is going to definitely failed, so as usual we need to have the factor of safety on the damage what we are calculated here. That means we can alive theoretical to one the ratio can become 1, but we cannot low because we need a safety factor and that is the typically like member designed.

We had a factor of safety of one point, how much 1.67, so typically here we see here in this table we have a factor safety of minimum to that was you have been using of factor of safety of many years as suggested by API. In the recent times, studies integrate that the scattering of the scattered data, you know basically the amount of information available to the design is quite limited. Nobody wants to spend time and money

measuring waves at the particular side, what they normally use to mathematical simulation, but they actually very well mathematical simulation has got serious limitations.

That is why you have too applied high higher factor of safety that is one of the reason, but the other reason you can see here inspect able not possible to inspect able. That means if you see a jacket 100 meters water depth, people can die if you have a gone for now without any assisting equipment. It can die probably for 10 meters, 15 meters, 20 meter, but after that you may not be able to go down, but with special equipments, you can read as much as 50 meter. The hand, which even though equipments may not be able to take, you may actually need a compression chamber.

So, when you have such requirements inspection becomes too expensive, maybe sometimes not a feasible. So, that is why we call it a possible to inspect or may not be able to inspect the reason why we need to see this inspection. The fatty damage is cumulative, for example if you go for five years plan, every five year will go down look at the joint whether any crack or any propagation or any initiation because you remember the threshold. Until the threshold is reached, joint is not going to show any failures, only the threshold is reached, then starts opening up and you can see so every five years, you have a plane to go on look at it.

If there is a problem, you can do two things you can actually prevent the joint structures from feeling by doing repairs on the structural connection you can shutdown perform not use it to avoid human laws. So, two things you can do and that is why this inspection is very important terms of fatigue evaluation. So, you need to define what is period of inspection, you would like to do, so in order to do that if it is possible to inspect by means of basically possible by the owners, this is left to the designer and owner. If you go to the company like SHELL, there may have all possibilities are equipments and facilities to do inspection, you come to some other companies you may not have they do not have anything to inspect.

You may have limitations, so that is why if you do not want to do inspections, you do not have means of inspection go for higher fixity. If you can do inspection every time in every year then you can reduce the risk is reduced, so that is why inspection possible

inspection not possible and failures critical and non critical. So, what you cannot inspect if the joint sales, if it is a secondary joints, does not make the structures to collapse.

That needs to be decided by the designer, designer knows which joins is critical joints, so you can identify whichever joint is very critical apply higher factor city that is the idea behind simple matrix which is normally applied to almost all jackets. You can see at the lower end of the matrix, which is 1, so that means you need the minimum factors to and as much as you can go to 10.