MoreVision Report

MoreVision Limited
Old School House
Stainburn
Otley
LS21 2LJ
UK
Tel :+44 113 8152220
Mob:+44 771 4291194
www.morevision.co.uk

DOCUMENT TITLE

Weld problems bought to the attention of John Doyle by engineers attending the ExcelCalcs “Fatigue of Welded Structures’ course in Dallas July 2011

Prepared for Client: Atlas Copco

Revision History

Revision	Description	Date	Prepared by	Checked by	Approved by
Rev. 01	First Issue preliminary results for client review.		John Doyle		

© MoreVision Limited. www.MoreVision.co.uk – ● Engineering Consultants ● Finite Element Analysis ● Strain Gauge Testing ● www.ExcelCalcs.com developers

Contents

© MoreVision Limited. www.MoreVision.co.uk – ● Engineering Consultants ● Finite Element Analysis ● Strain Gauge Testing ● www.ExcelCalcs.com developers

1 Attendees Weld/Fatigue Problems

This report documents the problems bought to the attention of John Doyle by engineers attending the ExcelCalcs “Fatigue of Welded Structures’ course in Dallas July 2011. It sets out his response in the form of ad hoc calculations. The problem and solution are described at the start of each section.

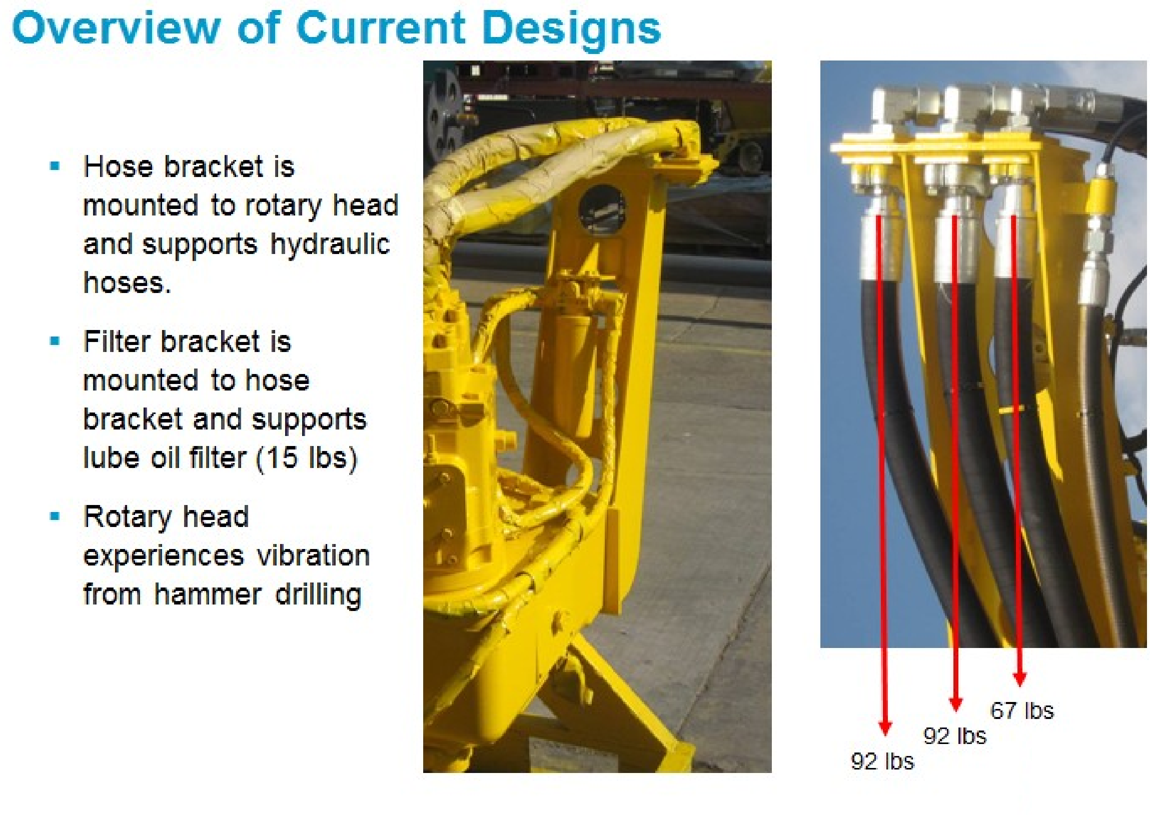
Given the type and nature of the problems presented it was concluded that all the course elements needed to be covered so that problems could be diagnosed correctly.

- Weld Static Strength – see problem in section 1.2 & 1.4
- Classic Fatigue Problems – see problem in section 1.5
- Fatigue of Welded Structures – see problem in section 1.1 & 1.3
- Case Studies – problem in see section 1.1

1.1 Peter’s Hose Bracket Problem

Peter showed John Doyle a problem where a hose bracket was cracking prematurely.

SOLUTION: John performed a modal analysis of the bracket and showed that one mode was coincident with the 30 Hertz hammer frequency which would give rise to resonance. The mode of vibration showed highest stress at the exact location where cracks were discovered. Assuming 2% damping which is typical of welded steel structures an impact factor is calculated. Redesign a stiffer bracket to separate its first mode of vibration at least 1.41 times greater than the forcing ‘hammer’ frequency.



© MoreVision Limited. www.MoreVision.co.uk - ● Engineering Consultants ● Finite Element Analysis ● Strain Gauge Testing ● www.ExcelCalcs.com developers

Filter Bracket Failure

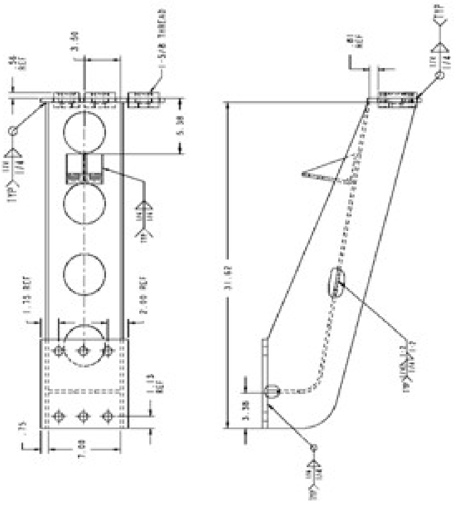
- Filter bracket fails between skip welds and nearby slots

End of skip weld

Macgyver??

Hose Bracket Failure

- Crack originates at the tip of the weld on the heavily loaded side



© MoreVision Limited. www.MoreVision.co.uk – • Engineering Consultants • Finite Element Analysis • Strain Gauge Testing • www.ExcelCalcs.com developers

Purpose of calculation:

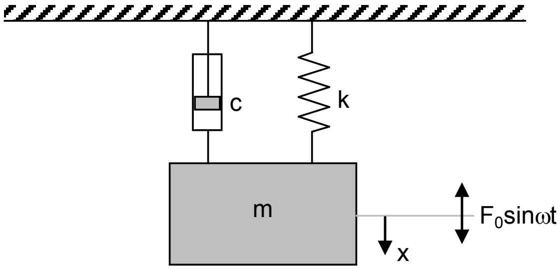
Calculate an impact factor applicable to forced vibration of a single degree of freedom.

Calculation Reference

Schaum's Mechanical Vibrations

Amazon.com Amazon.co.uk Amazon.fr Amazon.de Amazon.ca

Calculation Validation



Amplitude of alternating force

F_0 = 11193 N

Mass

m = 3.700 Te

Natural frequency

F_n = 30.451 Htz

Natural frequency of system

ω_n = 191.3 rads/sec = $2\pi F_n$

Stiffness

k = 135445 N/mm = $m\omega_n^2$

Time period of oscillating force

T_w = 0.0333333 s

Frequency of load application

F_{Load} = 30.0 Hertz = $1 / T_w$

Frequency of load application

ω = 188.5 rads/sec = $2\pi F_{Load}$

damping factor

ζ = 10% assumed (typical for steel structres)

System damping coefficient

c = 141.6 Ns/mm = $2m\zeta\omega_n$

Static deflection

x_0 = 0.1 mm = F_0 / k

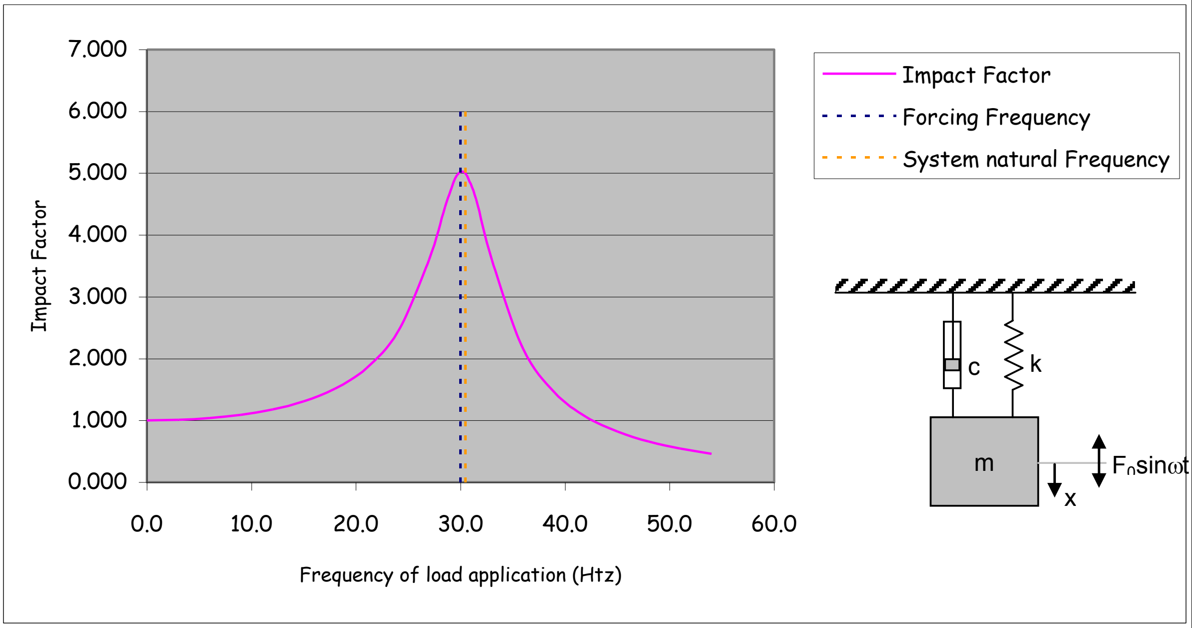
Dynamic amplidude of deflection

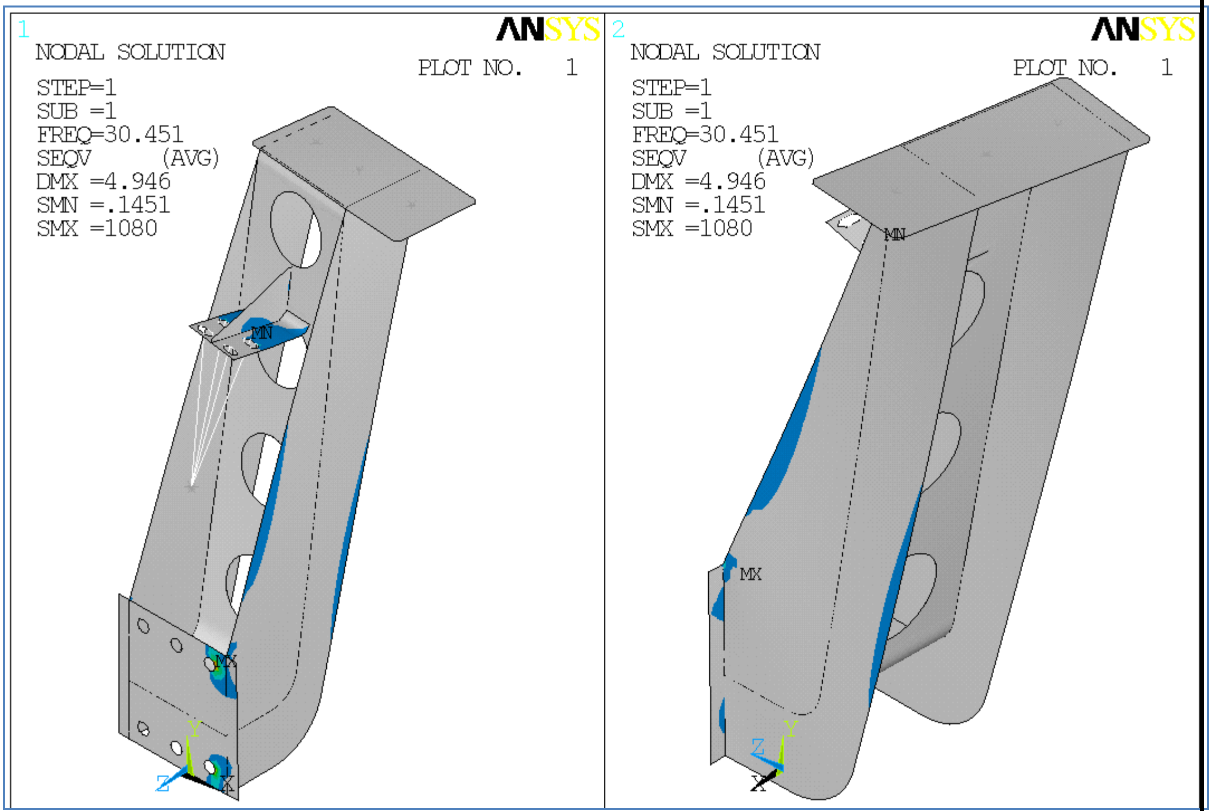
x_w = 0.4 mm = $\dfrac{F_0}{\sqrt{[\{k - m\omega^2\}^2 + \{c\omega\}^2]}}$

Impact Factor

F_{imp} = 5.020 = $\dfrac{x_w}{x_0}$

© MoreVision Limited. www.MoreVision.co.uk - ● Engineering Consultants ● Finite Element Analysis ● Strain Gauge Testing ● www.ExcelCalcs.com developers





Fundamental mode of vibrations is coincident with 30hertz hammer frequency. Thus large dynamic amplification.

© MoreVision Limited. www.MoreVision.co.uk - • Engineering Consultants • Finite Element Analysis • Strain Gauge Testing • www.ExcelCalcs.com developers

Purpose of calculation:

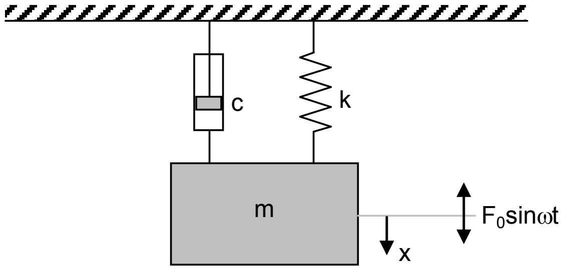
Calculate an impact factor applicable to forced vibration of a single degree of freedom.

Calculation Reference

Schaum's Mechanical Vibrations

Amazon.com Amazon.co.uk Amazon.fr Amazon.de Amazon.ca

Calculation Validation



Amplitude of alternating force

F_0 = 11193 N

Mass

m = 3.700 Te

Natural frequency

F_n = 38 Htz

Natural frequency of system

ω_n = 238.8 rads/sec = $2\pi F_n$

Stiffness

k = 210925 N/mm = $m\omega_n^2$

Time period of oscillating force

T_w = 0.0333333 s

Frequency of load application

F_{Load} = 30.0 Hertz = $1 / T_w$

Frequency of load application

ω = 188.5 rads/sec = $2\pi F_{Load}$

damping factor

ζ = 10% assumed (typical for steel structres)

System damping coefficient

c = 176.7 Ns/mm = $2m\zeta\omega_n$

Static deflection

x_0 = 0.1 mm = F_0 / k

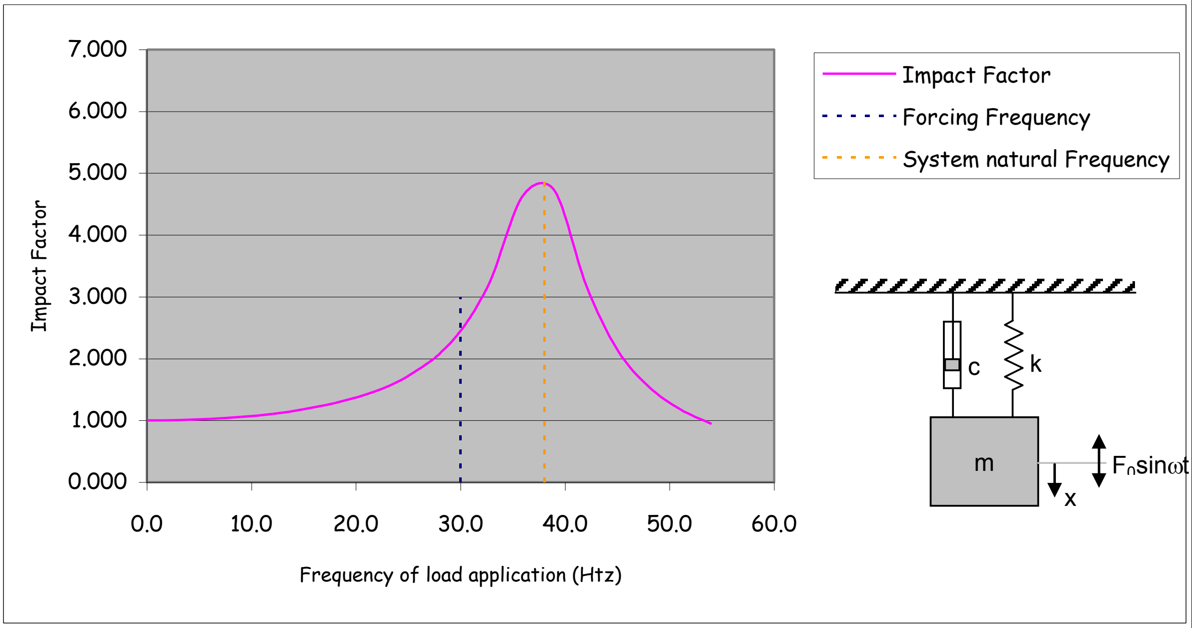
Dynamic amplidude of deflection

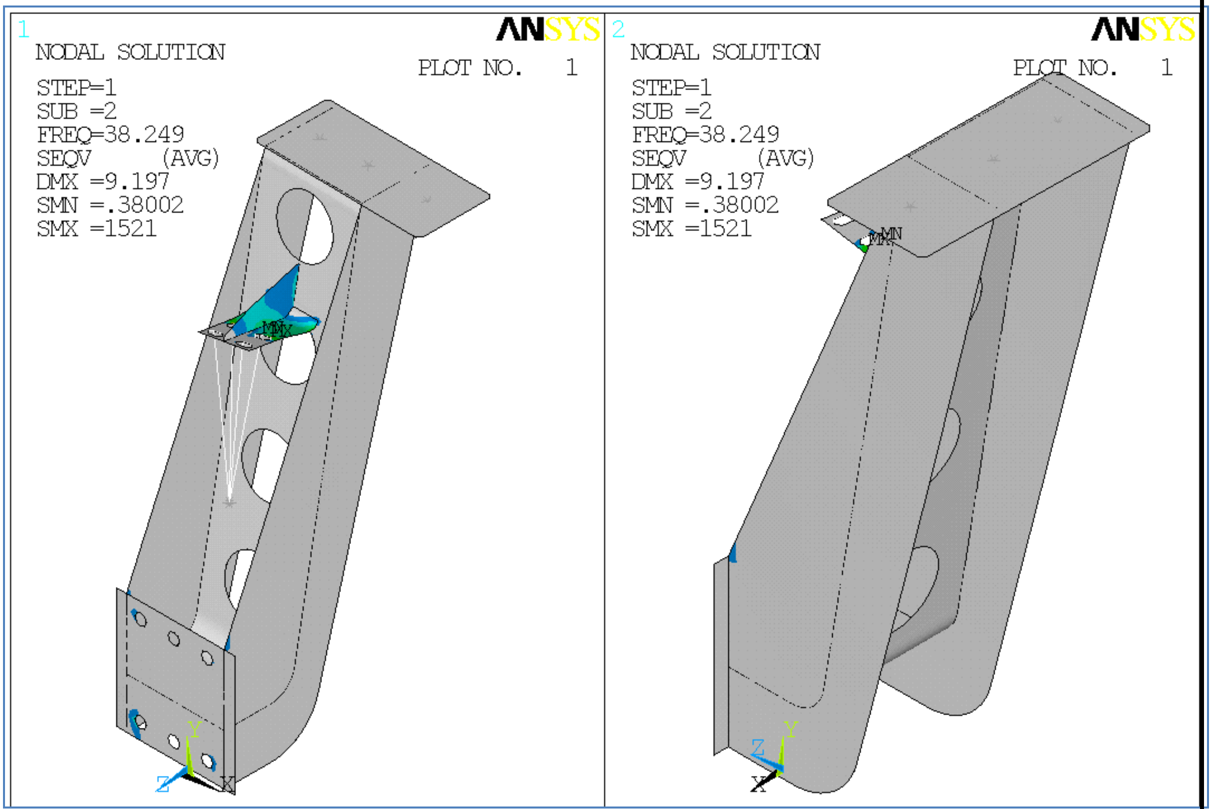
x_w = 0.1 mm = $\dfrac{F_0}{\sqrt{[\{k - m\omega^2\}^2 + \{c\omega\}^2]}}$

Impact Factor

F_{imp} = 2.448 = $\dfrac{x_w}{x_0}$

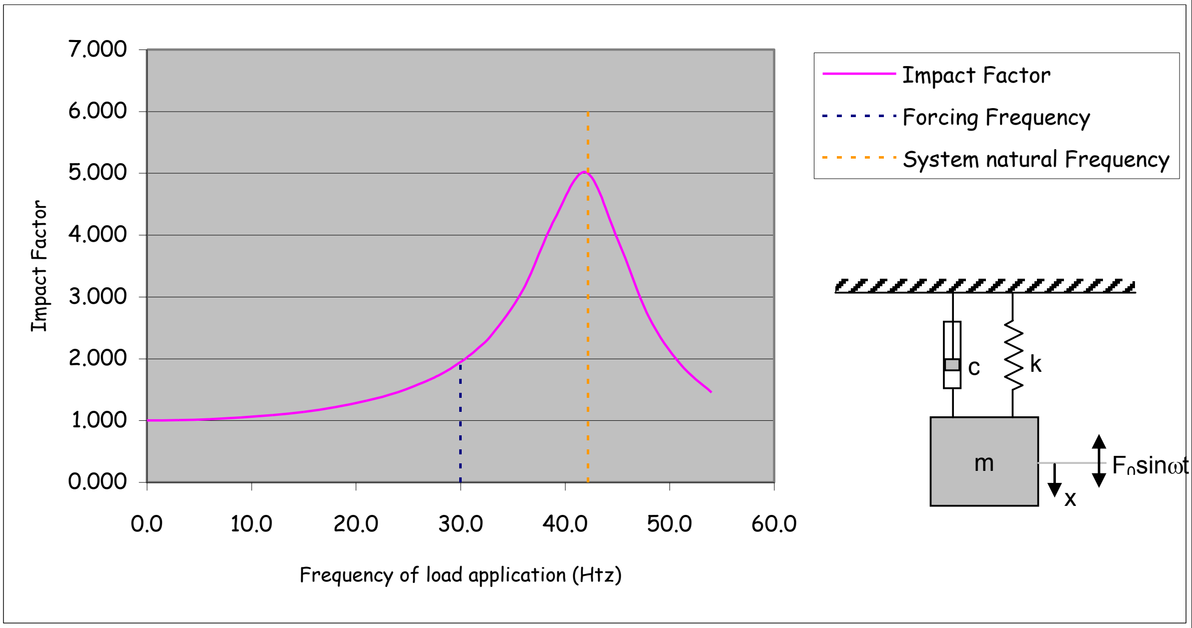
© MoreVision Limited. www.MoreVision.co.uk - ● Engineering Consultants ● Finite Element Analysis ● Strain Gauge Testing ● www.ExcelCalcs.com developers

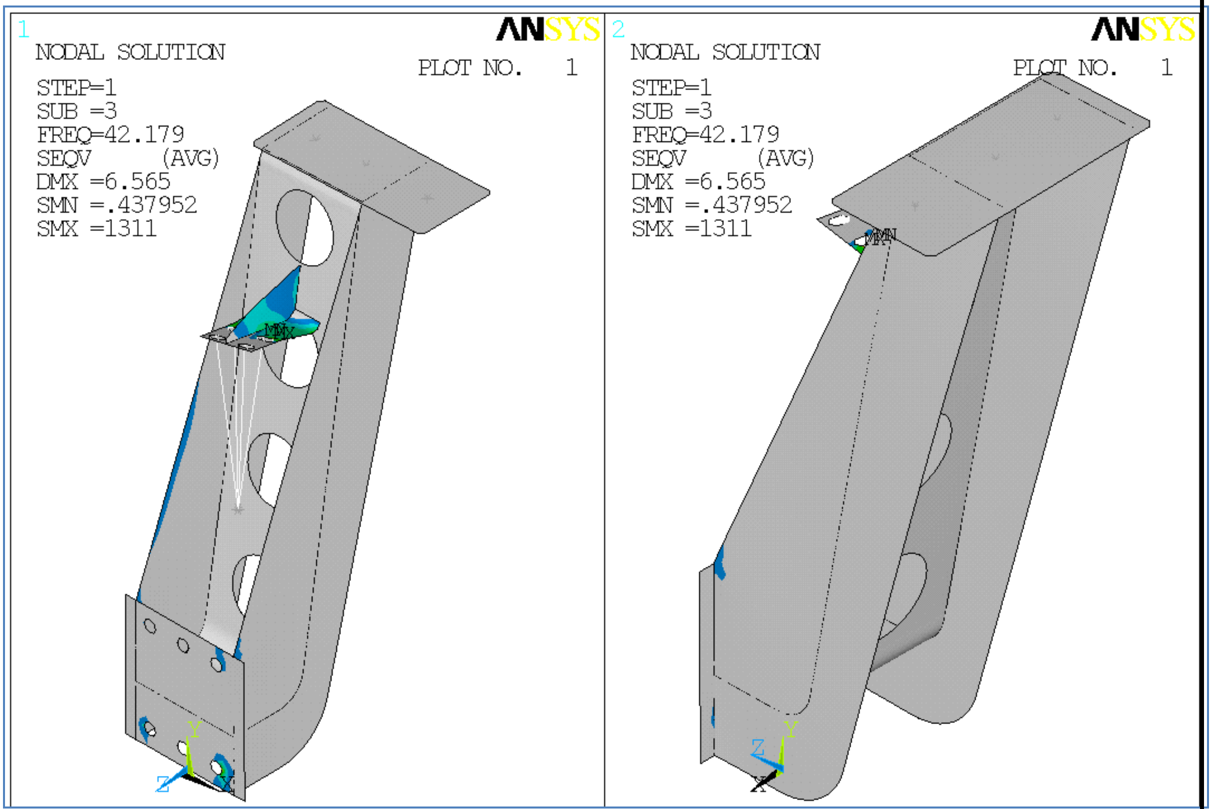




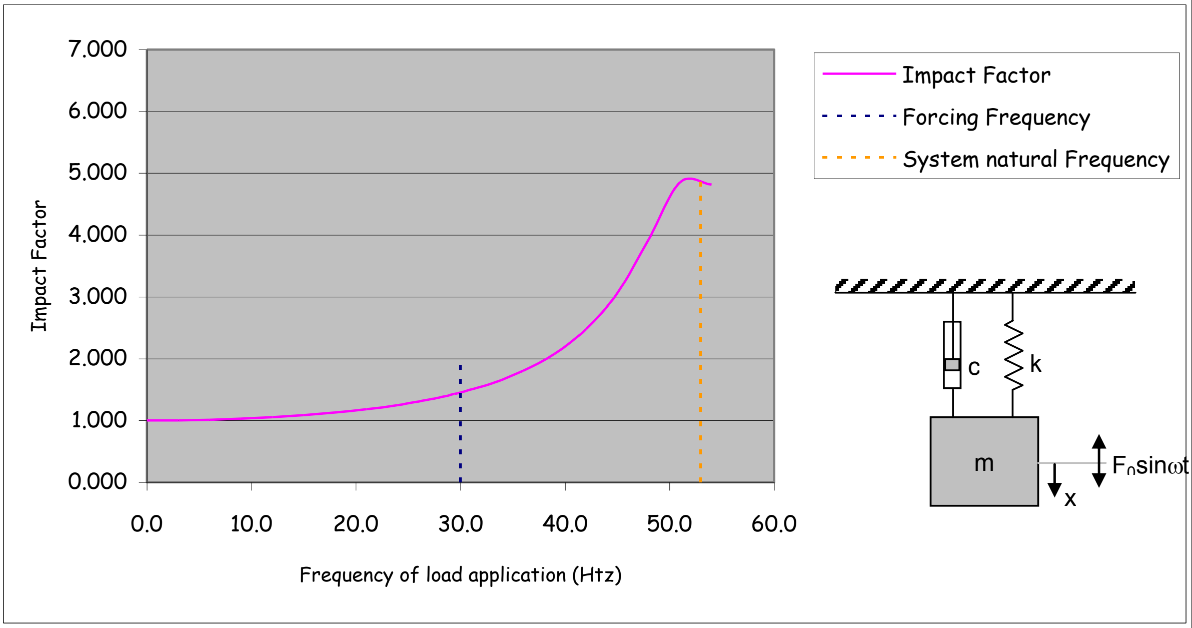
Second mode close to hammer frequency of 30Hertz

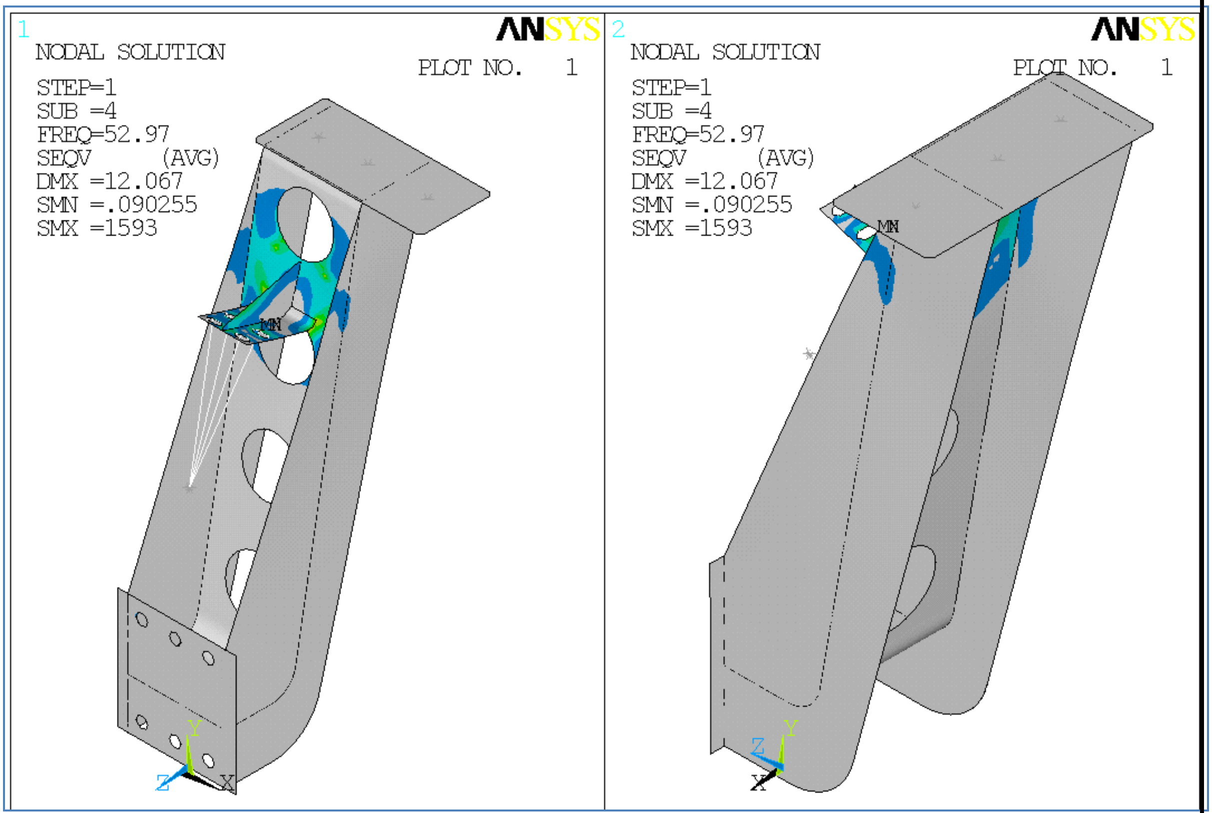
© MoreVision Limited. www.MoreVision.co.uk - • Engineering Consultants • Finite Element Analysis • Strain Gauge Testing • www.ExcelCalcs.com developers



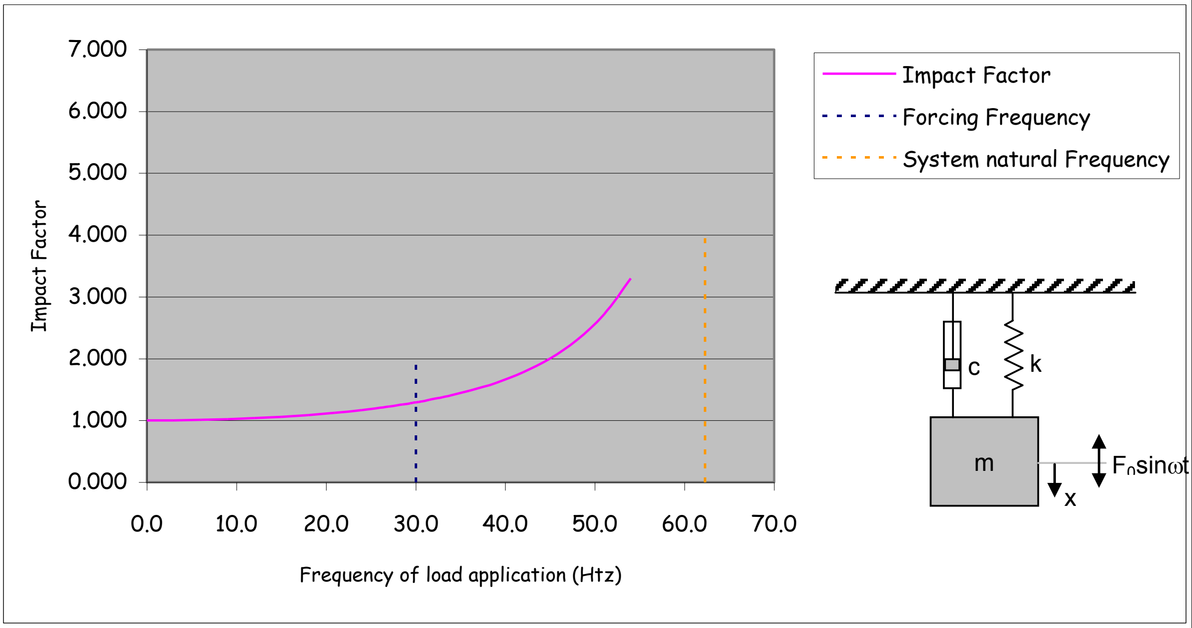


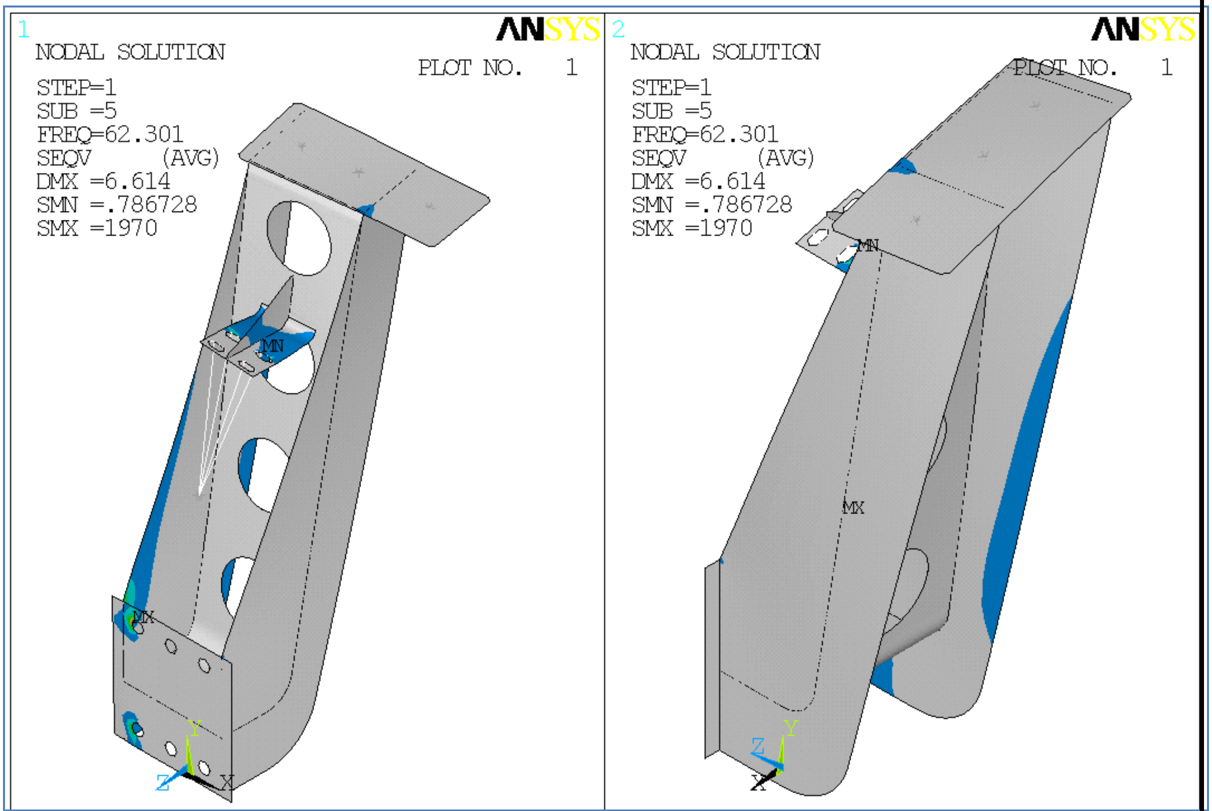
© MoreVision Limited. www.MoreVision.co.uk - • Engineering Consultants • Finite Element Analysis • Strain Gauge Testing • www.ExcelCalcs.com developers





© MoreVision Limited. www.MoreVision.co.uk - • Engineering Consultants • Finite Element Analysis • Strain Gauge Testing • www.ExcelCalcs.com developers





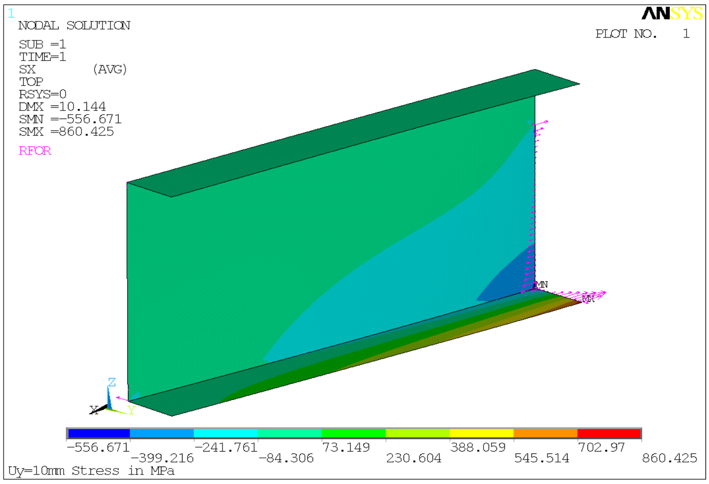
© MoreVision Limited. www.MoreVision.co.uk - • Engineering Consultants • Finite Element Analysis • Strain Gauge Testing • www.ExcelCalcs.com developers

1.2 James's End Bracket Problem

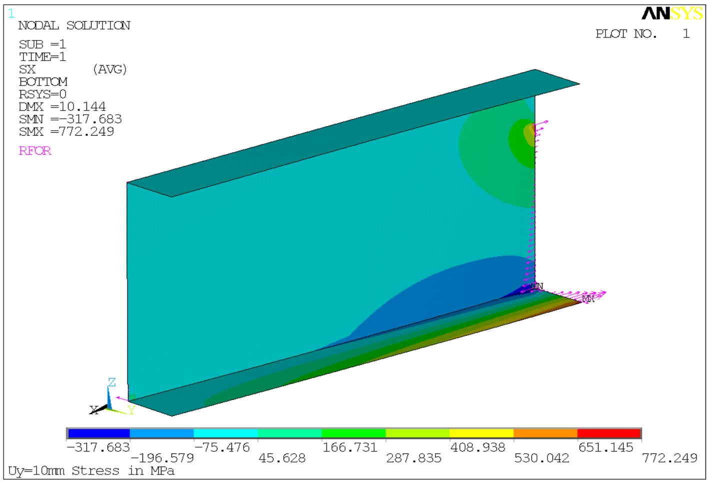
A cantilever beam welded to the main frame was cracking during manufacture of the frame.

SOLUTION: John Doyle discounted fatigue as the problem as cracks are observed during manufacture not in service. When a second part is attached using bolts at the end of the cantilever a displacement of around 10mm is imposed. John showed that the cantilever was so stiff that just a 2.5mm displacement would overload welds at the root of the cantilever. The connection could be reinforced at the cantilever root or the 10mm displacement could be minimised by redesign of the bolted joint.

© MoreVision Limited. www.MoreVision.co.uk – ● Engineering Consultants ● Finite Element Analysis ● Strain Gauge Testing ● www.ExcelCalcs.com developers



$\sigma_t =$ 860.425 MPa



$\sigma_b =$ 772.249 MPa

$\sigma_{dFE} =$ 816.337 MPa $= \dfrac{\sigma_t + \sigma_b}{2}$ 118399.9 psi

$\sigma_{bFE} =$ 44.088 MPa $= \dfrac{\sigma_t - \sigma_b}{2}$ 6394.435 psi

$\sigma_t =$ 860.425 MPa $= \sigma_{dFE} + \sigma_{bFE}$

$\sigma_b =$ 772.249 MPa $= \sigma_{dFE} - \sigma_{bFE}$

© MoreVision Limited. www.MoreVision.co.uk - • Engineering Consultants • Finite Element Analysis • Strain Gauge Testing • www.ExcelCalcs.com developers

Stress In Fillet Weld

1 Purpose of calculation

Calculate stress in a fillet weld from known plate stresses.

2 Calculation Reference

Calculated from first principles.

3 Calculation Validation

Cell formulae verified by XLC Addin.

4 Calculation Units

US Unit (in)

5 Sketch

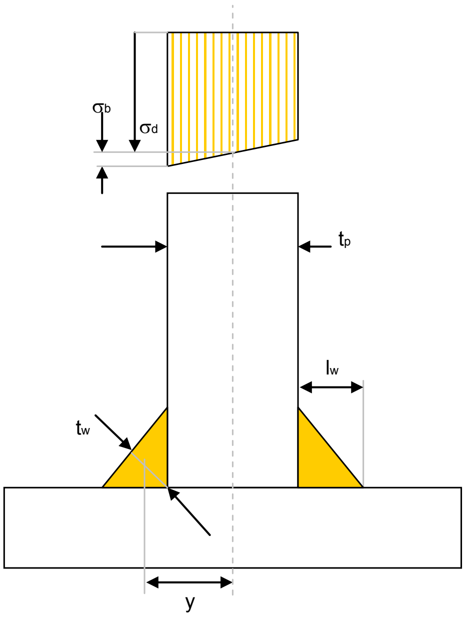


plate thickness

$t_p =$ 0.5 in

Weld leg length

$l_w =$ 0.5 in

Weld fillet throat

$t_w =$ 0.3535 in $= 0.707 l_w$

Weld shear to plate direct stress ratio

$R_d =$ 0.70721358 $= \dfrac{t_p}{2t_w}$

Plate bending section modulus per unit length

$Z_p =$ 0.04166667 in² $= \dfrac{t_p^3 / 12}{t_p / 2}$

plate centre line to weld thickness centriod

$y =$ 0.37496225 in $= \dfrac{t_p}{2} + \dfrac{0.707t_w}{2}$

Weld bending section modulus (parallel axis theorem)

$Z_w =$ 0.26509831 in² $= \dfrac{2t_w y^2}{y}$

Weld shear to plate bending stress ratio

$R_b =$ 0.1571744 $= \dfrac{Z_p}{Z_w}$

Deflection of Channel

$\delta =$ 0.09756679 in 2.48mm

Plate direct stress

$\sigma_d =$ 29,342 psi $= \sigma_{dFE} \cdot 145.038 \left(\dfrac{\delta}{10 / 25.4} \right)$ 145.038 to convert from Mpa to psi

Plate shear stress

$\tau_p =$ 0 psi

Plate bending stress

$\sigma_b =$ 1,585 psi $= \sigma_{bFE} \cdot 145.038 \left(\dfrac{\delta}{10 / 25.4} \right)$

Weld shear due to plate direct stress

$\tau_{wd} =$ 20750.931 psi $= \mathrm{abs}(\sigma_d R_d)$

Weld shear due to plate shear stress

$\tau_{ws} =$ 0 psi $= \mathrm{abs}(\tau_p R_d)$

Weld shear due to plate bending stress

$\tau_{wb} =$ 249.069019 psi $= \mathrm{abs}(\sigma_b R_b)$

Total weld shear stress

$\tau_w =$ 21000 psi $= \sqrt{([\tau_{wd} + \tau_{wb}]^2 + \tau_{ws}^2)}$

Allowable weld throat shear stress

$\tau_{wa} =$ 21000 psi

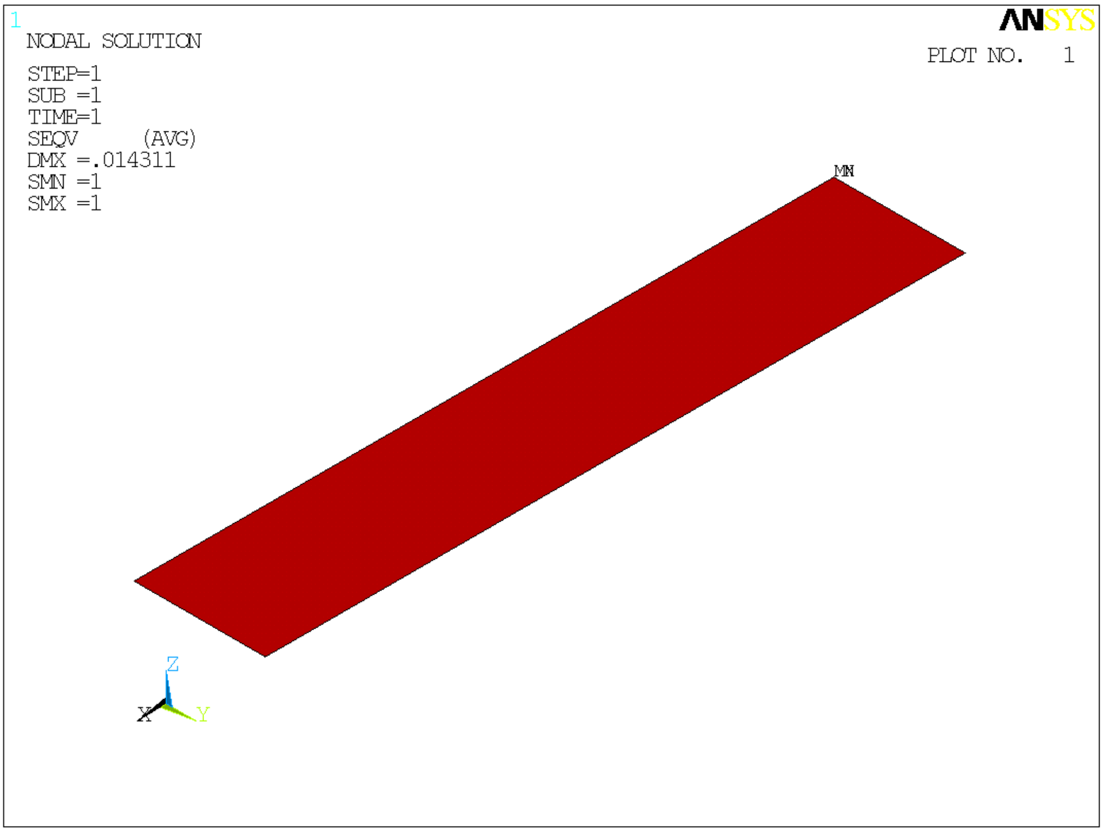
$F_{D:C} =$ 100% psi

© MoreVision Limited. www.MoreVision.co.uk - • Engineering Consultants • Finite Element Analysis • Strain Gauge Testing • www.ExcelCalcs.com developers

1.3 Steven's Main Frame Problem

A transverse member is welded to a longitudinal member which was cracking prematurely in service.

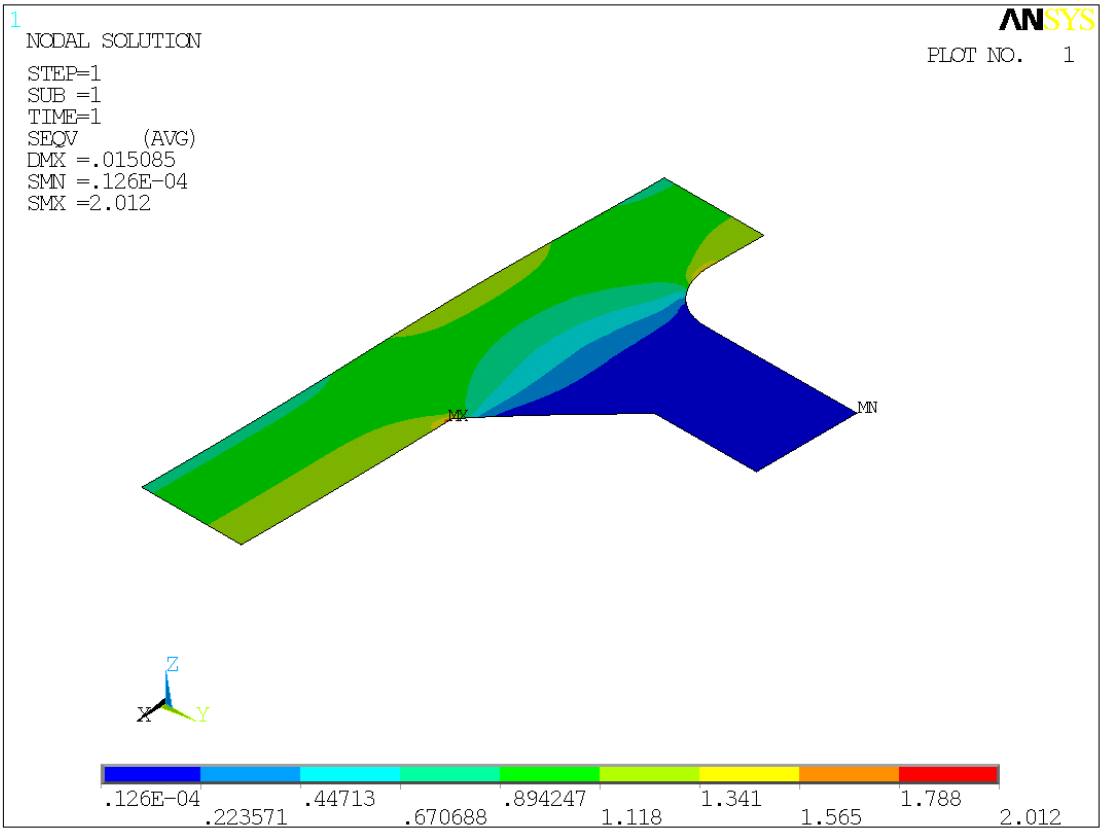
SOLUTION: John Doyle showed Steven how material could be removed so that the stress at the tip of the weld is reduced. Fatigue life is increased from 133,000cycles to an infinite life.



Flange with no transverse attachment – SCF = 1.000

Original Detail:

© MoreVision Limited. www.MoreVision.co.uk - • Engineering Consultants • Finite Element Analysis • Strain Gauge Testing • www.ExcelCalcs.com developers



Set the fatigue category using Table 2.4 AWS D1.1 2006 using the selector →

6.4 E Equal thickness loaded transverse member connection part pen ground R≤2in.

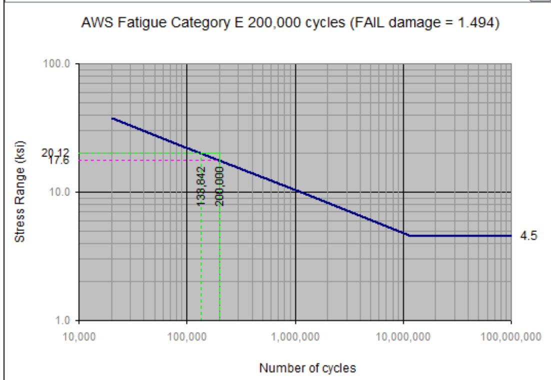
Fatigue category	FatCat=	E	
Fatigue constant from Table A-K3.1	C_f =	1100000000	
Threshold fatigue stress range	F_{TH} =	4.5	ksi [31MPa]
Fatigue Index	i =	0.333	
Reduction Factor (only cat C' & C")	R =	1	0
Number of cycles to threshold	N_{TH} =	12,016,930	$= C_f / ([F_{TH} / R]^{1/i})$

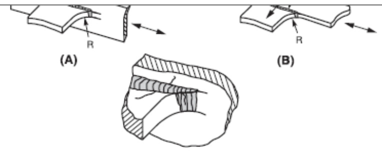
Calculate allowable stress range for a number of cycles

Number of stress fluctuations	n =	200,000	
Allowable stress Range	F_{SR} =	17.6	ksi $= R\left(\frac{C_f}{n}\right)^i$

Calculate fatigue damage for a given stress and number of cycles

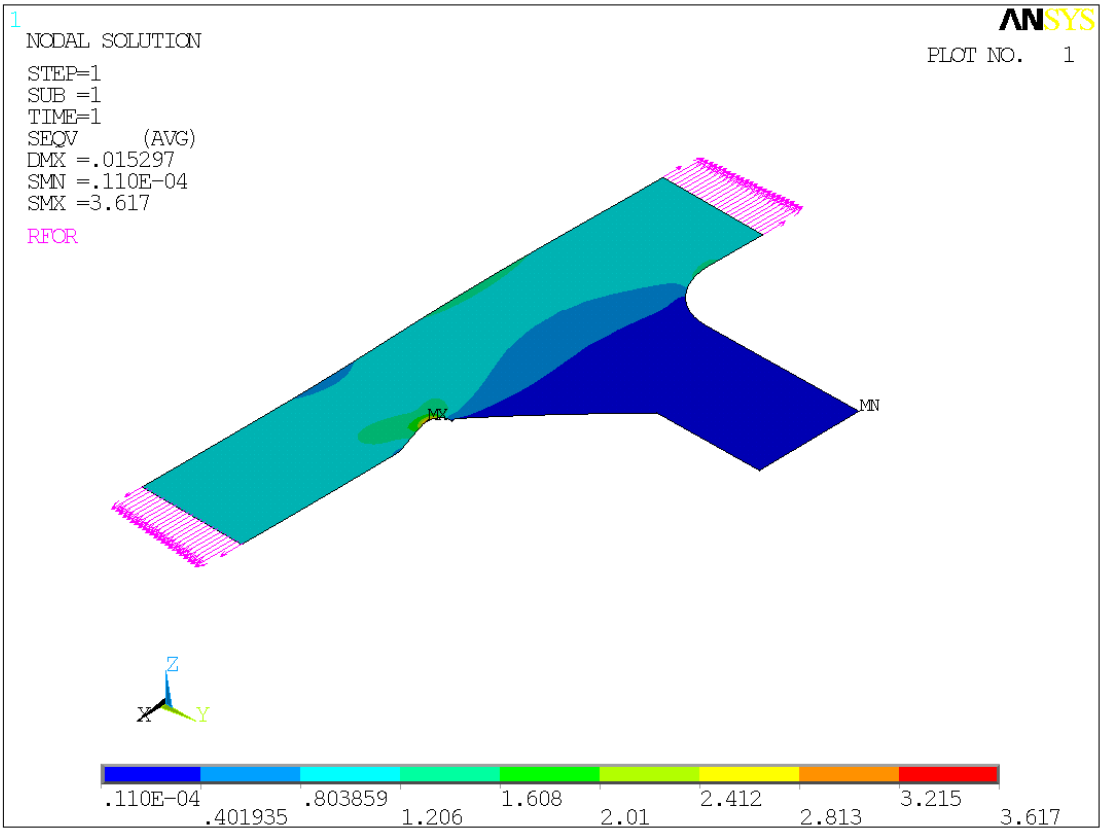
Applied Stress Range	F_{SRA} =	20.12	ksi
Number of cycles to failure	N_f =	133,842	$= C_f / ([F_{SRA} / R]^{1/i})$
Fatigue Damage	D =	1.494	$= \text{if}(F_{SRA}>F_{TH}, n / N_f, 0)$

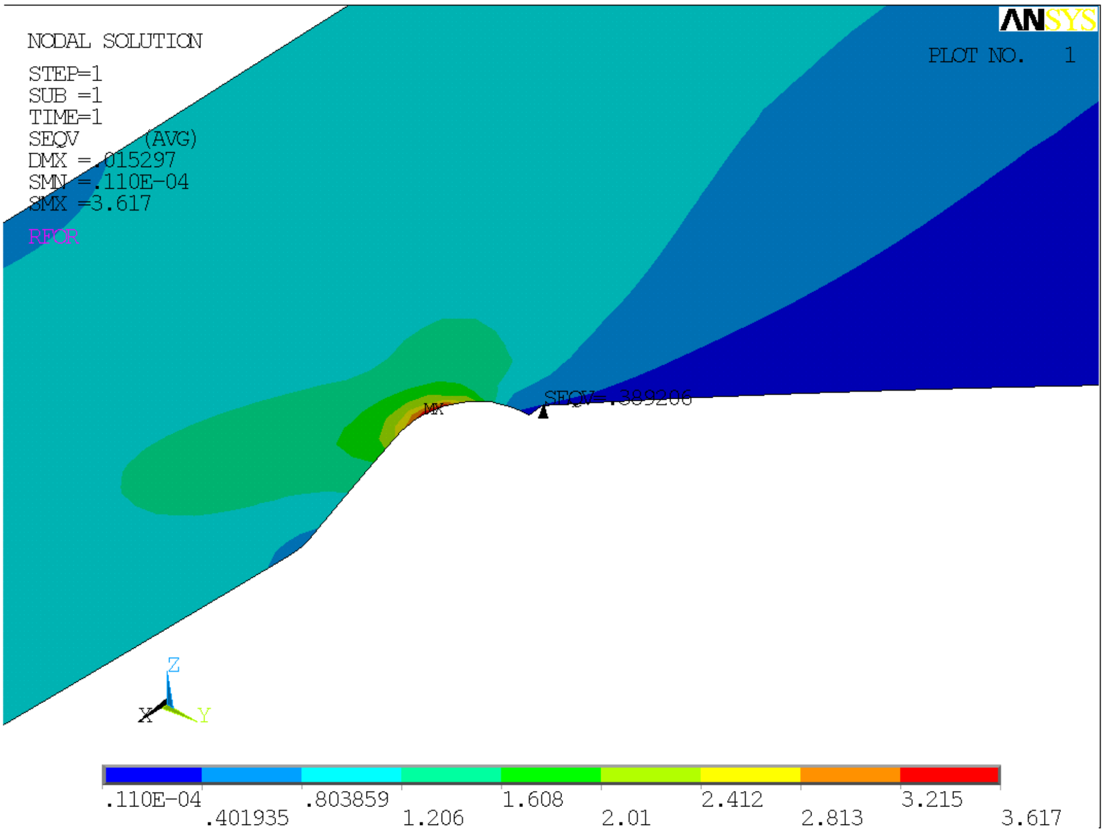


Description	Stress Category	Constant C_f	Threshold F_{TH} ksi (Mpa)	Potential Crack Initiation Point	Illustrative Typical Examples
stress at transverse members, with or without transverse stress, attached by fillet or PJP groove welds parallel to direction of stress when the detail embodies a transition radius, R, with weld termination ground smooth.				In weld termination or from the toe of the weld extending into member	
R > 2 in. [50 mm]	D	22×10^8	7 [48]		
R ≤ 2 in. [50 mm]	E	11×10^8	4.5 [31]		

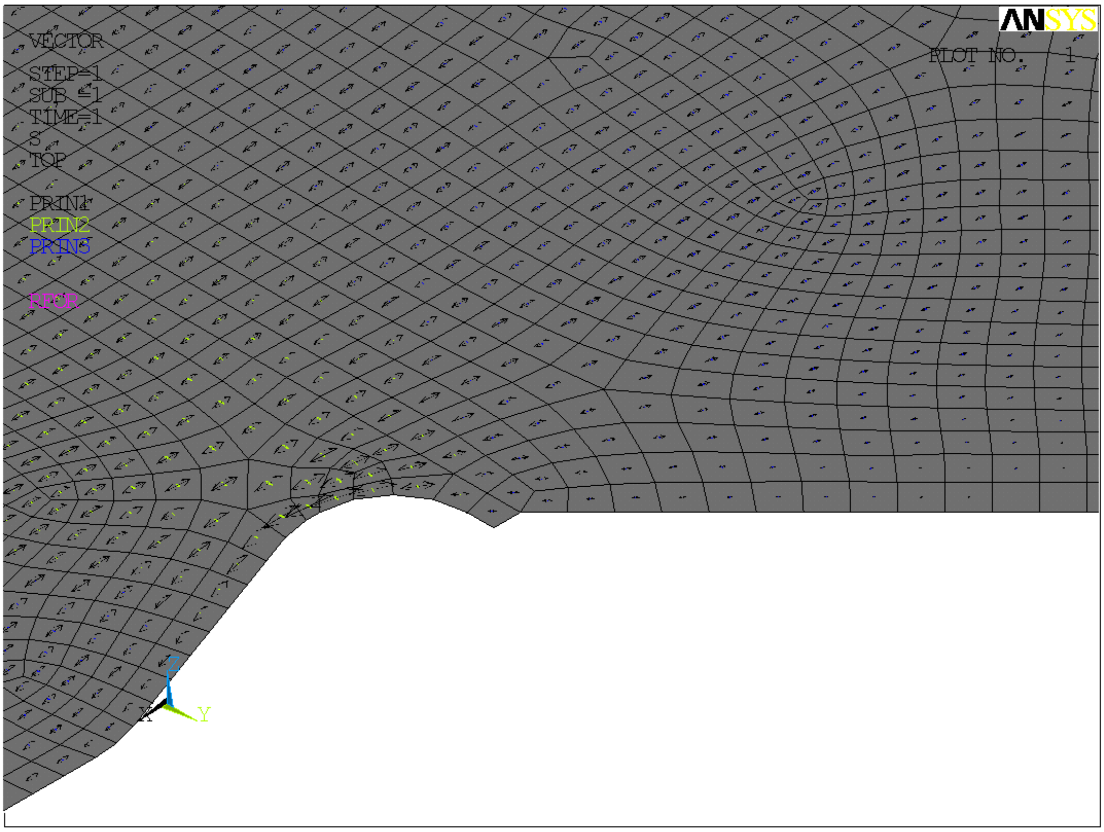
After Modification

© MoreVision Limited. www.MoreVision.co.uk - ● Engineering Consultants ● Finite Element Analysis ● Strain Gauge Testing ● www.ExcelCalcs.com developers





© MoreVision Limited. www.MoreVision.co.uk - • Engineering Consultants • Finite Element Analysis • Strain Gauge Testing • www.ExcelCalcs.com developers



Set the fatigue category using Table 2.4 AWS D1.1 2006 using the selector →

6.4 E Equal thickness loaded transverse member connection part pen ground R≤2in.

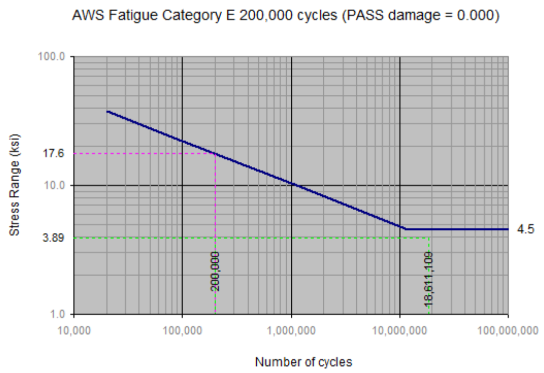
Fatigue category	FatCat=	E	
Fatigue constant from Table A-K3.1	C_f =	1100000000	
Threshold fatigue stress range	F_{TH} =	4.5	ksi [31MPa]
Fatigue Index	i =	0.333	
Reduction Factor (only cat C' & C")	R =	1	0
Number of cycles to threshold	N_{TH} =	12,016,930	$= C_f / ([F_{TH} / R]^{1/i})$

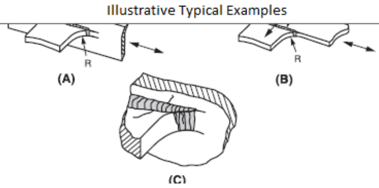
Calculate allowable stress range for a number of cycles

Number of stress fluctuations	n =	200,000	
Allowable stress Range	F_{SR} =	17.6	ksi $= R\left(\frac{C_f}{n}\right)^i$

Calculate fatigue damage for a given stress and number of cycles

Applied Stress Range	F_{SRA} =	3.89	ksi
Number of cycles to failure	N_f =	18,611,109	$= C_f / ([F_{SRA} / R]^{1/i})$
Fatigue Damage	D =	0.000	$= \text{if}(F_{SRA}>F_{TH}, n / N_f, 0)$



Description	Stress Category	Constant C_f	Threshold F_{TH} ksi (Mpa)	Potential Crack Initiation Point	Illustrative Typical Examples
stress at transverse members, with or without transverse stress, attached by fillet or PJP groove welds parallel to direction of stress when the detail embodies a transition radius, R, with weld termination ground smooth.				In weld termination or from the toe of the weld extending into member	
R > 2 in. [50 mm]	D	22×10^8	7 [48]		
R ≤ 2 in. [50 mm]	E	11×10^8	4.5 [31]		

© MoreVision Limited. www.MoreVision.co.uk - • Engineering Consultants • Finite Element Analysis • Strain Gauge Testing • www.ExcelCalcs.com developers

Check high stress in parent material – high stress but better fatigue detail. Fatigue damage only 0.383 compared to 1.494 in the original detail:

Set the fatigue category using Table 2.4 AWS D1.1 2006 using the selector →

Fatigue category	FatCat=	A	
Fatigue constant from Table A-K3.1	C_f =	25000000000	
Threshold fatigue stress range	F_{TH} =	24	ksi [165MPa]
Fatigue Index	i =	0.333	
Reduction Factor (only cat C' & C")	R =	1	
Number of cycles to threshold	N_{TH} =	1,791,272	$= C_f / ([F_{TH} / R]^{1/i})$

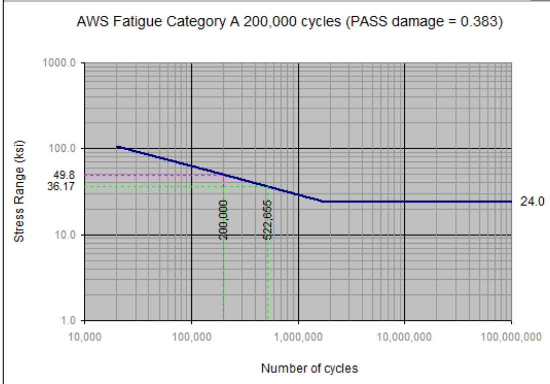
Calculate allowable stress range for a number of cycles

Number of stress fluctuations	n =	200,000	
Allowable stress Range	F_{SR} =	49.8	ksi $= R\left(\frac{C_f}{n}\right)^i$

Calculate fatigue damage for a given stress and number of cycles

Applied Stress Range	F_{SRA} =	36.17	ksi
Number of cycles to failure	N_f =	522,655	$= C_f / ([F_{SRA} / R]^{1/i})$
Fatigue Damage	D =	0.383	= if($F_{SRA}>F_{TH}$, n / N_f , 0)

1.1 A Plain material smooth edge



Description	Stress Category	Constant C_f	Threshold F_{TH} ksi (Mpa)	Potential Crack Initiation Point	Illustrative Typical Examples
Section 1—Plain Material Away from Any Welding					
1.1 Base metal, except non-coated weathering steel, with rolled or cleaned surface and rolled or flame-cut edges with ANSI smoothness of 1000 or less, but without re-entrant corners.	A	250×10^8	24 [166]	Away from all welds or structural connections	1.1/1.2 
1.2 Non-coated weathering steel base					

© MoreVision Limited. www.MoreVision.co.uk - ● Engineering Consultants ● Finite Element Analysis ● Strain Gauge Testing ● www.ExcelCalcs.com developers

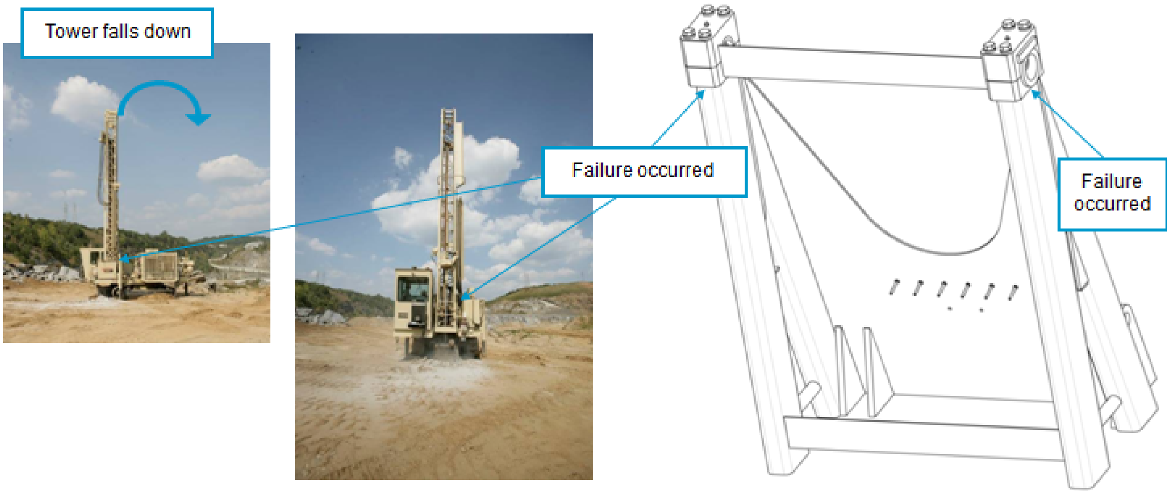
1.4 Tower Support Field Incident

Tower fall after failure of a weld.

John Doyle prepared calculations which agreed with Atlas Copco's showing the weld to be adequate. The failure is attributed to either problems with weld quality or pin seizure giving rise to overloading the weld. It was suggested that these lines of enquiry were pursued.

Tower Support Failure

This is weld failure occurred as a result of improper tower pinning procedure. The tower was in the raised position when the weld failed and then it fell to the horizontal position. No person was injured. Minor component damage. The product design is under revision.



© MoreVision Limited. www.MoreVision.co.uk – • Engineering Consultants • Finite Element Analysis • Strain Gauge Testing • www.ExcelCalcs.com developers

WELD GROUP ANALYSIS
Using the Elastic Method for up to 24 Total Welds

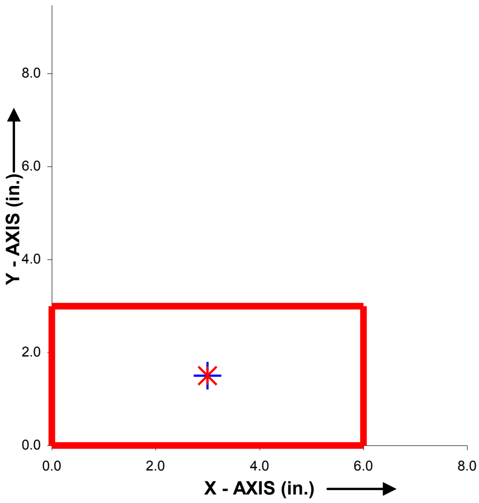
Job Name:		Subject:	
Job Number:		Originator:	Checker:

Input Data:

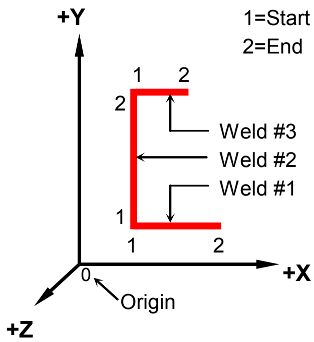
Number of Welds, Nw = 4

Weld Coordinates:

	Start X1 (in.)	Start Y1 (in.)	End X2 (in.)	End Y2 (in.)
Weld #1	0.000	0.000	6.000	0.000
Weld #2	0.000	0.000	0.000	3.000
Weld #3	0.000	3.000	6.000	3.000
Weld #4	6.000	3.000	6.000	0.000



WELD GROUP PLOT



NOMENCLATURE

No. of Load Points = 1

Load Point Data:

	Point #1			
X-Coordinate (in.) =	3.000			
Y-Coordinate (in.) =	1.500			
Z-Coordinate (in.) =	0.000			
Axial Load, Pz (k) =	16.82			
Shear Load, Px (k) =	1.14			
Shear Load, Py (k) =	0.00			
Moment, Mx (in-k) =	0.00			
Moment, My (in-k) =	0.00			
Moment, Mz (in-k) =	0.00			

(continued)

© MoreVision Limited. www.MoreVision.co.uk - ● Engineering Consultants ● Finite Element Analysis ● Strain Gauge Testing ● www.ExcelCalcs.com developers

Results:

Weld Group Properties:		
Lw =	18.000	in.
Xc =	3.000	in.
Yc =	1.500	in.
Ix =	31.50	in^3
Iy =	90.00	in^3
J =	121.50	in^3

Σ Loads @ C.G. of Weld Group:		
Σ Pz =	16.82	kips
Σ Px =	1.14	kips
Σ Py =	0.00	kips
Σ Mx =	0.00	in-k
Σ My =	0.00	in-k
Σ Mz =	0.00	in-k

	Weld Forces (k/in.)	
	Fw(1)	Fw(2)
Weld #1	0.936	0.936
Weld #2	0.936	0.936
Weld #3	0.936	0.936
Weld #4	0.936	0.936

Required E70XX Weld Size:		
Fw(max) =	0.936	kips/in.
Fillet (leg) =	0.063	in.
Throat (eff) =	0.045	in.

© MoreVision Limited. www.MoreVision.co.uk - ● Engineering Consultants ● Finite Element Analysis ● Strain Gauge Testing ● www.ExcelCalcs.com developers

1.5 Luke's Rod Support Pin Failure

The failure surface was explianed in terms of:

1) Crack initiation point at position of SCF in pin

2) Area showing fatigue striation marks evidence of crack growth under repeated loading.

3) Fast fracture area.

2 Conclusion

Given the type and nature of the problems presented it was concluded that all the course elements needed to be covered so that each problem could be diagnosed correctly.

- Weld Static Strength – see problem in section 1.2 & 1.4
- Classic Fatigue Problems – see problem in section 1.5
- Fatigue of Welded Structures – see problem in section 1.1 & 1.3
- Case Studies – problem in see section 1.1

© MoreVision Limited. www.MoreVision.co.uk - ● Engineering Consultants ● Finite Element Analysis ● Strain Gauge Testing ● www.ExcelCalcs.com developers