Weld & Base Metal Fatigue Analysis

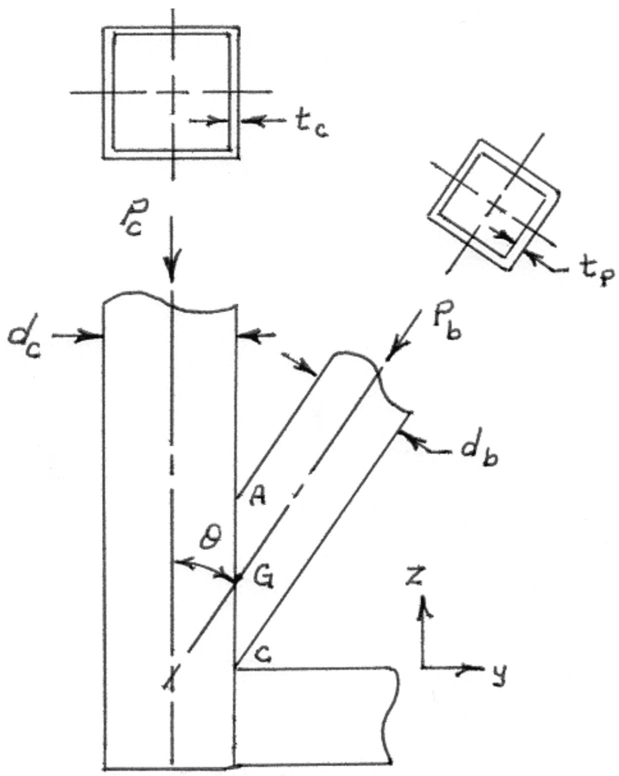
This analysis examines the factor of safety against fatigue failure of the inner, lower stepped hollow box beam connection of the fracsander supporting structure. Data used herein was obtained from finite element analysis: Frame_9_NL_RMS. The applied loads used on the finite element model comply with the specified transverse loads, obtained using the Lloyd's Register Rules for the Classification of Ships, Part 3: Ship Structures, General.

Other References:

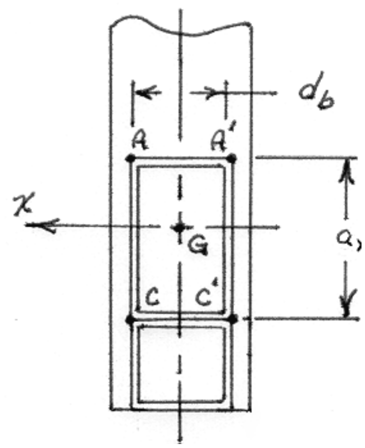
Lampman, Steve, "Weld Integrity and Performance", ASM International, 1997.

Shigley, Joseph E. and Charles R. Mischke, "Mechanical Engineering Design", McGraw-Hill, 1989 .

Marshall, Peter William, "Design of Welded Tubular Connections", Elsevier, 1992.



Stepped Box Beam Connection



Side View - Stepped Connection

Hollow Box Beams used in Support Structure:

Horizontal............: 4" x 4" x 0.250"

Verticals...............: 6" x 6" x 0.375"

Diagonal Braces: 4" x 4" x 0.250"

Product Design Life:

Number of Load Cycles...............................: $N := 1 \cdot 10^6$ cycles

Weld Metal - Mechanical Properties & Geometry

Note: Residual stresses greatly influence the fatigue life of weldments, and are limited (often controlled) by the yield strength of the metal. So, the yield strength of the constituent materials is of great importance in non-stress relieved weldments (pg 154-157, ref 1).

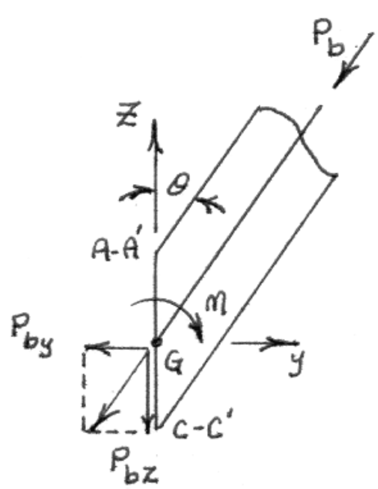
Minimum Weld Metal Properties (Ref. 2, pg 398)

AWS Electrode	**Tensile Strength (psi)**	**Yield Strength (psi)**
E70S-x	70,000	57,000

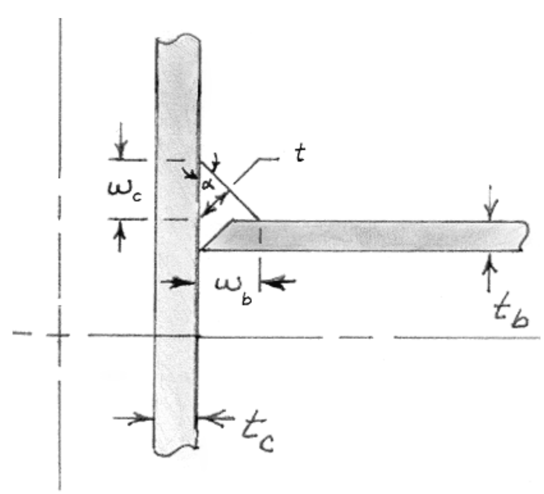
Minimum yield strength of Weld Metal:	$S_{yWM} := 57000$		psi
Minimum tensile strength of Weld Metal:	$S_{uWM} := 70000$		psi
Fillet Weld Leg Size on Column................:	$w_c := 0.25$	If legs are unequal, then wb < wc	in
Fillet Weld Leg Size on Brace..................:	$w_b := 0.25$		in

Hollow Box Beam Support - Mechanical Properties & Geometry

Hollow Box Beam Material.......................:	ASTM A36	
Minimum yield strength..............................:	$S_y := 36000$	psi
Minimum tensile strength...........................:	$S_u := 58000$	psi
Column - Box Beam Outer Dimension..........:	$d_c := 6.00$	in
Column - Box Beam Wall Thickness.........:	$t_c := 0.375$	in
Brace - Box Beam Outer Dimension............:	$d_b := 4.00$	in
Brace - Box Beam Wall Thickness..............:	$t_b := 0.25$	in
Brace - Cross Sectional Area......................:	$A_b := 3.59$	in^2
Brace - Second Moment of Area..............:	$I_b := 8.22$	in^4
Angle Between Column and Brace............:	$\theta := 35 \cdot \frac{\pi}{180}$	deg



Free Body Diagram of Diagonal Brace



Weld Joint Detail

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Weld Metal Fatigue Factor of Safety

Estimated rotating - beam endurance limit of the weld metal: $S_{erb} := 0.504 \cdot S_{uWM}$ $S_{erb} = 35280$ psi

Marin Factors

As forged surface finish factor & exponent used to obtain the Marin surface modifying factor for weldments (Ref. 2, pg 283): $k_a := 39.9 \cdot \left(\frac{S_{uWM}}{1000}\right)^{-0.995}$ $k_a = 0.5822$

To obtain the size surface modifying factor, first determine the equivalent size: $d_e := 0.808 \cdot \sqrt{\frac{w_b \cdot d_b}{\sqrt{2}}}$ $d_e = 0.6794$

Marin size surface modifying factor: $k_b := \left(\frac{d_e}{0.3}\right)^{-0.1133}$ $k_b = 0.9115$

For torsion, the load factor...............: $k_c := \frac{1}{\sqrt{3}}$ $k_c = 0.5774$

Temperature factor..............................: $k_d := 1$

Parallel Fillet Weld, Fatigue stress concentration factor (pg 399, ref. 2): $K_f := 2.70$

$k_e := \frac{1}{K_f}$ $k_e = 0.3704$

Fully corrected endurance limit of weld metal in shear for ~ 10^6 life cycles: $S_{se} := k_a \cdot k_b \cdot k_c \cdot k_d \cdot d_e \cdot S_{erb}$ $S_{se} = 7345$ psi

$a := \frac{(0.9 \cdot S_{uWM})^2}{S_{se}}$ $a = 540361$ psi

$b := \frac{-1}{3} \cdot \log\left(\frac{0.9 \cdot S_{uWM}}{S_{se}}\right)$ $b = -0.3111$

Estimated fatigue strength corresponding to the specified number of life load cycles: $S_f := a \cdot N^b$ $S_f = 7345$ psi

The Goodman Theory of Failure is used: $S_{su} := 0.67 \cdot S_{uWM}$ $S_{su} = 46900$ psi

For shear, the Goodman line is expressed as: $n := \frac{S_f \cdot S_{su}}{|\tau_a| \cdot S_{su} - |\tau_m| \cdot S_f}$ $n = 1.70$ psi

$$N_W := \begin{pmatrix} 10^0 \\ 5 \cdot 10^5 \\ 10^6 \end{pmatrix} \qquad S_{eW} := \begin{pmatrix} S_{uWM} \\ S_f \\ S_{se} \end{pmatrix}$$

Brace Base Metal - Minimum Load Condition:

Axial Stress in Brace.................................:	$\sigma_{1b} := \frac{P_{b1}}{A_b}$	$\sigma_{1b} = -6624$	psi
Bending Stress in Brace...............................:	$\sigma_{2b} := \frac{M_{G1} \cdot d_b}{2 \cdot I_b}$	$\sigma_{2b} = -1959$	psi
Combined Stress in Brace...............................:	$\sigma_{bmin} := \sigma_{1b} + \sigma_{2b}$	$\sigma_{bmin} = -8583$	psi

Brace: Base Metal - Maximum Load Condition

Axial Stress in Brace.................................:	$\sigma_{1b} := \frac{P_{b2}}{A_b}$	$\sigma_{1b} = 4153$	psi
Bending Stress in Brace...............................:	$\sigma_{2b} := \frac{M_{G2} \cdot d_b}{2 \cdot I_b}$	$\sigma_{2b} = 3114$	psi
Combined Stress in Brace...............................:	$\sigma_{bmax} := \sigma_{1b} + \sigma_{2b}$	$\sigma_{bmax} = 7268$	psi

Brace: Mean and Alternating Combined Stress Values

Mean Stress of Brace...........................:	$S_{mb} := \frac{\sigma_{bmax} + \sigma_{bmin}}{2}$	$S_{mb} = -658$	psi
Stress Range of Brace.........................:	$S_{rb} := \sigma_{bmax} - \sigma_{bmin}$	$S_{rb} = 15851$	psi
Stress Amplitude of Brace.....................:	$S_{ab} := \frac{\sigma_{bmax} - \sigma_{bmin}}{2}$	$S_{ab} = 7925$	psi
Alternating Stress Amplitude of Brace:	$A_{sb} := \frac{S_{ab}}{S_{mb}}$	$A_{sb} = -12.049$	psi
Stress Ratio of Brace..............................:	$R_{Ab} := \frac{\sigma_{bmin}}{\sigma_{bmax}}$	$R_{Ab} = -1.181$	psi

Brace: Base Metal Fatigue Factor of Safety

Estimated rotating - beam endurance limit of brace material: $S_{erb} := 0.504 \cdot S_u$ $S_{erb} = 29232$ psi

Marin Factors

Use surface finish factor & exponent for hot-rolled surface surface: $k_a := 14.4 \cdot \left(\frac{S_u}{1000}\right)^{-0.718}$ $k_a = 0.7802$

To obtain the size surface modifying factor, first determine the equivalent size: $d_e := 0.808 \cdot \sqrt{\frac{w_b \cdot d_b}{\sqrt{2}}}$ $d_e = 0.6794$

Marin size surface modifying factor: $k_b := \left(\frac{d_e}{0.3}\right)^{-0.1133}$ $k_b = 0.9115$

Axial loading, load factor (Ref. 2, pg 284)...: $k_c := 0.923$ $k_c = 0.9230$

Temperature factor..............................: $k_d := 1$

Parallel Fillet Weld, Fatigue stress concentration factor (pg 399, ref. 2): $K_f := 2.70$

$k_e := \frac{1}{K_f}$ $k_e = 0.3704$

Fully corrected endurance limit of bace metal for ~ 10^6 life cycles: $S_{se} := k_a \cdot k_b \cdot k_c \cdot k_d \cdot d_e \cdot S_{erb}$ $S_{se} = 13038$ psi

$a := \frac{(0.9 \cdot S_u)^2}{S_{se}}$ $a = 208993$ psi

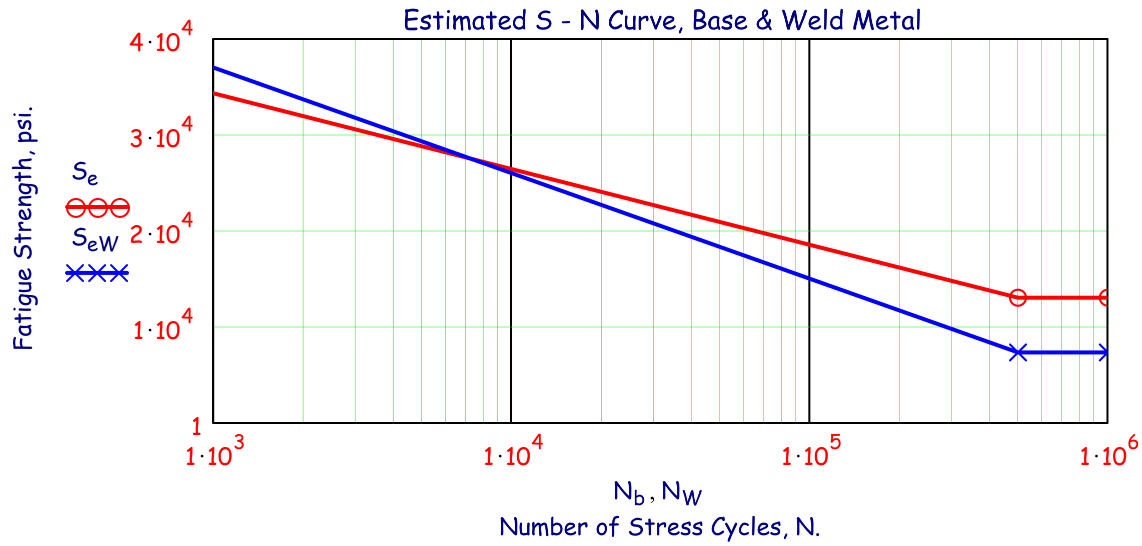
$b := \frac{-1}{3} \cdot \log\left(\frac{0.9 \cdot S_u}{S_{se}}\right)$ $b = -0.2008$

Estimated fatigue strength corresponding to the specified number of life load cycles: $S_f := a \cdot N^b$ $S_f = 13038$ psi

The Distortion Energy Theory is used to obtain a value for the yield strength of the base metal in shear: $S_{sy} := \frac{S_y}{\sqrt{3}}$

The Goodman line is use to obtain an estimate of the safety factor at N cycles. $n := \frac{S_f \cdot S_{sy}}{S_{ab} \cdot S_{sy} - S_{mb} \cdot S_f}$ $n = 1.56$ psi

$$N_b := \begin{pmatrix} 10^0 \\ 5 \cdot 10^5 \\ 10^6 \end{pmatrix} \qquad S_e := \begin{pmatrix} S_u \\ S_f \\ S_{se} \end{pmatrix}$$



$$G_y := \begin{pmatrix} S_{se} \\ 0 \end{pmatrix} \qquad G_x := \begin{pmatrix} 0 \\ S_u \end{pmatrix}$$

$$Y_y := \begin{pmatrix} S_y \\ 0 \end{pmatrix} \qquad Y_x := \begin{pmatrix} 0 \\ S_y \end{pmatrix}$$

$$F_y := \begin{pmatrix} S_{ab} \\ S_{ab} \end{pmatrix} \qquad F_x := \begin{pmatrix} 0 \\ |S_{mb}| \end{pmatrix}$$