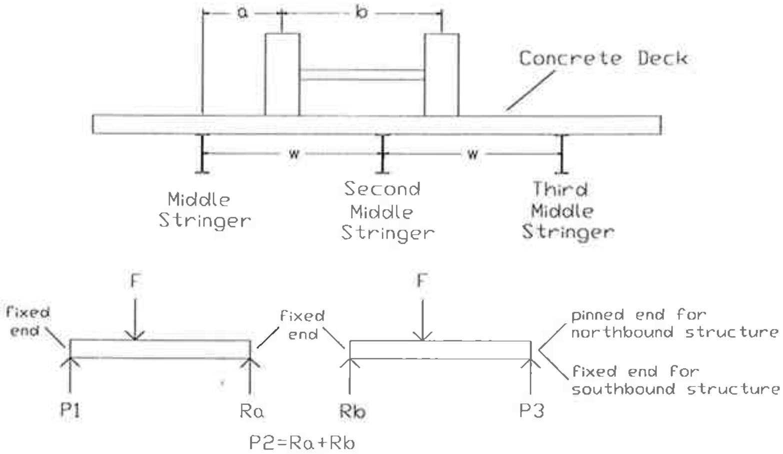
APPENDIX A

STRINGER LOADING ANALYSIS

STRINGER LOADING ANALYSIS FOR THE NORTHBOUND STRUCTURE



$F := 12000$ lbf Axle load carried by the three stringers

$b := 72$ in Axial Spacing $w := 84$ in Stringer Spacing

$a := 36$ in Distance from the middle stringer to nearest wheel

$c := 2 \cdot w - (a + b)$ $c = 60$ in

Formulas from [Shigley & Mischke, 1989]

Middle stringer

$$P_1 := \frac{F}{w^3} \cdot (w - a)^2 \cdot (2 \cdot a + w) \qquad P_1 = 7277 \text{ lbf} \qquad \frac{P_1 \cdot 100}{2 \cdot F} = 30 \ \%$$

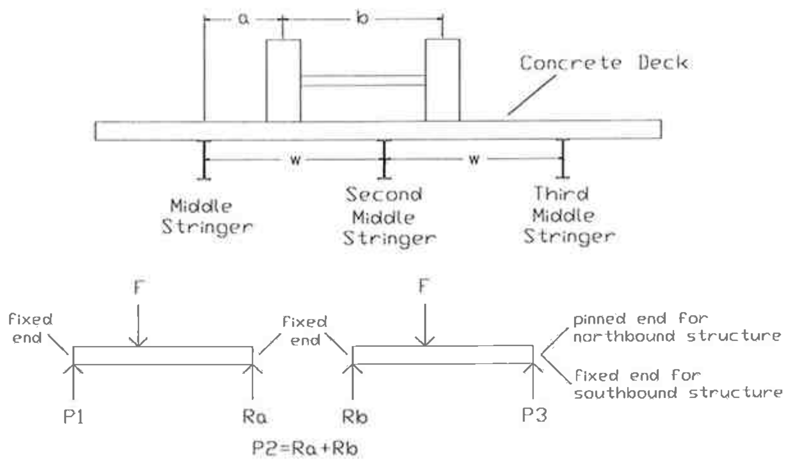
2nd from middle stringer

$$P_2 := \frac{F \cdot a^2}{w^3} \cdot (3 \cdot w - 2 \cdot a) + \frac{F \cdot c}{2 \cdot w^3} \cdot \left(3 \cdot w^2 - c^2\right) \qquad P_2 = 15394 \text{ lbf} \qquad \frac{P_2 \cdot 100}{2 \cdot F} = 64 \ \%$$

3rd from middle stringer

$$P_3 := \frac{F}{2 \cdot w^3} \cdot (w - c)^2 \cdot (2 \cdot w + c) \qquad P_3 = 1329 \text{ lbf} \qquad \frac{P_3 \cdot 100}{2 \cdot F} = 6 \ \%$$

STRINGER LOADING ANALYSIS FOR THE SOUTHBOUND STRUCTURE



$F := 12000$ lbf Axle load carried by the three stringers

$b := 72$ in Axial Spacing $w := 63$ in Stringer Spacing

$a := 36$ in Distance from middle stringer to nearest wheel

$c := 2 \cdot w - (a + b)$ $c = 18$ in

Formulas from [Shigley & Mischke, 1989]

Middle stringer

$$P_1 := \frac{F}{w^3} \cdot (w - a)^2 \cdot (2 \cdot a + w) \qquad P_1 = 4723 \text{ lbf} \qquad \frac{P_1 \cdot 100}{2 \cdot F} = 20\%$$

2nd from middle stringer

$$P_2 := \frac{F \cdot a^2}{w^3} \cdot (3 \cdot w - 2 \cdot a) + \frac{F \cdot c^2}{w^3} \cdot (3 \cdot w - 2 \cdot c) \qquad P_2 = 9656 \text{ lbf} \qquad \frac{P_2 \cdot 100}{2 \cdot F} = 40\%$$

3rd from middle stringer

$$P_3 := \frac{F}{w^3} \cdot (w - c)^2 \cdot (2 \cdot c + w) \qquad P_3 = 9621 \text{ lbf} \qquad \frac{P_3 \cdot 100}{2 \cdot F} = 40 \ \%$$

APPENDIX B

GLOBAL FEA MODEL

```
EGROUP 1 BEAM3D 0 0 0 0 0 0 0
MPROP 1 EX 30000000
RCONST 1 1 1 10 12 .78 .78 15 1.299 000000 000000 .2 0 0
ND 1 0 0 0 0 0 0 0 0 0
ND 2 .1 0 0 0 0 0 0 0 0
ND 3 209.9 0 0 0 0 0 0 0 0
ND 4 210 0 0 0 0 0 0 0 0
ND 5 0 0 -100 0 0 0 0 0 0
EL 1 CR 0 3 1 2 5 0 0 0 0 0 0
RCONST 1 2 1 10 12 .78 .78 15 1.299 000000 000000 .2 0 0
EL 2 CR 0 3 3 4 5 0 0 0 0 0 0
RCONST 1 3 1 10 14.7 802 802 18 18 000000 000000 1.25 0 0
MPROP 2 EX 30000000
pt 1 0 0 -100
Pt 2 .1 0 0
pt 3 209.9 0 0
crline 1 2 3
m_cr 1 1 1 3 10 1 1
nmerge 1 100 1 .01 1 1 0
ncompress 1 100
actset rc 1
elgen 4 1 1 1 0 0 84 0
actset rc 2
elgen 4 2 2 1 0 0 84 0
actset rc 3
ELGEN 4 3 12 1 0 0 84 0
nmerge 1 1000 1 .01 1 1 0
RCONST 1 10 1 10 22.4 2100 2100 23.91 23.91 000000 000000 2.7 0 0
pt 4 0 0 0
pt 5 0 336 0
CRLINE 2 4 5
m_cr 2 2 1 3 16 1 3
ELGEN 1 61 76 1 0 210 0 0
nmerge 1 1000 1 .01 1 1 1
ncompress 1 1000
DND 60 RY 0.000000 76 1
DND 78 Ry 0.000000 95 1
DND 82 ux 0 92 10 uy uz
DND 63 ux 0 73 10 uy uz
scale 0
pt 6 210 336 0
pt 7 210 0 0
sf4pt 1 4 5 6 7 0
EGROUP 2 SHELL4L 2 1 0 0 0 0 0
RCONST 2 14 1 5 3 0 6 1 0
```

```
MPROP 1 Ex .55E6
MPROP 1 Ey 1.3E6
ACTSET ECS 0
m_sf 1 1 1 4 48 30 1 1
nmerge 1 5000 1 .09 0 1 0
ncompress 1 5000 1
dnd 1504 ry 0 1535 1
dnd 96 ry 0 127 1
pel 773 61.2 6 774 1
pel 821 61.2 6 822 1
pel 783 61.2 6 784 1
pel 831 61.2 6 832 1
```

```
EGROUP 1 BEAM3D 0 0 0 0 0 0 0
MPROP 1 EX 30000000
RCONST 1 1 1 10 12 .78 .78 15 1.299 000000 000000 .2 0 0
ND 1 0 0 0 0 0 0 0 0 0
ND 2 .1 0 0 0 0 0 0 0 0
ND 3 209.9 0 0 0 0 0 0 0 0
ND 4 210 0 0 0 0 0 0 0 0
ND 5 0 0 -100 0 0 0 0 0 0
EL 1 CR 0 3 1 2 5 0 0 0 0 0 0
RCONST 1 2 1 10 12 .78 .78 15 1.299 000000 000000 .2 0 0
EL 2 CR 0 3 3 4 5 0 0 0 0 0 0
RCONST 1 3 1 10 13.2 706 706 17.86 17.86 000000 000000 .889 0 0
MPROP 2 EX 30000000
Pt 1 .1 0 0
pt 2 209.9 0 0
pt 3 0 0 -100
crline 1 1 2
m_cr 1 1 1 3 10 1 3
nmerge 1 100 1 .01 1 1 0
ncompress 1 100
actset rc 1
elgen 6 1 1 1 0 0 63 0
actset rc 2
elgen 6 2 2 1 0 0 63 0
actset rc 3
ELGEN 6 3 12 1 0 0 63 0
RCONST 1 10 1 10 24.2 2830 2830 26.7 26.7 000000 000000 2.79 0 0
pt 4 0 0 0
pt 5 0 378 0
CRLINE 2 4 5
m_cr 2 2 1 3 18 1 3
ELGEN 1 85 103 1 0 210 0 0
nmerge 1 1000 1 .01 1 1 1
ncompress 1 1000
DND 90 RY 0.000000 108 1
DND 110 Ry 0.000000 129 1
DND 93 ux 0 105 12 uy uz
DND 114 ux 0 126 12 uy uz
scale 0
pt 6 210 378 0
pt 7 210 0 0
sf4pt 1 4 5 6 7 0
EGROUP 2 SHELL4L 2 1 0 0 0 0 0
RCONST 2 14 1 5 3 0 6 1 0
MPROP 1 Ex .5458E6
```

```
MPROP 1 Ey 1.3E6
ACTSET ECS 0
m_sf 1 1 1 4 54 30 1 1
nmerge 1 4000 1 .09 0 1 0
ncompress 1 4000 1
dnd 1692 ry 0 1727 1
dnd 124 ry 0 159 1
pel 898 61.2 6 899 1
pel 952 61.2 6 953 1
pel 888 61.2 6 889 1
pel 942 61.2 6 943 1
```

APPENDIX C

REINFORCED CONCRETE DECK ANALYSIS

Depth = 6 in

Min. breaking Strength - f'_c = 3300 psi

Weight per cubic foot - Assumed to be:

$$W = 140 \ lb/ft^3$$

Modulus of Elasticity

$$E_c = 33 W^{1.5} \sqrt{f'_c}$$ (from Everard and Tanner, 1966 Eq 1.3)

$$E_c = 33 (140 \ lb/ft^3)^{1.5} \sqrt{3300 \ psi}$$

$$E_c = 3240 \ kpsi$$

Ratio of modulus of elasticity of steel to Concrete

$$n = \frac{E_s}{E_c} = \frac{29000 \ kpsi}{3240 \ kpsi} = 9.2$$

Transverse Steel

#5 straight bars at 11" centers top & bottom

#5 bent bars at 11" centers in tension regions of the deck

$d_s(\#5) = \frac{5}{8} \text{ in}$

Longitudinal Steel

77 - #4 longitudinal spacers

48 spacers in bottom of deck

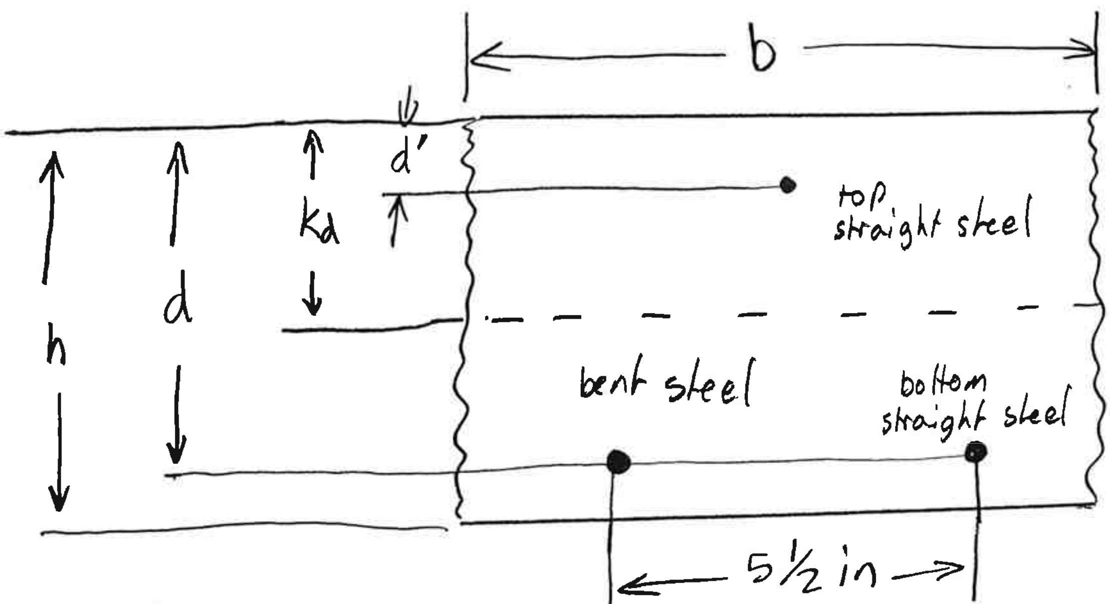
$$\frac{387 \text{ in}}{48 \text{ spacers}} = 8 \text{ in/spacer}$$

29 spacers in top of deck

$$\frac{387 \text{ in}}{29 \text{ spacers}} = 13.3 \text{ in/spacer}$$

$d_s(\#4) = \frac{1}{2} \text{ in}$

A: Since bent steel is always in tension region of the deck then it can be modeled as if it were an addition piece of straight steel in the tension section of the beam.



$h = 6in$

$d = 5in$

$d' = 1.5in$

$b = 11in$

$$A_s = 2\left(\frac{\pi d_s^2}{4}\right) = .6133\ in^2$$

$$A_s' = \frac{\pi d_s^2}{4} = .3066\ in^2$$

$$\rho = \frac{A_s}{bd} = 1.12 \times 10^{-2}$$

$$\rho' = \frac{A_s'}{bd} = 5.58 \times 10^{-3}$$

$$K = \sqrt{2n\left(\rho + \frac{\rho' d'}{d}\right) + n^2(\rho + \rho')^2} - n(\rho + \rho')$$

(from Everard and Tanner, 1966 Eq 4.21)

$$A_s = 2A_s'$$

$$\rho = 2\rho'$$

$$K = \sqrt{2n\left(2\rho' + \frac{\rho' d'}{d}\right) + n^2(2\rho' + \rho')^2} - n(2\rho' + \rho')$$

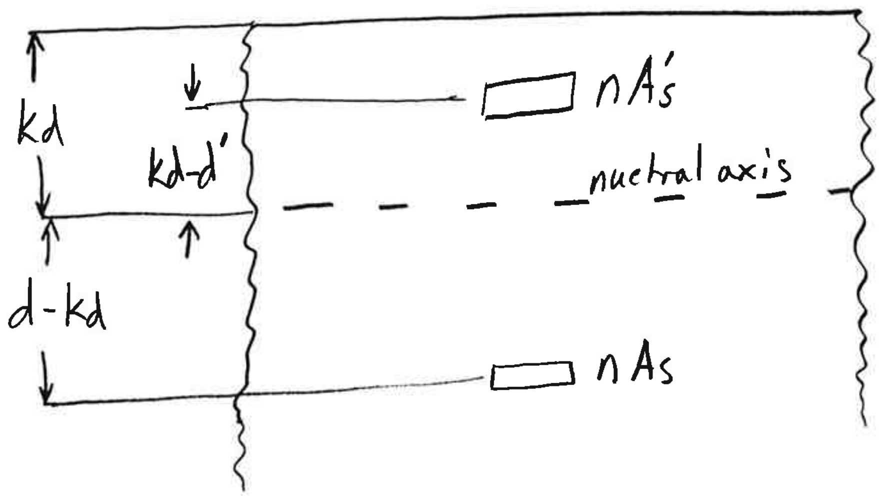
$$K = \sqrt{2n\rho'\left(2 + \frac{d'}{d}\right) + n^2(3\rho')^2} - 3n\rho'$$

$$K = \sqrt{2(9.2)(.0056)\left(2 + \frac{1.5}{5}\right) + (9.2)^2(3)^2(.0056)^2} - (9.2)(3)(.0056)$$

$$K = .356$$

$$Kd = (.356)(5\text{ in}) = \underline{\underline{1.78\text{ in}}}$$

Moment of Inertia



$$I_{n.a.}/\text{inch} = \frac{\frac{1}{3}(kd)^3 b + nA_s'(kd-d')^2 + nA_s(d-kd)^2}{b}$$

$$I_{n.a}/\text{inch} = \frac{\frac{1}{3}(1.78\,in)^3(11\,in) + (9.2)(.3066\,in^2)(1.78-1.5\,in)^2 + (9.2)(.6133)(5-1.78\,in)^2}{11\,in}$$

$$I_{na}/\text{inch} = \underline{\underline{7.218\,in^3}}$$

Equivalent Modulus of Elasticity for a homogenous slab 6" thick

$$\delta_1 = \delta_2$$

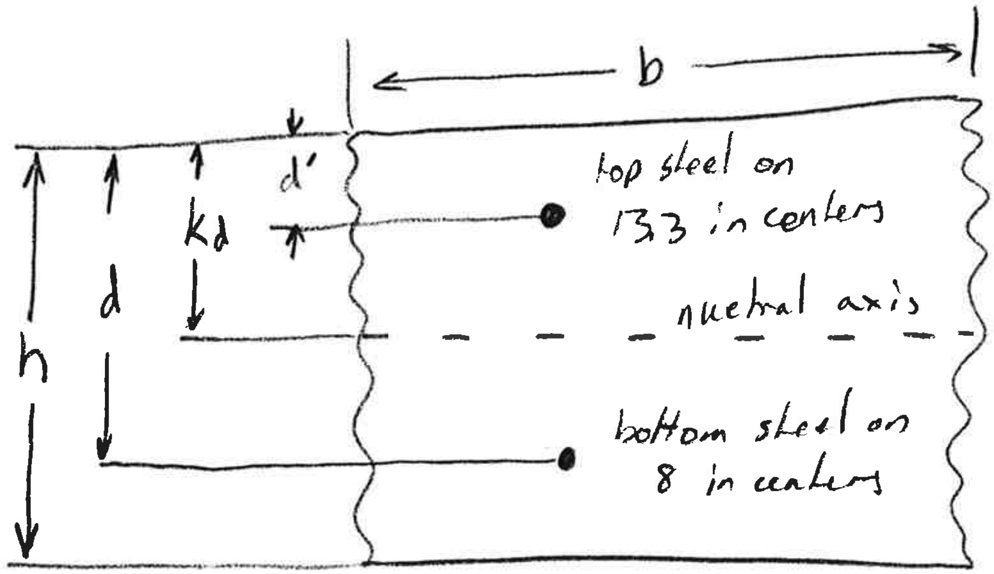
$$\frac{PL}{E_e I_{6/in}} = \frac{PL}{E_c I_{na/in}}$$

$$E_e = \frac{E_c I_{na}}{I_6}$$

$$I_{6/in} = \frac{h^3}{12} = \frac{(6\,in)^3}{12} = 18\,in^3$$

$$E_e = \frac{(3240\ kpsi)(7.218\ in^3)}{18\ in^3}$$

$$E_e = \underline{\underline{1300\ kpsi}}$$



$h = 6 \text{ in}$

$d = 4.44 \text{ in}$

$d' = 2.06 \text{ in}$

$b = 1 \text{ in}$

$$A_s = \frac{\pi d_s^2}{4}\left(\frac{b}{8 \text{ in}}\right) = .0245 \text{ in}^2$$

$$A_s' = \frac{\pi d_s^2}{4}\left(\frac{b}{13.3 \text{ in}}\right) = .0148 \text{ in}^2$$

$$\rho = \frac{A_s}{bd} = 5.53 \times 10^{-3}$$

$$\rho' = \frac{A_s'}{bd} = 3.32 \times 10^{-3}$$

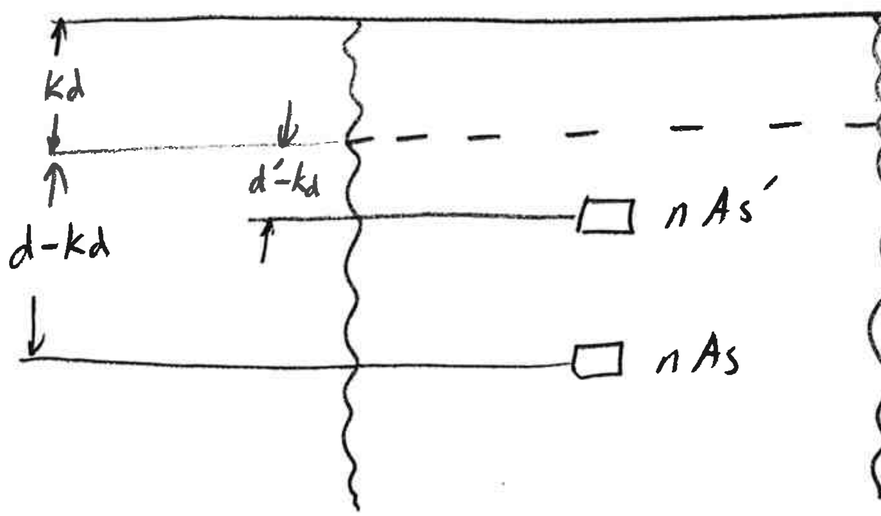
$$k = \sqrt{2n\left(\rho + \frac{\rho' d'}{d}\right) + n^2(\rho + \rho')^2} - n(\rho + \rho')$$

$$k = \frac{\sqrt{2(9.2)\left(.00553 + .0032\,\frac{2.06}{4.44}\right) + 9.2^2(.00553 + .0032)^2}}{b}$$

$$k = .288$$

$$kd = .288(4.44\ in) = \underline{\underline{1.28\ in}}$$

Moment of Inertia



$$I_{na}/in = \frac{\frac{b}{3}kd^3 + nA_s'(d'-kd)^2 + nA_s(d-kd)^2}{b}$$

$$I_{na}/in = \frac{\frac{1\,in}{3}(1.28\,in^3) + 9.2(.01476\,in^2)(2.06-1.28)^2 + 9.2(.0245\,in^2)(4.44-1.28\,in)^2}{1\,in}$$

$$I_{na}/in = 3.032\ in^3$$

Equivalent Modulus of Elasticity for a homogenous slab, 6" thick

$$\delta_1 = \delta_2$$

$$\frac{PL}{E_e I_6} = \frac{PL}{E_c I_{na}}$$

$$E_e = \frac{E_c I_{na}}{I_6}$$

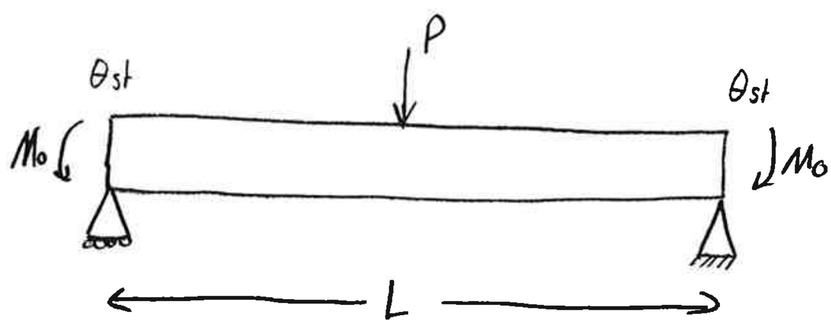
$$E_e = \frac{(3240 \text{ kpsi})(3.032 \text{ in}^3)}{18 \text{ in}^3}$$

$$E_e = \underline{\underline{546 \text{ kpsi}}}$$

APPENDIX D

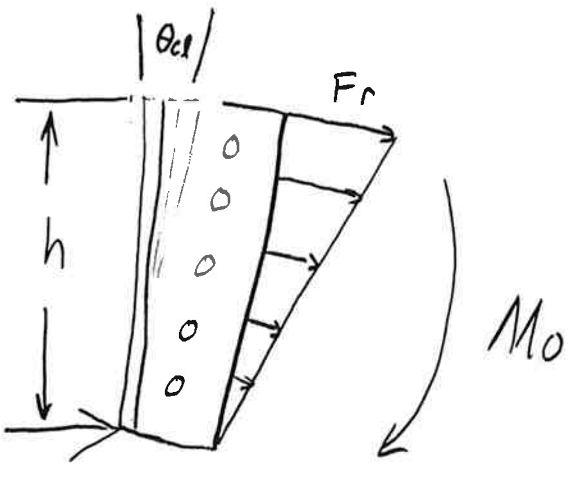
CLIP ANGLE DEFLECTION ANALYSIS

A: Stringers act like a simply supported beam with moments acting on the ends



$$\theta_{st} = \frac{-M_0 L}{2EI} + \frac{PL^2}{16EI} \qquad (1)$$

A: Center of Rotation of the clip angle is at bottom



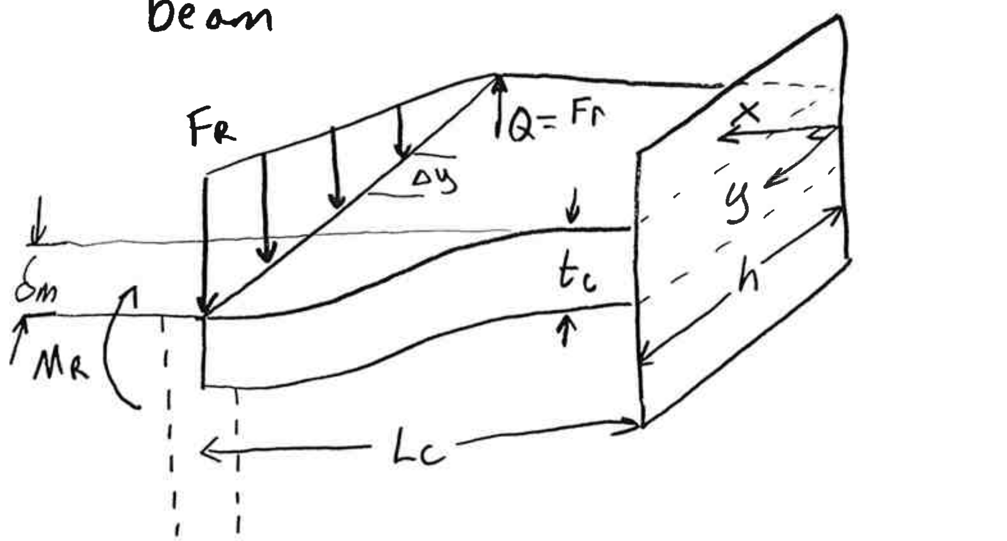
$$M_0 = 2\left(\tfrac{2}{3}h\right)\left(\frac{F_R h}{2}\right)$$

$$= \frac{2 F_R h^2}{3} \qquad (2)$$

$$\sin\theta_{cl} = \frac{\delta_m}{h} \Rightarrow \theta_{cl} = \frac{\delta_m}{h} \qquad (3)$$

(by small angle theorm)

A: Top of clip angles act like a cantilever beam



$\delta = 0$ at $y = 0$

$\delta = \delta_m$ at $y = h$

$\theta_R = 0$ at $x = L_c$

$$\theta_R = \frac{F_R \Delta y L_c^2}{2EI} - \frac{M_R \Delta y L_c}{EI} = 0$$

$$M_R = \frac{F_R L_c}{2} \qquad (4)$$

$$\delta_m = \frac{F_R \Delta y L_c^3}{3EI} - \frac{M_R \Delta y L_c^2}{2EI} \qquad (5)$$

sub (4) into (5)

$$\delta_m = \frac{F_R \Delta y L_c^3}{3EI} - \frac{F_R \Delta y L_c^3}{4EI}$$

$$\delta_m = \frac{F_R \Delta y L_c^3}{12EI}$$

$$I = \frac{\Delta y \, t_c^3}{12}$$

$$\delta_m = \frac{F_R L_c^3}{E t_c^3} \Longrightarrow F_R = \frac{\delta_m E t_c^3}{L_c^3} \qquad (6)$$

sub (6) into (2)

$$M_o = \frac{2 \delta_m E h^2 t_c^3}{3L_c^3}$$

$$\delta_m = M_o \left(\frac{3L_c^3}{2Eh^2 t_c^3} \right) \qquad (7)$$

sub (7) into (3)

$$\theta_{cl} = C_R M_o \qquad (8)$$

$$C_R = \frac{3L_c^3}{2E t_c^3 h^3} \qquad (9)$$

set (1) equal (8)

$$\theta_{st} = \theta_{cl}$$

$$M_o = \frac{\frac{PL^2}{16EI}}{C_R + \frac{L}{EI}} \qquad (10)$$

CLIP ANGLE DEFLECTION CALCULATION FOR NORTHBOUND STRUCTURE

$E := 30000000$ psi Youngs modulus of steel

$I := 802$ in^4 Area moment of inertia of the stringers

$L := 210$ in Stringer length

$h := 15$ in Height of the clip angle

$tc := .375$ in Thickness of the clip angle

$Lc := 1.4$ in Length of the beam model of the clip angle and point where the rotation is zero

$i := 1..2$ From Global FEA Analysis

$P_1 := 7300$ Middle stringer

$P_2 := 14500$ 2nd from middle stringer

$$C_R := \frac{3 \cdot Lc^3}{2 \cdot E \cdot tc^3 \cdot h^3} \qquad Mo_i := \frac{\frac{P_i \cdot L^2}{16 \cdot E \cdot I}}{C_R + \frac{L}{2 \cdot E \cdot I}}$$

From Clip Angle Deflection Analysis

$C_R = 7.709 \cdot 10^{-10}$

$Mo_1 = 162858$ in-lbf Middle stringer

$Mo_2 = 323484$ in-lbf 2nd from middle stringer

$$\delta m_i := C_R \cdot Mo_i \cdot h$$

From Clip Angle Deflection Analysis

$\delta m_1 = 0.0019$ in-lbf Middle stringer

$\delta m_2 = 0.0037$ in-lbf 2nd from middle stringer

CLIP ANGLE DEFLECTION CALCULATION FOR SOUTHBOUND STRUCTURE

$E = 30000000$ psi Youngs modulus of steel

$I = 706$ in^4 Area moment of inertia of the stringers

$L = 210$ in Stringer length

$h = 15$ in Height of the clip angle

$tc = .375$ in Thickness of the clip angle

$Lc = 1.4$ in Length of the beam model of the clip angle and point where the rotation is zero

$i := 1..3$ From Global FEA Analysis

$P_1 := 5500$ Middle stringer

$P_2 := 10960$ 2nd from middle stringer

$P_3 := 7950$ 3rd from middle stringer

$$C_R := \frac{3 \cdot Lc^3}{2 \cdot E \cdot tc^3 \cdot h^3} \qquad Mo_i := \frac{\dfrac{P_i \cdot L^2}{16 \cdot E \cdot I}}{C_R + \dfrac{L}{2 \cdot E \cdot I}}$$

From Clip Angle Deflection Analysis

$Mo_1 = 124946$ in-lbf Middle stringer

$Mo_2 = 248984$ in-lbf 2nd from middle stringer

$Mo_3 = 180604$ in-lbf 3rd from middle stringer

$$\delta m_i := C_R \cdot Mo_i \cdot h$$

From Clip Angle Deflection Analysis

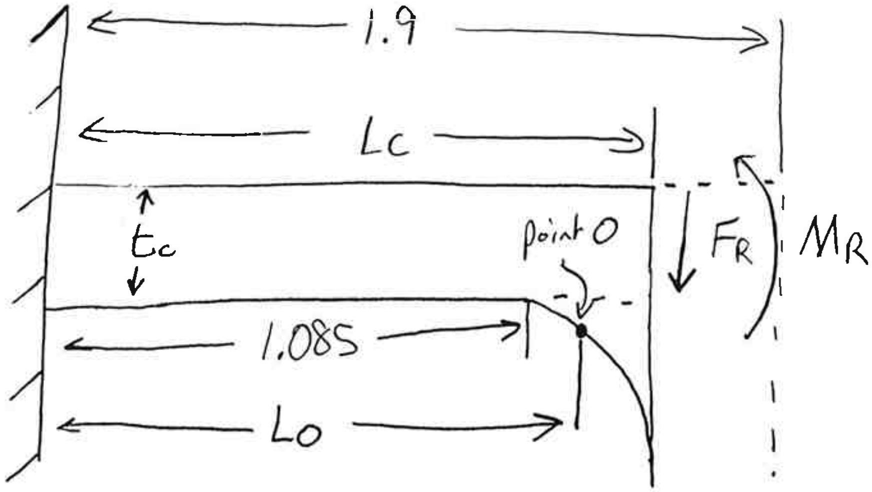
$\delta m_1 = 0.0014$ in-lbf Middle stringer

$\delta m_2 = 0.0029$ in-lbf 2nd from middle stringer

$\delta m_3 = 0.0021$ in-lbf 3rd from middle stringer

APPENDIX E

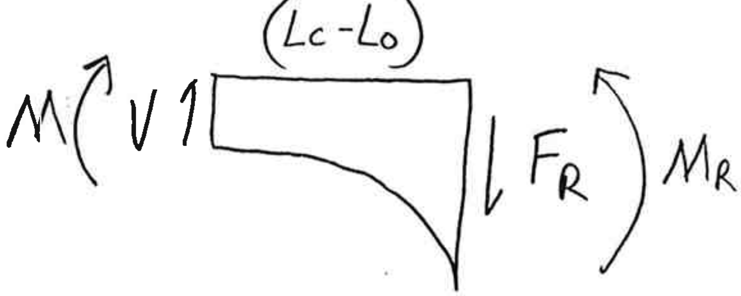
CLIP ANGLE STRESS ANALYSIS



from Clip Angle Deflection Analysis

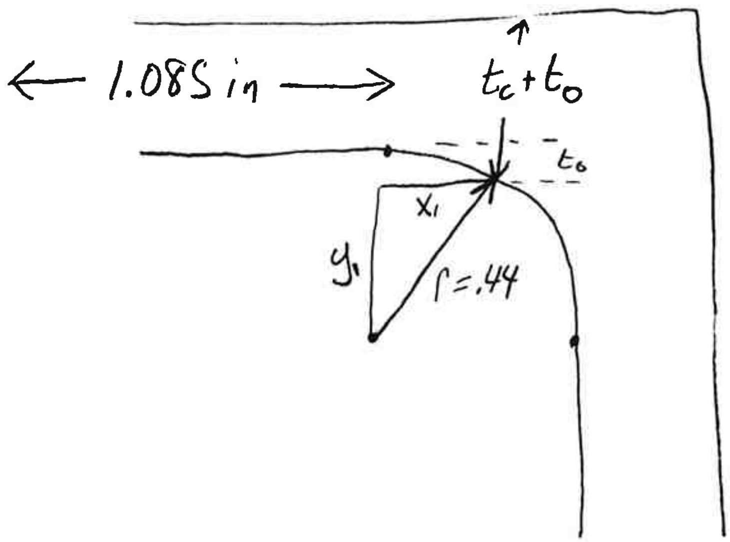
$$F_R = \frac{3M_o}{2h^2}, \qquad M_R = \frac{F_R L_c}{2} = \frac{3M_o L_c}{4h^2}$$

at point O



$$\frac{M}{dw} = M_R - F_R(L_c - L_o) = \frac{3M_o L_c}{4h^2} - \frac{3M_o}{2h^2}(L_c - L_o)$$

$$M = \frac{3M_o}{2h^2}\left(L_o - \frac{L_c}{2}\right)dw$$



$$t_o = r - y_1 = r - r\cos\left(\sin^{-1}\frac{x_1}{r}\right)$$

$$t_o = .44 - .44\cos\left[\sin^{-1}\left(\frac{L_o - 1.085}{.44}\right)\right]$$

$$\sigma = \frac{My}{I} = \frac{M\left(\frac{t_c+t_o}{2}\right)}{\frac{dw\,(t_c+t_o)^3}{12}} = \frac{6M}{dw(t_c+t_o)^2}$$

$$\sigma = \frac{6}{\cancel{dw}(t_c+t_o)^2}\left(\frac{3M_o}{2h^2}\left(L_o - \frac{L_c}{2}\right)\right]\cancel{dw}$$

$$\sigma = \frac{9M_o\left(L_o - \frac{L_c}{2}\right)}{h^2(t+t_o)^2}$$

$E := 30000000$ psi Youngs modulus of steel

$I := 802$ in^4 Area moment of inertia of the stringers

$L := 210$ in Stringer length

$h := 15$ in Height of the clip angle

$tc := .375$ in Thickness of the clip angle

$Lc := 1.4$ in Length of the beam model of the clip angle and point where the rotation is zero

$Lo := 1.25$ in Postion on clip angle where there is a maximum stress

$i := 1 .. 2$ From Global FEA Analysis

$P_1 := 7300$ Middle stringer

$P_2 := 14500$ 2nd from middle stringer

$$C_R := \frac{3 \cdot Lc^3}{2 \cdot E \cdot tc^3 \cdot h^3} \qquad Mo_i := \frac{\dfrac{P_i \cdot L^2}{16 \cdot E \cdot I}}{C_R + \dfrac{L}{2 \cdot E \cdot I}}$$

From Clip Angle Deflection Analysis

$Mo_1 = 162858$ in-lbf Middle stringer

$Mo_2 = 323484$ in-lbf 2nd from middle stringer

From Clip Angle Stress Analysis

$$to := .44 - .44 \cdot \cos\left(\operatorname{asin}\left(\frac{Lo - 1.085}{.44}\right)\right) \qquad to = 0.0321$$

Fillet compensation

$$\sigma_i := \frac{9 \cdot Mo_i \cdot \left(Lo - \dfrac{Lc}{2}\right)}{\left[(tc + to)^2 \cdot h^2\right]}$$

$\sigma_1 = 21618$ psi Middle stringer

$\sigma_2 = 42939$ psi 2nd from middle stringer

$E := 30000000$ psi Youngs modulus of steel

$I := 706$ in^4 Area moment of inertia of the stringers

$L := 210$ in Stringer length

$h := 15$ in Height of the clip angle

$tc := .375$ in Thickness of the clip angle

$Lc := 1.4$ in Length of the beam model of the clip angle and point where the rotation is zero

$Lo := 1.25$ in Postion on clip angle where there is a maximum stress

$i := 1..3$ From Global FEA Analysis

$P_1 := 5500$ Middle stringer

$P_2 := 10960$ 2nd from middle stringer

$P_3 := 7950$ 3rd from middle stringer

$$C_R := \frac{3 \cdot Lc^3}{2 \cdot E \cdot tc^3 \cdot h^3} \qquad Mo_i := \frac{\dfrac{P_i \cdot L^2}{16 \cdot E \cdot I}}{C_R + \dfrac{L}{2 \cdot E \cdot I}}$$

From Clip Angle Deflection Analysis

$Mo_1 = 124946$ in-lbf Middle stringer

$Mo_2 = 248984$ in-lbf 2nd from middle stringer

$Mo_3 = 180604$ in-lbf 3rd from middle stringer

From Clip Angle Stress Analysis

$$to := .44 - .44 \cdot \cos\left(\operatorname{asin}\left(\frac{Lo - 1.085}{.44}\right)\right)$$

$to = 0.0321$ Fillet compensation

$$\sigma_i := \frac{9 \cdot Mo_i \cdot \left(Lo - \dfrac{Lc}{2}\right)}{\left[(tc + to)^2 \cdot h^2\right]}$$

$\sigma_1 = 16585$ psi Middle stringer

$\sigma_2 = 33050$ psi 2nd from middle stringer

$\sigma_3 = 23973$ psi 3rd from middle stringer

APPENDIX F

2D FEA MODEL

```
1
ld 1 lp 2 0 0 .50314078 .50314078
ld 2 lp 2 0 0 0 1.9
ld 3 lp 2 0 1.9 0 2.4
ld 4 lp 2 0 2.4 .375 2.4
ld 5 lp 2 .375 2.4 .375 1.9
ld 6 lp 2 0 1.9 .375 1.9
ld 7 lp 2 .375 1.9 .375 .8125
lap .50314078 .50314078 .8125 .8125
ld 8 lp 2 1.5 .375 .8125 .375
lap .50314078 .50314078 .8125 .8125
ld 9 lp 2 0 0 1.5 0
ld 10 lp 2 1.5 0 1.5 .375
ld 11 lp 2 1.5 0 2 0
ld 12 lp 2 1.5 .375 2 .375
ld 13 lp 2 2 0 2 .375
lv
part 6 3 4 5 1 16 20 y
part 1 2 6 7 1 16 76 y
part 11 10 12 13 1 20 16 y
part 9 1 8 10 1 60 16 y
mg 2 4
assm
m 1 2
m 2 3
p 1 s b
nbcs 2 1
nbcs 3 2
nbcs 4 1
p 2 s b
nbc 1700 1700 2
p 3 s b
nbcs 1 2
nbcs 3 2
pbcs 2 1 1 1
lcd 1 2 0 0 .1 -100
lcv
plti .05
nstep 2
term .1
prtt .05
plane
anal 0
wbcd nike2d
mat 1 1
e 30000000 pr .29
endmat
```

2D FEA DEFLECTION CALCULATION FOR NORTHBOUND STRUCTURE

$E := 30000000$ psi Youngs modulus of steel

$I := 802$ in^4 Area moment of inertia of the stringers

$L := 210$ in Stringer length

$h := 15$ in Height of the clip angle

$tc := .375$ in Thickness of the clip angle

$Lc := 1.4$ in Length of the beam model of the clip angle and point where the rotation is zero

$Lo := 1.25$ in Postion on clip angle where there is a maximum stress

$i := 1..2$ From Global FEA Analysis

$P_1 := 7300$ Middle stringer

$P_2 := 14500$ 2nd from middle stringer

$$C_R := \frac{\theta cl}{Mo} = \frac{\frac{\delta}{h}}{\left(\frac{2\cdot\sigma_o\cdot tc\cdot h^2}{3}\right)} \qquad C_R := \frac{\frac{.0001663}{15}}{\left(\frac{100\cdot 2\cdot tc\cdot h^2}{3}\right)}$$

From 2D FEA

$$C_R = 1.971 \cdot 10^{-9}$$

$$\frac{100\cdot 2\cdot tc\cdot h^2}{3} = 5.625 \cdot 10^3$$

$$Mo_i := \frac{\frac{P_i\cdot L^2}{16\cdot E\cdot I}}{C_R + \frac{L}{2\cdot E\cdot I}}$$

From Clip Angle Deflection Analysis

$Mo_1 = 132007$ in-lbf Middle stringer

$Mo_2 = 262205$ in-lbf 2nd from middle stringer

$$\delta m_i := C_R\cdot Mo_i\cdot h$$

From Clip Angle Deflection Analysis

$\delta m_1 = 0.0039$ in-lbf Middle stringer

$\delta m_2 = 0.0078$ in-lbf 2nd from middle stringer

2D FEA DEFLECTION CALCULATION FOR SOUTHBOUND STRUCTURE

$E = 30000000$ psi Youngs modulus of steel

$I = 706$ in^4 Area moment of inertia of the stringers

$L = 210$ in Stringer length

$h = 15$ in Height of the clip angle

$tc = .375$ in Thickness of the clip angle

$Lc = 1.4$ in Length of the beam model of the clip angle and point where the rotation is zero

$Lo = 1.25$ in Postion on clip angle where there is a maximum stress

$i := 1..3$ From Global FEA Analysis

$P_1 := 5500$ Middle stringer

$P_2 := 10960$ 2nd from middle stringer

$P_3 := 7950$ 3rd from middle stringer

$$C_R := \frac{\theta cl}{Mo} = \frac{\frac{\delta}{h}}{\left(\frac{2 \cdot \sigma_o \cdot tc \cdot h^2}{3}\right)} \qquad C_R := \frac{\frac{.0001663}{15}}{\left(\frac{100 \cdot 2 \cdot tc \cdot h^2}{3}\right)}$$

From 2D FEA

$$Mo_i := \frac{\frac{P_i \cdot L^2}{16 \cdot E \cdot I}}{C_R + \frac{L}{2 \cdot E \cdot I}}$$

From Clip Angle Deflection Analysis

$Mo_1 = 103304$ in-lbf Middle stringer

$Mo_2 = 205857$ in-lbf 2nd from middle stringer

$Mo_3 = 149322$ in-lbf 3rd from middle stringer

$$\delta m_i := C_R \cdot Mo_i \cdot h$$

From Clip Angle Deflection Analysis

$\delta m_1 = 0.0031$ in-lbf Middle stringer

$\delta m_2 = 0.0061$ in-lbf 2nd from middle stringer

$\delta m_3 = 0.0044$ in-lbf 3rd from middle stringer

2D FEA STRESS CALCULATION FOR NORTHBOUND STRUCTURE

$E = 30000000$ psi Youngs modulus of steel

$I = 802$ in^4 Area moment of inertia of the stringers

$L = 210$ in Stringer length

$h = 15$ in Height of the clip angle

$tc = .375$ in Thickness of the clip angle

$Lc = 1.4$ in Length of the beam model of the clip angle and point where the rotation is zero

$Lo = 1.25$ in Postion on clip angle where there is a maximum stress

$i := 1 .. 2$ From Global FEA Analysis

$P_1 := 7300$ Middle stringer

$P_2 := 14500$ 2nd from middle stringer

$$C_R := \frac{\theta cl}{Mo} = \frac{\frac{\delta}{h}}{\left(\frac{2 \cdot \sigma_o \cdot tc \cdot h^2}{3}\right)} \qquad C_R := \frac{\frac{.0001663}{15}}{\left(\frac{100 \cdot 2 \cdot tc \cdot h^2}{3}\right)}$$

From 2D FEA

$$Mo_i := \frac{\frac{P_i \cdot L^2}{16 \cdot E \cdot I}}{C_R + \frac{L}{2 \cdot E \cdot I}}$$

From Clip Angle Deflection Analysis

$Mo_1 = 132007$ in-lbf Middle stringer

$Mo_2 = 262205$ in-lbf 2nd from middle stringer

$$\sigma_i := \frac{970 \cdot Mo_i}{Mo} \qquad \sigma_i := \frac{970 \cdot Mo_i}{\frac{100 \cdot 2 \cdot tc \cdot h^2}{3}}$$

From 2D FEA

$\sigma_1 = 22764$ psi Middle stringer

$\sigma_2 = 45216$ psi 2nd from middle stringer

$E = 30000000$ psi Youngs modulus of steel

$I = 706$ in^4 Area moment of inertia of the stringers

$L = 210$ in Stringer length

$h = 15$ in Height of the clip angle

$tc = .375$ in Thickness of the clip angle

$Lc = 1.4$ in Length of the beam model of the clip angle and point where the rotation is zero

$Lo = 1.25$ in Postion on clip angle where there is a maximum stress

$i := 1..3$ From Global FEA Analysis

$P_1 := 5500$ Middle stringer

$P_2 := 10960$ 2nd from middle stringer

$P_3 := 7950$ 3rd from middle stringer

$$C_R := \frac{\theta cl}{Mo} = \frac{\frac{\delta}{h}}{\left(\frac{2\cdot\sigma_o\cdot tc\cdot h^2}{3}\right)} \qquad C_R := \frac{\frac{.0001663}{15}}{\left(\frac{100\cdot 2\cdot tc\cdot h^2}{3}\right)}$$

From 2D FEA

$$Mo_i := \frac{\frac{P_i\cdot L^2}{16\cdot E\cdot I}}{C_R + \frac{L}{2\cdot E\cdot I}}$$

From Clip Angle Deflection Analysis

$Mo_1 = 103304$ in-lbf Middle stringer

$Mo_2 = 205857$ in-lbf 2nd from middle stringer

$Mo_3 = 149322$ in-lbf 3rd from middle stringer

$$\sigma_i := \frac{970\cdot Mo_i}{Mo} \qquad \sigma_i := \frac{970\cdot Mo_i}{\frac{100\cdot 2\cdot tc\cdot h^2}{3}}$$

From 2D FEA

$\sigma_1 = 17814$ psi Middle stringer

$\sigma_2 = 35499$ psi 2nd from middle stringer

$\sigma_3 = 25750$ psi 3rd from middle stringer

APPENDIX G

3D FEA MODEL

```
title end.375t6prfr
lsnike3d
lsnkopts teo 1 nsteps 2 delt .1 iprt .1;

c Material Definitions
nikemats 1 1 e 30000000 pr .29 ;   c clip angle (CL)
nikemats 2 1 e 30000000 pr .29 ;   c stringer (Str)
nikemats 3 1 e 30000000 pr .29 ;   c Str rivets
nikemats 4 1 e 30000000 pr .29 ;   c Str rivet heads
nikemats 5 1 e 30000000 pr .29 ;   c floor beam (FB) rivets
nikemats 6 1 e 30000000 pr .29 ;   c FB rivet heads
nikemats 7 1 e 30000000 pr .29 ;   c FB
nikemats 8 4 temp 0 10; e 30000000 30000000; pr .29 .29 ; alpha
 .0004 .0004 ;;   c material in rivets under preload

c   Slide Surface Definitions
SID 1 LSDSI 3 scoef .5 dcoef .5  ;  ; ;   c Str web & CL
SID 2 LSDSI 3 scoef .5 dcoef .5  ;  ; ;   c FB web & CL
SID 3 LSDSI 3 scoef .5 dcoef .5  ;  ; ;   c FB rivets & CL
SID 4 LSDSI 3 scoef .5 dcoef .5  ;  ; ;   c CL & FB rivet heads
SID 5 LSDSI 3 scoef .5 dcoef .5  ;  ; ;   c Str rivets & CL
SID 6 LSDSI 3 scoef .5 dcoef .5  ;  ; ;   c crack (not used)
SID 7 LSDSI 3 scoef .5 dcoef .5  ;  ; ;   c CL & Str rivet heads

c   Load curve definitions
lcd 1 0 10 .1 1.5 .2 1.5;   c rivet pre-load curve
lcd 2 0 0 .1 .1 .2 1;       c stringer load curve

tp .02                      c global node merging tolerance

c   Parameters to vary mesh density
para j .375;         c CL thickness
para h [.44+%j];     c position of rivet head projection surface
para g .25;          c distance between Str and FB
para t 6;            c # elements (EL) across CL thickness
para wid 3;          c parameter for # EL on the FB leg
para w 10;           c # EL up each section of CL on the Str leg
para ww 6;           c parameter for # EL on the Str leg
para www 5;          c parameter for # EL on the Str leg
para d 4;            c # EL from outside of CL to mesh around all the
                     c   all the rivet holes on the Str leg
para d1 4;           c # EL from outside of CL to mesh around
para d2 4;           c   each rivet hole on the FB leg
para d3 4;
para d4 5;
```

```
para d5 7;
para w1b 5;         c # EL up each section of the corner and fillet
para w1t 5;         c   of the CL
para w2b 5;
para w2t 5;
para w3b 5;
para w3t 6;
para w4b 8;
para w4t 9;
para w5b 11;
para w5t 11;
para w1 5;          c # EL across the clip angle between each rivet
para w12 5;         c   hole section on the FB leg of the CL
para w23 6;
para w34 8;
para w45 10;
para w5 10;

plane 2 0 0 0 0 1 0 .01 symm ;        c longitudinal symetry plane
plane 3 105 0 0 -1 0 0 .01 symm ;     c lateral symetry plane

c   Projection surface definitions
sd 1 cy 2 0 2.5 0 1 0 .45
sd 2 cy 2 0 5.5 0 1 0 .45
sd 3 cy 2 0 8.5 0 1 0 .45
sd 4 cy 2 0 11.5 0 1 0 .45
sd 5 cy 2 0 14.5 0 1 0 .45
sd 6 cy .9 -1.08 0  0 0 1  .5
sd 7 cy 2 0 2.5 0 1 0 .75
sd 8 cy 0 -2.68 2.5 1 0 0 .75
sd 15 pl3 rt [%h] 0 0 rt [%h] 1 0 rt [%h] 1 1
sd 16 pl3 rt 0 [-.18-%h] 0 rt 1 [-.18-%h] 0 rt 1 [-.18-%h] 1

bptol 1 2 .05   c between parts 1 & 2 node merging tolerance
c part 1:  stringer web
block
1 4 7 10 25 35 45 50; 1 2; 1 4 7 10 13 16 19 22 25 28 31 33 34;
[%g] 1.333 2.666 4.3 52.5 73.5 94.5 105
0 -.18
0 1.75 3.25 4.75 6.25 7.75 9.25 10.75 12.25 13.75 15.25 16.6 17
dei 1 4; ; 12 13;
dei 2 3; 1 2; 2 3 0 4 5 0 6 7 0 8 9 0 10 11;
sfi -2 -3;; -2 -3;sd 1
sfi -2 -3;; -4 -5;sd 2
sfi -2 -3;; -6 -7;sd 3
```

```
sfi -2 -3;; -8 -9;sd 4
sfi -2 -3;; -10 -11;sd 5
orpt - 0 0 0
sii 1 4;-2;;1 m ;
mate 2
endpart

c part 2:  stringer rivets
block
1 2 5 6; 1 2 7 10; 1 2 5 6;
1.75 1.75 2.25 2.25
0 -.18 [-.18-%j] [-.8-%j]
2.25 2.25 2.75 2.75
sd 25 sp 2 [-.0785-%j] 2.5 .7566375
dei 1 2 0 3 4;; 1 2 0 3 4;
sfi -1 -4; ; -1 -4;sd 1
sfi ;-4;;sd 25
lct 4 mz 3; mz 6; mz 9; mz 12;
lrep 0 1 2 3 4;
orpt + 2 -.38 2.5
sii -1 -4;2 3;-1 -4;5 m ;
mate 3
mti ;2 3;; 8
endpart

c part 3:  stringer upper flange
block
1 16 26 36 41; 1 2 7; 1 2;
4.3 52.5 73.5 94.5 105
0 -.18 -3.57
17 17.57
orpt - 100 -2 19
pri 4 5;;-2;2 -22.23
pri 3 4;;-2;2 -14.8
pri 2 3;;-2;2 -7.4
mate 2
endpart

c part 4:  stringer lower flange
block
1 4 7 10 25 35 45 50; 1 2 7; 1 2;
[%g] 1.333 2.666 4.3 52.5 73.5 94.5 105
0 -.18 -3.57
0 -.57
mate 2
```

```
orpt - 1 -2 -.25
endpart

c part 5:  mesh for the CL corner and fillet
block
1 [1+%t] [7+%t]; 1 [1+%t] [7+%t];
 1 [1+%w1b] [1+%w1b+%w1t] [1+%w1b+%w1t+%w2b]
 [1+%w1b+%w1t+%w2b+%w2t] [1+%w1b+%w1t+%w2b+%w2t+%w3b]
 [1+%w1b+%w1t+%w2b+%w2t+%w3b+%w3t]
 [1+%w1b+%w1t+%w2b+%w2t+%w3b+%w3t+%w4b]
 [1+%w1b+%w1t+%w2b+%w2t+%w3b+%w3t+%w4b+%w4t]
 [1+%w1b+%w1t+%w2b+%w2t+%w3b+%w3t+%w4b+%w4t+%w5b]
 [1+%w1b+%w1t+%w2b+%w2t+%w3b+%w3t+%w4b+%w4t+%w5b+%w5t];
0 0 [%h]
-.18 -.18 [-.18-%h]
1 2.5 4 5.5 7 8.5 10 11.5 13 14.5 16
sd 1 cy [%h] [-.18-%h] 0  0 0 1 .44
dei 2 3; 2 3; ;
dei 1 2; 1 2; ;
sfi -2 3; -2 3;;sd 1
sii ;-1;;1 s ;
sii 1 2;-2;;1 s ;
sii -1;;;2 s ;
sii -2;1 2;;2 s;
endpart

c part 6:  mesh around the 1st rivet hole of CL on the Str side
cylinder
1 3; 1 [1+%w] [1+%w+%ww]  [1+%w+%ww+%www] [1+%w+%ww+%www+%w1b]
[1+%w+%ww+%www+%w1b+%w1t] [1+%w+%ww+2*%www+%w1b+%w1t]
[1+%w+2*%ww+2*%www+%w1b+%w1t]; 1 [1+%t];
.45 .75
0 90 146 175 225 275 304 360
-.18 [-.18-%j]
lct 1 rz -45 rx -90 mx 2 mz 2.5;
lrep 1;
orpt - 0 2 0
sii ;;-1;1 s ;
sii -1;;;5 s ;
sii ;;-2;7 s ;
endpart

c part 7:  mesh around the 2nd rivet hole of CL on the Str side
cylinder
1 3; 1 [1+%w] [1+%w+%ww]  [1+%w+%ww+%www] [1+%w+%ww+%www+%w2b]
```

```
[1+%w+%ww+%www+%w2b+%w2t] [1+%w+%ww+2*%www+%w2b+%w2t]
[1+%w+2*%ww+2*%www+%w2b+%w2t]; 1 [1+%t];
.45 .75
0 90 146 175 225 275 304 360
-.18 [-.18-%j]
lct 1 rz -45 rx -90 mx 2 mz 5.5;
lrep 1;
orpt - 0 2 0
sii ;;-1;1 s ;
sii -1;;;5 s ;
sii ;;-2;7 s ;
endpart

c part 8:  mesh around the 3rd rivet hole of CL on the Str side
cylinder
1 3; 1 [1+%w] [1+%w+%ww]  [1+%w+%ww+%www] [1+%w+%ww+%www+%w3b]
[1+%w+%ww+%www+%w3b+%w3t] [1+%w+%ww+2*%www+%w3b+%w3t]
[1+%w+2*%ww+2*%www+%w3b+%w3t]; 1 [1+%t];
.45 .75
0 90 146 175 225 275 304 360
-.18 [-.18-%j]
lct 1 rz -45 rx -90 mx 2 mz 8.5;
lrep 1;
orpt - 0 2 0
sii ;;-1;1 s ;
sii -1;;;5 s ;
sii ;;-2;7 s ;
endpart

c part 9:  mesh around the 4th rivet hole of CL on the Str side
cylinder
1 3; 1 [1+%w] [1+%w+%ww]  [1+%w+%ww+%www] [1+%w+%ww+%www+%w4b]
[1+%w+%ww+%www+%w4b+%w4t] [1+%w+%ww+2*%www+%w4b+%w4t]
[1+%w+2*%ww+2*%www+%w4b+%w4t]; 1 [1+%t];
.45 .75
0 90 146 175 225 275 304 360
-.18 [-.18-%j]
lct 1 rz -45 rx -90 mx 2 mz 11.5;
lrep 1;
orpt - 0 2 0
sii ;;-1;1 s ;
sii -1;;;5 s ;
sii ;;-2;7 s ;
endpart
```

```
c part 10:  mesh around the 5th rivet hole of CL on the Str side
cylinder
1 4; 1 [1+%w] [1+%w+%ww]  [1+%w+%ww+%www] [1+%w+%ww+%www+%w5b]
[1+%w+%ww+%www+%w5b+%w5t] [1+%w+%ww+2*%www+%w5b+%w5t]
[1+%w+2*%ww+2*%www+%w5b+%w5t]; 1 [1+%t];
.45 .75
0 90 146 175 225 275 304 360
-.18 [-.18-%j]
lct 1 rz -45 rx -90 mx 2 mz 14.5;
lrep 1;
orpt - 0 2 0
sii ;;-1;1 s ;
sii -1;;;5 s ;
sii ;;-2;7 s ;
endpart

c part 11: mesh for the outer CL on the Str side
block
1 [1+%ww] [1+%ww+%d]; 1 [1+%t]; 1 [1+%d] [1+%d+%w] [1+%w+2*%d];
1.7 3.5 3.5
-.18 [-.18-%j]
1 1 4 4
dei 2 3;; 1 2 0 3 4;
dei 1 2;; 2 3;
lct 4 mz 3; mz 6; mz 9; mz 12;
lrep 0 1 2 3 4;
sfi 1 -2;; -2 -3;sd 7
orpt + 0 0 0
sii ;-1;;1 s ;
sii 1 -2;;-2 -3;1 s ;
endpart

c part 12: mesh for inner CL in the 1st section on the Str side
block
1 [1+%d] [1+%d+%www]; 1 [1+%t]; 1 [1+%d] [1+%d+%w1b]
[1+%d+%w1b+%w1t] [1+2*%d+%w1b+%w1t];
.77 .77 1.7
-.18 [-.18-%j]
1 1 2.5 4 4
dei 1 2;; 1 2 0 4 5;
dei 2 3;; 2 4;
sfi -2;;2 4;sd 7
sfi 2 3;;-2 -4;sd 7
sfi -1;;;sd 15
sfi -2;;-1 0 -5;sd 15
```

```
orpt + 0 0 0
sii ;-1;;1 s ;
sii -2 -3;;2 4;1 s ;
endpart

c part 13: mesh for inner CL in the 2nd section on the Str side
block
1 [1+%d] [1+%d+%www]; 1 [1+%t]; 1 [1+%d] [1+%d+%w2b]
[1+%d+%w2b+%w2t] [1+2*%d+%w2b+%w2t];
.77 .77 1.7
-.18 [-.18-%j]
1 1 2.5 4 4
dei 1 2;; 1 2 0 4 5;
dei 2 3;; 2 4;
lct 1 mz 3;
lrep 1;
sfi -2;;2 4;sd 7
sfi 2 3;;-2 -4;sd 7
sfi -1;;;sd 15
sfi -2;;-1 0 -5;sd 15
orpt + 0 0 0
sii ;-1;;1 s ;
sii -2 -3;;2 4;1 s ;
endpart

c part 14: mesh for inner CL in the 3rd section on the Str side
block
1 [1+%d] [1+%d+%www]; 1 [1+%t]; 1 [1+%d] [1+%d+%w3b]
[1+%d+%w3b+%w3t] [1+2*%d+%w3b+%w3t];
.77 .77 1.7
-.18 [-.18-%j]
1 1 2.5 4 4
dei 1 2;; 1 2 0 4 5;
dei 2 3;; 2 4;
lct 1 mz 6;
lrep 1;
sfi -2;;2 4;sd 7
sfi 2 3;;-2 -4;sd 7
sfi -1;;;sd 15
sfi -2;;-1 0 -5;sd 15
orpt + 0 0 0
sii ;-1;;1 s ;
sii -2 -3;;2 4;1 s ;
endpart
```

```
c part 15: mesh for inner CL in the 4th section on the Str side
block
1 [1+%d] [1+%d+%www]; 1 [1+%t]; 1 [1+%d] [1+%d+%w4b]
[1+%d+%w4b+%w4t] [1+2*%d+%w4b+%w4t];
.77 .77 1.7
-.18 [-.18-%j]
1 1 2.5 4 4
dei 1 2;; 1 2 0 4 5;
dei 2 3;; 2 4;
lct 1 mz 9;
lrep 1;
sfi -2;;2 4;sd 7
sfi 2 3;;-2 -4;sd 7
sfi -1;;;sd 15
sfi -2;;-1 0 -5;sd 15
orpt + 0 0 0
sii ;-1;;1 s ;
sii -2 -3;;2 4;1 s ;
endpart

c part 16: mesh for inner CL in the 5th section on the Str side
block
1 [1+%d] [1+%d+%www]; 1 [1+%t]; 1 [1+%d] [1+%d+%w5b]
[1+%d+%w5b+%w5t] [1+2*%d+%w5b+%w5t];
.77 .77 1.7
-.18 [-.18-%j]
1 1 2.5 4 4
dei 1 2;; 1 2 0 4 5;
dei 2 3;; 2 4;
lct 1 mz 12;
lrep 1;
sfi -2;;2 4;sd 7
sfi 2 3;;-2 -4;sd 7
sfi -1;;;sd 15
sfi -2;;-1 0 -5;sd 15
orpt + 0 0 0
sii ;-1;;1 s ;
sii -2 -3;;2 4;1 s ;
endpart


c part 17:  mesh around the 1st rivet hole of CL on the FB side
cylinder
1 3; 1 [1+%wid] [1+%wid+%w] [1+2*%wid+%w] [1+2*%wid+%w+%w12]
 [1+2*%wid+%w+%w12+%w1t] [1+2*%wid+%w+%w12+%w1t+%w1b]
```

```
 [1+2*%wid+%w+%w12+%w1t+%w1b+%w1]; 1 [1+%t];
.45 .75
0 30 120 150 213.5 255 296 360
0 [-%j]
lct 1 rz 195 ry -90 my -2.68 mz 2.5;
lrep 1;
orpt + -2 0 0
sii ;;-1;2 s ;
sii -1;;;3 s ;
sii ;;-2;4 s ;
endpart

c part 18:  mesh around the 2nd rivet hole of CL on the FB side
cylinder
1 3; 1 [1+%wid] [1+%wid+%w] [1+2*%wid+%w]  [1+2*%wid+%w+%w23]
 [1+2*%wid+%w+%w23+%w2t] [1+2*%wid+%w+%w23+%w2t+%w2b]
 [1+2*%wid+%w+%w23+%w2t+%w2b+%w12]; 1 [1+%t];
.45 .75
0 30 120 150 213.5 255 296 360
0 [-%j]
lct 1 rz 195 ry -90 my -2.68 mz 5.5;
lrep 1;
orpt + -2 0 0
sii ;;-1;2 s ;
sii -1;;;3 s ;
sii ;;-2;4 s ;
endpart

c part 19:  mesh around the 3rd rivet hole of CL on the FB side
cylinder
1 3; 1 [1+%wid] [1+%wid+%w] [1+2*%wid+%w] [1+2*%wid+%w+%w34]
 [1+2*%wid+%w+%w34+%w3t] [1+2*%wid+%w+%w34+%w3t+%w3b]
 [1+2*%wid+%w+%w34+%w3t+%w3b+%w23]; 1 [1+%t];
.45 .75
0 30 120 150 213.5 255 296 360
0 [-%j]
lct 1 rz 195 ry -90 my -2.68 mz 8.5;
lrep 1;
orpt + -2 0 0
sii ;;-1;2 s ;
sii -1;;;3 s ;
sii ;;-2;4 s ;
endpart

c part 20:  mesh around the 4th rivet hole of CL on the FB side
```

```
cylinder
1 3; 1 [1+%wid] [1+%wid+%w] [1+2*%wid+%w] [1+2*%wid+%w+%w45]
 [1+2*%wid+%w+%w45+%w4t] [1+2*%wid+%w+%w45+%w4t+%w4b]
 [1+2*%wid+%w+%w45+%w4t+%w4b+%w34]; 1 [1+%t];
.45 .75
0 30 120 150 213.5 255 296 360
0 [-%j]
lct 1 rz 195 ry -90 my -2.68 mz 11.5;
lrep 1;
orpt + -2 0 0
sii ;;-1;2 s ;
sii -1;;;3 s ;
sii ;;-2;4 s ;
endpart

c part 21:  mesh around the 5th rivet hole of CL on the FB side
cylinder
1 4; 1  [1+%wid] [1+%wid+%w] [1+2*%wid+%w] [1+2*%wid+%w+%w5]
 [1+2*%wid+%w+%w5+%w5t] [1+2*%wid+%w+%w5+%w5t+%w5b]
 [1+2*%wid+%w+%w5+%w5t+%w5b+%w45]; 1 [1+%t];
.45 .75
0 30 120 150 213.5 255 296 360
0 [-%j]
lct 1 rz 195 ry -90 my -2.68 mz 14.5;
lrep 1;
orpt + -2 0 0
sii ;;-1;2 s ;
sii -1;;;3 s ;
sii ;;-2;4 s ;
endpart

c part 22:  mesh for outside of the CL in the 1st section on the FB
 side
block
1 [1+%t]; 1 [1+%wid] [1+%wid+%d1]; 1 [1+%d1] [1+%d1+%w]
 [1+2*%d1+%w];
0 [%j]
-3.08 -4.18 -4.18
1 1 4 4
dei ; 2 3; 1 2 0 3 4;
dei ; 1 2; 2 3;
sfi ; 1 -2; -2 -3;sd 8
orpt + -2 0 0
sii -1;;;2 s ;
endpart
```

```
c part 23:  mesh for outside of the CL in the 2nd section on the FB
 side
block
1 [1+%t]; 1 [1+%wid] [1+%wid+%d2]; 1 [1+%d2] [1+%d2+%w]
 [1+2*%d2+%w];
0 [%j]
-3.08 -4.18 -4.18
1 1 4 4
dei ; 2 3; 1 2 0 3 4;
dei ; 1 2; 2 3;
lct 1 mz 3;
lrep 1;
sfi ; 1 -2; -2 -3;sd 8
orpt + -2 0 0
sii -1;;;2 s ;
endpart

c part 24:  mesh for outside of the CL in the 3rd section on the FB
 side
block
1 [1+%t]; 1 [1+%wid] [1+%wid+%d3]; 1 [1+%d3] [1+%d3+%w]
 [1+2*%d3+%w];
0 [%j]
-3.08 -4.18 -4.18
1 1 4 4
dei ; 2 3; 1 2 0 3 4;
dei ; 1 2; 2 3;
lct 1 mz 6;
lrep 1;
sfi ; 1 -2; -2 -3;sd 8
orpt + -2 0 0
sii -1;;;2 s ;
endpart

c part 25:  mesh for outside of the CL in the 4th section on the FB
 side
block
1 [1+%t]; 1 [1+%wid] [1+%wid+%d4]; 1 [1+%d4] [1+%d4+%w]
 [1+2*%d4+%w];
0 [%j]
-3.08 -4.18 -4.18
1 1 4 4
dei ; 2 3; 1 2 0 3 4;
dei ; 1 2; 2 3;
```

```
lct 1 mz 9;
lrep 1;
sfi ; 1 -2; -2 -3;sd 8
orpt + -2 0 0
sii -1;;;2 s ;
endpart

c part 26:  mesh for outside of the CL in the 5th section on the FB
 side
block
1 [1+%t]; 1 [1+%wid] [1+%wid+%d5]; 1 [1+%d5] [1+%d5+%w]
 [1+2*%d5+%w];
0 [%j]
-3.08 -4.18 -4.18
1 1 4 4
dei ; 2 3; 1 2 0 3 4;
dei ; 1 2; 2 3;
lct 1 mz 12;
lrep 1;
sfi ; 1 -2; -2 -3;sd 8
orpt + -2 0 0
sii -1;;;2 s ;
endpart

c part 27:  mesh for CL inner bottom of the 1st section on the FB s
ide
block
1 [1+%t]; 1 [1+%d1] [1+%d1+%w1]; 1 [1+%d1] [1+%d1+%w1b];
0 [%j]
-.95 -.95 -3.08
1 1 2.5
dei ; 2 3; 2 3;
dei ; 1 2; 1 2;
sfi ; -2 3; -2 3;sd 8
sfi ;-1;;sd 16
sfi ;-2;-1;sd 16
orpt + -2 0 0
sii -1;;;2 s ;
endpart

c part 28:  mesh for CL inner bottom of the 2nd section on the FB s
ide
block
1 [1+%t]; 1 [1+%d2] [1+%d2+%w12]; 1 [1+%d2] [1+%d2+%w2b];
0 [%j]
```

```
-.95 -.95 -3.08
1 1 2.5
dei ; 2 3; 2 3;
dei ; 1 2; 1 2;
lct 1 mz 3;
lrep 1;
sfi ; -2 3; -2 3;sd 8
sfi ;-1;;sd 16
sfi ;-2;-1;sd 16
orpt + -2 0 0
sii -1;;;2 s ;
endpart

c part 29:  mesh for CL inner bottom of the 3rd section on the FB s
ide
block
1 [1+%t]; 1 [1+%d3] [1+%d3+%w23]; 1 [1+%d3] [1+%d3+%w3b];
0 [%j]
-.95 -.95 -3.08
1 1 2.5
dei ; 2 3; 2 3;
dei ; 1 2; 1 2;
lct 1 mz 6;
lrep 1;
sfi ; -2 3; -2 3;sd 8
sfi ;-1;;sd 16
sfi ;-2;-1;sd 16
orpt + -2 0 0
sii -1;;;2 s ;
endpart

c part 30:  mesh for CL inner bottom of the 4th section on the FB s
ide
block
1 [1+%t]; 1 [1+%d4] [1+%d4+%w34]; 1 [1+%d4] [1+%d4+%w4b];
0 [%j]
-.95 -.95 -3.08
1 1 2.5
dei ; 2 3; 2 3;
dei ; 1 2; 1 2;
lct 1 mz 9;
lrep 1;
sfi ; -2 3; -2 3;sd 8
sfi ;-1;;sd 16
sfi ;-2;-1;sd 16
```

```
orpt + -2 0 0
sii -1;;;2 s ;
endpart

c part 31:  mesh for CL inner bottom of the 5th section on the FB s
ide
block
1 [1+%t]; 1 [1+%d5] [1+%d5+%w45]; 1 [1+%d5] [1+%d5+%w5b];
0 [%j]
-.95 -.95 -3.08
1 1 2.5
dei ; 2 3; 2 3;
dei ; 1 2; 1 2;
lct 1 mz 12;
lrep 1;
sfi ; -2 3; -2 3;sd 8
sfi ;-1;;sd 16
sfi ;-2;-1;sd 16
orpt + -2 0 0
sii -1;;;2 s ;
endpart

c part 32:  mesh for CL inner top of the 1st section on the FB side

block
1 [1+%t]; 1 [1+%d1] [1+%d1+%w12]; 1 [1+%w1t] [1+%w1t+%d1];
0 [%j]
-.95 -.95 -3.08
2.5 4 4
dei ; 2 3; 1 2;
dei ; 1 2; 2 3;
sfi ; -2 3; 1 -2;sd 8
sfi ;-1;;sd 16
sfi ;-2;-3;sd 16
orpt + -2 0 0
sii -1;;;2 s ;
endpart

c part 33:  mesh for CL inner top of the 2nd section on the FB side
 block
block
1 [1+%t]; 1 [1+%d2] [1+%d2+%w23]; 1 [1+%w2t] [1+%w2t+%d2];
0 [%j]
-.95 -.95 -3.08
2.5 4 4
```

```
dei ; 2 3; 1 2;
dei ; 1 2; 2 3;
lct 1 mz 3;
lrep 1;
sfi ; -2 3; 1 -2;sd 8
sfi ;-1;;sd 16
sfi ;-2;-3;sd 16
orpt + -2 0 0
sii -1;;;2 s ;
endpart

c part 34:  mesh for CL inner top of the 3rd section on the FB side

block
1 [1+%t]; 1 [1+%d3] [1+%d3+%w34]; 1 [1+%w3t] [1+%w3t+%d3];
0 [%j]
-.95 -.95 -3.08
2.5 4 4
dei ; 2 3; 1 2;
dei ; 1 2; 2 3;
lct 1 mz 6;
lrep 1;
sfi ; -2 3; 1 -2;sd 8
sfi ;-1;;sd 16
sfi ;-2;-3;sd 16
orpt + -2 0 0
sii -1;;;2 s ;
endpart

c part 35:  mesh for CL inner top of the 4th section on the FB side

block
1 [1+%t]; 1 [1+%d4] [1+%d4+%w45]; 1 [1+%w4t] [1+%w4t+%d4];
0 [%j]
-.95 -.95 -3.08
2.5 4 4
dei ; 2 3; 1 2;
dei ; 1 2; 2 3;
lct 1 mz 9;
lrep 1;
sfi ; -2 3; 1 -2;sd 8
sfi ;-1;;sd 16
sfi ;-2;-3;sd 16
orpt + -2 0 0
sii -1;;;2 s ;
```

```
endpart

c part 36:  mesh for CL inner top of the 5th section on the FB side

block
1 [1+%t]; 1 [1+%d5] [1+%d5+%w5]; 1 [1+%w5t] [1+%w5t+%d5];
0 [%j]
-.95 -.95 -3.08
2.5 4 4
dei ; 2 3; 1 2;
dei ; 1 2; 2 3;
lct 1 mz 12;
lrep 1;
sfi ; -2 3; 1 -2;sd 8
sfi ;-1;;sd 16
sfi ;-2;-3;sd 16
orpt + -2 0 0
sii -1;;;2 s ;
endpart

c part 37:  floor beam rivets
bptol 37 39 .05
block
1 2 7 10; 1 2 5 6; 1 2 5 6;
-.44 0 [%j] [.62+%j]
-.25 -.25 .25 .25
-.25 -.25 .25 .25
dei ; 1 2 0 3 4; 1 2 0 3 4;
sd 1 cy 0 0 0 1 0 0 .45
sd 26 sp [-.1015+%j] 0 0 .7566375
sfi ;-1 -4; -1 -4;sd 1
sfi -4;;;sd 26
sii 2 3;-1 -4;-1 -4;3  m ;
orpt + .2 0 0
lct 5 my -2.68 mz 2.5; my -2.68 mz 5.5; my -2.68 mz 8.5;
my -2.68 mz 11.5; my -2.68 mz 14.5;
lrep 1 2 3 4 5;
mate 5
mti 2 3;;;8
endpart

c part 38:  floor beam rivet heads
cylinder
1 3; 1 7 13; 1 4;
.45 .75
```

```
0 180 360
[%j] [.4+%j]
sd 35 cy 0 0 0 0 0 1 .45
sd 27 sp 0 0 [-.1015+%j] .7566375
sfi -2;;;sd 27
sfi ;;-2;sd 27
sfi -1;;;sd 35
sii ; ;-1;4 m ;
lct 5 rz 15 ry 90 my -2.68 mz 2.5; rz 15 ry 90 my -2.68 mz 5.5;
rz 15 ry 90 my -2.68 mz 8.5; rz 15 ry 90 my -2.68 mz 11.5;
rz 15 ry 90 my -2.68 mz 14.5;
lrep 1 2 3 4 5;
mate 6
endpart

c part 39:  mesh for floor beam web
block
1 2; 1 4 7 9 67; 1 9 12 15 18 21 24 27 30 33 36 39 42;
-.44 0
0 -2.01333 -3.34667 -4.25 -84
-5.658 0 1.75 3.25 4.75 6.25 7.75 9.25 10.75 12.25 13.75 15.25 16.9
dei ; 2 3; 3 4 0 5 6 0 7 8 0 9 10 0 11 12;
sd 1 cy 0 -2.68 2.5 1 0 0 .45
sd 2 cy 0 -2.68 5.5 1 0 0 .45
sd 3 cy 0 -2.68 8.5 1 0 0 .45
sd 4 cy 0 -2.68 11.5 1 0 0 .45
sd 5 cy 0 -2.68 14.5 1 0 0 .45
sfi ; -2 -3; -3 -4;sd 1
sfi ; -2 -3; -5 -6;sd 2
sfi ; -2 -3; -7 -8;sd 3
sfi ; -2 -3; -9 -10;sd 4
sfi ; -2 -3; -11 -12;sd 5
sii -2;;2 13;2 m ;
bi ;;-13; dx 1 dz 1 dy 1 ;
mate 7
endpart

c part 40:  mesh for floor beam lower flange
block
1 6 7 12; 1 4 7 9 67; 1 2;
-4.7125 -.44 0 4.2725
0 -2.01333 -3.34667 -4.25 -84
-5.658 -6.34
mate 7
endpart
```

```
c part 41:  mesh for stringer rivet heads
cylinder
1 3; 1 13; 1 4;
.45 .75
0 360
[-.18-%j] [-.58-%j]
sd 28 sp 0 0 [-.0785-%j] .7566375
sd 36 cy 0 0 0 0 0 1 .45
sfi -1;;;sd 36
sfi -2;;;sd 28
sfi ;;-2;sd 28
orpt - 0 2 0
sii ;;-1;7 m ;
lct 5 rz 15 rx -90 mx 2 mz 2.5; rz 15 rx -90 mx 2 mz 5.5;
 rz 15 rx -90 mx 2 mz 8.5; rz 15 rx -90 mx 2 mz 11.5;
 rz 15 rx -90 mx 2 mz 14.5;
lrep 1 2 3 4 5;
mate 4
endpart

merge
```

	Stress (psi)		Stringer Deflection (in)		Stringer	Clip Angle Deflection (in)		Clip Angle
	Floor Beam	Stringer	Top	Bottom	Rotation (rad)	Top	Bottom	Rotation (rad)
	Side	Side	Flange	Flange				
mid.5t5	8200	9900						
mid.5t6	10300	11900						
mid.5t7	11000	12500	0.00659	-0.00515	0.000647	0.00384	0	0.000256
mid.5t7prfr	13900	15700	0.00574	-0.00472	0.000577	0.00324	0	0.000216
mid.5t7fr		11600	0.00490	-0.00500	0.000546			
mid.5t7pr	8900	10500	0.00665	-0.00600	0.000697			
mid.375t4	9000	12000						
mid.375t5	10100	13100						
mid.375t6	10650	13700	0.00760	-0.00560	0.000728	0.00525	0	0.000350
mid.375t6prfr	14050	17100	0.00672	-0.00507	0.000650	0.00453	0	0.000302
mid.375t6fr	10500	14000	0.00765	-0.00552	0.000726	0.00553	0	0.000369
mid.375t6pr		10800	0.00705	-0.00645	0.000744	0.00265	0	0.000177
end.375t6prfr	11700	14700	0.00784	-0.00942	0.000951	0.00606	-0.00776	0.000921
end.375t6	9400	10300	0.00855	-0.00960	0.001001	0.00564	-0.00832	0.000931
Retro 2 - 4 x 6 x 3/8 inch clip angle								
new.375t6		10000	0.00805	-0.00560	0.000752	0.00577	0	0.000385
new.375t6prfr	8150	11200	0.00769	-0.00518	0.000709	0.00591	0	0.000394
Retro 2 - 4 x 6 x 1/2 inch clip angle								
new.5t5	5200	6600						
new.5t6	5800	7200						
new.5t7		8100	0.00780	-0.00530	0.000722	0.00553	0	0.000369
new.5t7prfr	8300	9900	0.00740	-0.00491	0.000679	0.00558	0	0.000372
Retro 3 - Remove top row of rivets								
mid.375t6r1		6200	0.00730	-0.00570	0.000717	0.00206		
mid.375t6r1prfr	9600	11600	0.00780	-0.00535	0.000725	0.00401		
Retro 4 - Remove top two rows of rivets								
mid.375t6r2		2600	0.00800	-0.00590	0.000766	0.00024		
mid.375t6r2prfr		5100	0.00841	-0.00547	0.000765	0.00096		
Retro 5 - Geometric stiffening								
ret.375t6prfr10ksi	10700	13000	0.00467	-0.00171	0.000352	0.0034	0	0.000227

CLIP ANGLE ROTATION CONSTANT CALCULATION

$E := 30000000$ psi Youngs Modulus of stringer $L := 210$ in Stringer Length

$I := 802$ in^4 Moment of Inertia of stringer $P := 10000$ Stringer Load

$$\theta cl := \theta st$$

$$\theta cl := C_R \cdot Mo$$

$$\theta st := \frac{-Mo \cdot L}{2 \cdot E \cdot I} + \frac{P \cdot L^2}{16 \cdot E \cdot I}$$

$$Mo(\theta st) := \frac{\frac{P \cdot L^2}{16 \cdot E \cdot I} - \theta st}{\frac{L}{2 \cdot E \cdot I}}$$

$Mo(.000650) = 113557$

$Mo(.000951) = 44585$

$Mo(.000577) = 130285$

$$C_R(\theta st) := \frac{\theta st}{Mo(\theta st)}$$

$C_R(.000650) = 5.724 \cdot 10^{-9}$ Interior 0.375 clip angles from 3D FEA

$C_R(.000950) = 2.12 \cdot 10^{-8}$ End 0.375 clip angles from 3D FEA

$C_R(.000577) = 4.429 \cdot 10^{-9}$ Interior 0.5 clip angles from 3D FEA

$$C_S(\sigma, \theta st) := \frac{\sigma}{Mo(\theta st)}$$

$C_S(17100, .000650) = 0.1506$ Interior 0.375 clip angles from 3D FEA

$C_S(14700, .000951) = 0.3297$ End 0.375 clip angles from 3D FEA

$C_S(15700, .000577) = 0.1205$ Interior 0.5 clip angles from 3D FEA

Note: This page is used to determine the maximum end moments for the interior panel clip angles, end panel clip angles 1st and 2nd floorbeams. These equation are for a stringer with different boundary conditions on each end

$E := 30000000$	psi	Youngs Modulus of stringer	$L := 210$ in	Stringer Length
$I := 802$	in^4	Stringer area moment of inertia	$P := 10000$ lb	Stringer Load

$Cb := Ca$ $\quad\quad$ $Ca := Cb$

$Ca := 5.724 \cdot 10^{-9}$ $\quad\quad$ $Cb := 2.12 \cdot 10^{-8}$

$$\theta a = Ca \cdot Ma \qquad \theta b := Cb \cdot Mb$$

$$\theta a = \left(-\frac{Ma \cdot L}{3 \cdot E \cdot I} - \frac{Mb \cdot L}{6 \cdot E \cdot I}\right) + \frac{P \cdot L^2}{16 \cdot E \cdot I} \qquad \theta b := \left(-\frac{Mb \cdot L}{3 \cdot E \cdot I} - \frac{Ma \cdot L}{6 \cdot E \cdot I}\right) + \frac{P \cdot L^2}{16 \cdot E \cdot I}$$

$$A := \frac{P \cdot L^2}{16 \cdot E \cdot I} \qquad B := \frac{L}{3 \cdot E \cdot I}$$

$$Ca \cdot Ma := -Ma \cdot B - \frac{Mb \cdot B}{2} + A \qquad Cb \cdot Mb := -Mb \cdot B - \frac{Ma \cdot B}{2} + A$$

$$Ma := \left(A - \frac{Mb \cdot B}{2}\right) \cdot \frac{1}{Ca + B}$$

$$Ma := \left[\frac{A}{Ca + B} - \frac{Mb \cdot B}{2 \cdot (Ca + B)}\right]$$

$$Cb \cdot Mb := -Mb \cdot B - \frac{B}{2} \cdot \left[\frac{A}{Ca + B} - \frac{Mb \cdot B}{2 \cdot (Ca + B)}\right] + A$$

$$Cb \cdot Mb := -Mb \cdot B - \frac{B \cdot A}{2 \cdot (Ca + B)} + \frac{Mb \cdot B^2}{4 \cdot (Ca + B)} + A$$

$$Cb \cdot Mb + Mb \cdot B - \frac{Mb \cdot B^2}{4 \cdot (Ca + B)} := A - \frac{B \cdot A}{2 \cdot (Ca + B)}$$

$$Mb\cdot\left[Cb + B - \frac{B^2}{4\cdot(Ca+B)}\right] := A - \frac{B\cdot A}{2\cdot(Ca+B)}$$

3

$$Mb := \frac{A - \frac{B\cdot A}{2\cdot(Ca+B)}}{Cb + B - \frac{B^2}{4\cdot(Ca+B)}} \qquad Mb = 39915$$

$$Ma := \left(A - Mb\cdot\frac{B}{2}\right)\cdot\frac{1}{Ca+B} \qquad Ma = 125965$$

Moments for 10000 lb load in the middle of the stringer (I = 802 in^4)

$M_{int} := 113557$ $\qquad$ $M_{end} := 49750$

Maximum Moments for 10000 lb load

	Northbound Structure (I = 802 in^4)		Southbound Structure (I = 706 in^4)	
Interior Panels	$M_{ni} := 113557$	in-lb	$M_{si} := 121832$	in-lb
End Panel 2nd Floorbeam	$M_{ne2} := 125965$	in-lb	$M_{se2} := 136090$	in-lb
End Panel 1st Floorbeam	$M_{ne1} := 39913$	in-lb	$M_{se1} := 43928$	in-lb

DEFLECTION CALCULATIONS

Clip angle deflection for 10000 lb load in the middle of the stringer (I = 802 in^4)

$\delta_{int} := .00453$ — From 3D FEA Analysis

Clip angle max stress range for 10000 lb load in the middle of the stringer (I = 802 in^4)

$\sigma_{int} := 17100$ $\quad$ $\sigma_{end} := 14700$ — From 3D FEA Analysis

Moments for 10000 lb load in the middle of the stringer (I = 802 in^4)

$M_{int} := 113557$ $\quad$ $M_{end} := 49750$

Maximum Moments for 10000 lb load

	Northbound Structure (I = 802 in^4)		Southbound Structure (I = 706 in^4)	
Interior Panels	$M_{ni} := 113557$	in-lb	$M_{si} := 121832$	in-lb
End Panel 2nd Floorbeam	$M_{ne2} := 125965$	in-lb	$M_{se2} := 136090$	in-lb
End Panel 1st Floorbeam	$M_{ne1} := 39913$	in-lb	$M_{se1} := 43928$	in-lb

Stringer Loads (from Global FEA Analysis)

Northbound Structure

$P_1 := 7300$	lb	Middle Stringer
$P_2 := 14500$	lb	2nd Middle Stringer

Southbound Structure

$P_3 := 5500$	lb	Middle Stringer
$P_4 := 10960$	lb	2nd Middle Stringer
$P_5 := 7950$	lb	3rd Middle Stringer

Deflection for clip angles located in interior panels

$i := 1 .. 5$

$$\delta m_i := \frac{\delta_{int} \cdot P_i}{10000}$$

Northbound Structure

$\delta m_1 = 0.0033$	in	Middle stringer
$\delta m_2 = 0.0066$	in	2nd from middle stringer

Southbound Structure

$\delta m_3 = 0.0025$	in	Middle stringer
$\delta m_4 = 0.005$	in	2nd from middle stringer
$\delta m_5 = 0.0036$	in	3rd from middle stringer

$$\sigma_{max}(\sigma, P, M_{max}, M) := \sigma \cdot \frac{P}{10000} \cdot \frac{M_{max}}{M}$$

Northbound Structure

	Middle stringer	2nd from middle stringer
Interior Panels	$\sigma_{max}(\sigma_{int}, P_1, M_{ni}, M_{int}) = 12483$	$\sigma_{max}(\sigma_{int}, P_2, M_{ni}, M_{int}) = 24795$
End Panel 2nd Floorbeam	$\sigma_{max}(\sigma_{int}, P_1, M_{ne2}, M_{int}) = 13847$	$\sigma_{max}(\sigma_{int}, P_2, M_{ne2}, M_{int}) = 27504$
End Panel 1st Floorbeam	$\sigma_{max}(\sigma_{end}, P_1, M_{ne1}, M_{end}) = 8609$	$\sigma_{max}(\sigma_{int}, P_2, M_{ne1}, M_{end}) = 19892$

Southbound Structure

	Middle stringer	2nd from middle stringer
Interior Panels	$\sigma_{max}(\sigma_{int}, P_3, M_{si}, M_{int}) = 10090$	$\sigma_{max}(\sigma_{int}, P_4, M_{si}, M_{int}) = 20107$
End Panel 2nd Floorbeam	$\sigma_{max}(\sigma_{int}, P_3, M_{se2}, M_{int}) = 11271$	$\sigma_{max}(\sigma_{int}, P_4, M_{se2}, M_{int}) = 22460$
End Panel 1st Floorbeam	$\sigma_{max}(\sigma_{end}, P_3, M_{se1}, M_{end}) = 7139$	$\sigma_{max}(\sigma_{end}, P_4, M_{se1}, M_{end}) = 14226$

	3rd from middle stringer
Interior Panels	$\sigma_{max}(\sigma_{int}, P_5, M_{si}, M_{int}) = 14585$
End Panel 2nd Floorbeam	$\sigma_{max}(\sigma_{int}, P_5, M_{se2}, M_{int}) = 16292$
End Panel 1st Floorbeam	$\sigma_{max}(\sigma_{end}, P_5, M_{se1}, M_{end}) = 10319$

APPENDIX H

STRESS-LIFE

$\sigma_{min} := 5.5$ Minimum stress level

$\sigma_{max}(\Delta\sigma) := \Delta\sigma + \sigma_{min}$ Maximum stress level

$t := 0.53$ Clip angle thickness at peak stress area

$\sigma_{ys} := 36$ Minimum Expected yield strength

$S_{UT} := 58$ Minimum Expected ultimate tensile strength

$$\sigma_a(\Delta\sigma) := \frac{\sigma_{max}(\Delta\sigma) - \sigma_{min}}{2}$$ Stress amplitude calculation

$$\sigma_m(\Delta\sigma) := \frac{\sigma_{max}(\Delta\sigma) + \sigma_{min}}{2}$$ Stress mean calculation

$Se' := .504 \cdot S_{UT}$ Ideal constant amplitude fatigue limit

Surface Finish Factor - (hot-rolled)

$a := 14.4$ $b := -.718$

$C_{SF} := a \cdot S_{UT}^{\,b}$ $C_{SF} = 0.78$

Size Factor $d := t$

$$C_S := \left(\frac{d}{0.3}\right)^{-0.1133} \qquad C_S = 0.938$$

Loading Factor

$C_{Lb} := 1$ for bending loading $C_{La} := .92$ for axial loading

$$C_L := \frac{C_{Lb} + C_{La}}{2}$$ for combination of bending and axial

Temperature Factor

$C_T := 1$

Constant Amplitude Fatigue Limit

$$Se := C_{SF} \cdot C_S \cdot C_L \cdot C_T \cdot Se' \qquad Se = 20.528$$

Equivelant Alternating Stress Calculation

Goodman

$$S_N(\Delta\sigma) := \frac{\sigma_a(\Delta\sigma)}{1 - \frac{\sigma_m(\Delta\sigma)}{S_{UT}}}$$

Number of cycles to failure calculation

$$b := -\frac{1}{3} \cdot \log\left(\frac{0.9 \cdot S_{UT}}{Se}\right) \qquad C := \log\left[\frac{\left(0.9 \cdot S_{UT}\right)^2}{Se}\right]$$

$$b = -0.135 \qquad C = 2.123$$

$$N_L(\Delta\sigma) := 10^{-\frac{C}{b}} \cdot S_N(\Delta\sigma)^{\frac{1}{b}}$$

y = the age of the structure

$F_T := \frac{.3 + 4.3 + 1 + 1.7 + 1.5 + 16.1 + 1.7}{100}$ $F_T = 0.266$ Percentage truck traffic

$F_L := .85$ Percentage of trucks in Slow Lane $g := 525$ Traffic growth rate

$C_L := 2$ Number of load cycle per truck $G := 30600$ Current ADT

$ADT(Y) := G + g \cdot Y$ Function of average daily traffic

$ADTT(Y) := \frac{ADT(Y)}{2} \cdot F_T \cdot F_L$ Average Daily Truck Traffic (one lane)

$$N_L := (365 \cdot C_L) \cdot \int_{-y}^{L} ADTT(Y)\, dY$$

$$N_L := \left(\frac{365 \cdot C_L \cdot F_T \cdot F_L}{2}\right) \cdot \int_{-y}^{L} (g \cdot Y + G)\, dY$$

$$N_L := \frac{365 \cdot C_L \cdot F_T \cdot F_L}{2} \cdot \left[\left(\frac{g \cdot L^2}{2} + G \cdot L\right) - \left(\frac{g \cdot y^2}{2} - G \cdot y\right)\right]$$

$$\frac{g \cdot L^2}{2} + G \cdot L + \left[\left(\frac{-g \cdot y^2}{2} + G \cdot y\right) - \frac{2 \cdot N_L}{365 \cdot C_L \cdot F_T \cdot F_L}\right] := 0$$

$$L(\Delta\sigma, y) := \frac{-G + \sqrt{G^2 - 4 \cdot \frac{g}{2} \cdot \left[\left(\frac{-g \cdot y^2}{2} + G \cdot y\right) - \frac{2 \cdot N_L(\Delta\sigma)}{365 \cdot C_L \cdot F_T \cdot F_L}\right]}}{2 \cdot \frac{g}{2}}$$

Remaining life in years

Northbound Structure

	Middle	2nd from middle
Interior Panels	L(12.5,44) = 182	L(24.8,44) = -40
End Panel 1st Floorbeam	L(13.8,44) = 100	L(27.5,44) = -42
End Panel 2nd Floorbeam	L(8.6,44) = 1056	L(19.9,44) = -24

Southbound Structure

	Middle	2nd from middle	3rd from middle
Interior Panels	L(10.1,34) = 522	L(20.1,34) = -20	L(14.6,34) = 68
End Panel 1st Floorbeam	L(11.3,34) = 308	L(22.5,34) = -28	L(16.3,34) = 22
End Panel 2nd Floorbeam	L(7.1,34) = 2340	L(14.2,34) = 83	L(10.3,34) = 477

APPENDIX I

LINEAR ELASTIC FRACTURE MECHANICS

$m := 3.0$
$C := 3.6 \cdot 10^{-10}$ Paris Equation constants for ferrite-pearlite low carbon steel

$\sigma_{ys} := 36$ ksi Minimum Expected yield strength

$t := 0.53$ Clip angle thickness at peak stress area

$a_f := 0.53$ Final Crack Length

$a_i := .01$ Initial Crack Length

Crack Shape factor, Fe (For eliptical crack)

$c(a) := a + 2.5 \cdot a^2$ (c is half the crack width, a is half the crack length)

$$\phi(a) := \int_0^{\frac{\pi}{2}} \left[1 - \left(\frac{c(a)^2 - a^2}{c(a)^2}\right) \cdot \sin(\theta)^2\right]^{\frac{1}{2}} d\theta$$

$$Q(a, \Delta\sigma) := \phi(a)^2 + .05 \cdot \frac{\Delta\sigma}{\sigma_{ys}}$$

$$F_e(a, \Delta\sigma) := \frac{1}{\sqrt{Q(a, \Delta\sigma)}}$$

Free Surface Factor, Fs $F_s := 1.12$

Finite Width Factor, Fw

$$M_k(a) := 1.0 + 1.2 \cdot \left(\frac{a}{t} - 0.5\right)$$

$$F_w(a) := M_k(a)$$

Stress intensity Range

$$\Delta K(a, \Delta\sigma) := F_e(a, \Delta\sigma) \cdot F_s \cdot F_w(a) \cdot \Delta\sigma \cdot \sqrt{\pi \cdot a}$$

Paris Equation

$$N_L(a_i, \Delta\sigma) := \int_{a_i}^{a_f} \frac{1}{C \cdot (\Delta K(a, \Delta\sigma))^m} da$$ Total Life in cycles

REMAINING LIFE CALCULATIONS

y = the age of the structure

$$F_T := \frac{.3 + 4.3 + 1 + 1.7 + 1.5 + 16.1 + 1.7}{100}$$ Percentage truck traffic

$F_L := .85$ Percentage of trucks in Slow Lane

$g := 525$ Traffic growth rate

$C_L := 2$ Number of load cycle per truck

$G := 30600$ Current ADT

$ADT(Y) := G + g \cdot Y$ Function of average daily traffic

$ADTT(Y) := \frac{ADT(Y)}{2} \cdot F_T \cdot F_L$ Average Daily Truck Traffic (one lane)

$$N_L := (365 \cdot C_L) \cdot \int_{-y}^{L} ADTT(Y)\, dY$$

$$N_L := \left(\frac{365 \cdot C_L \cdot F_T \cdot F_L}{2}\right) \cdot \int_{-y}^{L} (g \cdot Y + G)\, dY$$

$$N_L := \frac{365 \cdot C_L \cdot F_T \cdot F_L}{2} \cdot \left[\left(\frac{g \cdot L^2}{2} + G \cdot L\right) - \left(\frac{g \cdot y^2}{2} - G \cdot y\right)\right]$$

$$\frac{g \cdot L^2}{2} + G \cdot L + \left[\left(\frac{-g \cdot y^2}{2} + G \cdot y\right) - \frac{2 \cdot N_L}{365 \cdot C_L \cdot F_T \cdot F_L}\right] := 0$$

$$L(\Delta\sigma, y) := \frac{-G + \sqrt{G^2 - 4 \cdot \frac{g}{2} \cdot \left[\left(\frac{-g \cdot y^2}{2} + G \cdot y\right) - \frac{2 \cdot N_L(a_i, \Delta\sigma)}{365 \cdot C_L \cdot F_T \cdot F_L}\right]}}{2 \cdot \frac{g}{2}}$$ Remaining life in years

Northbound Structure

	Middle	2nd from middle
Middle Panels	L(12.5,44) = 9	L(24.8,44) = -31
End Panel 1st Floorbeam	L(13.8,44) = 0	L(27.5,44) = -34
End Panel 2nd Floorbeam	L(8.6,44) = 57	L(19.9,44) = -23

Southbound Structure

	Middle	2nd from middle	3rd from middle
Middle Panels	L(10.1,34) = 35	L(20.1,34) = -18	L(14.6,34) = -1
End Panel 1st Floorbeam	L(11.3,34) = 22	L(22.5,34) = -22	L(16.3,34) = -8
End Panel 2nd Floorbeam	L(7.1,34) = 96	L(14.2,34) = 1	L(10.3,34) = 33

APPENDIX J

IDENTIFICATION METHODOLOGY

$E := 30000000$ psi	Youngs Modulus of stringer	$L := 210$ in	Stringer Length
$I := 802$ in^4	Moment of Inertia of stringer	$P := 10000$	Stringer Load

$S := 84$ in — Stringer Spacing

$t := 6$ in — Thickness of Reinforced Concrete Deck

$C_{R.375} := 5.724 \cdot 10^{-9}$ Clip angle rotation constant for 4 x 3.5 x 3/8 in clip angle

$C_{R.5} := 4.429 \cdot 10^{-9}$ Clip angle rotation constant for 4 x 3.5 x 1/2 in clip angle

$C_{S.375} := 0.1506$ Clip angle stress constant for 4 x 3.5 x 3/8 in clip angle

$C_{S.5} := 0.1205$ Clip angle stress constant for 4 x 3.5 x 1/2 in clip angle

Equation for maximum stringer loading for different deck thickness and stringer spacing

$$P(S,t) := (S \cdot 162 + 700) \cdot \left(1 - \frac{t - 5.9}{17}\right)$$

$$P(S,t) := \left[12000 + \frac{S \cdot 172 - 12000}{\left(\frac{72^{150}}{S^{150}} + 1\right)}\right] \cdot \left(1 - \frac{t - 5.9}{17}\right)$$

Simplified Equation for moment from Clip Angle Deflection Analysis

$$Mo(S,t,I,L,C_R) := \frac{\frac{P(S,t) \cdot L^2}{16 \cdot E \cdot I}}{C_R + \frac{L}{2 \cdot E \cdot I}} \qquad Mo(84,6,802,210,C_{R.375}) = 163102 \text{ in-lb}$$

Where S is stringer spacing, t is deck thickness, I is stringer moment of inertia L is stringer length, and C is the clip angle constant obtained from 3D FEA Analysis.

$$\sigma := Mo \cdot C_S$$

$$\sigma(S,t,I,L,C_R,C_S) := \frac{\frac{P(S,t) \cdot L^2}{16 \cdot E \cdot I}}{C_R + \frac{L}{2 \cdot E \cdot I}} \cdot C_S \qquad \sigma(84,6,802,210,C_{R.375},C_{S.375}) = 24563 \text{ psi}$$