13.122 Design Process

$$ksi := \frac{1000 \cdot lbf}{in^2} \qquad lton := 2240 \cdot lbf$$

1. MATERIALS

For HTS Components:

$$\sigma_Y := 47 \cdot ksi \qquad \sigma_{max} := 21.28 \cdot ksi \qquad \sigma_{max} = 9.5 \frac{lton}{in^2} \qquad E := 29.6 \cdot 10^3 \cdot ksi \qquad \nu := .30 \qquad G := \frac{E}{2 \cdot (1 + \nu)}$$

For HY-80 Components:

$$\sigma_{Y2} := 80 \cdot ksi \qquad \sigma_{max} := 23.52 \cdot ksi \qquad \sigma_{max} = 10.5 \frac{lton}{in^2} \qquad E := 29.6 \cdot 10^3 \cdot ksi \qquad \nu := .30$$

2. GEOMETRY

section spacing = frame spacing = a   longitudinal position from AP := x

$$y := \frac{y_{IB} + y_{OB}}{2} \qquad z := \frac{z_{IB} + z_{OB}}{2} \qquad B := \sqrt{(y_{IB} - y_{OB})^2 + (z_{IB} - z_{OB})^2}$$

Assume for 1st design iteration: $y_{NA} := \frac{y_D}{2}$

Select number of stiffeners,N so that 23in<b<28in: $b := \frac{B}{N + 1} \cdot in$

3. PRIMARY STRESS

$$M_{bH} := -\left(0.000457 \cdot L^{2.5} \cdot B \cdot \frac{lton}{ft^{2.5}}\right) \qquad M_{bS} := 0.000381 \cdot L^{2.5} \cdot B \cdot \frac{lton}{ft^{2.5}}$$

B in this context is maximum beam at the DWL not plate breadth.

$$\sigma_{DHM} := \frac{-[M_{bH} \cdot (y_D - y_{NA})]}{I_{yy}} \qquad \sigma_{KHM} := \frac{-[M_{bH} \cdot (y_K - y_{NA})]}{I_{yy}}$$

$$\sigma_{DSM} := \frac{-[M_{bS} \cdot (y_D - y_{NA})]}{I_{yy}} \qquad \sigma_{KSM} := \frac{-[M_{bS} \cdot (y_K - y_{NA})]}{I_{yy}}$$

Or for 1st iteration before having I_{yy}:

$$\sigma_{DHM} := \sigma_{max} \qquad \sigma_{KHM} := -\sigma_{max} \qquad \sigma_{DSM} := -\sigma_{max} \qquad \sigma_{KSM} := \sigma_{max} \qquad \tau := 0 \cdot psi$$

At NA for external shell:

$$\sigma_{CNA} := -\left[.5 \cdot \max\left(\begin{pmatrix} |\sigma_{DSM}| \\ |\sigma_{KHM}| \end{pmatrix}\right)\right] \qquad \sigma_{TNA} := .5 \cdot \max\left(\begin{pmatrix} \sigma_{DHM} \\ \sigma_{KSM} \end{pmatrix}\right)$$

Below neutral axis, external shell:

$$\sigma_T := \sigma_{TNA} + (\sigma_{KSM} - \sigma_{TNA}) \cdot \left(\frac{y_{NA} - y}{y_{NA}}\right) \qquad \sigma_C := \sigma_{CNA} + (\sigma_{KHM} - \sigma_{CNA}) \cdot \left(\frac{y_{NA} - y}{y_{NA}}\right)$$

Above neutral axis, external shell:

$$\sigma_T := \sigma_{TNA} + (\sigma_{DHM} - \sigma_{TNA}) \cdot \left(\frac{y - y_{NA}}{y_D - y_{NA}}\right) \qquad \sigma_C := \sigma_{CNA} + (\sigma_{DSM} - \sigma_{CNA}) \cdot \left(\frac{y - y_{NA}}{y_D - y_{NA}}\right)$$

Above neutral axis, internal decks:

$$\sigma_T := \sigma_{DHM} \cdot \frac{y - y_{NA}}{y_D - y_{NA}} \qquad \sigma_C := \sigma_{DSM} \cdot \frac{y - y_{NA}}{y_D - y_{NA}}$$

$$\sigma_{MAX} := \max\left(\begin{pmatrix} \sigma_T \\ -\sigma_C \end{pmatrix}\right)$$

Below neutral axis, internal decks:

$$\sigma_T := \sigma_{KSM} \cdot \frac{y_{NA} - y}{y_{NA}} \qquad \sigma_C := \sigma_{KHM} \cdot \frac{y_{NA} - y}{y_{NA}}$$

4. LOCAL LOADS:

Sea and weather; choose largest

Passing waves: $H_{WV}(y) := y_{DWL} + .55 \cdot \sqrt{L \cdot ft} - y$ (4-1)

Heel: $H_H(y) := \left(y_{DWL} + z \cdot \tan\left(\frac{\pi}{6}\right) - y\right) \cdot \cos\left(\frac{\pi}{6}\right)$ (4-2)

Green Seas: $H_{GS}(y) := \max\left[\left[\begin{matrix} y_D + 4 \cdot ft - y \\ 2 \cdot \frac{y_D + 8 \cdot ft}{L} \cdot \left(x - \frac{L}{2}\right) - y \end{matrix}\right]\right]$ (4-3)

Waveslap: $H_{WS} := 7.82 \cdot ft$ (4-4)

Independent

Dead Load: $H_{DL} := 1.72 \cdot \frac{ft}{in} \cdot t$ t = plate thickness (4-5)

Live Load: $H_{LL} := 2.37 \cdot ft$ (4-6)

Damage: $H_{DAM}(y) := \max\left[\left[\begin{matrix} \left(y_D + z \cdot \tan\left(\frac{\pi}{6}\right) - y\right) \cdot \cos\left(\frac{\pi}{6}\right) \\ y_D - y \end{matrix}\right]\right]$ (4-7)

5. PLATE LIMIT STATES

- assume values for b,t; refine t as required so all gRL<1

$$\sigma_{ax} := \sigma_{MAX} \qquad \tau_{xy} := 0 \qquad D := \frac{E\cdot(t)^3}{12\cdot\left(1-\nu^2\right)} \qquad (5\text{-}1)$$

PSPBT -Panel Serviceability Plate Bending Transverse -

$$\sigma_{bx} := 0\cdot psi \qquad \sigma_x := \sigma_{ax} + \sigma_{bx} \qquad \sigma_{by} := -\left[.5\cdot p\cdot\left(\frac{b}{t}\right)^2\right] \qquad \sigma_y := \sigma_{by} \qquad \gamma_S := 1.25$$

$$\sigma_{VM} := \sqrt{.5\cdot\left[\left(\sigma_x-\sigma_y\right)^2+\left(\sigma_y\right)^2+\left(\sigma_x\right)^2\right]+3\cdot\tau^2} \qquad \gamma R_{PSPBT} := \gamma_S\cdot\frac{\sigma_{VM}}{\sigma_Y} \qquad (5\text{-}2)$$

PSPBL - Panel Serviceability Plate Bending Longitudinal -

$$\sigma_{bx} := .34\cdot p\cdot\left(\frac{b}{t}\right)^2 \qquad \sigma_x := \sigma_{ax} + \sigma_{bx} \qquad \sigma_{by} := 0\cdot psi \qquad \sigma_y := \sigma_{by}$$

(5-3)

$$\sigma_{VM} := \sqrt{.5\cdot\left[\left(\sigma_x-\sigma_y\right)^2+\left(\sigma_y\right)^2+\left(\sigma_x\right)^2\right]+3\cdot\tau^2} \qquad \gamma R_{PSPBL} := \gamma_S\cdot\frac{\sigma_{VM}}{\sigma_Y}$$

- PCMY - Panel Collapse Membrane Yield (or PFMY)

$$\sigma_x := \sigma_{ax} \qquad \sigma_y := 0\cdot psi \qquad \gamma_C := 1.5$$

(5-4)

$$\sigma_{VM} := \sqrt{.5\cdot\left[\left(\sigma_x-\sigma_y\right)^2+\left(\sigma_y\right)^2+\left(\sigma_x\right)^2\right]+3\cdot\tau^2} \qquad \gamma R_{PCMY} := \gamma_C\cdot\frac{\sigma_{VM}}{\sigma_Y}$$

- PFLB - Plate Failure Local Buckling

Use Equation 12.4.7. (or PCLB)

$$\sigma_{axcr} := -4\cdot\frac{\pi^2\cdot D}{b^2\cdot t} \qquad k_s := 5.35 + 4\cdot\left(\frac{b}{a}\right)^2 \qquad \tau := 0\cdot psi \qquad \tau_{cr} := -k_s\cdot\frac{\pi^2\cdot D}{b^2\cdot t} \qquad R_s := \frac{\tau}{\tau_{cr}}$$

(5-5)

interaction formula:

$$R_c := 1 - R_s^2 \qquad \sigma_o := R_c\cdot\sigma_{axcr} \qquad R_{PFLB} := \frac{\sigma_C}{\sigma_o} \qquad \gamma R_{PFLB} := \gamma_S\cdot R_{PFLB}$$

6. STIFFENED PANEL LIMIT STATES

$HSW := DEPTH - TSF \quad A_w := (DEPTH - TSF) \cdot TSW \quad A_f := BSF \cdot TSF \quad A_s := A_w + A_f \quad A_p := b \cdot t$ (6-1)

Combination of plate and stiffeners (from p287, equation 8.3.6 in text): $L := a$

$$d := DEPTH - \frac{TSF}{2} + \frac{t}{2} \qquad A := A_s + A_p \qquad C_1 := \frac{A_w \cdot \left(\frac{A}{3} - \frac{A_w}{4}\right) + A_f \cdot A_p}{(A)^2} \qquad I := A \cdot d^2 \cdot C_1$$

$$y_f := -\left(d \cdot \frac{\frac{A_w}{2} + A_p}{A}\right) \qquad y_p := d \cdot \left(1 - \frac{\frac{A_w}{2} + A_p}{A}\right) \qquad M_{bend} := -\left(p \cdot b \cdot \frac{L^2}{12}\right)$$ (6-2)

$$c_f := y_f - .5 \cdot TSF \qquad c_p := .5 \cdot t + y_p$$ (y is to mid-point) $$M_{bcen} := p \cdot b \cdot \frac{L^2}{12}$$

- PYTF - Panel Yield Tension Flange

$\gamma_S := 1.25$

$$\sigma_{ax} := \sigma_T \qquad \sigma_{bx} := \frac{-(M_{bcen} \cdot c_f)}{I} \qquad \sigma_x := \sigma_{ax} + \sigma_{bx} \qquad R_{PYTF} := \frac{\sigma_x}{\sigma_Y} \qquad \gamma R_{PYTF} := \gamma_S \cdot R_{PYTF}$$ (6-3)

- PYCF - Panel Yield Compression Flange

$$\sigma_{ax} := \sigma_C \qquad \sigma_{bx} := \frac{-(M_{bend} \cdot c_f)}{I} \qquad \sigma_x := \sigma_{ax} + \sigma_{bx} \qquad R_{PYCF} := \frac{-\sigma_x}{\sigma_Y} \qquad \gamma R_{PYCF} := \gamma_S \cdot R_{PYCF}$$ (6-4)

- PYTP - Panel Yield Tension Plate

- usually much smaller than PYTF, plate closer to NA

$$\sigma_{ax} := \sigma_T \qquad \sigma_{ay} := 0.0 \cdot psi \qquad \sigma_{bx} := \frac{-(M_{bend} \cdot c_p)}{I}$$

assume for simplicity: $\sigma_{by} := 0 \cdot psi \quad \sigma_x := \sigma_{ax} + \sigma_{bx} \quad \sigma_y := \sigma_{ay} + \sigma_{by}$

(6-5)

$$\tau_{xy} := 0.0 \cdot psi \qquad \sigma_{VM} := \sqrt{.5 \cdot \left[(\sigma_x - \sigma_y)^2 + \sigma_y^2 + \sigma_x^2\right] + 3 \cdot \tau_{xy}^2} \qquad R_{PYTP} := \frac{\sigma_{VM}}{\sigma_Y} \qquad \gamma R_{PYTP} := \gamma_S \cdot R_{PYTP}$$

- PYCP - Panel Yield Compression Plate -

usually much smaller than PYCF, plate closer to NA

$$\sigma_{ax} := \sigma_C \qquad \sigma_{ay} := 0.0 \cdot psi \qquad \sigma_{bx} := \frac{-(M_{bcen} \cdot c_p)}{I}$$

assume for simplicity: $\sigma_{by} := 0 \cdot psi \quad \sigma_x := \sigma_{ax} + \sigma_{bx} \quad \sigma_y := \sigma_{ay} + \sigma_{by}$

(6-6)

$$\tau_{xy} := 0.0 \cdot psi \qquad \sigma_{VM} := \sqrt{.5 \cdot \left[(\sigma_x - \sigma_y)^2 + \sigma_y^2 + \sigma_x^2\right] + 3 \cdot \tau_{xy}^2} \qquad R_{PYCP} := \frac{\sigma_{VM}}{\sigma_Y} \qquad \gamma R_{PYCP} := \gamma_S \cdot R_{PYCP}$$

- PCCB - Panel Collapse Combined Buckling.

let: $b_e := b_{rat} \cdot b$ $\quad A_e := A_s + b_e \cdot t$ $\quad C_1 := \dfrac{A_w \cdot \left(\dfrac{A_e}{3} - \dfrac{A_w}{4}\right) + A_f \cdot b_e \cdot t}{A_e^{\,2}}$ $\quad I_e := A_e \cdot d^2 \cdot C_1$ (6-7)

$$\rho_e := \sqrt{\frac{I_e}{A_e}} \qquad \gamma_x := \frac{12 \cdot \left(1 - \nu^2\right) \cdot I_e}{b_e \cdot t^3} \qquad (6\text{-}8)$$

$$C_\pi := \min\left[\left[\frac{B}{a} \cdot \sqrt{\frac{\gamma_x}{2 \cdot \left(1 + \sqrt{1 + \gamma_x}\right)}} \quad 1\right]\right] \qquad \sigma_{ecr} := \frac{\pi^2 \cdot E}{\left(\dfrac{C_\pi \cdot L}{\rho_e}\right)^2} \qquad b_e := \frac{C_{\pi_i} \cdot L \cdot t}{\rho_e \cdot \sqrt{3 \cdot \left(1 - \nu^2\right)}} \qquad \frac{b_e}{b} = \blacksquare$$

Check, must equal b_{rat} (6-9)

can also use: $b_e := b$ starting point

$$b_e := \text{root}\left(b_e - b_r\left(b_e\right), b_e\right)$$

$$\sigma_{axcr} := -\left(\frac{b_e \cdot t + A_s}{b \cdot t + A_s}\right) \cdot \sigma_{ecr} \qquad \gamma R_{PCCB} := \gamma_C \cdot \frac{\sigma_C}{\sigma_{axcr}} \qquad (6\text{-}10)$$

- PCSB - Panel Collapse Stiffener Buckling

$$I_{sz} := \frac{1}{12} \cdot \left(HSW \cdot TSW^3 + TSF \cdot BSF^3\right) \qquad I_{sp} := d^2 \cdot \left(A_f + \frac{A_w}{3}\right) \qquad (6\text{-}11)$$

$$J := \frac{BSF \cdot TSF^3 + (HSW) \cdot TSW^3}{3} \qquad C_r := \frac{1}{1 + .4 \cdot \left(\dfrac{t}{TSW}\right)^3 \cdot \dfrac{d}{b}} \qquad m := \frac{a}{\pi} \cdot \left(\frac{4 \cdot D \cdot C_r}{E \cdot I_{sz} \cdot d^2 \cdot b}\right)^{\frac{1}{4}} \qquad (6\text{-}12)$$

for m=1:
$$\sigma_{at1} := \frac{1}{I_{sp} + \dfrac{2 \cdot C_r \cdot b^3 \cdot t}{\pi^4}} \cdot \left[G \cdot J + \frac{\pi^2 \cdot E \cdot I_{sz} \cdot d^2}{a^2} + \frac{4 \cdot D \cdot C_r \cdot \left(a^2 + b^2\right)}{\pi^2 \cdot b}\right] \qquad (6\text{-}13)$$

for m=2:
$$\sigma_{at2} := \frac{1}{I_{sp} + \dfrac{2 \cdot C_r \cdot b^3 \cdot t}{\pi^4}} \cdot \left(G \cdot J + 4 \cdot \sqrt{\frac{D \cdot C_r \cdot E \cdot I_{sz} \cdot d^2}{b}} + \frac{4 \cdot D \cdot C_r \cdot b}{\pi^2}\right) \qquad (6\text{-}14)$$

$$\sigma_{at} := -\min\left(\begin{pmatrix} \sigma_{at1} \\ \sigma_{at2} \end{pmatrix}\right)$$

recalling that; if 1< m < 2, value obtained is conservative

$$\gamma R_{PCSB} := \gamma_C \cdot \frac{\sigma_C}{\sigma_{at}} \qquad (6\text{-}15)$$

- PCSF - Panel Collapse Stiffener Flexure

Use limiting mode (Mode I, II, or III). See text Sec 14.2.

Rule of thumb for eccentricity of welded panels: $\Delta := \frac{a}{750}$ $\sigma_{ax} := \sigma_C$ (6-16)

a. Mode I Compression failure of flange

$M_o := 0 \cdot lbf \cdot in$ $\delta_o := 0 \cdot in$ $\Delta_I := -\Delta$ (6-17)

(Point E of fig. 14.2):

Beam column parameters:

$$\rho_I := \sqrt{\frac{I}{A}} \qquad \lambda_I := \frac{a}{\pi \cdot \rho_I} \sqrt{\frac{\sigma_Y}{E}} \qquad \eta_I := \frac{(\delta_o + \Delta_I) \cdot y_f}{(\rho_I)^2} \qquad \mu_I := \frac{M_o \cdot y_f}{I \cdot \sigma_Y} \qquad \zeta_I := 1 - \mu_I + \frac{1 + \eta_I}{(\lambda_I)^2}$$

limit state

$$R := \frac{\zeta_I}{2} - \sqrt{\frac{(\zeta_I)^2}{4} - \frac{1 - \mu_I}{(\lambda_I)^2}} \qquad \sigma_{axu} := -R \cdot \sigma_Y \qquad R_{PCSF1} := \frac{\sigma_{ax}}{\sigma_{axu}} \qquad \gamma R_{PCSF1} := \gamma_C \cdot R_{PCSF1} \qquad (6\text{-}18)$$

b. Mode II Compression failure of plate:

For maximum moment and center deflection assume simply supported beam:

$$q := p \cdot b \qquad M_o := \frac{q \cdot a^2}{8} \qquad \delta_o := \frac{5 \cdot q \cdot a^4}{384 \cdot E \cdot I} \qquad (6\text{-}23)$$

determine failure stress using plate parameters

$$\beta := \frac{b}{t} \cdot \sqrt{\frac{\sigma_Y}{E}} \qquad \xi := 1 + \frac{2.75}{(\beta)^2} \qquad T := .25 \cdot \left[2 + \xi - \sqrt{(\xi)^2 - \frac{10.4}{(\beta)^2}} \right] \qquad (6\text{-}19)$$

$$b_{tr} := T \cdot b \qquad \sigma_F := \frac{T - .1}{T} \cdot \sigma_Y \cdot \sqrt{1 - 3 \cdot \left(\frac{\tau}{\sigma_Y} \right)^2} \qquad (6\text{-}20)$$

For combination (from equation 8.3.6 in text) and transformed plate:

$$A_{ptr} := b_{tr} \cdot t \qquad A_{tr} := A_s + A_{ptr} \qquad C_{1tr} := \frac{A_w \cdot \left(\frac{A_{tr}}{3} - \frac{A_w}{4} \right) + A_f \cdot A_{ptr}}{(A_{tr})^2} \qquad I_{tr} := A_{tr} \cdot (d)^2 \cdot C_{1tr} \qquad (6\text{-}21)$$

$$y_{ftr} := -d \cdot \frac{\frac{A_w}{2} + b_{tr} \cdot t}{A_{tr}} \qquad y_{ptr} := d \cdot \left(1 - \frac{\frac{A_w}{2} + b_{tr} \cdot t}{A_{tr}} \right) \qquad \rho_{tr} := \sqrt{\frac{I_{tr}}{A_{tr}}} \qquad \lambda := \frac{a}{\pi \cdot \rho_{tr}} \cdot \sqrt{\frac{\sigma_F}{E}} \qquad (6\text{-}22)$$

Correction for load eccentricity:

$$h := SCG + \frac{t}{2} \qquad \Delta_p := h \cdot A_s \cdot \left(\frac{1}{A_{tr}} - \frac{1}{A} \right) \qquad \eta_p := \Delta_p \cdot \frac{y_{ptr}}{(\rho_{tr})^2} \qquad (6\text{-}24)$$

Beam column with σ_F and transformed geometry

$$\eta := \frac{(\delta_o + \Delta) \cdot y_{ptr}}{(\rho_{tr})^2} \qquad \mu := \frac{M_o \cdot y_{ptr}}{I_{tr} \cdot \sigma_F} \qquad \zeta := \frac{1 - \mu}{1 + \eta_p} + \frac{1 + \eta_p + \eta}{(1 + \eta_p) \cdot (\lambda)^2} \qquad R := \frac{\zeta}{2} - \sqrt{\frac{(\zeta)^2}{4} - \frac{1 - \mu}{(1 + \eta_p) \cdot (\lambda)^2}} \qquad (6\text{-}25)$$

limit state

$$\sigma_{axtru} := -R \cdot \sigma_F \qquad \sigma_{axu} := \frac{A_{tr}}{A} \cdot \sigma_{axtru} \qquad R_{PCSF2} := \frac{\sigma_{ax}}{\sigma_{axu}} \qquad \gamma R_{PCSF2} := \gamma_C \cdot R_{PCSF2} \qquad (6\text{-}26)$$

c. Mode III tension failure in flange:

To determine intersection at G: Assume value for M_{oG} and iterate (M_{oG}>Mo; fails in Mode I or II)

$$\lambda_{GH} := \frac{a}{\pi \cdot \rho_{tr}} \cdot \sqrt{\frac{\sigma_Y}{E}} \qquad \delta_{oG} := \frac{5 \cdot M_{oG} \cdot a^2}{48 \cdot E \cdot I} \qquad \eta_{pGH} := \Delta_p \cdot \frac{y_{ftr}}{(\rho_{tr})^2} \qquad \eta_{GH} := \frac{(\delta_{oG} + \Delta) \cdot y_{ftr}}{(\rho_{tr})^2} \qquad (6\text{-}27)$$

$$\mu_{GH} := \frac{-M_{oG} \cdot y_{ftr}}{I_{tr} \cdot \sigma_Y} \qquad \zeta_{GH} := \frac{1 - \mu_{GH}}{1 + \eta_{pGH}} - \frac{1 + \eta_{pGH} + \eta_{GH}}{(1 + \eta_{pGH}) \cdot (\lambda_{GH})^2}$$

$$R_{GHneg} := \frac{\zeta_{GH}}{2} - \sqrt{\frac{(\zeta_{GH})^2}{4} + \frac{1 - \mu_{GH}}{(1 + \eta_{pGH}) \cdot (\lambda_{GH})^2}} \qquad R_{GHpos} := \frac{\zeta_{GH}}{2} + \sqrt{\frac{(\zeta_{GH})^2}{4} + \frac{1 - \mu_{GH}}{(1 + \eta_{pGH}) \cdot (\lambda_{GH})^2}}$$

For Mode II at point G:

$$\eta_p := \Delta_p \cdot \frac{y_{ptr}}{(\rho_{tr})^2} \qquad \eta := \frac{(\delta_{oG} + \Delta) \cdot y_{ptr}}{(\rho_{tr})^2} \qquad \mu := \frac{M_{oG} \cdot y_{ptr}}{I_{tr} \cdot \sigma_F} \qquad \zeta := \frac{1 - \mu}{1 + \eta_p} + \frac{1 + \eta_p + \eta}{(1 + \eta_p) \cdot (\lambda)^2} \qquad (6\text{-}28)$$

$$R_{II} := \frac{\zeta}{2} - \sqrt{\frac{(\zeta)^2}{4} - \frac{1 - \mu}{(1 + \eta_p) \cdot (\lambda)^2}} \qquad (6\text{-}29)$$

Adjust M_{oG} until these are equal: $\sigma_{axtruck} := R_{GH} \cdot \sigma_Y \qquad \sigma_{axtru} := -R_{II} \cdot \sigma_F$ (6-30)

For line GH:

From Section 16.1 plastic moment:

$$C_{P1} := \frac{A_p - A_w - A_f}{2 \cdot A_p} \qquad C_{P2} := (C_{P1})^2 - C_{P1} + .5 \qquad g := C_{P1} \cdot t \qquad Z_f := A_f \cdot (HSW + g + .5 \cdot TSF)$$

$$Z_w := A_w \cdot (.5 \cdot HSW + g) \qquad Z_p := A_p \cdot t \cdot C_{P2} \qquad Z_P := Z_f + Z_w + Z_p \qquad M_P := \sigma_Y \cdot Z_P \qquad (6\text{-}31)$$

limit state

$$\sigma_{auG} := \sigma_Y \cdot \frac{A_{tr}}{A} \cdot R_{GH} \qquad \sigma_{au} := \frac{M_P - M_o}{M_P - M_{oG}} \cdot \sigma_{auG} \qquad \gamma R_{PCSF3} := \gamma_C \cdot \frac{\sigma_C}{\sigma_{au}} \qquad (6\text{-}32)$$

7. GIRDER BENDING CALCULATIONS

$B_G := \frac{B_1 + B_2}{2}$ $\quad t_G := \frac{B_1 \cdot t_1 + B_2 \cdot t_2}{B_1 + B_2}$ $\quad L_G$ = unsupported length (between bulkheads and stanchions) (7-1)

Loads: Calculate <u>at girder location</u>, then: $q := p \cdot B_G$ $\quad L_G := 2 \cdot a$ (7-2)

Geometry: $HGW := DEPTH - TGF$ $\quad A_w := (DEPTH - TGF) \cdot TGW$ $\quad A_f := BGF \cdot TGF$ $\quad A_G := A_w + A_f$ (7-3)

For plate: $A_p := B_G \cdot t_G$ $\quad A := A_G + A_p$ (7-4)

For Girder:

$$d := DEPTH - \frac{TGF}{2} + \frac{t_G}{2} \qquad C_1 := \frac{A_w \cdot \left(\frac{A}{3} - \frac{A_w}{4}\right) + A_f \cdot A_p}{A^2} \qquad I := A \cdot (d)^2 \cdot C_1$$

For combination of plate and girder (from p287, equation 8.3.6 in text): (7-5)

$$y_f := -\left(d \cdot \frac{\frac{A_w}{2} + A_p}{A}\right) \qquad y_p := d \cdot \left(1 - \frac{\frac{A_w}{2} + A_p}{A}\right)$$

$$c_f := y_f - .5 \cdot TGF \qquad c_p := .5 \cdot t_G + y_p$$

Considering shear lag (Fig 3.36):

$$B_{Ge} := .75 \cdot B_G \quad A_{pe} := B_{Ge} \cdot t_G \quad A_e := A_G + A_{pe} \quad C_{1e} := \frac{A_w \cdot \left(\frac{A_e}{3} - \frac{A_w}{4}\right) + A_f \cdot A_{pe}}{A_e^{\,2}} \quad I_e := A_e \cdot (d)^2 \cdot C_{1e} \qquad (7\text{-}6)$$

Bending moments: $M_{bend} := -\left(p \cdot B_G \cdot \frac{L_G^{\,2}}{12}\right)$ $\quad M_{bcen} := p \cdot B_G \cdot \frac{L_G^{\,2}}{12}$ (7-7)

- GYCF - Girder Yield Compression Flange

$$\sigma_{ax} := \sigma_C \quad \sigma_{bx} := \frac{-(M_{bend} \cdot c_f)}{I_e} \quad \sigma_x := \sigma_{ax} + \sigma_{bx} \quad R_{GYCF} := \frac{-\sigma_x}{\sigma_Y} \quad \gamma R_{GYCF} := \gamma_S \cdot R_{GYCF} \qquad (7\text{-}9)$$

- GYCP (GYBP) - Girder Yield Compression Plate

- usually much smaller than GYCF and state of stress in plate more complex; we will not use (7-8)

- GYTF - Panel Yield Tension Flange

$$\sigma_{ax} := \sigma_T \quad \sigma_{bx} := \frac{-(M_{bcen} \cdot c_f)}{I_e} \quad \sigma_x := \sigma_{ax} + \sigma_{bx} \quad R_{GYTF} := \frac{\sigma_x}{\sigma_Y} \quad \gamma R_{GYTF} := \gamma_S \cdot R_{GYTF} \qquad (7\text{-}10)$$

- GYTP - Girder Yield Tension Plate -

usually much smaller than GYTF, plate closer to NA

$\sigma_{ax} := \sigma_T$ $\quad \sigma_{ay} := 0.0 \cdot psi$ $\quad \sigma_{bx} := \frac{-(M_{bend} \cdot c_p)}{I_e}$ $\quad$ assume for simplicity: $\sigma_{by} := 0 \cdot psi$ $\quad \sigma_x := \sigma_{ax} + \sigma_{bx}$ $\quad \sigma_y := \sigma_{ay} + \sigma_{by}$

(7-11)

$$\tau_{xy} := 0.0 \cdot psi \quad \sigma_{VM} := \sqrt{.5 \cdot \left[(\sigma_x - \sigma_y)^2 + (\sigma_y)^2 + (\sigma_x)^2\right] + 3 \cdot \tau_{xy}^{\,2}} \quad R_{GYTP} := \frac{\sigma_{VM}}{\sigma_Y} \quad \gamma R_{GYTP} := \gamma_S \cdot R_{GYTP}$$

8. FRAME BENDING CALCULATIONS

$B_F := a \quad t_F := t$ LF = unsupported length (between bulkheads, supported girders, deck edge, turn of bilge, continuous decks) (8-1)

Loads: Calculate at frame panel location, then: $q := p \cdot B_F$ (8-2)

Geometry: $HFW := DEPTH - TFF \quad A_w := (DEPTH - TFF) \cdot TFW \quad A_f := BFF \cdot TFF \quad A_F := A_w + A_f$ (8-3)

For plate: $A_p := B_F \cdot t_F \quad A := A_F + A_p$ (8-4)

For Frame: $d := DEPTH - \frac{TFF}{2} + \frac{t_G}{2} \quad C_1 := \frac{A_w \cdot \left(\frac{A}{3} - \frac{A_w}{4}\right) + A_f \cdot A_p}{A^2} \quad I := A \cdot (d)^2 \cdot C_1$ (8-5)

For combination of plate and stiffeners (from p287, equation 8.3.6 in text):

$c_f := y_f - .5 \cdot TFF \quad c_p := .5 \cdot t_F + y_p \quad y_f := -\left(d \cdot \frac{\frac{A_w}{2} + A_p}{A}\right) \quad y_p := d \cdot \left(1 - \frac{\frac{A_w}{2} + A_p}{A}\right)$ (8-6)

Considering shear lag (Fig 3.36):

$B_{Fe} := .75 \cdot B_F \quad A_{pe} := B_{Fe} \cdot t_F \quad A_e := A_F + A_{pe} \quad C_{1e} := \frac{A_w \cdot \left(\frac{A_e}{3} - \frac{A_w}{4}\right) + A_f \cdot A_{pe}}{A_e^2} \quad I_e := A_e \cdot (d)^2 \cdot C_{1e}$ (8-7)

$M_{bend} := -\left(p \cdot B_F \cdot \frac{L_F^2}{12}\right) \quad M_{bcen} := p \cdot B_F \cdot \frac{L_F^2}{12}$ (8-8)

- FYTF - Frame Yield Tension Flange

$\gamma_S := 1.25$

$\sigma_{ay} := 0 \cdot psi \quad \sigma_{by} := \frac{-(M_{bcen} \cdot c_f)}{I_e} \quad \sigma_y := \sigma_{ay} + \sigma_{by} \quad R_{FYTF} := \frac{\sigma_y}{\sigma_Y} \quad \gamma R_{FYTF} := \gamma_S \cdot R_{FYTF}$ (8-9)

- FYCF - Frame Yield Compression Flange

- consider when say<0

$\sigma_{ay} := 0 \cdot psi \quad \sigma_{by} := \frac{-(M_{bend} \cdot c_f)}{I_e} \quad \sigma_y := \sigma_{ay} + \sigma_{by} \quad R_{FYCF} := \frac{-\sigma_y}{\sigma_Y} \quad \gamma R_{FYCF} := \gamma_S \cdot R_{FYCF}$ (8-10)

- FYTP - Frame Yield Tension Plate

usually much smaller than FYTF, plate closer to NA

$\sigma_{ax} := \sigma_C \quad \sigma_{ay} := 0.0 \cdot psi \quad \sigma_{by} := \frac{-(M_{bend} \cdot c_p)}{I_e}$ assume for simplicity: $\sigma_{bx} := 0 \cdot psi \quad \sigma_x := \sigma_{ax} + \sigma_{bx} \quad \sigma_y := \sigma_{ay} + \sigma_{by}$

(8-11)

$\tau_{xy} := 0.0 \cdot psi \quad \sigma_{VM} := \sqrt{.5 \cdot \left[(\sigma_x - \sigma_y)^2 + \sigma_y^2 + \sigma_x^2\right] + 3 \cdot \tau_{xy}^2} \quad R_{FYTP} := \frac{\sigma_{VM}}{\sigma_Y} \quad \gamma R_{FYTP} := \gamma_S \cdot R_{FYTP}$

- FYCP - Frame Yield Compression Plate

usually much smaller than FYCF, plate closer to NA

$\sigma_{ax} := \sigma_T \quad \sigma_{ay} := 0.0 \cdot psi \quad \sigma_{by} := \frac{-(M_{bcen} \cdot c_p)}{I_e}$ assume for simplicity: $\sigma_{bx} := 0 \cdot psi \quad \sigma_x := \sigma_{ax} + \sigma_{bx} \quad \sigma_y := \sigma_{ay} + \sigma_{by}$

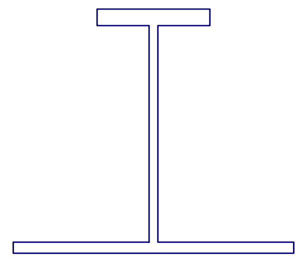
(8-12)

$\tau_{xy} := 0.0 \cdot psi \quad \sigma_{VM} := \sqrt{.5 \cdot \left[(\sigma_x - \sigma_y)^2 + \sigma_y^2 + \sigma_x^2\right] + 3 \cdot \tau_{xy}^2} \quad R_{FYCP} := \frac{\sigma_{VM}}{\sigma_Y} \quad \gamma R_{FYCP} := \gamma_S \cdot R_{FYCP}$

9. FRAME COLLAPSE PLASTIC HINGE (FCPH)

From Section 16.1: (can also use Hughes Table 16.1

breadth of plate is "effective breadth



$$A_w := t_w \cdot h_w$$

$$A_p := t_p \cdot b_{pe} \qquad A_f := t_f \cdot b_f \qquad \gamma_C := 1.5$$

$$A_T := A_p + A_w + A_f \qquad (9\text{-}1)$$

if Ap>Aw+Af; i.e. Ap>At/2 => g (distance from top of plate to PNA) is in plate

$$g := \frac{A_p - A_w - A_f}{2 \cdot b_{pe}} \qquad (9\text{-}2a)$$

centroid of upper half

$$y_1 := \frac{\left[\frac{b_{pe} \cdot g^2}{2} + A_w \cdot \left(\frac{h_w}{2} + g\right)\right] + A_f \left(g + h_w + \frac{t_f}{2}\right)}{\frac{A_T}{2}}$$

centroid of lower half

$$y_2 := \frac{t_p - g}{2} \qquad (9\text{-}3a)$$

plastic section modulus, if Ap>At/2

$$Z_{P1} := \frac{A_T}{2} \cdot (y_1 + y_2) \qquad (9\text{-}4a)$$

---

if Ap<Aw+Af; i.e. Ap<At/2 => g is is web

$$g := \frac{A_f + A_w - A_p}{2 \cdot t_w} \qquad (9\text{-}2b)$$

centroid of upper half

$$y_1 := \frac{A_f \left(h_w - g + \frac{t_f}{2}\right) + \frac{t_w \cdot (h_w - g)^2}{2}}{A_f + A_w - g \cdot t_w}$$

centroid of lower half

$$y_2 := \frac{A_p \cdot \left(g + \frac{t_p}{2}\right) + \frac{t_w \cdot g^2}{2}}{A_p + g \cdot t_w} \qquad (9\text{-}3b)$$

plastic section modulus, if Ap<At/2

$$Z_{P2} := \frac{A_T}{2} \cdot (y_1 + y_2) \qquad (9\text{-}4b)$$

Calculate FCPH ----------------------------

$$Z_P := \text{if}\left(A_p > \frac{A_T}{2}, Z_{P1}, Z_{P2}\right) \qquad (9\text{-}5)$$

$$M_P := \sigma_Y \cdot Z_P \qquad R_{FCPH} := \frac{M_{bcen}}{M_p} \qquad \gamma R_{FCPH} := \gamma_C \cdot R_{FCPH} \qquad (9\text{-}6)$$

10. COLUMN COLLAPSE BUCKLING (CCB):

Tube Geometry: $I := \frac{\pi \cdot \left(d^4 - d_I^4\right)}{64}$ $\quad A := \frac{\pi \cdot \left(d^2 - d_I^2\right)}{4}$ $\quad \gamma_C := 1.5$ (10-1)

for a pinned column: $L_e := .7 \cdot L_{col}$ $\quad \rho := \sqrt{\frac{I}{A}}$ $\quad \lambda := \frac{L_e}{\pi \cdot \rho} \cdot \sqrt{\frac{\sigma_Y}{E}}$ (10-2)

Eccentricity Ratio: $\alpha := .002$ $\quad \eta := \alpha \cdot \left(\frac{L_{col}}{\rho}\right)$ (10-3)

$$R := .5 \cdot \left(1 + \frac{1 + \eta}{\lambda^2}\right) - \sqrt{.25 \cdot \left(1 + \frac{1 + \eta}{\lambda^2}\right)^2 - \frac{1}{\lambda^2}} \quad \sigma_{ult} := R \cdot \sigma_Y \quad \sigma_a := \frac{P}{A} \quad \gamma R_{CCB} := \gamma_C \cdot \left(\frac{\sigma_a}{\sigma_{ult}}\right) \quad (10\text{-}4)$$

11. GIRDER BUCKLING CALCULATIONS

- GCCP1, pinned/center:

$L := 2 \cdot a$ $\quad L_e := L$ $\quad r_c := \frac{I}{c_p \cdot A}$ $\quad \delta_o := \frac{5 \cdot q \cdot (L)^4}{384 \cdot E \cdot I}$ $\quad \rho := \sqrt{\frac{I}{A}}$ (11-1)

$\alpha := .0035$ $\quad \eta := \alpha \cdot \frac{L}{\rho} + \frac{\delta_o}{r_c}$ $\quad \mu := \frac{q \cdot L^2 \cdot c_p}{8 \cdot I \cdot \sigma_Y}$ $\quad$ column slenderness parameter: $\lambda := \frac{L_e}{\pi \cdot \rho} \cdot \sqrt{\frac{\sigma_Y}{E}}$

$$R := .5 \cdot \left[1 - \mu + \frac{1 + \eta}{(\lambda)^2}\right] - \sqrt{.25 \cdot \left(1 - \mu + \frac{1 + \eta}{\lambda^2}\right)^2 - \frac{1 - \mu}{\lambda^2}} \quad \sigma_a := \sigma_C \quad \sigma_{ult} := -(R \cdot \sigma_Y) \quad \gamma R_{GCCP1} := \gamma_C \cdot \frac{\sigma_a}{\sigma_{ult}}$$

(11-2)

- GCCP2, clamped/center:

$L_e := .577 \cdot L$ $\quad r_c := \frac{I}{c_p \cdot A}$ $\quad \delta_o := \frac{.556 \cdot q \cdot L^4}{384 \cdot E \cdot I}$ $\quad \rho := \sqrt{\frac{I}{A}}$ $\quad \eta := \alpha \cdot \frac{L_e}{\rho} + \frac{\delta_o}{r_c}$

$\mu := \frac{q \cdot L^2 \cdot c_p}{24 \cdot I \cdot \sigma_Y}$ $\quad \lambda := \frac{L_e}{\pi \cdot \rho} \cdot \sqrt{\frac{\sigma_Y}{E}}$ (11-3)

$$R := .5 \cdot \left(1 - \mu + \frac{1 + \eta}{\lambda^2}\right) - \sqrt{.25 \cdot \left(1 - \mu + \frac{1 + \eta}{\lambda^2}\right)^2 - \frac{1 - \mu}{\lambda^2}} \quad \sigma_a := \sigma_C \quad \sigma_{ult} := -(R \cdot \sigma_Y) \quad \gamma R_{GCCP2} := \gamma_C \cdot \frac{\sigma_a}{\sigma_{ult}}$$

- GCCF, clamped/end:

$L_e := .423 \cdot L$ $\quad r_c := \frac{-I}{c_f \cdot A}$ $\quad \delta_o := \frac{.444 \cdot q \cdot L^4}{384 \cdot E \cdot I}$ $\quad \rho := \sqrt{\frac{I}{A}}$ $\quad \eta := \alpha \cdot \frac{L_e}{\rho} + \frac{\delta_o}{r_c}$

$\mu := \frac{-q \cdot L^2 \cdot c_f}{12 \cdot I \cdot \sigma_Y}$ $\quad \lambda := \frac{L_e}{\pi \cdot \rho} \cdot \sqrt{\frac{\sigma_Y}{E}}$ (11-4)

$$R := .5 \cdot \left(1 - \mu + \frac{1 + \eta}{\lambda^2}\right) - \sqrt{.25 \cdot \left(1 - \mu + \frac{1 + \eta}{\lambda^2}\right)^2 - \frac{1 - \mu}{\lambda^2}} \quad \sigma_a := \sigma_C \quad \sigma_{ult} := -(R \cdot \sigma_Y) \quad \gamma R_{GCCF} := \gamma_C \cdot \frac{\sigma_a}{\sigma_{ult}}$$