

Steel Beam with Circular Unreinforced Opening

	$F_y := 36\cdot\text{ksi}$	$E := 29000\cdot\text{ksi}$	compression flange assumed continuously braced			
Beam Data	$w_{\text{dead}} := 0.607\cdot\frac{\text{kip}}{\text{ft}}$	$w_{\text{live}} := 0.8\cdot\frac{\text{kip}}{\text{ft}}$	simple span		area of the whole section (unperforated)	plastic modulus of the whole section (unperforated)
			$L := 36\cdot\text{ft}$			
Section Properties	$d := 23.57\cdot\text{in}$	$t_w := 0.395\cdot\text{in}$	$b_f := 7.005\cdot\text{in}$	$t_f := 0.505\cdot\text{in}$	$A_s := 16.2\cdot\text{in}^2$	$Z := 134\cdot\text{in}^3$
Circular Opening Data	$D_0 := 13\cdot\text{in}$	Diameter of cut opening	$\text{ecc} := 0\cdot\text{in}$	positive if downwards of cog (make always positive)		

</

$$h_0 := 0.9 \cdot D_0$$

$$s_b := \frac{d}{2} - \left(\frac{h_0}{2} + ecc\right) \qquad s_b = 5.93 \text{ in} \qquad s_t := \frac{d}{2} - \left(\frac{h_0}{2} - ecc\right) \qquad s_t = 5.93 \text{ in}$$

$$v_b := \frac{a_0}{s_b} \qquad v_b = 0.99 \qquad v_t := \frac{a_0}{s_t} \qquad v_t = 0.99$$

$$\mu := 0$$

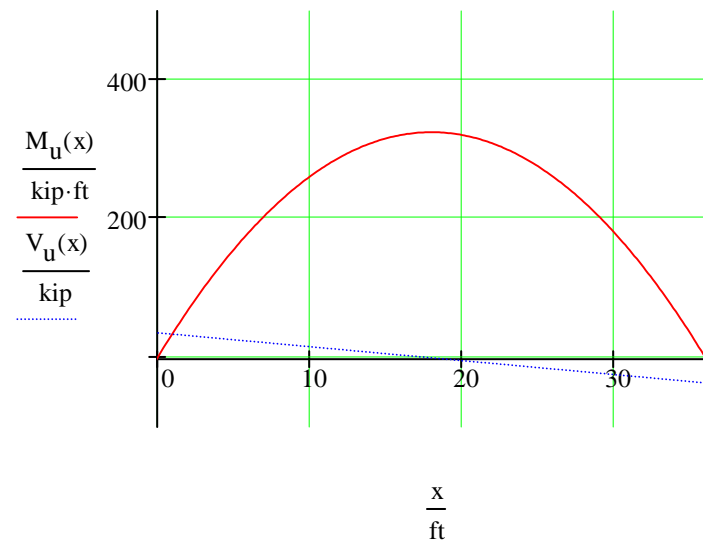
$$V_{pb} := \frac{F_y \cdot t_w \cdot s_b}{\sqrt{3}} \qquad V_{pb} = 48.73 \text{ kip} \qquad \alpha_{vb} := \min \left(\left(\frac{\sqrt{6} + \mu}{v_b + \sqrt{3}} \right) \right. \\ \left. \left(\frac{1}{1} \right) \right) \qquad \alpha_{vb} = 0.9 \qquad V_{mb} := V_{pb} \cdot \alpha_{vb} \qquad V_{mb} = 43.92 \text{ kip}$$

$$V_{pt} := \frac{F_y \cdot t_w \cdot s_t}{\sqrt{3}} \qquad V_{pt} = 48.73 \text{ kip} \qquad \alpha_{vt} := \min \left(\left(\frac{\sqrt{6} + \mu}{v_t + \sqrt{3}} \right) \right. \\ \left. \left(\frac{1}{1} \right) \right) \qquad \alpha_{vt} = 0.9 \qquad V_{mt} := V_{pt} \cdot \alpha_{vt} \qquad V_{mt} = 43.92 \text{ kip}$$

$$V_m := V_{mb} + V_{mt} \qquad \phi_s := 0.9$$

$$\phi V_m := \phi_s \cdot V_m \qquad \phi V_m = 79.05 \text{ kip}$$

$$M_u(x) := w_u \cdot \frac{L}{2} \cdot x - w_u \cdot x \cdot \frac{x}{2} \qquad V_u(x) := w_u \cdot \frac{L}{2} - w_u \cdot x$$



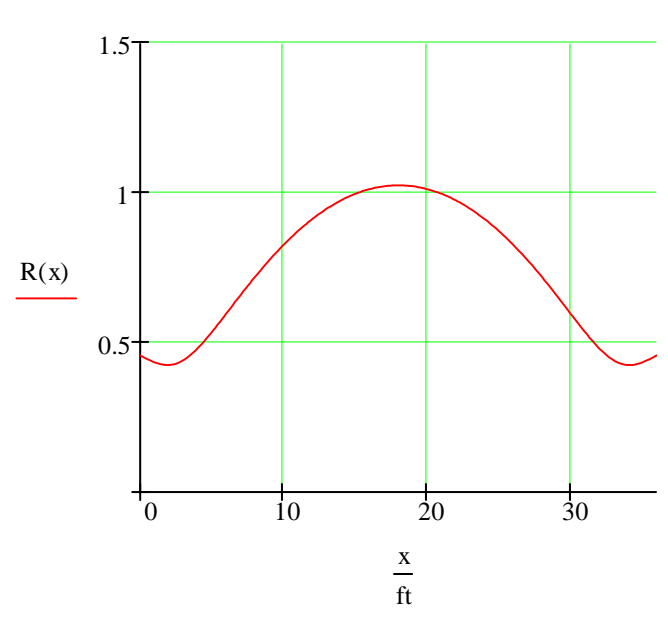
$$R(x) := \left[\left(\frac{M_u(x)}{\phi M_m} \right)^3 + \left(\frac{|V_u(x)|}{\phi V_m} \right)^3 \right]^{\frac{1}{3}}$$

$$r_{\min} := \max \left(\left(\frac{2 \cdot t_w}{5} \right), \left(\frac{5}{8} \cdot \text{in} \right) \right) \quad \text{min radius}$$



Check for UNREINFORCED Opening

all the checks below must be less than or at most equal to 1 to be OK



$\frac{h_0}{d} = 0.71$

$\frac{P_0}{5.6} = 0.67$

$\frac{s_b}{s_t} = 1$

$\frac{v_b}{12} = 0.08$

$\frac{v_t}{4} = 0.25$

$\frac{\frac{b_f}{2 \cdot t_f}}{\frac{65}{\sqrt{F_y}} \text{ ksi}} = 0.64$

$\frac{\frac{d-2 \cdot t_f}{t_w}}{\frac{420}{\sqrt{F_y}} \text{ ksi}} = 0.82$

$\frac{V_m}{\frac{2}{3} \cdot \frac{F_y \cdot d \cdot t_w}{\sqrt{3}}} = 0.68$

$\frac{a_0}{\frac{h_0}{3}} = 0.17$

$\frac{0.15}{\frac{s_b}{d}} = 0.6$

$\frac{0.15}{\frac{s_t}{d}} = 0.6$

As long as all the checks in yellow till the asterisks are met, you can place this opening anywhere R(x) in the chart is **less** than 1 starting from distances from ends bigger than the depth of the beam

X := 20·ft

R(X) = 1.01

r_{min} = 0.79 in

minimum radius of the cut in the opening

Check the Opening with Stiffeners

b_r := 3·in

t_r := 1·in

width and thickness of a stiffener (both atop and under the opening)



h₀ := D₀

a₀ := 0.45·D₀

$s_b := \frac{d}{2} - \left(\frac{h_0}{2} + ecc \right)$

s_b = 5.28 in

$s_t := \frac{d}{2} - \left(\frac{h_0}{2} - ecc \right)$

s_t = 5.28 in

$v_b := \frac{a_0}{s_b}$
 $v_b = 1.11$
 $v_t := \frac{a_0}{s_t}$
 $v_t = 1.11$

$p_0 := \frac{a_0}{h_0} + \frac{6 \cdot h_0}{d}$

$A_r := b_r \cdot t_r$
 $A_r = 3 \text{ in}^2$

section of any of both the top or bottom stiffener

$\Delta A_s := h_0 \cdot t_w - 2 \cdot A_r$

$M_m := \min \left[\left[\begin{array}{l} M_p \cdot \left[1 - \frac{t_w \cdot \left(\frac{h_0^2}{4} + h_0 \cdot ecc - ecc^2 \right) - A_r \cdot h_0}{Z} \right] \text{ if } t_w \cdot ecc < A_r \\ M_p \cdot \left[1 - \frac{\Delta A_s \cdot \left(\frac{h_0}{4} + ecc \right)}{Z} \right] \text{ otherwise} \\ M_p \end{array} \right] \right]$

$\phi M_m := \phi_b \cdot M_m$
 $\phi M_m = 4341.61 \text{ in} \cdot \text{kip}$

$P_r := \min \left(\left(\frac{F_y \cdot A_r}{\frac{F_y \cdot t_w \cdot a_0}{2 \cdot \sqrt{3}}} \right) \right)$
 $P_r = 24.01 \text{ kip}$

$d_{rb} := s_b - \frac{t_r}{2}$
 $s_{b1} := s_b - \frac{A_r}{2 \cdot b_f}$
 $v_b := \frac{a_0}{s_{b1}}$
 $V_{pb} := \frac{F_y \cdot t_w \cdot s_b}{\sqrt{3}}$
 $V_{pb} = 43.39 \text{ kip}$
 $\mu_b := \frac{2 \cdot P_r \cdot d_{rb}}{V_{pb} \cdot s_b}$

$$\alpha_{vb} := \min \left(\left(\frac{\sqrt{6} + \mu_b}{v_b + \sqrt{3}} \right) \right) \qquad \alpha_{vb} = 1 \qquad V_{mb1} := V_{pb} \cdot \alpha_{vb} \qquad V_{mb1} = 43.39 \text{ kip}$$

$$d_{rt} := s_t - \frac{t_r}{2} \qquad s_{t1} := s_t - \frac{A_r}{2 \cdot b_f} \qquad v_t := \frac{a_0}{s_{t1}} \qquad V_{pt} := \frac{F_y \cdot t_w \cdot s_t}{\sqrt{3}} \qquad V_{pt} = 43.39 \text{ kip} \qquad \mu_t := \frac{2 \cdot P_r \cdot d_{rt}}{V_{pt} \cdot s_t}$$

$$\alpha_{vt} := \min \left(\left(\frac{\sqrt{6} + \mu_t}{v_t + \sqrt{3}} \right) \right) \qquad \alpha_{vt} = 1 \qquad V_{mt1} := V_{pt} \cdot \alpha_{vt} \qquad V_{mt1} = 43.39 \text{ kip}$$

$$V_{m1} := V_{mb1} + V_{mt1} \qquad \phi_s := 0.9$$

$$\phi V_m := \phi_s \cdot V_{m1} \qquad \phi V_m = 78.1 \text{ kip}$$

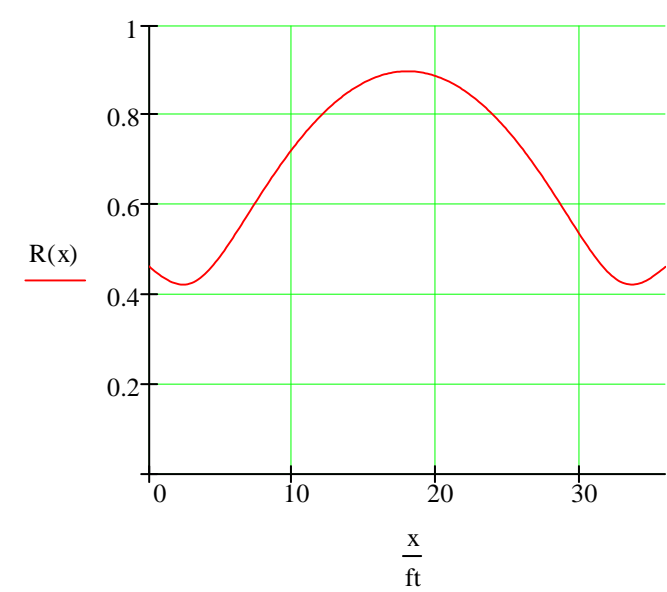
$$R(x) := \left[\left(\frac{M_u(x)}{\phi M_m} \right)^3 + \left(\frac{\left| V_u(x) \right|}{\phi V_m} \right)^3 \right]^{\frac{1}{3}}$$

$$r_{min} := \max \left(\left(\frac{2 \cdot t_w}{\frac{5}{8} \cdot in} \right) \right) \qquad r_{min} = 0.79 \text{ in}$$



all the checks below must be less than or at most equal to 1 to be OK with stiffeners' reinforcement atop and below the opening

Check for REINFORCED Opening



$$\frac{\frac{h_0}{d}}{0.7} = 0.79$$

$$\frac{P_0}{5.6} = 0.67$$

$$\frac{s_b}{s_t} = 1$$

$$\frac{v_b}{12} = 0.1$$

$$\frac{v_t}{12} = 0.1$$

$$\frac{\frac{\frac{b_f}{2 \cdot t_f}}{65}}{\sqrt{\frac{F_y}{\text{ksi}}}} = 0.64$$

$$\frac{\frac{\frac{d-2 \cdot t_f}{t_w}}{420}}{\sqrt{\frac{F_y}{\text{ksi}}}} = 0.82$$

$$\frac{V_m}{\frac{2}{3} \cdot \frac{F_y \cdot d \cdot t_w}{\sqrt{3}}}} = 0.68$$

$$\frac{0.15}{\frac{s_b}{d}} = 0.67$$

$$\frac{0.15}{\frac{s_t}{d}} = 0.67$$

$$\frac{\frac{a_0}{h_0}}{3} = 0.15$$

$$\frac{\frac{\frac{s_b}{t_w}}{140}}{\sqrt{\frac{F_y}{\text{ksi}}}} = 0.57$$

$$\frac{\frac{\frac{s_t}{t_w}}{140}}{\sqrt{\frac{F_y}{\text{ksi}}}} = 0.57$$

X := 20·ft

R(X) = 0.89

r_{min} = 0.79 in minimum radius of the cut opening

Weld Design of the Stiffener

Of course this section becomes non meaningful for a circular opening but keep it for reference

L₁ := 5·in length of stiffener beyond opening width

F_{wu} := 70·ksi limit tensile strength of weld metal

F_{yu} := 58·ksi limit tensile strength of base metal



F_w := 0.6·F_{wu}

R_{wri} := 0.9·2·P_r R_{wri} = 43.23 kip to be developed in the length of the opening

$R_{wro} := 0.9 \cdot F_y \cdot A_r$
 $R_{wro} = 97.2 \text{ kip}$
to be developed in every extension beyond the opening

$Size_{in_opening_1_side} := \frac{1}{16} \cdot in \cdot ceil \left(\frac{R_{wri}}{0.75 \cdot F_w \cdot a_0 \cdot \frac{\sqrt{2}}{2} \cdot \frac{1}{16} \cdot in} \right)$

$Size_{in_extensions_2_sides} := \frac{1}{16} \cdot in \cdot ceil \left(\frac{R_{wro}}{2 \cdot 0.75 \cdot F_w \cdot L_1 \cdot \frac{\sqrt{2}}{2} \cdot \frac{1}{16} \cdot in} \right)$



all the checks below **must be less than or at most equal to 1 for the weld be OK**

$\frac{P_r}{\frac{F_y \cdot t_w \cdot a_0}{2 \cdot \sqrt{3}}} = 1$

$\frac{0.9 \cdot 2 \cdot P_r \cdot \left(\frac{b_r - Size_{in_opening_1_side}}{b_r} \right)}{0.75 \cdot 0.6 \cdot F_{yu} \cdot t_r \cdot a_0} = 0.25$

$\frac{\frac{a_0}{4}}{L_1} = 0.29$

$\frac{\frac{\sqrt{3} \cdot A_r}{2 \cdot t_w}}{L_1} = 1.32$

$\frac{\frac{M_u(X)}{|V_u(X)| \cdot d}}{20} = 2.04$

$\frac{\frac{a_0}{h_0}}{2.5} = 0.18$

$\frac{\frac{A_r}{b_f \cdot t_f}}{3} = 2.54$

the 3 conditions in this line need be further be complied with for the stiffener be positioned to one side of the web

then ...

$Size_{in_opening_1_side} = 6 \frac{in}{16}$

a fillet weld of this (leg) size is required at one side of the stiffener within the opening width

$Size_{in_extensions_2_sides} = 7 \frac{in}{16}$

a fillet weld of this (leg) size is required at both sides of the stiffener extensions beyond the opening width

Minimum Separation between Openings



$$V_p := \frac{F_y \cdot t_w \cdot d}{\sqrt{3}}$$

$$S(X) := \max \left(\left(\begin{array}{c} 1.5 \cdot D_0 \\ \frac{V_u(X)}{\phi_s \cdot V_p} \\ a_0 \cdot \frac{V_u(X)}{1 - \frac{V_u(X)}{\phi_s \cdot V_p}} \end{array} \right) \right)$$



$$S(X) = 19.5 \text{ in}$$

- keep at least this uninterrupted web between openings
- note as well that even 1 single opening affects significantly deflection and needs be taken into account for deflection calculations