

Vertically Centered Circular Web Opening in RC Rectangular Beam



Setup for Units is the default to SI.

Initialization

ORIGIN ≡ 1 Count with fingers

TOL := 1 CTOL := 1 N := newton

ton := 1000·kgf ksi := 70.307· $\frac{\text{kgf}}{\text{cm}^2}$ psi := $\frac{\text{ksi}}{1000}$ kip := 453.592·kgf MPa := 10.197· $\frac{\text{kgf}}{\text{cm}^2}$ kN := 1000·N

Reference is ACI Structural Journal September-October 1999 Vol. 96 N° 5, p. 679

AND2(a,b) := $\left\{ \begin{array}{l} \text{if } a = 1 \\ \quad \left\{ \begin{array}{l} 1 \text{ if } b = 1 \\ 0 \text{ otherwise} \end{array} \right. \\ 0 \text{ otherwise} \end{array} \right.$

OR2(a,b) := $\left\{ \begin{array}{l} 1 \text{ if } a = 1 \\ \text{otherwise} \\ \quad \left\{ \begin{array}{l} 1 \text{ if } b = 1 \\ 0 \text{ otherwise} \end{array} \right. \end{array} \right.$



f_c := 30·MPa f_y := 420·MPa f_{yw} := f_y f_{yv} := f_y E_s := 200000·MPa ϕ_b := 0.9 ϕ_s := 0.85

b := 35·cm width of section D := 80·cm depth of section d₀ := 30·cm ecc := 0·cm λ := 1 1.00 for Normal weight
0.75 fo all-lightweight
0.85 for sand-lightweight

M_u := 250·kN·m T_u := 120·kN·m V_u := 100·kN

d_{bar}_{long} := 25·mm d_{bar}_{stirrups} := 10·mm min_{cover} := 25·mm clear J := 1.0 1.1 for joist construction
1.0 for beam or other



ϕ₁ := d_{bar}_{long} bottom bars ϕ₂ := d_{bar}_{long} top bars

d := D − $\left(\text{min}_{\text{cover}} + \text{dbar}_{\text{stirrups}} + \frac{\text{dbar}_{\text{long}}}{2} \right)$

d = 75.25 cm

$$V_{eq_sc} := V_u + \frac{\left(1.6 - \frac{d_0}{D}\right)}{b} \cdot T_u$$

$$V_{eq_sc} = 520 \text{ kN}$$

$$V_{u_max} := \phi_s \cdot 0.83 \cdot \sqrt{\frac{f_c}{\text{MPa}}} \cdot \text{MPa} \cdot b \cdot (d - d_0)$$

$$V_{u_max} = 611.98 \text{ kN}$$

$$\frac{V_{eq_sc}}{V_{u_max}} = 0.85$$

$$\alpha := \frac{D}{b}$$

$$\mu := \frac{b^2 + b \cdot D}{2 \cdot b + 4 \cdot D}$$

$$\alpha = 2.29$$

$$\mu = 103.21 \text{ mm}$$

$$M_{eq_1} := (T_u + V_u \cdot \mu) \cdot \sqrt{1 + 2 \cdot \alpha}$$

$$M_{eq_1} = 307.61 \text{ kN}\cdot\text{m}$$

$$M_{01} := M_{eq_1} + M_u$$

$$M_{01} = 557.61 \text{ kN}\cdot\text{m}$$

Design the section in flexure for this moment

$$c_1 := \text{min}_{cover} + \text{dbar}_{stirrups} + \frac{\text{dbar}_{long}}{2}$$

$$c_2 := c_1$$

$$h := D$$

$$\varepsilon_y := \frac{f_y}{E_s}$$

$$\varepsilon_y = 0.0021$$

This block seems to be fully conservative till fc=22.5 MPa and can (without bending strength reduction factor) give unconservative results for higher strengths (see ACI SJ Vol 94 N°1 p. 44 fig 6)

$$\alpha := 0.85$$

depth in fc

$$\beta_1 := \begin{cases} 0.85 & \text{if } f_c \leq 4 \cdot \text{ksi} \\ \text{otherwise} & \\ \begin{cases} \frac{f_c}{\text{psi}} - 4000 \\ 0.85 - \frac{\frac{f_c}{\text{psi}} - 4000}{1000} \cdot 0.05 \end{cases} & \text{if } 0.85 - \frac{\frac{f_c}{\text{psi}} - 4000}{1000} \cdot 0.05 > 0.65 \\ 0.65 & \text{otherwise} \end{cases}$$

geometrical depth of stress block, fraction of depth to Neutral Axis

$$f_s(\epsilon) := \begin{cases} (-f_y) & \text{if } \epsilon \leq -\epsilon_y \\ \text{otherwise} & \\ \begin{cases} E_s \cdot \epsilon & \text{if } \epsilon \leq \epsilon_y \\ f_y & \text{otherwise} \end{cases} \end{cases}$$

$$\epsilon_2 := 0.003 \quad \epsilon_1 := -0.004 \quad A_{s1} := 30 \quad A_{s2} := 0$$

unwarranted guesses of final status, areas adimensionalized for minimize block use but assumed cm2

$$A_{\text{tot}}(\epsilon_1, \epsilon_2, A_{s1}, A_{s2}) := A_{s1} + A_{s2} \quad \text{needed a function of all to meet equilibrium below and to the purpose of its minimization}$$

$$\text{MaxMoment}_{bh}(A_{s1}, A_{s2}) := 0.375 \cdot [0.85 \cdot f_c \cdot b \cdot (h - c_2)] \cdot (h - c_2) + A_{s2} \cdot \text{cm}^2 \cdot (h - c_1 - c_2) \cdot f_y$$

the maximum moment that is accepted for any section b·h having As2 compression steel, whatever tensile steel area As1, as a measure of protection against fragile (compressive side) failure

$$c(\epsilon_2, \epsilon_1) := \frac{h \cdot \epsilon_2}{\epsilon_2 - \epsilon_1} \quad a(\epsilon_2, \epsilon_1) := \beta_1 \cdot c(\epsilon_2, \epsilon_1)$$

$$Fc2(\epsilon_1, \epsilon_2) := \begin{cases} \alpha \cdot f_c & \text{if } c_2 \leq a(\epsilon_2, \epsilon_1) \\ 0 \cdot \frac{\text{kgf}}{\text{cm}^2} & \text{otherwise} \end{cases}$$

$$Fs2(\epsilon_1, \epsilon_2) := f_s \left[\epsilon_1 + \frac{\epsilon_2 - \epsilon_1}{h} \cdot (h - c_2) \right] \quad Fs1(\epsilon_1, \epsilon_2) := f_s \left(\epsilon_1 + \frac{\epsilon_2 - \epsilon_1}{h} \cdot c_1 \right)$$

$$\text{Steel}_{\text{Force}}\left(\varepsilon_1,\varepsilon_2,A_{s1},A_{s2}\right):=A_{s1}\cdot\text{cm}^2\cdot\text{Fs1}\left(\varepsilon_1,\varepsilon_2\right)+A_{s2}\cdot\text{cm}^2\cdot\left(\text{Fs2}\left(\varepsilon_1,\varepsilon_2\right)-\text{Fc2}\left(\varepsilon_1,\varepsilon_2\right)\right)$$

$$\text{Concrete}_{\text{Force}}\left(\varepsilon_1,\varepsilon_2\right):=\text{b}\cdot\text{a}\left(\varepsilon_2,\varepsilon_1\right)\cdot0.85\cdot\text{f}_{\text{c}}$$

$$\text{Steel}_{\text{moment}}\left(\varepsilon_1,\varepsilon_2,A_{s1},A_{s2}\right):=c_1\cdot A_{s1}\cdot\text{cm}^2\cdot\text{Fs1}\left(\varepsilon_1,\varepsilon_2\right)+\left(h-c_2\right)\cdot A_{s2}\cdot\text{cm}^2\cdot\left(\text{Fs2}\left(\varepsilon_1,\varepsilon_2\right)-\text{Fc2}\left(\varepsilon_1,\varepsilon_2\right)\right)$$

$$\text{Concrete}_{\text{moment}}\left(\varepsilon_2,\varepsilon_1\right):=\left(h-\frac{\text{a}\left(\varepsilon_2,\varepsilon_1\right)}{2}\right)\cdot\text{b}\cdot\text{a}\left(\varepsilon_2,\varepsilon_1\right)\cdot0.85\cdot\text{f}_{\text{c}}$$

$$\text{Total}_{\text{Force}}\left(\varepsilon_1,\varepsilon_2,A_{s1},A_{s2}\right):=\text{Steel}_{\text{Force}}\left(\varepsilon_1,\varepsilon_2,A_{s1},A_{s2}\right)+\text{Concrete}_{\text{Force}}\left(\varepsilon_1,\varepsilon_2\right)$$

$$\text{Total}_{\text{Moment}}\left(\varepsilon_1,\varepsilon_2,A_{s1},A_{s2}\right):=\text{Steel}_{\text{moment}}\left(\varepsilon_1,\varepsilon_2,A_{s1},A_{s2}\right)+\text{Concrete}_{\text{moment}}\left(\varepsilon_2,\varepsilon_1\right)$$

Given

$$\text{Total}_{\text{Force}}\left(\varepsilon_1,\varepsilon_2,A_{s1},A_{s2}\right)=0\cdot\text{ton}\qquad \varepsilon_2\leq 0.003$$

$$\text{Total}_{\text{Moment}}\left(\varepsilon_1,\varepsilon_2,A_{s1},A_{s2}\right)=\frac{M_{01}}{\phi_{\text{b}}}$$

$$M_{01}\leq \text{Max}_{\text{Moment_bh}}\left(A_{s1},A_{s2}\right)\quad \frac{c\left(\varepsilon_2,\varepsilon_1\right)}{h}<120\cdot0.003\qquad \text{two conditions to enforce ductile design}$$

$$A_{s1}>0\qquad A_{s2}\geq 0$$

$$P:=\text{Minimize}\left(A_{\text{tot}},\varepsilon_1,\varepsilon_2,A_{s1},A_{s2}\right)\quad \text{Result must be in black and not surrounded by a white square to be OK}$$

in case the minimization of area always fails you can still find some (if not optimum) solution by disabling the equation above and enabling...

$$P := \text{Find}\left(\varepsilon_1, \varepsilon_2, A_{s1}, A_{s2}\right) \blacksquare$$

$$P = \begin{pmatrix} -0.00253224 \\ 0.00044075 \\ 20.97994095 \\ 0 \end{pmatrix} \qquad \varepsilon_1 := P_1 \qquad \varepsilon_2 := P_2 \qquad A_{s1} := P_3 \qquad A_{s2} := P_4$$

$$\text{Top}_{\text{strength}} := \begin{cases} \text{"O.K."} & \text{if } \text{Max}_{\text{Moment_bh}}\left(A_{s1}, A_{s2}\right) \geq M_{01} \\ \text{"Momento Tope is exceeded so better enlarge the section"} & \text{otherwise} \end{cases} \qquad \text{here the control is set}$$

We additionally investigate fragile rupture by

$$\text{Failure} := \begin{cases} \text{"Ductile as below reinforced, O.K."} & \text{if } \frac{c\left(\varepsilon_2, \varepsilon_1\right)}{h} \leq 120 \cdot 0.003 + 0.001 \\ \text{"Stress block so deep that fragile failure is expected "} & \text{otherwise} \end{cases}$$

Criteria is one as per Skogman, Tadros and Grasmic in PCI Journal separata JR 352.

$$\kappa := \frac{\varepsilon_2 - \varepsilon_1}{h} \qquad R := \frac{1}{\kappa}$$

$$n_1 := \text{ceil}\left(\frac{A_{s1} \cdot \text{cm}^2}{\pi \cdot \frac{\phi_1^2}{4}}\right) \qquad \text{percent}_1 := \frac{n_1 \cdot \pi \frac{\phi_1^2}{4}}{A_{s1} \cdot \text{cm}^2}$$

$$n_2 := \begin{cases} \text{ceil}\left(\frac{A_{s2} \cdot \text{cm}^2}{\pi \cdot \frac{\phi_2^2}{4}}\right) & \text{if } A_{s2} \geq 0.01 \\ 0 & \text{otherwise} \end{cases} \quad \text{percent}_2 := \begin{cases} \frac{n_2 \cdot \pi \cdot \frac{\phi_2^2}{4}}{A_{s2} \cdot \text{cm}^2} & \text{if } n_2 > 0 \\ 1 & \text{otherwise} \end{cases}$$



Flexural Reinforcement

Failure = "Ductile as below reinforced, O.K."

$n_1 = 5$	$\phi_1 = 25 \text{ mm}$	$\text{percent}_1 = 116.99 \%$	of required reinforcement=	$A_{s1} \cdot \text{cm}^2 = 20.98 \text{ cm}^2$
$n_2 = 0$	$\phi_2 = 25 \text{ mm}$	$\text{percent}_2 = 100 \%$	of required reinforcement=	$A_{s2} \cdot \text{cm}^2 = 0 \text{ cm}^2$

Top_{strength} = "O.K." if n2=0 bars in compression put some



Equilibrium

TotalMoment($\epsilon_1, \epsilon_2, A_{s1}, A_{s2}$) = 63.18 m·ton

$\frac{M_{01}}{\phi_b} = 63.18 \text{ m} \cdot \text{ton}$

Further information

$c(\epsilon_2, \epsilon_1) = 11.86 \text{ cm}$ depth of neutral axis from top

$a(\epsilon_2, \epsilon_1) = 9.87 \text{ cm}$ accepted depth of the compressed stress block

$F_{s1}(\epsilon_1, \epsilon_2) = -4282.74 \frac{\text{kgf}}{\text{cm}^2}$ at bottom, negative is tensile

$F_{s2}(\epsilon_1, \epsilon_2) = 538.87 \frac{\text{kgf}}{\text{cm}^2}$ atop, positive is compressive

$f_y = 420 \text{ MPa}$

$A_{s1} \cdot \text{cm}^2 \cdot F_{s1}(\epsilon_1, \epsilon_2) = -89.85 \text{ ton}$

$\epsilon_1 = -0.00253$

$\epsilon_2 = 0.00044$

$\kappa = 0.00372 \frac{\text{rad}}{\text{m}}$

$R = 269.09 \text{ m}$ at the equilibrated moment

$$M_{eq_3} := (T_u + V_u \cdot \mu) \cdot \sqrt{1 + 2 \cdot \alpha}$$

$$M_{eq_3} = 214.14 \text{ kN} \cdot \text{m}$$

$$x_1 := \min\left(\left(\frac{D}{b}\right)\right) - c_1 - c_2$$

$$y_1 := \max\left(\left(\frac{D}{b}\right)\right) - c_1 - c_2$$

$$y_{1b} := 2 \cdot \left(\frac{D}{2} - \frac{d_0}{2} - c_1 - c_2\right)$$

$$x_1 = 25.5 \text{ cm}$$

$$y_1 = 70.5 \text{ cm}$$

$$y_{1b} = 31 \text{ cm}$$

$$M_{eq_2} := \left(T_u - V_u \cdot \frac{x_1}{2}\right) \cdot \sqrt{1 + \frac{2}{\alpha}}$$

$$M_{eq_2} = 196.39 \text{ kN} \cdot \text{m}$$

A. Stirrups design for torsion in the opening and adjacent solid section

$$A_w := 1 \cdot \pi \cdot \frac{d_{bar_stirrups}^2}{4}$$

$$A_w = 78.54 \text{ mm}^2$$

$$1 \text{ leg counts}$$

$$s_{\text{torsion}} := \frac{A_w}{\max \left[\left[\frac{1}{\phi_s} \cdot \left(\frac{M_{\text{eq}_1}}{4 \cdot x_1 \cdot y_1 \cdot f_{yw}} \right) \right] \left[\frac{1}{\phi_s} \cdot \left(\frac{M_{\text{eq}_2}}{4 \cdot x_1 \cdot y_1 \cdot f_{yw}} \right) \right] \right]}$$

$s_{\text{torsion}} = 6.55 \text{ cm}$

max separation of stirrups in opening and

$\frac{D - d_0}{2} + b = 60 \text{ cm}$

to each side

B. Stirrups design for shear in the adjacent solid section

$$A_v := 2 \cdot A_w \qquad \text{assuming 2 legs}$$

$$d_v := D - c_1 - c_2 \qquad d_v = 70.5 \text{ cm}$$

$$s_{\text{shear}} := \frac{A_w}{\left[\frac{1}{\phi_s} \cdot \left[\frac{V_{\text{eq_sc}}}{2 \cdot f_{yw} \cdot (d_v - d_0)} \right] \right]}$$

$s_{\text{shear}} = 4.37 \text{ cm}$

max separation of stirrups in

$\frac{d_v - d_0}{2} = 20.25 \text{ cm}$

each side

C. Stirrups design in the opening chords for frame-type failure

Resumes in the design for one horizontal and one vertical shear

Vertical Shear

$$h := \frac{D}{2} - \frac{d_0}{2} \qquad d_1 := c_1 \qquad d := h - d_1 \qquad d = 20.25 \text{ cm}$$

$$\phi_{\text{st}} := \text{dbar}_{\text{stirrups}} \qquad N_{\text{legs}} := 2$$

$$V_u := \frac{V_u}{2} \qquad \text{factored shear for design}$$

$$A_v := 2 \cdot \pi \cdot \frac{\phi_{st}^2}{4} \qquad A_v = 1.57 \text{ cm}^2 \qquad \text{per plane of stirrups}$$

$$SR := \lambda \cdot J \cdot \sqrt{\frac{f_c}{\text{psi}}}$$

$$V_c := 2 \cdot SR \cdot b \cdot d \cdot \text{psi} \qquad V_c = 6.57 \text{ ton}$$

$$V_s := \frac{V_u}{\phi_s} - V_c \qquad V_s := \left\{ \begin{array}{l} V_s \text{ if } V_s > 0 \cdot \text{ton} \\ 0 \cdot \text{ton} \text{ otherwise} \end{array} \right. \qquad V_s = 0 \text{ ton}$$

$$\text{Check}_{\text{section}V} := \left\{ \begin{array}{l} \text{"O.K. on size"} \text{ if } V_s \leq 4 \cdot V_c \\ \text{"Not O.K., enlarge size"} \text{ otherwise} \end{array} \right.$$

$$V_c := 0 \cdot \text{ton}$$

$$V_s := \frac{V_u}{\phi_s} - V_c \qquad V_s := \left\{ \begin{array}{l} V_s \text{ if } V_s > 0 \cdot \text{ton} \\ 0 \cdot \text{ton} \text{ otherwise} \end{array} \right. \qquad V_s = 6 \text{ ton}$$

$$\text{The}_{\text{min}} := \frac{A_v \cdot \frac{f_y}{\text{psi}}}{50 \cdot b} \cdot \left\{ \begin{array}{l} 1 \text{ if } f_c \leq 10 \cdot \text{ksi} \\ \text{otherwise} \\ \left\{ \begin{array}{l} \frac{f_c}{5000 \cdot \text{psi}} \text{ if } \frac{f_c}{5000 \cdot \text{psi}} \leq 3 \\ 3 \text{ otherwise} \end{array} \right. \end{array} \right.$$

$$s_1 := \min \left(\left(\begin{array}{c} \frac{d}{2} \\ \text{The_min} \\ \left| \frac{A_v \cdot f_y \cdot d}{V_s} \right| \text{ if } V_s > 0 \cdot \text{ton} \\ 1000 \cdot \text{cm} \text{ otherwise} \end{array} \right) \right)$$

$$s := \left| \begin{array}{l} 1000 \cdot \text{cm} \text{ if } V_u \leq \phi_s \cdot \frac{V_c}{2} \\ \text{otherwise} \\ \left| \begin{array}{l} s_1 \text{ if } \text{AND2} \left(V_u > \phi_s \cdot \frac{V_c}{2}, V_u \leq \phi_s \cdot V_c \right) \\ \text{otherwise} \\ \left| \begin{array}{l} \min \left(\left(\begin{array}{c} s_1 \\ 24 \cdot \text{in} \end{array} \right) \right) \text{ if } \text{AND2} \left(V_u > \phi_s \cdot V_c, V_u \leq \phi_s \cdot 2 \cdot V_c \right) \\ \min \left(\left(\begin{array}{c} s_1 \\ 12 \cdot \text{in} \end{array} \right) \right) \text{ otherwise} \end{array} \right. \end{array} \right.$$

$$s_{\text{ver}} := \left| \begin{array}{l} \text{floor} \left(\frac{s}{\text{cm}} \right) \cdot \text{cm} \text{ if } \text{floor} \left(\frac{s}{\text{cm}} \right) \cdot \text{cm} < s \\ s \text{ otherwise} \end{array} \right.$$

$$\phi_{\text{st}} = 10 \text{mm}$$

$$N_{\text{legs}} = 2$$

$$s_{\text{ver}} = 10 \text{cm}$$

Horizontal Shear

$$\text{bb} := \text{b}$$

$$\text{b} := \text{h}$$

$$\text{h} := \text{bb}$$

as a code of no neccessity of stirrups

$d_1 := c_1$
 $d := h - d_1$
 $d = 30.25\text{ cm}$

$\phi_{st} := \text{dbar}_{\text{stirrups}}$
 $N_{\text{legs}} := 2$

$$V_u := \frac{T_u}{D - \left(\frac{D}{2} - \frac{d_0}{2}\right)}$$

factored shear for design

$V_u = 22.25\text{ ton}$

$$A_v := 2 \cdot \pi \cdot \frac{\phi_{st}^2}{4}$$

$A_v = 1.57\text{ cm}^2$
per plane of stirrups

$$SR := \lambda \cdot J \cdot \sqrt{\frac{f_c}{\text{psi}}}$$

$V_c := 2 \cdot SR \cdot b \cdot d \cdot \text{psi}$
 $V_c = 7.01\text{ ton}$

$$V_s := \frac{V_u}{\phi_s} - V_c$$

$$V_s := \begin{cases} V_s & \text{if } V_s > 0 \cdot \text{ton} \\ 0 \cdot \text{ton} & \text{otherwise} \end{cases}$$

$V_s = 19.16\text{ ton}$

$$\text{Check}_{\text{sectionH}} := \begin{cases} \text{"O.K. on size"} & \text{if } V_s \leq 4 \cdot V_c \\ \text{"Not O.K., enlarge size"} & \text{otherwise} \end{cases}$$

$V_c := 0 \cdot \text{ton}$

$$V_s := \frac{V_u}{\phi_s} - V_c$$

$$V_s := \begin{cases} V_s & \text{if } V_s > 0 \cdot \text{ton} \\ 0 \cdot \text{ton} & \text{otherwise} \end{cases}$$

$V_s = 26.17\text{ ton}$

$$\text{The_min} := \frac{A_v \cdot \frac{f_y}{\text{psi}}}{50 \cdot b} \cdot \left\{ \begin{array}{l} 1 \text{ if } f_c \leq 10 \cdot \text{ksi} \\ \text{otherwise} \\ \left\{ \begin{array}{l} \frac{f_c}{5000 \cdot \text{psi}} \text{ if } \frac{f_c}{5000 \cdot \text{psi}} \leq 3 \\ 3 \text{ otherwise} \end{array} \right. \end{array} \right.$$

$$s_1 := \min \left(\left(\begin{array}{c} \frac{d}{2} \\ \text{The_min} \\ \left\{ \begin{array}{l} \frac{A_v \cdot f_y \cdot d}{V_s} \text{ if } V_s > 0 \cdot \text{ton} \\ 1000 \cdot \text{cm} \text{ otherwise} \end{array} \right. \end{array} \right) \right)$$

$$s := \left\{ \begin{array}{l} 1000 \cdot \text{cm} \text{ if } V_u \leq \phi_s \cdot \frac{V_c}{2} \\ \text{otherwise} \\ \left\{ \begin{array}{l} s_1 \text{ if } \text{AND2} \left(V_u > \phi_s \cdot \frac{V_c}{2}, V_u \leq \phi_s \cdot V_c \right) \\ \text{otherwise} \\ \left\{ \begin{array}{l} \min \left(\left(\begin{array}{c} s_1 \\ 24 \cdot \text{in} \end{array} \right) \right) \text{ if } \text{AND2} \left(V_u > \phi_s \cdot V_c, V_u \leq \phi_s \cdot 2 \cdot V_c \right) \\ \min \left(\left(\begin{array}{c} s_1 \\ 12 \cdot \text{in} \end{array} \right) \right) \text{ otherwise} \end{array} \right. \end{array} \right. \end{array} \right.$$

$$s_{\text{hor}} := \left\{ \begin{array}{l} \text{floor} \left(\frac{s}{\text{cm}} \right) \cdot \text{cm} \text{ if } \text{floor} \left(\frac{s}{\text{cm}} \right) \cdot \text{cm} < s \\ s \text{ otherwise} \end{array} \right.$$

as a code of no neccessity of stirrups

$$\phi_{st} = 10\text{ mm}$$

$$N_{legs} = 2$$

$$s_{hor} = 7\text{ cm}$$

$$s_{in_opening} := \text{floor}\left[\frac{\min\left(\left(\begin{matrix} s_{torsion} \\ s_{ver} \\ s_{hor} \end{matrix}\right)\right)}{cm}\right]\cdot cm$$

$$s_{in_adjacent_zone} := \text{floor}\left[\frac{\min\left(\left(\begin{matrix} s_{torsion} \\ s_{shear} \end{matrix}\right)\right)}{cm}\right]\cdot cm$$

$$\text{dist}_{adjacent} := \text{ceil}\left[\frac{\max\left(\left(\begin{matrix} \frac{D-d_0}{2} + b \\ d_v-d_0 \\ \frac{d_v-d_0}{2} \end{matrix}\right)\right)}{cm}\right]\cdot cm$$



Modes 2 and 3 of failure should be impossible for the sheet be valid for the case

$$\frac{0.5\cdot M_{eq_2}}{M_u} = 0.39$$

if less than 1 the Mode 2 of failure is not possible. In mode 2 failure the compression zone is located along a lateral side of the beam.

$$\frac{M_{eq_3}}{M_u} = 0.86$$

if less than 1 the Mode 3 of failure is not possible. In mode 3, the skewed compression zone is at bottom. The equations for Mode 1 -that in the sheet analyzed- can be used for Mode 3 by turning the beam upside down and taking M= -M and V= -V

$$\frac{a\left(\varepsilon_2,\varepsilon_1\right)}{\frac{D}{2}-\frac{d_0}{2}} = 0.39$$

must be less than 1 for the opening not messing with the flexure compressive stress block

$$\text{Check}_{sectionV} = \text{"O.K. on size"}$$

$$\text{Check}_{sectionH} = \text{"O.K. on size"}$$

section for the chords in shear from frame action

$$s_{in_opening} = 6\text{ cm}$$

$$s_{in_adjacent_zone} = 4\text{ cm}$$

in

$$\text{dist}_{adjacent} = 50\text{ cm}$$

to each side of the opening

Invariably choose the lesser for the whole arrangement