T.P.N°7: Pandeo

1. Se tiene una columna compuesta por perfiles UPN de 35 cm x 60cm, donde se aplica una carga de 1000 kN en el baricentro de la sección. La altura es de 5m y se considera como condición de vínculo empotrado - articulado en el plano YZ y empotrado libre en el plano XZ. Uno de los cordones está formado por 2UPN 160 (unidos por diagonales) y el otro por dos UPN 140 (unidos por diagonales). Ambos cordones se encuentran unidos mediante diagonales y montantes como se indican en el dibujo. El acero a utilizar es F-24. Se requiere:

   - Verificar la columna, en caso de no ser así, redimensionar
   - Dimensionar los elementos de enlace

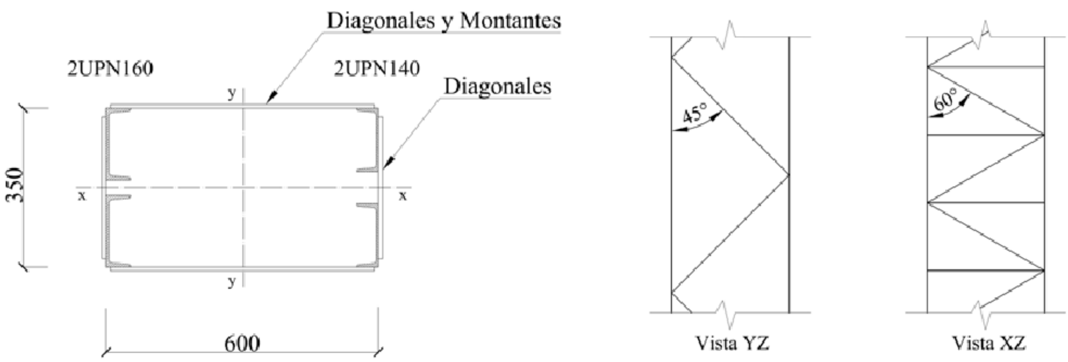

Figura 1: Columna compuesta por perfiles UPN de 35 cm x 60cm

2. Determinar la carga ultima de una columna formada por 4 perfiles ángulos de 3 $\frac{1}{2}$" x $\frac{1}{2}$". La altura es de 6m y se considera como condición de vínculo empotrado - articulado en el plano YZ y empotrado libre en el plano XZ. La unión en el plano YZ son mediante diagonales y la unión en el plano XZ son mediante diagonales y montantes. El acero a utilizar es F-24. Dimensionar los elementos de enlaces.

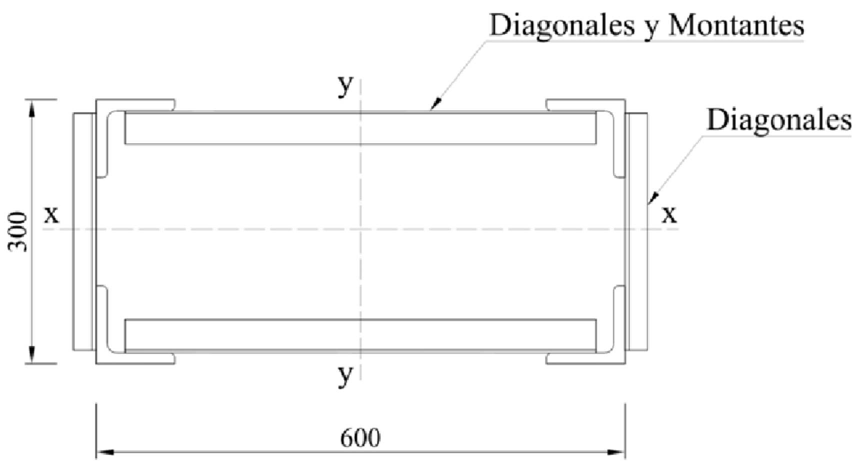

Figura 2: Columna compuesta por perfiles L 3 $\frac{1}{2}$" x 3 $\frac{1}{2}$" x $\frac{1}{2}$"

Solución

1. Resolver una columna compuesta por perfiles UPN de 35 cm x 60cm.

   - Datos

$$\begin{aligned}
&\text{Acero F-24}\\
&E = 200000MPa\\
&f_y = 235MPa\\
&P_u = 1000KN\\
&L = 500cm\\
&K_{yz} = 0{,}7\\
&K_{xz} = 2
\end{aligned}$$

Perfil	UPN160	UPN140
$I_x =$	$925cm^4$	$605cm^4$
$I_y =$	$85{,}3cm^4$	$62{,}7cm^4$
$r_x =$	$6{,}21cm$	$5{,}45cm$
$r_y = r_1 =$	$1{,}89cm$	$1{,}75cm$
$A_g =$	$24cm^2$	$20{,}4cm^2$
$e_x =$	$1{,}84cm$	$1{,}75cm$

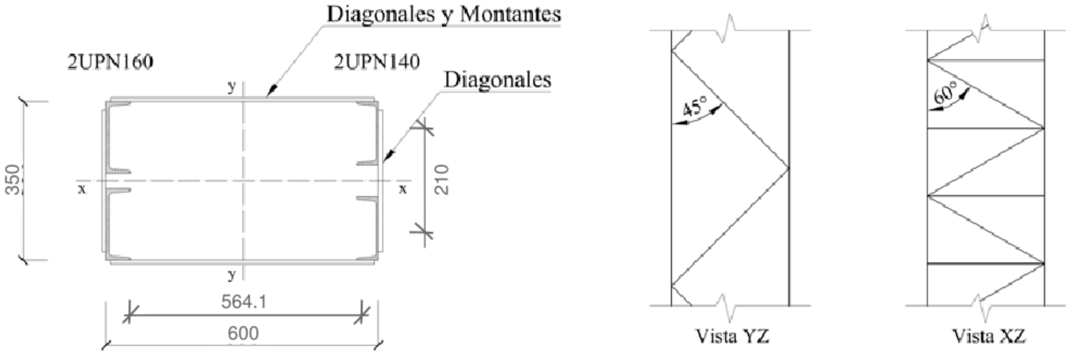

Figura 3: Columna compuesta por perfiles UPN de 35 cm x 60cm

- Eje libre x-x → Plano YZ
  Condición de sustentación empotrado-articulado $\Rightarrow K_{yz} = 0{,}70$
- Momentos de Inercia y Radio de Giro

$$d_1 = \frac{35cm}{2} - 8cm = 9{,}5cm$$
$$d_2 = \frac{35cm}{2} - 7cm = 10{,}5cm$$
$$d_3 = \frac{60cm}{2} - e_x = \frac{60cm}{2} - 1{,}84cm = 28{,}16cm$$
$$d_4 = \frac{60cm}{2} - e_x = \frac{60cm}{2} - 1{,}75cm = 28{,}25cm$$
$$I_{xx} = [(I_{xxUPN160} + A_g \cdot d_1^2) + (I_{xxUPN140} + A_g \cdot d_2^2)] \cdot 2$$
$$I_{xx} = [(925cm^4 + 24cm^2 \cdot (9{,}5cm)^2) + (605cm^4 + 20{,}4cm^2 \cdot (10{,}5cm)^2)] \cdot 2 = \boxed{11890{,}2cm^4}$$
$$r_x = \sqrt{\frac{I_{xx}}{A_t}} = \sqrt{\frac{11890{,}2cm^4}{2 \cdot (24cm^2 + 20{,}4cm^2)}} = \boxed{11{,}57cm}$$

- Esbeltez modificada

$$\lambda_0 = \frac{K_{yz} \cdot L}{r_x} = \frac{0{,}70 \cdot 500cm}{11{,}57cm} = \boxed{30{,}25}$$
$$\lambda_0 < 200$$
$$30{,}25 < 200 \quad \surd \quad \text{Verifica}$$
$$\alpha = 45°$$
$$h = 2 \cdot d_2 = 2 \cdot 10{,}5cm = \boxed{21cm}$$
$$a = 2 \cdot \frac{h}{tg\alpha} = 2 \cdot \frac{21cm}{tg(45°)} = \boxed{42cm}$$
$$d = \frac{h}{Sen\alpha} = \frac{21cm}{Sen(45°)} = \boxed{29{,}70cm}$$

Adopto diagonales de perfil L 1 $\frac{1}{2}$" x 1 $\frac{1}{2}$" x 3/16"

$$A_d = 3{,}46cm^2$$
$$r_1 = 0{,}72cm$$
$$\lambda_1 = \pi \cdot \sqrt{\frac{2 \cdot A_g \cdot d^3}{n_0 \cdot A_d \cdot a \cdot h^2}}$$

n_0 = n° de planos de celosía = 2

$$\lambda_1 = \pi \cdot \sqrt{\frac{2 \cdot (2 \cdot (24cm^2 + 20{,}4cm^2)) \cdot (29{,}70cm)^3}{2 \cdot 3{,}46cm^2 \cdot 42cm \cdot (21cm)^2}} = \boxed{18{,}93}$$
$$\lambda_m = \sqrt{\lambda_0^2 + \lambda_1^2} = \sqrt{(30{,}25)^2 + (18{,}93)^2} = \boxed{35{,}68}$$

- <u>Resistencia de diseño local</u>

$$P_{cm} = \frac{\pi^2 \cdot E \cdot A_g}{\lambda_m^2} \cdot 10^{-1}$$

$$P_{cm} = \frac{\pi^2 \cdot 200000MPa \cdot 2 \cdot (24cm^2 + 20{,}4cm^2)}{(35{,}68)^2} \cdot 10^{-1} = \boxed{13768{,}38KN}$$

$$e_0 = \frac{K_{yz} \cdot L}{500} = \frac{0{,}70 \cdot 500cm}{500} = \boxed{0{,}70cm}$$

$$M_s = \frac{P_u \cdot e_0}{1 - \frac{P_u}{P_{cm}}} \cdot 10^{-2} = \frac{1000KN \cdot 0{,}70cm}{1 - \frac{1000KN}{13768{,}38KN}} \cdot 10^{-2} = \boxed{7{,}55KN.m}$$

$$P_{u1} = \frac{P_u}{n} + \frac{M_s}{n_1 \cdot h} \cdot 10^2$$

$$P_{u1} = \frac{1000KN}{4} + \frac{7{,}55KN.m}{2 \cdot 21cm} \cdot 10^2 = \boxed{267{,}97KN}$$

$n =$ n° de barras de la columna armada $\Rightarrow 4$

$n_1 =$ n° de barras que forman el cordón $\Rightarrow 2$

$$\lambda_{c1} = \frac{1}{\pi} \cdot \frac{L_1}{r_1} \cdot \sqrt{\frac{f_y}{E}}$$

$$L_1 = a = 42cm$$

$$\lambda_{c1} = \frac{1}{\pi} \cdot \frac{42cm}{1{,}75cm} \cdot \sqrt{\frac{235MPa}{200000MPa}} = \boxed{0{,}26}$$

$$\lambda_{c1} < 1{,}5$$

$0{,}26 < 1{,}5 \quad \surd$ Verifica

$$F_{cr} = 0{,}658^{\lambda_{c1}^2} \cdot f_y = 0{,}658^{0{,}26^2} \cdot 235MPa = \boxed{228{,}35MPa}$$

$$P_{d1} = 0{,}85 \cdot F_{cr} \cdot A_g \cdot 10^{-1} = 0{,}85 \cdot 228{,}35MPa \cdot 20{,}40cm^2 \cdot 10^{-1} = \boxed{395{,}96KN}$$

$$P_{d1} > P_{u1}$$

$395{,}96KN > 267{,}97KN \quad \surd$ Verifica

- <u>Verificación de las diagonales</u>

Corte V_{eu}

$V_{eu} = \beta_1 \cdot P_u$

$\beta_1 = \frac{\pi}{500} \cdot \left[\frac{1}{1 - \frac{P_u}{P_{cm}}}\right] = \frac{\pi}{500} \cdot \left[\frac{1}{1 - \frac{1000KN}{13768{,}38KN}}\right] = \boxed{0{,}00678}$

$V_{eu} = 0{,}00678 \cdot 1000KN = \boxed{6{,}78KN}$

El esfuerzo que solicita a la diagonal es D_u

$D_u = \frac{V_{eu}}{2 \cdot Cos\alpha} = \frac{6{,}78KN}{2 \cdot Cos(45°)} = \boxed{4{,}79KN}$

La resistencia de diseño del perfil ángulo es R_d

$R_d = \phi_c \cdot P_n$

$R_d > D_u$

Se determina el factor de esbeltez adimensional λ_c

$\lambda_c = \frac{1}{\pi} \cdot \frac{K_{yz} \cdot L_1}{r_1} \cdot \sqrt{\frac{f_y}{E}}$

$L_1 = d = 29{,}70cm$

$\lambda_c = \frac{1}{\pi} \cdot \frac{0{,}70 \cdot 29{,}70cm}{0{,}72cm} \cdot \sqrt{\frac{235MPa}{200000MPa}} = \boxed{0{,}32}$

$\lambda_c < 1{,}5$

$0{,}32 < 1{,}5 \quad \surd$ Verifica

$F_{cr} = 0{,}658^{\lambda_c^2} \cdot f_y = 0{,}658^{0{,}32^2} \cdot 235MPa = \boxed{225{,}44MPa}$

$P_n = F_{cr} \cdot A_g \cdot 10^{-1} = 225{,}44MPa \cdot 20{,}40cm^2 \cdot 10^{-1} = \boxed{78KN}$

$R_d = \phi_c \cdot P_n = 0{,}85 \cdot 78KN = \boxed{66{,}30KN}$

$R_d > D_u$

$66{,}30KN > 4{,}79KN \quad \surd$ Verifica

- Eje libre y-y → Plano XZ
  Condición de sustentación empotrado-libre $\Rightarrow K_{xz} = 2$
- Momentos de Inercia y Radio de Giro

$$d_1 = \frac{35cm}{2} - 8cm = 9{,}5cm$$
$$d_2 = \frac{35cm}{2} - 7cm = 10{,}5cm$$
$$d_3 = \frac{60cm}{2} - e_x = \frac{60cm}{2} - 1{,}84cm = 28{,}16cm$$
$$d_4 = \frac{60cm}{2} - e_x = \frac{60cm}{2} - 1{,}75cm = 28{,}25cm$$
$$I_{yy} = [(I_{yyUPN160} + A_g \cdot d_3^2) + (I_{yyUPN140} + A_g \cdot d_4^2)] \cdot 2$$
$$I_{yy} = [(85{,}3cm^4 + 24cm^2 \cdot (28{,}16cm)^2) + (62{,}7cm^4 + 20{,}4cm^2 \cdot (28{,}25cm)^2)] \cdot 2$$
$$I_{yy} = \boxed{70920{,}25cm^4}$$
$$r_y = \sqrt{\frac{I_{yy}}{A_t}} = \sqrt{\frac{70920{,}25cm^4}{2 \cdot (24cm^2 + 20{,}4cm^2)}} = \boxed{28{,}26cm}$$

- Esbeltez modificada

$$\lambda_0 = \frac{K_{xz} \cdot L}{r_y} = \frac{2 \cdot 500cm}{28{,}26cm} = \boxed{35{,}39}$$
$$\lambda_0 < 200$$
$$35{,}39 < 200 \quad \checkmark \quad \text{Verifica}$$
$$\alpha = 60°$$
$$h = d_3 + d_4 = 28{,}16cm + 28{,}25cm = \boxed{56{,}41cm}$$
$$a = \frac{h}{tg\alpha} = \frac{56{,}41cm}{tg(60°)} = \boxed{32{,}57cm}$$
$$d = \frac{h}{Sen\alpha} = \frac{56{,}41cm}{Sen(60°)} = \boxed{65{,}14cm}$$

Adopto diagonales de perfil L 2” x 2” x 3/16”

$$A_d = 4{,}72cm^2$$
$$r_1 = 0{,}97cm$$
$$\lambda_1 = \pi \cdot \sqrt{\frac{A_g \cdot d^3}{n_0 \cdot A_d \cdot a \cdot h^2}}$$

$n_0 =$ n° de planos de celosía $= 2$

$$\lambda_1 = \pi \cdot \sqrt{\frac{(2 \cdot (24cm^2 + 20{,}4cm^2)) \cdot (65{,}14cm)^3}{2 \cdot 4{,}72cm^2 \cdot 32{,}57cm \cdot (56{,}41cm)^2}} = \boxed{15{,}73}$$
$$\lambda_m = \sqrt{\lambda_0^2 + \lambda_1^2} = \sqrt{(35{,}39)^2 + (15{,}73)^2} = \boxed{38{,}73}$$

- <u>Resistencia de diseño local</u>

$$P_{cm} = \frac{\pi^2 \cdot E \cdot A_g}{\lambda_m^2} \cdot 10^{-1}$$

$$P_{cm} = \frac{\pi^2 \cdot 200000MPa \cdot 2 \cdot (24cm^2 + 20{,}4cm^2)}{(38{,}73)^2} \cdot 10^{-1} = \boxed{11688{,}05KN}$$

$$e_0 = \frac{K_{xz} \cdot L}{500} = \frac{2 \cdot 500cm}{500} = \boxed{2cm}$$

$$M_s = \frac{P_u \cdot e_0}{1 - \frac{P_u}{P_{cm}}} \cdot 10^{-2} = \frac{1000KN \cdot 2cm}{1 - \frac{1000KN}{11688{,}05KN}} \cdot 10^{-2} = \boxed{21{,}87KN.m}$$

$$P_{u1} = \frac{P_u}{n} + \frac{M_s}{n_1 \cdot h} \cdot 10^2$$

$$P_{u1} = \frac{1000KN}{4} + \frac{21{,}87KN.m}{2 \cdot 56{,}41cm} \cdot 10^2 = \boxed{269{,}39KN}$$

$n =$ n° de barras de la columna armada $\Rightarrow 4$

$n_1 =$ n° de barras que forman el cordón $\Rightarrow 2$

$$\lambda_{c1} = \frac{1}{\pi} \cdot \frac{L_1}{r_1} \cdot \sqrt{\frac{f_y}{E}}$$

$$L_1 = a = 32{,}57cm$$

$$\lambda_{c1} = \frac{1}{\pi} \cdot \frac{32{,}57cm}{1{,}75cm} \cdot \sqrt{\frac{235MPa}{200000MPa}} = \boxed{0{,}20}$$

$$\lambda_{c1} < 1{,}5$$

$0{,}20 < 1{,}5 \quad \surd$ Verifica

$$F_{cr} = 0{,}658^{\lambda_{c1}^2} \cdot f_y = 0{,}658^{0{,}20^2} \cdot 235MPa = \boxed{230{,}98MPa}$$

$$P_{d1} = 0{,}85 \cdot F_{cr} \cdot A_g \cdot 10^{-1} = 0{,}85 \cdot 230{,}98MPa \cdot 20{,}40cm^2 \cdot 10^{-1} = \boxed{400{,}52KN}$$

$$P_{d1} > P_{u1}$$

$400{,}52KN > 269{,}39KN \quad \surd$ Verifica

- Verificación de las diagonales

Corte V_{eu}

$V_{eu} = \beta_1 \cdot P_u$

$\beta_1 = \frac{\pi}{500} \cdot \left[\frac{1}{1 - \frac{P_u}{P_{cm}}}\right] = \frac{\pi}{500} \cdot \left[\frac{1}{1 - \frac{1000KN}{11688{,}05KN}}\right] = \boxed{0{,}00687}$

$V_{eu} = 0{,}00687 \cdot 1000KN = \boxed{6{,}87KN}$

El esfuerzo que solicita a la diagonal es D_u

$D_u = \frac{V_{eu}}{2 \cdot Cos\alpha} = \frac{6{,}87KN}{2 \cdot Cos(60°)} = \boxed{6{,}87KN}$

La resistencia de diseño del perfil ángulo es R_d

$R_d = \phi_c \cdot P_n$

$R_d > D_u$

Se determina el factor de esbeltez adimensional λ_c

$\lambda_c = \frac{1}{\pi} \cdot \frac{K_{xz} \cdot L_1}{r_1} \cdot \sqrt{\frac{f_y}{E}}$

$L_1 = d = 65{,}14cm$

$\lambda_c = \frac{1}{\pi} \cdot \frac{2 \cdot 65{,}14cm}{0{,}97cm} \cdot \sqrt{\frac{235MPa}{200000MPa}} = \boxed{1{,}47}$

$\lambda_c < 1{,}5$

$1{,}47 < 1{,}5$ $\surd$ Verifica

$F_{cr} = 0{,}658^{\lambda_c^2} \cdot f_y = 0{,}658^{1{,}47^2} \cdot 235MPa = \boxed{95{,}66MPa}$

$P_n = F_{cr} \cdot A_g \cdot 10^{-1} = 95{,}66MPa \cdot 20{,}40cm^2 \cdot 10^{-1} = \boxed{45{,}15KN}$

$R_d = \phi_c \cdot P_n = 0{,}85 \cdot 45{,}15KN = \boxed{38{,}38KN}$

$R_d > D_u$

$38{,}38KN > 4{,}79KN$ $\surd$ Verifica

2. Determinar la carga última de una columna de 30 cm x 60cm, compuesta por 4 perfiles ángulos L 3 $\frac{1}{2}$" x 3 $\frac{1}{2}$" x 1/2".

   - <u>Datos</u>

$$\begin{aligned}&\text{Acero F-24}\\&E = 200000MPa\\&f_y = 235MPa\\&L = 600cm\\&K_{yz} = 0{,}7\\&K_{xz} = 2\end{aligned}$$

Perfil	L 3 $\frac{1}{2}$" x 3 $\frac{1}{2}$" x 1/2"
$I_x = I_y =$	$149{,}65cm^4$
$r_x = r_y =$	$2{,}66cm$
$r_1 =$	$1{,}70cm$
$e_x = e_y =$	$2{,}66cm$
$A_g =$	$21{,}12cm^2$

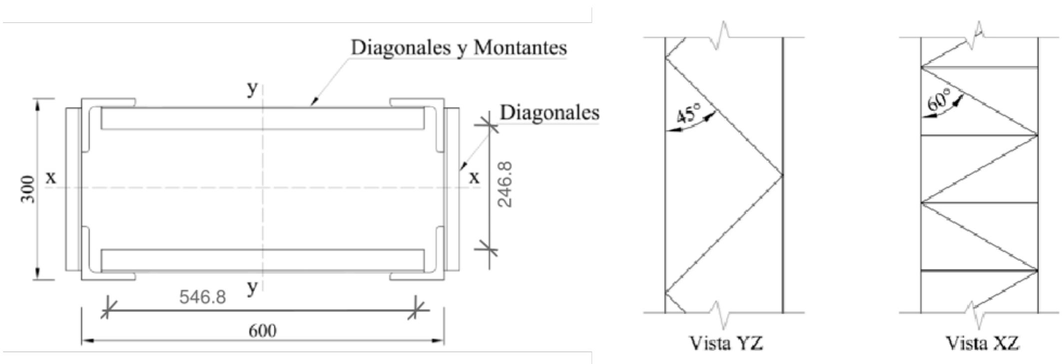

Figura 4: Columna de 30 cm x 60cm compuesta por perfiles ángulo

- Eje libre x-x → Plano YZ
  Condición de sustentación empotrado-articulado $\Rightarrow K_{yz} = 0{,}70$
- Momentos de Inercia y Radio de Giro

$$d_1 = \frac{Lado_y}{2} - e_y$$
$$d_1 = \frac{30cm}{2} - 2{,}66cm = 12{,}34cm$$
$$I_{xx} = (I_{xx} + A_g \cdot d_1^2) \cdot 4$$
$$I_{xx} = (149{,}65cm^4 + 21{,}12cm^2 \cdot (12{,}34cm)^2) \cdot 4 = \boxed{13462{,}84cm^4}$$
$$r_x = \sqrt{\frac{I_{xx}}{A_t}} = \sqrt{\frac{13462{,}84cm^4}{4 \cdot (21{,}12cm^2)}} = \boxed{12{,}62cm}$$

- Esbeltez modificada

$$\lambda_0 = \frac{K_{yz} \cdot L}{r_x} = \frac{0{,}70 \cdot 600cm}{2{,}66cm} = \boxed{33{,}27}$$
$$\lambda_0 < 200$$
$$33{,}27 < 200 \quad \checkmark \quad \text{Verifica}$$
$$\alpha = 45°$$
$$h = 30cm - 2 \cdot e_y = 30cm - 2 \cdot 2{,}66cm = \boxed{24{,}68cm}$$
$$a = 2 \cdot \frac{h}{tg\alpha} = 2 \cdot \frac{24{,}68cm}{tg(45°)} = \boxed{49{,}36cm}$$
$$d = \frac{h}{Sen\alpha} = \frac{24{,}68cm}{Sen(45°)} = \boxed{34{,}90cm}$$

Adopto diagonales de perfil L 2" x 2" x 1/4"

$$A_d = 6{,}17cm^2$$
$$r_1 = 0{,}97cm$$
$$\lambda_1 = \pi \cdot \sqrt{\frac{2 \cdot A_g \cdot d^3}{n_0 \cdot A_d \cdot a \cdot h^2}}$$

$n_0 =$ n° de planos de celosía $= 2$

$$\lambda_1 = \pi \cdot \sqrt{\frac{2 \cdot (4 \cdot (21{,}12cm^2)) \cdot (34{,}90cm)^3}{2 \cdot 6{,}17cm^2 \cdot 49{,}36cm \cdot (24{,}68cm)^2}} = \boxed{13{,}82}$$
$$\lambda_m = \sqrt{\lambda_0^2 + \lambda_1^2} = \sqrt{(33{,}27)^2 + (13{,}82)^2} = \boxed{36{,}03}$$

- <u>Resistencia de diseño local</u>

$$P_{cm} = \frac{\pi^2 \cdot E \cdot A_g}{\lambda_m^2} \cdot 10^{-1}$$

$$P_{cm} = \frac{\pi^2 \cdot 200000MPa \cdot 4 \cdot (21{,}12cm^2)}{(36{,}03)^2} \cdot 10^{-1} = \boxed{12846{,}93KN}$$

$$e_0 = \frac{K_{yz} \cdot L}{500} = \frac{0{,}70 \cdot 600cm}{500} = \boxed{0{,}84cm}$$

$$\lambda_{c1} = \frac{1}{\pi} \cdot \frac{L_1}{r_1} \cdot \sqrt{\frac{f_y}{E}}$$

$$L_1 = a = 49{,}36cm$$

$$\lambda_{c1} = \frac{1}{\pi} \cdot \frac{49{,}36cm}{0{,}97cm} \cdot \sqrt{\frac{235MPa}{200000MPa}} = \boxed{0{,}32}$$

$$\lambda_{c1} < 1{,}5$$

$0{,}32 < 1{,}5 \quad \surd$ Verifica

$$F_{cr} = 0{,}658^{\lambda_{c1}^2} \cdot f_y = 0{,}658^{0{,}32^2} \cdot 235MPa = \boxed{225{,}33MPa}$$

$$P_{d1} = 0{,}85 \cdot F_{cr} \cdot A_g \cdot 10^{-1} = 0{,}85 \cdot 225{,}33MPa \cdot 21{,}12cm^2 \cdot 10^{-1} = \boxed{404{,}52KN}$$

$$P_{u1} = \frac{P_u}{n} + \frac{P_u \cdot e_0}{1 - \frac{P_u}{P_{cm}}} \cdot 10^{-2} \cdot \frac{1}{n_1 \cdot h} \cdot 10^2$$

$n =$ n° de barras de la columna armada $\Rightarrow 4$

$n_1 =$ n° de barras que forman el cordón $\Rightarrow 2$

$$P_{u1} = \frac{P_u}{4} + \frac{P_u \cdot 0{,}84}{1 - \frac{P_u}{12846{,}93KN}} \cdot 10^{-2} \cdot \frac{1}{2 \cdot 24{,}68cm} \cdot 10^2$$

Dandole valores a Pu hasta que se verifique la condición $P_{d1} > P_{u1}$

$\boxed{P_u = 1500{,}36KN} \Rightarrow P_{u1} = 404KN$

$$P_{d1} > P_{u1}$$

$404{,}52KN > 404KN \quad \surd$ Verifica

- Verificación de las diagonales

Corte V_{eu}

$V_{eu} = \beta_1 \cdot P_u$

$\beta_1 = \frac{\pi}{500} \cdot \left[\frac{1}{1 - \frac{P_u}{P_{cm}}}\right] = \frac{\pi}{500} \cdot \left[\frac{1}{1 - \frac{1500{,}36KN}{12846{,}93KN}}\right] = \boxed{0{,}00711}$

$V_{eu} = 0{,}00711 \cdot 1500{,}36KN = \boxed{10{,}67KN}$

El esfuerzo que solicita a la diagonal es D_u

$D_u = \frac{V_{eu}}{2 \cdot Cos\alpha} = \frac{10{,}67KN}{2 \cdot Cos(45°)} = \boxed{7{,}55KN}$

La resistencia de diseño del perfil ángulo es R_d

$R_d = \phi_c \cdot P_n$

$R_d > D_u$

Se determina el factor de esbeltez adimensional λ_c

$\lambda_c = \frac{1}{\pi} \cdot \frac{K_{yz} \cdot L_1}{r_1} \cdot \sqrt{\frac{f_y}{E}}$

$L_1 = d = 34{,}90cm$

$\lambda_c = \frac{1}{\pi} \cdot \frac{0{,}70 \cdot 34{,}90cm}{0{,}97cm} \cdot \sqrt{\frac{235MPa}{200000MPa}} = \boxed{0{,}27}$

$\lambda_c < 1{,}5$

$0{,}27 < 1{,}5 \quad \surd \quad$ Verifica

$F_{cr} = 0{,}658^{\lambda_c^2} \cdot f_y = 0{,}658^{0{,}27^2} \cdot 235MPa = \boxed{227{,}69MPa}$

$P_n = F_{cr} \cdot A_g \cdot 10^{-1} = 227{,}69MPa \cdot 21{,}12cm^2 \cdot 10^{-1} = \boxed{140{,}48KN}$

$R_d = \phi_c \cdot P_n = 0{,}85 \cdot 140{,}48KN = \boxed{119{,}41KN}$

$R_d > D_u$

$119{,}41KN > 7{,}55KN \quad \surd \quad$ Verifica

- Eje libre y-y $\rightarrow$ Plano XZ
  Condición de sustentación empotrado-libre $\Rightarrow K_{xz} = 2$
- Momentos de Inercia y Radio de Giro

$$d_2 = \frac{Lado_x}{2} - e_x$$
$$d_2 = \frac{60cm}{2} - 2{,}66cm = 27{,}34cm$$
$$I_{yy} = (I_{yy} + A_g \cdot d_2^2) \cdot 4$$
$$I_{yy} = (149{,}65cm^4 + 21{,}12cm^2 \cdot (27{,}34cm)^2) \cdot 4 = \boxed{63745{,}34cm^4}$$
$$r_y = \sqrt{\frac{I_{yy}}{A_t}} = \sqrt{\frac{63745{,}34cm^4}{4 \cdot (21{,}12cm^2)}} = \boxed{27{,}47cm}$$

- Esbeltez modificada

$$\lambda_0 = \frac{K_{xz} \cdot L}{r_y} = \frac{2 \cdot 600cm}{27{,}47cm} = \boxed{43{,}69}$$
$$\lambda_0 < 200$$
$$43{,}69 < 200 \quad \surd \quad \text{Verifica}$$
$$\alpha = 60°$$
$$h = 60cm - 2 \cdot e_x = 60cm - 2 \cdot 2{,}66cm = \boxed{54{,}68cm}$$
$$a = \frac{h}{tg\alpha} = \frac{54{,}68cm}{tg(60°)} = \boxed{31{,}57cm}$$
$$d = \frac{h}{Sen\alpha} = \frac{54{,}68cm}{Sen(60°)} = \boxed{63{,}14cm}$$

Adopto diagonales de perfil L 2” x 2” x 1/4”

$$A_d = 6{,}17cm^2$$
$$r_1 = 0{,}97cm$$
$$\lambda_1 = \pi \cdot \sqrt{\frac{A_g \cdot d^3}{n_0 \cdot A_d \cdot a \cdot h^2}}$$

$n_0 =$ n° de planos de celosía = 2

$$\lambda_1 = \pi \cdot \sqrt{\frac{4 \cdot (21{,}12cm^2) \cdot (63{,}14cm)^3}{2 \cdot 6{,}17cm^2 \cdot 31{,}57cm \cdot (54{,}68cm)^2}} = \boxed{13{,}42}$$
$$\lambda_m = \sqrt{\lambda_0^2 + \lambda_1^2} = \sqrt{(43{,}69)^2 + (13{,}42)^2} = \boxed{45{,}70}$$

- Resistencia de diseño local

$$P_{cm} = \frac{\pi^2 \cdot E \cdot A_g}{\lambda_m^2} \cdot 10^{-1}$$

$$P_{cm} = \frac{\pi^2 \cdot 200000MPa \cdot 4 \cdot (21{,}12cm^2)}{(45{,}70)^2} \cdot 10^{-1} = \boxed{7984{,}24KN}$$

$$e_0 = \frac{K_{xz} \cdot L}{500} = \frac{2 \cdot 600cm}{500} = \boxed{2{,}4cm}$$

$$\lambda_{c1} = \frac{1}{\pi} \cdot \frac{L_1}{r_1} \cdot \sqrt{\frac{f_y}{E}}$$

$$L_1 = a = 31{,}57cm$$

$$\lambda_{c1} = \frac{1}{\pi} \cdot \frac{31{,}57cm}{0{,}97cm} \cdot \sqrt{\frac{235MPa}{200000MPa}} = \boxed{0{,}20}$$

$$\lambda_{c1} < 1{,}5$$

$0{,}20 < 1{,}5$ $\surd$ Verifica

$$F_{cr} = 0{,}658^{\lambda_{c1}^2} \cdot f_y = 0{,}658^{0{,}20^2} \cdot 235MPa = \boxed{231MPa}$$

$$P_{d1} = 0{,}85 \cdot F_{cr} \cdot A_g \cdot 10^{-1} = 0{,}85 \cdot 231MPa \cdot 21{,}12cm^2 \cdot 10^{-1} = \boxed{414{,}68KN}$$

$$P_{u1} = \frac{P_u}{n} + \frac{P_u \cdot e_0}{1 - \frac{P_u}{P_{cm}}} \cdot 10^{-2} \cdot \frac{1}{n_1 \cdot h} \cdot 10^2$$

$n =$ n° de barras de la columna armada $\Rightarrow 4$

$n_1 =$ n° de barras que forman el cordón $\Rightarrow 2$

$$P_{u1} = \frac{P_u}{4} + \frac{P_u \cdot 2{,}4}{1 - \frac{P_u}{7984{,}24KN}} \cdot 10^{-2} \cdot \frac{1}{2 \cdot 54{,}68cm} \cdot 10^2$$

Dandole valores a Pu hasta que se verifique la condición $P_{d1} > P_{u1}$

$\boxed{P_u = 1494{,}58KN} \Rightarrow P_{u1} = 414KN$

$P_{d1} > P_{u1}$

$414{,}68KN > 414KN$ $\surd$ Verifica

- Verificación de las diagonales

Corte V_{eu}

$V_{eu} = \beta_1 \cdot P_u$

$\beta_1 = \frac{\pi}{500} \cdot \left[\frac{1}{1-\frac{P_u}{P_{cm}}}\right] = \frac{\pi}{500} \cdot \left[\frac{1}{1-\frac{1494{,}58KN}{7984{,}24KN}}\right] = \boxed{0{,}00773}$

$V_{eu} = 0{,}00773 \cdot 1494{,}58KN = \boxed{11{,}55KN}$

El esfuerzo que solicita a la diagonal es D_u

$D_u = \frac{V_{eu}}{2 \cdot Cos\alpha} = \frac{11{,}55KN}{2 \cdot Cos(60°)} = \boxed{11{,}55KN}$

La resistencia de diseño del perfil ángulo es R_d

$R_d = \phi_c \cdot P_n$

$R_d > D_u$

Se determina el factor de esbeltez adimensional λ_c

$\lambda_c = \frac{1}{\pi} \cdot \frac{K_{xz} \cdot L_1}{r_1} \cdot \sqrt{\frac{f_y}{E}}$

$L_1 = d = 63{,}14cm$

$\lambda_c = \frac{1}{\pi} \cdot \frac{2 \cdot 63{,}14cm}{0{,}97cm} \cdot \sqrt{\frac{235MPa}{200000MPa}} = \boxed{1{,}42}$

$\lambda_c < 1{,}5$

$1{,}42 < 1{,}5 \quad \checkmark$ Verifica

$F_{cr} = 0{,}658^{\lambda_c^2} \cdot f_y = 0{,}658^{1{,}42^2} \cdot 235MPa = \boxed{101MPa}$

$P_n = F_{cr} \cdot A_g \cdot 10^{-1} = 101MPa \cdot 21{,}12cm^2 \cdot 10^{-1} = \boxed{62{,}32KN}$

$R_d = \phi_c \cdot P_n = 0{,}85 \cdot 62{,}32KN = \boxed{52{,}97KN}$

$R_d > D_u$

$52{,}97KN > 11{,}55KN \quad \checkmark$ Verifica