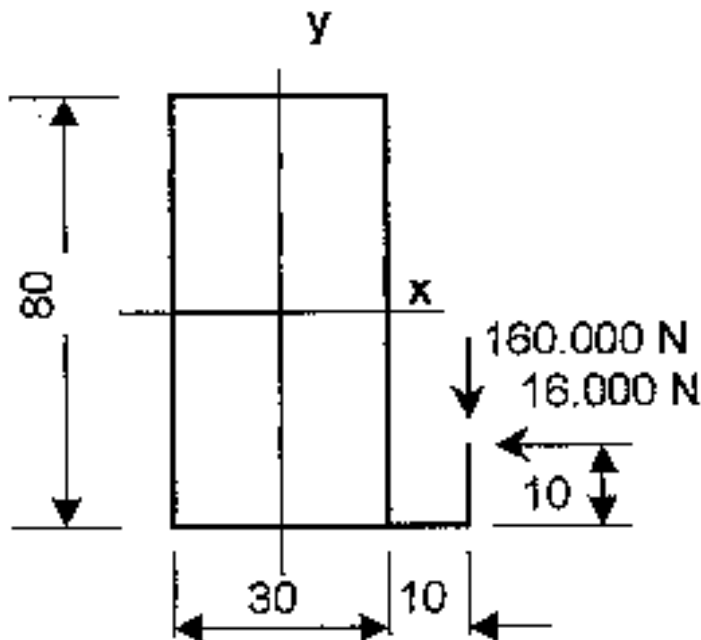


CALCULO TEORICO DE VIGA CAJON DE PUENTE GRUA

Nota: Se considera el mismo utilizando tensiones admisibles y desde el punto de vista académico, sin considerar los factores de compensación y de choque que establece la Norma DIN (Ver Dübbel)



Datos:

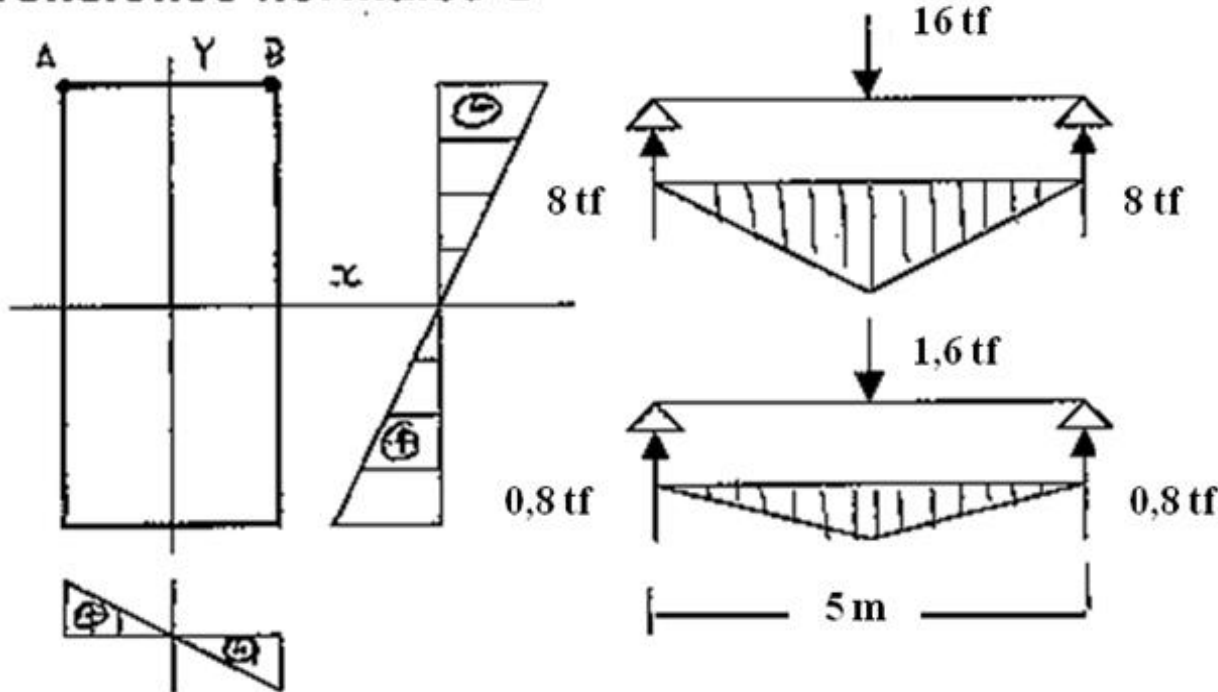
Luz de la viga: 5 m

Cargas de cálculo: Vertical 160.000 N
Horizontal 16.000 N
(Criterio: $P / 10$ por

frenado en la misma sección)

Medidas en cm

a) Tensiones normales σ



$$M_x = \frac{16000 \text{ kgf} * 5\text{m}}{4}$$

$$M_x = 20.000 \text{ kgfm}$$

$$M_x = 2 * 10^8 \text{ Nmm}$$

$$M_y = \frac{1.600\text{kgf} * 5\text{m}}{4}$$

$$M_y = 2.000 \text{ kgfm}$$

$$M_y = 2 * 10^7 \text{ Nmm}$$

$$I_x = 2 * \left[\frac{e * (80cm)^3}{12} + e * 30cm * (40cm)^2 + \frac{30cm * e^3}{12} \right]$$

$$I_x = e * 181.400 \text{ cm}^3$$

$$I_y = 2 * \left[\frac{e * (30cm)^3}{12} + e * 80cm * (15cm)^2 + \frac{80cm * e^3}{12} \right]$$

$$I_y = e * 40.500 \text{ cm}^3$$

Por norma debe cumplirse $\Rightarrow \frac{I_x}{I_y} = \frac{e * 181.400 \text{ cm}^3}{e * 40.500 \text{ cm}^3} = 4,48 \leq 7 \text{ B.C.}$

$$\sigma_B = \sigma_{Bx} + \sigma_{By} = -\frac{Mx}{Ix} * Y_B - \frac{My}{Iy} * X_B$$

$$\sigma_{Bx} = -\frac{Mx}{Ix} * Y_B = -\frac{2 * 10^8 \text{ Nmm} * 400 \text{ mm}}{e * 1,81 * 10^8 * \text{ mm}^3} = -\frac{441,98 \text{ N}}{e \text{ mm}}$$

$$\sigma_{By} = -\frac{My}{Iy} * X_B = -\frac{2 * 10^7 \text{ Nmm} * 150 \text{ mm}}{e * 4,05 * 10^7 * \text{ mm}^3} = -\frac{74,078 \text{ N}}{e \text{ mm}}$$

$$\sigma_B = -\frac{441,98 \text{ N}}{e \text{ mm}} - \frac{74,078 \text{ N}}{e \text{ mm}} = -\frac{516 \text{ N}}{e \text{ mm}}$$

$$\sigma_B = -\frac{516 \text{ N}}{e \text{ mm}} \text{ COMPRESION}$$

$$\sigma_A = \sigma_{Ax} + \sigma_{Ay} = -\frac{Mx}{Ix} * Y_A + \frac{My}{Iy} * X_A$$

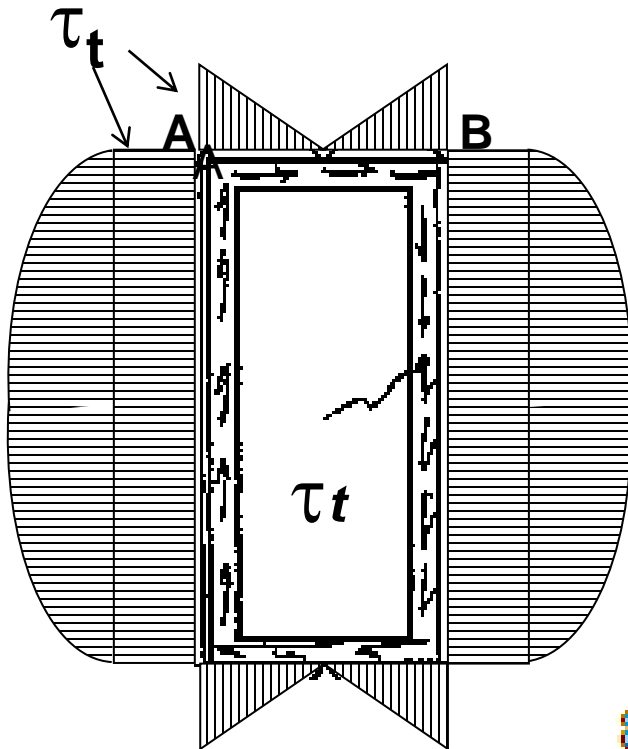
$$\sigma_{Ax} = -\frac{Mx}{Ix} * Y_A = -\frac{2 * 10^8 \text{ Nmm} * 400 \text{ mm}}{e * 1,81 * 10^8 \text{ mm}^3} = -\frac{441,98 \text{ N}}{e \text{ mm}}$$

$$\sigma_{Ay} = +\frac{My}{Iy} * X_A = +\frac{2 * 10^7 \text{ Nmm} * 150 \text{ mm}}{e * 4,05 * 10^7 \text{ mm}^3} = \frac{74,07 \text{ N}}{e \text{ mm}}$$

$$\sigma_A = -\frac{441,98 \text{ N}}{e \text{ mm}} + \frac{74,07 \text{ N}}{e \text{ mm}} = -\frac{367,91 \text{ N}}{e \text{ mm}}$$

$$\sigma_A = -\frac{367,91 \text{ N}}{e \text{ mm}} \text{ COMPRESION}$$

b) Tensiones tangenciales τ debida a la flexión (despreciamos los esfuerzos tangenciales producidos por la carga horizontal)



$$\tau_f = \frac{Q * S}{I * b}$$

Stiopin – Pag. 165
Feodosiev – Pag 364

$$Sx = e * 300 \text{ mm} * 400 \text{ mm} = 120.000 * e \text{ mm}^2$$

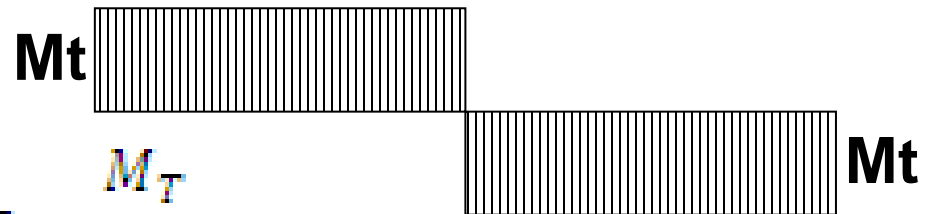
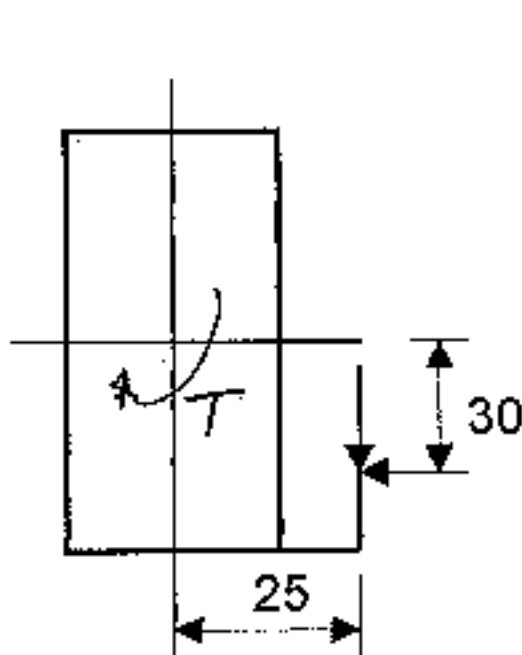
$$Ix = 1,81 * 10^8 * e \text{ mm}^3$$

$$b = 2 * e \text{ mm}$$

$$Q = \frac{160.000 \text{ N}}{2} = 80.000 \text{ N}$$

$$\tau_f = \frac{80.000 \text{ N} * 120.000 \text{ mm}^2 * e}{e * 1,81 * 10^8 \text{ mm}^3 * e} = \frac{26,47}{e} \frac{\text{N}}{\text{mm}}$$

c) Tensiones tangenciales de torsión



$$\tau_T = \frac{M_T}{2 * F * \delta}$$

$$T_1 = 160.000 \text{ N} * 250 \text{ mm} = 4 * 10^7 \text{ Nmm}$$

$$T_2 = 16.000 \text{ N} * 300 \text{ mm} = 0,48 * 10^7 \text{ Nmm}$$

$$T = T_1 + T_2 = 4,48 * 10^7 \text{ Nmm}$$

$$M_T = \frac{T}{2} = 2,24 * 10^7 \quad \delta = e$$

$$\tau_T = \frac{2,24 * 10^7 \text{ Nmm}}{2 * 300 * 800 * e \text{ mm}^2} = \frac{46,66 \text{ N}}{e \text{ mm}}$$

d) Cálculo de la tensión de comparación

$$\tau_{TOTALB} = \tau_{fB} + \tau_{TB} = \frac{26,47 \text{ N}}{e \text{ mm}} + \frac{46,66 \text{ N}}{e \text{ mm}}$$

$$\tau_{TOTALB} = \frac{73,13 \text{ N}}{e \text{ mm}} \quad \sigma_B = -\frac{516 \text{ N}}{e \text{ mm}} \text{ COMPRESION}$$

$$\sigma_c = \sqrt{\sigma^2 + 3 * \tau^2} = \frac{1}{e} * \sqrt{(516)^2 + 3 * (73,13)^2} \frac{\text{N}}{\text{mm}^2}$$

$$\sigma_c = \frac{530,5 \text{ N}}{e \text{ mm}}$$

Tensión admisible según Norma
C.M.A.A.:

$$\sigma_{ADM} = 105 \frac{N}{mm^2}$$

$$\sigma_{ADM} = 105 \frac{N}{mm^2} \geq \frac{530,50}{e} \frac{N}{mm}$$

$$e \geq \frac{530,50}{105} mm = 5,05 mm$$

ADOPTAMOS: $e = 5 mm$

VERIFICACION DE LA INERCIA PARA LA FLECHA ADMISIBLE

Carga por rueda (P) =	8000	kgf
Luz de la viga (L) =	500	cm
Flecha (f) =	0,67	cm
Distancia entre ruedas (a) =	120	cm
Flecha admisible (fadm) =	0,67	cm
E =	2100000	kgf/cm ²

La flecha admisible depende del tipo de servicio

$$\text{Servicio pesado } f_{ADM} = \frac{L}{1000} = \frac{500 \text{ cm}}{1000} = 0,50 \text{ cm}$$

$$\text{Servicio mediano } f_{ADM} = \frac{L}{750} = \frac{500 \text{ cm}}{750} = 0,67 \text{ cm}$$

$$\text{Servicio manual } f_{ADM} = \frac{L}{500} = \frac{500 \text{ cm}}{500} = 1,00 \text{ cm}$$

$$\text{Adoptamos: } f_{ADM} = \frac{L}{750} = \frac{500 \text{ cm}}{750} = 0,67 \text{ cm}$$

$$I_{XNEC} = \frac{P * (L - a) * [3 * L^2 - (L - a)^2]}{48 * E * f}$$

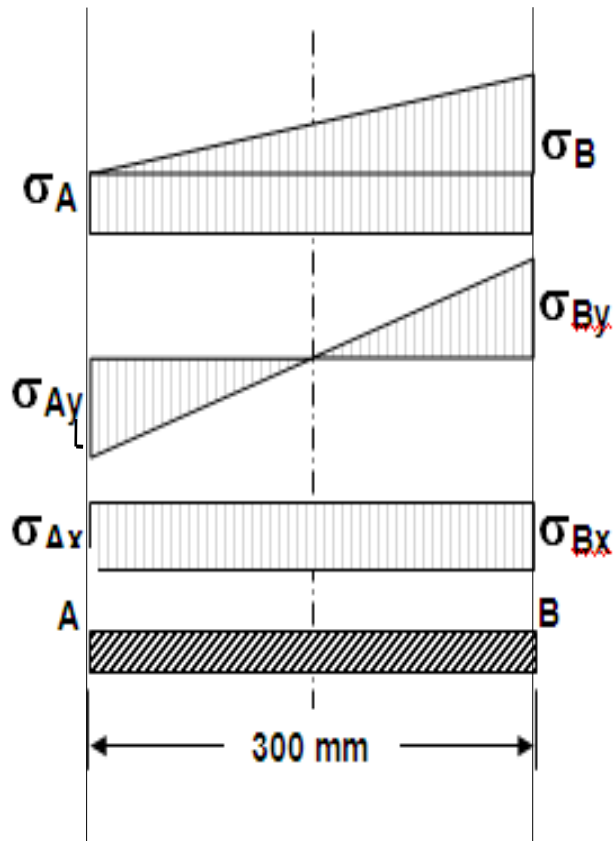
$$I_{XNEC} = \frac{8000 * (500 - 120) * [3 * (500)^2 - (500 - 120)^2]}{48 * 2.100.00 * 0,67} \text{ cm}^4$$

$$I_{XNEC} = \frac{8000 * 380 * [3 * 250.000 - 144.400]}{48 * 2.100.00 * 0,67} \text{ cm}^4$$

$$I_{XNEC} = 27.397 \text{ cm}^4$$

$$I_X = 0,5 * 181.400 \text{ cm}^4 = 90.700 \text{ cm}^4$$

$$I_X = 90.700 \text{ cm}^4 > I_{XNEC} = 27.397 \text{ cm}^4 \Rightarrow B.C.$$



$$\sigma_{Bx} = -\frac{441,98}{5} \frac{N}{mm^2} = -88,4 \frac{N}{mm^2}$$

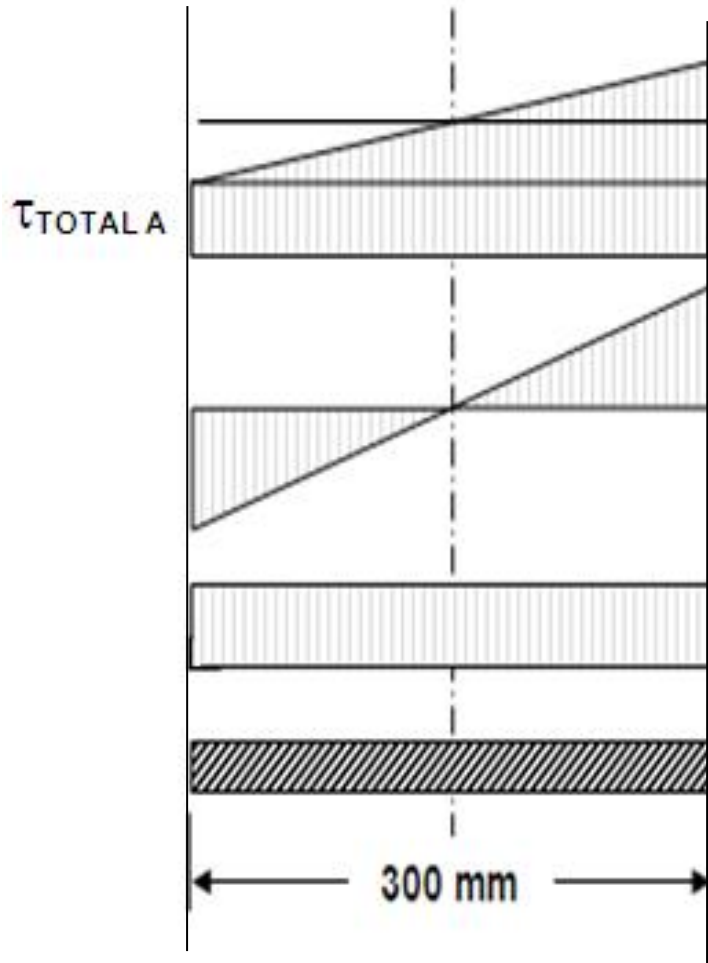
$$\sigma_{By} = -\frac{74,078}{5} \frac{N}{mm^2} = -14,81 \frac{N}{mm^2}$$

$$\sigma_B = -88,4 \frac{N}{mm^2} - 14,81 \frac{N}{mm^2} = -103,21 \frac{N}{mm^2}$$

$$\sigma_{Ax} = -\frac{441,98}{5} \frac{N}{mm^2} = -88,4 \frac{N}{mm^2}$$

$$\sigma_{Ay} = +\frac{74,07}{5} \frac{N}{mm^2} = +14,81 \frac{N}{mm^2}$$

$$\sigma_A = -88,4 \frac{N}{mm^2} + 14,81 \frac{N}{mm^2} = -73,59 \frac{N}{mm^2}$$



$$\tau_f = \frac{26,47 \text{ N}}{5 \text{ mm}^2} = 5,3 \frac{\text{N}}{\text{mm}^2}$$

$$\tau_T = \frac{46,66 \text{ N}}{5 \text{ mm}^2} = 9,3 \frac{\text{N}}{\text{mm}^2}$$

$$\tau_{TOTALA} = \tau_{fA} + \tau_{TA}$$

$$\tau_{TOTALB} = \tau_{fB} + \tau_{TB}$$

$$\tau_{TOTALA} = -5,3 \frac{N}{mm^2} + 9,3 \frac{N}{mm^2} = 4 \frac{N}{mm^2}$$

$$\tau_{TOTALB} = 5,3 \frac{N}{mm^2} + 9,3 \frac{N}{mm^2} = 14,6 \frac{N}{mm^2}$$

$$\tau_{PROM} = \frac{\tau_{TOTALA} + \tau_{TOTALB}}{2}$$

$$\tau_{PROM} = \frac{14,6 + 4}{2} \frac{N}{mm^2} = 9,31 \frac{N}{mm^2}$$

$$\sigma_C = \sqrt{\sigma^2 + 3 * \tau^2} \quad \sigma_{MAX} = \sigma_B = \sigma_1$$

$$\sigma_C = \sqrt{(103,21)^2 + 3 * (9,31)^2} \frac{N}{mm^2} = 104,46 \frac{N}{mm^2}$$

Según tabla N° 10 de página 32

$$\alpha = \frac{a}{b} = \frac{5000}{800} = 16,6 > 1$$

$$\psi = \frac{\sigma_A}{\sigma_B} = \frac{-73,59}{-103,21} = 0,713$$

$$k = \frac{8,4}{\psi + 1,1} = \frac{8,4}{0,713 + 1,1} = 4,63$$

$$\sigma_e = 0,901 * E * \left(\frac{t}{b}\right)^2$$

$$\sigma_e = 0,901 * 210.000 * \left(\frac{5}{300}\right)^2 \frac{N}{mm^2} = 52,55 \frac{N}{mm^2}$$

$$\sigma_{1ki} = k * \sigma_e = 4,63 * 52,55 \frac{N}{mm^2} = 243,30 \frac{N}{mm^2}$$

Debemos calcular por separado τ_{ki} - De tabla 10 para $\alpha > 1$

$$k = 5,34 + \frac{4}{\alpha^2} = 5,34 + \frac{4}{(16,6)^2} = 5,3544$$

$$\tau_{ki} = k * \sigma_e = 5,3544 * 52,55 \frac{N}{mm^2} = 281,37 \frac{N}{mm^2}$$

$$\sigma_{vki} = \frac{\sqrt{\sigma_1^2 + 3 * \tau^2}}{\frac{1 + \psi}{4} * \frac{\sigma_1}{\sigma_{1ki}} + \sqrt{\left(\frac{3 - \psi}{4} * \frac{\sigma_1}{\sigma_{1ki}}\right)^2 + \left(\frac{\tau}{\tau_{ki}}\right)^2}}$$

$$\sigma_{vki} = \frac{104,46}{0,18 + 0,318} \frac{N}{mm^2} = 209 \frac{N}{mm^2}$$

De tabla N° 11 página 34 $\Rightarrow \sigma_{vki} \Rightarrow \sigma_{vk} = 201,6 \frac{N}{mm^2}$

$$\gamma_B = \frac{\sigma_{vk}}{\sigma_c} = \frac{201,6}{104,46} = 1,92$$

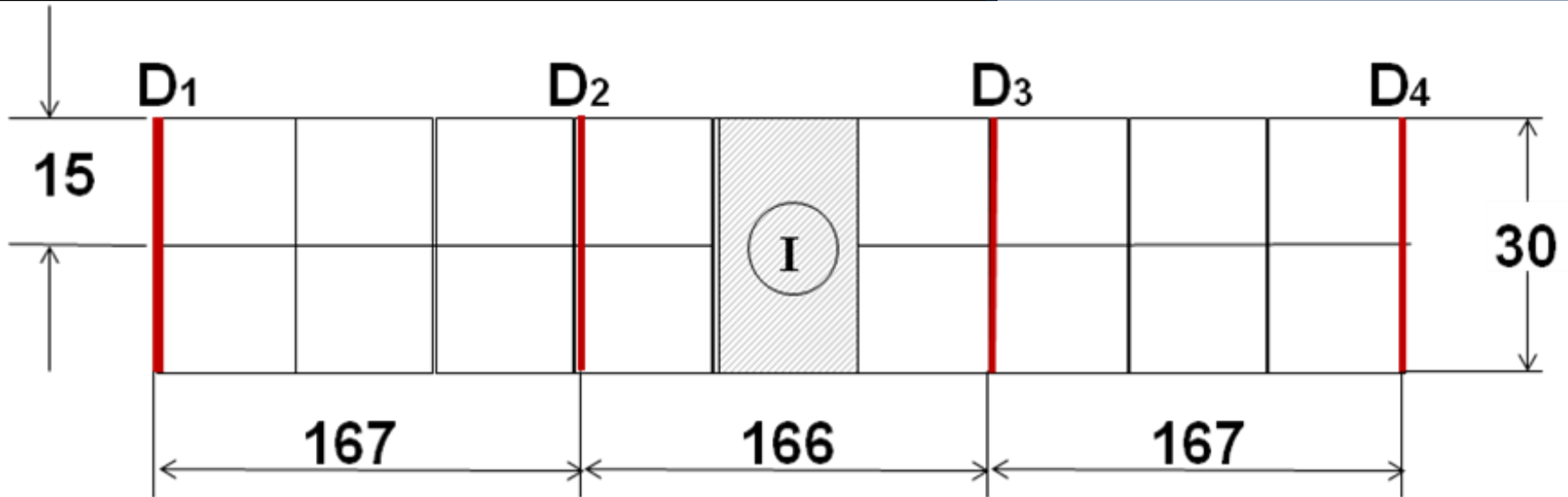
$\gamma_{BNEC} = \gamma_k$ según punto 6.2.5 de página 31

$\gamma_k = \rho * \gamma$ Donde $\rho = 1,818$ para F – 24 (pag. 34)

$$\gamma = 1,5$$

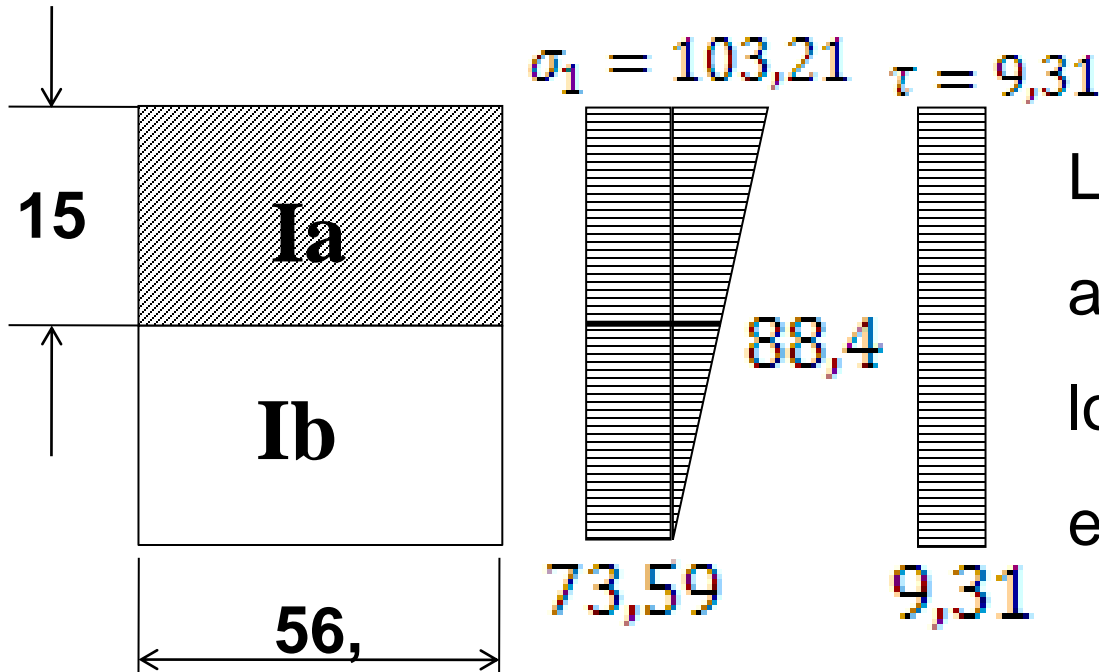
$$\gamma_k = 1,818 * 1,5 = 2,727 > \gamma_B \text{ M.C.}$$

Es necesario aplicar un rigidizador



Se utilizan diafragmas o mamparos D_1 ; D_2 ; D_3 y D_4 y se aplican rigidizadores longitudinales y transversales.

Debemos verificar al abollamiento la chapa (I) más solicitada.



La parte más solicitada al aplicar el rigidizador longitudinal en la chapa es la **(Ia)**

$$\psi = \frac{5}{88,4} = 0,0566$$

$$\alpha = \frac{56,5}{15} = 3,76 > 1$$

El coeficiente de abollamiento: $k = \frac{8,4}{0,856 + 1,1} = 4,294$

$$\sigma_s = 0,901 * 210.000 * \left(\frac{5}{150}\right)^2 \frac{N}{mm^2} = 210,23 \frac{N}{mm^2}$$

$$\sigma_{1ki} = 4,294 * 210,23 \frac{N}{mm^2} = 902,74 \frac{N}{mm^2}$$

$$k = 5,34 + \frac{4,00}{\alpha^2} = 5,34 + \frac{4,00}{(3,76)^2} = 5,62$$

$$\tau_{ki} = k * \sigma_s = 5,62 * 210,23 \frac{N}{mm^2} = 1.181,49 \frac{N}{mm^2}$$

$$\sigma_c = 104,46 \frac{N}{mm^2}$$

$$\sigma_{vki} = \frac{104,46 \frac{N}{mm^2}}{\frac{1,856}{4} * \frac{103,21}{902,74} + \sqrt{\left(\frac{2,14}{4} * \frac{103,21}{902,74}\right)^2 + \left(\frac{9,31}{181,49}\right)^2}} = 910,55 \frac{N}{mm^2}$$

$$\sigma_{vki} = 910,55 \frac{N}{mm^2}$$

Según tabla N° 11 debemos reducir a σ_{vk} – Interpolando:

$$\sigma_{vk} = 233,28 \frac{N}{mm^2}$$

$$\text{Calculamos } \gamma_B = \frac{233,28}{104,46} = 2,23$$

Como $\sigma_{vki} > \sigma^* = 375 \frac{N}{mm^2}$ debemos aplicar:

$$\gamma_{BNEC} = \left[0,9 + 0,1 * \left(\frac{375}{910,55} \right)^2 \right] * \gamma_k$$

$$\gamma_k = \rho * \gamma = 1,34 * 1,5 = 2$$

$$\gamma_{BNEC} = [0,9 + 0,1 * 0,1696] * 2 = 1,833$$

$$(\gamma_{BNEC} = 1,833) < (\gamma_B = 2,23) \Rightarrow B. C.$$

Nos resta realizar el diseño del rigidizador

Cálculo de rigidizadores longitudinales (los transversales se adoptarán de igual sección que los longitudinales)

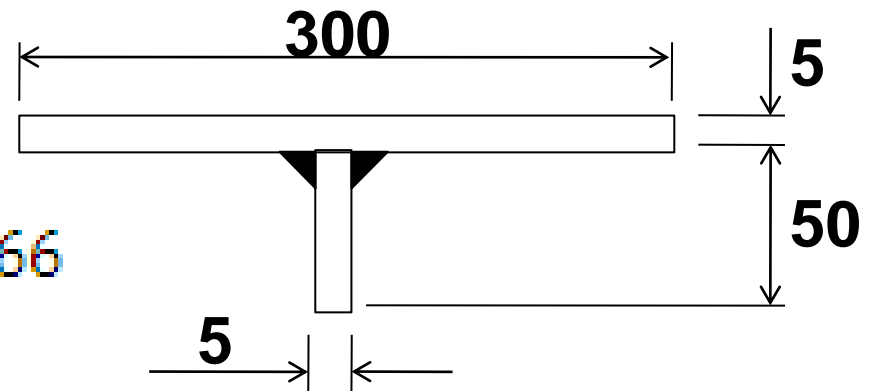
*Diseñamos el rigidizador de área $F = 5 \text{ mm} * 50 \text{ mm}$*

$b =$ ancho de la chapa a rigidizar

$\delta =$ magnitud auxiliar

$$\delta = \frac{F}{b * t} = \frac{5 * 50 \text{ mm}^2}{300 * 5 \text{ mm}^2} = 0,166$$

$$\alpha = \frac{a}{b} = \frac{56,5}{30} = 1,88$$



De Tabla N° 9 – Pagina 37 – Primer renglón:

$$\alpha = 1,88 < \sqrt{8 * (1 + 2 * \delta) - 1} = 3,10$$

$$\theta^* = (0,53 + 0,47 * \psi) * \left\{ \frac{\alpha^2}{2} * [16 * (1 + 2 * \delta) - 2] - \frac{\alpha^4}{2} + \frac{(1 + 2 * \delta)}{2} \right\}$$

$$\theta^* = 24,11$$

$$I_{NEC} = \theta^* * 0,092 * b * t^3$$

$$I_{NEC} = 24,11 * 0,092 * 300 * (5)^3 = 83.180 \text{ mm}^4$$

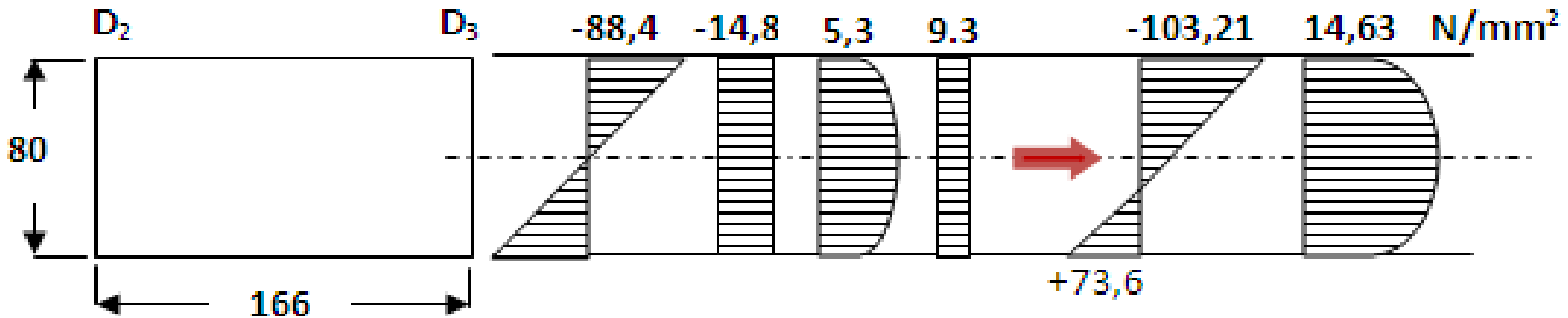
El momento de inercia del rigidizador, lo calculamos con respecto al eje en la junta de unión (despreciamos la mitad del espesor de la chapa)

$$I = \frac{b * h^3}{12} + F * a^2$$

$$I = \frac{5 * (50)^3}{12} + 5 * 50 * (25)^2 = 208.333 \text{ mm}^4$$

$$I \gg I_{NEC} \Rightarrow B.C.$$

Como es muy grande el momento de inercia, deberemos realizar un nuevo cálculo con una planchuela de menor ancho, por ejemplo 30 mm



Quando las tensiones tangenciales son del tipo graficado, se considera el valor máximo y no el promedio.

$$\psi = -0,713 \quad \alpha = \frac{a}{b} = \frac{166}{80} = 2,075$$

De tabla N° 10 – Renglón 3 \Rightarrow

$$k = (1 + \psi) * k' - \psi * k'' + 10 * \psi * (1 + \psi)$$

Donde k' es el coeficiente para $\psi = 0$ Línea 2

Donde k'' es el coeficiente para $\psi = -1$ Línea 4

(O de figura 30 – Página 33)

$$k' = \frac{8,4}{\psi + 1,1} = \frac{8,4}{0 + 1,1} = 7,636$$

$$k'' = 23,9 \Rightarrow \text{reemplazando } k = 17,17$$

$$\sigma_g = 0,901 * 210.000 * \left(\frac{5}{800}\right)^2 = 7,39 \frac{N}{mm^2}$$

$$\sigma_{1ki} = k * \sigma_g = 17,17 * 7,39 \frac{N}{mm^2} = 126,90 \frac{N}{mm^2}$$

$$\tau_{ki} = k * \sigma_g$$

$$k = 5,34 + \frac{4}{(2,075)^2} = 6,269$$

$$\tau_{ki} = 6,269 * 7,39 \frac{N}{mm^2} = 46,32 \frac{N}{mm^2}$$

$$\sigma_c = \sqrt{(103,21)^2 + 3 * (14,63)^2} \frac{N}{mm^2} = 106,27 \frac{N}{mm^2}$$

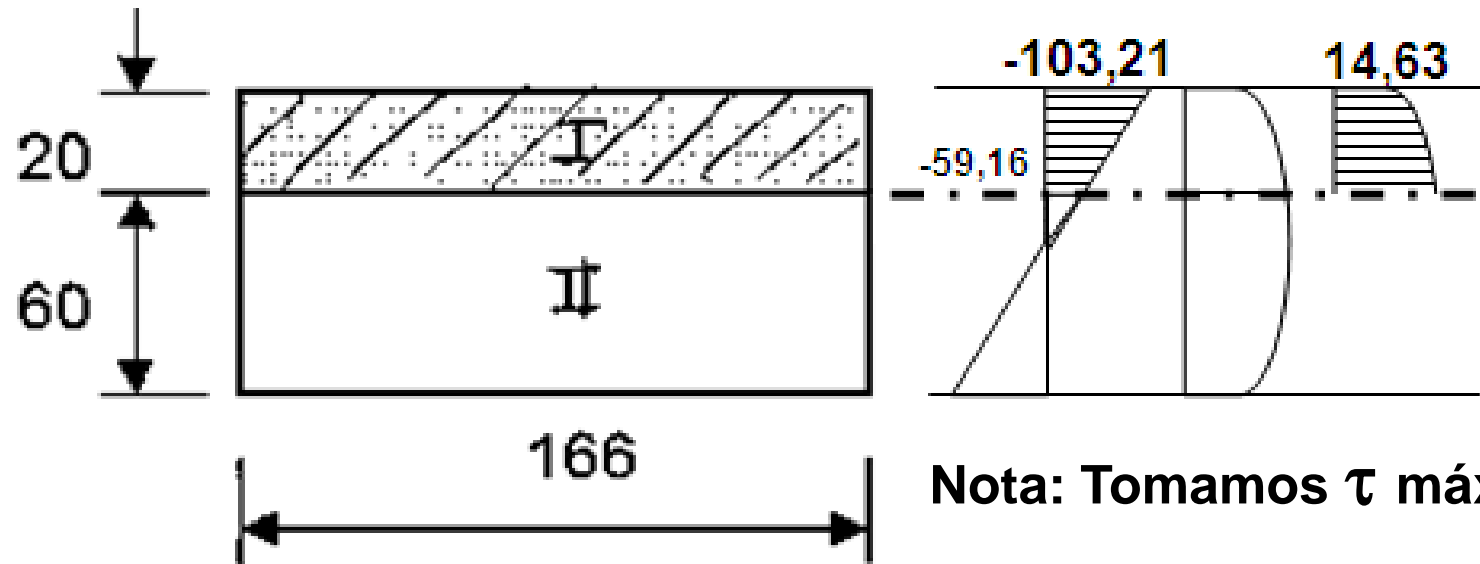
$$\sigma_{vki} = \frac{\sqrt{(103,21)^2 + 3 * (14,63)^2}}{\frac{1 - 0,713}{4} * \frac{103,21}{126,90} + \sqrt{\left[\left(\frac{3 + 0,713}{4}\right) * \frac{103,21}{126,90}\right]^2 + \left(\frac{14,63}{46,32}\right)^2}} \frac{N}{mm^2}$$

$$\sigma_{vki} = \frac{106,27}{0,876} \frac{N}{mm^2} = 121,21 \frac{N}{mm^2}$$

No supera el límite de proporcionalidad $\Rightarrow \sigma_{vk} = 121,21 \frac{N}{mm^2}$

$$\gamma_B = \frac{\sigma_{vk}}{\sigma_c} = \frac{121,21}{106,27} = 1,14 \quad \gamma_{BNEC} > \gamma_B \Rightarrow \text{HAY QUE RIGIDIZAR}$$

$$\gamma_{BNEC} = 0,93 * \gamma = 0,93 * 1,5 = 1,392 > \gamma_B = 1,14 \Rightarrow M.C.$$



Nota: Tomamos τ máxima

VERIFICACION AL ABOLLAMIENTO DE LA CHAPA (I)

$$\alpha = \frac{166}{20} = 8,3 \quad \psi = \frac{\sigma_2}{\sigma_1} = \frac{-59,16}{-103,21} = 0,573 \quad k = \frac{8,4}{\psi + 1,1} = 5,34$$

$$\sigma_e = 0,901 * 210.000 * \left(\frac{5}{800} \right)^2 = 118,21 \frac{N}{mm^2}$$

$$\sigma_{1ki} = k * \sigma_s = 5,34 * 118,21 \frac{N}{mm^2} = 631,25 \frac{N}{mm^2}$$

$$k_\tau = 5,34 + \frac{4}{(8,3)^2} = 5,4 \quad \tau_{ki} = k_\tau * \sigma_s = 5,4 * 118,21 \frac{N}{mm^2} = 638 \frac{N}{mm^2}$$

$$\sigma_{vki} = \frac{\sqrt{(103,21)^2 + 3 * (14,63)^2}}{\frac{(1 + 0,573)}{4} * \frac{103,21}{631,25} + \sqrt{\left[\left(\frac{3 - 0,573}{4}\right) * \frac{103,21}{631,25}\right]^2 + \left(\frac{14,63}{638}\right)^2}}$$

$$\sigma_{vki} = \frac{106,27}{0,166} \frac{N}{mm^2} = 639,73 \frac{N}{mm^2}$$

$$\sigma_{vk} = 230,42 \frac{N}{mm^2} \text{ Interpolando}$$

$$\gamma_B = \frac{\sigma_{vk}}{\sigma_C} = \frac{230,42}{106,27} = 2,168$$

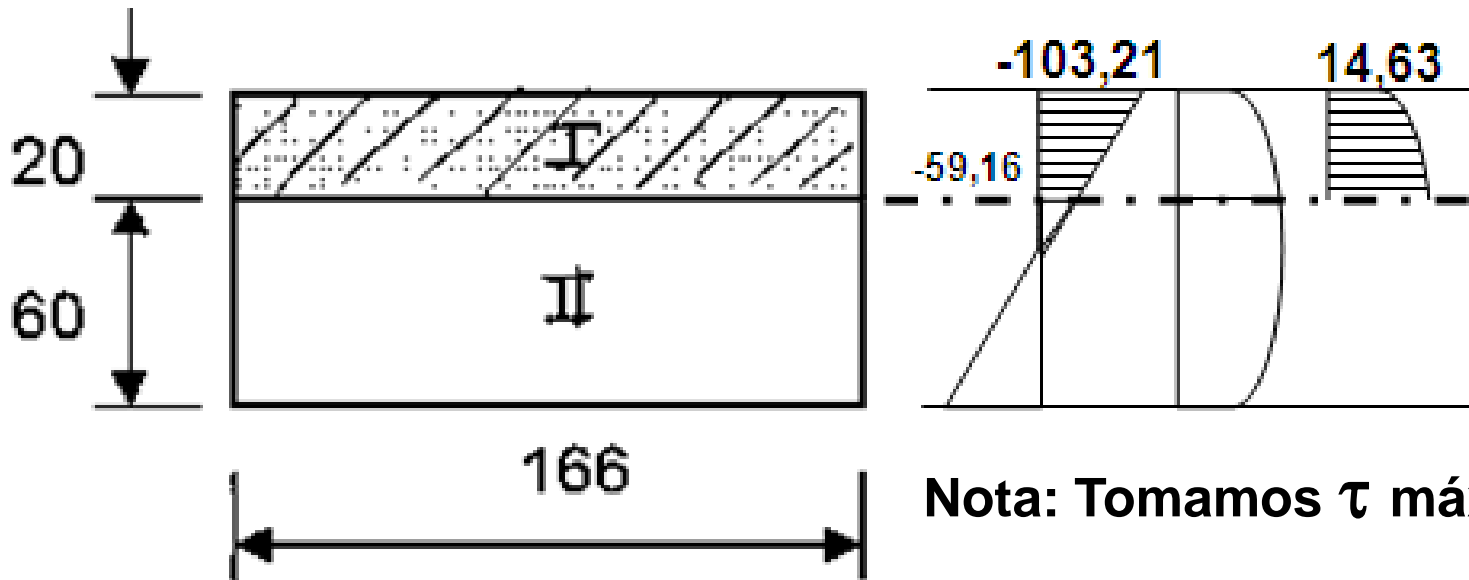
$$\gamma_k = \rho * \gamma = 1,4 * 1,5 = 2,1$$

Como $\sigma_{vki} > \sigma^* \Rightarrow \gamma_{BNEC} = \left[0,9 + 0,1 * \left(\frac{375}{639,73} \right)^2 \right] * \gamma_k$

$$\gamma_{BNEC} = \left[0,9 + 0,1 * \left(\frac{375}{639,73} \right)^2 \right] * 2,1 = 1,96$$

$$\gamma_{BNEC} = 1,96 < \gamma_B = 2,168 \Rightarrow B.C.$$

VERIFICACION AL ABOLLAMIENTO DE LA CHAPA (II)



Nota: Tomamos τ máxima

$$\alpha = \frac{166}{60} = 2,766$$

$$\psi = \frac{\sigma_2}{\sigma_1} = \frac{73,6}{-59,16} = -1,24$$

Según Tabla N° 10 – Renglón 4

$$\sigma_g = 0,901 * 210.000 * \left(\frac{5}{600}\right)^2 \frac{N}{mm^2} = 13,14 \frac{N}{mm^2}$$

Como $\alpha \geq 0,66 \Rightarrow k = 23,9$

$$\sigma_{1ki} = k * \sigma_g = 23,9 * 13,14 \frac{N}{mm^2} = 314 \frac{N}{mm^2}$$

$$k_\tau = 5,34 + \frac{4}{(2,766)^2} = 5,86$$

$$\tau_{ki} = k_\tau * \sigma_g = 5,86 * 13,14 \frac{N}{mm^2} = 77 \frac{N}{mm^2}$$

$$\sigma_{vki} = \frac{\sqrt{(59,16)^2 + 3 * (14,63)^2}}{\frac{(1 - 1,24)}{4} * \frac{59,16}{314} + \sqrt{\left[\frac{(3 + 1,24)}{4} * \frac{59,16}{314}\right]^2 + \left(\frac{14,63}{77}\right)^2}}$$

$$\sigma_c = \sqrt{(59,16)^2 + 3 * (14,63)^2} \frac{N}{mm^2} = 64,36 \frac{N}{mm^2}$$

$$\sigma_{vki} = \frac{64,36 \frac{N}{mm^2}}{0,264 mm^2} = 243,46 \frac{N}{mm^2}$$

De tabla N° 11 $\Rightarrow \sigma_{vk} = 209,74 \frac{N}{mm^2}$ Interpolando

$\rho = 1,758$ Interpolando

$$\gamma_B = \frac{\sigma_{vk}}{\sigma_C} = \frac{209,74}{64,36} = 3,25$$

Como $\sigma_{vk} < \sigma^* \Rightarrow \gamma_{BNEC} \geq \gamma_k$

$$\gamma_k = \rho * \gamma = 1,758 * 1,5 = 2,637$$

$$\gamma_{BNEC} = 2,637 < \gamma_B = 3,25 \Rightarrow B.C.$$

Se deja a los alumnos el diseño del rigidizador