TALAT Lecture 2301

Design of Members

Axial Force

Example 5.6 : Axial force resistance of orthotropic plate. Open or closed stiffeners

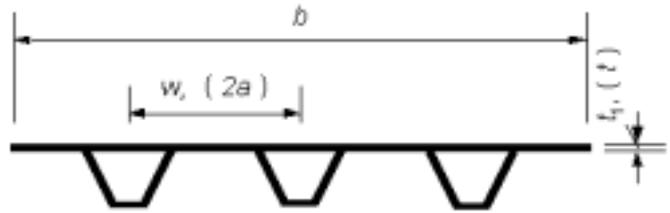5 pages

Advanced Level

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Example 5.6. Axial force resistance of orthotropic plate. Open or closed stiffeners

Dimensions (highlighted)

Plate thickness $\quad t := 16.5 \cdot mm \qquad t_1 := t \qquad\qquad f_o := 240 \cdot MPa \qquad N \equiv newton$

Plate width $\quad b := 1500 \cdot mm \qquad\qquad\qquad f_u := 260 \cdot MPa \qquad kN \equiv 1000 \cdot newton$

Plate length $\quad L := 2200 \cdot mm \qquad\qquad\qquad E := 70000 \cdot MPa \qquad MPa \equiv 10^6 \cdot Pa$

Stiffener pitch $\quad w := 300 \cdot mm \qquad a := \dfrac{w}{2} \qquad\qquad \gamma_{M1} := 1.1$

If heat-treated alloy, then $ht = 1$ else $ht = 0 \qquad\qquad ht := 1$

If cold formed (trapezoidal), then $cf. = 1$ else $cf. = 0 \qquad\qquad cf := 0$

a) Open stiffeners

Half stiffener pitch $\qquad a = 150 \circ mm$

Half bottom flange $\qquad a_2 := 50 \cdot mm$

Thickness of bottom flange $\qquad t_2 := 10 \cdot mm$

Stiffener depth $\qquad h := 160 \cdot mm$

Half web thickness $\qquad t_3 := 4.4 \cdot mm$

Half width of trapezoidal stiffener at the top $\qquad a_1 := 0 \cdot mm$

Width of web $\qquad a_3 := h \qquad a_3 = 160 \circ mm$
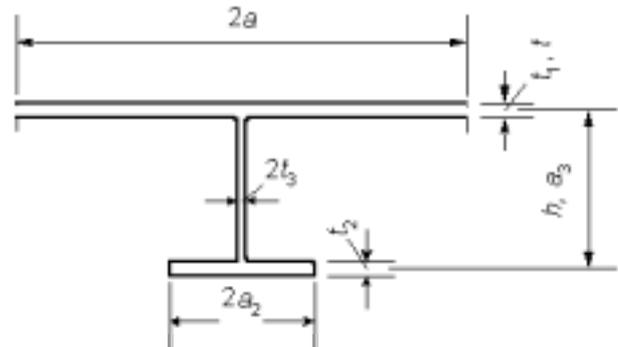
Local buckling

Internal elements $\quad \beta_{1i} := \dfrac{2 \cdot a}{t_1} \qquad \beta_{2i} := \dfrac{a_3}{2 \cdot t_3} \qquad \beta_i = \begin{bmatrix} 18.182 \\ 18.182 \end{bmatrix} \qquad \beta := max(\beta_i) \qquad \beta = 18.182$

[1] Tab. 5.1 $\quad \varepsilon := \sqrt{\dfrac{250 \cdot MPa}{f_o}} \qquad\qquad \beta_1 = 9 \cdot \varepsilon \qquad\qquad \beta_1 = 9.186$

$\beta_2 = 11 \cdot \varepsilon \qquad\qquad \beta_2 = 11.227$

$\beta_3 = 18 \cdot \varepsilon \qquad\qquad \beta_3 = 18.371$

$class_i := if(\beta > \beta_1, if(\beta > \beta_2, if(\beta > \beta_3, 4, 3), 2), 1) \qquad\qquad class_i = 3$

Outstand $\quad \beta := \dfrac{a_2}{t_2} \qquad\qquad \beta_1 := 2.5 \cdot \varepsilon \qquad\qquad \beta_1 = 2.552$

[1] Tab. 5.1 $\quad \beta = 5 \qquad\qquad \beta_2 = 4 \cdot \varepsilon \qquad\qquad \beta_2 = 4.082$

$\beta_3 = 5 \cdot \varepsilon \qquad\qquad \beta_3 = 5.103$

$class_o := if(\beta > \beta_1, if(\beta > \beta_2, if(\beta > \beta_3, 4, 3), 2), 1) \qquad\qquad class_o = 3$

$class := if(class_o > class_i, class_o, class_i) \qquad\qquad class = 3$

No reduction for local buckling

5.11.6 Overall buckling, uniform compression

Cross sectional area $\quad A := 2 \cdot t_1 \cdot a + 2 \cdot t_2 \cdot a_2 + 2 \cdot t_3 \cdot a_3 - 2 \cdot t_1 \cdot a_1 \qquad\qquad A = 7.358 \cdot 10^3 \circ mm^2$

Gravity centre

$$e := \frac{2 \cdot t_2 \cdot a_2 \cdot h + 2 \cdot t_3 \cdot a_3 \cdot \dfrac{h}{2}}{A} \qquad\qquad e = 37.054 \circ mm$$

Second moment of area

$$I_L := 2 \cdot t_2 \cdot a_2 \cdot h^2 + 2 \cdot t_3 \cdot a_3 \cdot \frac{h^2}{3} - A \cdot e^2 \qquad\qquad I_L = 2.751 \cdot 10^7 \circ mm^4$$

$$s := if\left[cf = 1, \left[2 \cdot a + 2 \cdot a_3 - 2 \cdot (a_1 - a_2)\right], 2 \cdot a\right] \qquad s = 300 \circ mm$$

Rigidities of orthotropic plate

Table 5.10 $\qquad B_x := \dfrac{E \cdot I_L}{2 \cdot a}$

$v := 0.3$ $\qquad\qquad B_x = 6.42 \cdot 10^9 \circ \left(\dfrac{N \cdot mm^2}{mm}\right)$

$G := \dfrac{E}{2 \cdot (1 + v)}$

Table 5.10 $\qquad B_y := \dfrac{2 \cdot a}{s} \cdot \dfrac{E \cdot t^3}{12 \cdot \left(1 - v^2\right)} \qquad\qquad B_y = 2.88 \cdot 10^7 \circ \left(\dfrac{N \cdot mm^2}{mm}\right)$

Table 5.10 $\qquad H := \dfrac{2 \cdot a}{s} \cdot \dfrac{G \cdot t^3}{6} \qquad\qquad H = 2.016 \cdot 10^7 \circ \left(\dfrac{N \cdot mm^2}{mm}\right)$

Elastic buckling load

(5.77)

(5.78)

$$N_{cr} := \begin{vmatrix} \dfrac{\pi^2}{b} \cdot \left[\dfrac{B_x}{\left(\dfrac{L}{b}\right)^2} + 2 \cdot H + B_y \cdot \left(\dfrac{L}{b}\right)^2\right] & if \ \dfrac{L}{b} < \sqrt[4]{\dfrac{B_x}{B_y}} \\[2em] \dfrac{2 \cdot \pi^2}{b} \cdot \left(\sqrt{B_x \cdot B_y} + H\right) & otherwise \end{vmatrix} \qquad N_{cr} = 2.031 \cdot 10^4 \circ kN$$

Buckling resistance

$$A_{ef} := A \qquad\qquad A_{ef} = 7.358 \cdot 10^3 \circ mm^2$$

(5.69) $\qquad \lambda_c := \sqrt{\dfrac{A_{ef} f_o}{N_{cr}}} \qquad\qquad \lambda_c = 0.295$

Table 5.6

$\alpha := if(ht > 0, 0.2, 0.32) \qquad \lambda_0 := if(ht > 0, 0.1, 0) \qquad\qquad \alpha = 0.2$

$\lambda_0 = 0.1$

$$\phi := 0.5 \cdot \left[1 + \left[\alpha \cdot \left(\lambda_c - \lambda_0\right) + \lambda_c^2\right]\right]$$

$\phi = 0.563$

(5.33) $\qquad \chi_c := \dfrac{1}{\phi + \sqrt{\phi^2 - \lambda_c^2}}$

$\chi_c = 0.959$

(5.68) $\qquad N_{cRd} := A_{ef} \chi_c \cdot \dfrac{f_o}{\gamma_{M1}} \qquad\qquad$ for one stiffener $\qquad N_{cRd} = 1.54 \cdot 10^3 \circ kN$

b) Closed stiffeners

Half stiffener pitch	$a = 150 \cdot mm$
Plate thickness	$t_1 = 16.5 \cdot mm$
Half bottom flange	$a_2 = 50 \cdot mm$
Thickness of bottom flange	$t_2 = 10 \cdot mm$
Stiffener depth	$h = 160 \cdot mm$
Web thickness	$t_3 := 9 \cdot mm$
Half width of trapezoidal stiffener at the top	$a_1 := 80 \cdot mm$
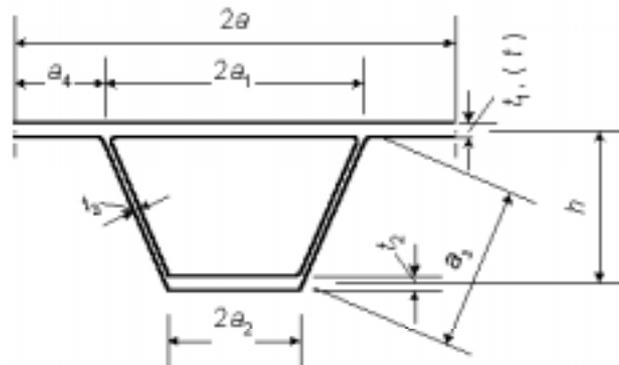
width of web
$$a_3 := \sqrt{(a_1 - a_2)^2 + h^2} \qquad a_3 = 162.8 \cdot mm$$

$$a_4 := a - a_1 \qquad\qquad a_4 = 70 \cdot mm$$

Local buckling

Internal elements
$$\beta_{1i} := \frac{2 \cdot a_1}{t_1} \qquad \beta_{2i} := \frac{2 \cdot a_2}{t_2} \qquad \beta_{3i} := \frac{a_3}{t_3} \qquad \beta_{i_4} := \frac{2 \cdot a_4}{t_1} \qquad \beta_{\overline{i}} \begin{bmatrix} 9.697 \\ 10 \\ 18.088 \\ 8.485 \end{bmatrix}$$

$$\beta := max(\beta_i) \qquad\qquad \beta = 18.1$$

[1] Tab. 5.1
$$\varepsilon := \sqrt{\frac{250}{f_o} \cdot \frac{newton}{mm^2}}$$

$$\beta_{\overline{1}} = 9 \cdot \varepsilon \qquad\qquad \beta_{\overline{1}} = 9.186$$
$$\beta_{\overline{2}} = 13 \cdot \varepsilon \qquad\qquad \beta_{\overline{2}} = 13.268$$
$$\beta_{\overline{3}} = 18 \cdot \varepsilon \qquad\qquad \beta_{\overline{3}} = 18.371$$

$$class_i := if\left(\beta > \beta_1, if\left(\beta > \beta_2, if\left(\beta > \beta_3, 4, 3\right), 2\right), 1\right) \qquad\qquad class_i = 3$$

No reduction for local buckling

Cross sectional area
$$A := 2 \cdot t_1 \cdot a + 2 \cdot t_2 \cdot a_2 + 2 \cdot t_3 \cdot a_3 \qquad\qquad A = 8.88 \cdot 10^3 \cdot mm^2$$

Gravity centre
$$e := \frac{2 \cdot t_2 \cdot a_2 \cdot h + 2 \cdot t_3 \cdot a_3 \cdot \dfrac{h}{2}}{A} \qquad\qquad e = 44.415 \cdot mm$$

Second moment of area
$$I_L := 2 \cdot t_2 \cdot a_2 \cdot h^2 + 2 \cdot t_3 \cdot a_3 \cdot \frac{h^2}{3} - A \cdot e^2 \qquad\qquad I_L = 3.309 \cdot 10^7 \cdot mm^4$$

Torsion constant
$$I_T := \frac{4 \cdot \left[h \cdot (a_1 + a_2)\right]^2}{\dfrac{2 \cdot a_1}{t_1} + \dfrac{2 \cdot a_2}{t_2} + 2 \cdot \dfrac{a_3}{t_3}} \qquad\qquad I_T = 3.097 \cdot 10^7 \cdot mm^4$$

(5.79c)
$$C_1 := 4 \cdot (1 - v^2) \cdot (a_2 + a_3) \cdot a_1^2 \cdot a_4^2 \cdot h^2 \cdot \frac{t_2}{3 \cdot a \cdot t_1^3} \qquad\qquad C_1 = 3.076 \cdot 10^9 \cdot mm^4$$

(5.79d)
$$B := \frac{E \cdot t^3}{12 \cdot (1 - v^2)} \qquad\qquad B = 2.88 \cdot 10^7 \cdot N \cdot mm$$

(5.79e)
$$C_2 := \frac{4 \cdot (a_1 + a_2)^2 \cdot a_1 \cdot a_4 \cdot \left(1 + \dfrac{a_1}{a_2} + \dfrac{a_2}{a_1} + \dfrac{a^2}{a_1 \cdot a_3}\right)}{a_2^3 \cdot (3 \cdot a_3 + 4 \cdot a_2)} \cdot \left(\frac{t_2}{t_1}\right)^3 \qquad C_2 = 4.851$$

Rigidities of orthotropic plate

Table 5.10
$$B_x := \frac{E \cdot I_L}{2 \cdot a} \qquad v := 0.3 \qquad G := \frac{E}{2 \cdot (1 + v)} \qquad B_x = 7.72 \cdot 10^9 \circ \left(\frac{N \cdot mm^2}{mm}\right)$$

(5.79a)
$$B_y := \frac{2 \cdot B \cdot a}{2 \cdot a_4 + \dfrac{2 \cdot a_1 \cdot a_3 \cdot t_1^3 \cdot \left(4 \cdot a_2 \cdot t_3^3 - a_3 \cdot t_2^3\right)}{a_3 \cdot t_1^3 \cdot \left(4 \cdot a_2 \cdot t_3^3 - a_3 \cdot t_2^3\right) + a_1 \cdot t_3^3 \cdot \left(12 \cdot a_2 \cdot t_3^3 - 4 \cdot a_3 \cdot t_2^3\right)}}$$

$$B_y = 3.929 \cdot 10^7 \circ \left(\frac{N \cdot mm^2}{mm}\right)$$

(5.79b)
$$H := 2 \cdot B + \frac{\dfrac{G \cdot I_T}{6 \cdot a}}{1 + \dfrac{1.6 \cdot G \cdot I_T \cdot a_4^2}{L^2 \cdot a \cdot B} \cdot \left[1 + \dfrac{1}{\pi^4 \cdot \dfrac{C_1}{L^4} + C_2}\right]}$$

$$H = 7.305 \cdot 10^8 \circ \left(\frac{N \cdot mm^2}{mm}\right)$$

Elastic buckling load

(5.77)

$$N_{cr} := \left| \begin{array}{l} \dfrac{\pi^2}{b} \cdot \left[\dfrac{B_x}{\left(\dfrac{L}{b}\right)^2} + 2 \cdot H + B_y \cdot \left(\dfrac{L}{b}\right)^2\right] \quad if \ \dfrac{L}{b} < \sqrt[4]{\dfrac{B_x}{B_y}} \\[4mm] \dfrac{2 \cdot \pi^2}{b} \cdot \left(\sqrt{B_x \cdot B_y} + H\right) \quad otherwise \end{array} \right.$$

$$N_{cr} = 3.378 \cdot 10^4 \circ kN$$

(5.78)

Buckling resistance

$$A_{ef} := A \qquad\qquad A_{ef} = 8.88 \cdot 10^3 \circ mm^2$$

(5.69)
$$\lambda_{\bar{c}} := \sqrt{\frac{A_{ef} f_o}{N_{cr}}} \qquad\qquad \lambda_{\bar{c}} = 0.251$$

$$\alpha := if(ht > 0, 0.2, 0.32) \qquad \lambda_{\bar{0}} := if(ht > 0, 0.1, 0) \qquad \alpha = 0.2$$

$$\lambda_{\bar{0}} = 0.1$$

$$\phi := 0.5 \cdot \left[1 + \left[\alpha \cdot \left(\lambda_c - \lambda_0\right) + \lambda_c^2\right]\right] \qquad\qquad \phi = 0.547$$

(5.33)
$$\chi_{\bar{c}} := \frac{1}{\phi + \sqrt{\phi^2 - \lambda_c^2}} \qquad\qquad \chi_c = 0.969$$

(5.68)
$$N_{cRd} := A_{ef} \chi_{\bar{c}} \cdot \frac{f_o}{\gamma_{M1}} \qquad\qquad for\ one\ stiffener \quad N_{cRd} = 1.877 \cdot 10^3 \circ kN$$