MŰEGYETEM 1782

Steel Buildings
BMEEOHSA-A1

Checking the Buckling Stability of a Frame Using the Reduction Method and the General Method

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1.Initial data:

Span of the main frame: $l := 14.4\ m$

Corner height of main frame: $h := 5.2\ m$

Slope of the roof: $\alpha_{inc} := 7\ deg$

Cross section of columns: $HEA400$

Cross-section of beams: $IPE500$

Number of purlins on one beam: $n_p := 4$

Number of wall-beams on one column: $n_w := 5$

Design load acting on the beams: $p_d := 13\ \frac{kN}{m}$ $\gamma_G := 1.35$

Characteristic load acting on the beams: $p_k := \frac{p_d}{\gamma_G} = 9.63\ \frac{kN}{m}$

Wind pressure: $w_{pd} := 2.5\ \frac{kN}{m}$

Wind suction: $w_{sd} := 1\ \frac{kN}{m}$

Characteristic wind loads on the columns: $\gamma_Q := 1.5$

$$w_{pk} := \frac{w_{pd}}{\gamma_Q} = 1.667\ \frac{kN}{m}$$
$$w_{sk} := \frac{w_{sd}}{\gamma_Q} = 0.667\ \frac{kN}{m}$$

2. Data of used materials

2.1 Beam section data, section IPE 500:

Height of cross-section: $h_b := 500\ mm$
Width of a flange: : $b_b := 200\ mm$
Thickness of web: $t_{w.b} := 10.2\ mm$
Thickness of flange: $t_{f.b} := 16\ mm$
Radius of rounding of web: $r_b := 21\ mm$
Cross-sectional area: $A_b := 11600\ mm^2$
Inertia around the strong axis: $I_{y.b} := 48017\ cm^4$
Inertia around the weak axis: $I_{z.b} := 2141\ cm^4$
Torsional inertia: $I_{t.b} := 89.6\ cm^4$

Warping modulus:

$$I_{w.b} := I_{z.b} \cdot \frac{\left(h_b - t_{f.b}\right)^2}{4} = \left(1.254 \cdot 10^6\right)\ cm^6$$

Plastic cross-sectional modulus around the strong axis:

$$W_{pl.y.b} := 2200\ cm^3$$

Radius of gyration around the strong axis: $i_{y.b} := \sqrt[2]{\left(\frac{I_{y.b}}{A_b}\right)} = 20.346\ cm$

Radius of gyration around the weak axis: $i_{z.b} := \sqrt[2]{\left(\frac{I_{z.b}}{A_b}\right)} = 4.296\ cm$

$\frac{h_b}{b_b} = 2.5$ > 1.2, $t_{f.b} = 16\ mm$ < 40mm

Buckling curve for FB for buckling around the strong axis: curve "a"
Buckling curve for FB for buckling around the weak axis: curve "b"

$\frac{h_b}{b_b} = 2.5$ > 2 Buckling curve for LT buckling: curve "b"

2.1 Column section data, section HEA400:

Height of cross-section: $h_c := 390\ mm$

Width of a flange: : $b_c := 300\ mm$

Thickness of web: $t_{w.c} := 11\ mm$

Thickness of flange: $t_{f.c} := 19\ mm$

Radius of rounding of web: $r_c := 27\ mm$

Cross-sectional area: $A_c := 15900\ mm^2$

Inertia around the strong axis: $I_{y.c} := 45070\ cm^4$

Inertia around the weak axis: $I_{z.c} := 8564\ cm^4$

Torsional inertia: $I_{t.c} := 189\ cm^4$

Warping modulus: $I_{w.c} := I_{z.c} \cdot \frac{\left(h_c - t_{f.c}\right)^2}{4} = \left(2.947 \cdot 10^6\right)\ cm^6$

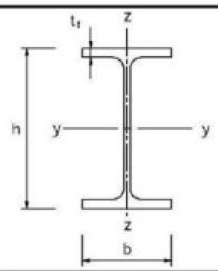
Plastic cross-sectional modulus around the strong axis:
$W_{pl.y.c} := 2562\ cm^3$

Radius of gyration around the strong axis: $i_{y.c} := \sqrt[2]{\left(\frac{I_{y.c}}{A_c}\right)} = 16.836\ cm$

Radius of gyration around the weak axis: $i_{z.c} := \sqrt[2]{\left(\frac{I_{z.c}}{A_c}\right)} = 7.339\ cm$

$\frac{h_c}{b_c} = 1.3$ > 1.2, $t_{f.c} = 19\ mm$ < 40mm

Buckling curve for FB for buckling around the strong axis: curve "b"
Buckling curve for FB for buckling around the weak axis: curve "c"
$\frac{h_c}{b_c} = 1.3$ < 2 Buckling curve for LT buckling: curve "a"

Cross section		Limits		Buckling about axis	Buckling curve S 235 S 275 S 355 S 420	Buckling curve S 460
Rolled sections		$h/b > 1,2$	$t_f \leq 40$ mm	y – y z – z	a b	a_0 a_0
			40 mm $< t_f \leq 100$	y – y z – z	b c	a a
		$h/b \leq 1,2$	$t_f \leq 100$ mm	y – y z – z	b c	a a
			$t_f > 100$ mm	y – y z – z	d d	c c

Buckling curve	α Imperfection factor
a_0	0,13
a	0,21
b	0,34
c	0,49
d	0,76

Table 10.3. Imperfection factors for buckling curves

Cross-section type	restriction	Buckling curve
Hot-rolled I-section	$h/b \leq 2$ $h/b > 2$	a b
Welded I-section	$h/b \leq 2$ $h/b > 2$	c d
Other		d

2.3 Data of the used steel:

Modulus of elasticity: $E := 210 \ GPa$

Steel grade: S275 $f_y := 275 \ MPa$

Slenderness limit: $\lambda_1 := \pi \cdot \sqrt{\frac{E}{f_y}} = 86.815$

$$\varepsilon := \sqrt{\frac{235}{f_y} MPa} = 0.924$$

Partial factor for the resistance: $\gamma_{m1} := 1$

Poisson ratio of : $\nu_a := 0.3$

Shear modulus of steel: $G := \frac{E}{2 \cdot (1 + \nu_a)} = 80.769 \ GPa$

3. Classifications of the cross-sections:
3.1. Beam section, section IPE 500:
Flanges classification:

$$c_{f.b} := \frac{b_b - t_{w.b} - 2 \cdot r_b}{2} = 73.9\ mm$$

$$\frac{c_{f.b}}{t_{f.b}} = 4.619 \quad < \quad 9 \cdot \varepsilon = 8.32$$

The flange is of class 1

Web classification:

$$c_{w.b} := h_b - 2 \cdot t_{f.b} = 468\ mm$$

$$\frac{c_{w.b}}{t_{w.b}} = 45.882 \quad < \quad 72 \cdot \varepsilon = 66.558$$

The web is of class 1
From this cross-section is of class 1

3.2. Column section, section HEA 400:
Flanges classification:

$$c_{f.c} := \frac{b_c - t_{w.c} - 2 \cdot r_c}{2} = 117.5\ mm$$

$$\frac{c_{f.c}}{t_{f.c}} = 6.184 \quad < \quad 9 \cdot \varepsilon = 8.32$$

The flange is of class 1

Web classification:

$$c_{w.c} := h_c - 2 \cdot t_{f.c} = 352\ mm$$

$$\frac{c_{w.c}}{t_{w.c}} = 32 \quad < \quad 72 \cdot \varepsilon = 66.558$$

The web is of class 1
From this cross-section is of class 1

4. Column stability checks using the reduction factor method:

4.1. Flexural buckling check:

$$c := min\left(\frac{I_{y.c}}{I_{y.b} \cdot h} \cdot l , 10\right) = 2.599$$

$$\alpha := min\left(4 \cdot \frac{I_{y.c}}{l^2 \cdot A_c} , 0.2\right) = 5.468 \cdot 10^{-4}$$

Buckling length factor (pinned base connection):

$$\nu_y := \sqrt{4 + 1.4 \cdot (c + 6 \cdot \alpha) + 0.02 \cdot (c + 6 \cdot \alpha)^2} = 2.789$$

$\nu'_z := 1.0$ (for hinged)

$$\nu_z := \frac{\nu'_z}{n_w - 1} = 0.25$$

Column slenderness around the strong axis: $\lambda_y := \frac{\nu_y \cdot h}{i_{y.c}} = 86.143$

$\lambda_y = 86.143$ < $\lambda_1 = 86.815$

yielding of the cross-section

Column slenderness around the weak axis: $\lambda_z := \frac{\nu_z \cdot h}{i_{z.c}} = 17.713$

$\lambda_z = 17.713$ < $\lambda_1 = 86.815$

yielding of the cross-section

critical normal force around the strong axis:

$$N_{cr.y} := \pi^2 \cdot E \cdot \frac{A_c}{\lambda_y^{\,2}} = \left(4.441 \cdot 10^3\right)\ kN$$

critical normal force around the weak axis:

$$N_{cr.z} := \pi^2 \cdot E \cdot \frac{A_c}{\lambda_z^{\,2}} = \left(1.05 \cdot 10^5\right)\ kN$$

Cross-sectional resistance: $N_{pl.Rk} := A_c \cdot f_y = \left(4.373 \cdot 10^3\right)\ kN$

Relative slenderness around the strong axis: $\lambda'_y := \frac{N_{pl.Rk}}{N_{cr.y}} = 0.985$

Relative slenderness around the weak axis: $\lambda'_z := \frac{N_{pl.Rk}}{N_{cr.z}} = 0.042$

Imperfection factor around the strong axis (curve a): $\alpha_y := 0.21$

$\phi_y := 0.5 \cdot \left(1 + \alpha_y \cdot \left(\lambda'_y - 0.2\right)\right) + {\lambda'_y}^2 = 1.552$

Imperfection factor around the weak axis (curve b): $\alpha_z := 0.34$

$\phi_z := 0.5 \cdot \left(1 + \alpha_z \cdot \left(\lambda'_z - 0.2\right)\right) + {\lambda'_z}^2 = 0.475$

Reduction factor for buckling around the strong axis:

$$\chi_y := min\left(\frac{1}{\phi_y + \sqrt{{\phi_y}^2 - {\lambda'_y}^2}}, 1\right) = 0.363$$

Reduction factor for buckling around the weak axis:

$$\chi_z := min\left(\frac{1}{\phi_z + \sqrt{{\phi_z}^2 - {\lambda'_z}^2}}, 1\right) = 1$$

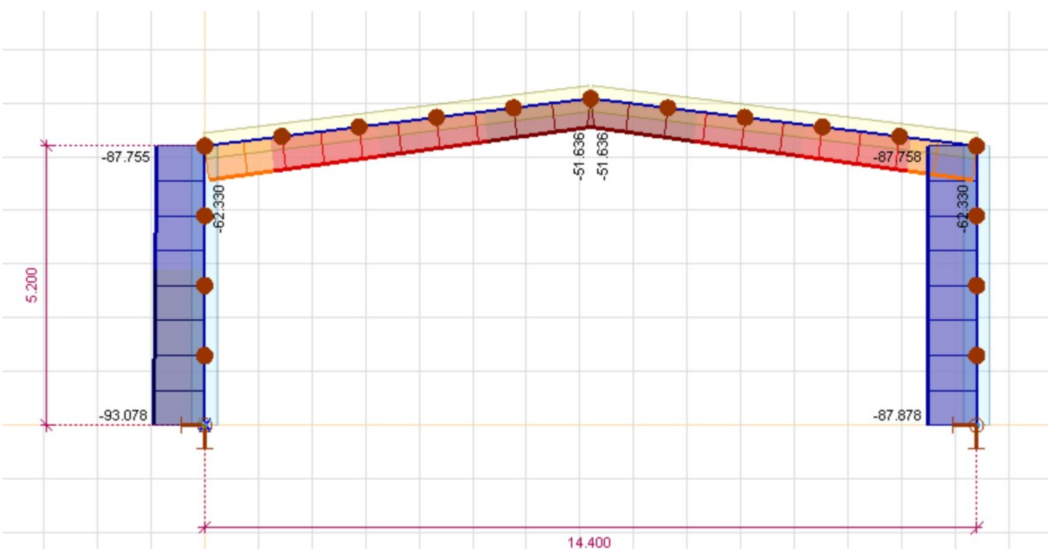
$\chi := min\left(\chi_y, \chi_z\right) = 0.363$

Design buckling resistance:

$$N_{b.Rd} := \chi \cdot \frac{N_{pl.Rk}}{\gamma_{m1}} = 1589.28\ \boldsymbol{kN}$$

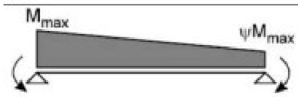
$N_{Ed} := 87.878\ \boldsymbol{kN}$ (from Axis Vm)

Utilisation ratio: $\eta := \dfrac{N_{Ed}}{N_{b.Rd}} = 0.055$ Adequate!



4.2 Lateral torsional buckling check:

$M_{ed} := 194.607\ kN \cdot m$

Statical system	ψ	k	C_1	C_2	C_3
	0	1,0 0,7 0,5	1,879 2,092 2,150	–	0,939 1,473 2,150

$\psi := 0$ $\quad C_1 := 1.879$ $\quad C_2 := 0$ $\quad C_3 := 0.939$ $\quad L := h$

$k := 1$ $\quad k_w := 1$ $\quad z_j := 0\ mm$ (double symmetric cross section)

$$M_{cr} := C_1 \cdot \frac{\pi^2 \cdot E \cdot I_{z.c}}{(k \cdot L)^2} \cdot \left(\sqrt{\left(\frac{k}{k_w}\right)^2 \cdot \frac{I_{w.c}}{I_{z.c}} + \frac{(k \cdot L)^2 \cdot G \cdot I_{t.c}}{\pi^2 \cdot E \cdot I_{z.c}} + \left(0 - C_3 \cdot z_j\right)^2} - \left(0 - C_3 \cdot z_j\right) \right)$$

$M_{cr} = \left(2.962 \cdot 10^3\right)\ kN \cdot m$

Non-dimensional slenderness: $\quad \lambda'_{LT} := \sqrt{W_{pl.y.c} \cdot \frac{f_y}{M_{cr}}} = 0.488$

$M_{pl.y.Rk} := W_{pl.y.c} \cdot f_y = 704.55\ kN \cdot m$

reduction factor of curve A: $\quad \chi_{LT} := 0.927852$

Design resistance for LT buckling: $\quad M_{b.Rd} := \chi_{LT} \cdot \frac{M_{pl.y.Rk}}{\gamma_{m1}} = 653.718\ kN \cdot m$

Utilization ratio: $\quad \eta := \frac{M_{ed}}{M_{b.Rd}} = 0.298 \quad Adequate!$

4.3. FB and LT buckling interaction check:

$N_{Rk} := N_{pl.Rk} = \left(4.373 \cdot 10^{3}\right)\ \boldsymbol{kN}$

$M_{y.Ed} := M_{ed} = 194.607\ \boldsymbol{kN \cdot m}$

$M_{y.Rk} := f_y \cdot W_{pl.y.c} = 704.55\ \boldsymbol{kN \cdot m}$

$C_{my} := 0.9$

$\psi := 0$

$C_{mLT} := 0.6$

$$k_{yy} := C_{my} \cdot min\left(1 + \left(\lambda'_y - 0.2\right) \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{m1}}}, \left(1 + 0.8 \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{m1}}}\right)\right) = 0.939$$

$\lambda'_z = 0.042 \quad < \quad 0.4$

$$k_{zy} := \max\left(0.6 + \lambda'_z, 1 - \frac{0.1 \cdot \lambda'_y}{\left(C_{my} - 0.25\right)} \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{m1}}}\right) = 0.992$$

$$\frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{m1}}} + k_{yy} \cdot \frac{M_{y.Ed}}{\chi_{LT} \cdot \frac{M_{y.Rk}}{\gamma_{m1}}} = 0.335$$

$$\frac{N_{Ed}}{\chi_z \cdot \frac{N_{Rk}}{\gamma_{m1}}} + k_{zy} \cdot \frac{M_{y.Ed}}{\chi_{LT} \cdot \frac{M_{y.Rk}}{\gamma_{m1}}} = 0.315$$

The member is adequate for flexural buckling and for LTB

5.. Beam stability checks using the reduction factor method:

$$l_{beam} := \frac{l}{\cos(\alpha_{inc})} = 14.508\ m$$

$$\frac{l_{beam}}{6} = 2.418\ m$$

$$\nu_y := 1$$

$$\nu'_z := 1.0$$

$$\nu_z := \frac{\nu'_z}{n_p + 2} = 0.167$$

Column slenderness around the strong axis: $\lambda_y := \nu_y \cdot \frac{l_{beam}}{i_{y.b}} = 71.309$

$\lambda_y < \lambda_1$

Column slenderness around the weak axis: $\lambda_z := \nu_z \cdot \frac{l_{beam}}{i_{z.b}} = 56.284$

$\lambda_z < \lambda_1$

$$N_{cr.y} := \pi^2 \cdot E \cdot \frac{A_b}{\lambda_y^{\ 2}} = \left(4.728 \cdot 10^3\right)\ kN$$

$$N_{cr.z} := \pi^2 \cdot E \cdot \frac{A_b}{\lambda_z^{\ 2}} = \left(7.59 \cdot 10^3\right)\ kN$$

$$N_{pl.Rk} := A_b \cdot f_y = \left(3.19 \cdot 10^3\right)\ kN$$

Relative slenderness around the strong axis: $\lambda'_y := \frac{N_{pl.Rk}}{N_{cr.y}} = 0.675$

Relative slenderness around the weak axis: $\lambda'_z := \frac{N_{pl.Rk}}{N_{cr.z}} = 0.42$

Imperfection factor around the strong axis (curve a): $\alpha_y := 0.21$

$$\phi_y := 0.5 \cdot \left(1 + \alpha_y \cdot \left(\lambda'_y - 0.2\right)\right) + \lambda'^{\ 2}_y = 1.005$$

Imperfection factor around the weak axis (curve b): $\alpha_z := 0.34$

$$\phi_z := 0.5 \cdot \left(1 + \alpha_z \cdot \left(\lambda'_z - 0.2\right)\right) + \lambda'^{\ 2}_z = 0.714$$

Reduction factor for buckling around the strong axis:

$$\chi_y := min\left(\frac{1}{\phi_y + \sqrt{\phi_y^{\ 2} - \lambda'^{\ 2}_y}}, 1\right) = 0.571$$

Reduction factor for buckling around the weak axis:

$$\chi_z := min\left(\frac{1}{\phi_z + \sqrt{{\phi_z}^2 - {\lambda'_z}^2}}, 1\right) = 0.774$$

$$\chi := min\left(\chi_y, \chi_z\right) = 0.571$$

Design buckling resistance:

$$N_{b.Rd} := \chi \cdot \frac{N_{pl.Rk}}{\gamma_{m1}} = 1822.898\ \boldsymbol{kN}$$

$N_{Ed} := 87.878\ \boldsymbol{kN}$ (from Axis Vm)

Utilisation ratio: $\eta := \frac{N_{Ed}}{N_{b.Rd}} = 0.048$ Adequate!

Suggestions for efficient design (100% utilisation):

1. Decreasing the size of the elements. The steel grade can be decreased to utilize 100%.
2. Installing knee bars, especially for the wall beams.
3. Changing the inclination of the roof. A more inclined roof may result in a buckling mode for the beams with a buckling length equal to half of the length of the roof..
4. Changing the number of the lateral supports .

5.2 Lateral torsional buckling check

$$M_{cr} := C_1 \cdot \frac{\pi^2 \cdot E \cdot I_{z.b}}{(k \cdot L)^2} \cdot \left(\sqrt{\left(\frac{k}{k_w}\right)^2 \cdot \frac{I_{w.b}}{I_{z.b}} + \frac{(k \cdot L)^2 \cdot G \cdot I_{t.b}}{\pi^2 \cdot E \cdot I_{z.b}} + (0 - C_3 \cdot z_j)^2} - (0 - C_3 \cdot z_j) \right)$$

$$L := 2 \cdot \frac{l_{beam}}{(n_p + 2)} = 4.836\ m$$

$k = 1$

$k_w := 1$

$M_{ed.2} := -105.848\ kN \cdot m$ $\qquad$ $M_{ed} := 194.607\ kN \cdot m$

$$\psi := \frac{M_{ed.2}}{M_{ed}} = -0.544$$

$C_1 := 2.806$

$C_2 = 0$

$C_3 := 0.864$

$M_{cr} = 988.011\ kN \cdot m$

Non-dimensional slenderness: $\lambda'_{LT} := \sqrt{W_{pl.y.b} \cdot \frac{f_y}{M_{cr}}} = 0.783$

$M_{pl.y.Rk} := W_{pl.y.b} \cdot f_y = 605\ kN \cdot m$

reduction factor of curve B: $\chi_{LT} := 0.735$

Design resistance for LT buckling: $M_{b.Rd} := \chi_{LT} \cdot \frac{M_{pl.y.Rk}}{\gamma_{m1}} = 444.675\ kN \cdot m$

Utilization ratio: $\eta := \frac{M_{ed}}{M_{b.Rd}} = 0.438$ $\qquad$ $Adequate!$

Project

Analysis by Amgalantuul Purevsuren

AxisVM X6 R2b · Registered to Amgalantuul Purevsuren

Model 5.axs

Report

Project

Analysis by Amgalantuul Purevsuren

Model: **Model 5.axs** 5/15/2022

Materials

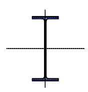
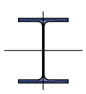
	Name	Type	National design code	Material code	Model	E_x [N/mm^2]	E_y [N/mm^2]	ν	α_T [1/°C]	ρ [kg/m^3]
1	S 275	Steel	Eurocode-H	10025-2	Linear	210000	210000	0.30	1.2E-5	7850

	Name	Material color	Contour color	Texture	P_1	P_2	P_3
1	S 275			Steel	f_y[N/mm^2] = 275.00	f_u[N/mm^2] = 430.00	f_y^*[N/mm^2] = 255.00

	Name	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}
1	S 275	f_u^*[N/mm^2] = 410.00										

Name: Material name; **Type:** Type of material; **Model:** Material model; **E_x:** Young's modulus of elasticity in local x direction; **E_y:** Young's modulus of elasticity in local y direction; **ν:** Poisson's ratio; **α_T:** Thermal expansion coefficient; **ρ:** Density; **Contour color:** Material outline color; **P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_8, P_9, P_{10}, P_{11}, P_{12}, P_{13}, P_{14}:** Design parameter;

Cross-sections

	Name	Drawing	Process	Shape	h [mm]	b [mm]	tw [mm]	tf [mm]	r_1 [mm]	r_2 [mm]	r_3 [mm]
1	IPE 500		Rolled	I	500.0	200.0	10.2	16.0	21.0	0	0
2	HE 400 A		Rolled	I	390.0	300.0	11.0	19.0	27.0	0	0

	Name	Ax [mm^2]	Ay [mm^2]	Az [mm^2]	Ix [mm^4]	Iy [mm^4]	Iz [mm^4]	Iyz [mm^4]	I_1 [mm^4]	I_2 [mm^4]	α [°]
1	IPE 500	11553.92	5887.51	4968.85	903296.5	4.8208E+8	2.1417E+7	0	4.8208E+8	2.1417E+7	0
2	HE 400 A	15900.68	10298.69	4201.46	1953265.0	4.5077E+8	8.5639E+7	0	4.5077E+8	8.5639E+7	0

	Name	Iω [mm^6]	$W_{1,el,t}$ [mm^3]	$W_{1,el,b}$ [mm^3]	$W_{2,el,t}$ [mm^3]	$W_{2,el,b}$ [mm^3]	$W_{1,pl}$ [mm^3]	$W_{2,pl}$ [mm^3]	i_y [mm]	i_z [mm]
1	IPE 500	1.2346E+12	1928302.0	1928302.0	214172.4	214172.4	2194516.0	335901.4	204.3	43.1
2	HE 400 A	2.8902E+12	2311663.0	2311663.0	570927.7	570927.7	2562282.0	872908.3	168.4	73.4

	Name	Hy [mm]	Hz [mm]	y_G [mm]	z_G [mm]	y_s [mm]	z_s [mm]	β_y [mm]	β_z [mm]	β_w []	S.p.
1	IPE 500	200.0	500.0	100.0	250.0	0	0	0	0	0	9
2	HE 400 A	300.0	390.0	150.0	195.0	0	0	0	0	0	9

Name: Cross-section name; **Process:** Manufacturing process; **h:** Cross-section height; **b:** Cross-section width; **tw:** Web thickness; **tf:** Flange thickness; **r_1, r_2, r_3:** Rounding radius; **Ax:** Cross-section area; **Ay, Az:** Shear area; **Ix:** Torsional inertia; **Iy, Iz:** Flexural inertia; **Iyz:** Centrifugal inertia; **I_1, I_2:** Principal flexural inertia; **α:** Principal directions; **Iω:** Warping constant; **$W_{1,el,t}$, $W_{1,el,b}$, $W_{2,el,t}$, $W_{2,el,b}$:** Elastic section modulus; **$W_{1,pl}$, $W_{2,pl}$:** Plastic section modulus; **i_y, i_z:** Radius of inertia; **Hy:** Dimension in local y direction; **Hz:** Dimension in local z direction; **y_G:** y coordinate of the center of gravity; **z_G:** z coordinate of the center of gravity; **y_s:** y coordinate of the shear (torsion) center relative to the center of gravity; **z_s:** z coordinate of the shear (torsion) center relative to the center of gravity; **β_y, β_z, β_w:** Wagner's coefficient; **S.p.:** Stress calculation points;

Spring characteristics

	Name	*Type*	*Degree of freedom*	*Model*	*K*	K_V	P_1
1	Soft - Translational	N-N	Translational	Linear	1E+0 kN/m	1E+0 kN/m	—
2	Rigid - Translational	N-N	Translational	Linear	1E+10 kN/m	1E+10 kN/m	—
3	Soft - Rotational	N-N	Rotational	Linear	1E+0 kNm/rad	1E+0 kNm/rad	—
4	Rigid - Rotational	N-N	Rotational	Linear	1E+10 kNm/rad	1E+10 kNm/rad	—
5	Complete - inverse	Warping transmission	Warping	Linear	—	—	WF = -1
6	Complete - direct	Warping transmission	Warping	Linear	—	—	WF = 1
7	Rigid	Warping transmission	Warping	Linear	—	—	WF = 0

Name: Name of the spring characteristics; **Model:** Material model; **K:** Initial stiffness; $\mathbf{K_V}$**:** Vibration stiffness; $\mathbf{P_1}$**:** Parameter;

References

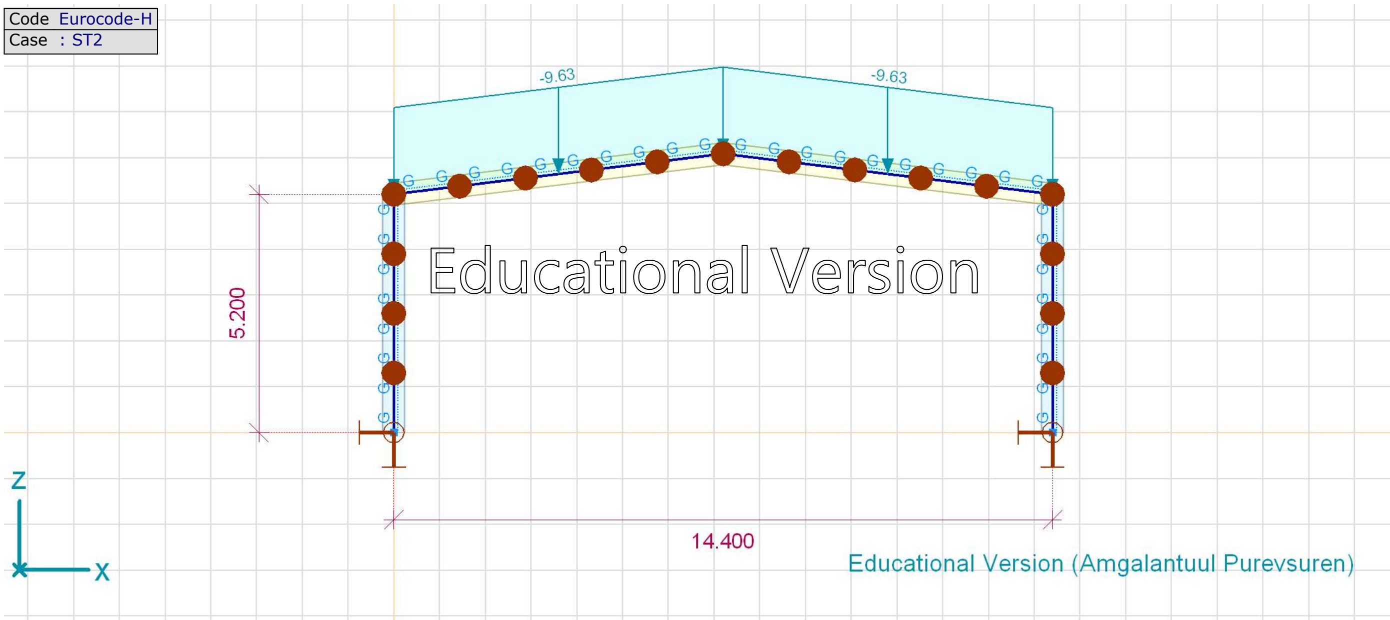
	Name	*Type*	X_1 *[m]*	Y_1 *[m]*	Z_1 *[m]*	X_2 *[m]*	Y_2 *[m]*	Z_2 *[m]*	X_3 *[m]*	Y_3 *[m]*	Z_3 *[m]*
1	R1		7.00								

Name: Reference name; **Type:** Type of %s;

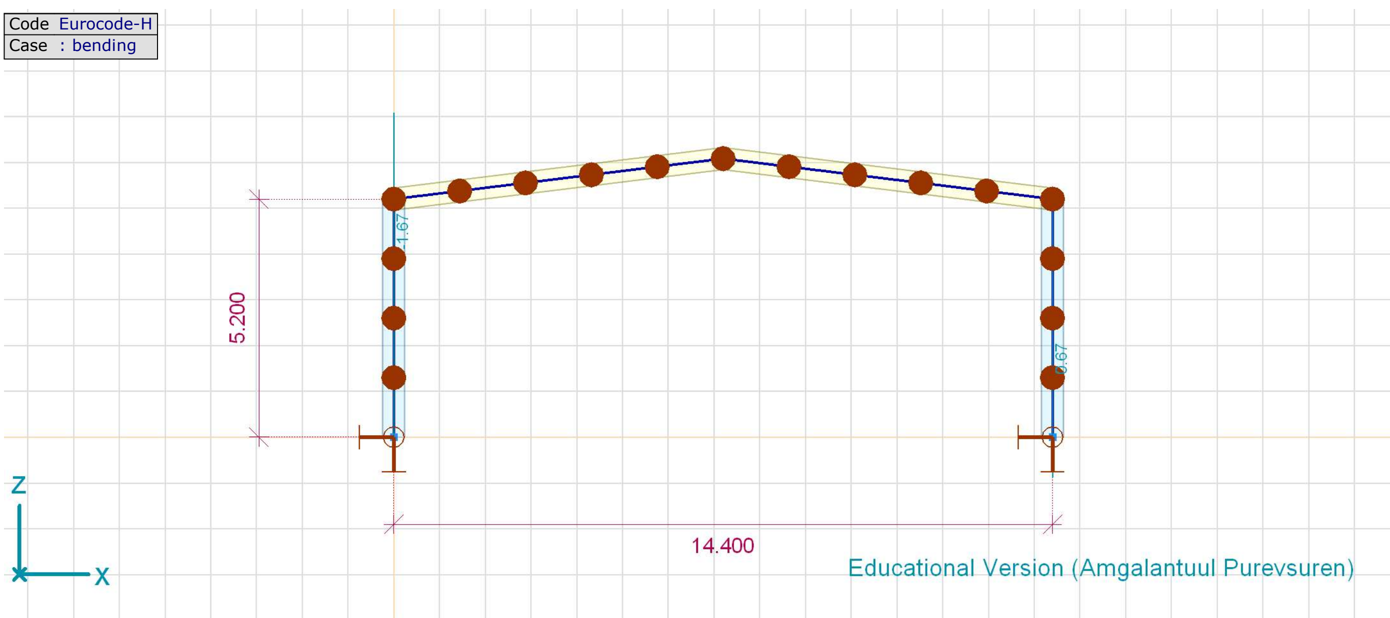
Nodes

	X [m]	*Y [m]* ▼	*Z [m]*	e_X	e_Y	e_Z	θ_X	θ_Y	θ_Z
1	0	0	0	f	Con	f	Con	f	Con
2	14.400	0	0	f	Con	f	Con	f	Con
3	0	0	5.200	f	f	f	f	f	f
4	14.400	0	5.200	f	f	f	f	f	f
5	7.200	0	6.084	f	f	f	f	f	f
6	0	0	1.300	f	f	f	f	f	f
7	0	0	2.600	f	f	f	f	f	f
8	0	0	3.900	f	f	f	f	f	f
9	14.400	0	3.900	f	Con	f	Con	f	Con
10	14.400	0	2.600	f	f	f	f	f	f
11	14.400	0	1.300	f	f	f	f	f	f
12	1.440	0	5.377	f	Con	f	Con	f	Con
13	2.880	0	5.554	f	Con	f	Con	f	Con
14	4.320	0	5.730	f	Con	f	Con	f	Con
15	5.760	0	5.907	f	Con	f	Con	f	Con
16	8.640	0	5.907	f	Con	f	Con	f	Con
17	10.080	0	5.730	f	f	f	f	f	f
18	11.520	0	5.554	f	f	f	f	f	f
19	12.960	0	5.377	f	Con	f	Con	f	Con

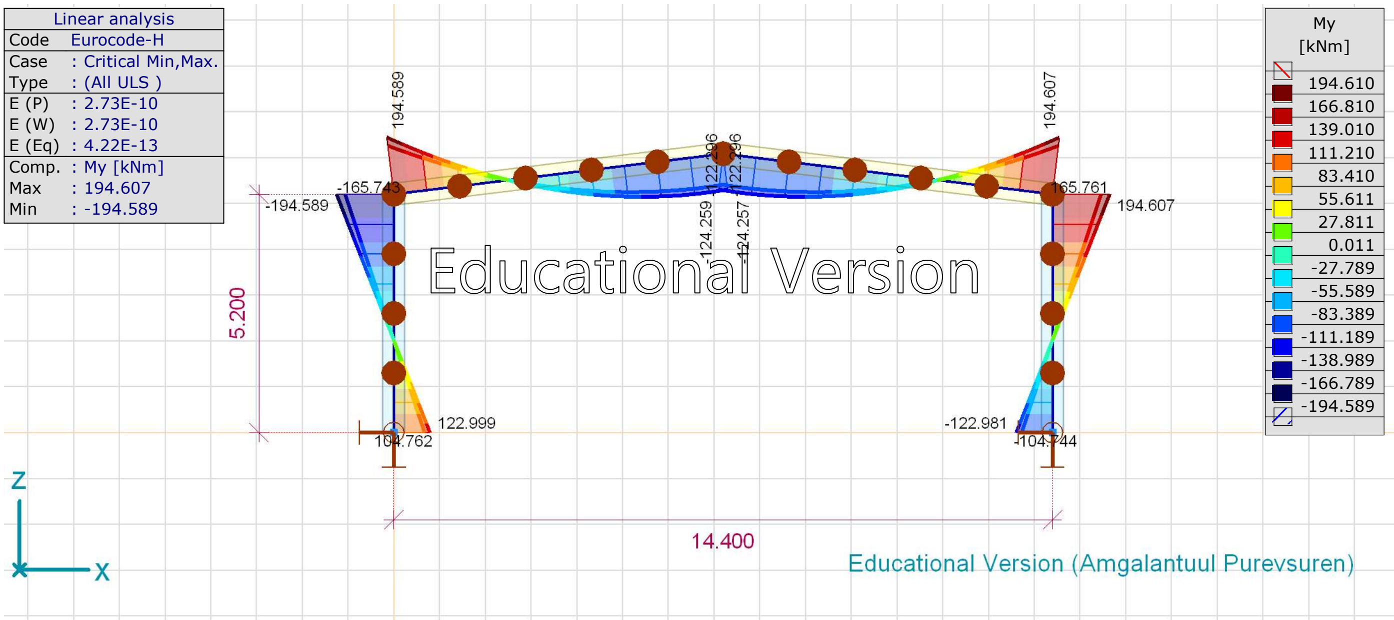
$\mathbf{e_X}$**:** Nodal DOF (translation constraint X); $\mathbf{e_Y}$**:** Nodal DOF (translation constraint Y); $\mathbf{e_Z}$**:** Nodal DOF (translation constraint Z); $\boldsymbol{\theta_X}$**:** Nodal DOF (rotation constraint about X-Axis); $\boldsymbol{\theta_Y}$**:** Nodal DOF (rotation constraint about Y-Axis); $\boldsymbol{\theta_Z}$**:** Nodal DOF (rotation constraint about Z-Axis);



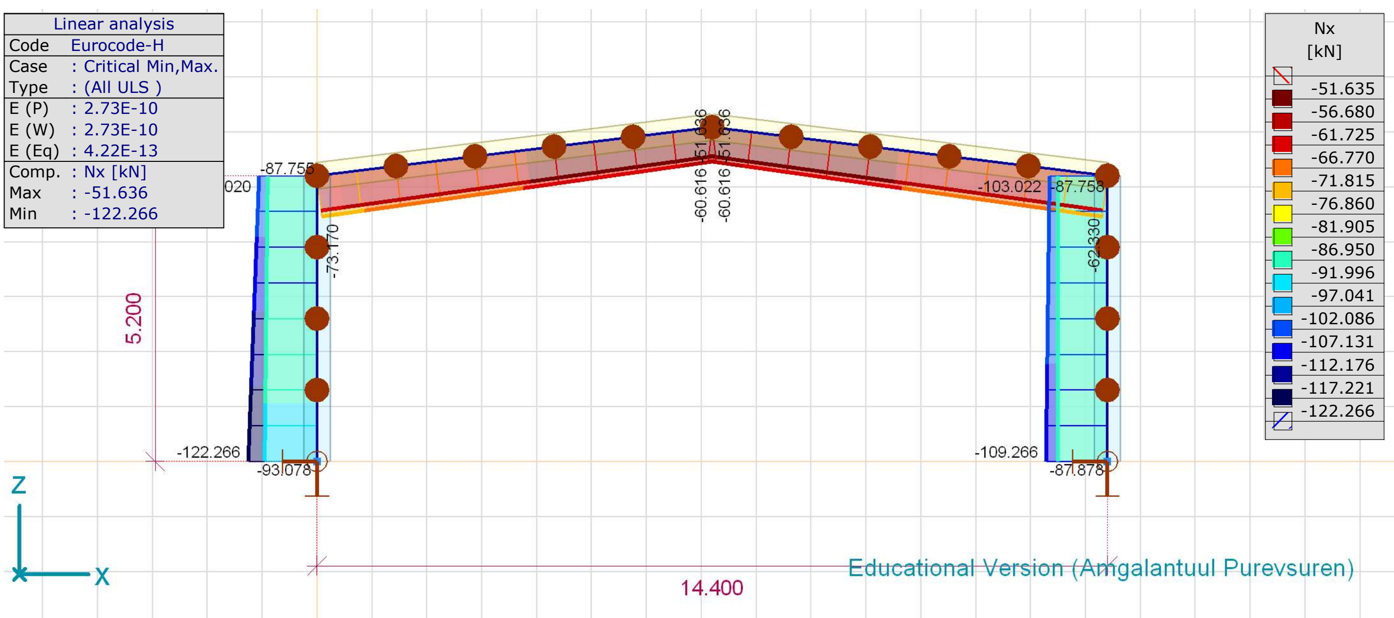
ST2, Front view



bending, Front view



[I], Linear,(Auto) Critical, My, Filled diagram, Front view



[I], Linear,(Auto) Critical, Nx, Filled diagram, Front view