ПРОЕКТСОФТ

Software Package

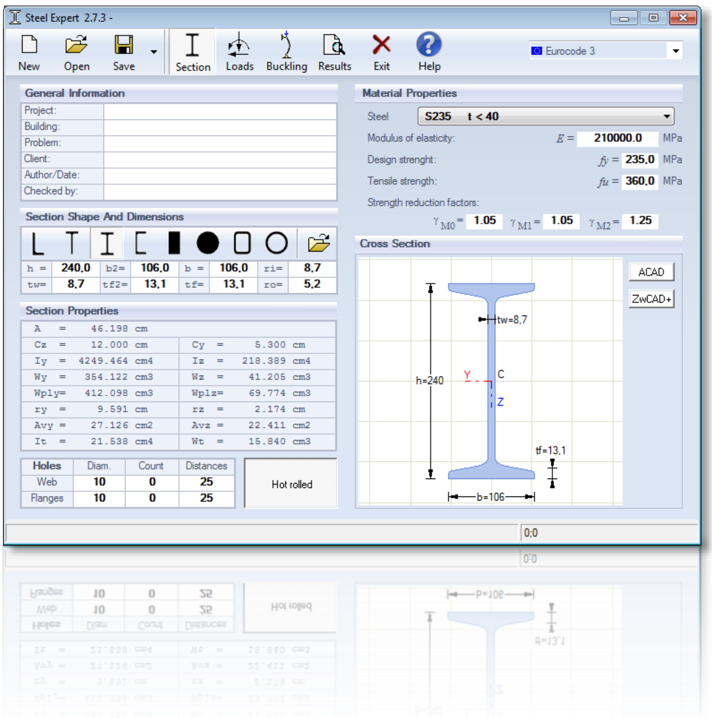
Design Expert version 2.7

Structural Design and Detailing to Eurocode

Steel Expert EC

Design of steel elements according to EN 1993-1-1:2005

User manual



2014

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About the program

Steel expert is a software for design of steel elements according to Eurocode 3 (EN 1993-1-1:2005). Calculations include elastic and plastic section design, local buckling and element buckling for combined axial force (tension or compression), bending moments in two directions, shear forces and torsion. Eight different types of sections are available L T I [● ○ ▮ ▯. The program includes a library of standard steel sections. Option for holes in webs and flanges is available as well. Results are presented in professional looking **HTML** format report for viewing and printing.

Data input

Program data is divided into several pages:

Materials and Sections Data   Buckling Data   Loading Data   Design Results

Click the respective button to switch between pages. The "**Results**" button starts calculations and generates an **html** report, which is displayed on the screen. Input values are entered in the respective tables or text fields on each page. You can move to the next field either by mouse click or using the **Tab** key. You can go back to the previous field with **Shift+Tab** keys combination.

Files

Steel Expert has its own file format and the data for each problem can be saved to a file on the disk. Input files have *** .stl** extension, while design results are stored in *** .stl.html** files.

New file

Click the **"New"** button to save current data to a new file. A standard file selection dialog appears. Select or write down file path and name and click **"Save"**.

Open a file

Click the "**Open**" button. A standard file selection dialog appears. Select or write down file path and name and click "**Open**".

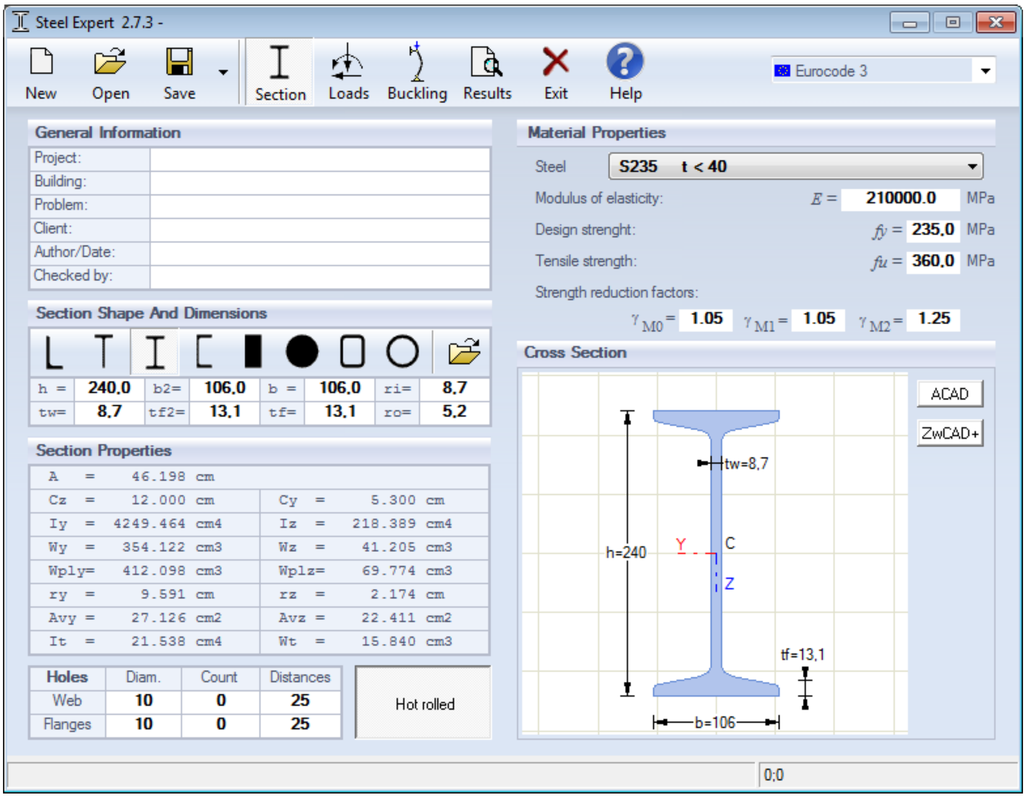
Save a file

Click the **"Save"** button. A standard file selection dialog appears. Select or write down file name. If file already exists, you can overwrite it or select a different name.

Input data

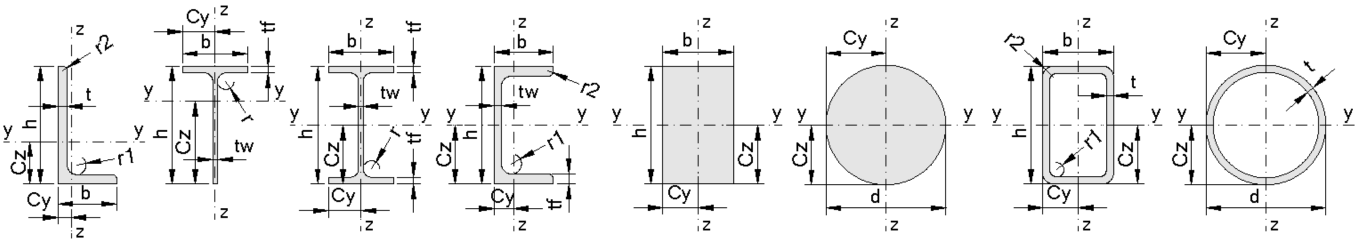
Materials

Select steel grade from the "**Steel**" combo box. The program automatically fills in the respective strength properties f_{yk} and f_{uk}. You can also input custom values for f_y and f_u for steel grades that are not included in the library. Partial safety factors are also required. Default values are: $\gamma_{M0} = 1.05$, $\gamma_{M1} = 1.05$, $\gamma_{M2} = 1.25$.



Cross sections

Eight different shape types are available. Sections can be standard hot-rolled, cold formed, built-up, welded etc. If you have a non-standard cross section, you should select the shape from the respective button (L T I [▮ ● ▢ ○) and enter the dimensions manually. Notations for dimensions and axes for different shapes are as follows:



Area properties are calculated precisely, including fillets. **There is no option for tapered flanges of non-standard sections, so they should be entered as parallel with average thickness.** In this case section properties are approximate. Torsional properties are calculated by approximate formulas with precision of 1% – 2%.

Standard cross sections can be selected from the "**Steel Sections Library**. The library is opened by the "**Open**" button located next to shapes buttons. Select section type according to the respective standard - European, British, Russian or Bulgarian.

European

- L Hot rolled equal angles to EN 10056-1
- L Hot rolled unequal angles to EN 10056-1
- [Hot rolled normal channels to NF A 45-202
- I Hot rolled I-sections IPE to EN 89

- Hot rolled wide flange I-sections HE to EN 53-62
- Hot rolled circular hollow sections CHS to EN 10210-2
- Hot rolled square hollow sections SHS to EN 10210-2
- Hot rolled rectangular hollow sections RHS to EN 10210-2
- Cold formed square hollow sections SHS to EN 10219-2
- Cold formed rectangular hollow sections RHS to EN 10219-2

British

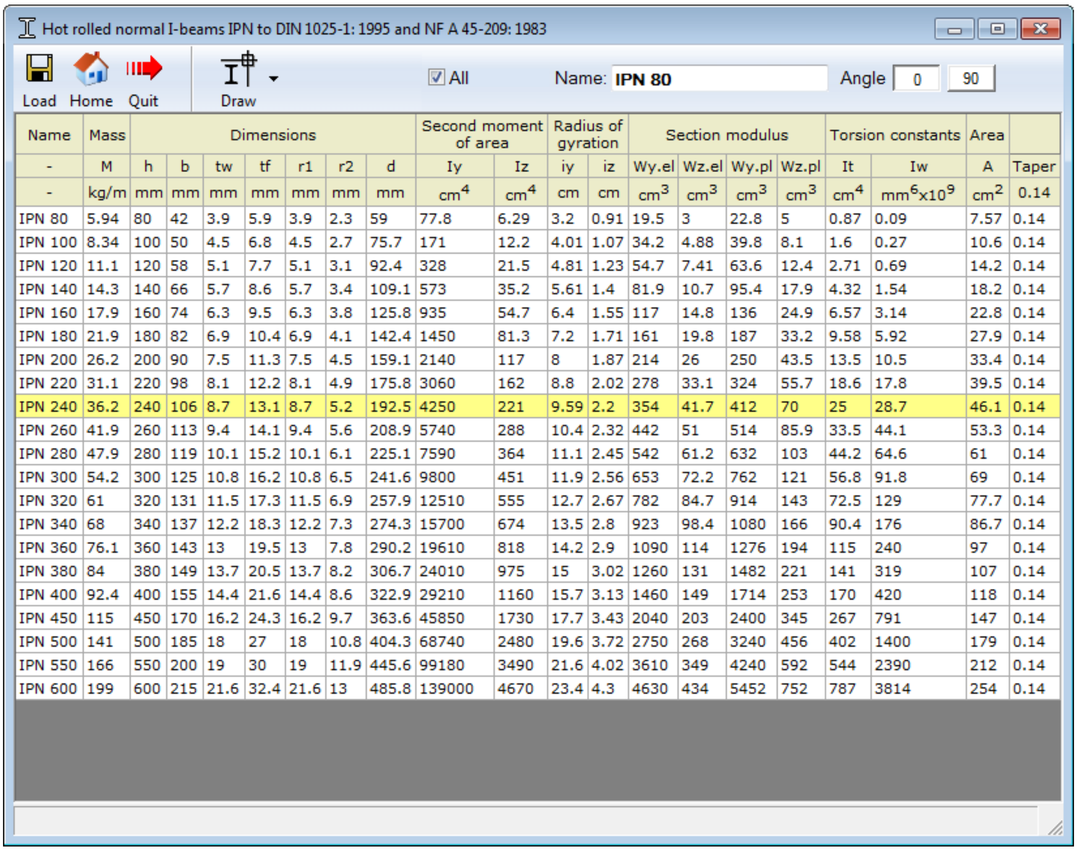
- Hot rolled channels with taper flanges **RSC** to BS4
- Hot rolled channels with parallel flanges **PFC** to BS4
- Hot rolled joists with taper flanges **RSJ** to BS4
- Hot rolled universal beams **UB** to BS4
- Hot rolled universal columns **UC** to BS4

Russian

- Hot rolled unequal angles to GOST 8510-72
- Hot rolled I-sections with parallel flanges to GOST 2620-83
- Hot rolled wide flange I-sections to GOST 2620-83
- Hot rolled I-columns to GOST 2620-83

Bulgarian

- Hot rolled equal angles to BDS 2612-73
- Hot rolled channels with tapered flanges to BDS 6176-75
- Hot rolled channels with parallel flanges to BDS 6176-75
- Hot rolled I-sections to BDS 5951-75



Name	Mass	Dimensions							Second moment of area		Radius of gyration		Section modulus				Torsion constants		Area	
-	M	h	b	tw	tf	r1	r2	d	Iy	Iz	iy	iz	Wy.el	Wz.el	Wy.pl	Wz.pl	It	Iw	A	Taper
-	kg/m	mm	mm	mm	mm	mm	mm	mm	cm^4	cm^4	cm	cm	cm^3	cm^3	cm^3	cm^3	cm^4	mm^6x10^9	cm^2	0.14
IPN 80	5.94	80	42	3.9	5.9	3.9	2.3	59	77.8	6.29	3.2	0.91	19.5	3	22.8	5	0.87	0.09	7.57	0.14
IPN 100	8.34	100	50	4.5	6.8	4.5	2.7	75.7	171	12.2	4.01	1.07	34.2	4.88	39.8	8.1	1.6	0.27	10.6	0.14
IPN 120	11.1	120	58	5.1	7.7	5.1	3.1	92.4	328	21.5	4.81	1.23	54.7	7.41	63.6	12.4	2.71	0.69	14.2	0.14
IPN 140	14.3	140	66	5.7	8.6	5.7	3.4	109.1	573	35.2	5.61	1.4	81.9	10.7	95.4	17.9	4.32	1.54	18.2	0.14
IPN 160	17.9	160	74	6.3	9.5	6.3	3.8	125.8	935	54.7	6.4	1.55	117	14.8	136	24.9	6.57	3.14	22.8	0.14
IPN 180	21.9	180	82	6.9	10.4	6.9	4.1	142.4	1450	81.3	7.2	1.71	161	19.8	187	33.2	9.58	5.92	27.9	0.14
IPN 200	26.2	200	90	7.5	11.3	7.5	4.5	159.1	2140	117	8	1.87	214	26	250	43.5	13.5	10.5	33.4	0.14
IPN 220	31.1	220	98	8.1	12.2	8.1	4.9	175.8	3060	162	8.8	2.02	278	33.1	324	55.7	18.6	17.8	39.5	0.14
IPN 240	36.2	240	106	8.7	13.1	8.7	5.2	192.5	4250	221	9.59	2.2	354	41.7	412	70	25	28.7	46.1	0.14
IPN 260	41.9	260	113	9.4	14.1	9.4	5.6	208.9	5740	288	10.4	2.32	442	51	514	85.9	33.5	44.1	53.3	0.14
IPN 280	47.9	280	119	10.1	15.2	10.1	6.1	225.1	7590	364	11.1	2.45	542	61.2	632	103	44.2	64.6	61	0.14
IPN 300	54.2	300	125	10.8	16.2	10.8	6.5	241.6	9800	451	11.9	2.56	653	72.2	762	121	56.8	91.8	69	0.14
IPN 320	61	320	131	11.5	17.3	11.5	6.9	257.9	12510	555	12.7	2.67	782	84.7	914	143	72.5	129	77.7	0.14
IPN 340	68	340	137	12.2	18.3	12.2	7.3	274.3	15700	674	13.5	2.8	923	98.4	1080	166	90.4	176	86.7	0.14
IPN 360	76.1	360	143	13	19.5	13	7.8	290.2	19610	818	14.2	2.9	1090	114	1276	194	115	240	97	0.14
IPN 380	84	380	149	13.7	20.5	13.7	8.2	306.7	24010	975	15	3.02	1260	131	1482	221	141	319	107	0.14
IPN 400	92.4	400	155	14.4	21.6	14.4	8.6	322.9	29210	1160	15.7	3.13	1460	149	1714	253	170	420	118	0.14
IPN 450	115	450	170	16.2	24.3	16.2	9.7	363.6	45850	1730	17.7	3.43	2040	203	2400	345	267	791	147	0.14
IPN 500	141	500	185	18	27	18	10.8	404.3	68740	2480	19.6	3.72	2750	268	3240	456	402	1400	179	0.14
IPN 550	166	550	200	19	30	19	11.9	445.6	99180	3490	21.6	4.02	3610	349	4240	592	544	2390	212	0.14
IPN 600	199	600	215	21.6	32.4	21.6	13	485.8	139000	4670	23.4	4.3	4630	434	5452	752	787	3814	254	0.14

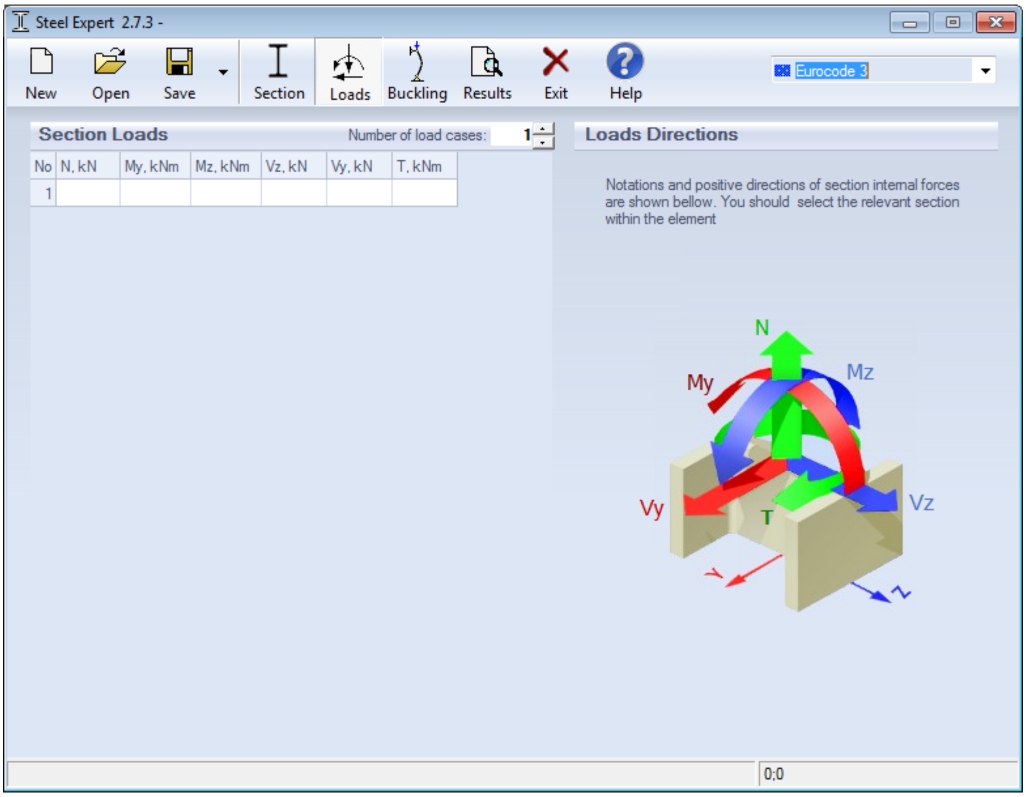
Section dimensions and properties are displayed in tables. Select a section with the mouse and click the "**Load**" button. Section dimensions are loaded into the program and area properties are re-calculated. Properties presented in the library tables are for information only and they are not used further. Library sections can be additionally modified after loading. For example, you can enter a T-section made by cutting a standard I-section in two. Select the I-section from the library, load it into the program, change shape to T and height to half.

Holes/openings in sections

Holes in webs and flanges are entered by specifying diameter, number and distance between holes. The section drawing is updated with the specified holes. Holes outside the section are colored in red. Holes with spacing and edge distances smaller than the required ones are colored in yellow. This alerts the user that distances are non-compliant to code requirements for bolt connections, but it does not stop further work because holes may have another purpose. Holes are considered in section analysis. They are not considered in element buckling checks.

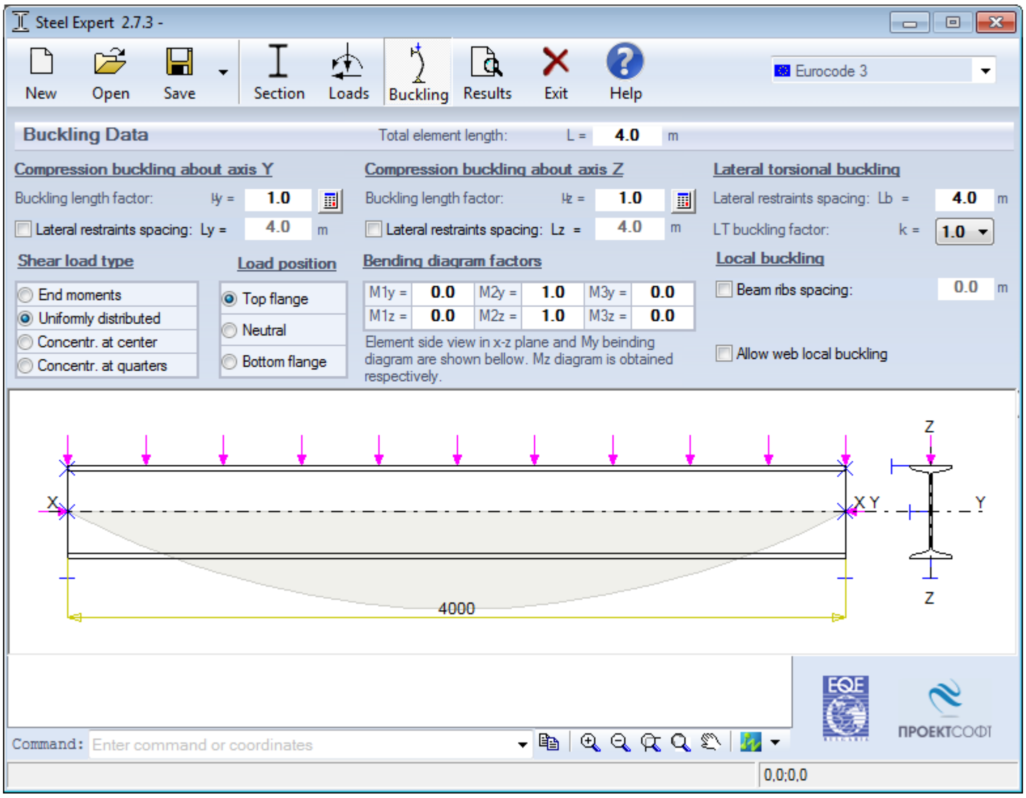
Loading

Select the number of load cases first. Then enter axial force ***N***, bending moments ***M***$_y$, ***M***$_z$, shear forces ***V***$_y$, ***V***$_z$ and torsion ***T*** for each load case in the table. All components will be considered as acting both separately and simultaneously for a given load case. Positive axial force is tension and negative is compression.



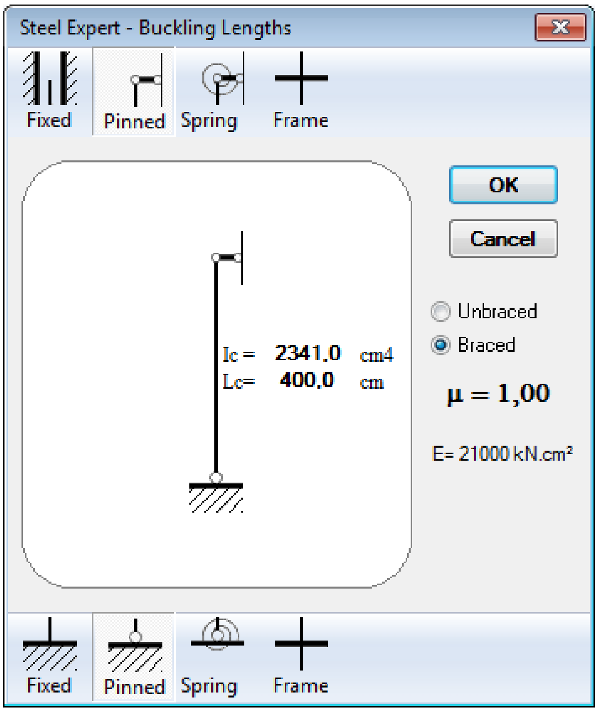
Effective lengths

Effective lengths are required for buckling analysis of steel elements. Buckling factors for both main planes μ_y and μ_z shall be entered and the program calculates the respective effective lengths L_{efy} and L_{efz} . You can also input spacing between lateral restraints. Recommendations for buckling factor values for different types of structural elements are given in the design codes.



The button opens the "Buckling calculator" window, where μ can be calculated depending on the selected support conditions. You can have pinned, fixed or spring restraint as well as restraint provided by beams in frames.

Effective length for lateral-torsional buckling is defined as the distance between lateral restraints of compressed flange. Load positions (top flange, neutral or bottom flange) and load patterns (end moments, distributed or concentrated) are also required as well as the shapes of bending moment diagram. Local buckling of beam webs is also checked. Stiffening ribs can be defined and rib spacing ***a*** can be entered.



Design to EN 1993-1-1:2005

Classification of cross sections

Section class is determined based on the assumption that section is loaded either with uniform compression or bending. Class is determined for each part of the section, using Table 5.1 for the respective stress diagram. In case of bending of non-symmetrical sections, equations for bending and compressive stress calculation are used. Factor c/t is determined assuming that neutral line passes through the center of area.

Sections class 1 and 2 are designed for plastic resistance and sections class 3 – for elastic resistance. Sections class 4 are not designed in the current version. In these sections local buckling occurs before steel yielding.

The most conservative result from the classification of separate parts is relevant for the whole section. If no compression is defined, classification for compression is not taken into account. If no bending moments are defined, classification for bending is not taken into account, respectively.

In case of bending with axial force this approach gives conservative results. Take for instance a beam with IPE 400 section, loaded with bending moment of 300 KN.m and compression of -0,10 KN. Web shall be classified as Class 1 for bending and Class 4 for compression. But final class for the section is Class 4, due to the presence of compression. In such cases, when the effects of compressive force upon the final stresses is negligible, it is better to assume exactly zero.

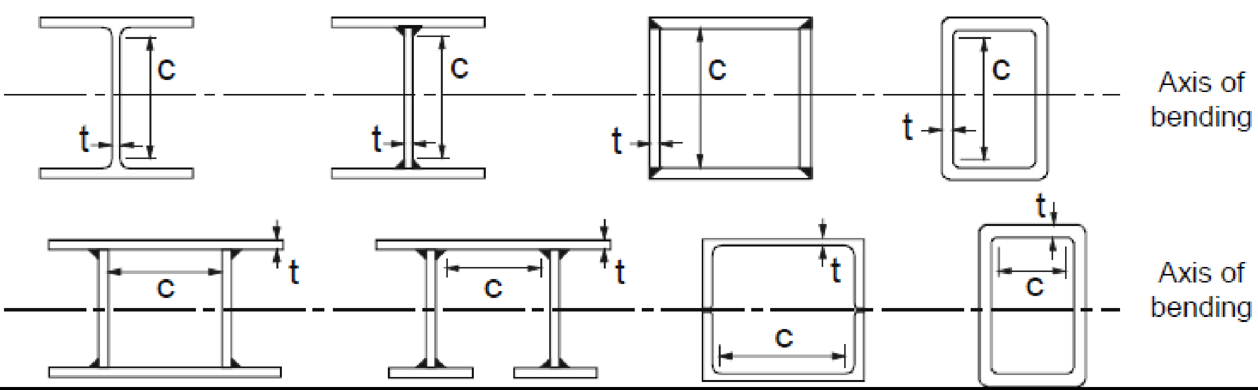
Results of section classification are provided in tabular form:

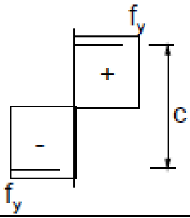
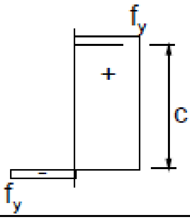
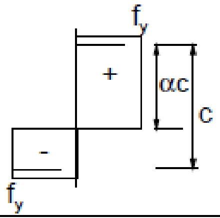
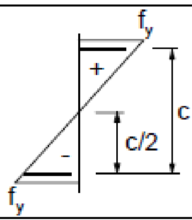
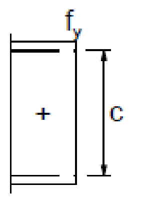
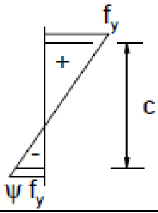
	Compression	**Bending**
Web	Class 4	Class 1
Flanges	Class 1	Class 1

Table 5.2. Maximum width-to-thickness ratios for compression parts

Sheet 1 of 3. Internal compression parts.

Internal compression parts

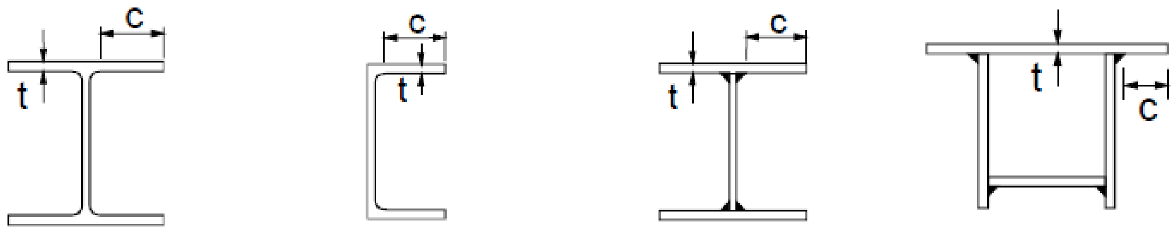


Class	Part subject to bending	Part subject to compression	Part subject to bending and compression
Stress distribution in parts (compression positive)			
1	$c/t \le 72\varepsilon$	$c/t \le 33\varepsilon$	when $\alpha > 0{,}5$: $c/t \le \dfrac{396\varepsilon}{13\alpha - 1}$ when $\alpha \le 0{,}5$: $c/t \le \dfrac{36\varepsilon}{\alpha}$
2	$c/t \le 83\varepsilon$	$c/t \le 38\varepsilon$	when $\alpha > 0{,}5$: $c/t \le \dfrac{456\varepsilon}{13\alpha - 1}$ when $\alpha \le 0{,}5$: $c/t \le \dfrac{41{,}5\varepsilon}{\alpha}$
Stress distribution in parts (compression positive)			
3	$c/t \le 124\varepsilon$	$c/t \le 42\varepsilon$	when $\psi > -1$: $c/t \le \dfrac{42\varepsilon}{0{,}67 + 0{,}33\psi}$ when $\psi \le -1^{*)}$: $c/t \le 62\varepsilon(1-\psi)\sqrt{(-\psi)}$

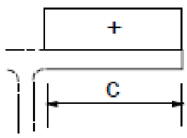
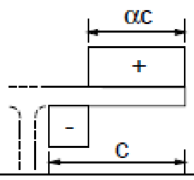
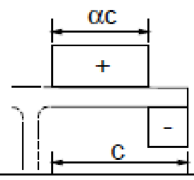
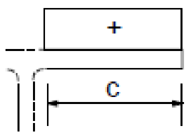
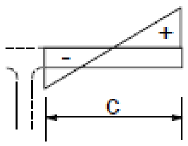
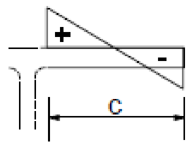
$\varepsilon = \sqrt{235/f_y}$	f_y	235	275	355	420	460
	ε	1,00	0,92	0,81	0,75	0,71

Sheet 2 of 3. Outstand flanges.

Outstand flanges



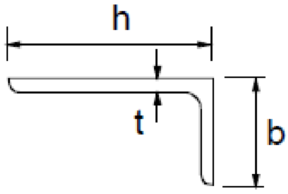
Rolled sections | Welded sections

Class	Part subject to compression	Part subject to bending and compression: Tip in compression	Part subject to bending and compression: Tip in tension
Stress distribution in parts (compression positive)			
1	$c/t \le 9\varepsilon$	$c/t \le \frac{9\varepsilon}{\alpha}$	$c/t \le \frac{9\varepsilon}{\alpha\sqrt{\alpha}}$
2	$c/t \le 10\varepsilon$	$c/t \le \frac{10\varepsilon}{\alpha}$	$c/t \le \frac{10\varepsilon}{\alpha\sqrt{\alpha}}$
Stress distribution in parts (compression positive)			
3	$c/t \le 14\varepsilon$	$c/t \le 21\varepsilon\sqrt{k_\sigma}$ For k_σ see EN 1993-1-5	

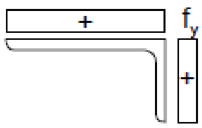
$\varepsilon = \sqrt{235/f_y}$	f_y	235	275	355	420	460
	ε	1,00	0,92	0,81	0,75	0,71

Sheet 3 of 3. Angles

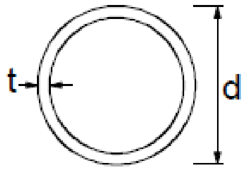
Angles



Refer also to “Outstand flanges” (see sheet 2 of 3)	Does not apply to angles in continuous contact with other components

Class	Section in compression
Stress distribution across section (compression positive)	
3	$h/t \le 15\varepsilon: \dfrac{b+h}{2t} \le 11{,}5\varepsilon$

Tubular sections



Class	Section in bending and/or compression
1	$d/t \le 50\varepsilon^2$
2	$d/t \le 70\varepsilon^2$
3	$d/t \le 90\varepsilon^2$ NOTE For $d/t > 90\varepsilon^2$ see EN 1993-1-6.

$\varepsilon = \sqrt{235/f_y}$						
	f_y	235	275	355	420	460
	ε	1,00	0,92	0,81	0,75	0,71
	ε^2	1,00	0,85	0,66	0,56	0,51

Resistance of cross sections

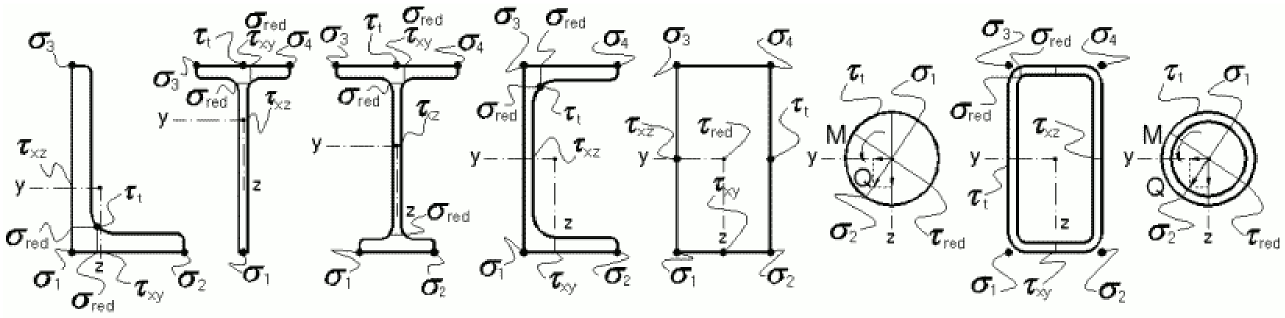
Elastic design

Class 3 sections are checked using the following equation:

$$\sqrt{\left(\frac{\sigma_{x,Ed}}{f_y/\gamma_{M0}}\right)^2 + \left(\frac{\sigma_{z,Ed}}{f_y/\gamma_{M0}}\right)^2 - \left(\frac{\sigma_{x,Ed}}{f_y/\gamma_{M0}}\right)\left(\frac{\sigma_{z,Ed}}{f_y/\gamma_{M0}}\right) + 3\left(\frac{\tau_{Ed}}{f_y/\gamma_{M0}}\right)^2} \le 1 \ (6.1)^*$$

*In Eurocode this equation is presented without the square root operation. However, the original form of the equation is used in the program in order to obtain realistic factor of safety (FOS) and safety margin for the section. In this manual, the original notations of equations according to EN 1993-1-1 are presented in brackets.

This equation is applied to different points of the cross section and stresses are calculated according to the principles of structural mechanics.



Design checks for points with maximum values for normal, shear and combined stresses are relevant. Results are presented in tabular form.

$\frac{\sigma_{x,Ed}}{f_y/\gamma_{M0}}$ (6.42)	$\frac{\tau_{xy,Ed}}{f_y/\sqrt{3}\gamma_{M0}}$ (6.19)	$\frac{\tau_{xz,Ed}}{f_y/\sqrt{3}\gamma_{M0}}$ (6.19)	$\frac{\tau_{max,Ed}}{f_y/\sqrt{3}\gamma_{M0}}$	$\frac{\sqrt{\sigma_{x,Ed}{}^2+3\tau_{Ed}{}^2}}{f_y/\gamma_{M0}}$

Equations (6.19) and (6.42) may be considered as partial cases of (6.1).

$$1/\sqrt{3} \approx 0.58$$

$$\sigma_{x,Ed}(y,z) = \frac{N_{Ed}}{A} \pm \frac{M_{y,Ed}}{I_y} \cdot z \pm \frac{M_{z,Ed}}{I_z} \cdot y$$

$$\tau_{xz,Ed}(y) = \frac{V_{z,Ed} \cdot S_z(y)}{b(y) \cdot I_y} \quad (6.20)$$

$$\tau_{xy,Ed}(z) = \frac{V_{y,Ed} \cdot S_y(z)}{b(z) \cdot I_z} \quad (6.20)$$

$$\tau_{T,Ed} = \frac{T_{Ed}}{W_t}$$

$$\tau_{red,Ed} = \sqrt{\tau_{xy,Ed}{}^2 + \tau_{xz,Ed}{}^2}$$

$$\tau_{Max,Ed} = \max(\tau_{xy,Ed} | \tau_{xz,Ed} | \tau_{T,Ed} | \tau_{red,Ed})$$

$$\sigma_{x,Ed} = \max(\sigma_1 | \sigma_2 | \sigma_3 | \sigma_4)$$

Normal stress $\sigma_{z,Ed}$, due to local transverse load, is not considered in this version of the software. Additional design checks should be performed in zones with local effects from significant transverse loads (for instance, under supports of secondary beams or crane wheels). If holes are specified, they are always considered in the calculation of the effective section properties. For unsymmetrical I sections, shear force $V_{y,Ed}$ is distributed between bottom (1) and top (2) flange according to the equations:

$$V_{y,1} = V_{y,Ed} \frac{I_{f1}}{I_{f1} + I_{f2}}$$

$$V_{y,2} = V_{y,Ed} \frac{I_{f2}}{I_{f1} + I_{f2}}$$

Plastic design

Plastic design is performed for sections Class 1 and Class 2. Elastic design is also performed but the results are presented for information only. They are not relevant for the final bearing capacity of the section.

Design checks for uniform tension:

$$\frac{N_{Ed}}{N_{t,Rd}} \leq 1 \ (6.5)$$

Tension capacity of the section is determined according to the equation:

$$N_{pl,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} \ (6.6)$$

In case of holes, this check is performed using the effective section properties.

$$N_{u,Rd} = \frac{0.9A_{net} \cdot f_u}{\gamma_{M2}} (6.7)$$

Design check for uniform compression:

$$\frac{N_{Ed}}{N_{c,Rd}} \leq 1 \ (6.9)$$

Compression capacity of the section is determined according to the equation:

$$N_{c,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} \ (6.10)$$

Reduced bearing capacity for axial force $N_{pl,V,Rd}$ is calculated instead of $N_{pl,Rd}$ and $N_{c,Rd}$ in case of design shear force $V_{Ed} \geq 0.5V_{pl,Rd}$ and reduced yield strength is used for shear area instead of f_y:

$$(1-\rho)f_y \ (6.29) \text{ , where } \rho = \left(\frac{2V_{Ed}}{V_{pl,Rd}} - 1\right)^2$$

When torsion is present, factor ρ is computed with $V_{pl,T,Rd}$ instead of $V_{pl,Rd}$.

Bending check

$$\frac{M_{Ed}}{M_{c,Rd}} \leq 1 \ (6.12)$$

Bending capacity of the section is determined according to the equations:

$$M_{y,Rd} = M_{pl,y,Rd} = \frac{W_{pl,y} \cdot f_y}{\gamma_{M0}} \ (6.13)$$

$$M_{z,Rd} = M_{pl,z,Rd} = \frac{W_{pl,z} \cdot f_y}{\gamma_{M0}} \ (6.13)$$

When bending moment and axial force are present, design check is performed according to equation:

$$\frac{M_{Ed}}{M_{N,Rd}} \leq 1 \ (6.31)$$

Bearing capacity of the section for bending with axial force is determined according to the equations:

For rectangular section:

$$M_{N,Rd} = M_{pl,Rd}\left[1 - \left(\frac{N_{Ed}}{N_{pl,Rd}}\right)^2\right] \ (6.32)$$

For I section:

$$M_{N,y,Rd} = M_{pl,y,Rd}\frac{1-n}{1-0.5a} (6.36)$$

For $n \leq a$: $M_{N,z,Rd} = M_{pl,z,Rd} (6.37)$

For $n > a$: $M_{N,z,Rd} = M_{pl,z,Rd}\left[1 - \left(\frac{n-a}{1-a}\right)^2\right] (6.38)$

$$n = \frac{N_{Ed}}{N_{pl,Rd}}$$

$$a = \frac{A - 2bt_f}{A}$$

For hollow sections:

$$M_{N,y,Rd} = M_{pl,y,Rd} \cdot \frac{1-n}{1-0.5a_w} \ (6.39)$$

$$M_{N,z,Rd} = M_{pl,z,Rd} \cdot \frac{1-n}{1-0.5a_f} \ (6.40)$$

$$a_w = \frac{A - 2bt_f}{A}$$

$$a_f = \frac{A - 2bt_w}{A}$$

<u>Design check for biaxial bending</u>

$$\left(\frac{M_{y,Ed}}{M_{y,Rd}}\right)^{\alpha} + \left(\frac{M_{z,Ed}}{M_{z,Rd}}\right)^{\beta} \leq 1 \ (6.41)$$

For I sections: $\alpha = 2$, $\beta = 5n \geq 1$

For circular hollow sections: $\alpha = 2$, $\beta = 2$

For rectangular hollow sections: $\alpha = \beta = 1.66/(1-1.13n^2)$

For biaxial bending with axial force, $M_{y,Rd}$ and $M_{z,Rd}$ are replaced in equation 6.41 by $M_{N,y,Rd}$ and $M_{N,z,Rd}$, respectively.

When V_{Ed} exceeds 50% of $V_{pl,Rd}$, the design resistance for combined bending with axial force should be calculated using reduced yield strength for calculation of shear area:

$$(1-\rho)f_y \ (6.29), \text{where } \rho = \left(\frac{2V_{Ed}}{V_{pl,Rd}} - 1\right)^2$$

If torsion moment is present, the ρ factor is calculated with $V_{pl,T,Rd}$ instead of $V_{pl,Rd}$.

<u>Shear force check</u>

$$\frac{V_{Ed}}{V_{c,Rd}} \leq 1 \ (6.17)$$

Bearing capacity of the section for shear is determined by the following formulas:

$$V_{y,Rd} = V_{pl,y,Rd} = \frac{A_{vy} \cdot f_y}{\sqrt{3}\,\gamma_{M0}} \ (6.18)$$

$$V_{z,Rd} = V_{pl,z,Rd} = \frac{A_{vz} \cdot f_y}{\sqrt{3}\,\gamma_{M0}} \ (6.18)$$

Shear area A_V, is calculated according to 6.2.6 (3).

When shear force and torsion moment are present, the check is performed according to the following formulas:

$$\frac{V_{Ed}}{V_{pl,T,Rd}} \leq 1 \ (6.25)$$

For I section:

$$V_{pl,T,Rd} = \sqrt{1 - \frac{\tau_{t,\mathrm{Ed}}}{1.25\left(f_y/\sqrt{3}\right)/\gamma_{M0}}}\, V_{pl,Rd}\ (6.26)$$

For U section:

$$V_{pl,T,Rd} = \left(\sqrt{1 - \frac{\tau_{t,\mathrm{Ed}}}{1.25\left(f_y/\sqrt{3}\right)/\gamma_{M0}}} - \frac{\tau_{w,\mathrm{Ed}}}{\left(f_y/\sqrt{3}\right)/\gamma_{M0}}\right) V_{pl,Rd}\ (6.27)$$

For hollow sections:

$$V_{pl,T,Rd} = \left(1 - \frac{\tau_{t,\mathrm{Ed}}}{1.25\left(f_y/\sqrt{3}\right)/\gamma_{M0}}\right) V_{pl,Rd}\ (6.28)$$

<u>Torsion check</u>

$$\frac{T_{Ed}}{T_{Rd}} \le 1\ (6.23)$$

Torsion capacity of the section is determined by the following formula:

$$T_{Rd} = \frac{W_t \cdot f_y}{\gamma_{M0}}$$

Results from design checks are presented in tabular form.

$\frac{N_{Ed}}{N_{Rd}}$ (6.5) (6.9)	$\frac{N_{Ed}}{N_{u,Rd}}$ (6.7) -	$\frac{M_{y,Ed}}{M_{y,Rd}}$ (6.12) (6.31)	$\frac{M_{z,Ed}}{M_{z,Rd}}$ (6.12) (6.31)	$\frac{V_{z,Ed}}{V_{z,Rd}}$ (6.17) (6.25)	$\frac{V_{y,Ed}}{V_{y,Rd}}$ (6.17) (6.25)	$\frac{T_{Ed}}{T_{Rd}}$ (6.23) -	$\left(\frac{M_{y,Ed}}{M_{y,Rd}}\right)^{\alpha} + \left(\frac{M_{z,Ed}}{M_{z,Rd}}\right)^{\beta}$ (6.12) (6.31)

Buckling design of members

Uniform members in compression

Compression members are designed for buckling as follows:

$$\frac{N_{Ed}}{N_{b,Rd}} \le 1\ (6.47)$$

$$N_{b,Rd} = \frac{\chi A f_y}{\gamma_{M1}}\ (6.48)$$

$$\chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}} \le 1\ (6.49)$$

$$\Phi = 0.5\left[1 + \alpha\left(\bar{\lambda} - 0.2\right) + \bar{\lambda}^2\right]$$

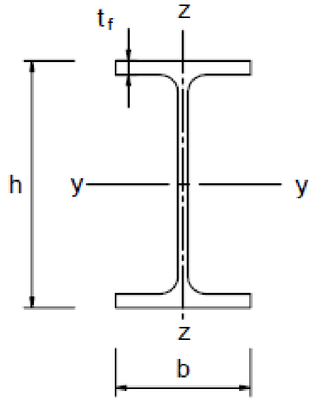
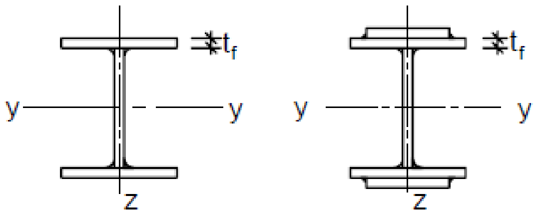
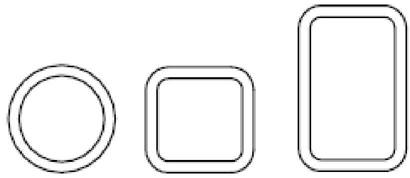
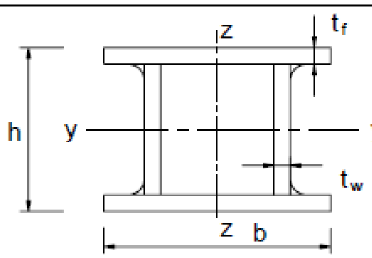
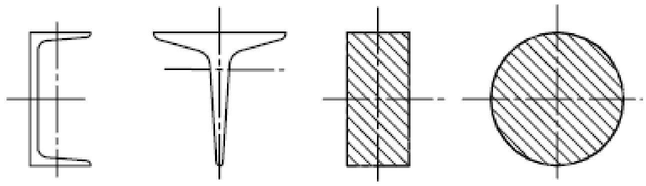
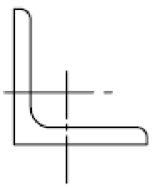
$$\bar{\lambda} = \sqrt{\frac{A f_y}{N_{cr}}};\ N_{cr} = \frac{\pi^2 E A}{\lambda^2};\ \lambda = \frac{l_{eff}}{r};\ r = \sqrt{\frac{I}{A}}$$

Factor α considers initial imperfections. It is provided in Table 6.1 for the respective buckling curves depending on cross section type:

Buckling curve	a_0	a	b	c	d
Imperfection factor	0.13	0.21	0.34	0.49	0.76

Verification is performed for the two principle axis with the respective section properties and effective lengths. Effective length l_{eff} in Steel Expert is defined as either $L*\mu_y$ or L_y (depending on user selection) for buckling about “y” axis. For buckling about “z” axis, it can be $L*\mu_z$ or L_z, respectively. L_y and L_z are distances between lateral restraints. In the current version of the program no check for torsional-flexural buckling under uniform compression is performed. Buckling curves are selected from Table 6.2 depending on section type and steel class.

Table 6.2 Selection of buckling curve for a cross-section

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
Welded I-sections			$t_f \leq 40$ mm	y – y z – z	b c	b c
			$t_f > 40$ mm	y – y z – z	c d	c d
Hollow sections			hot finished	any	a	a_0
			cold formed	any	c	c
Welded box sections			generally (except as below)	any	b	b
			thick welds: $a > 0,5t_f$ $b/t_f < 30$ $h/t_w < 30$	any	c	c
U-, T- and solid sections				any	c	c
L-sections				any	b	b

Uniform members in bending

$$\frac{M_{Ed}}{M_{b,Rd}} \leq 1 \;(6.54)$$

$$M_{b,Rd} = \frac{\chi_{LT} W_y f_y}{\gamma_{M1}} \;(6.55)$$

$W_y = W_{pl,y}$ for sections class 1 and 2 and $W_y = W_{el,y}$ for sections class 3.

$$\chi_{LT} = \frac{1}{\Phi_{\mathrm{LT}} + \sqrt{\Phi_{LT}^2 - \bar{\lambda}_{LT}^2}} \leq 1 \;(6.56)$$

$$\Phi_{\mathrm{LT}} = 0.5\left[1 + \alpha_{LT}\left(\bar{\lambda}_{LT} - 0.2\right) + \bar{\lambda}_{LT}^2\right]$$

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y f_y}{M_{cr}}}$$

$$M_{cr} = C_1 \frac{\pi^2 E I_z}{(kL)^2}\left[\sqrt{\left(\frac{k}{k_w}\right)^2 \frac{I_w}{I_z} + \frac{(kL)^2 G I_t}{\pi^2 E I_z} + \left(C_2 z_g - C_3 z_j\right)^2} - \left(C_2 z_g - C_3 z_j\right)\right]$$

The factor k depends on the support conditions against rotation at supports around vertical axis. It have to be entered 0.5 for both ends fixed, 0.7 for one fixed and one hinged and 1.0 for both ends hinged.

L is defined in Steel Expert as “Lateral restraints spacing” L_b. Factors C_1, C_2 and C_3 are provided in a tabular form depending on the type of transverse load (shape of M diagram) and the k factor. Factor k_w takes into account the possibility for rotation at member ends. It is accepted to be equal to 1.0 conservatively. $z_g = z_a - z_s$ is the height between loading point and shear center. Loading point can be selected to be: bottom flange (favorable), top flange (unfavorable) and neutral ($z_g = 0$).

$$z_j = z_s - \frac{\int_A (y^2 + z^2) z \, \mathrm{d}A}{2 I_y}$$

Factor α_{LT} accounts for initial imperfections. It is defined in Table 6.3 for the respective lateral-torsional buckling curves, depending on the cross section type.

Buckling curve	a	b	c	d
Imperfection factor α_{LT}	0.21	0.34	0.49	0.76

Members in combined bending with axial compression

Members which are subjected to combined bending and axial compression should satisfy:

$$\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}} + k_{yy} \frac{M_{y,Ed}}{\chi_{LT} M_{y,Rk}/\gamma_{M1}} + k_{yz} \frac{M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} \leq 1 \;(6.61)$$

$$\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}} + k_{zy} \frac{M_{y,Ed}}{\chi_{LT} M_{y,Rk}/\gamma_{M1}} + k_{zz} \frac{M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} \leq 1 \;(6.62)$$

$$N_{Rk} = A f_y$$

$M_{y,Rk} = W_{pl,y} f_y$ – for sections of class 1 and 2

$M_{y,Rk} = W_{el,y} f_y$ – for sections of class 3

$M_{z,Rk} = W_{pl,z} f_y$ – for sections of class 1 and 2

$M_{z,Rk} = W_{el,z} f_y$ – for sections of class 3

Interaction factors k_{yy}, k_{yz}, k_{zy} и k_{zz} are defined in Table B1 and table B2 in Annex B of EN 1993-1-1.

Table B1. Interaction factors for members, not susceptible to torsional deformations

Interaction factors	Type of sections	Design assumption	
		elastic cross-sectional properties class 3, class 4	plastic cross-sectional properties class 1, class 2
k_{yy}	I-sections RHS-sections	$C_{my}\left(1+0,6\bar{\lambda}_y \frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}}\right) \le C_{my}\left(1+0,6\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}}\right)$	$C_{my}\left(1+\left(\bar{\lambda}_y-0,2\right)\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}}\right) \le C_{my}\left(1+0,8\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}}\right)$
k_{yz}	I-sections RHS-sections	k_{zz}	$0,6\ k_{zz}$
k_{zy}	I-sections RHS-sections	$0,8\ k_{yy}$	$0,6\ k_{yy}$
k_{zz}	I-sections	$C_{mz}\left(1+0,6\bar{\lambda}_z \frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right) \le C_{mz}\left(1+0,6\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right)$	$C_{mz}\left(1+\left(2\bar{\lambda}_z-0,6\right)\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right) \le C_{mz}\left(1+1,4\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right)$
	RHS-sections		$C_{mz}\left(1+\left(\bar{\lambda}_z-0,2\right)\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right) \le C_{mz}\left(1+0,8\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right)$
For I- and H-sections and rectangular hollow sections under axial compression and uniaxial bending $M_{y,Ed}$ the coefficient k_{zy} may be $k_{zy} = 0$.			

Table B2. Interaction factors for elements, susceptible to torsion deformations

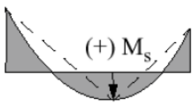
Interaction factors	Design assumptions	
	elastic cross-sectional properties class 3, class 4	plastic cross-sectional properties class 1, class 2
k_{yy}	k_{yy} from Table B.1	k_{yy} from Table B.1
k_{yz}	k_{yz} from Table B.1	k_{yz} from Table B.1
k_{zy}	$\left[1-\frac{0,05\bar{\lambda}_z}{\left(C_{mLT}-0,25\right)}\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right] \ge \left[1-\frac{0,05}{\left(C_{mLT}-0,25\right)}\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right]$	$\left[1-\frac{0,1\bar{\lambda}_z}{\left(C_{mLT}-0,25\right)}\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right] \ge \left[1-\frac{0,1}{\left(C_{mLT}-0,25\right)}\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right]$ for $\bar{\lambda}_z < 0,4$: $k_{zy} = 0,6+\bar{\lambda}_z \le 1-\frac{0,1\bar{\lambda}_z}{\left(C_{mLT}-0,25\right)}\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}$
k_{zz}	k_{zz} from Table B.1	k_{zz} from Table B.1

For members not susceptible to torsional deformations, flexural form of buckling will occur. For those susceptible to torsional deformations, torsional-flexural buckling will occur. Members not susceptible to torsional deformations are assumed to be those with $\chi_{LT} = 1$.

Equivalent uniform moment factors C_{my}, C_{mz} and C_{mLT} are defined in Table B3 depending on the diagram type between points of lateral restraints:

Factor	Bending axis	Points braced in direction	Steel Expert Notations
C_{my}	y-y	z-z	Distance between restraints: L_y
C_{mz}	z-z	y-y	Distance between restraints: L_z
C_{mLT}	y-y	y-y	Distance between restraints: L_b

Table B3. Equivalent uniform moment factors C_{my}, C_{mz} and C_{mLT}

Moment Diagram	Range		C_{my}, C_{mz} and C_{mLT} under loading	
			Distributed	Concentrated
M  ψM	$-1 \le \psi \le 1$		$0{,}6 + 0.4\,\psi \ge 0{,}4$	
(–) M_h ψM_h  (+) M_s $\alpha_s = M_s/M_h$	$0 \le \alpha_s \le 1$	$-1 \le \psi \le 1$	$0{,}2 + 0.8\,\alpha_s \ge 0{,}4$	$0{,}2 + 0.8\alpha_s \ge 0{,}4$
	$-1 \le \alpha_s < 0$	$0 \le \psi \le 1$	$0{,}1 - 0.8\,\alpha_s \ge 0{,}4$	$-0.8\alpha_s \ge 0{,}4$
		$-1 \le \psi < 0$	$0{,}1(1-\psi) - 0.8\,\alpha_s \ge 0{,}4$	$0{,}2(-\psi) - 0.8\,\alpha_s \ge 0{,}4$
(+) M_s  (+) M_h ψM_h $\alpha_h = M_h/M_s$	$0 \le \alpha_h \le 1$	$-1 \le \psi \le 1$	$0{,}95 + 0{,}05\,\alpha_h$	$0{,}90 + 0{,}10\,\alpha_h$
	$-1 \le \alpha_h < 0$	$0 \le \psi \le 1$	$0{,}95 + 0{,}05\,\alpha_h$	$0{,}90 + 0{,}10\,\alpha_h$
		$-1 \le \psi < 0$	$0{,}95 + 0{,}05\,\alpha_h(1+2\psi)$	$0{,}90 - 0{,}10\,\alpha_h(1+2\psi)$

Local buckling resistance of beam webs

For I and C sections, the design check is performed according to EN 1993-1-5 using the following formula:

$$\frac{V_{Ed}}{V_{b,Rd}} \le 1 \; (5.10)$$

$$V_{b,Rd} = V_{bw,Rd} = \frac{\chi_w h_w s f_y}{\sqrt{3}\gamma_{M1}} \le \frac{\eta h_w s f_y}{\sqrt{3}\gamma_{M1}} \; (5.1), (5.2)$$

Webs can be stiffened with transverse ribs or unstiffened. The contribution of flanges is neglected conservatively.

Factor χ_w is defined in Table 5.1 for rigid end posts.

$$\chi_w = \eta - \text{за}\ \bar{\lambda}_w < \frac{0{,}83}{\eta}$$

$$\chi_w = \frac{0{,}83}{\bar{\lambda}_w} - \text{за}\ \frac{0{,}83}{\eta} \le \bar{\lambda}_w < 1{,}08$$

$$\chi_w = \frac{1{,}37}{0{,}7 + \bar{\lambda}_w} - \text{за } \bar{\lambda}_w \geq 1{,}08$$

Slenderness parameter $\bar{\lambda}_w$ is defined by the following formulas:

- When the web is not stiffened:

$$\bar{\lambda}_w = \frac{h_w}{86{,}4s\varepsilon} \ (5.5)$$

$$\varepsilon = \sqrt{\frac{235}{f_y}}$$

- When the web is stiffened with transverse ribs:

$$\bar{\lambda}_w = \frac{h_w}{37.4s\varepsilon\sqrt{k_\tau}} \ (5.6)$$

Shear buckling factor is defined according to Annex A.3:

$$k_\tau = \begin{cases} 5{,}34 + \dfrac{4{,}00}{\alpha^2} \text{ за } \alpha \geq 1 \\ 4{,}00 + \dfrac{5{,}34}{\alpha^2} \text{ за } \alpha < 1 \end{cases} \ (A.5)$$

$\alpha = a/h_w$; h_w = h – t – t' – height of the web; a – spacing between ribs

s – Web thickness

Results are displayed in tabular form

$\frac{N_{Ed}}{N_{by,Rd}}$ (6.46)	$\frac{N_{Ed}}{N_{bz,Rd}}$ (6.46)	$\frac{M_{y,Ed}}{M_{b,Rd}}$ (6.54)	$\frac{V_{z,Ed}}{V_{bw,Rd}}$ (5.10)*	(6.61)	(6.62)

Examples to EN 1993 1-1:2005

Example 1.

Find the cross section capacity of hot rolled IPE 300 section loaded with design axial force N_{Ed} = 300 kN and design bending moment $M_{y,Ed}$ = 120 kN.m

Design checks using Steel Expert

Proektsoft - Steel Expert EC 2.0/2010

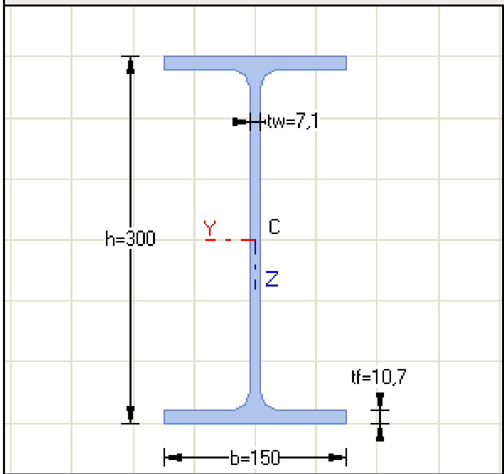
Steel Element Design To Eurocode 3

Project:	Example 5.1	Element:	
Building:		Author/Date:	
Client:		Checked By:	

Input Data

Steel S235 - t < 40 - fy = 235 MPa γ_{M0} = 1,05 γ_{M1} = 1,05 γ_{M2} = 1,25

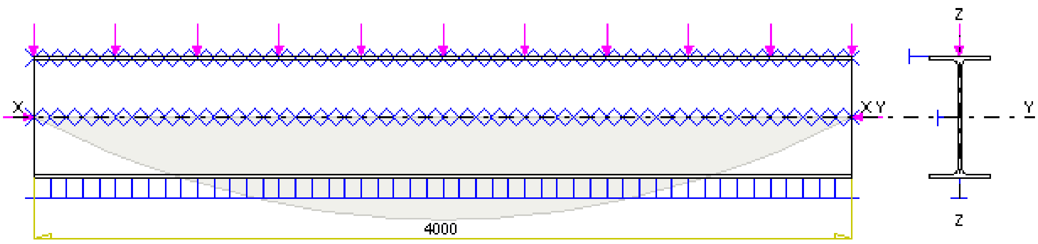
Section Dimensions And Properties - IPE 300 - I-SECTION



h [mm]	t_w [mm]	b [mm]	t_f [mm]	b_2 [mm]	t_{f2} [mm]
300,0	7,1	150,0	10,7	150,0	10,7
r_i [mm]	r_o [mm]	A [cm^2]	A_{vz} [cm^2]	A_{vy} [cm^2]	
15,0		53,8	25,7	32,1	
I_y [cm^4]	I_z [cm^4]	$W_{el,y}$ [cm^3]	$W_{el,z}$ [cm^3]	$W_{pl,y}$ [cm^3]	$W_{pl,z}$ [cm^3]
8356,1	603,8	557,1	80,5	628,4	125,2
r_y [cm]	r_z [cm]	C_z [cm]	C_y [cm]	I_t [cm^4]	W_t [cm^3]
12,5	3,3	15,0	7,5	19,9	18,4

Buckling Lengths
About axis "y" - $L_{eff,y}$ = 0,0cm
About axis "z" - $L_{eff,z}$ = 0,0cm
LT buckling - $L_{eff,b}$ = 0,0cm

Lateral-Torsional Buckling
Load position - Top flange
Load Type - Uniformly distributed
Web stiffeners at 0,0cm



Internal Forces

Case	N_{Ed} [kN]	$M_{y,Ed}$ [kNm]	$M_{z,Ed}$ [kN]	$V_{z,Ed}$ [kN]	$V_{y,Ed}$ [kN]	T_{Ed} [kNm]
1	350,0	120,0	0,0	0,0	0,0	0,0

Design Results

Section Classification

	Compression	Bending
Web	Class 2	Class 1
Flange	Class 1	Class 1

Section Elastic Design To Eq (6.1.)

Case	$\sigma_{x,Ed}$	$\tau_{xy,Ed}$	$\tau_{xz,Ed}$	$\tau_{max,Ed}$	$(\sigma_{x,Ed}^2 + 3\tau_{Ed}^2)^{1/2}$
1	280,5	0,0	0,0	0,0	258,6

Case	$\frac{\sigma_{x,Ed}}{f_y/\gamma_{M0}}$	$\frac{\tau_{xy,Ed}}{0.58f_y/\gamma_{M0}}$	$\frac{\tau_{xz,Ed}}{0.58f_y/\gamma_{M0}}$	$\frac{\tau_{max,Ed}}{0.58f_y/\gamma_{M0}}$	$\frac{(\sigma_{x,Ed}^2 + 3\tau_{Ed}^2)^{1/2}}{f_y/\gamma_{M0}}$
1	1,25	0,00	0,00	0,00	1,16

Section Plastic Design For Class 1 Or 2

Case	$N_{Rd}^{(2)}$ (6.6)(6.10)	$N_{u,Rd}$ (6.7)	$M_{y,Rd}^{(2)(3)}$ (6.13)	$M_{z,Rd}^{(2)(3)}$ (6.13)	$V_{z,Rd}^{(1)}$ (6.18)	$V_{y,Rd}^{(1)}$ (6.18)	T_{Rd}
1	1204,4	1394,8	125,0	28,0	331,9	414,8	2,4

Case	$\frac{N_{Ed}}{N_{Rd}}$ (6.5) (6.9)	$\frac{N_{Ed}}{N_{u,Rd}}$ (6.7) -	$\frac{M_{y,Ed}}{M_{y,Rd}}$ (6.12) (6.31)	$\frac{M_{z,Ed}}{M_{z,Rd}}$ (6.12) (6.31)	$\frac{V_{z,Ed}}{V_{z,Rd}}$ (6.17) (6.25)	$\frac{V_{y,Ed}}{V_{y,Rd}}$ (6.17) (6.25)	$\frac{T_{Ed}}{T_{Rd}}$ (6.23) -	$\frac{M_{y,Ed}}{M_{Ny,Rd}}^{\alpha} + \frac{M_{z,Ed}}{M_{Nz,Rd}}^{\beta}$ (6.12) (6.31)
1	0,29	0,25	0,96	0,00	0,00	0,00	0,00	0,92

(1) Reduced values $V_{T,Rd}$ are calculated to eq. (6.26) - (6.28) in case of shear combined with torsion T_{Ed}

(2) Reduced values $N_{V,Rd}$ and $M_{V,Rd}$ are calculated to eq. (6.29) in case of axial load or bending combined with shear V_{Ed}

(3) Reduced values $M_{N(V),Rd}$ are calculated to eq. (6.32) - (6.40) in case of bending combined with axial load N_{Ed}

Manual checks

$$M_{pl,y,Rd} = \frac{W_{pl,y} \cdot f_y}{\gamma_{M0}} = \frac{628 \cdot 23{,}5}{1{,}05} = 14055\ kNcm = 140{,}55\ kNm$$

$$N_{pl,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} = \frac{53{,}8 \cdot 23{,}5}{1{,}05} = 1204\ kN$$

$$n = \frac{N_{Ed}}{N_{pl,Rd}} = \frac{350}{1204} = 0{,}291$$

$$a = \frac{A - 2bt_f}{A} = \frac{53{,}8 - 2 \cdot 15 \cdot 1{,}07}{53{,}8} = 0{,}403$$

$$M_{N,y,Rd} = M_{pl,y,Rd} \frac{1-n}{1-0.5a} = 140{,}55 \frac{1 - 0{,}291}{1 - 0.5 \cdot 0{,}403} = 124.8\ kNm$$

$$\frac{M_{Ed}}{M_{N,Rd}} = \frac{120}{124.8} = 0.96 < 1$$

Example 2.

Verify bearing capacity of an IPE 400 section. Steel is S235 with $f_y = 23{,}5\ \mathrm{kN/cm^2}$, $\gamma_{M0} = 1{,}05$. Section is class 1. Design loads are $M_{y,Ed} = 240$ kNm; $N_{Ed} = 96$ kN; $V_{Ed} = 315$ kN

Design checks using Steel Expert

Proektsoft - Steel Expert EC 2.0/2010

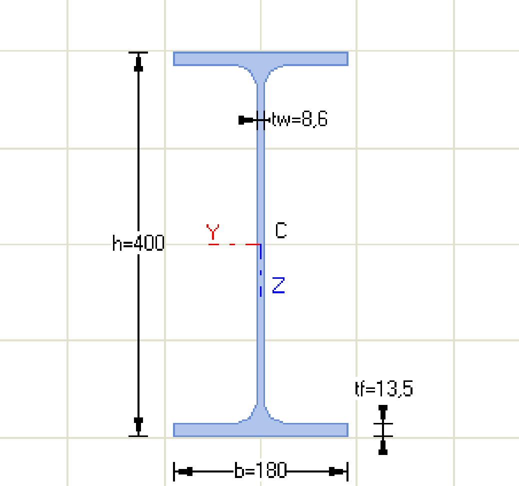
Steel Element Design To Eurocode 3

Project:	Example 5.2	Element:	
Building:		Author/Date:	
Client:		Checked By:	

Input Data

Steel S235 ëè.è ïð. t < 40 - fy = 235 MPa $\gamma_{M0} = 1{,}05$ $\gamma_{M1} = 1{,}05$ $\gamma_{M2} = 1{,}25$

Section Dimensions And Properties - 00 - I-SECTION



h [mm]	t_w [mm]	b [mm]	t_f [mm]	b_2 [mm]	t_{f2} [mm]
400,0	8,6	180,0	13,5	180,0	13,5
r_i [mm]	r_o [mm]	A [cm²]	A_{vz} [cm²]	A_{vy} [cm²]	
21,0		84,5	42,7	48,6	
I_y [cm⁴]	I_z [cm⁴]	$W_{el,y}$ [cm³]	$W_{el,z}$ [cm³]	$W_{pl,y}$ [cm³]	$W_{pl,z}$ [cm³]
23128,4	1317,8	1156,4	146,4	1307,1	229,0
r_y [cm]	r_z [cm]	C_z [cm]	C_y [cm]	I_t [cm⁴]	W_t [cm³]
16,5	3,9	20,0	9,0	50,5	37,3

Buckling Lengths

About axis "y" - $L_{eff,y}$ = 0,0cm

About axis "z" - $L_{eff,z}$ = 0,0cm

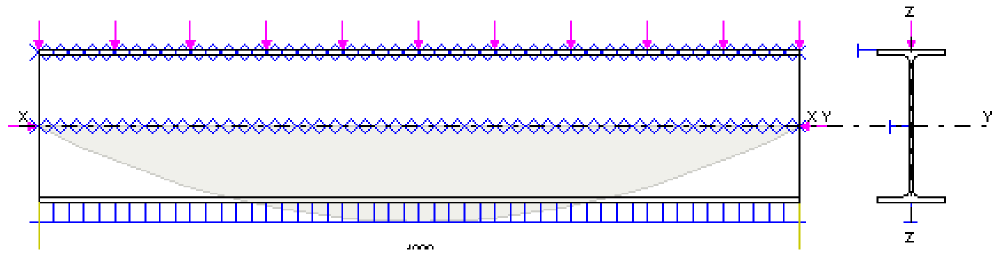
LT buckling - $L_{eff,b}$ = 0,0cm

Lateral-Torsional Buckling

Load position - Top flange

Load Type - Uniformly distributed

Web stiffeners at 0,0cm



Internal Forces

Case	N_{Ed} [kN]	$M_{y,Ed}$ [kNm]	$M_{z,Ed}$ [kN]	$V_{z,Ed}$ [kN]	$V_{y,Ed}$ [kN]	T_{Ed} [kNm]
1	96,0	240,0	0,0	315,0	0,0	0,0

Design Results

Section Classification

	Compression	Bending
Web	Class 3	Class 1
Flange	Class 1	Class 1

Section Elastic Design To Eq (6.1.)

Case	$\sigma_{x,Ed}$	$\tau_{xy,Ed}$	$\tau_{xz,Ed}$	$\tau_{max,Ed}$	$(\sigma_{x,Ed}^2 + 3\tau_{Ed}^2)^{1/2}$
1	218,9	0,0	98,1	98,1	205,8

Case	$\frac{\sigma_{x,Ed}}{f_y/\gamma_{M0}}$	$\frac{\tau_{xy,Ed}}{0.58f_y/\gamma_{M0}}$	$\frac{\tau_{xz,Ed}}{0.58f_y/\gamma_{M0}}$	$\frac{\tau_{max,Ed}}{0.58f_y/\gamma_{M0}}$	$\frac{(\sigma_{x,Ed}^2 + 3\tau_{Ed}^2)^{1/2}}{f_y/\gamma_{M0}}$
1	0,98	0,00	0,76	0,76	0,92

Section Plastic Design For Class 1 Or 2

Case	$N_{Rd}^{(2)}$ (6.6)(6.10)	$N_{u,Rd}$ (6.7)	$M_{y,Rd}^{(2)(3)}$ (6.13)	$M_{z,Rd}^{(2)(3)}$ (6.13)	$V_{z,Rd}^{(1)}$ (6.18)	$V_{y,Rd}^{(1)}$ (6.18)	T_{Rd}
1	1871,1	2189,3	291,2	51,2	551,7	628,0	4,8

Case	$\frac{N_{Ed}}{N_{Rd}}$ (6.5) (6.9)	$\frac{N_{Ed}}{N_{u,Rd}}$ (6.7) -	$\frac{M_{y,Ed}}{M_{y,Rd}}$ (6.12) (6.31)	$\frac{M_{z,Ed}}{M_{z,Rd}}$ (6.12) (6.31)	$\frac{V_{z,Ed}}{V_{z,Rd}}$ (6.17) (6.25)	$\frac{V_{y,Ed}}{V_{y,Rd}}$ (6.17) (6.25)	$\frac{T_{Ed}}{T_{Rd}}$ (6.23) -	$\left[\frac{M_{y,Ed}}{M_{Ny,Rd}}\right]^{\alpha} + \left[\frac{M_{z,Ed}}{M_{Nz,Rd}}\right]^{\beta}$ (6.12) (6.31)
1	0,05	0,04	0,82	0,00	0,57	0,00	0,00	0,68

(1) Reduced values $V_{T,Rd}$ are calculated to eq. (6.26) - (6.28) in case of shear combined with torsion T_{Ed}

(2) Reduced values $N_{V,Rd}$ and $M_{V,Rd}$ are calculated to eq. (6.29) in case of axial load or bending combined with shear V_{Ed}

(3) Reduced values $M_{N(V),Rd}$ are calculated to eq. (6.32) - (6.40) in case of bending combined with axial load N_{Ed}

Manual checks

$$V_{pl,z,Rd} = \frac{A_{vz} \cdot f_y}{\sqrt{3}\,\gamma_{M0}} = \frac{42{,}7 \cdot 23{,}5}{\sqrt{3}\, \cdot 1{,}05} = 551{,}75\,kN; \qquad V_{Ed} = 315kN \geq 0.5V_{pl,Rd} = 275{,}8\,kN$$

$$\rho = \left(\frac{2V_{Ed}}{V_{pl,Rd}} - 1\right)^2 = \left(\frac{2 \cdot 315}{551{,}75} - 1\right)^2 = 0.02$$

$$N_{pl,V,Rd} = \frac{A - \rho A_{vz}}{\gamma_{M0}} f_y = \frac{84{,}5 - 0{,}02 \cdot 42{,}7}{1{,}05} 23{,}5 = 1872\,kN$$

$$M_{pl,V,y,Rd} = \frac{W_{pl,y} - \rho s h_w{}^2/4}{\gamma_{M0}} f_y = \frac{1307{,}1 - 0{,}02 \cdot 0{,}86 \cdot 37{,}3^2/4}{1{,}05} 23{,}5 = 29120\,kNcm = 291{,}2\,kNm$$

$$n_v = \frac{N_{Ed}}{N_{pl,V,Rd}} = \frac{96}{1872} = 0{,}0513; \qquad a_v = \frac{A - 2bt_f}{A}(1-\rho) = \frac{84{,}5 - 2 \cdot 18 \cdot 1{,}35}{84{,}5}(1 - 0{,}02) = 0{,}416$$

$$M_{NV,y,Rd} = M_{pl,V,y,Rd}\frac{1 - n_v}{1 - 0.5a_v} = 291{,}2\frac{1 - 0{,}0513}{1 - 0.5 \cdot 0{,}416} = 348{,}8\,kNm > M_{pl,V,y,Rd} = 291{,}2\,kNm$$

$$\frac{M_{Ed}}{M_{pl,V,y,Rd}} = \frac{240}{291{,}2} = 0.82 < 1$$

Example 3.

Find the bearing capacity for the welded I section, presented on the figure, steel class S235. Design loads are $M_{y,Ed}$ = 405 kN.m; V_{Ed} = 338 kN

Design checks using Steel Expert

Proektsoft - Steel Expert EC 2.0/2010

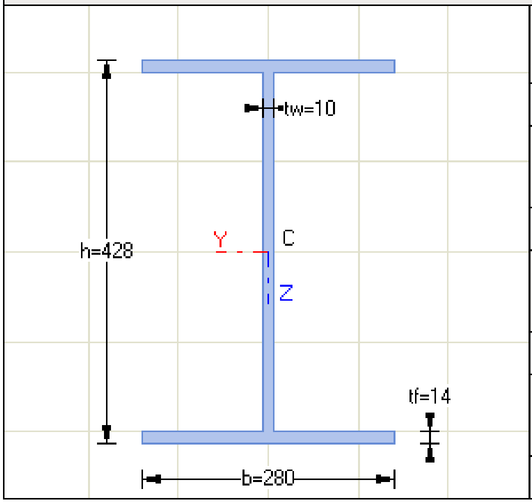
Steel Element Design To Eurocode 3

Project:	Example 5.3	Element:	
Building:		Author/Date:	
Client:		Checked By:	

Input Data

Steel S235 ëè.è ïð. t < 40 - fy = 235 MPa γ_{M0} = 1,05 γ_{M1} = 1,05 γ_{M2} = 1,25

Section Dimensions And Properties - 28 - I-SECTION



h [mm]	t_w [mm]	b [mm]	t_f [mm]	b_2 [mm]	t_{f2} [mm]
428,0	10,0	280,0	14,0	280,0	14,0
r_i [mm]	r_o [mm]	A [cm^2]	A_{vz} [cm^2]	A_{vy} [cm^2]	
		118,4	48,0	78,4	
I_y [cm^4]	I_z [cm^4]	$W_{el,y}$ [cm^3]	$W_{el,z}$ [cm^3]	$W_{pl,y}$ [cm^3]	$W_{pl,z}$ [cm^3]
38939,8	5125,5	1819,6	366,1	2022,9	558,8
r_y [cm]	r_z [cm]	C_z [cm]	C_y [cm]	I_t [cm^4]	W_t [cm^3]
18,1	6,6	21,4	14,0	64,1	42,6

Buckling Lengths

About axis "y" - $L_{eff,y}$ = 0,0cm

About axis "z" - $L_{eff,z}$ = 0,0cm

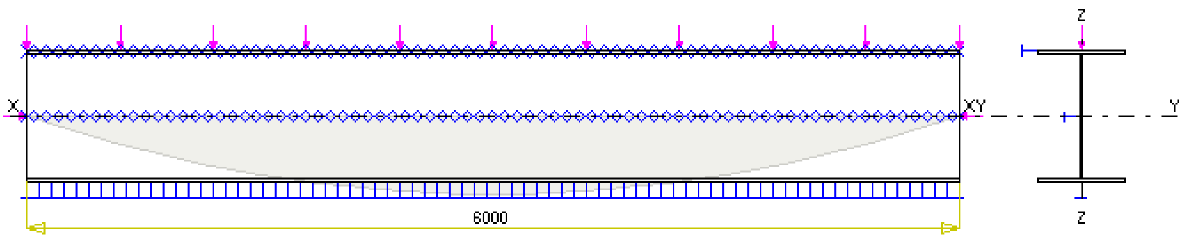
LT buckling - $L_{eff,b}$ = 0,0cm

Lateral-Torsional Buckling

Load position - Top flange

Load Type - Uniformly distributed

Web stiffeners at 0,0cm



Internal Forces

Case	N_{Ed} [kN]	$M_{y,Ed}$ [kNm]	$M_{z,Ed}$ [kN]	$V_{z,Ed}$ [kN]	$V_{y,Ed}$ [kN]	T_{Ed} [kNm]
1	0,0	405,0	0,0	338,0	0,0	0,0

Design Results

Section Classification

	Compression	Bending
Web	Class 3	Class 1
Flange	Class 2	Class 2

Section Elastic Design To Eq (6.1.)

Case	$\sigma_{x,Ed}$	$\tau_{xy,Ed}$	$\tau_{xz,Ed}$	$\tau_{max,Ed}$	$(\sigma_{x,Ed}{}^2 + 3\tau_{Ed}{}^2)^{1/2}$
1	222,6	0,0	87,8	87,8	241,1

Case	$\frac{\sigma_{x,Ed}}{f_y/\gamma_{M0}}$	$\frac{\tau_{xy,Ed}}{0.58f_y/\gamma_{M0}}$	$\frac{\tau_{xz,Ed}}{0.58f_y/\gamma_{M0}}$	$\frac{\tau_{max,Ed}}{0.58f_y/\gamma_{M0}}$	$\frac{(\sigma_{x,Ed}{}^2 + 3\tau_{Ed}{}^2)^{1/2}}{f_y/\gamma_{M0}}$
1	0,99	0,00	0,68	0,68	1,08

Section Plastic Design For Class 1 Or 2

Case	$N_{Rd}{}^{(2)}$ (6.6)(6.10)	$N_{u,Rd}$ (6.7)	$M_{y,Rd}{}^{(2)(3)}$ (6.13)	$M_{z,Rd}{}^{(2)(3)}$ (6.13)	$V_{z,Rd}{}^{(1)}$ (6.18)	$V_{y,Rd}{}^{(1)}$ (6.18)	T_{Rd}
1	2641,2	0,0	452,0	125,0	620,2	1013,1	5,5

Case	$\frac{N_{Ed}}{N_{Rd}}$ (6.5) (6.9)	$\frac{N_{Ed}}{N_{u,Rd}}$ (6.7) -	$\frac{M_{y,Ed}}{M_{y,Rd}}$ (6.12) (6.31)	$\frac{M_{z,Ed}}{M_{z,Rd}}$ (6.12) (6.31)	$\frac{V_{z,Ed}}{V_{z,Rd}}$ (6.17) (6.25)	$\frac{V_{y,Ed}}{V_{y,Rd}}$ (6.17) (6.25)	$\frac{T_{Ed}}{T_{Rd}}$ (6.23) -	$\frac{M_{y,Ed}}{M_{Ny,Rd}}^{\alpha} + \frac{M_{z,Ed}}{M_{Nz,Rd}}^{\beta}$ (6.12) (6.31)
1	0,00	0,00	0,90	0,00	0,54	0,00	0,00	0,80

(1) Reduced values $V_{T,Rd}$ are calculated to eq. (6.26) - (6.28) in case of shear combined with torsion T_{Ed}

(2) Reduced values $N_{V,Rd}$ and $M_{V,Rd}$ are calculated to eq. (6.29) in case of axial load or bending combined with shear V_{Ed}

(3) Reduced values $M_{N(V),Rd}$ are calculated to eq. (6.32) - (6.40) in case of bending combined with axial load N_{Ed}

Manual checks

$$A_{vz} = \eta \cdot h_w \cdot s = 1.2 \cdot 40 \cdot 10 = 48cm^2$$

$$M_{pl,y,Rd} = \frac{W_{pl,y} \cdot f_y}{\gamma_{M0}} = \frac{2022{,}9 \cdot 23{,}5}{1{,}05} = 45274\ kNcm = 452{,}74\ kNm$$

$$V_{pl,z,Rd} = \frac{A_{vz} \cdot f_y}{\sqrt{3}\ \gamma_{M0}} = \frac{48 \cdot 23{,}5}{\sqrt{3} \cdot 1{,}05} = 620{,}2\ kN$$

$$V_{Ed} = 338\ kN \geq 0.5V_{pl,Rd} = 310{,}1\ kN; \quad \rho = \left(\frac{2V_{Ed}}{V_{pl,Rd}} - 1\right)^2 = \left(\frac{2 \cdot 338}{620{,}2} - 1\right)^2 = 0.00809$$

$$M_{pl,V,y,Rd} = \frac{W_{pl,y} - \rho s h_w{}^2/4}{\gamma_{M0}} f_y = \frac{2022{,}9 - 0.00809 \cdot 1{,}0 \cdot 40^2/4}{1{,}05} 23{,}5 = 45202\ kNcm = 452\ kNm$$

$$\frac{M_{Ed}}{M_{pl,V,y,Rd}} = \frac{405}{452} = 0{,}90 > 1$$

Example 4.

Design an axially loaded column, with 6m length, loaded with force N_{Ed} = 840 kN. Cross section is hot rolled circular hollow section with D = 219 mm and t = 7 mm, steel S235JR.

The column is fixed at bottom and hinged at top, L_{eff} = 0,7*600 = 420 cm.

Design checks using Steel Expert

Proektsoft - Steel Expert EC 2.0/2010

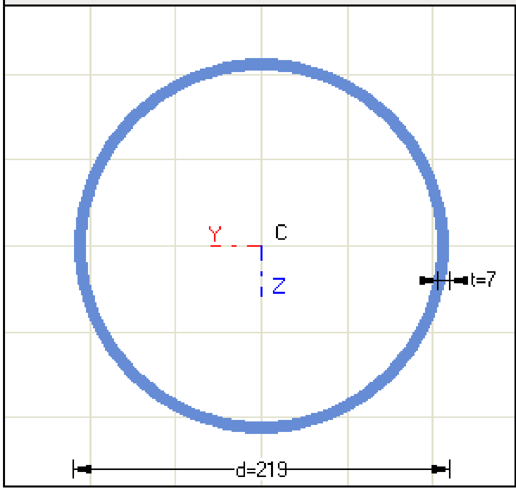
Steel Element Design To Eurocode 3

Project:	Example 6.1	Element:	
Building:		Author/Date:	
Client:		Checked By:	

Input Data

Steel S235 ëè.è ïð. t < 40 - fy = 235 MPa γ_{M0} = 1,05 γ_{M1} = 1,05 γ_{M2} = 1,25

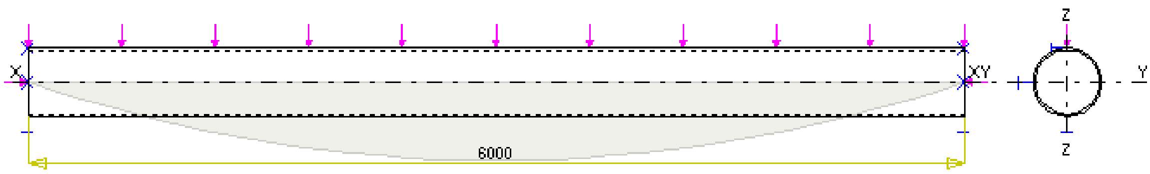
Section Dimensions And Properties - 219x7 - CIRCULAR TUBE



		d [mm]	t [mm]		
		219,0	7,0		
		A [cm^2]	A_{vz} [cm^2]	A_{vy} [cm^2]	
		46,6	29,7	29,7	
I_y [cm^4]	I_z [cm^4]	$W_{el,y}$ [cm^3]	$W_{el,z}$ [cm^3]	$W_{pl,y}$ [cm^3]	$W_{pl,z}$ [cm^3]
2622,0	2622,0	239,5	239,5	2517,8	2517,8
r_y [cm]	r_z [cm]	C_z [cm]	C_y [cm]	I_t [cm^4]	W_t [cm^3]
7,5	7,5	11,0	11,0	5244,1	478,9

Buckling Lengths
About axis "y" - $L_{eff,y}$ = 420,0cm
About axis "z" - $L_{eff,z}$ = 420,0cm
LT buckling - $L_{eff,b}$ = 600,0cm

Lateral-Torsional Buckling
Load position - Top flange
Load Type - Uniformly distributed
Web stiffeners at 0,0cm



Internal Forces

Case	N_{Ed} [kN]	$M_{y,Ed}$ [kNm]	$M_{z,Ed}$ [kN]	$V_{z,Ed}$ [kN]	$V_{y,Ed}$ [kN]	T_{Ed} [kNm]
1	-840,0	0,0	0,0	0,0	0,0	0,0

Design Results

Section Classification

	Compression	Bending
Web	Class 1	Class 1
Flange	Class 1	Class 1

Element Design

λ_y	λ_z	λ_{LT}	λ_w	χ_y	χ_z	χ_{LT}	χ_w	k_{yy}	k_{yz}	k_{zy}	k_{zz}
0,60	0,60	0,00	0,00	0,89	0,89	1,00	1,20	1,29	0,88	0,77	1,46

$N_{by,Rd}$ (6.47)	$N_{bz,Rd}$ (6.47)	$M_{b,Rd}$ (6.55)	$V_{bw,Rd}$ (5.2)*
930,1	930,1	563,5	383,5

Case	$\frac{N_{Ed}}{N_{by,Rd}}$ (6.46)	$\frac{N_{Ed}}{N_{bz,Rd}}$ (6.46)	$\frac{M_{y,Ed}}{M_{b,Rd}}$ (6.54)	$\frac{V_{z,Ed}}{V_{bw,Rd}}$ (5.10)*	To Eq. (6.61)	To Eq. (6.62)
1	0,90	0,90	0,00	0,00	0,90	0,90

*according to EN1993-1-5

$$\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}} + k_{yy}\frac{M_{y,Ed}}{\chi_{LT} M_{y,Rk}/\gamma_{M1}} + k_{yz}\frac{M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} \leq 1 \quad (6.61)$$

$$\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}} + k_{zy}\frac{M_{y,Ed}}{\chi_{LT} M_{y,Rk}/\gamma_{M1}} + k_{zz}\frac{M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} \leq 1 \quad (6.62)$$

Design checks are satisfied: K = 0.90

Manual checks

$$r = \sqrt{\frac{I}{A}} = \sqrt{\frac{2622}{46,6}} = 7,5\ cm; \quad \lambda = \frac{l_{eff}}{r} = \frac{420}{7,5} = 56; \quad N_{cr} = \frac{\pi^2 EA}{\lambda^2} = \frac{\pi^2 \cdot 21000 \cdot 46,6}{56^2} = 3021\ kN$$

$$\bar{\lambda} = \sqrt{\frac{Af_y}{N_{cr}}} = \sqrt{\frac{46,4 \cdot 23,5}{3021}} = 0,60; \quad buckling\ curve: a \ \rightarrow \ \alpha = 0,21$$

$$\Phi = 0.5\left[1 + \alpha\left(\bar{\lambda} - 0,2\right) + \bar{\lambda}^2\right] = 0.5 \cdot [1 + 0,21 \cdot (0,60 - 0,2) + 0,60^2] = 0,722$$

$$\chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}} = \frac{1}{0,722 + \sqrt{0,722^2 - 0,60^2}} = 0,89 < 1$$

$$N_{b,Rd} = \frac{\chi A f_y}{\gamma_{M1}} = \frac{0,89 \cdot 46,6 \cdot 23,5}{1,05} = 928\ kN$$

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{840}{928} = 0,90 < 1$$

Example 5.

Check the resistance of an 8m long column, loaded with axial force N_{Ed} = 3025 kN, cross section is hot-rolled HE360B, steel is S235JR.

Buckling lengths are $L_{eff,y}$ = 0,7·800 = 560 cm, $L_{eff,y}$ = 0,5·800 = 400 cm.

Design checks using Steel Expert

Proektsoft - Steel Expert EC 2.0/2010

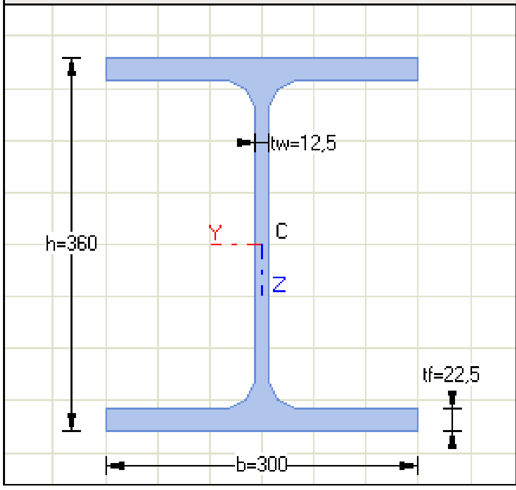
Steel Element Design To Eurocode 3

Project:	Example 6.2	Element:	
Building:		Author/Date:	
Client:		Checked By:	

Input Data

Steel S235 ëè.è ïð. t < 40 - fy = 235 MPa γ_{M0} = 1,05 γ_{M1} = 1,05 γ_{M2} = 1,25

Section Dimensions And Properties - HE 360 B - I-SECTION



h [mm]	t_w [mm]	b [mm]	t_f [mm]	b_2 [mm]	t_{f2} [mm]
360,0	12,5	300,0	22,5	300,0	22,5
r_i [mm]	r_o [mm]	A [cm^2]	A_{vz} [cm^2]	A_{vy} [cm^2]	
27,0		180,6	60,6	135,0	
I_y [cm^4]	I_z [cm^4]	$W_{el,y}$ [cm^3]	$W_{el,z}$ [cm^3]	$W_{pl,y}$ [cm^3]	$W_{pl,z}$ [cm^3]
43193,5	10141,2	2399,6	676,1	2683,0	1032,5
r_y [cm]	r_z [cm]	C_z [cm]	C_y [cm]	I_t [cm^4]	W_t [cm^3]
15,5	7,5	18,0	15,0	300,5	127,9

Buckling Lengths

About axis "y" - $L_{eff,y}$ = 560,0cm

About axis "z" - $L_{eff,z}$ = 400,0cm

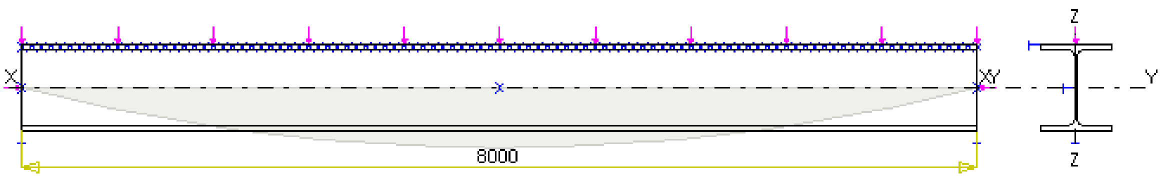
LT buckling - $L_{eff,b}$ = 0,0cm

Lateral-Torsional Buckling

Load position - Top flange

Load Type - Uniformly distributed

Web stiffeners at 0,0cm



Internal Forces

Case	N_{Ed} [kN]	$M_{y,Ed}$ [kNm]	$M_{z,Ed}$ [kN]	$V_{z,Ed}$ [kN]	$V_{y,Ed}$ [kN]	T_{Ed} [kNm]
1	-3025,0	0,0	0,0	0,0	0,0	0,0

Design Results

Section Classification

	Compression	Bending
Web	Class 1	Class 1
Flange	Class 1	Class 1

Element Design

λ_y	λ_z	λ_{LT}	λ_w	χ_y	χ_z	χ_{LT}	χ_w	k_{yy}	k_{yz}	k_{zy}	k_{zz}
0,39	0,57	0,00	0,29	0,93	0,80	1,00	1,20	1,09	0,72	0,65	1,20

$N_{by,Rd}$ (6.47)	$N_{bz,Rd}$ (6.47)	$M_{b,Rd}$ (6.55)	$V_{bw,Rd}$ (5.2)*
3766,8	3250,1	600,5	610,5

Case	$\frac{N_{Ed}}{N_{by,Rd}}$ (6.46)	$\frac{N_{Ed}}{N_{bz,Rd}}$ (6.46)	$\frac{M_{y,Ed}}{M_{b,Rd}}$ (6.54)	$\frac{V_{z,Ed}}{V_{bw,Rd}}$ (5.10)*	To Eq. (6.61)	To Eq. (6.62)
1	0,80	0,93	0,00	0,00	0,80	0,93

*according to EN1993-1-5

$$\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}} + k_{yy}\frac{M_{y,Ed}}{\chi_{LT} M_{y,Rk}/\gamma_{M1}} + k_{yz}\frac{M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} \leq 1 \quad (6.61)$$

$$\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}} + k_{zy}\frac{M_{y,Ed}}{\chi_{LT} M_{y,Rk}/\gamma_{M1}} + k_{zz}\frac{M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} \leq 1 \quad (6.62)$$

Design checks are satisfied: K = 0,93

Manual checks

$$\lambda_z = \frac{l_{eff,z}}{r} = \frac{400}{7,5} = 53,33; \quad N_{cr} = \frac{\pi^2 EA}{\lambda^2} = \frac{\pi^2 \cdot 21000 \cdot 180,6}{53,33^2} = 13161\ kN$$

$$\bar{\lambda} = \sqrt{\frac{Af_y}{N_{cr}}} = \sqrt{\frac{180,6 \cdot 23,5}{13161}} = 0,568; \quad \frac{h}{b} = 1,2\ buckling\ curve: c \ \rightarrow \ \alpha = 0,49$$

$$\Phi = 0.5\left[1 + \alpha\left(\bar{\lambda} - 0,2\right) + \bar{\lambda}^2\right] = 0.5 \cdot [1 + 0,49 \cdot (0,568 - 0,2) + 0,568^2] = 0,753$$

$$\chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}} = \frac{1}{0,753 + \sqrt{0,753^2 - 0,568^2}} = 0,802 < 1$$

$$N_{b,Rd} = \frac{\chi A f_y}{\gamma_{M1}} = \frac{0,802 \cdot 180,6 \cdot 23,5}{1,05} = 3240\ kN$$

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{3025}{3240} = 0,93 < 1$$

Example 6.

Find the bearing capacity of the column from Example 5, in case it is made from the given built-up section and steel S275.

Design checks using Steel Expert

Proektsoft - Steel Expert EC 2.0/2010

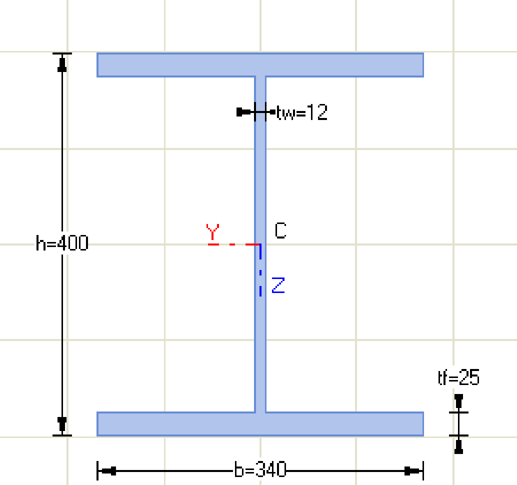
Steel Element Design To Eurocode 3

Project:	Example 6.3	Element:	
Building:		Author/Date:	
Client:		Checked By:	

Input Data

Steel S275 ëè.è ïð. t < 40 - fy = 275 MPa γ_{M0} = 1,05 γ_{M1} = 1,05 γ_{M2} = 1,25

Section Dimensions And Properties - 00 - I-SECTION



h [mm]	t_w [mm]	b [mm]	t_f [mm]	b_2 [mm]	t_{f2} [mm]
400,0	12,0	340,0	25,0	340,0	25,0
r_i [mm]	r_o [mm]	A [cm^2]	A_{vz} [cm^2]	A_{vy} [cm^2]	
		212,0	50,4	170,0	
I_y [cm^4]	I_z [cm^4]	$W_{el,y}$ [cm^3]	$W_{el,z}$ [cm^3]	$W_{pl,y}$ [cm^3]	$W_{pl,z}$ [cm^3]
64141,7	16381,7	3207,1	963,6	3555,0	1457,6
r_y [cm]	r_z [cm]	C_z [cm]	C_y [cm]	I_t [cm^4]	W_t [cm^3]
17,4	8,8	20,0	17,0	363,0	140,3

Buckling Lengths

About axis "y" - $L_{eff,y}$ = 560,0cm

About axis "z" - $L_{eff,z}$ = 400,0cm

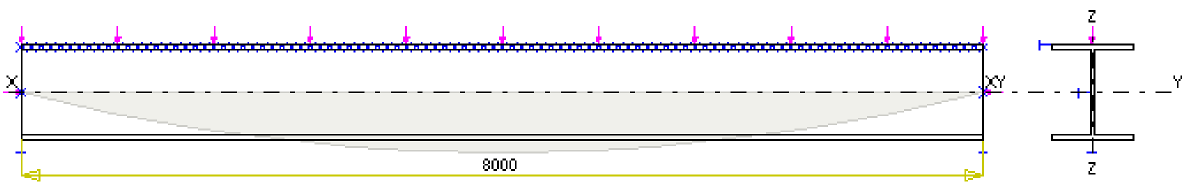
LT buckling - $L_{eff,b}$ = 0,0cm

Lateral-Torsional Buckling

Load position - Top flange

Load Type - Uniformly distributed

Web stiffeners at 0,0cm



Internal Forces

Case	N_{Ed} [kN]	$M_{y,Ed}$ [kNm]	$M_{z,Ed}$ [kN]	$V_{z,Ed}$ [kN]	$V_{y,Ed}$ [kN]	T_{Ed} [kNm]
1	-3025,0	0,0	0,0	0,0	0,0	0,0

Design Results

Section Classification

	Compression	Bending
Web	Class 1	Class 1
Flange	Class 1	Class 1

Element Design

λ_y	λ_z	λ_{LT}	λ_w	χ_y	χ_z	χ_{LT}	χ_w	k_{yy}	k_{yz}	k_{zy}	k_{zz}
0,37	0,52	0,00	0,37	0,94	0,83	1,00	1,20	1,04	0,74	0,63	1,23

$N_{by,Rd}$ (6.47)	$N_{bz,Rd}$ (6.47)	$M_{b,Rd}$ (6.55)	$V_{bw,Rd}$ (5.2)*
5205,3	4605,1	931,1	762,1

Case	$\frac{N_{Ed}}{N_{by,Rd}}$ (6.46)	$\frac{N_{Ed}}{N_{bz,Rd}}$ (6.46)	$\frac{M_{y,Ed}}{M_{b,Rd}}$ (6.54)	$\frac{V_{z,Ed}}{V_{bw,Rd}}$ (5.10)*	To Eq. (6.61)	To Eq. (6.62)
1	0,58	0,66	0,00	0,00	0,58	0,66

*according to EN1993-1-5

$$\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}} + k_{yy}\frac{M_{y,Ed}}{\chi_{LT} M_{y,Rk}/\gamma_{M1}} + k_{yz}\frac{M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} \leq 1 \quad (6.61)$$

$$\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}} + k_{zy}\frac{M_{y,Ed}}{\chi_{LT} M_{y,Rk}/\gamma_{M1}} + k_{zz}\frac{M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} \leq 1 \quad (6.62)$$

Design checks are satisfied: K = 0,66

Manual checks

$$\lambda_z = \frac{l_{eff,z}}{r} = \frac{400}{8,8} = 45,45; \quad N_{cr} = \frac{\pi^2 EA}{\lambda^2} = \frac{\pi^2 \cdot 21000 \cdot 212}{45,45^2} = 21271\ kN$$

$$\bar{\lambda} = \sqrt{\frac{Af_y}{N_{cr}}} = \sqrt{\frac{212 \cdot 27,5}{21271}} = 0,524; \quad buckling\ curve: c \ \rightarrow \ \alpha = 0,49$$

$$\Phi = 0.5[1 + \alpha(\bar{\lambda} - 0,2) + \bar{\lambda}^2] = 0.5 \cdot [1 + 0,49 \cdot (0,524 - 0,2) + 0,524^2] = 0,717$$

$$\chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}} = \frac{1}{0,717 + \sqrt{0,717^2 - 0,524^2}} = 0,829 < 1$$

$$N_{b,Rd} = \frac{\chi A f_y}{\gamma_{M1}} = \frac{0,829 \cdot 212 \cdot 27,5}{1,05} = 4602\ kN$$

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{3025}{4602} = 0,66 < 1$$

Example 7.

Design an 1.9 m long diagonal lattice column bracing, loaded with axial force 210 KN, with single L100x10 angle section to EN10056-1, steel S235JR.

Calculations using Steel Expert

Proektsoft - Steel Expert EC 2.0/2010

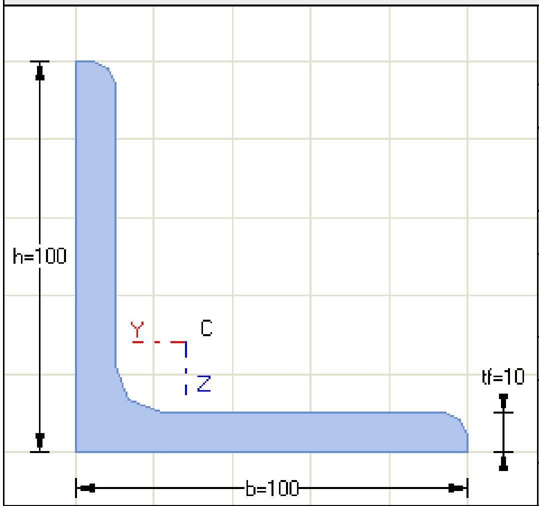
Steel Element Design To Eurocode 3

Project:	Example 6.4	Element:	
Building:		Author/Date:	
Client:		Checked By:	

Input Data

Steel S235 ëè.è ïð. t < 40 - fy = 235 MPa γ_{M0} = 1,05 γ_{M1} = 1,05 γ_{M2} = 1,25

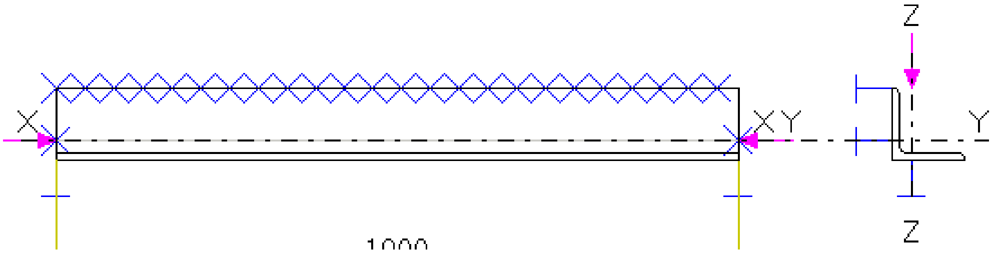
Section Dimensions And Properties - L100x100x10 - ANGLE



h [mm]	t_w [mm]	b [mm]	t_f [mm]		
100,0	10,0	100,0	10,0		
r_i [mm]	r_o [mm]	A [cm^2]	A_{vz} [cm^2]	A_{vy} [cm^2]	
12,0	6,0	19,2	10,0	10,0	
I_y [cm^4]	I_z [cm^4]	$W_{el,y}$ [cm^3]	$W_{el,z}$ [cm^3]	$W_{pl,y}$ [cm^3]	$W_{pl,z}$ [cm^3]
176,7	176,7	24,6	24,6	50,4	50,4
r_y [cm]	r_z [cm]	C_z [cm]	C_y [cm]	I_t [cm^4]	W_t [cm^3]
3,0	3,0	2,8	2,8	7,2	4,3

Buckling Lengths
About axis "y" - $L_{eff,y}$ = 190,0cm
About axis "z" - $L_{eff,z}$ = 190,0cm
LT buckling - $L_{eff,b}$ = 0,0cm

Lateral-Torsional Buckling
Load position - Top flange
Load Type - End moments
Web stiffeners at 0,0cm



Internal Forces

Case	N_{Ed} [kN]	$M_{y,Ed}$ [kNm]	$M_{z,Ed}$ [kN]	$V_{z,Ed}$ [kN]	$V_{y,Ed}$ [kN]	T_{Ed} [kNm]
1	-210,0	0,0	0,0	0,0	0,0	0,0

Design Results

Section Classification

	Compression	Bending
Web	Class 1	Class 1
Flange	Class 1	Class 1

Element Design

λ_y	λ_z	λ_{LT}	λ_w	χ_y	χ_z	χ_{LT}	χ_w	k_{yy}	k_{yz}	k_{zy}	k_{zz}
1,05	0,00	0,00	0,00	0,57	1,00	1,00	1,20	1,69	0,42	1,01	0,71

$N_{by,Rd}$ (6.47)	$N_{bz,Rd}$ (6.47)	$M_{b,Rd}$ (6.55)	$V_{bw,Rd}$ (5.2)*
243,5	428,7	11,3	129,2

Case	$\frac{N_{Ed}}{N_{by,Rd}}$ (6.46)	$\frac{N_{Ed}}{N_{bz,Rd}}$ (6.46)	$\frac{M_{y,Ed}}{M_{b,Rd}}$ (6.54)	$\frac{V_{z,Ed}}{V_{bw,Rd}}$ (5.10)*	To Eq. (6.61)	To Eq. (6.62)
1	0,86	0,49	0,00	0,00	0,86	0,00

*according to EN1993-1-5

$$\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}} + k_{yy}\frac{M_{y,Ed}}{\chi_{LT} M_{y,Rk}/\gamma_{M1}} + k_{yz}\frac{M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} \leq 1 \quad (6.61)$$

$$\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}} + k_{zy}\frac{M_{y,Ed}}{\chi_{LT} M_{y,Rk}/\gamma_{M1}} + k_{zz}\frac{M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} \leq 1 \quad (6.62)$$

Design checks are satisfied: K = 0,86

Manual checks

$$r_{min} = 1{,}95\ cm; \quad \lambda = \frac{l_{eff}}{r} = \frac{190}{1{,}95} = 97{,}44; \quad N_{cr} = \frac{\pi^2 EA}{\lambda^2} = \frac{\pi^2 \cdot 21000 \cdot 19{,}2}{97{,}44^2} = 419{,}1\ kN$$

$$\bar{\lambda} = \sqrt{\frac{Af_y}{N_{cr}}} = \sqrt{\frac{19{,}2 \cdot 23{,}5}{419{,}1}} = 1{,}038; \quad \text{крива на изкълчване:}\, b \ \rightarrow \ \alpha = 0{,}34$$

$$\Phi = 0.5\left[1 + \alpha\left(\bar{\lambda} - 0{,}2\right) + \bar{\lambda}^2\right] = 0.5 \cdot [1 + 0{,}34 \cdot (1{,}038 - 0{,}2) + 1{,}038^2] = 1{,}181$$

$$\chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}} = \frac{1}{1{,}181 + \sqrt{1{,}181^2 - 1{,}038^2}} = 0{,}573 < 1$$

$$N_{b,Rd} = \frac{\chi A f_y}{\gamma_{M1}} = \frac{0{,}573 \cdot 19{,}2 \cdot 23{,}5}{1{,}05} = 246\ kN$$

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{210}{246} = 0{,}85 < 1$$

All examples are developed using

„Manual for design of steel structures to Eurocode 3" 2009.

Prof. Ph.D. Eng. Ljubcho Venkov

Assoc. Prof. Ph.D. Eng. Borislav Belev

Eng. Chavdar Penelov

A lot of additional sources have been used for verification, including older manuals, foreign books, etc. The book "Design of steel members to Eurocode 3", 2006 by Prof. Nicola Draganov was very helpful as well, providing a lot of examples.

Calculation Report

Calculation report in **html** format is generated for each problem by selecting the "**Results**" button. Report is viewed in **Internet Explorer**, but other web programs may be also used. Most text editors like e.g. MS Word, can also open **html** files. Report file is named **name_of_ data _file.html**.

A directory named **name_of_ data _file.html_files** is created with each file. It should always be kept together with the html file, otherwise pictures and formats will be lost.