Extracts from EC3 Design of Steel Structures

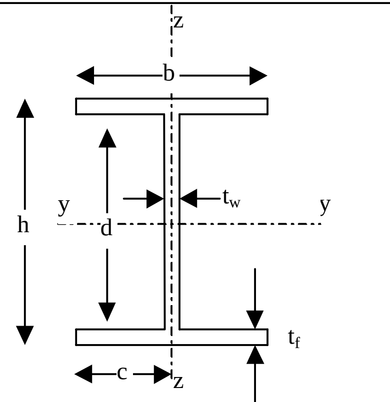


Figure 1.1 Dimensions and axes

Table 3.1 EC3 Nominal yield and ultimate tensile strength

Nominal steel grade	Nominal Thickness t (mm)			
	t <= 40		40< t <=100*	
	fy (N/mm²)	fu (N/mm²)	fy (N/mm²)	fu (N/mm²)
S275	275	390	255	370
S355	355	490	335	470
S235	235	360	215	340

Table 3.3 Nominal values for yield (f_{yb}) and ultimate tensile strength of bolts f_{ub} for bolts

Bolt grade	4.6	4.8	5.6	5.8	6.8	8.8	10.9
f_{yb} (N/mm²)	240	320	300	400	480	640	900
f_{ub} (N/mm²)	400	400	500	500	600	800	1000

UK NAD Partial Safety Factors:
$\gamma_{M0} = 1.05$
$\gamma_{M1} = 1.05$
$\gamma_{M2} = 1.20$
$\gamma_{Mb} = 1.35$
$\gamma_{Mw} = 1.35$

Table 4.1 EC3 Recommended maximum deflections

Conditions	Limits with reference to EC3 Fig 4.1	
	δ_{max}	δ_2
Roofs generally	L/200	L/250
Roofs with public access	L/250	L/300
Floors generally	L/250	L/300
Floors and roofs supporting brittle finishes	L/250	L/350
Floors supporting columns	L/400	L/500
Where δ_{max} can impair the appearance of the building (e.g. exposed beams)	L/250	

4.2.2 Deflection

$\boldsymbol{\delta_1}$, the deflection due to permanent loads $\boldsymbol{\delta_2}$, due to variable loads. The total deflection, $\boldsymbol{\delta_{max}}$ is given in Clause 4.2.2 as $\boldsymbol{\delta_{max} = \delta_1 + \delta_2 - \delta_0}$ where δ_0 is the pre-camber.

5.3 Classification of cross sections

Table 5.3.1 Maximum Width to thickness ratios for compression elements (EXTRACT only)

Class	Web subject to bending	Web subject to compression	Web subject to bending & compression	
1	$d/t_w \le 72\varepsilon$	$d/t_w \le 33\varepsilon$	When $\alpha > 0.5$: $d/t_w \le 396\varepsilon/(13\alpha - 1)$ When $\alpha < 0.5$: $d/t_w \le 36\varepsilon/\alpha$	
2	$d/t_w \le 83\varepsilon$	$d/t_w \le 38\varepsilon$	When $\alpha > 0.5$: $d/t_w \le 456\varepsilon/(13\alpha - 1)$ When $\alpha < 0.5$: $d/t_w \le 41.5\varepsilon/\alpha$	
3	$d/t_w \le 124\varepsilon$	$d/t_w \le 42\varepsilon$	When $\psi > -1$: $d/t_w \le 42\varepsilon/(0.67+0.33\psi)$ When $\psi \le -1$: $d/t_w \le 62\varepsilon(1-\psi)\sqrt{(-\psi)}$	
Maximum width to thickness ratios for compression elements: outstand flanges				
Class	Flange in comp	Tip in comp	Tip in tension	
1 (hot-rolled) **1** (welded)	$c/t_f \le 10\varepsilon$ $c/t_f \le 9\varepsilon$	$c/t_f \le 10\varepsilon/\alpha$ $c/t_f \le 9\varepsilon/\alpha$	$c/t_f \le 10\varepsilon/(\alpha\sqrt{\alpha})$ $c/t_f \le 9\varepsilon/(\alpha\sqrt{\alpha})$	
2 (hot-rolled) **2** (welded)	$c/t_f \le 11\varepsilon$ $c/t_f \le 10\varepsilon$	$c/t_f \le 11\varepsilon/\alpha$ $c/t_f \le 10\varepsilon/\alpha$	$c/t_f \le 11\varepsilon/(\alpha\sqrt{\alpha})$ $c/t_f \le 10\varepsilon/(\alpha\sqrt{\alpha})$	
3 (hot-rolled) **3** (welded)	$c/t_f \le 15\varepsilon$ $c/t_f \le 14\varepsilon$	$c/t_f \le 23\varepsilon\sqrt{k_\sigma}$ (For k_σ see table 5.3.3) $c/t_f \le 21\varepsilon\sqrt{k_\sigma}$		
	f_y	235	275	355
$\varepsilon = \sqrt{(235/f_y)}$	ε	1	0.92	0.81

5.4 Resistance of cross sections

5.4.3 Tension

The design plastic resistance for the gross cross section is $N_{pl,Rd} = Af_y/\gamma_{M0}$

5.4.4 Compression

The design compression resistance for Class 1, 2 or 3 cross sections is $N_{c,Rd} = Af_y/\gamma_{M0}$

5.4.5 Bending moment

5.4.5.2 Bending about one axis

In the absence of shear the design moment resistance is $M_{c,Rd} = W_{pl}\, f_y/\gamma_{M0}$ for Class 1 or 2 cross sections.

For Class 3 sections $M_{c,Rd} = W_{el}\, f_y/\gamma_{M0}$

5.4.6 Shear

The design plastic shear resistance is

$V_{pl,Rd} = A_v\,(f_y/\ 3^{0.5})/\gamma_{M0}$

For a hot rolled I or H section $A_v = 1.04 t_w h$

Shear buckling resistance must be checked according to 5.6 when $d/t_w > 69\varepsilon$ for an unstiffened web or $d/t_w > 30\varepsilon\,(k_r)^{0.5}$ for a stiffened web, where kr is given in 5.6.3

5.4.7 Bending and Shear

If VSd is less than 50% of Vpl,Rd then no reduction in design resistance moment is required.

When VSd exceeds 50% of Vpl,Rd the design resistance moment is reduced to

$$M_{V,Rd} = [W_{pl} - \frac{\rho A_v^2}{4t_w}]\, f_y/\gamma_{M0} \quad but \quad M_{V,Rd} \le M_{c,Rd} \quad and \quad \rho = \left(\frac{2V_{Sd}}{V_{pl.Rd}} - 1\right)^2 \qquad (5.22)$$

5.4.8 **Bending and Axial force**. For Class 1 and 2 cross sections without bolt holes

$$\frac{M_{Sd}}{M_{p\ell.Rd}} + \left[\frac{N_{Sd}}{N_{p\ell.Rd}}\right]^2 \le 1.0 \qquad (5.24)$$

5.5 Buckling Resistance of members

5.5.1.1 The design Buckling resistance of a member in compression is

$$N_{b,Rd} = \chi \beta_a A\, f_y / \gamma_{M1} \qquad (5.45)$$

where β_a is 1.0 for class 1 2 or 3 cross section, A is the area, f_y is the characteristic yield stress, $\gamma_{M1} = 1.05$ (NAD Tab 1)

$$\chi = \frac{1}{\phi + \left[\phi^2 - \bar{\lambda}^2\right]^{0.5}} \quad but \quad \chi \le 1 \qquad (5.46)$$

Values may be obtained from the equations or from Table 5.5.2

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

$$\bar{\lambda} = \left[\beta_a A\, f_y / N_{cr}\right]^{0.5} = \lambda/\lambda_1, \quad \lambda_1 = \pi\sqrt{E/f_y}$$

Ncr is the elastic critical force.

The imperfection parameter, α, is given in Table 5.5.1

Table 5.5.1 Imperfection factors				
Buckling curve	a	b	c	d
Imperfection factor, α	0.21	0.34	0.49	0.76
Use for Rolled Column Sections, Buckling about	Any hot rolled tube	t_f<100mm y-y axis	t_f<100mm z-z axis	100mm<t_f y-y or z-z axis

5.5.2 Lateral torsional buckling of beams

$M_{b.Rd} = \chi_{LT}\beta_W W_{pl.y} f_y/\gamma_{M1}$ (5.48)

where $\beta_W = 1$ for Class 1 and 2 cross sections

χ_{LT} is a reduction factor to allow for lateral torsional buckling which may be obtained from Table 5.5.2 using $\bar{\lambda} = \bar{\lambda}_{LT}$ and curve a for rolled sections or curve c for welded sections.

Table 5.5.2 Reduction factors χ

	Buckling Curve			
α	0.21	0.34	0.49	0.76
λbar	a	b	c	d
0.2	1.0000	1.0000	1.0000	1.0000
0.3	0.9775	0.9641	0.9491	0.9235
0.4	0.9528	0.9261	0.8973	0.8504
0.5	0.9243	0.8842	0.8430	0.7793
0.6	0.8900	0.8371	0.7854	0.7100
0.7	0.8477	0.7837	0.7247	0.6431
0.8	0.7957	0.7245	0.6622	0.5797
0.9	0.7339	0.6612	0.5998	0.5208
1	0.6656	0.5970	0.5399	0.4671
1.1	0.5960	0.5352	0.4842	0.4189
1.2	0.5300	0.4781	0.4338	0.3762
1.3	0.4703	0.4269	0.3888	0.3385
1.4	0.4179	0.3817	0.3492	0.3055
1.5	0.3724	0.3422	0.3145	0.2766
1.6	0.3332	0.3079	0.2842	0.2512
1.7	0.2994	0.2781	0.2577	0.2289
1.8	0.2702	0.2521	0.2345	0.2093
1.9	0.2449	0.2294	0.2141	0.1920
2	0.2229	0.2095	0.1962	0.1766
2.1	0.2036	0.1920	0.1803	0.1630
2.2	0.1867	0.1765	0.1662	0.1508
2.3	0.1717	0.1628	0.1537	0.1399
2.4	0.1585	0.1506	0.1425	0.1302
2.5	0.1467	0.1397	0.1325	0.1214
2.6	0.1362	0.1299	0.1234	0.1134
2.7	0.1267	0.1211	0.1153	0.1062
2.8	0.1182	0.1132	0.1079	0.0997
2.9	0.1105	0.1060	0.1012	0.0937
3	0.1036	0.0994	0.0951	0.0882

$$\bar{\lambda}_{LT} = (\lambda_{LT}/\lambda_1)\sqrt{\beta_w} \quad , \quad \lambda_1 = 93.9\varepsilon$$

For rolled I or H sections

$$\lambda_{LT} = \frac{L/i_{LT}}{\sqrt{C_1}\left(1+\frac{1}{20}\left(\frac{L/i_{LT}}{h/t_f}\right)^2\right)^{0.25}}$$

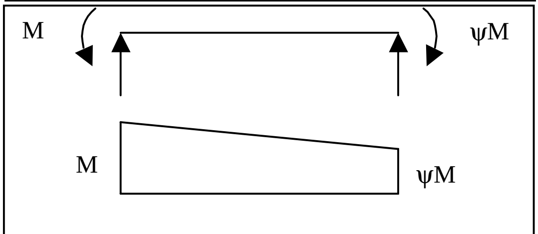
Where i_{LT} is a lateral torsional radius of gyration and C_1 is a factor corresponding to the shape of the bending moment diagram and the effective length factor k.

For a doubly symmetric cross section, i_{LT} is approximately = $[I_z/(A-0.5t_w(h-t_f))]^{0.5}$

The extract from Table F.1.1 gives C_1.

Table F.1.1 Values of Factors C_1 Extract

ψ	k	C_1
+1	1 0.7 0.5	1.0 1.0 1.0
+0.75	1 0.7 0.5	1.141 1.270 1.305
+0.5	1 0.7 0.5	1.323 1.473 1.514
+0.25	1 0.7 0.5	1.563 1.739 1.788
0	1 0.7 0.5	1.879 2.092 2.150
-0.5	1 0.7 0.5	2.704 3.009 3.093



Moment diagram for Table F.1.1

No fixity implies k=1.0. Full fixity, k=0.5.

5.5.3 Bending and axial tension

Members to be checked for resistance to Lateral Torsional Buckling using the vector sum of axial force and bending moment. Where the bending and tension can vary independently, the axial tension is multiplied by a reduction factor, $\psi_{vec} = 0.7$ (from UK NAD). The net stress, $\sigma_{com.Ed}$ (which can be greater than f_y), is

$\sigma_{com.Ed} = (M_{Sd}/W_{com}) - \psi_{vec} N_{t.Sd}/A$ (5.50)

where W_{com} is the elastic section modulus for the extreme fibre in compression. An effective internal design moment is obtained from $M_{eff.Sd} = W_{com}\sigma_{com.Ed}$ which should be $\leq M_{bRd}$ from 5.5.2

5.5.4 Bending and axial compression

(1) Class 1 and 2 members subject to combined bending and axial compression must satisfy

$$\frac{N_{Sd}}{\chi_{\min} A f_y / \gamma_{M1}} + \frac{k_y M_{y.Sd}}{W_{pl.y} f_y / \gamma_{M1}} + \frac{k_z M_{z.Sd}}{W_{pl.z} f_y / \gamma_{M1}} \leq 1.0 \qquad (5.51)$$

where $k_y = 1-(\mu_y N_{Sd}/\chi_y A f_y)$ but ≤ 1.5 and $k_z = 1-(\mu_z N_{Sd}/\chi_z A f_y)$ but ≤ 1.5 and

$$\mu_y = \bar{\lambda}_y (2\beta_{My} - 4) + \left[\frac{W_{pl.y} - W_{el.y}}{W_{el.y}}\right] \quad but \quad \mu_y \leq 0.9$$

$$\mu_z = \bar{\lambda}_z (2\beta_{Mz} - 4) + \left[\frac{W_{pl.z} - W_{el.z}}{W_{el.z}}\right] \quad but \quad \mu_z \leq 0.9$$

χ_{min} is the smaller of the reduction factors, χ_y and χ_z which are obtained from 5.5.1 or Table 5.5.2
β_{My} and β_{Mz} are the equivalent uniform moment factors for moments about y-y and z-z axes respectively from Figure 5.5.3

(2) Class 1 and 2 members where lateral torsional buckling is a possible failure mode must also satisfy

$$\frac{N_{Sd}}{\chi_z A f_y / \gamma_{M1}} + \frac{k_{LT} M_{y.Sd}}{\chi_{LT} W_{pl.y} f_y / \gamma_{M1}} + \frac{k_z M_{z.Sd}}{W_{pl.z} f_y / \gamma_{M1}} \leq 1.0 \qquad (5.52)$$

where $k_{LT} = 1 - (\mu_{LT} N_{Sd}/\chi_z A f_y)$ but $k_{LT} \leq 1$

$$\mu_{LT} = 0.15\,\bar{\lambda}_Z \beta_{M.LT} - 0.15 \quad but \quad \mu_{LT} \leq 0.9$$

and $\beta_{M.LT}$ is the equivalent uniform moment factor for lateral torsional buckling from Figure 5.5.3

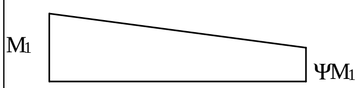
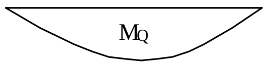
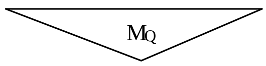
Equivalent uniform moment factor β_M	Moment Diagram
$\beta_{M,\psi} = 1.8 - 0.7\psi$	 $-1 \leq \psi \leq 1$
$\beta_{M,Q} = 1,3$	
$\beta_{M,Q} = 1.4$	

Figure 5.5.3 (Extract) Equivalent uniform moment factors

5.7 Resistance of Webs to transverse forces

5.71 Length of stiff bearing, s_s is obtained by considering a dispersion of the load through SOLID material which is fixed in place (i.e. not packing) at a slope of 1:1.

5.7.3 Crushing Resistance, $R_{y.Rd} = (s_s + s_y) t_w f_{yw}/\gamma_{M1}$ where $s_y = 2t_f(b_f/t_w)^{0.5}[f_{yf}/f_{yw}]^{0.5}[1-(\sigma_{f.Ed}/f_{yf})^2]^{0.5}$

5.7.4 Crippling Resistance, $R_{aRd} = 0.5 t_w^2 (E f_{yw})^{0.5}[(t_f/t_w)^{0.5} + 3(t_w/t_f)(s_s/d)]/\gamma_{M1}$,, where s_s/d should not be taken as more than 0.2

5.7.5 Buckling Resistance: beff = $[h^2 + s_s^2]^{0.5}$. Use buckling curve c with β_a=1.

5.7.6 Transverse Stiffeners: Effective cross section of stiffeners based on length of web = $15\varepsilon t_w$ either side of the stiffener and the area of the stiffener itself. Use buckling curve c and a buckling length not less than 0.75d or more is the restraint conditions merit it.

5.7.7 Flange induced buckling: d/t_w β $k(E/f_{yf})[A_w/A_{fc}]^{0.5}$, where k = 0.3 for Class 1 flanges k=0.4 for Class 2. A_w = area of web, A_{fc} = area of compression flange.

6 Connections subject to static loading

6.1.1(1) The partial safety factor for bolted connections is γ_{Mb} = 1.35 (UKNAD) and that for welds is γ_{Mw} = 1.35 (UK NAD).

6.5.1 Positioning of holes for bolts and rivets

The end distance, $e_1 \geq 1.2d_0$, and the pitch, $p_1 \geq 2.2d_0$ are in the direction parallel to the load. The transverse edge distance, $e_2 \geq 1.5d_0$ and the transverse pitch, $p_2 \geq 3d_0$ are perpendicular to the load direction. Maximum values for end and edge distances is 12t and the maximum spacing in compression members is 14t where t is the thickness of the thinner ply.

Hole diameters, d_0, should be 1mm larger than the bolt for M12 and M14, 2mm larger for M16 to M24 and 3mm larger for M27 and up.

6.5.2.2 Design shear rupture resistance is

$V_{eff.Rd} = (f_y/\sqrt{3})\, A_{v.eff} / \gamma_{M0}$ (6.1)

where $A_{v.eff} = t\, L_{v.eff}$, and $L_{v.eff} = L_v + L_1 + L_2$

but $L_{v.eff} \leq L_3$.

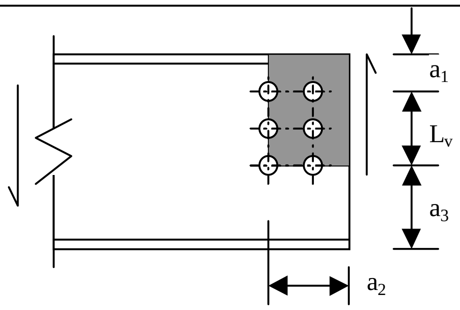
The individual lengths are obtained with reference to Figure 6.5.5 as follows:

$L_1 = a_1$ but $L_1 \leq 5d$

$L_2 = (a_2 - k\, d_{0.t})(f_u/f_y)$

$L_3 = L_v + a_1 + a_3$ but $L_3 \leq (L_v + a_1 + a_3 - n\, d_{o.v})(f_u/f_y)$

The coefficient k = 0.5 for a single row of bolts and for two rows k = 2.5. For circular holes $d_{0.v} = d_{0.t} = d_0$, the hole diameter. For slotted holes, $d_{0.v}$ is parallel to the shear while $d_{0.t}$ is perpendicular to it.



Extract from Figure 6.5.5

6.5.5 Design resistance of bolts are given by Table 6.5.3 as:

Shear resistance per shear plane

$F_{v.Rd} = 0.6 f_{ub} A_s / \gamma_{Mb}$ for Grades 4.6, 5.6 and 8.8 and $F_{v.Rd} = 0.5 f_{ub} A_s / \gamma_{Mb}$ for Grades 4.8, 5.8 and 10.9 where A_s is the tensile area of the bolt. If the shear plane does not pass through the threaded part resistance for all grades is : $F_{v.Rd} = 0.6 f_{ub} A / \gamma_{Mb}$ where A is the cross sectional area of the bolt shaft.

Bearing resistance

$F_{b.Rd} = 2.5 \alpha f_u d\, t / \gamma_{Mb}$ where α is the smallest of : $(e_1/3d_0)$, $(p_1/3d_0 - 0.25)$, (f_{ub}/f_u) or 1.0

t is the thickness of the plate, d is the diameter of the bolt and d_0 the diameter of the hole. For a single shear connection, t must be the thickness of the thinner plate.

Tension resistance will be the smaller of

$F_{t.Rd} = 0.9\, f_{ub}\, A_s / \gamma_{Mb}$ and the design punching shear resistance given in 6.5.5(4)

6.5.5(4) The design punching shear resistance is:

$B_{p.Rd} = 0.6\, \pi\, d_m\, t_p\, f_u / \gamma_{Mb}$

where d_m is the mean diameter of the hexagon bolt head or nut, whichever is smaller, t_p is the plate thickness directly under the bolt or nut.

6.5.5(5) Bolts subject to combined shear and tension must also satisfy:

$$\frac{F_{V.Sd}}{F_{V.Rd}} + \frac{F_{t.Sd}}{1.4 F_{t.Rd}} \leq 1.0 \qquad (6.6)$$

6.6.5 Design resistance of fillet welds

The effective length of a filled may be taken as the overall length of the full size weld. Welds of length less than 40 mm or 6a should be ignored for design purposes. The throat thickness, a, is the height of the largest triangle which can be drawn within the fusion faces. The throat thickness must be greater than 3mm. Irrespective of the orientation of the weld to the load direction the design resistance per unit length is:

$F_{w.Rd} = f_{vw.d}\, a$ where

$$f_{vw.d} = \frac{f_u / \sqrt{3}}{\beta_w \gamma_{Mw}} \quad \text{Equations 6.14 and 6.15}$$

where f_u is 390 N/mm² for S275 and the correlation factor β_w is 0.8 for S275 and f_u is 490 N/mm² and β_w is 0.9 for S355. γ_{Mw} = 1.35 (from UK NAD).

Grade 4.6 Bolt Strengths

	Hole dia (mm)	Tensile area (mm^2)	Single Shear cap (kN)	Double Shear (kN)	Tension capacity (kN)
M12	14	84.3	15.0	30.0	22.5
M16	18	157	27.9	55.8	41.9
M20	22	245	43.6	87.1	65.3
M24	26	353	62.8	125.5	94.1
M30	33	561	99.7	199.5	149.6

Grade 8.8 Bolt Strengths

	Hole dia (mm)	Tensile area (mm^2)	Single Shear cap (kN)	Double Shear (kN)	Tension capacity (kN)
M12	14	84.3	30.0	59.9	45.0
M16	18	157	55.8	111.6	83.7
M20	22	245	87.1	174.2	130.7
M24	26	353	125.5	251.0	188.3
M30	33	561	199.5	398.9	299.2