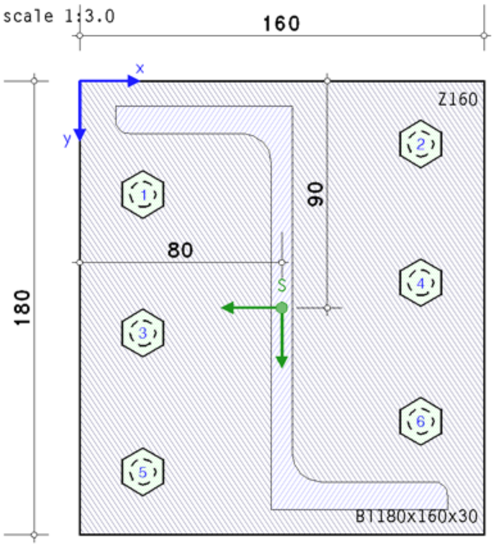
4H-EC3FS version: 2/2017-1d

bolted end-plate connection

EC 3-1-8 (12.10), NA: Deutschland

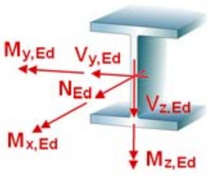


steel grade
steel grade S355
bolts
bolt class 8.8, bolt size M10, thread included in the shear plane
connection
end-plate: thickness t_p = 30.0 mm, width b_p = 160.0 mm, length l_p = 180.0 mm
beam: section Z160
beam-end-plate: surrounding fillet weld, weld thickness a = 10.0 mm
beam section centric on end-plate (coinciding centroids)
coordinates of beam centroid on end-plate x_s = 80.0 mm, y_s = 90.0 mm
bolts:
coordinates of bolt axis:

x_1 = 25.0 mm, y_1 = 45.0 mm x_2 = 135.0 mm, y_2 = 25.0 mm x_3 = 25.0 mm, y_3 = 100.0 mm
x_4 = 135.0 mm, y_4 = 80.0 mm x_5 = 25.0 mm, y_5 = 155.0 mm x_6 = 135.0 mm, y_6 = 135.0 mm

calculation
verification:
calculation and verification of internal forces and moments (FEM)
verification of end-plate with the plastic method
verification of beam section with the plastic method
verification of welds with the directional method
verification of bolts, check of distances
FEM-calculation:
bolts are plasticly calculated, spring constant of bolts c_f = 2357.9 kN/cm
plastic limit force $F_{t,f} = f_{t,f} \cdot F_{t,Rd}$ = 31.7 kN, $f_{t,f}$ = 0.950, $F_{t,Rd}$ = 33.4 kN, effective elongation at failure $\varepsilon_{t,f}$ = 6.0%
without preloading ($F_{p,C}$ = 0)
effective foundation modulus of end plate c_b = 14000.0 kN/cm³
number / dimension of finite elements each direction n_x / Δx = 20 / 8.0 mm, n_y / Δy = 21 / 8.6 mm
max. 50 iteration steps (tolerance limit 5‰)
internal forces and moments

Lk	N_{Ed} kN	$M_{y,Ed}$ kNm	$V_{z,Ed}$ kN	$M_{z,Ed}$ kNm	$V_{y,Ed}$ kN	$M_{x,Ed}$ kNm
1	-9.6	-0.5	0.8	2.6	1.4	0.8
2	8.4	3.0	23.1	10.4	5.1	0.0
3	-3.7	0.0	0.6	-5.6	-2.9	0.8
4	3.0	2.8	23.2	12.1	6.0	0.0
5	-8.9	-0.0	0.7	3.3	1.7	0.0
6	5.4	2.4	23.2	6.2	3.0	1.2
7	-2.9	0.5	0.5	-4.9	-2.6	-0.0
8	1.9	2.1	23.3	11.1	5.5	1.2
9	-3.9	1.3	16.6	9.6	4.8	0.8
10	-3.2	1.8	16.5	10.3	5.1	0.0



partial safety factors for material
resistance of cross-sections γ_{M0} = 1.00

resistance of bolts, welds, plates in bearing γ_{M2} = 1.25

Calculation

utilizations

Lk	U_p	U_σ	U_b	U_{wt}	$U_{t,s}$	$U_{vt,s}$	$U_{b,s}$	U_q	$U_{c/t}$	U_w	U
- -	-	-	-	-	-	-	-	-	-	-	-
1	0.065	0.065	0.054	0.015	0.196	0.227	0.010	0.354	0.204	0.204	0.354
2	0.295	0.295	0.245	0.129	0.950	0.709	0.034	0.419	0.479	0.748	0.950*
3	0.142	0.142	0.115	0.041	0.524	0.432	0.011	0.406	0.292	0.420	0.524
4	0.358	0.358	0.292	0.166	0.950	0.741	0.043	0.506	0.476	0.875	0.950*
5	0.086	0.086	0.070	0.022	0.275	0.208	0.002	0.160	0.226	0.250	0.275
6	0.161	0.161	0.142	0.061	0.780	0.586	0.030	0.541	0.487	0.441	0.780
7	0.122	0.122	0.096	0.035	0.445	0.332	0.002	0.254	0.275	0.373	0.445
8	0.320	0.320	0.248	0.117	0.950	0.690	0.033	0.666	0.473	0.808	0.950*
9	0.262	0.262	0.205	0.078	0.932	0.674	0.023	0.535	0.471	0.701	0.932
10	0.287	0.287	0.224	0.093	0.950	0.697	0.024	0.443	0.474	0.747	0.950*

U_p: utilization of end-plate; U_σ: utilization of end-plate due to stress; U_p: utilization of end-plate due to compression by contact
$U_{wt,s}$: utilization of bolts due to elongation; $U_{t,s}$: utilization of bolts due to tension; $U_{vt,s}$: utilization of bolts due to shear in tension
$U_{b,s}$: utilization of bolts due to bearing resistance; U_q: stress utilization of beam; U_{ct}: c/t-utilization of beam
U_w: utilization of welds; U: total utilization
*) maximum utilization

Final Result

maximum utilization [Lk 2] max U = 0.950 < 1 ok.

verification succeeded

Regulations

DIN EN 1990, Eurocode 0: Grundlagen der Tragwerksplanung;
Deutsche Fassung EN 1990:2002 + A1:2005 + A1:2005/AC:2010, Ausgabe Dezember 2010
DIN EN 1990/NA, Nationaler Anhang zur DIN EN 1990, Ausgabe Dezember 2010

DIN EN 1993-1-1, Eurocode 3: Bemessung und Konstruktion von Stahlbauten -
Teil 1-1: Allgemeine Bemessungsregeln und Regeln für den Hochbau;
Deutsche Fassung EN 1993-1-1:2005 + AC:2009, Ausgabe Dezember 2010
DIN EN 1993-1-1/NA, Nationaler Anhang zur DIN EN 1993-1-1, Ausgabe Dezember 2010

DIN EN 1993-1-8, Eurocode 3: Bemessung und Konstruktion von Stahlbauten -
Teil 1-8: Bemessung von Anschlüssen;
Deutsche Fassung EN 1993-1-8:2005 + AC:2009, Ausgabe Dezember 2010
DIN EN 1993-1-8/NA, Nationaler Anhang zur DIN EN 1993-1-8, Ausgabe Dezember 2010

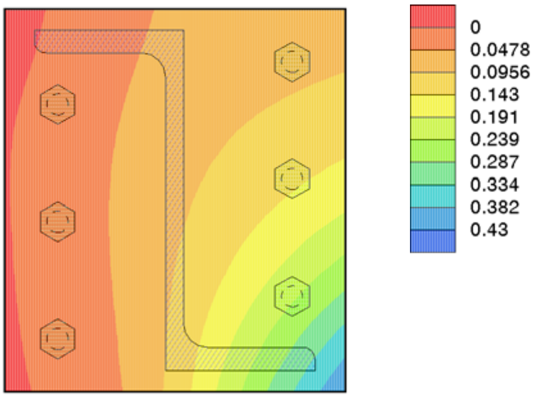
Detailed edition of Lk 2 (decisive)

Lk 2: N_{Ed} = 8.4 kN, $M_{y,Ed}$ = 3.0 kNm , $V_{z,Ed}$ = 23.1 kN, $M_{z,Ed}$ = 10.4 kNm , $V_{y,Ed}$

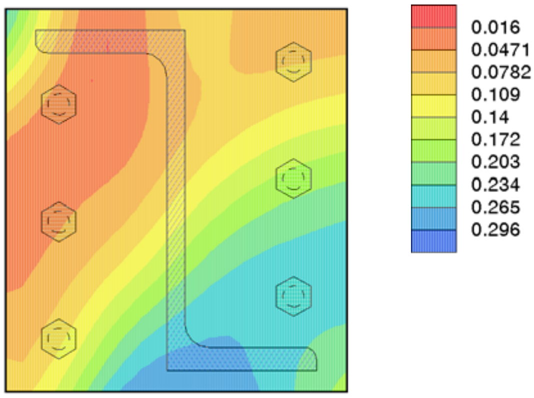
end-plate

design values: N = 8.45 kN, M_y = 2.97 kNm, M_z = 10.43 kNm

deformations u_z [mm], lifting off positive
min u_z = -0.02 mm, max u_z = 0.43 mm



utilization of end-plate U_p
min U_p = 0.016, max U_p = 0.295



utilization of end-plate

Kno	x mm	y mm	u_z mm	U_σ	U_b	U_p
220	72.0	180.0	0.087	0.295	---	0.295
462	160.0	180.0	0.426	0.192	---	0.192

x,y: node coordinates; u_z: deformations (lifting off positive); U_σ: utilization due to moment with shear force; U_b: utilization due to compression by contact
U_p: utilization of end-plate

tension force of bolts

	x mm	y mm	w_t mm	F_t kN	ε_{wt} %	U_{wt}
1	25.0	45.0	0.017	3.89	0.055	0.009
2	135.0	25.0	0.085	20.04	0.283	0.047
3	25.0	100.0	0.021	4.94	0.070	0.012
4	135.0	80.0	0.135	30.84	0.449	0.075
5	25.0	155.0	0.014	3.38	0.048	0.008
6	135.0	135.0	0.232	31.74	0.774	0.129

x,y: bolt coordinates; w_t: deformation (tension positive); F_t: bolt force; ε_{wt}: elongation
U_{wt}: utilization due to elongation

utilization of end-plate [node 220] U_{max} = 0.295 < 1 ok.
utilization of bolts due to elongation [bolt 6] U_{max} = 0.129 < 1 ok.

bolts

design values: max F_t = 31.74 kN, V_z = 23.13 kN, V_y = 5.10 kN, M_x = 0.05 kNm

verification of bolts
U_{tp} utilization due to tension/punching shear failure, U_{vt} utilization due to shear in tension, U_b utilization due to bearing resistance, U utilization of bolts

bolt 1	$U_{tp,1}$ = 0.117	$U_{vt,1}$ = 0.333	$U_{b,1}$ = 0.019	U_1 = 0.333
bolt 2	$U_{tp,2}$ = 0.600	$U_{vt,2}$ = 0.667	$U_{b,2}$ = 0.024	U_2 = 0.667
bolt 3	$U_{tp,3}$ = 0.148	$U_{vt,3}$ = 0.356	$U_{b,3}$ = 0.020	U_3 = 0.356
bolt 4	$U_{tp,4}$ = 0.923	$U_{vt,4}$ = 0.704	$U_{b,4}$ = 0.003	U_4 = 0.923
bolt 5	$U_{tp,5}$ = 0.101	$U_{vt,5}$ = 0.409	$U_{b,5}$ = 0.034	U_5 = 0.409
bolt 6	$U_{tp,6}$ = 0.950	$U_{vt,6}$ = 0.709	$U_{b,6}$ = 0.002	U_6 = 0.950
total Max:	U_{tp} = 0.950	U_{vt} = 0.709	U_b = 0.034	U = 0.950 < 1 ok.

utilization of bolts [bolt 6] U_{max} = 0.950 < 1 ok.

beam

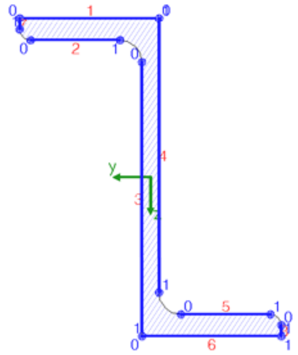
plastic cross-sectional check for N = 8.45 kN, M_y = 6.31 kNm, V_z = 20.07 kN,
M_z = 8.82 kNm, V_y = 12.58 kN, M_x = 0.05 kNm
valid normal-/shear stress: zul σ_{Rd} = 35.50 kN/cm², zul τ_{Rd} = 20.50 kN/cm²
top flange: shear force V_O = 2.55 kN, torsion T_{pO} = 0.02 kNm, shear stress τ_O = 0.59 kN/cm² ⇒ $U_{\tau,O}$ = 0.029
flange bending $M_{\sigma,O}$ = 5.06 kNm, bending stress σ_O = 8.72 kN/cm² ⇒ $U_{\sigma,O}$ = 0.246
design resistance forces $N_{max,O}$ = -4.41 kN, $N_{min,O}$ = -136.06 kN
bottom flange: shear force V_U = 2.55 kN, torsion T_{pU} = 0.02 kNm, shear stress τ_O = 0.59 kN/cm² ⇒ $U_{\tau,U}$ = 0.029
flange bending $M_{\sigma,U}$ = 5.37 kNm, bending stress σ_U = 9.25 kN/cm² ⇒ $U_{\sigma,U}$ = 0.261
design resistance forces $N_{max,U}$ = 139.81 kN, $N_{min,U}$ = 9.27 kN
web: shear force V_S = 23.13 kN, torsion T_{pS} = 0.01 kNm, shear stress τ_S = 2.12 kN/cm² ⇒ $U_{\tau,S}$ = 0.104
design resistance forces $N_{max,S}$ = 414.17 kN, $N_{min,S}$ = -414.17 kN
main bending: axial force N = 8.45 kN, design resistance forces N_{max} = 549.58 kN, N_{min} = -540.96 kN ⇒ U_N = 0.015
moment M_y = 2.97 kNm, design resistance moments $M_{y,max}$ = 34.84 kNm, $M_{y,min}$ = -13.27 kNm ⇒ U_{My} = 0.085
total (possibly due to load increase): max U = 0.419 < 1 ok.

utilizations: design resistance $U_\sigma = 0.419 < 1$ ok., c/t-ratio $U_{c/t} = 0.479 < 1$ ok.

utilization of beam $\max(U_\sigma, U_{c/t}) = 0.479 < 1$ ok.

welds

design values: $N = 8.45$ kN, $M_y = 2.97$ kNm, $V_z = 23.13$ kN, $M_z = 10.43$ kNm,
$V_y = 5.10$ kN, $M_x = 0.05$ kNm
weld 3: weld thickness $a = 10.0 \text{ mm} > a_{max} = t_{min} = 6.0$ mm !!
weld 4: weld thickness $a = 10.0 \text{ mm} > a_{max} = t_{min} = 6.0$ mm !!



weld 1:	$a_w = 10.0$ mm	$l_w = 70.0$ mm
weld 2:	$a_w = 10.0$ mm	$l_w = 45.0$ mm
weld 3:	$a_w = 10.0$ mm	$l_w = 138.0$ mm
weld 4:	$a_w = 10.0$ mm	$l_w = 138.0$ mm
weld 5:	$a_w = 10.0$ mm	$l_w = 45.0$ mm
weld 6:	$a_w = 10.0$ mm	$l_w = 70.0$ mm
weld 7:	$a_w = 10.0$ mm	$l_w = 5.5$ mm
weld 8:	$a_w = 10.0$ mm	$l_w = 5.5$ mm

Max: $\sigma_{1,w,Ed} = 32.57 \text{ kN/cm}^2 < f_{1,w,Rd} = 43.56 \text{ kN/cm}^2$,
$\sigma_{2,w,Ed} = 16.29 \text{ kN/cm}^2 < f_{2,w,Rd} = 35.28 \text{ kN/cm}^2 \Rightarrow U_w = 0.748 < 1$ ok.

utilization of welds $U_{max} = 0.748 < 1$ ok.

utilization Lk 2 $U_{max} = 0.950 < 1$ ok.