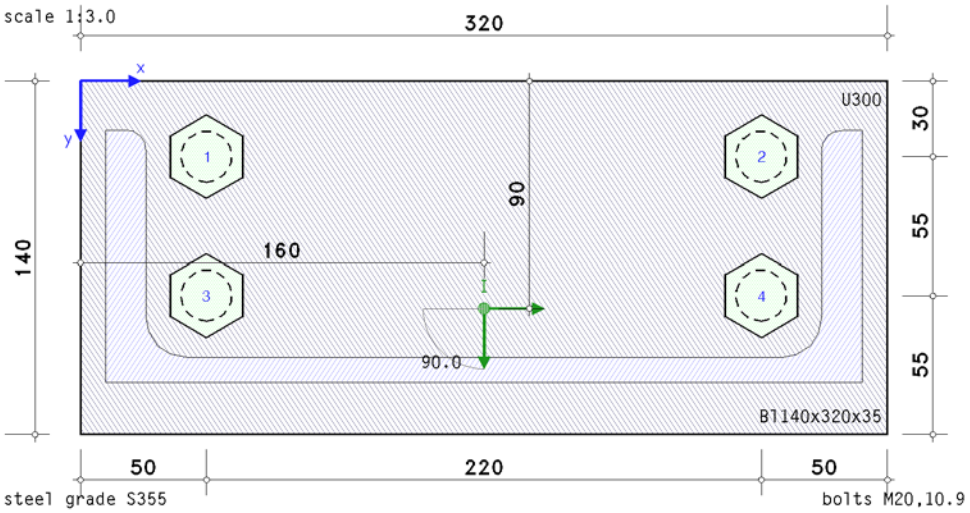
4H-EC3FS version: 2/2017-1d

bolted end-plate connection

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



steel grade

steel grade S355

bolts

bolt class 10.9, bolt size M20, thread included in the shear plane

connection

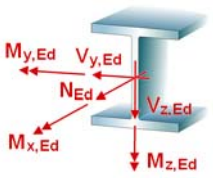
end-plate: thickness t_p = 35.0 mm, width b_p = 320.0 mm, length l_p = 140.0 mm
beam: section U300
rotation of cross-section arround section centroid β = 90.0°
beam-end-plate: surrounding fillet weld, weld thickness a = 10.0 mm
coordinates of centroid of beam section bei x_p = 160.0 mm, y_p = 90.0 mm
coordinates of beam centroid on end-plate x_s = 160.0 mm, y_s = 90.0 mm
bolts:
uniform arrangement of bolts, 2 vertical and 2 horizontal rows
edge distances top e_o = 30.0 mm, bottom e_u = 55.0 mm
distances between bolts $p_{x,1-2}$ = 220.0 mm
edge distances left e_l = 50.0 mm, right e_r = 50.0 mm
distances between bolts $p_{y,1-2}$ = 55.0 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 = 7433.6 kN/cm
plastic limit force $F_{t,f} = f_{t,f} \cdot F_{t,Rd}$ = 167.6 kN, $f_{t,f}$ = 0.950, $F_{t,Rd}$ = 176.4 kN, effective elongation at failure $\varepsilon_{t,f}$ = 4.5%
without preloading ($F_{p,C}$ = 0)
effective foundation modulus of end plate c_b = 12000.0 kN/cm³
number / dimension of finite elements each direction n_x / Δx = 32 / 10.0 mm, n_y / Δy = 20 / 7.0 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	-33.5	81.2	-21.2	-6.1	-4.4	-0.9
2	0.3	4.7	1.3	-5.7	2.4	-0.0
3	-33.2	80.9	-21.4	-5.8	-4.2	-0.9
4	0.1	4.9	1.5	-5.9	2.3	-0.0
5	-7.8	7.8	-5.1	14.0	5.8	-0.1
6	-26.5	71.3	-17.8	-15.7	-8.5	-0.9
7	-28.3	69.2	-20.0	-7.7	-5.4	-0.9
8	-3.4	13.1	0.5	-4.6	3.1	0.0
9	-25.6	72.3	-16.6	-18.9	-7.0	-0.9
10	-30.8	84.4	-17.8	-17.3	-6.0	-0.9
11	-4.1	-0.6	-4.3	12.9	5.1	-0.1



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	0.380	0.353	0.380	0.456	0.950	0.695	0.039	0.526	0.353	0.570	0.950*
2	0.101	0.041	0.101	0.038	0.249	0.185	0.003	0.133	0.200	0.192	0.249
3	0.378	0.343	0.378	0.441	0.950	0.695	0.039	0.519	0.349	0.559	0.950*
4	0.104	0.043	0.104	0.039	0.260	0.193	0.003	0.139	0.204	0.199	0.260
5	0.202	0.144	0.202	0.056	0.371	0.278	0.009	0.306	0.281	0.450	0.450
6	0.527	0.460	0.527	0.599	0.950	0.696	0.038	0.660	0.614	0.804	0.950*
7	0.310	0.276	0.310	0.332	0.950	0.688	0.035	0.501	0.348	0.558	0.950*
8	0.084	0.057	0.084	0.050	0.331	0.243	0.003	0.152	0.206	0.200	0.331
9	0.629	0.545	0.629	0.733	0.950	0.699	0.039	0.726	0.614	0.905	0.950*
10	0.712	0.666	0.712	0.921	0.950	0.707	0.045	0.752	0.614	0.916	0.950*
11	0.171	0.111	0.171	0.044	0.290	0.225	0.008	0.254	0.274	0.386	0.386

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 1] 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

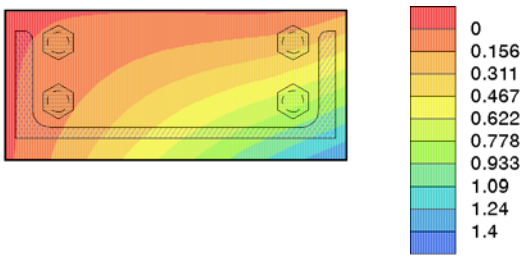
Detailed edition of Lk 1 (decisive)

Lk 1: N_{Ed} = -33.5 kN, $M_{y,Ed}$ = 81.2 kNm , $V_{z,Ed}$ = -21.2 kN, $M_{z,Ed}$ = -6.1 kNm , V_y

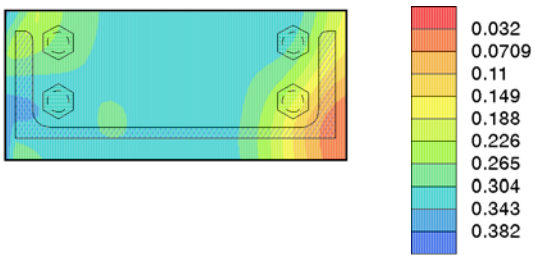
end-plate

design values: N = -33.47 kN, M_y = 81.25 kNm, M_z = -6.13 kNm

deformations u_z [mm], lifting off positive
min u_z = -0.04 mm, max u_z = 1.40 mm



utilization of end-plate U_p
min U_p = 0.032, max U_p = 0.380



utilization of end-plate

Kno	x mm	y mm	u_z mm	U_σ	U_b	U_p
19	0.0	126.0	-0.041	0.292	0.380	0.380
693	320.0	140.0	1.400	0.036	---	0.036

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	wt mm	Ft kN	ε_{wt} %	U_{wt}
1	50.0	30.0	0.022	16.57	0.064	0.014
2	270.0	30.0	0.248	148.88	0.708	0.157
3	50.0	85.0	0.096	71.71	0.276	0.061
4	270.0	85.0	0.718	167.58	2.050	0.456

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 20] $U_{max} = 0.380 < 1$ ok.
utilization of bolts due to elongation [bolt 4] $U_{max} = 0.456 < 1$ ok.

bolts

design values: max $F_t = 167.58$ kN, $V_z = -21.16$ kN, $V_y = -4.35$ kN, $M_x = -0.92$ 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	$U_{tp,1} = 0.094$	$U_{vt,1} = 0.157$	$U_{b,1} = 0.039$	$U_1 = 0.157$
bolt 2	$U_{tp,2} = 0.844$	$U_{vt,2} = 0.654$	$U_{b,2} = 0.022$	$U_2 = 0.844$
bolt 3	$U_{tp,3} = 0.407$	$U_{vt,3} = 0.360$	$U_{b,3} = 0.024$	$U_3 = 0.407$
bolt 4	$U_{tp,4} = 0.950$	$U_{vt,4} = 0.695$	$U_{b,4} = 0.006$	$U_4 = 0.950$
total Max:	$U_{tp} = 0.950$	$U_{vt} = 0.695$	$U_b = 0.039$	$U = 0.950 < 1$ ok.

utilization of bolts [bolt 4] $U_{max} = 0.950 < 1$ ok.

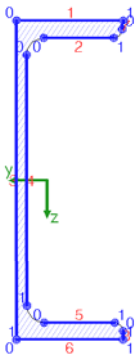
beam

plastic cross-sectional check for $N = -33.47$ kN, $M_y = 81.25$ kNm, $V_z = -21.16$ kN,
$M_z = -6.13$ kNm, $V_y = -4.35$ kN, $M_x = -0.92$ kNm
valid normal-/shear stress: zul $\sigma_{Rd} = 35.50$ kN/cm², zul $\tau_{Rd} = 20.50$ kN/cm²
top flange: shear force $V_O = -4.66$ kN, torsion $T_{pO} = -0.35$ kNm, shear stress $\tau_O = 2.98$ kN/cm² $\Rightarrow$ $U_{\tau,O} = 0.145$
flange bending $M_{\sigma,O} = -12.99$ kNm, bending stress $\sigma_O = 17.95$ kN/cm² $\Rightarrow$ $U_{\sigma,O} = 0.511$
design resistance forces $N_{max,O} = 22.94$ kN, $N_{min,O} = -423.59$ kN
bottom flange: shear force $V_U = 0.30$ kN, torsion $T_{pU} = -0.35$ kNm, shear stress $\tau_O = 2.95$ kN/cm² $\Rightarrow$ $U_{\tau,U} = 0.144$
flange bending $M_{\sigma,U} = 6.04$ kNm, bending stress $\sigma_U = 8.35$ kN/cm² $\Rightarrow$ $U_{\sigma,U} = 0.238$
design resistance forces $N_{max,U} = 335.40$ kN, $N_{min,U} = -154.40$ kN
web: shear force $V_S = -21.16$ kN, torsion $T_{pS} = -0.23$ kNm, shear stress $\tau_S = 2.03$ kN/cm² $\Rightarrow$ $U_{\tau,S} = 0.099$
design resistance forces $N_{max,S} = 946.71$ kN, $N_{min,S} = -946.71$ kN
main bending: axial force $N = -33.47$ kN, design resistance forces $N_{max} = 1305.04$ kN, $N_{min} = -1524.70$ kN $\Rightarrow$ $U_N = 0.022$
moment $M_y = 81.25$ kNm, design resistance moments $M_{y,max} = 170.99$ kNm, $M_{y,min} = -87.93$ kNm $\Rightarrow$ $U_{My} = 0.475$
total (possibly due to load increase): max $U = 0.526 < 1$ ok.
utilizations: design resistance $U_\sigma = 0.526 < 1$ ok., c/t-ratio $U_{c/t} = 0.353 < 1$ ok.

utilization of beam $\max(U_\sigma, U_{c/t}) = 0.526 < 1$ ok.

welds

design values: $N = -33.47$ kN, $M_y = 81.25$ kNm, $V_z = -21.16$ kN, $M_z = -6.13$ kNm,
$V_y = -4.35$ kN, $M_x = -0.92$ kNm
weld 3: weld thickness $a = 10.0$ mm > $a_{max} = t_{min} = 7.1$ mm !!
weld 4: weld thickness $a = 10.0$ mm > $a_{max} = t_{min} = 7.1$ mm !!



weld 1:	a_w = 10.0 mm	l_w = 100.0 mm
weld 2:	a_w = 10.0 mm	l_w = 66.0 mm
weld 3:	a_w = 10.0 mm	l_w = 300.0 mm
weld 4:	a_w = 10.0 mm	l_w = 236.0 mm
weld 5:	a_w = 10.0 mm	l_w = 66.0 mm
weld 6:	a_w = 10.0 mm	l_w = 100.0 mm
weld 7:	a_w = 10.0 mm	l_w = 8.0 mm
weld 8:	a_w = 10.0 mm	l_w = 8.0 mm

Max: $\sigma_{1,w,Ed}$ = 24.81 kN/cm² < $f_{1,w,Rd}$ = 43.56 kN/cm²,
$\sigma_{2,w,Ed}$ = 12.40 kN/cm² < $f_{2,w,Rd}$ = 35.28 kN/cm² ⇒ U_w = 0.570 < 1 **ok.**

utilization of welds U_{max} = 0.570 < 1 **ok.**

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