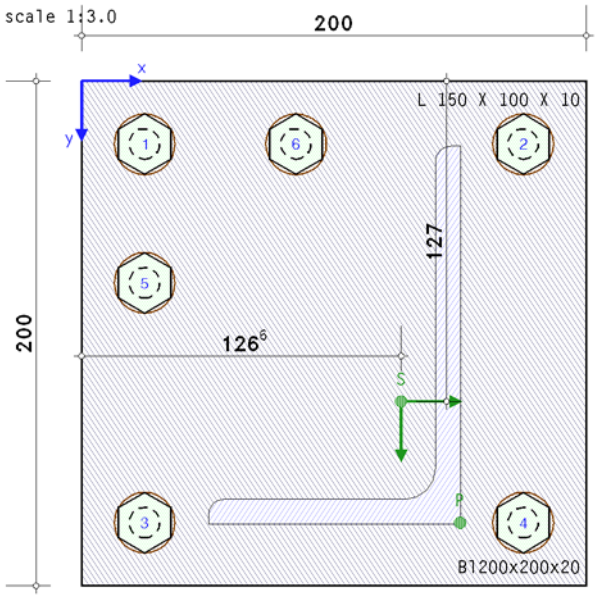
bolted end-plate connection

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



steel grade

steel grade S235

bolts

bolts with big width across flats have to be preloaded with $F_{p,C}$!!

bolt class 8.8, bolt size M12

large width across flats (high strength bolt), controlled preloaded

preloading $F_{p,C}^* = 0.7 \cdot f_{yb} \cdot A_s = 37.8$ kN, thread included in the shear plane

connection

end-plate: thickness $t_p = 20.0$ mm, width $b_p = 200.0$ mm, length $l_p = 200.0$ mm

beam: mirrored section L 150 X 100 X 10

beam-end-plate: surrounding fillet weld, weld thickness a = 7.0 mm

coordinates left top of surrounding rectangle of beam section at $x_p = 150.0$ mm, $y_p = 175.0$ mm

coordinates of beam centroid on end-plate $x_s = 126.6$ mm, $y_s = 127.0$ mm

bolts:

coordinates of bolt axis:

$x_1 = 25.0$ mm, $y_1 = 25.0$ mm | $x_2 = 175.0$ mm, $y_2 = 25.0$ mm | $x_3 = 25.0$ mm, $y_3 = 175.0$ mm

$x_4 = 175.0$ mm, $y_4 = 175.0$ mm | $x_5 = 25.0$ mm, $y_5 = 80.0$ mm | $x_6 = 85.0$ mm, $y_6 = 25.0$ 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 $c_f = 4338.0$ kN/cm

plastic limit force $F_{t,f} = f_{t,f} \cdot F_{t,Rd} = 46.1$ kN, $f_{t,f} = 0.950$, $F_{t,Rd} = 48.6$ kN, effective elongation at failure $\varepsilon_{t,f} = 6.0\%$

preload force $F_{p,C} = 37.8$ kN

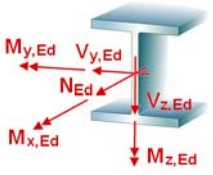
effective foundation modulus of end plate $c_b = 21000.0$ kN/cm³

number / dimension of finite elements each direction $n_x / \Delta x = 20 / 10.0$ mm, $n_y / \Delta y = 20 / 10.0$ mm

max. 50 iteration steps (tolerance limit 5‰)

internal forces and moments

Lk	N_{Ed} kN	$M_{y,Ed}$ kNcm	$V_{z,Ed}$ kN	$M_{z,Ed}$ kNcm	$V_{y,Ed}$ kN	$M_{x,Ed}$ kNcm
1	-17.9	-88.2	16.4	-375.5	-1.7	-1.4
2	1.0	-29.9	0.6	-88.6	-0.4	111.3
3	-11.3	312.8	-0.1	-607.2	-2.9	79.0
4	-11.4	-722.9	24.4	424.7	2.2	-3.8
5	-5.2	-208.1	1.0	316.8	1.5	0.0
6	-14.3	-427.0	23.7	-191.5	-0.7	107.7
7	-11.2	-735.0	24.4	407.2	2.2	-4.8
8	-6.4	184.8	0.1	-398.3	-1.9	113.0



Lk	N_{Ed} kN	$M_{y,Ed}$ kNcm	$V_{z,Ed}$ kN	$M_{z,Ed}$ kNcm	$V_{y,Ed}$ kN	$M_{x,Ed}$ kNcm
9	-10.1	-751.7	24.4	318.1	1.8	106.7
10	-12.2	333.0	-0.2	-532.6	-2.6	1.6
11	-10.9	-629.3	17.6	473.8	2.4	-3.0

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	0.122	0.084	0.122	0.029	0.804	0.676	0.035	0.391	0.498	0.491	0.804
2	0.077	0.029	0.077	0.027	0.778	0.635	0.023	0.724	0.750	0.107	0.778
3	0.226	0.226	0.123	0.046	0.934	0.695	0.030	0.857	0.750	0.883	0.934
4	0.183	0.183	0.114	0.032	0.839	0.774	0.064	0.682	0.585	0.858	0.858
5	0.106	0.037	0.106	0.027	0.779	0.574	0.005	0.369	0.142	0.458	0.779
6	0.134	0.073	0.134	0.027	0.780	0.682	0.037	0.726	1.000	0.204	1.000*
7	0.187	0.187	0.111	0.033	0.842	0.776	0.065	0.674	0.580	0.849	0.849
8	0.109	0.109	0.100	0.031	0.830	0.663	0.030	0.853	0.750	0.573	0.853
9	0.193	0.193	0.100	0.033	0.847	0.703	0.042	0.923	0.557	0.774	0.923
10	0.176	0.176	0.110	0.039	0.907	0.659	0.008	0.624	0.750	0.792	0.907
11	0.149	0.149	0.123	0.030	0.813	0.710	0.045	0.677	0.607	0.846	0.846

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 3] max U = 0.934 < 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

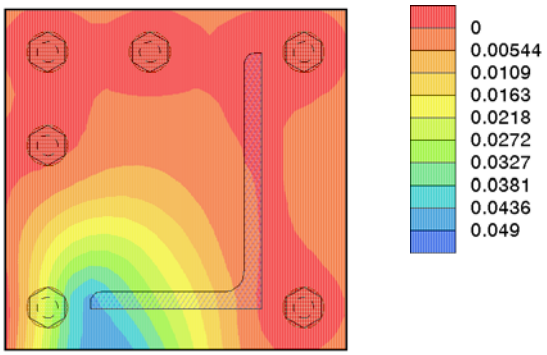
Detailed edition of Lk 3 (decisive)

Lk 3: N_{Ed} = -11.3 kN, $M_{y,Ed}$ = 312.8 kNcm, $V_{z,Ed}$ = -0.1 kN, $M_{z,Ed}$ = -607.2 kNcm, V

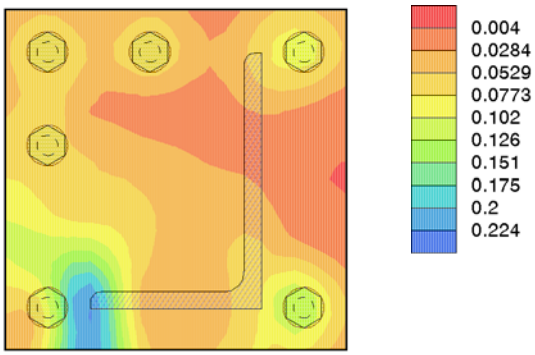
end-plate

design values: N = -11.31 kN, M_y = 3.13 kNm, M_z = -6.07 kNm

deformations u_z [mm], lifting off positive
min u_z = -0.00 mm, max u_z = 0.05 mm



utilization of end-plate U_p
min U_p = 0.004, max U_p = 0.226



utilization of end-plate

Kno	x mm	y mm	u_z mm	U_σ	U_b	U_p
124	50.0	180.0	0.046	0.226	---	0.226
147	60.0	200.0	0.049	0.188	---	0.188

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	F_t kN	ε_{wt} %	U_{wt}
1	25.0	25.0	-0.000	37.77	0.159	0.027
2	175.0	25.0	-0.000	37.77	0.159	0.027
3	25.0	175.0	0.023	45.33	0.274	0.046
4	175.0	175.0	-0.000	37.77	0.159	0.027
5	25.0	80.0	-0.001	37.78	0.159	0.027
6	85.0	25.0	-0.000	37.77	0.159	0.027

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

utilization of end-plate [node 124] U_{max} = 0.226 < 1 ok.
utilization of bolts due to elongation [bolt 3] U_{max} = 0.046 < 1 ok.

bolts

design values: max F_t = 45.33 kN, V_z = -0.14 kN, V_y = -2.90 kN, M_x = 0.79 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	$U_{tp,1}$ = 0.778	$U_{vt,1}$ = 0.602	$U_{b,1}$ = 0.014	U_1 = 0.778
bolt 2	$U_{tp,2}$ = 0.778	$U_{vt,2}$ = 0.612	$U_{b,2}$ = 0.017	U_2 = 0.778
bolt 3	$U_{tp,3}$ = 0.934	$U_{vt,3}$ = 0.695	$U_{b,3}$ = 0.008	U_3 = 0.934
bolt 4	$U_{tp,4}$ = 0.778	$U_{vt,4}$ = 0.657	$U_{b,4}$ = 0.030	U_4 = 0.778
bolt 5	$U_{tp,5}$ = 0.778	$U_{vt,5}$ = 0.605	$U_{b,5}$ = 0.010	U_5 = 0.778
bolt 6	$U_{tp,6}$ = 0.778	$U_{vt,6}$ = 0.570	$U_{b,6}$ = 0.003	U_6 = 0.778
total Max:	U_{tp} = 0.934	U_{vt} = 0.695	U_b = 0.030	U = 0.934 < 1 ok.

utilization of bolts [bolt 3] U_{max} = 0.934 < 1 ok.

beam

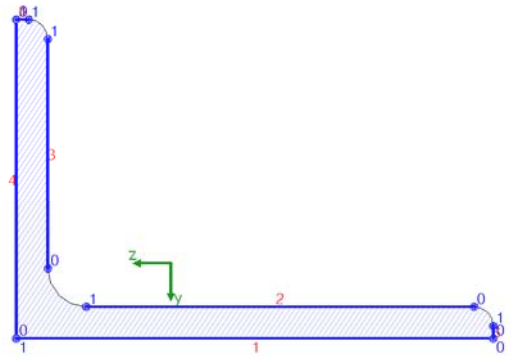
plastic cross-sectional check for N = -11.31 kN, M_y = 0.41 kNm, V_z = 1.04 kN,
M_z = -6.82 kNm, V_y = -2.71 kN, M_x = 0.79 kNm
valid normal-/shear stress: zul σ_{Rd} = 23.50 kN/cm², zul τ_{Rd} = 13.57 kN/cm²
bottom flange: shear force V_U = -2.90 kN, torsion T_{pU} = 0.33 kNm, shear stress τ_O = 6.94 kN/cm² ⇒ $U_{\tau,U}$ = 0.511
flange bending $M_{\sigma,U}$ = -6.28 kNm, bending stress σ_U = 13.89 kN/cm² ⇒ $U_{\sigma,U}$ = 0.688
design resistance forces $N_{max,U}$ = -29.91 kN, $N_{min,U}$ = -171.21 kN
web: shear force V_S = -0.14 kN, torsion T_{pS} = 0.46 kNm, shear stress τ_S = 6.82 kN/cm² ⇒ $U_{\tau,S}$ = 0.503
design resistance forces $N_{max,S}$ = 284.37 kN, $N_{min,S}$ = -284.37 kN
main bending: axial force N = -11.31 kN, design resistance forces N_{max} = 254.46 kN, N_{min} = -455.58 kN ⇒ U_N = 0.025
moment M_y = 3.13 kNm, design resistance moments $M_{y,max}$ = 8.02 kNm, $M_{y,min}$ = -19.29 kNm ⇒ U_{My} = 0.390

total (possibly due to load increase): max U = 0.857 < 1 ok.
utilizations: design resistance U_σ = 0.857 < 1 ok., c/t-ratio $U_{c/t}$ = 0.750 < 1 ok.

utilization of beam max(U_σ,$U_{c/t}$) = 0.857 < 1 ok.

welds

design values: N = -11.31 kN, M_y = 3.13 kNm, V_z = -0.14 kN, M_z = -6.07 kNm,
V_y = -2.90 kN, M_x = 0.79 kNm



weld 1:	a_w = 7.0 mm	l_w = 150.0 mm
weld 2:	a_w = 7.0 mm	l_w = 122.0 mm
weld 3:	a_w = 7.0 mm	l_w = 72.0 mm
weld 4:	a_w = 7.0 mm	l_w = 100.0 mm
weld 5:	a_w = 7.0 mm	l_w = 4.0 mm
weld 6:	a_w = 7.0 mm	l_w = 4.0 mm

Max: $\sigma_{1,w,Ed}$ = 31.79 kN/cm² < $f_{1,w,Rd}$ = 36.00 kN/cm²,
$\sigma_{2,w,Ed}$ = 15.90 kN/cm² < $f_{2,w,Rd}$ = 25.92 kN/cm² ⇒ U_w = 0.883 < 1 ok.

utilization of welds U_{max} = 0.883 < 1 ok.

utilization Lk 3 U_{max} = 0.934 < 1 ok.