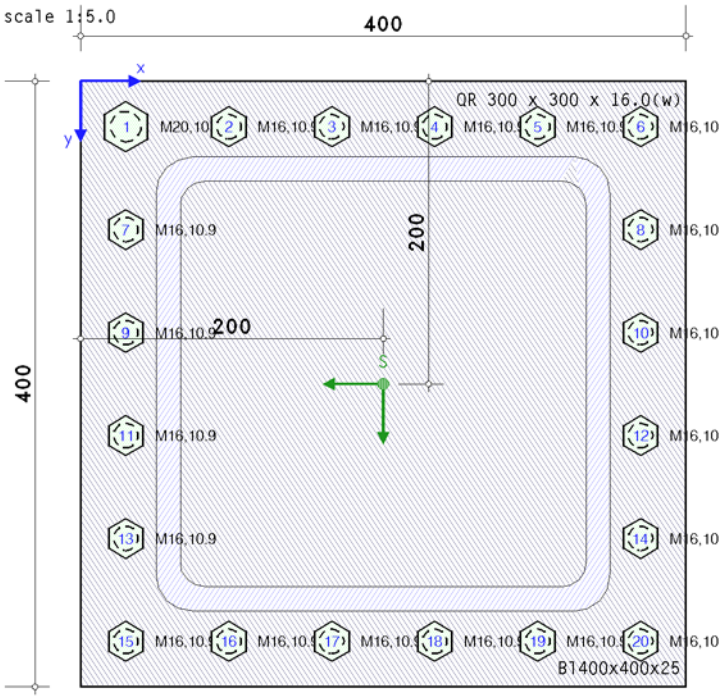
4H-EC3FS version: 2/2017-1d

bolted end-plate connection

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



steel grade

steel grade S235

bolts

thread included in the shear plane

--	FK	f_{yb} N/mm²	f_{ub} N/mm²	ε_{ub} %	TP	Schlüss	d mm	Δd mm	A mm²	A_s mm²	d_{ks} mm	d_{ke} mm	t_k mm	t_m mm	d_p mm	t_p mm
1	10.9	900.0	1000.0	9.0	M20	normal	20.0	2.0	314.2	245.0	30.0	33.0	12.5	19.0	37.0	3.0
2	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
3	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
4	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
5	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
6	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
7	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
8	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
9	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
10	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
11	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
12	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
13	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
14	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
15	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
16	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
17	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
18	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
19	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0
20	10.9	900.0	1000.0	9.0	M16	normal	16.0	2.0	201.1	157.0	24.0	26.2	10.0	15.9	30.0	3.0

FK: bolt class; f_{yb}: char. yield strength; f_{ub}: char. tensile strength; ε_{ub}: elongation at failure
TP: bolt size; Schlüss: across flats dimension; d: nominal value of bolt diameter; Δd: clearance
A: gross section (shaft); A_s: cross-section under stress; d_{ks}: across flats dimension of bolt head; d_{ke}: across points dimension of bolt head
t_k: thickness of the bolt head; t_m: nut height; d_p: diameter of a washer; t_p: plate thickness of a washer

connection

end-plate: thickness t_p = 25.0 mm, width b_p = 400.0 mm, length l_p = 400.0 mm
beam: section QR 300 x 300 x 16.0(w)
beam-end-plate: surrounding butt weld (full penetrated)
beam section centric on end-plate (coinciding centroids)
coordinates of beam centroid on end-plate x_s = 200.0 mm, y_s = 200.0 mm
bolts:

	x mm	y mm	FK	TP	Schlüss	c_f kN/cm	$f_{t,f}$	$F_{t,Rd}$ kN	$F_{t,f}$ kN	$\varepsilon_{t,f}$ %	$F_{p,C}$ kN
1	30.0	30.0	10.9	M20	normal	9596.1	0.950	176.4	167.6	4.5	--
2	98.0	30.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--
3	166.0	30.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--
4	234.0	30.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--
5	302.0	30.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--
6	370.0	30.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--
7	30.0	98.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--

	x mm	y mm	FK	TP	Schlüss	c_f kN/cm	$f_{t,f}$	$F_{t,Rd}$ kN	$F_{t,f}$ kN	$\varepsilon_{t,f}$ %	$F_{p,C}$ kN
8	370.0	98.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--
9	30.0	166.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--
10	370.0	166.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--
11	30.0	234.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--
12	370.0	234.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--
13	30.0	302.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--
14	370.0	302.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--
15	30.0	370.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--
16	98.0	370.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--
17	166.0	370.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--
18	234.0	370.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--
19	302.0	370.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--
20	370.0	370.0	10.9	M16	normal	6402.3	0.950	113.0	107.4	4.5	--

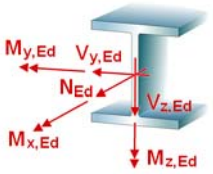
x,y: coordinates of bolt axis on end-plate; FK: bolt class; TP: bolt size
Schlüss: across flats dimension; c_f: spring stiffness of bolt (FEM); $f_{t,f}$: usage factor of spring (FEM)
$F_{t,Rd}$: max. tension force of bolt (FEM); $F_{t,f} = f_{t,f} \cdot F_{t,Rd}$: plastic limit force of bolt (FEM); $\varepsilon_{t,f}$: elongation at failure of bolt (FEM)
$F_{p,C}$: preload force of bolt (FEM); $F_{p,C}$: preload force of bolt (FEM)

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 elastic method
verification of welds with the directional method
verification of bolts, check of distances
FEM-calculation:
bolts are plasticly calculated (c_f, $F_{t,Rd}$, $F_{t,f}$, $f_{t,f}$, $\varepsilon_{t,f}$, $F_{p,C}$ s. table)
effective foundation modulus of end plate c_b = 16800.0 kN/cm³
number / dimension of finite elements each direction n_x / Δx = 25 / 16.0 mm, n_y / Δy = 25 / 16.0 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	-171.7	-199.4	-44.3	-130.9	29.1	10.6
2	33.3	6.5	1.5	103.0	-12.8	22.5
3	-160.3	-156.0	-34.7	-190.0	42.2	-13.5
4	-70.5	-30.1	-6.7	-169.5	37.7	-36.4
5	-109.3	-177.4	-39.4	32.6	-1.2	45.9



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	0.631	0.631	0.392	0.197	0.949	0.683	0.046	0.885	0.248	0.763	0.949*
2	0.218	0.218	0.123	0.072	0.459	0.410	0.076	0.307	0.175	0.256	0.459
3	0.659	0.659	0.417	0.249	0.950	0.685	0.060	0.922	0.241	0.792	0.950*
4	0.370	0.370	0.235	0.098	0.607	0.529	0.094	0.550	0.230	0.464	0.607
5	0.374	0.374	0.245	0.127	0.807	0.650	0.135	0.585	0.238	0.498	0.807

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 = 0.949 < 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

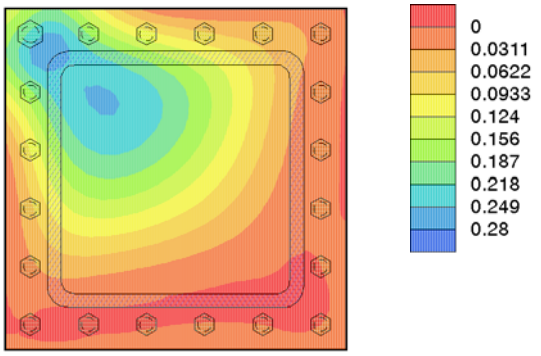
Detailed edition of Lk 1 (decisive)

Lk 1: N_{Ed} = -171.7 kN, $M_{y,Ed}$ = -199.4 kNm , $V_{z,Ed}$ = -44.3 kN, $M_{z,Ed}$ = -130.9 kNm ,

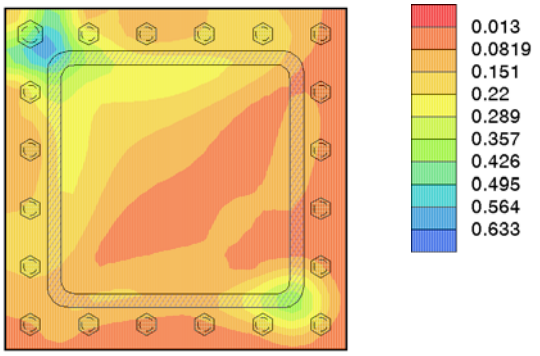
end-plate

design values: N = -171.66 kN, M_y = -199.41 kNm, M_z = -130.93 kNm

deformations u_z [mm], lifting off positive
min u_z = -0.01 mm, max u_z = 0.28 mm



utilization of end-plate U_p
min U_p = 0.013, max U_p = 0.631



utilization of end-plate

Kno	x mm	y mm	u_z mm	U_σ	U_b	U_p
82	48.0	48.0	0.278	0.631	---	0.631

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	εwt %	Uwt
1	30.0	30.0	0.222	167.46	0.888	0.197
2	98.0	30.0	0.187	105.21	0.746	0.166
3	166.0	30.0	0.104	66.67	0.417	0.093
4	234.0	30.0	0.066	42.43	0.265	0.059
5	302.0	30.0	0.046	29.60	0.185	0.041
6	370.0	30.0	0.018	11.66	0.073	0.016
7	30.0	98.0	0.182	103.91	0.726	0.161
8	370.0	98.0	0.012	7.46	0.047	0.010
9	30.0	166.0	0.097	61.79	0.386	0.086
10	370.0	166.0	0.006	3.87	0.024	0.005
11	30.0	234.0	0.055	35.13	0.219	0.049
12	370.0	234.0	0.002	1.53	0.010	0.002
13	30.0	302.0	0.025	15.71	0.098	0.022
14	370.0	302.0	-0.000	0.33	---	---
15	30.0	370.0	-0.001	0.12	---	---
16	98.0	370.0	-0.001	0.01	---	---
17	166.0	370.0	-0.001	0.15	---	---
18	234.0	370.0	0.000	0.61	0.002	---
19	302.0	370.0	-0.000	0.75	---	---
20	370.0	370.0	0.000	1.10	---	---

x,y: bolt coordinates; wt: deformation (tension positive); Ft: bolt force; εwt: elongation
Uwt: utilization due to elongation

utilization of end-plate [node 82] U_{max} = 0.631 < 1 **ok.**
utilization of bolts due to elongation [bolt 1] U_{max} = 0.197 < 1 **ok.**

bolts

design values: max F_t = 167.46 kN, V_z = -44.31 kN, V_y = 29.10 kN, M_x = 10.62 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	$U_{tp,1} = 0.949$	$U_{vt,1} = 0.683$	$U_{b,1} = 0.004$	$U_1 = 0.949$
bolt 2	$U_{tp,2} = 0.931$	$U_{vt,2} = 0.672$	$U_{b,2} = 0.001$	$U_2 = 0.931$
bolt 3	$U_{tp,3} = 0.590$	$U_{vt,3} = 0.462$	$U_{b,3} = 0.010$	$U_3 = 0.590$
bolt 4	$U_{tp,4} = 0.375$	$U_{vt,4} = 0.336$	$U_{b,4} = 0.018$	$U_4 = 0.375$
bolt 5	$U_{tp,5} = 0.262$	$U_{vt,5} = 0.275$	$U_{b,5} = 0.025$	$U_5 = 0.275$
bolt 6	$U_{tp,6} = 0.103$	$U_{vt,6} = 0.192$	$U_{b,6} = 0.046$	$U_6 = 0.192$
bolt 7	$U_{tp,7} = 0.919$	$U_{vt,7} = 0.663$	$U_{b,7} = 0.002$	$U_7 = 0.919$
bolt 8	$U_{tp,8} = 0.066$	$U_{vt,8} = 0.157$	$U_{b,8} = 0.033$	$U_8 = 0.157$
bolt 9	$U_{tp,9} = 0.547$	$U_{vt,9} = 0.416$	$U_{b,9} = 0.010$	$U_9 = 0.547$
bolt 10	$U_{tp,10} = 0.034$	$U_{vt,10} = 0.126$	$U_{b,10} = 0.028$	$U_{10} = 0.126$
bolt 11	$U_{tp,11} = 0.311$	$U_{vt,11} = 0.248$	$U_{b,11} = 0.010$	$U_{11} = 0.311$
bolt 12	$U_{tp,12} = 0.014$	$U_{vt,12} = 0.104$	$U_{b,12} = 0.023$	$U_{12} = 0.104$
bolt 13	$U_{tp,13} = 0.139$	$U_{vt,13} = 0.117$	$U_{b,13} = 0.005$	$U_{13} = 0.139$
bolt 14	$U_{tp,14} = 0.003$	$U_{vt,14} = 0.092$	$U_{b,14} = 0.020$	$U_{14} = 0.092$
bolt 15	$U_{tp,15} = 0.001$	$U_{vt,15} = 0.018$	$U_{b,15} = 0.007$	$U_{15} = 0.018$
bolt 16	$U_{tp,16} = 0.000$	$U_{vt,16} = 0.000$	$U_{b,16} = 0.003$	$U_{16} = 0.010$
bolt 17	$U_{tp,17} = 0.001$	$U_{vt,17} = 0.029$	$U_{b,17} = 0.011$	$U_{17} = 0.029$
bolt 18	$U_{tp,18} = 0.005$	$U_{vt,18} = 0.052$	$U_{b,18} = 0.019$	$U_{18} = 0.052$
bolt 19	$U_{tp,19} = 0.007$	$U_{vt,19} = 0.073$	$U_{b,19} = 0.027$	$U_{19} = 0.073$
bolt 20	$U_{tp,20} = 0.010$	$U_{vt,20} = 0.096$	$U_{b,20} = 0.035$	$U_{20} = 0.096$
total Max:	$U_{tp} = 0.949$	$U_{vt} = 0.683$	$U_b = 0.046$	$U = 0.949 < 1$ ok.

utilization of bolts [bolt 1] $U_{max} = 0.949 < 1$ ok.

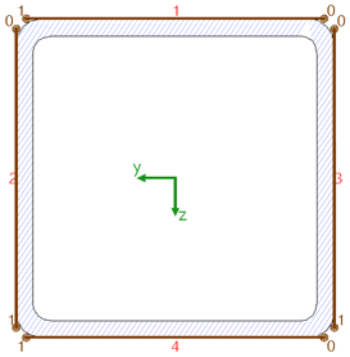
beam

elastic cross-sectional check for N = -171.66 kN, M_y = -199.41 kNm, V_z = -44.31 kN,
M_z = -130.93 kNm, V_y = 29.10 kN, M_x = 10.62 kNm
max σ_v bei y = -143.0 mm, z = 143.0 mm: $\sigma_x = -20.76$ kN/cm², $\tau = 0.58$ kN/cm², $\sigma_v = 20.79$ kN/cm²
verification: $\sigma_v = 20.79$ kN/cm < zul $\sigma_v = 23.50$ kN/cm ⇒ $U = 0.885 < 1$ ok.
utilizations: design resistance $U_\sigma = 0.885 < 1$ ok., c/t-ratio $U_{c/t} = 0.248 < 1$ ok.

utilization of beam $\max(U_\sigma, U_{c/t}) = 0.885 < 1$ ok.

welds

design values: N = -171.66 kN, M_y = -199.41 kNm, V_z = -44.31 kN, M_z = -130.93 kNm,
V_y = 29.10 kN, M_x = 10.62 kNm



weld 1:	$a_w = 16.0$ mm	$l_w = 281.2$ mm
weld 2:	$a_w = 16.0$ mm	$l_w = 281.2$ mm
weld 3:	$a_w = 16.0$ mm	$l_w = 281.2$ mm
weld 4:	$a_w = 16.0$ mm	$l_w = 281.2$ mm

Max: $\sigma_{1,w,Ed} = 27.46$ kN/cm² < $f_{1,w,Rd} = 36.00$ kN/cm²,
$\sigma_{2,w,Ed} = 13.73$ kN/cm² < $f_{2,w,Rd} = 25.92$ kN/cm² ⇒ $U_w = 0.763 < 1$ ok.

utilization of welds $U_{max} = 0.763 < 1$ ok.

utilization Lk 1 $U_{max} = 0.949 < 1$ ok.