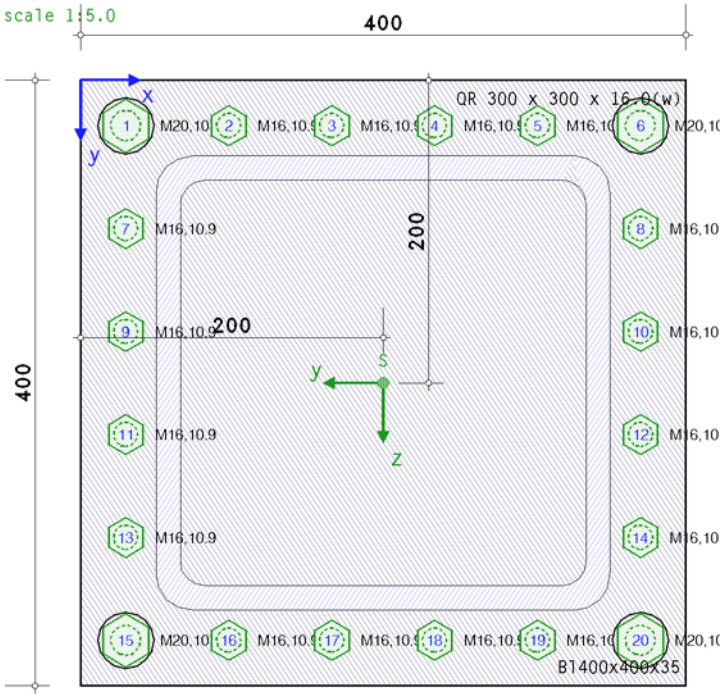
POS. 5: QR

bolted end plate connection EC 3-1-8 (04.25), NA: Deutschland

1. input report



steel grade

steel grade S355

bolts

bolts have to be preloaded with $F_{p,C}$!!

thread included in the shear plane

--	FK	TP	Senk	Schlüss	--	FK	TP	Senk	Schlüss	--	FK	TP	Senk	Schlüss
1	10.9	M20	no	big	8	10.9	M16	no	normal	15	10.9	M20	no	big
2	10.9	M16	no	normal	9	10.9	M16	no	normal	16	10.9	M16	no	normal
3	10.9	M16	no	normal	10	10.9	M16	no	normal	17	10.9	M16	no	normal
4	10.9	M16	no	normal	11	10.9	M16	no	normal	18	10.9	M16	no	normal
5	10.9	M16	no	normal	12	10.9	M16	no	normal	19	10.9	M16	no	normal
6	10.9	M20	no	big	13	10.9	M16	no	normal	20	10.9	M20	no	big
7	10.9	M16	no	normal	14	10.9	M16	no	normal					

FK: bolt class; TP: bolt size; Senk: countersunk bolt; Schlüss: across flats dimension

connection

end plate (rectangular): thickness t_p = 35.0 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 (beam centroid in plate centre)

coordinates of the beam centroid on end plate x_s = 200.0 mm, y_s = 200.0 mm

bolts:

plastic limit force $F_{t,f} = f_{t,f} \cdot F_{t,Rd}$, $f_{t,f}$ = 0.950

effective elongation at failure $\varepsilon_{t,f} = f_{t,\varepsilon} \cdot \varepsilon_{ub}$, $f_{t,\varepsilon}$ = 0.250

	x mm	y mm	c_f kN/cm	$F_{t,f}$ kN	$\varepsilon_{t,f}$ %	$F_{p,C}$ kN		x mm	y mm	c_f kN/cm	$F_{t,f}$ kN	$\varepsilon_{t,f}$ %	$F_{p,C}$ kN
1	30.0	30.0	5512.9	167.4	2.25	154.2	11	30.0	234.0	3828.6	107.2	2.25	--
2	98.0	30.0	3828.6	107.2	2.25	--	12	370.0	234.0	3828.6	107.2	2.25	--
3	166.0	30.0	3828.6	107.2	2.25	--	13	30.0	302.0	3828.6	107.2	2.25	--
4	234.0	30.0	3828.6	107.2	2.25	--	14	370.0	302.0	3828.6	107.2	2.25	--
5	302.0	30.0	3828.6	107.2	2.25	--	15	30.0	370.0	5512.9	167.4	2.25	154.2
6	370.0	30.0	5512.9	167.4	2.25	154.2	16	98.0	370.0	3828.6	107.2	2.25	--
7	30.0	98.0	3828.6	107.2	2.25	--	17	166.0	370.0	3828.6	107.2	2.25	--
8	370.0	98.0	3828.6	107.2	2.25	--	18	234.0	370.0	3828.6	107.2	2.25	--
9	30.0	166.0	3828.6	107.2	2.25	--	19	302.0	370.0	3828.6	107.2	2.25	--
10	370.0	166.0	3828.6	107.2	2.25	--	20	370.0	370.0	5512.9	167.4	2.25	154.2

x,y: coordinates of bolt axis on end plate; c_f: spring stiffness of bolt (FEM); $F_{t,f}$: plastic limit force of bolt (FEM)
$\varepsilon_{t,f}$: effective elongation at failure of bolt (FEM); $F_{p,C} \le F_{t,Rk}$: preload force of bolt (FEM)

calculation

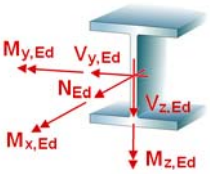
verification:

calculation of internal forces and moments (FEM) and verifications of resistance

verification of end plate with the plastic method, verification of compression by contact

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, $F_{t,Rk}$, $F_{t,f}$, $f_{t,\varepsilon}$, $F_{p,C}$ s. table)
effective foundation modulus of end plate c_b = 6000.0 kN/cm³
number / dimension of finite elements each direction n_x / Δx = 80 / 5.0 mm, n_y / Δy = 80 / 5.0 mm
max. 50 iteration steps (tolerance limit 5‰)
internal forces and moments refering to local axes of cross-section

Lc	N_{Ed} kN	$M_{y,Ed}$ kNm	$V_{z,Ed}$ kN	$M_{z,Ed}$ kNm	$V_{y,Ed}$ kN	$M_{x,Ed}$ kNm
1	-171.66	-199.41	-44.31	-130.93	29.10	10.62
2	33.33	6.55	1.45	103.02	-12.77	22.46
3	-160.29	-156.01	-34.67	-189.96	42.21	-13.55
4	-70.53	-30.08	-6.69	-169.52	37.67	-36.39
5	-109.35	-177.44	-39.43	32.59	-1.17	45.93



partial safety factors for material
resistance of cross-sections γ_{M0} = 1.00
resistance of bolts, welds, plates in bearing γ_{M2} = 1.25

local stresses especially of the beam and of welds are not considered !

utilizations

Lc	U_p	U_σ	U_b	U_{pl}	$U_{pl,s}$	$U_{wt,s}$	$U_{t,s}$	$U_{vt,s}$	$U_{b,s}$	U_q	$U_{c/t}$	U_w	U
1	0.447	0.447	0.349	0.363	0.588	0.198	0.193	0.685	0.021	0.586	0.248	0.550	0.685
2	0.243	0.187	0.243	0.242	0.257	0.134	0.182	0.658	0.019	0.203	0.175	0.186	0.658
3	0.472	0.472	0.333	0.347	0.605	0.206	0.193	0.688	0.027	0.610	0.241	0.571	0.688
4	0.335	0.286	0.335	0.342	0.394	0.153	0.189	0.687	0.035	0.364	0.230	0.337	0.687
5	0.339	0.293	0.339	0.342	0.404	0.154	0.189	0.698	0.045	0.387	0.238	0.364	0.698*

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

2. final result

maximum utilization of end plate due to 5 Lc: max U_p with corresponding values

node	x mm	y mm	u_z mm	b_z N/mm²	m_{xx} kNm/m	m_{yy} kNm/m	m_{xy} kNm/m	q_x kN/m	q_y kN/m	U_p
739	45.0	45.0	0.114	0.00	-32.48	-31.61	2.96	-1832.14	-1873.11	0.472

x,y: node coordinates; u_z: deformations (lifting off positive); b_z: compression by contact (compression positive); m_{xx},m_{yy},m_{xy}: moments
q_x,q_y: shear forces; q_x,q_y: shear forces; U_p: utilization of end plate

maximum utilization of bolts due to 5 Lc: max U_s with corresponding values

	x mm	y mm	F_t kN	U_{wt}	U_{vt}	U_b	U_s
1	30.0	30.0	167.44	0.206	0.688	0.002	0.688
2	98.0	30.0	98.46	0.165	0.641	0.002	0.641
3	166.0	30.0	102.66	0.176	0.662	0.001	0.662
4	234.0	30.0	84.85	0.141	0.626	0.010	0.626
5	302.0	30.0	64.57	0.107	0.582	0.023	0.582
6	370.0	30.0	164.24	0.154	0.698	0.008	0.698
7	30.0	98.0	100.96	0.172	0.658	0.002	0.658
8	370.0	98.0	38.67	0.064	0.512	0.035	0.512
9	30.0	166.0	101.99	0.174	0.663	0.002	0.663
10	370.0	166.0	31.97	0.053	0.458	0.030	0.458
11	30.0	234.0	76.82	0.127	0.576	0.010	0.576
12	370.0	234.0	50.78	0.084	0.395	0.009	0.395
13	30.0	302.0	48.52	0.080	0.488	0.023	0.488
14	370.0	302.0	0.53	0.000	0.355	0.041	0.355
15	30.0	370.0	159.48	0.139	0.681	0.009	0.681
16	98.0	370.0	18.36	0.030	0.378	0.035	0.378
17	166.0	370.0	12.54	0.021	0.320	0.029	0.320
18	234.0	370.0	2.40	0.004	0.262	0.027	0.262
19	302.0	370.0	0.00	---	0.313	0.045	0.313
20	370.0	370.0	154.22	0.133	0.675	0.013	0.675

x,y: bolt coordinates; F_t: bolt force; U_{wt}: utilization due to elongation; U_{vt}: utilization due to shear
U_b: utilization due to bearing resistance; U_s: utilization of bolts

maximum utilization of end plate [Lc 3]	max U_p = 0.472 < 1 ok
maximum utilization of bolts due to elongation [Lc 3]	max $U_{wt,s}$ = 0.206 < 1 ok
maximum utilization of bolts [Lc 5]	max U_s = 0.698 < 1 ok
maximum utilization of the beam [Lc 3]	max (U_q,U_{ct}) = 0.610 < 1 ok

maximum utilization of welds [Lc 3] max U_w = 0.571 < 1 ok
maximum utilization [Lc 5] **max U = 0.698 < 1 ok**

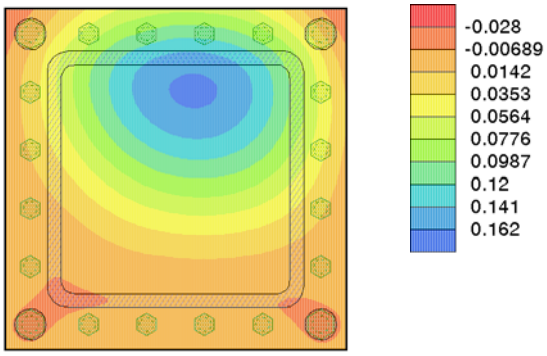
verification succeeded

3. Lc 5 (decisive)

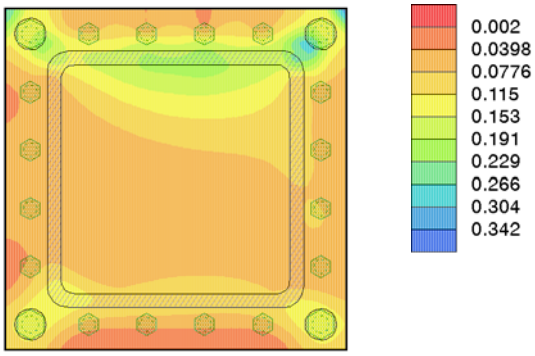
3.1. end plate

design values: N = -109.35 kN, M_y = -177.44 kNm, M_z = 32.59 kNm

deformations u_z [mm]
min u_z = -0.0281 mm, max u_z = 0.1661 mm



utilization of end plate U_p
min U_p = 0.002, max U_p = 0.339



deformations lifting off positive

utilization of end plate

node	x mm	y mm	u_z mm	U_p
3421	210.0	90.0	0.165	0.172
6481	400.0	0.0	-0.028	0.339

x,y: node coordinates; u_z: deformations (lifting off positive); U_p: utilization of end plate

utilization of bolts

	x mm	y mm	wt mm	Ft kN	εwt %	Uwt
1	30.0	30.0	0.004	159.58	0.312	0.139
2	98.0	30.0	0.065	49.52	0.185	0.082
3	166.0	30.0	0.103	78.62	0.293	0.130
4	234.0	30.0	0.111	84.85	0.317	0.141
5	302.0	30.0	0.084	64.57	0.241	0.107
6	370.0	30.0	0.017	164.24	0.347	0.154
7	30.0	98.0	0.024	18.23	0.068	0.030
8	370.0	98.0	0.051	38.67	0.144	0.064
9	30.0	166.0	0.016	12.04	0.045	0.020
10	370.0	166.0	0.042	31.97	0.119	0.053
11	30.0	234.0	0.003	1.95	0.007	0.003
12	370.0	234.0	0.018	13.45	0.050	0.022
13	30.0	302.0	-0.000	0.00	-0.000	---
14	370.0	302.0	0.000	0.53	0.001	0.000
15	30.0	370.0	-0.000	154.22	0.300	0.133
16	98.0	370.0	-0.000	0.00	-0.000	---
17	166.0	370.0	-0.000	0.00	-0.000	---
18	234.0	370.0	-0.000	0.00	-0.000	---
19	302.0	370.0	-0.000	0.00	-0.000	---
20	370.0	370.0	-0.000	154.22	0.300	0.133

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

utilization of end plate [node 6481] U_{max} = 0.339 < 1 ok
utilization of bolts due to elongation [bolt 6] $U_{s,max}$ = 0.154 < 1 ok
minimum plastic utilization of the connection $U_{pl,min}$ = 0.342 < 1 ok
plastic utilization of tensile forces of bolts $U_{pl,t,s}$ = 0.404 < 1 ok

3.2. bolts

design values: max F_t = 164.24 kN, V_z = -39.43 kN, V_y = -1.17 kN, M_x = 45.93 kNm

verification of bolts

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

bolt 1	$U_{tp,1}$ = 0.184	$U_{vt,1}$ = 0.685	$U_{b,1}$ = 0.010	U_1 = 0.685
bolt 2	$U_{tp,2}$ = 0.076	$U_{vt,2}$ = 0.512	$U_{b,2}$ = 0.023	U_2 = 0.512
bolt 3	$U_{tp,3}$ = 0.121	$U_{vt,3}$ = 0.600	$U_{b,3}$ = 0.011	U_3 = 0.600
bolt 4	$U_{tp,4}$ = 0.131	$U_{vt,4}$ = 0.626	$U_{b,4}$ = 0.010	U_4 = 0.626
bolt 5	$U_{tp,5}$ = 0.100	$U_{vt,5}$ = 0.582	$U_{b,5}$ = 0.023	U_5 = 0.582
bolt 6	$U_{tp,6}$ = 0.189	$U_{vt,6}$ = 0.698	$U_{b,6}$ = 0.008	U_6 = 0.698
bolt 7	$U_{tp,7}$ = 0.028	$U_{vt,7}$ = 0.378	$U_{b,7}$ = 0.038	U_7 = 0.378
bolt 8	$U_{tp,8}$ = 0.060	$U_{vt,8}$ = 0.512	$U_{b,8}$ = 0.035	U_8 = 0.512
bolt 9	$U_{tp,9}$ = 0.019	$U_{vt,9}$ = 0.295	$U_{b,9}$ = 0.027	U_9 = 0.295
bolt 10	$U_{tp,10}$ = 0.049	$U_{vt,10}$ = 0.458	$U_{b,10}$ = 0.030	U_{10} = 0.458
bolt 11	$U_{tp,11}$ = 0.003	$U_{vt,11}$ = 0.225	$U_{b,11}$ = 0.023	U_{11} = 0.225
bolt 12	$U_{tp,12}$ = 0.021	$U_{vt,12}$ = 0.382	$U_{b,12}$ = 0.032	U_{12} = 0.382
bolt 13	$U_{tp,13}$ = 0.000	$U_{vt,13}$ = 0.240	$U_{b,13}$ = 0.030	U_{13} = 0.240
bolt 14	$U_{tp,14}$ = 0.001	$U_{vt,14}$ = 0.355	$U_{b,14}$ = 0.041	U_{14} = 0.355
bolt 15	$U_{tp,15}$ = 0.178	$U_{vt,15}$ = 0.663	$U_{b,15}$ = 0.010	U_{15} = 0.663
bolt 16	$U_{tp,16}$ = 0.000	$U_{vt,16}$ = 0.240	$U_{b,16}$ = 0.030	U_{16} = 0.240
bolt 17	$U_{tp,17}$ = 0.000	$U_{vt,17}$ = 0.216	$U_{b,17}$ = 0.024	U_{17} = 0.216
bolt 18	$U_{tp,18}$ = 0.000	$U_{vt,18}$ = 0.245	$U_{b,18}$ = 0.031	U_{18} = 0.245
bolt 19	$U_{tp,19}$ = 0.000	$U_{vt,19}$ = 0.313	$U_{b,19}$ = 0.045	U_{19} = 0.313
bolt 20	$U_{tp,20}$ = 0.178	$U_{vt,20}$ = 0.675	$U_{b,20}$ = 0.013	U_{20} = 0.675
total:	U_{tp} = 0.189	U_{vt} = 0.698	U_b = 0.045	U = 0.698 < 1 ok

in utilization of bolts U_{max} ist minimum plastic utilization of the connection $U_{pl,min}$ = 0.342
and plastic utilization of tensile forces of bolts $U_{pl,s}$ = 0.404 is included.

utilization of bolts U_{max} = 0.698 < 1 ok

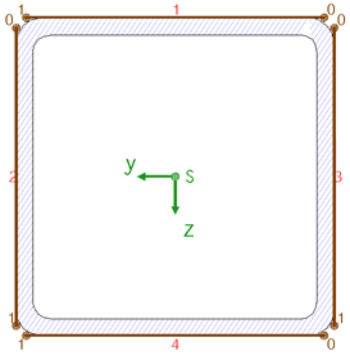
3.3. beam

elastic verification for N = -109.35 kN, M_y = -177.44 kNm, V_z = -39.43 kN, M_z = 32.59 kNm
V_y = -1.17 kN, T_t = 45.93 kNm
verification: σ_v = 137.39 N/mm² < $\sigma_{v,Rd}$ = 355.00 N/mm² ⇒ U_σ = 0.387 < 1 ok
c/t-verification: utilization $U_{c/t}$ = 0.238 < 1 ok

utilization of the beam max(U_σ,$U_{c/t}$) = 0.387 < 1 ok

3.4. welds

design values: N = -109.35 kN, M_y = -177.44 kNm, V_z = -39.43 kN, M_z = 32.59 kNm,
V_y = -1.17 kN, M_x = 45.93 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: $F_{w,Ed}$ = 2053.55 kN/m < $F_{w,Rd}$ = 5644.80 kN/m ⇒ U_w = 0.364 < 1 ok

utilization of welds U_{max} = 0.364 < 1 ok

3.5. total

utilization Lc 5 U_{max} = 0.698 < 1 ok

4. Regulations

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

EN 1993-1-1, Eurocode 3: Bemessung und Konstruktion von Stahlbauten -
Teil 1-1: Allgemeine Bemessungsregeln und Regeln für den Hochbau;

Deutsche Fassung EN 1993-1-1:2022, Ausgabe April 2025
EN 1993-1-1/NA, Nationaler Anhang zur EN 1993-1-1, Ausgabe April 2026

EN 1993-1-8, Eurocode 3: Bemessung und Konstruktion von Stahlbauten -
Teil 1-8: Bemessung von Anschlüssen; Deutsche Fassung EN 1993-1-8:2024, Ausgabe April 2025
EN 1993-1-8/NA, Nationaler Anhang zur EN 1993-1-8, Ausgabe April 2026

prEN 1993-1-14, Eurocode 3: Bemessung und Konstruktion von Stahlbauten -
Teil 1-14: Bemessung mithilfe von Finite-Element-Berechnung;
Deutsche und englische Fassung prEN 1993-1-14:2023, Ausgabe September 2023