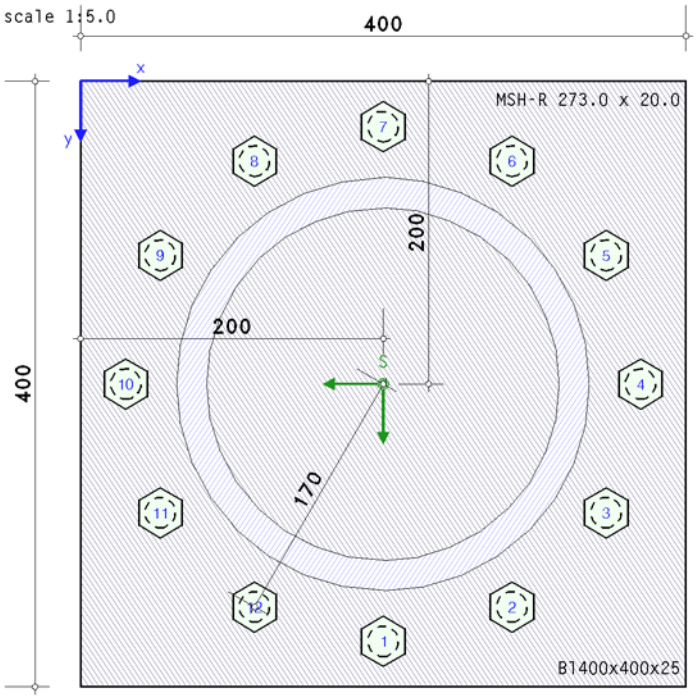
bolted end-plate connection

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



steel grade

steel grade S235

bolts

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

connection

end-plate: thickness t_p = 25.0 mm, width b_p = 400.0 mm, length l_p = 400.0 mm

beam: section MSH-R 273.0 x 20.0

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:

circular arrangement of 12 bolts with radius r = 170.0 mm arround centroid of beam section

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 = 9596.1 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)

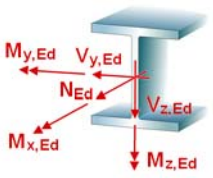
effective foundation modulus of end plate c_b = 16800.0 kN/cm³

number / dimension of finite elements each direction n_x / Δx = 20 / 20.0 mm, n_y / Δy = 20 / 20.0 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	-169.4	-183.9	-36.8	91.7	-18.3	50.1
2	60.3	22.7	4.5	-184.5	18.1	-83.6
3	-143.3	-138.7	-27.7	127.8	-25.6	63.4
4	23.4	-40.9	-8.2	-182.8	17.8	-87.4
5	-106.4	-75.1	-15.0	126.1	-25.2	67.2
6	-168.1	-175.7	-35.1	89.6	-17.9	54.8
7	59.4	17.0	3.4	-183.0	17.9	-86.9



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	0.694	0.694	0.335	0.264	0.950	0.714	0.149	0.718	0.195	0.736	0.950*
2	0.731	0.731	0.288	0.262	0.950	0.921	0.293	0.696	0.115	0.660	0.950*
3	0.649	0.649	0.314	0.194	0.941	0.728	0.181	0.680	0.126	0.678	0.941
4	0.718	0.718	0.294	0.244	0.950	0.912	0.325	0.707	0.117	0.659	0.950*
5	0.458	0.458	0.237	0.133	0.800	0.698	0.168	0.557	0.097	0.535	0.800
6	0.648	0.648	0.321	0.226	0.950	0.714	0.154	0.697	0.132	0.709	0.950*
7	0.727	0.727	0.286	0.245	0.950	0.935	0.296	0.695	0.114	0.655	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 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

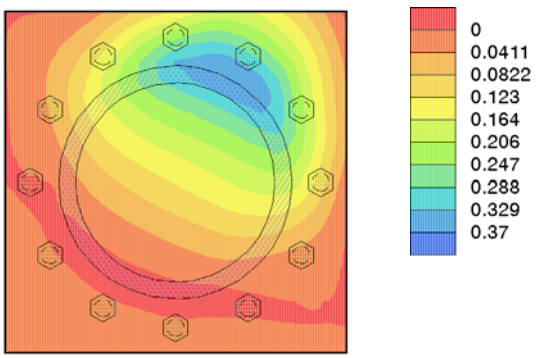
Detailed edition of Lk 1 (decisive)

Lk 1: N_{Ed} = -169.4 kN, $M_{y,Ed}$ = -183.9 kNm , $V_{z,Ed}$ = -36.8 kN, $M_{z,Ed}$ = 91.7 kNm , V

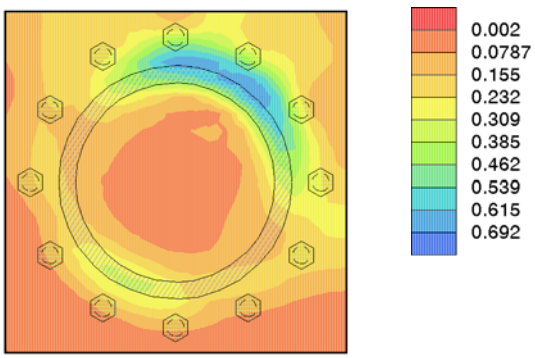
end-plate

design values: N = -169.42 kN, M_y = -183.86 kNm, M_z = 91.74 kNm

deformations u_z [mm], lifting off positive
min u_z = -0.01 mm, max u_z = 0.37 mm



utilization of end-plate U_p
min U_p = 0.002, max U_p = 0.694



utilization of end-plate

Kno	x mm	y mm	u_z mm	U_σ	U_b	U_p
278	260.0	80.0	0.370	0.656	---	0.656
321	300.0	100.0	0.360	0.694	---	0.694

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	200.0	370.0	0.005	4.63	0.018	0.004
2	285.0	347.2	-0.001	0.15	---	---
3	347.2	285.0	0.028	27.12	0.113	0.025
4	370.0	200.0	0.100	95.38	0.398	0.089
5	347.2	115.0	0.219	165.53	0.874	0.194
6	285.0	52.8	0.298	167.58	1.190	0.264
7	200.0	30.0	0.234	166.36	0.935	0.208
8	115.0	52.8	0.131	123.92	0.524	0.117
9	52.8	115.0	0.044	42.42	0.177	0.039
10	30.0	200.0	-0.000	0.46	---	---
11	52.8	285.0	0.002	2.75	0.008	0.002
12	115.0	347.2	0.006	5.74	0.022	0.005

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 321] $U_{max} = 0.694 < 1$ **ok.**
utilization of bolts due to elongation [bolt 6] $U_{max} = 0.264 < 1$ **ok.**

bolts

design values: max $F_t = 167.58$ kN, $V_z = -36.77$ kN, $V_y = -18.35$ kN, $M_x = 50.10$ 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	$U_{tp,1} = 0.026$	$U_{vt,1} = 0.368$	$U_{b,1} = 0.132$	$U_1 = 0.368$
bolt 2	$U_{tp,2} = 0.001$	$U_{vt,2} = 0.000$	$U_{b,2} = 0.149$	$U_2 = 0.467$
bolt 3	$U_{tp,3} = 0.154$	$U_{vt,3} = 0.593$	$U_{b,3} = 0.132$	$U_3 = 0.593$
bolt 4	$U_{tp,4} = 0.541$	$U_{vt,4} = 0.685$	$U_{b,4} = 0.103$	$U_4 = 0.685$
bolt 5	$U_{tp,5} = 0.938$	$U_{vt,5} = 0.713$	$U_{b,5} = 0.013$	$U_5 = 0.938$
bolt 6	$U_{tp,6} = 0.950$	$U_{vt,6} = 0.714$	$U_{b,6} = 0.010$	$U_6 = 0.950$
bolt 7	$U_{tp,7} = 0.943$	$U_{vt,7} = 0.712$	$U_{b,7} = 0.013$	$U_7 = 0.943$
bolt 8	$U_{tp,8} = 0.702$	$U_{vt,8} = 0.679$	$U_{b,8} = 0.049$	$U_8 = 0.702$
bolt 9	$U_{tp,9} = 0.240$	$U_{vt,9} = 0.548$	$U_{b,9} = 0.120$	$U_9 = 0.548$
bolt 10	$U_{tp,10} = 0.003$	$U_{vt,10} = 0.386$	$U_{b,10} = 0.148$	$U_{10} = 0.386$
bolt 11	$U_{tp,11} = 0.016$	$U_{vt,11} = 0.303$	$U_{b,11} = 0.081$	$U_{11} = 0.303$
bolt 12	$U_{tp,12} = 0.033$	$U_{vt,12} = 0.298$	$U_{b,12} = 0.078$	$U_{12} = 0.298$
total Max:	$U_{tp} = 0.950$	$U_{vt} = 0.714$	$U_b = 0.149$	$U = 0.950 < 1$ **ok.**

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

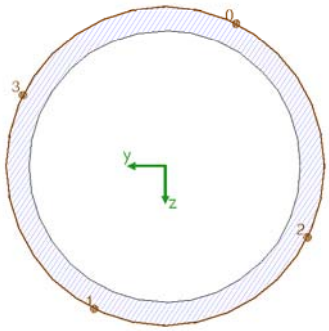
beam

plastic cross-sectional check for $N = -169.42$ kN, $M_y = -183.86$ kNm, $V_z = -36.77$ kN,
$M_z = 91.74$ kNm, $V_y = -18.35$ kN, $M_x = 50.10$ kNm
valid normal-/shear stress: zul $\sigma_{Rd} = 23.50$ kN/cm², zul $\tau_{Rd} = 13.57$ kN/cm²
web: shear force $V_S = 41.10$ kN, torsion $T_{pS} = 50.10$ kNm, shear stress $\tau_S = 2.89$ kN/cm² $\Rightarrow$ $U_{\tau,S} = 0.213$
design resistance forces $N_{max,S} = 3649.79$ kN, $N_{min,S} = -3649.79$ kN
main bending: axial force $N = -169.42$ kN, design resistance forces $N_{max} = 3649.79$ kN, $N_{min} = -3649.79$ kN $\Rightarrow$ $U_N = 0.046$
moment $M_y = 205.48$ kNm, design resistance moments $M_{y,max} = 293.76$ kNm, $M_{y,min} = -293.76$ kNm $\Rightarrow$ $U_{My} = 0.69$
total (possibly due to load increase): max $U = 0.718 < 1$ **ok.**
utilizations: design resistance $U_\sigma = 0.718 < 1$ **ok.**, c/t-ratio $U_{c/t} = 0.195 < 1$ **ok.**

utilization of beam $\max(U_\sigma, U_{c/t}) = 0.718 < 1$ **ok.**

welds

design values: $N = -169.42$ kN, $M_y = -183.86$ kNm, $V_z = -36.77$ kN, $M_z = 91.74$ kNm,
$V_y = -18.35$ kN, $M_x = 50.10$ kNm



weld 1: a_w = 20.0 mm l_w = 857.7 mm

Max: $\sigma_{1,w,Ed}$ = 26.48 kN/cm² < $f_{1,w,Rd}$ = 36.00 kN/cm²,
$\sigma_{2,w,Ed}$ = 13.11 kN/cm² < $f_{2,w,Rd}$ = 25.92 kN/cm² ⇒ U_w = 0.736 < 1 **ok.**

utilization of welds U_{max} = 0.736 < 1 **ok.**

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