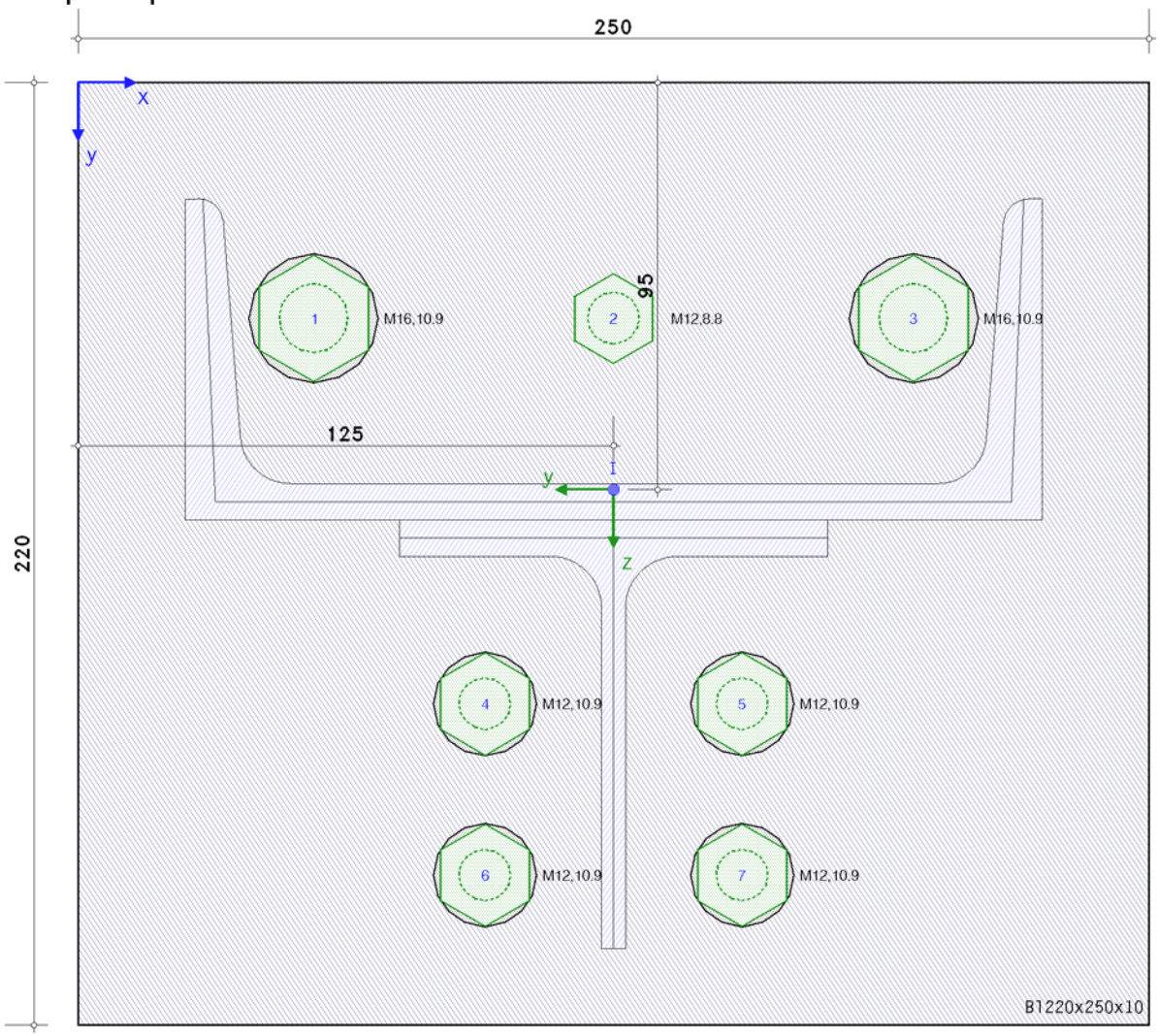
POS. 10: U + T

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
1	10.9	M16	no	big	5	10.9	M12	no	big
2	8.8	M12	no	normal	6	10.9	M12	no	big
3	10.9	M16	no	big	7	10.9	M12	no	big
4	10.9	M12	no	big					

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

connection

end plate (rectangular): thickness t_p = 10.0 mm, width b_p = 250.0 mm, length l_p = 220.0 mm

beam: h = 175.0 mm, b = 200.0 mm, A = 46.45 cm², y_s = -100.0 mm, z_s = 67.9 mm, y_M = 0.0 mm, z_M = 26.6 mm

I_y = 445.06 cm⁴, I_z = 1983.90 cm⁴, I_T = 13.72 cm⁴, I_ω = 9245.50 cm⁶

beam-end plate: surrounding fillet weld, weld thickness a = 4.0 mm

coordinates of centroid of beam section at x_p = 125.0 mm, y_p = 95.0 mm

coordinates of the beam centroid on end plate x_s = 125.0 mm, y_s = 95.0 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	55.0	55.0	8145.3	107.2	2.25	98.7	5	155.0	145.0	5036.4	57.7	2.25	53.1
2	125.0	55.0	5472.3	46.1	3.00	--	6	95.0	185.0	5036.4	57.7	2.25	53.1
3	195.0	55.0	8145.3	107.2	2.25	98.7	7	155.0	185.0	5036.4	57.7	2.25	53.1
4	95.0	145.0	5036.4	57.7	2.25	53.1							

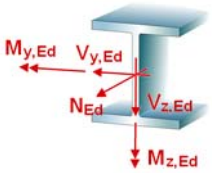
x,y: coordinates of bolt axis on end plate; c_f: spring stiffness of bolt (FEM); $F_{t,f}$: plastic limit force of bolt (FEM)
$\varepsilon_{t,f}$: effective elongation at failure of bolt (FEM); $F_{p,C} \le F_{t,Rk}$: preload force of bolt (FEM)

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 welds with the simplified 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 = 21000.0 kN/cm³
number / dimension of finite elements each direction n_x / Δx = 62 / 4.0 mm, n_y / Δy = 55 / 4.0 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
1	-0.35	0.38	0.23	0.00	0.00
2	-2.36	11.22	-5.40	-0.03	-0.02
3	-7.50	7.51	4.45	0.04	0.02
4	-3.19	18.89	-9.28	0.02	0.01
5	-10.12	10.42	6.34	-0.02	-0.01
6	-0.88	0.29	0.17	0.04	0.02
7	-8.98	18.43	-1.12	-0.03	-0.02
8	-0.88	0.07	0.28	-0.03	-0.02
9	-10.20	10.47	6.31	0.00	0.00
10	-2.83	18.95	-9.25	0.00	0.00



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 !
4H-QUER-cross-sections are described by their centre lines.
edge- and distances between bolts must therefore be checked separately !!

minimum distances of bolts on end plate

bolt 1:	e_1 = 55.0 mm > 1.2·d_0 = 21.6 mm,	e_1 = 55.0 mm < 4·t + 40 mm = 80.0 mm
bolt 1:	p_1 = 70.0 mm > 2.2·d_0 = 39.6 mm,	p_1 = 70.0 mm < min(14·t, 200 mm) = 140.0 mm
bolt 2:	e_1 = 55.0 mm > 1.2·d_0 = 15.6 mm,	e_1 = 55.0 mm < 4·t + 40 mm = 80.0 mm
bolt 2:	p_1 = 70.0 mm > 2.2·d_0 = 28.6 mm,	p_1 = 70.0 mm < min(14·t, 200 mm) = 140.0 mm
bolt 3:	e_1 = 55.0 mm > 1.2·d_0 = 21.6 mm,	e_1 = 55.0 mm < 4·t + 40 mm = 80.0 mm
bolt 3:	p_1 = 98.5 mm > 2.2·d_0 = 39.6 mm,	p_1 = 98.5 mm < min(14·t, 200 mm) = 140.0 mm
bolt 4:	e_1 = 75.0 mm > 1.2·d_0 = 15.6 mm,	e_1 = 75.0 mm < 4·t + 40 mm = 80.0 mm
bolt 4:	p_1 = 40.0 mm > 2.2·d_0 = 28.6 mm,	p_1 = 40.0 mm < min(14·t, 200 mm) = 140.0 mm
bolt 5:	e_1 = 75.0 mm > 1.2·d_0 = 15.6 mm,	e_1 = 75.0 mm < 4·t + 40 mm = 80.0 mm
bolt 5:	p_1 = 40.0 mm > 2.2·d_0 = 28.6 mm,	p_1 = 40.0 mm < min(14·t, 200 mm) = 140.0 mm
bolt 6:	e_1 = 35.0 mm > 1.2·d_0 = 15.6 mm,	e_1 = 35.0 mm < 4·t + 40 mm = 80.0 mm
bolt 6:	p_1 = 60.0 mm > 2.2·d_0 = 28.6 mm,	p_1 = 60.0 mm < min(14·t, 200 mm) = 140.0 mm
bolt 7:	e_1 = 35.0 mm > 1.2·d_0 = 15.6 mm,	e_1 = 35.0 mm < 4·t + 40 mm = 80.0 mm

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_w	U
1	0.354	0.109	0.354	0.007	0.133	0.133	0.472	0.625	---	0.036	0.625
2	0.484	0.484	0.359	0.221	0.135	0.135	0.472	0.651	0.020	1.071	1.071!
3	0.355	0.304	0.355	0.137	0.133	0.133	0.472	0.638	0.016	0.712	0.712
4	0.923	0.923	0.365	0.374	0.228	0.228	0.472	0.678	0.036	1.804	1.804!
5	0.440	0.440	0.356	0.191	0.133	0.133	0.472	0.649	0.023	0.988	0.988
6	0.354	0.109	0.354	0.004	0.133	0.133	0.472	0.625	---	0.027	0.625
7	0.890	0.890	0.363	0.354	0.217	0.217	0.472	0.668	0.004	1.756	1.756!
8	0.355	0.110	0.355	---	---	0.133	0.472	0.626	0.001	0.006	0.626
9	0.443	0.443	0.356	0.192	0.133	0.133	0.472	0.649	0.023	0.993	0.993
10	0.927	0.927	0.365	0.376	0.229	0.229	0.472	0.678	0.036	1.811	1.811*

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_w: utilization of welds; U: total utilization
*) maximum utilization

2. final result

maximum utilization of end plate due to 10 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
1783	125.0	184.0	0.142	0.00	-9.21	-2.59	-0.00	0.22	-1.32	0.927

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 10 Lc: max U_s with corresponding values

	x mm	y mm	F_t kN	U_{wt}	U_{vt}	U_b	U_s
1	55.0	55.0	98.72	0.133	0.645	0.007	0.645
2	125.0	55.0	3.26	0.010	0.206	0.036	0.472
3	195.0	55.0	98.72	0.133	0.645	0.007	0.645
4	95.0	145.0	55.80	0.168	0.670	0.004	0.670
5	155.0	145.0	55.80	0.168	0.670	0.004	0.670
6	95.0	185.0	56.75	0.229	0.678	0.003	0.678
7	155.0	185.0	56.75	0.229	0.678	0.003	0.678

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 10]	max U_p = 0.927 < 1 ok
maximum utilization of bolts due to elongation [Lc 10]	max $U_{wt,s}$ = 0.229 < 1 ok
maximum utilization of bolts [Lc 10]	max U_s = 0.678 < 1 ok
maximum utilization of welds [Lc 10]	max U_w = 1.811 > 1 not ok !!
maximum utilization [Lc 10]	**max U = 1.811 > 1 not ok !!**

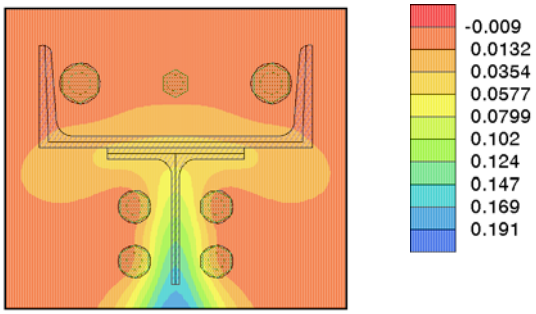
resistance not ensured !!

3. Lc 10 (decisive)

3.1. end plate

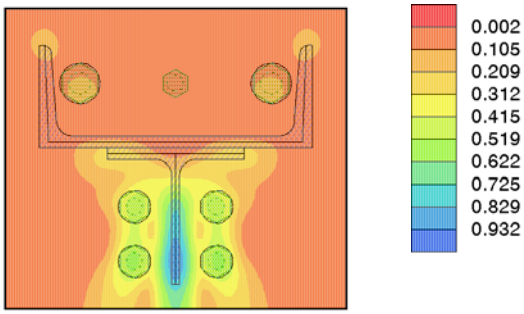
design values: N = -2.83 kN, M_y = 18.95 kNm

deformations u_z [mm]
min u_z = -0.0085 mm, max u_z = 0.1896 mm

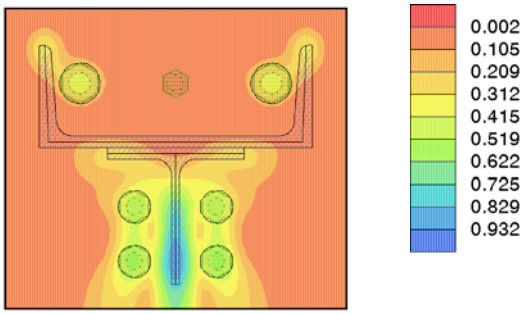


deformations lifting off positive

utilization due to stress U_σ
min U_σ = 0.002, max U_σ = 0.927



utilization of end plate U_p
min U_p = 0.002, max U_p = 0.927



utilization of end plate

node	x mm	y mm	u_z mm	U_σ	U_b	U_p
1783	125.0	184.0	0.142	0.927	---	0.927
1792	125.0	220.0	0.190	0.637	---	0.637

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

utilization of bolts

	x mm	y mm	wt mm	Ft kN	εwt %	Uwt
1	55.0	55.0	-0.005	98.72	0.300	0.133
2	125.0	55.0	0.003	3.26	0.030	0.010
3	195.0	55.0	-0.005	98.72	0.300	0.133
4	95.0	145.0	0.008	55.80	0.379	0.168
5	155.0	145.0	0.008	55.80	0.379	0.168
6	95.0	185.0	0.022	56.75	0.516	0.229
7	155.0	185.0	0.022	56.75	0.516	0.229

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

FEM-calculation
number of iteration steps 10 of 50, accuracy 5.0‰
6 bolts preloaded, no bolt plastified
sum of forces due to external loads -2.8 kN
sum of bolt forces 425.8 kN
sum of bedding reactions 428.6 kN
compression area 82.6 cm² = 15.02% of end plate area
rotational plane regarding the centroid of cross-section $u_{z,m}$ = 0.033 mm, φ_y = 0.056°, φ_z = -0.000°
rotational angle of end plate connection $2\cdot\varphi_y$ = 0.113°, $2\cdot\varphi_z$ = -0.000°
lower limit of plastic utilization of the connection $U_{pl,min}$ = 0.376

utilization of end plate [node 1783] U_{max} = 0.927 < 1 ok
utilization of bolts due to elongation [bolt 6] $U_{s,max}$ = 0.229 < 1 ok
minimum plastic utilization of the connection $U_{pl,min}$ = 0.376 < 1 ok
plastic utilization of tensile forces of bolts $U_{pl,t,s}$ = 0.229 < 1 ok

3.2. bolts

design values: min F_t = 3.26 kN, max F_t = 98.72 kN, V_z = -9.25 kN

cross-section of points
y_i,z_i coordinates refering to load application point (beam centroid), $F_{t,i}$ tension forces, $f_{vt,i}$ weighting factors

bolt 1	y_1 = 70.0 mm	z_1 = -40.0 mm	$F_{t,1}$ = 98.72 kN	$f_{vt,1}$ = 0.187
bolt 2	y_2 = 0.0 mm	z_2 = -40.0 mm	$F_{t,2}$ = 3.26 kN	$f_{vt,2}$ = 0.749
bolt 3	y_3 = -70.0 mm	z_3 = -40.0 mm	$F_{t,3}$ = 98.72 kN	$f_{vt,3}$ = 0.187
bolt 4	y_4 = 30.0 mm	z_4 = 50.0 mm	$F_{t,4}$ = 55.80 kN	$f_{vt,4}$ = 0.065
bolt 5	y_5 = -30.0 mm	z_5 = 50.0 mm	$F_{t,5}$ = 55.80 kN	$f_{vt,5}$ = 0.065
bolt 6	y_6 = 30.0 mm	z_6 = 90.0 mm	$F_{t,6}$ = 56.75 kN	$f_{vt,6}$ = 0.052
bolt 7	y_7 = -30.0 mm	z_7 = 90.0 mm	$F_{t,7}$ = 56.75 kN	$f_{vt,7}$ = 0.052

calculation of the point section
shear forces

point 1:	y_1' = 70.0 mm	z_1' = -18.6 mm	$T_{y,1}$ = 0.00 kN	$T_{z,1}$ = -1.27 kN	T_1 = 1.27 kN
point 2:	y_2' = -0.0 mm	z_2' = -18.6 mm	$T_{y,2}$ = 0.00 kN	$T_{z,2}$ = -5.11 kN	T_2 = 5.11 kN
point 3:	y_3' = -70.0 mm	z_3' = -18.6 mm	$T_{y,3}$ = 0.00 kN	$T_{z,3}$ = -1.27 kN	T_3 = 1.27 kN
point 4:	y_4' = 30.0 mm	z_4' = 71.4 mm	$T_{y,4}$ = -0.00 kN	$T_{z,4}$ = -0.44 kN	T_4 = 0.44 kN
point 5:	y_5' = -30.0 mm	z_5' = 71.4 mm	$T_{y,5}$ = -0.00 kN	$T_{z,5}$ = -0.44 kN	T_5 = 0.44 kN
point 6:	y_6' = 30.0 mm	z_6' = 111.4 mm	$T_{y,6}$ = -0.00 kN	$T_{z,6}$ = -0.36 kN	T_6 = 0.36 kN
point 7:	y_7' = -30.0 mm	z_7' = 111.4 mm	$T_{y,7}$ = -0.00 kN	$T_{z,7}$ = -0.36 kN	T_7 = 0.36 kN

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	$U_{tp,1}$ = 0.472	$U_{vt,1}$ = 0.645	$U_{b,1}$ = 0.007	U_1 = 0.645
bolt 2	$U_{tp,2}$ = 0.023	$U_{vt,2}$ = 0.206	$U_{b,2}$ = 0.036	U_2 = 0.206
bolt 3	$U_{tp,3}$ = 0.472	$U_{vt,3}$ = 0.645	$U_{b,3}$ = 0.007	U_3 = 0.645
bolt 4	$U_{tp,4}$ = 0.329	$U_{vt,4}$ = 0.670	$U_{b,4}$ = 0.004	U_4 = 0.670
bolt 5	$U_{tp,5}$ = 0.329	$U_{vt,5}$ = 0.670	$U_{b,5}$ = 0.004	U_5 = 0.670
bolt 6	$U_{tp,6}$ = 0.335	$U_{vt,6}$ = 0.678	$U_{b,6}$ = 0.003	U_6 = 0.678
bolt 7	$U_{tp,7}$ = 0.335	$U_{vt,7}$ = 0.678	$U_{b,7}$ = 0.003	U_7 = 0.678
total:	U_{tp} = 0.472	U_{vt} = 0.678	U_b = 0.036	U = 0.678 < 1 ok

in utilization of bolts U_{max} ist minimum plastic utilization of the connection $U_{pl,min}$ = 0.376
and plastic utilization of tensile forces of bolts $U_{pl,s}$ = 0.229 is included.

utilization of bolts U_{max} = 0.678 < 1 ok

3.3. welds

design values: N = -2.83 kN, M_y = 18.95 kNm, V_z = -9.25 kN
U_w = 1.811 > 1 not ok !!

utilization of welds U_{max} = 1.811 > 1 not ok !!

3.4. total

utilization Lc 10 $U_{max} = 1.811 > 1$ not 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