POS. 1: 2 BOLTS (BEAM-COLUMN)

standardized IM-joint

moment resistant joints IM acc. to EC 3-1-8 (12.10), NA: Deutschland

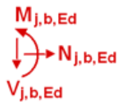
dimensions of beam, bolts, end-plate and welds, material
and arrangement of bolts are taken of the following literature:
'Typisierte Anschlüsse im Stahlhochbau nach DIN EN 1993-1-8, Ergänzungsband 2018,
Stahlbau Verlags- und Service GmbH, Ausgabe 2018'
the current number and associated parameters are recorded.
the column has no reference to the literature, web stiffeners are continuously fixed.
MN-interaction follows Cerfontaine (in Jaspart/Weynand: Design of Joints in Steel Structures).

beam-column connection, steel grade S235, bolt class of bolts 10.9

10760: beam section HEA240, bolt size M24, connection with 2 bolts per row
end-plate: t_p = 30 mm, b_p = 240 mm, h_p = 440 mm, e_1 = 55 mm, $p_{1,1}$ = 110 mm, $p_{1,2}$ = 110 mm
$p_{1,3}$ = 110 mm, u_1 = 105 mm, w = 130 mm
fillet welds: a_f = 6 mm, a_w = 4 mm

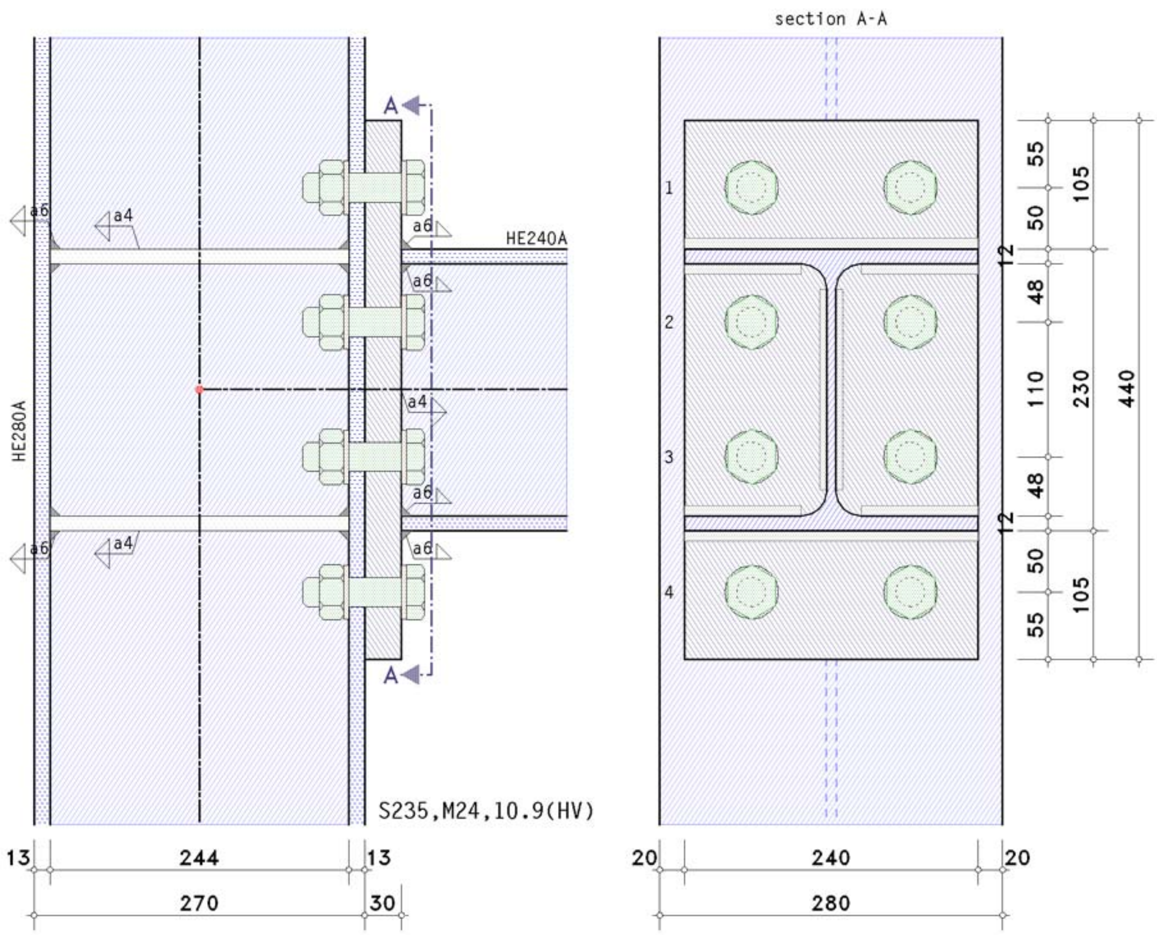
column: section HE280A
horizontal web stiffeners

internal forces and moments in the intersection point of system axes:
$M_{j,b1,Ed}$, $V_{j,b1,Ed}$: internal forces and moments by sign definition of statics

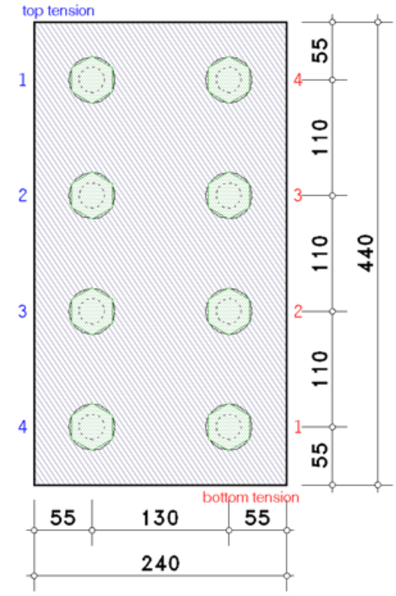


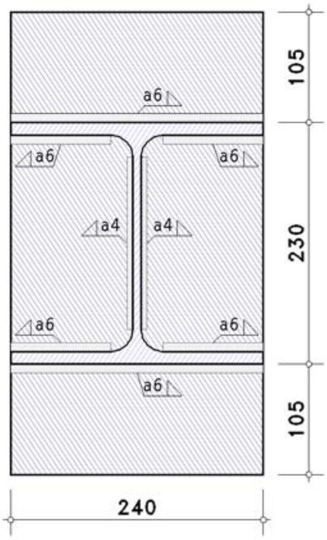
Lk	$M_{j,b1,Ed}$	$V_{j,b1,Ed}$	Lk	$M_{j,b1,Ed}$	$V_{j,b1,Ed}$	Lk	$M_{j,b1,Ed}$	$V_{j,b1,Ed}$
--	kNm	kN	--	kNm	kN	--	kNm	kN
1	-76.27	43.37	8	-159.20	121.63	15	-63.37	50.48
2	-122.52	84.96	9	-173.45	125.19	16	-10.59	6.38
3	-39.91	48.47	10	14.32	0.73	17	-101.25	80.43
4	-44.37	36.57	11	10.68	1.85	18	-133.92	91.46
5	-89.61	73.99	12	-69.74	40.86	19	-71.81	55.26
6	-14.16	7.17	13	-42.10	45.95			
7	-102.02	84.67	14	-48.47	36.33			

Rigid beam connection



details





Component method

notes
connection is verified due to EC 3-1-8 regardless of preloading.
however, connections may be constructed with prestressed high strength bolts.
no verification for cross-sections.
the welds are not regarded by calculation the T-stub resistance.
simplified calculation of shear force resistance takes all bolt-rows into account.

utilizations

Lk	$U_{\sigma,b}$	U_{MNV}	U_{wp}	U_{pl}	U_{ep}	U_{sb}	U_{ss}	U
--	---	---	---	---	---	---	---	---
1	0.418	0.679	0.750	0.254	0.159	0.497	0.611	0.750
2	0.662	1.074	1.184	0.497	0.312	0.788	0.969	1.184!
3	0.220	0.326	0.359	0.284	0.178	0.249	0.296	0.359
4	0.237	0.380	0.421	0.214	0.134	0.278	0.341	0.421
5	0.480	0.774	0.851	0.433	0.271	0.569	0.701	0.851
6	0.078	0.128	0.140	0.042	0.026	0.094	0.115	0.140
7	0.545	0.877	0.968	0.496	0.310	0.643	0.792	0.968
8	0.857	1.382	1.525	0.712	0.446	1.013	1.247	1.525!
9	0.936	1.515	1.670	0.733	0.459	1.111	1.367	1.670*
10	0.086	0.136	0.152	0.004	0.003	0.102	0.125	0.152
11	0.065	0.103	0.115	0.011	0.007	0.077	0.094	0.115
12	0.381	0.619	0.684	0.239	0.150	0.453	0.557	0.684
13	0.225	0.350	0.385	0.269	0.169	0.258	0.318	0.385
14	0.260	0.420	0.465	0.213	0.133	0.307	0.377	0.465
15	0.340	0.549	0.604	0.296	0.185	0.404	0.498	0.604
16	0.058	0.094	0.104	0.037	0.023	0.069	0.085	0.104
17	0.542	0.875	0.966	0.471	0.295	0.642	0.790	0.966
18	0.725	1.176	1.296	0.536	0.335	0.862	1.061	1.296!
19	0.386	0.625	0.687	0.324	0.203	0.459	0.566	0.687

$U_{\sigma,b}$: stress utilization at the beam; U_{MNV}: utilization due to MNV-interaction; U_{wp}: utilization due to shear in column web panel
U_{pl}: utilization due to shear (plastic); U_{pl}: utilization due to shear in end-plate; U_{sb}: utilization due to weld
U_{ss}: utilization due to stiffeners/ribs; U: total utilization
*) maximum utilization

Final Result

maximum utilization [Lk 9]:	max U = 1.670 > 1 **fault !!**
minimum rotational stiffness [Lk 9]:	min S_j = 3.0 MNm/rad, $S_{j,ini}$ = 27.9 MNm/rad
maximum rotation [Lk 9]:	max $\varphi_{j,Ed}$ = 2.858°

resistance not ensured !!

Detailed edition of Lk 9 (decisive)

design values

internal forces and moments in the periphery
$N_{b,Ed}$ = $-N_{j,b,Ed}$ = 45.53 kN
$M_{b,Ed}$ = $-M_{j,b,Ed} - V_{j,b,Ed} \cdot e_1$ = 156.55 kNm, e_1 = 135.0 mm
$V_{b,Ed}$ = $V_{j,b,Ed}$ = 125.19 kN
internal forces and moments perpendicular to the connection plane
N_d = $N_{b,Ed}$ = 45.53 kN
M_d = $M_{b,Ed}$ = 156.55 kNm
V_d = $V_{b,Ed}$ = 125.19 kN
partial internal forces and moments
internal forces and moments in the periphery end-plate-beam: $M'_d = M_d - V_d \cdot t_{ep}$ = 152.79 kNm
$N_{b,t}$ = $-N_d \cdot z_{bu}/z_b + M'_d/z_b$ = 678.11 kN, z_b = 218.0 mm, z_{bu} = 109.0 mm
$N_{b,c}$ = $N_d \cdot z_{bo}/z_b + M'_d/z_b$ = 723.64 kN, z_b = 218.0 mm, z_{bo} = 109.0 mm

resistance of cross-section

plastic cross-sectional check for N = -45.53 kN, M_y = -152.79 kNm, V_z = 125.19 kN
valid normal/shear stress: zul σ_{Rd} = 23.50 kN/cm², zul τ_{Rd} = 13.57 kN/cm²
top flange: resistance forces $N_{max,O}$ = 676.80 kN, $N_{min,O}$ = -676.80 kN
bottom flange: resistance forces $N_{max,U}$ = 676.80 kN, $N_{min,U}$ = -676.80 kN
web: shear force V_S = 125.19 kN, shear stress τ_S = 7.66 kN/cm² $\Rightarrow$ $U_{\tau,S}$ = 0.564
resistance forces $N_{max,S}$ = 317.19 kN, $N_{min,S}$ = -317.19 kN
main bending: axial force N = -45.53 kN, resistance forces N_{max} = 1670.79 kN, N_{min} = -1670.79 kN $\Rightarrow$ U_N = 0.027
moment M_y = -152.79 kNm, resistance moments $M_{y,max}$ = 164.47 kNm, $M_{y,min}$ = -164.47 kNm $\Rightarrow$ U_{My} = 0.929
total (possibly due to load increase): max U = 0.936 < 1 ok
utilizations: resistance U_σ = 0.936 < 1 ok, c/t-ratio $U_{c/t}$ = 0.794 < 1 ok

connection capacity

moment resistance

distance of tension-bolt-rows from centre of compression: h_1 = 274.0 mm, h_2 = 164.0 mm, h_3 = 54.0 mm

resistance per bolt-row (MNV-interaction)
row 1: $F_{tr,Rd}$ = 309.8 kN
row 2: $F_{tr,Rd}$ = 92.6 kN
row 3: $F_{tr,Rd}$ = 0.0 kN
$\Sigma F_{tr,Rd}$ = 402.3 kN

resistance of flanges (MNV-interaction)
$F_{c,Rd}$ = 432.4 kN

moment resistance
$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r)$ = 100.1 kNm
tension resistance
$N_{j,t,Rd} = \Sigma F_{tr,Rd}$ = 402.3 kN
compression resistance
$N_{j,c,Rd} = F_{c,Rd}$ = 432.4 kN

shear/bearing resistance

$V_{j,Rd}$ = 82.6 kN (MNV-interaction)

shear resistance

shear resistance of end plate
plate: $V_{ep,Rd}$ = 667.53 kN
resistance of a weld (req.1): $f_{1w,d} = f_u / (\beta_w \cdot \gamma_{M2})$ = 360.0 N/mm²
welds: $F_{w,Rd}$ = 272.69 kN
shear resistance of end plate: $V_{ep,Rd} = F_{w,Rd}$ = 272.69 kN

shear resistance of column web
$V_{wp,Rd}/\beta$ = 432.4 kN

plastic shear resistance
$V_{pl,Rd} = 0.5 \cdot A_v \cdot (f_y/3^{1/2}) / \gamma_{M0}$ = 170.8 kN (requirement, s. 'Typisierte Anschlüsse')

total

$M_{j,Rd}$ = 100.1 kNm $N_{j,t,Rd}$ = 402.3 kN $N_{j,c,Rd}$ = 432.4 kN $V_{j,Rd}$ = 82.6 kN $V_{wp,Rd}/\beta$ = 432.4 kN $V_{pl,Rd}$ = 170.8 kN

$V_{ep,Rd}$ = 272.7 kN

verifications

verification of the connection capacity by means of the component method

U_{MNV} = 1.515 > 1 fault !!
$V_{wp,Ed}/(V_{wp,Rd}/\beta)$ = 1.670 > 1 fault !!
$V_{Ed}/V_{pl,Rd}$ = 0.733 < 1 ok
$V_{Ed}/V_{ep,Rd}$ = 0.459 < 1 ok

verification of welds at beam section

weld 1: beam flange in tension outer
welds 2,3: beam flange in tension inner
welds 4,5: beam web double-sided
weld 8: beam flange in compression outer
welds 6,7: beam flange in compression inner

weld 4: NA-DE: plate thickness $t_{max} \geq 30$ mm: weld thickness a = 4.0 mm < a_{min} = 5 mm !!
weld 4: weld thickness a = 4.0 mm > $a_{max} = 0.7 \cdot t_{min}$ = 3.7 mm !!
weld 5: NA-DE: plate thickness $t_{max} \geq 30$ mm: weld thickness a = 4.0 mm < a_{min} = 5 mm !!
weld 5: weld thickness a = 4.0 mm > $a_{max} = 0.7 \cdot t_{min}$ = 3.7 mm !!

welds:

weld 1:	a_w = 6.0 mm	l_w = 240.0 mm
weld 2:	a_w = 6.0 mm	l_w = 95.3 mm
weld 3:	siehe weld 2	
weld 4:	a_w = 4.0 mm	l_w = 164.0 mm
weld 5:	siehe weld 4	
weld 6:	a_w = 6.0 mm	l_w = 95.3 mm
weld 7:	siehe weld 6	
weld 8:	a_w = 6.0 mm	l_w = 240.0 mm

design values refering to centroid of the section:
N_{Ed} = -45.53 kN, $M_{y,Ed}$ = -156.55 kNm, $V_{z,Ed}$ = 125.19 kN
cross-sectional properties refering to centroid of the line cross-section:
ΣA_w = 64.78 cm², $A_{w,z}$ = 13.12 cm², Σl_w = 118.9 cm
$I_{w,y}$ = 6528.08 cm⁴, $I_{w,z}$ = 2754.52 cm⁴, $W_{w,t}$ = 61.47 cm³, Δz_w = 0.0 mm
verifications in the edge points of the individual welds:

weld 1,	pt. 0:	$\sigma_{w,x}$ = 268.75 N/mm²		⇒ U_w = 1.056 > 1 fault !!
weld 2,	pt. 0:	$\sigma_{w,x}$ = 239.97 N/mm²		⇒ U_w = 0.943 < 1 ok
weld 4,	pt. 0:	$\sigma_{w,x}$ = 189.61 N/mm²	$\tau_{w,z}$ = 95.42 N/mm²	⇒ U_w = 0.875 < 1 ok
	pt. 1:	$\sigma_{w,x}$ = -203.67 N/mm²	$\tau_{w,z}$ = 95.42 N/mm²	⇒ U_w = 0.922 < 1 ok
weld 6,	pt. 0:	$\sigma_{w,x}$ = -254.03 N/mm²		⇒ U_w = 0.998 < 1 ok
weld 8,	pt. 0:	$\sigma_{w,x}$ = -282.80 N/mm²		⇒ U_w = 1.111 > 1 fault !!

Result:
weld 8, pt. 0: $\sigma_{w,x}$ = -282.80 N/mm²
Max: $\sigma_{1,w,Ed}$ = 39.99 kN/cm² > $f_{1w,d}$ = 36.00 kN/cm²,
$\sigma_{2,w,Ed}$ = 20.00 kN/cm² < $f_{2w,d}$ = 25.92 kN/cm² ⇒ U_w = 1.111 > 1 fault !!

verification of web stiffeners

compression stiffener
$F_{c,Ed}$ = 737.69 kN
forces per rib
$F = 0.5 \cdot F_{c,Ed} \cdot (b_f - 2 \cdot r - t_w)/b_f$ = 295.1 kN, $H = F \cdot e_F/e_H$ = 96.7 kN
assumption: stiffeners do not buckle: $c/t = 10.3 \cdot \varepsilon \leq 33 \cdot \varepsilon$ ⇒ section class 1 ≤ 2 ok
cross-section at flange
compression resistance $N_{c,Rd} = (A \cdot f_y) / \gamma_{M0}$ = 248.16 kN
design value: $F_{Ed} = (F^2 + 3 \cdot H^2)^{1/2}$ = 339.3 kN
F_{Ed} = 339.3 kN > F_{Rd} = 248.2 kN ⇒ U = 1.367 > 1 fault !!
cross-section at web
shear resistance V_{Rd} = 397.26 kN
design value: F_{Ed} = F = 295.1 kN
F_{Ed} = 295.1 kN < F_{Rd} = 397.3 kN ⇒ U = 0.743 < 1 ok
flange welds
design values: $F_{Ed}(\sigma_s) = F / (2 \cdot b_1)$ = 16.77 kN/cm, $F_{Ed}(\tau_p) = H / (2 \cdot b_1)$ = 5.50 kN/cm, b_1 = 88.0 mm
$\sigma_{1,w,Ed}$ = 32.13 kN/cm² < $f_{1w,d}$ = 36.00 kN/cm² ⇒ U = 0.893 < 1 ok
$\sigma_{2,w,Ed}$ = 27.94 kN/cm² > $f_{2w,d}$ = 25.92 kN/cm² ⇒ U = 1.078 > 1 fault !!
web welds
design value: $F_{Ed}(\tau_p) = F / (2 \cdot l_1)$ = 8.58 kN/cm, l_1 = 172.0 mm
$\sigma_{1,w,Ed}$ = 37.14 kN/cm² > $f_{1w,d}$ = 36.00 kN/cm² ⇒ U = 1.032 > 1 fault !!
stiffener in tension
$F_{t,Ed}$ = 692.16 kN
forces per rib
$F = 0.5 \cdot F_{t,Ed} \cdot (b_f - 2 \cdot r - t_w)/b_f$ = 276.9 kN, $H = F \cdot e_F/e_H$ = 90.8 kN
cross-section at flange
tension resistance $N_{t,Rd}$ = 248.16 kN

design value: $F_{Ed} = (F^2 + 3 \cdot H^2)^{1/2} = 318.4$ kN
$F_{Ed} = 318.4$ kN $>$ $F_{Rd} = 248.2$ kN $\Rightarrow$ $U = 1.283 > 1$ fault !!
cross-section at web
shear resistance $V_{Rd} = 397.26$ kN
design value: $F_{Ed} = F = 276.9$ kN
$F_{Ed} = 276.9$ kN $<$ $F_{Rd} = 397.3$ kN $\Rightarrow$ $U = 0.697 < 1$ ok
flange welds
design values: $F_{Ed}(\sigma_s) = F / (2 \cdot b_1) = 15.73$ kN/cm, $F_{Ed}(\tau_p) = H / (2 \cdot b_1) = 5.16$ kN/cm, $b_1 = 88.0$ mm
$\sigma_{1,w,Ed} = 30.15$ kN/cm² $<$ $f_{1w,d} = 36.00$ kN/cm² $\Rightarrow$ $U = 0.838 < 1$ ok
$\sigma_{2,w,Ed} = 26.22$ kN/cm² $>$ $f_{2w,d} = 25.92$ kN/cm² $\Rightarrow$ $U = 1.012 > 1$ fault !!
web welds
design value: $F_{Ed}(\tau_p) = F / (2 \cdot l_1) = 8.05$ kN/cm, $l_1 = 172.0$ mm
$\sigma_{1,w,Ed} = 34.85$ kN/cm² $<$ $f_{1w,d} = 36.00$ kN/cm² $\Rightarrow$ $U = 0.968 < 1$ ok

verification result

maximum utilization: max $U = 1.670 > 1$ fault !!
failure at verification of bending: U = 1.515
failure at verification shear in column web panel: U = 1.670
failure at verification of welds: U = 1.111
failure at verification of web stiffeners: U = 1.367

rotational stiffness

stiffness coefficients
$k_1 = 0.38 \cdot A_{vc} / (\beta \cdot z) = 5.51$ mm
$k_2 = \infty$ (stiffened)
equivalent stiffness coefficient for 2 tension-bolt-rows:
1: $k_3 = 7.50$ mm, $k_4 = 7.11$ mm, $k_5 = 36.14$ mm, $k_{10} = 8.25$ mm $\Rightarrow$ $k_{eff,1} = 1 / \Sigma(1/k_{i,1}) = 2.365$ mm
2: $k_3 = 6.49$ mm, $k_4 = 6.15$ mm, $k_5 = 32.82$ mm, $k_{10} = 8.25$ mm $\Rightarrow$ $k_{eff,2} = 1 / \Sigma(1/k_{i,2}) = 2.134$ mm
$k_{eq} = \Sigma(k_{eff,r} \cdot h_r) / z_{eq} = 4.239$ mm, $z_{eq} = \Sigma(k_{eff,r} \cdot h_r^2) / \Sigma(k_{eff,r} \cdot h_r) = 235.4$ mm
rotational stiffness
initial rotational stiffness: $S_{j,ini} = (E \cdot z^2) / \Sigma(1/k_i) = 27881.2$ kNm/rad, $z = z_{eq} = 235.4$ mm, $\Sigma(1/k_i) = 0.417$ mm^{-1}
$N_{b,Ed} = N_d = 45.53$ kN
$|N_{b,Ed}| = 45.53$ kN $<$ $5\% \cdot N_{pl,Rd} = 90.28$ kN ok
$|M_{j,Ed}| = 151.58$ kNm $>$ $2/3\ M_{j,Rd} = 66.7$ kNm $\Rightarrow$ $\mu = ((1.5 \cdot M_{j,Ed}) / M_{j,Rd})^{\Psi} = 9.174$, $\Psi = 2.7$
rotational stiffness: $S_{j,Rd} = S_{j,ini} / \mu = 3039.2$ kNm/rad
rotation: $\varphi_{j,Ed} = M_{j,Ed} / S_{j,Rd} = 2.858°$