POS. 3: BEAM-COLUMN M. STIFFENERN

4H-EC3IH version: 7/2014-1k

Standardized IH-Joints

IH-joint due to EC 3-1-8 (12.10), NA: Deutschland

connection type and dimensions of beam, of bolts, of end-plate, of welds
and material are taken of the following literature:
'Typisierte Anschlüsse im Stahlhochbau nach DIN EN 1993-1-8, Stahlbau Verlags- und Service GmbH, Ausgabe 2013'
the current number and associated parameters are recorded.
the column has no reference to the literature. continuous web stiffeners.
verification method is 'elastic-plastic'. bolts are preloaded.

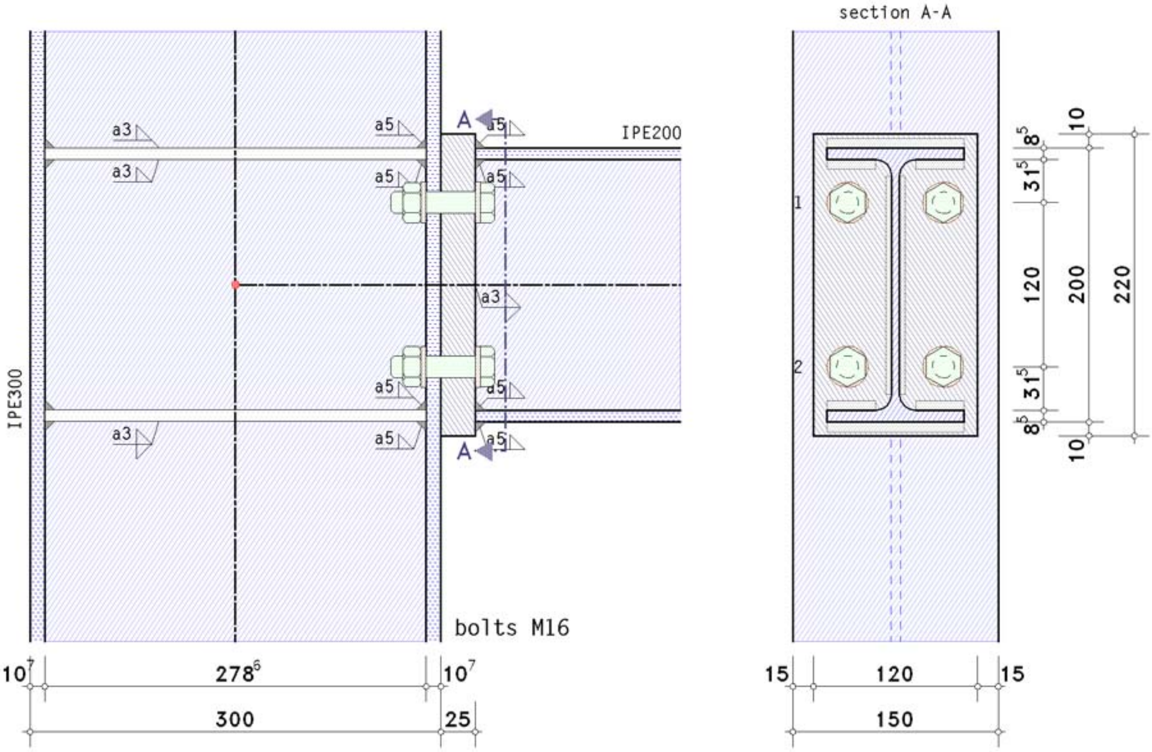
beam-column connection, steel grade S 235, bolt class of bolts 8.8

76: beam section IPE200, connection type IH1.1, bolt size M16
end-plate: t_p = 25 mm, b_p = 120 mm, h_p = 220 mm, e_1 = 50 mm, $p_{1,1}$ = 120 mm, e_{1n} = 50 mm
u_1 = 10 mm, u_{1n} = 10 mm, w = 70 mm, e_2 = 25 mm
fillet welds: a_w = 3 mm, a_f = 5 mm

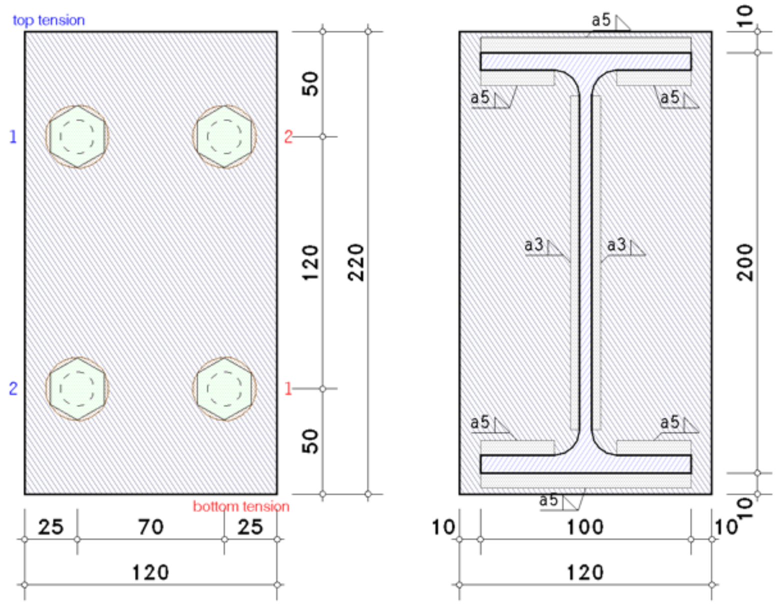
column: section IPE300, horizontal web stiffeners

internal forces and moments in the intersection point of system axes (sign convention of statics):
Lk 1: $M_{j,b,Ed}$ = 20.00 kNm $V_{j,b,Ed}$ = 30.00 kN

Rigid beam connection



details



Component method

notes
high strength bolts have to be controlled prestressed, bolt category D (tension), A (shear).
welds are not regarded by calculation the T-stub design resistance.

Lk 1:

design values

internal forces and moments in the periphery
$M_{b,Ed} = -M_{j,b,Ed} - V_{j,b,Ed} \cdot e_1 = -24.50$ kNm, $e_1 = 150.0$ mm
$V_{b,Ed} = V_{j,b,Ed} = 30.00$ kN
internal forces and moments perpendicular to the connection plane
$M_d = M_{b,Ed} = -24.50$ kNm
$V_d = V_{b,Ed} = 30.00$ kN
negative internal moment $M_d \Rightarrow$ mirrored joint model
$M_d = 24.50$ kNm, $V_d = -30.00$ kN
partial internal forces and moments refering to the mirrored model
internal forces and moments in the periphery end-plate-beam: $M'_d = M_d - V_d \cdot t_{ep} = 25.25$ kN
$N_{b,t} = -N_d \cdot z_{bu}/z_b + M'_d/z_b = 131.85$ kN, $z_b = 191.5$ mm, $z_{bu} = 95.7$ mm
$N_{b,c} = N_d \cdot z_{bo}/z_b + M'_d/z_b = 131.85$ kN, $z_b = 191.5$ mm, $z_{bo} = 95.7$ mm

resistance of cross section

plastic cross-sectional check for $M_{Ed} = -25.25$ kNm, $V_{Ed} = -30.00$ kN
elastic stresses: max $\sigma_x = 13.02$ kN/cm², min $\sigma_x = -13.02$ kN/cm², max $\tau = 3.04$ kN/cm², max $\sigma_v = 13.09$ kN/cm²
plastic design resistance moment: $M_{pl,N,Q} = 50.06$ kNm
utilizations: design resistance $U_\sigma = 0.513 < 1$ **ok.**, c/t-ratio $U_{c/t} = 0.219 < 1$ **ok.**

connection design capacity

moment resistance

distance between bolt-row(s) in tension and centre of compression:
$h_1 = 155.7$ mm, $h_2 = 35.7$ mm

design resistance per bolt-row
row 1: $F_{tr,Rd} = 142.3$ kN
row 2: $F_{tr,Rd} = 93.7$ kN
potential failure by basic component 2, 4

moment resistance
$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r) = 25.5$ kNm

shear/design bearing resistance

design resistance per bolt-row
row 1: $F_{vr,Rd}$ = 67.6 kN
row 2: $F_{vr,Rd}$ = 97.3 kN

shear/design bearing resistance
$V_{j,Rd} = \Sigma F_{vr,Rd}$ = 164.9 kN

shear resistance

$V_{wp,Rd}/\beta$ = 329.6 kN
zul $V_{pl,Rd} = 0.5 \cdot A_v \cdot (f_y/3^{1/3}) / \gamma_{M0}$ = 95.0 kN (requirement, s. 'Typisierte Anschlüsse')

total

$M_{j,Rd}$ = 25.5 kNm $V_{j,Rd}$ = 164.9 kN $V_{wp,Rd}/\beta$ = 329.6 kN $V_{pl,Rd}$ = 95.0 kN

verifications

verification of the connection design capacity by means of the component method

internal moment: $M_{Ed} = M_d$ = 24.50 kNm
shear force: $V_{Ed} = |V_d|$ = 30.00 kN
shear force: $V_{wp,Ed} = M_{d,w}/z - (V_{c1}-V_{c2})/2$ = 181.32 kN, $M_{d,w}$ = 24.2 kNm , $z = z_{eq}$ = 133.3 mm

$M_{Ed}/M_{j,Rd} = 0.960 < 1$ ok.
$V_{wp,Ed}/(V_{wp,Rd}/\beta) = 0.550 < 1$ ok.
$V_{Ed}/V_{pl,Rd} = 0.316 < 1$ ok.
$V_{Ed}/V_{j,Rd} = 0.182 < 1$ 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 $t_{max} \geq 3$ mm: weld thickness $a = 3.0$ mm $< a_{min} = t_{max}^{1/2} - 0.5 = 4.50$ mm !!
weld 5: NA-DE: plate thickness $t_{max} \geq 3$ mm: weld thickness $a = 3.0$ mm $< a_{min} = t_{max}^{1/2} - 0.5 = 4.50$ mm !!
design values:
$M_{y,Ed}$ = -24.50 kNm, $V_{z,Ed}$ = -30.00 kN
cross-sectional properties refering to centroid of the line cross section:
ΣA_w = 26.58 cm², $A_{w,z}$ = 9.54 cm², Σl_w = 65.9 cm
$I_{w,y}$ = 1790.75 cm⁴, $I_{w,z}$ = 165.32 cm⁴, Δz_w = 0.0 mm
verifications in the edge points of the individual welds:

weld 1,	pt. 0:	$\sigma_{w,x}$ = 136.81 N/mm²		$\Rightarrow U_w = 0.537 < 1$ ok.
weld 2,	pt. 0:	$\sigma_{w,x}$ = 125.19 N/mm²		$\Rightarrow U_w = 0.492 < 1$ ok.
weld 4,	pt. 0:	$\sigma_{w,x}$ = 108.77 N/mm²	$\tau_{w,z}$ = 31.45 N/mm²	$\Rightarrow U_w = 0.453 < 1$ ok.
	pt. 1:	$\sigma_{w,x}$ = -108.77 N/mm²	$\tau_{w,z}$ = 31.45 N/mm²	$\Rightarrow U_w = 0.453 < 1$ ok.
weld 6,	pt. 0:	$\sigma_{w,x}$ = -125.19 N/mm²		$\Rightarrow U_w = 0.492 < 1$ ok.
weld 8,	pt. 0:	$\sigma_{w,x}$ = -136.81 N/mm²		$\Rightarrow U_w = 0.537 < 1$ ok.

Result:
weld 1, pt. 0: $\sigma_{w,x}$ = 136.81 N/mm²
$\sigma_{1,w,Ed}$ = 19.35 kN/cm² $< f_{1,w,Rd}$ = 36.00 kN/cm²,
$\sigma_{2,w,Ed}$ = 9.67 kN/cm² $< f_{2,w,Rd}$ = 25.92 kN/cm² $\Rightarrow U_w = 0.537 < 1$ ok.

verification of web stiffeners (ribs)

column
compression stiffener
$F_{c,Ed}$ = 183.73 kN
forces per rib
$F = 0.5 \cdot F_{c,Ed} \cdot (b_f - 2 \cdot r - t_w)/b_f$ = 69.1 kN, $H = F \cdot e_F/e_H$ = 10.4 kN
assumption: stiffeners do not buckle: $c/t = 7.2 \cdot \varepsilon \leq 33 \cdot \varepsilon \Rightarrow$ section class $1 \leq 2$ ok.
cross section at flange
compression resistance: $F_{c,Rd} = (A \cdot f_y) / \gamma_{M0}$ = 77.80 kN
design value: $F_{Ed} = (F^2 + 3 \cdot H^2)^{1/2}$ = 71.5 kN
F_{Ed} = 71.5 kN $< F_{Rd}$ = 77.8 kN $\Rightarrow U = 0.918 < 1$ ok.
cross section at web
shear resistance: $V_{p,Rd} = (f_y \cdot A_v) / (3^{1/2} \cdot \gamma_{M0})$ = 321.30 kN
design value: $F_{Ed} = F$ = 69.1 kN
F_{Ed} = 69.1 kN $< F_{Rd}$ = 321.3 kN $\Rightarrow U = 0.215 < 1$ ok.
flange welds

design values: $F_{Ed}(\sigma_s) = F / (2 \cdot b_1) = 8.88$ kN/cm, $F_{Ed}(\tau_p) = H / (2 \cdot b_1) = 1.34$ kN/cm, $b_1 = 39.0$ mm
$\sigma_{1,w,Ed} = 18.35$ kN/cm² $<$ $f_{1,w,Rd} = 36.00$ kN/cm² $\Rightarrow$ utilization U = 0.510 $<$ 1 **ok.**
$\sigma_{2,w,Ed} = 17.75$ kN/cm² $<$ $f_{2,w,Rd} = 25.92$ kN/cm² $\Rightarrow$ utilization U = 0.685 $<$ 1 **ok.**

web welds

design value: $F_{Ed}(\tau_p) = F / (2 \cdot l_1) = 1.48$ kN/cm, $l_1 = 233.6$ mm
$\sigma_{1,w,Ed} = 8.54$ kN/cm² $<$ $f_{1,w,Rd} = 36.00$ kN/cm² $\Rightarrow$ utilization U = 0.237 $<$ 1 **ok.**

stiffener in tension

$F_{t,Ed} = 183.73$ kN

forces per rib

$F = 0.5 \cdot F_{t,Ed} \cdot (b_f - 2 \cdot r - t_w)/b_f = 69.1$ kN, $H = F \cdot e_F/e_H = 10.4$ kN

cross section at flange

tension resistance: $F_{t,Rd} = \min(N_{pl,Rd}, N_{u,Rd}) = 77.80$ kN
design value: $F_{Ed} = (F^2 + 3 \cdot H^2)^{1/2} = 71.5$ kN
$F_{Ed} = 71.5$ kN $<$ $F_{Rd} = 77.8$ kN $\Rightarrow$ U = 0.918 $<$ 1 **ok.**

cross section at web

shear resistance: $V_{p,Rd} = (f_y \cdot A_v) / (3^{1/2} \cdot \gamma_{M0}) = 321.30$ kN
design value: $F_{Ed} = F = 69.1$ kN
$F_{Ed} = 69.1$ kN $<$ $F_{Rd} = 321.3$ kN $\Rightarrow$ U = 0.215 $<$ 1 **ok.**

flange welds

design values: $F_{Ed}(\sigma_s) = F / (2 \cdot b_1) = 8.88$ kN/cm, $F_{Ed}(\tau_p) = H / (2 \cdot b_1) = 1.34$ kN/cm, $b_1 = 39.0$ mm
$\sigma_{1,w,Ed} = 18.35$ kN/cm² $<$ $f_{1,w,Rd} = 36.00$ kN/cm² $\Rightarrow$ utilization U = 0.510 $<$ 1 **ok.**
$\sigma_{2,w,Ed} = 17.75$ kN/cm² $<$ $f_{2,w,Rd} = 25.92$ kN/cm² $\Rightarrow$ utilization U = 0.685 $<$ 1 **ok.**

web welds

design value: $F_{Ed}(\tau_p) = F / (2 \cdot l_1) = 1.48$ kN/cm, $l_1 = 233.6$ mm
$\sigma_{1,w,Ed} = 8.54$ kN/cm² $<$ $f_{1,w,Rd} = 36.00$ kN/cm² $\Rightarrow$ utilization U = 0.237 $<$ 1 **ok.**

verification result

maximum utilization: max U = 0.960 $<$ 1 **ok.**

rotational stiffness

stiffness coefficients

$k_1 = 0.38 \cdot A_{vc} / (\beta \cdot z) = 7.32$ mm
$k_2 = \infty$ (stiffened)
equivalent stiffness coefficient for 2 bolt-rows:
$k_3 = 2.44$ mm, $k_4 = 18.31$ mm, $k_5 = 94.57$ mm, $k_{10} = 4.55$ mm $\Rightarrow$ $k_{eff,1} = 1 / \Sigma(1/k_{i,1}) = 1.440$ mm
$k_3 = 2.44$ mm, $k_4 = 18.31$ mm, $k_5 = 94.57$ mm, $k_{10} = 4.55$ mm $\Rightarrow$ $k_{eff,2} = 1 / \Sigma(1/k_{i,2}) = 1.440$ mm
$k_{eq} = \Sigma(k_{eff,r} \cdot h_r) / z_{eq} = 2.069$ mm, $z_{eq} = \Sigma(k_{eff,r} \cdot h_r^2) / \Sigma(k_{eff,r} \cdot h_r) = 133.3$ mm

rotational stiffness

initial rotational stiffness: $S_{j,ini} = (E \cdot z^2) / \Sigma(1/k_i) = 6022.3$ kNm/rad, $z = z_{eq} = 133.3$ mm, $\Sigma(1/k_i) = 0.620$ mm^{-1}
$|M_{j,Ed}| = 20.00$ kNm $>$ $2/3\, M_{j,Rd} = 17.0$ kNm $\Rightarrow$ $\mu = ((1.5 \cdot M_{j,Ed}) / M_{j,Rd})^{\Psi} = 1.548$, $\Psi = 2.7$
rotational stiffness: $S_{j,Rd} = S_{j,ini} / \mu = 3891.2$ kNm/rad
rotation: $\varphi_{j,Ed} = M_{j,Ed} / S_{j,Rd} = 0.294°$

Final result

maximum utilization:	max U = 0.960 $<$ 1 **ok.**
minimum rotational stiffness:	min $S_j = 3.9$ MNm/rad, $S_{j,ini} = 6.0$ MNm/rad
maximum rotation:	max $\varphi_{j,Ed} = 0.294°$

verification succeeded