standardized IM-joint

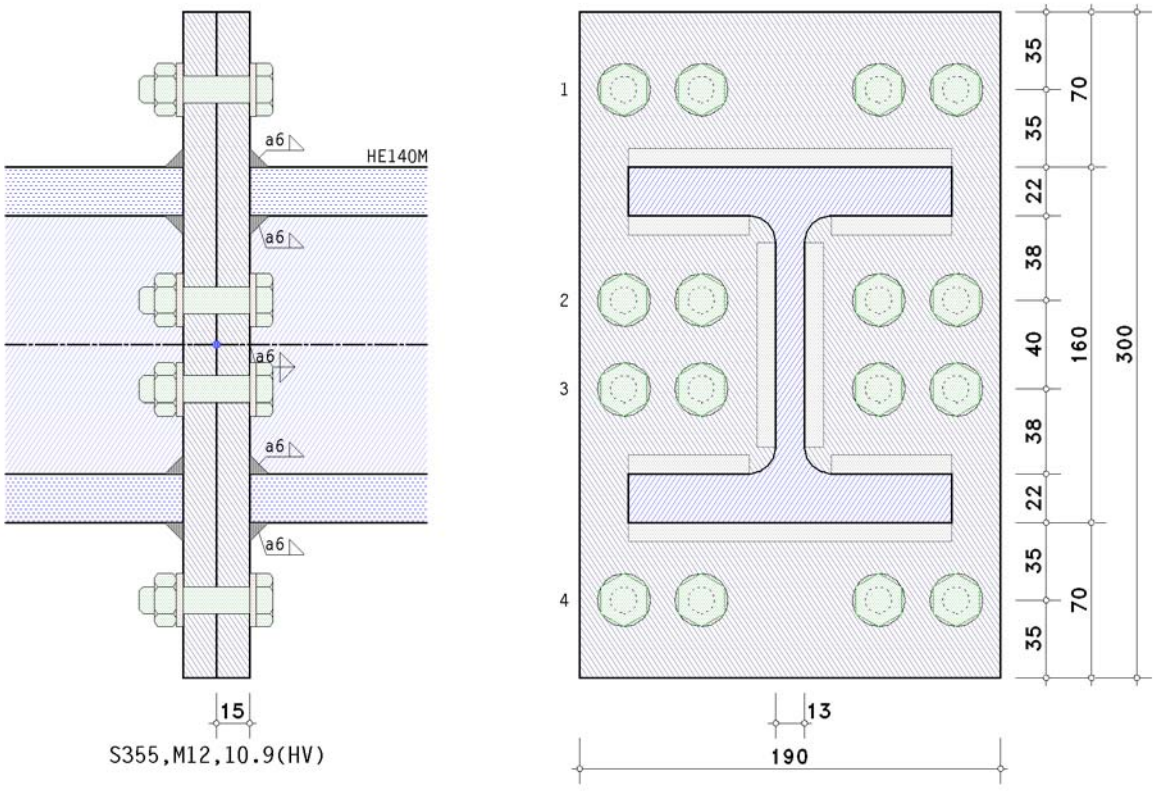
moment resistant joints IM acc. to EC 3-1-8 (12.10), NA: Deutschland

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.
MN-interaction follows Cerfontaine (in Jaspart/Weynand: Design of Joints in Steel Structures).
connections with 4 bolts per row are verified with AIF-Forschnungsbericht Nr. 15059.
maximum resistance of normal forces are calculated without components of compression/shear and linearization.

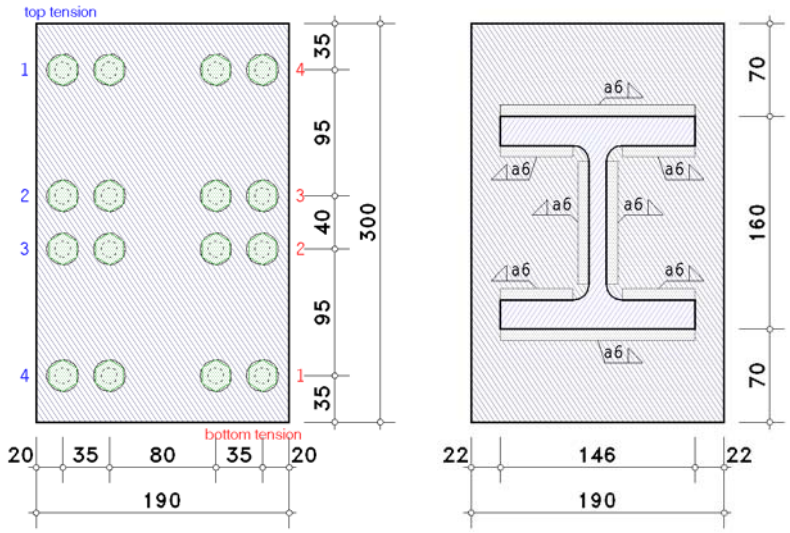
beam splice, steel grade S355, bolt class of bolts 10.9

21471: beam section HEM140, bolt size M12, connection with 4 bolts per row
end-plate: t_p = 15 mm, b_p = 190 mm, h_p = 300 mm, e_1 = 35 mm, $p_{1,1}$ = 95 mm, $p_{1,2}$ = 40 mm
$p_{1,3}$ = 95 mm, u_1 = 70 mm, w = 80 mm, p_2 = 35 mm
fillet welds: a_f = 6 mm, a_w = 6 mm

Rigid beam splice



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.
the welds are not regarded by calculation the T-stub resistance.
simplified calculation of shear force resistance takes all bolt-rows into account.
no consideration of bolt groups in joints with 4 bolts per row.

Lk 1: internal moment (top tension) + shear force

resistance of cross-section

plastic resistance moment: $M_{pl,N,Q}$ = 179.33 kNm

connection capacity

moment resistance

distance of tension-bolt-rows from centre of compression: h_1 = 184.0 mm, h_2 = 89.0 mm, h_3 = 49.0 mm

resistance per bolt-row
row 1: $F_{tr,Rd}$ = 194.4 kN
row 2: $F_{tr,Rd}$ = 189.1 kN
row 3: $F_{tr,Rd}$ = 121.4 kN
$\Sigma F_{tr,Rd}$ = 504.9 kN
potential failure by basic component 5

resistance of flanges
$F_{c,Rd}$ = 1270.8 kN

moment resistance
$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r)$ = 58.6 kNm
tension resistance
$N_{j,t,Rd} = \Sigma F_{tr,Rd}^{*}$ = 504.9 kN
compression resistance
$N_{j,c,Rd} = F_{c,Rd}$ = 1270.8 kN

shear/bearing resistance

resistance per bolt-row
row 1: $F_{vr,Rd}$ = 62.0 kN
row 2: $F_{vr,Rd}$ = 62.0 kN
row 3: $F_{vr,Rd}$ = 62.0 kN
row 4: $F_{vr,Rd}$ = 62.0 kN
$\Sigma F_{vr,Rd}$ = 248.2 kN

shear/bearing resistance
$V_{j,Rd} = \Sigma F_{vr,Rd}$ = 248.2 kN

shear resistance

shear resistance of end plate

plate: $V_{ep,Rd}$ = 282.84 kN
resistance of a weld (req.1): $f_{1w,d} = f_u / (\beta_w \cdot \gamma_{M2})$ = 435.6 N/mm²
welds: $F_{w,Rd}$ = 277.62 kN
shear resistance of end plate: $V_{ep,Rd} = F_{w,Rd}$ = 277.62 kN

plastic shear resistance
$V_{pl,Rd} = 0.5 \cdot A_v \cdot (f_y/3^{1/2}) / \gamma_{M0}$ = 250.6 kN (requirement, s. 'Typisierte Anschlüsse')

total

$M_{j,Rd}$ = 58.6 kNm $N_{j,t,Rd}$ = 504.9 kN $N_{j,c,Rd}$ = 1270.8 kN $V_{j,Rd}$ = 248.2 kN $V_{pl,Rd}$ = 250.6 kN $V_{ep,Rd}$ = 277.6 kN

rotational stiffness

stiffness coefficients
equivalent stiffness coefficient for 3 tension-bolt-rows:
1: k_5 = 12.85 mm, k_{10} = 3.01 mm $\Rightarrow$ $k_{eff,1} = 1 / \Sigma(1/k_{i,1})$ = 3.110 mm
2: k_5 = 31.49 mm, k_{10} = 3.01 mm $\Rightarrow$ $k_{eff,2} = 1 / \Sigma(1/k_{i,2})$ = 4.359 mm
3: k_5 = 26.75 mm, k_{10} = 3.01 mm $\Rightarrow$ $k_{eff,3} = 1 / \Sigma(1/k_{i,3})$ = 2.460 mm
$k_{eq} = \Sigma(k_{eff,r} \cdot h_r) / z_{eq}$ = 8.015 mm, $z_{eq} = \Sigma(k_{eff,r} \cdot h_r^2) / \Sigma(k_{eff,r} \cdot h_r)$ = 134.8 mm
rotational stiffness
initial rotational stiffness: $S_{j,ini} = (E \cdot z^2) / \Sigma(1/k_i)$ = 30604.6 kNm/rad, $z = z_{eq}$ = 134.8 mm, $\Sigma(1/k_i)$ = 0.125 mm^{-1}
$|M_{j,Ed}|$ = 1.00 kNm $\leq$ 2/3 $M_{j,Rd}$ = 39.0 kNm $\Rightarrow$ μ = 1
rotational stiffness: $S_{j,Rd} = S_{j,ini} / \mu$ = 30604.6 kNm/rad
rotation: $\varphi_{j,Ed} = M_{j,Ed} / S_{j,Rd}$ = 0.002°

Lk 2: internal moment (bottom tension) + shear force

resistance of cross-section

plastic resistance moment: $M_{pl,N,Q}$ = 179.33 kNm

connection capacity

moment resistance

distance of tension-bolt-rows from centre of compression: h_1 = 184.0 mm, h_2 = 89.0 mm, h_3 = 49.0 mm

resistance per bolt-row
row 1: $F_{tr,Rd}$ = 194.4 kN
row 2: $F_{tr,Rd}$ = 189.1 kN
row 3: $F_{tr,Rd}$ = 121.4 kN
$\Sigma F_{tr,Rd}$ = 504.9 kN
potential failure by basic component 5

resistance of flanges
$F_{c,Rd}$ = 1270.8 kN

moment resistance
$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r)$ = 58.6 kNm
tension resistance
$N_{j,t,Rd} = \Sigma F_{tr,Rd}^*$ = 504.9 kN
compression resistance
$N_{j,c,Rd} = F_{c,Rd}$ = 1270.8 kN

shear/bearing resistance

resistance per bolt-row
row 1: $F_{vr,Rd}$ = 62.0 kN
row 2: $F_{vr,Rd}$ = 62.0 kN
row 3: $F_{vr,Rd}$ = 62.0 kN
row 4: $F_{vr,Rd}$ = 62.0 kN
$\Sigma F_{vr,Rd}$ = 248.2 kN

shear/bearing resistance
$V_{j,Rd} = \Sigma F_{vr,Rd}$ = 248.2 kN

shear resistance

shear resistance of end plate
plate: $V_{ep,Rd}$ = 282.84 kN
resistance of a weld (req.1): $f_{1w,d} = f_u / (\beta_w \cdot \gamma_{M2})$ = 435.6 N/mm²
welds: $F_{w,Rd}$ = 277.62 kN
shear resistance of end plate: $V_{ep,Rd} = F_{w,Rd}$ = 277.62 kN

plastic shear resistance
$V_{pl,Rd} = 0.5 \cdot A_v \cdot (f_y/3^{1/2}) / \gamma_{M0} = 250.6$ kN (requirement, s. 'Typisierte Anschlüsse')

total

$M_{j,Rd} = 58.6$ kNm $N_{j,t,Rd} = 504.9$ kN $N_{j,c,Rd} = 1270.8$ kN $V_{j,Rd} = 248.2$ kN $V_{pl,Rd} = 250.6$ kN $V_{ep,Rd} = 277.6$ kN

rotational stiffness

stiffness coefficients
equivalent stiffness coefficient for 3 tension-bolt-rows:
1: $k_5 = 12.85$ mm, $k_{10} = 3.01$ mm $\Rightarrow$ $k_{eff,1} = 1 / \Sigma(1/k_{i,1}) = 3.110$ mm
2: $k_5 = 31.49$ mm, $k_{10} = 3.01$ mm $\Rightarrow$ $k_{eff,2} = 1 / \Sigma(1/k_{i,2}) = 4.359$ mm
3: $k_5 = 26.75$ mm, $k_{10} = 3.01$ mm $\Rightarrow$ $k_{eff,3} = 1 / \Sigma(1/k_{i,3}) = 2.460$ mm
$k_{eq} = \Sigma(k_{eff,r} \cdot h_r) / z_{eq} = 8.015$ mm, $z_{eq} = \Sigma(k_{eff,r} \cdot h_r^2) / \Sigma(k_{eff,r} \cdot h_r) = 134.8$ mm
rotational stiffness
initial rotational stiffness: $S_{j,ini} = (E \cdot z^2) / \Sigma(1/k_i) = 30604.6$ kNm/rad, $z = z_{eq} = 134.8$ mm, $\Sigma(1/k_i) = 0.125$ mm^{-1}
$|M_{j,Ed}| = 1.00$ kNm $\leq$ 2/3 $M_{j,Rd} = 39.0$ kNm $\Rightarrow$ $\mu = 1$
rotational stiffness: $S_{j,Rd} = S_{j,ini} / \mu = 30604.6$ kNm/rad
rotation: $\varphi_{j,Ed} = M_{j,Ed} / S_{j,Rd} = 0.002°$

Lk 3: tension force + internal moment (top tension) + shear force

resistance of cross-section

plastic resistance moment: $M_{pl,N,Q} = 179.33$ kNm

connection capacity

bending/tension resistance

distance of tension-bolt-rows from centre of compression:
$h_1 = 184.0$ mm, $h_2 = 89.0$ mm, $h_3 = 49.0$ mm, $h_4 = -46.0$ mm

resistance per bolt-row
row 1: $F_{tr,Rd} = 194.4$ kN
row 2: $F_{tr,Rd} = 189.1$ kN
row 3: $F_{tr,Rd} = 189.1$ kN
row 4: $F_{tr,Rd} = 194.4$ kN
$\Sigma F_{tr,Rd} = 767.1$ kN
potential failure by basic component 5

moment resistance
$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r) = 61.9$ kNm for $h_r \geq 0$
tension resistance
$N_{j,t,Rd} = \Sigma F_{tr,Rd}^* = 767.1$ kN

shear/bearing resistance

resistance per bolt-row
row 1: $F_{vr,Rd} = 62.0$ kN
row 2: $F_{vr,Rd} = 62.0$ kN
row 3: $F_{vr,Rd} = 62.0$ kN
row 4: $F_{vr,Rd} = 62.0$ kN
$\Sigma F_{vr,Rd} = 248.2$ kN

shear/bearing resistance
$V_{j,Rd} = \Sigma F_{vr,Rd} = 248.2$ kN

shear resistance

shear resistance of end plate
plate: $V_{ep,Rd} = 282.84$ kN
resistance of a weld (req.1): $f_{1w,d} = f_u / (\beta_w \cdot \gamma_{M2}) = 435.6$ N/mm²
welds: $F_{w,Rd} = 277.62$ kN
shear resistance of end plate: $V_{ep,Rd} = F_{w,Rd} = 277.62$ kN

plastic shear resistance
$V_{pl,Rd} = 0.5 \cdot A_v \cdot (f_y/3^{1/2}) / \gamma_{M0} = 250.6$ kN (requirement, s. 'Typisierte Anschlüsse')

total

$M_{j,Rd} = 61.9$ kNm $N_{j,t,Rd} = 767.1$ kN $V_{j,Rd} = 248.2$ kN $V_{pl,Rd} = 250.6$ kN $V_{ep,Rd} = 277.6$ kN

rotational stiffness

rotational stiffness only für bending connections !!

Lk 4: tension force + internal moment (bottom tension) + shear force

resistance of cross-section

plastic resistance moment: $M_{pl,N,Q}$ = 179.33 kNm

connection capacity

bending/tension resistance

distance of tension-bolt-rows from centre of compression:
h_1 = 184.0 mm, h_2 = 89.0 mm, h_3 = 49.0 mm, h_4 = -46.0 mm

resistance per bolt-row
row 1: $F_{tr,Rd}$ = 194.4 kN
row 2: $F_{tr,Rd}$ = 189.1 kN
row 3: $F_{tr,Rd}$ = 189.1 kN
row 4: $F_{tr,Rd}$ = 194.4 kN
$\Sigma F_{tr,Rd}$ = 767.1 kN
potential failure by basic component 5

moment resistance
$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r)$ = 61.9 kNm for $h_r \geq 0$
tension resistance
$N_{j,t,Rd} = \Sigma F_{tr,Rd}^{*}$ = 767.1 kN

shear/bearing resistance

resistance per bolt-row
row 1: $F_{vr,Rd}$ = 62.0 kN
row 2: $F_{vr,Rd}$ = 62.0 kN
row 3: $F_{vr,Rd}$ = 62.0 kN
row 4: $F_{vr,Rd}$ = 62.0 kN
$\Sigma F_{vr,Rd}$ = 248.2 kN

shear/bearing resistance
$V_{j,Rd} = \Sigma F_{vr,Rd}$ = 248.2 kN

shear resistance

shear resistance of end plate
plate: $V_{ep,Rd}$ = 282.84 kN
resistance of a weld (req.1): $f_{1w,d} = f_u / (\beta_w \cdot \gamma_{M2})$ = 435.6 N/mm²
welds: $F_{w,Rd}$ = 277.62 kN
shear resistance of end plate: $V_{ep,Rd} = F_{w,Rd}$ = 277.62 kN

plastic shear resistance
$V_{pl,Rd} = 0.5 \cdot A_v \cdot (f_y / 3^{1/2}) / \gamma_{M0}$ = 250.6 kN (requirement, s. 'Typisierte Anschlüsse')

total

$M_{j,Rd}$ = 61.9 kNm $N_{j,t,Rd}$ = 767.1 kN $V_{j,Rd}$ = 248.2 kN $V_{pl,Rd}$ = 250.6 kN $V_{ep,Rd}$ = 277.6 kN

rotational stiffness

rotational stiffness only für bending connections !!

Lk 5: compression force + internal moment (top tension)

resistance of cross-section

plastic resistance moment: $M_{pl,N,Q}$ = 179.33 kNm

connection capacity

bending/comporession resistance

distance of tension-bolt-rows from centre of compression: h_1 = 184.0 mm, h_2 = 89.0 mm, h_3 = 49.0 mm

resistance per bolt-row
row 1: $F_{tr,Rd}$ = 121.4 kN
row 2: $F_{tr,Rd}$ = 58.7 kN
row 3: $F_{tr,Rd}$ = 32.3 kN
$\Sigma F_{tr,Rd}$ = 212.4 kN

resistance of flanges
$\Sigma F_{c,Rd}$ = 1270.8+1270.8 = 2541.6 kN

moment resistance
$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r)$ = 29.1 kNm
compression resistance
$N_{j,c,Rd} = \Sigma F_{c,Rd}$ = 2541.6 kN

shear/bearing resistance

resistance per bolt-row
row 1: $F_{vr,Rd}$ = 62.0 kN
row 2: $F_{vr,Rd}$ = 62.0 kN
row 3: $F_{vr,Rd}$ = 62.0 kN
row 4: $F_{vr,Rd}$ = 62.0 kN
$\Sigma F_{vr,Rd}$ = 248.2 kN

shear/bearing resistance
$V_{j,Rd} = \Sigma F_{vr,Rd}$ = 248.2 kN

shear resistance

shear resistance of end plate
plate: $V_{ep,Rd}$ = 282.84 kN
resistance of a weld (req.1): $f_{1w,d} = f_u / (\beta_w \cdot \gamma_{M2})$ = 435.6 N/mm²
welds: $F_{w,Rd}$ = 277.62 kN
shear resistance of end plate: $V_{ep,Rd} = F_{w,Rd}$ = 277.62 kN

plastic shear resistance
$V_{pl,Rd} = 0.5 \cdot A_v \cdot (f_y / 3^{1/2}) / \gamma_{M0}$ = 250.6 kN (requirement, s. 'Typisierte Anschlüsse')

total

$M_{j,Rd}$ = 29.1 kNm $N_{j,c,Rd}$ = 2541.6 kN $V_{j,Rd}$ = 248.2 kN $V_{pl,Rd}$ = 250.6 kN $V_{ep,Rd}$ = 277.6 kN

rotational stiffness

rotational stiffness only für bending connections !!

Lk 6: compression force + internal moment (bottom tension)

resistance of cross-section

plastic resistance moment: $M_{pl,N,Q}$ = 179.33 kNm

connection capacity

bending/comporession resistance

distance of tension-bolt-rows from centre of compression: h_1 = 184.0 mm, h_2 = 89.0 mm, h_3 = 49.0 mm

resistance per bolt-row
row 1: $F_{tr,Rd}$ = 121.4 kN
row 2: $F_{tr,Rd}$ = 58.7 kN
row 3: $F_{tr,Rd}$ = 32.3 kN
$\Sigma F_{tr,Rd}$ = 212.4 kN

resistance of flanges

$\Sigma F_{c,Rd}$ = 1270.8+1270.8 = 2541.6 kN

moment resistance
$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r)$ = 29.1 kNm
compression resistance
$N_{j,c,Rd} = \Sigma F_{c,Rd}$ = 2541.6 kN

shear/bearing resistance

resistance per bolt-row
row 1: $F_{vr,Rd}$ = 62.0 kN
row 2: $F_{vr,Rd}$ = 62.0 kN
row 3: $F_{vr,Rd}$ = 62.0 kN
row 4: $F_{vr,Rd}$ = 62.0 kN
$\Sigma F_{vr,Rd}$ = 248.2 kN

shear/bearing resistance
$V_{j,Rd} = \Sigma F_{vr,Rd}$ = 248.2 kN

shear resistance

shear resistance of end plate
plate: $V_{ep,Rd}$ = 282.84 kN
resistance of a weld (req.1): $f_{1w,d} = f_u / (\beta_w \cdot \gamma_{M2})$ = 435.6 N/mm²
welds: $F_{w,Rd}$ = 277.62 kN
shear resistance of end plate: $V_{ep,Rd} = F_{w,Rd}$ = 277.62 kN

plastic shear resistance
$V_{pl,Rd} = 0.5 \cdot A_v \cdot (f_y / 3^{1/2}) / \gamma_{M0}$ = 250.6 kN (requirement, s. 'Typisierte Anschlüsse')

total

$M_{j,Rd}$ = 29.1 kNm $N_{j,c,Rd}$ = 2541.6 kN $V_{j,Rd}$ = 248.2 kN $V_{pl,Rd}$ = 250.6 kN $V_{ep,Rd}$ = 277.6 kN

rotational stiffness

rotational stiffness only für bending connections !!

Final Result

initial stiffness:	$S_{j,ini}$	= 30.6 MNm/rad
moment resistance (M+):	$M_{j1,Rd}$	= 58.6 kNm
moment resistance (M-):	$M_{j2,Rd}$	= 58.6 kNm
tension resistance:	$N_{jt,Rd}$	= 767.1 kNm
compression resistance:	$N_{jc,Rd}$	= 2541.6 kNm
shear force resistance:	$V_{j,Rd}$	= 248.2 kNm
moment resistance of beam section:	$M_{c,Rd}$	= 179.3 kNm