Business from technology

Lap shear tests of bolted and screwed ferritic stainless steel connections

Stainless Steel in Structures Experts Seminar
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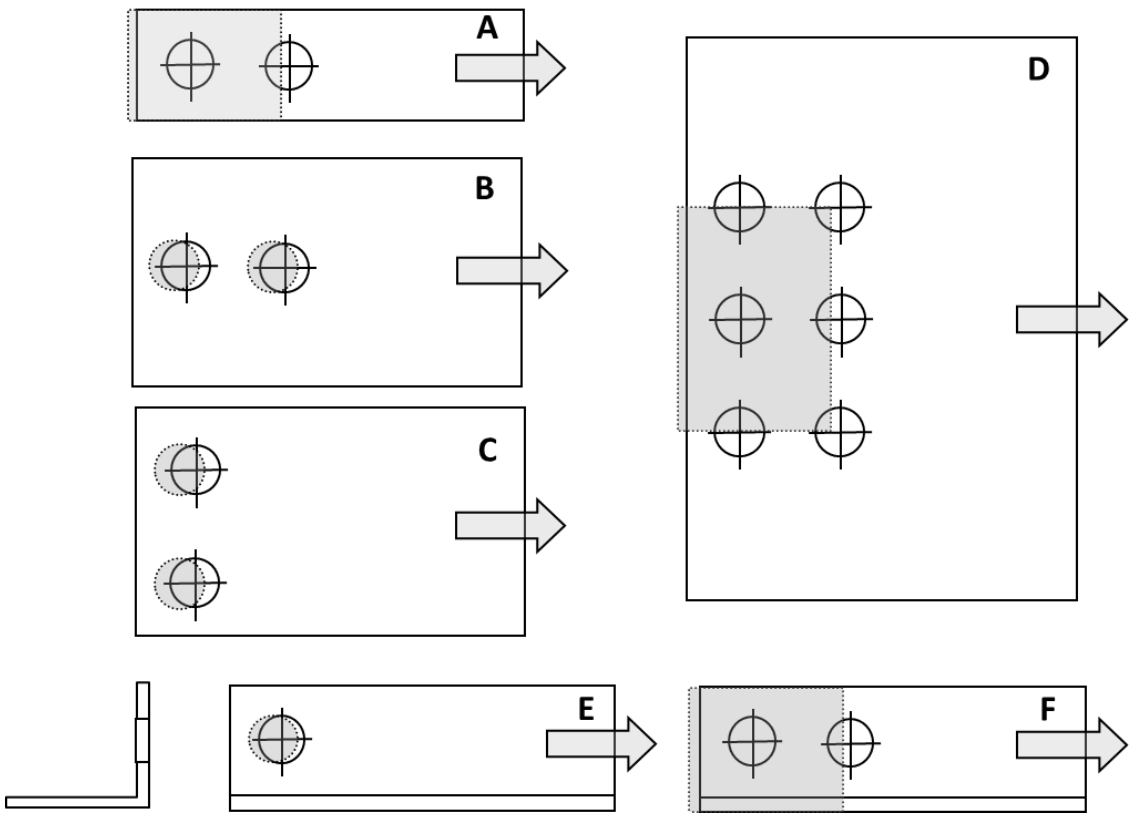
Bolted connections, specimens



Failure mode	Single shear	Double shear
Net section	A1	A2
Bearing	B1	B2
Bearing	C1	C2
Block tearing	D1	D2
Bearing	E1	-
Net section	F1	-

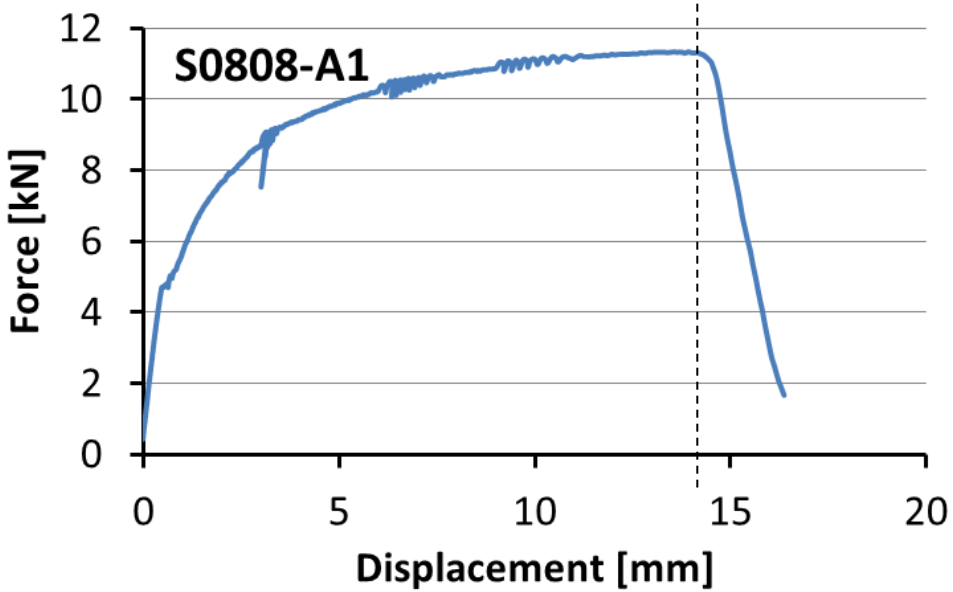
Materials

EN 1.4509 (ASTM 441)
Hole ∅13 mm
Bolt M12

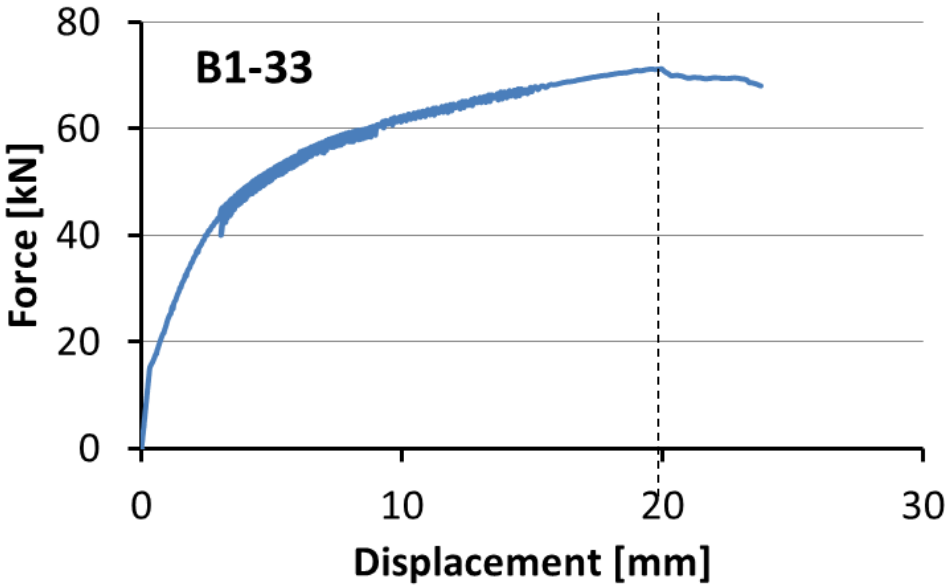
Thicknesses

A-D: t = 0.8, 1.2, 2.0, 3.0, 4.5
E-F: t = 3.0, 4.5

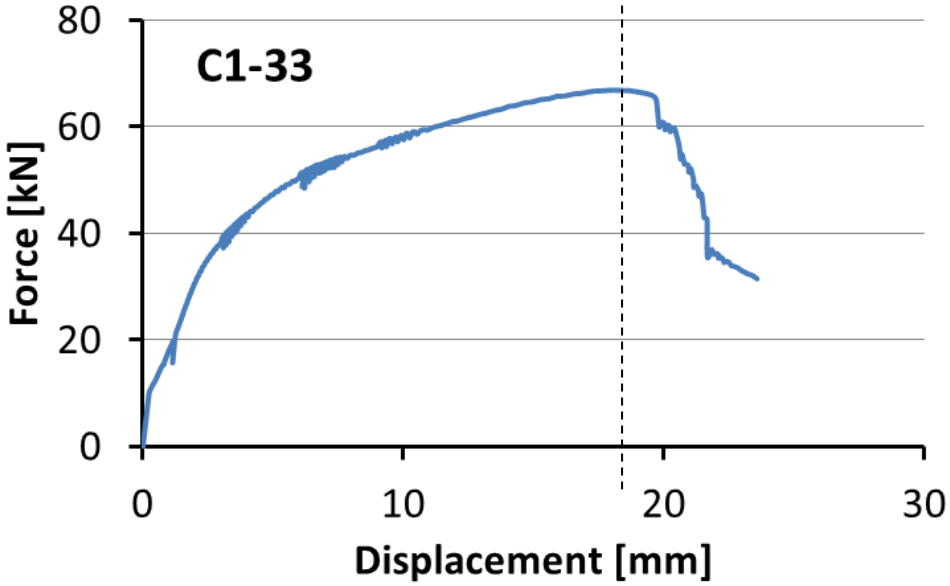
Net section failure

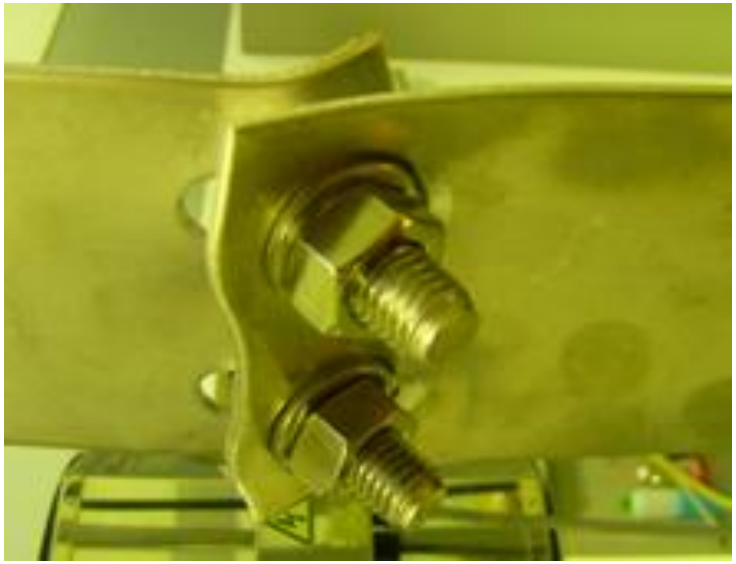


Bearing failure

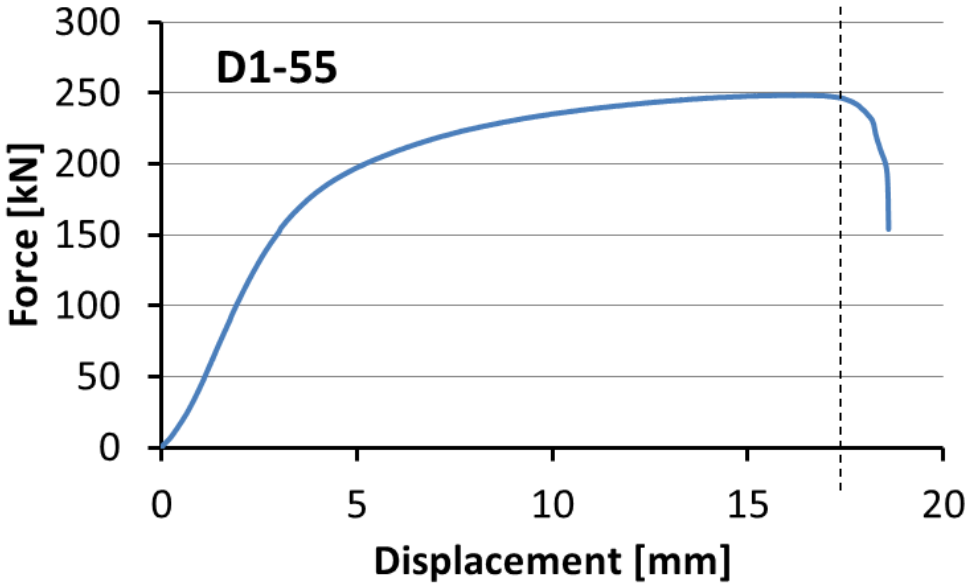


Bearing failure

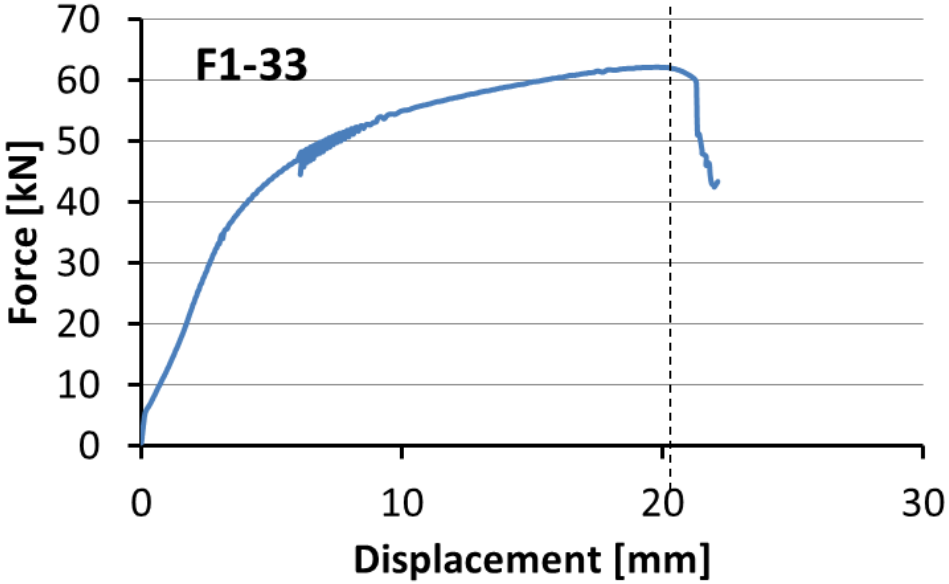




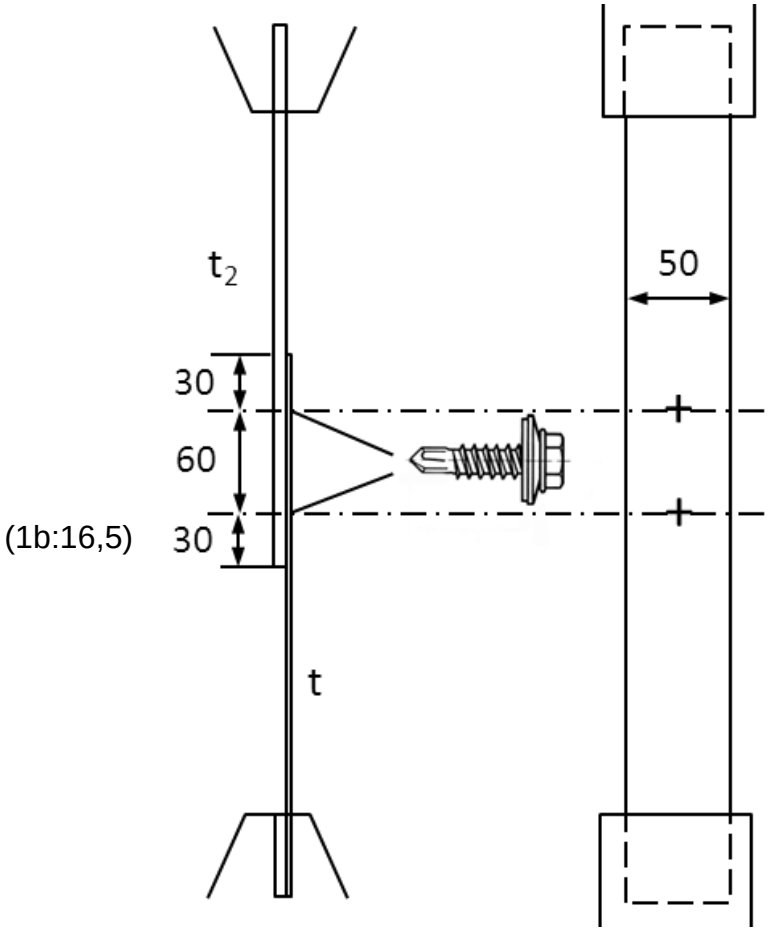
Block tearing failure

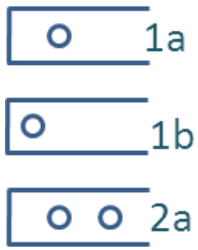


Net section failure, angles



Screwed connections, specimens





Thicknesses

t [mm]	t_2 [mm]
0.5	0.5
0.5	2
0.8	0.8
0.8	2
1.2	1.2
1.2	2

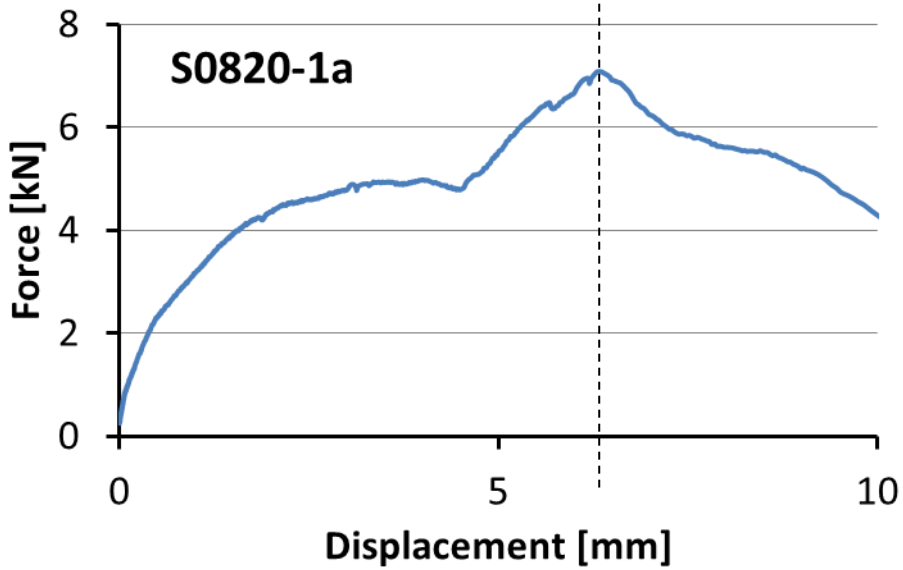
Materials

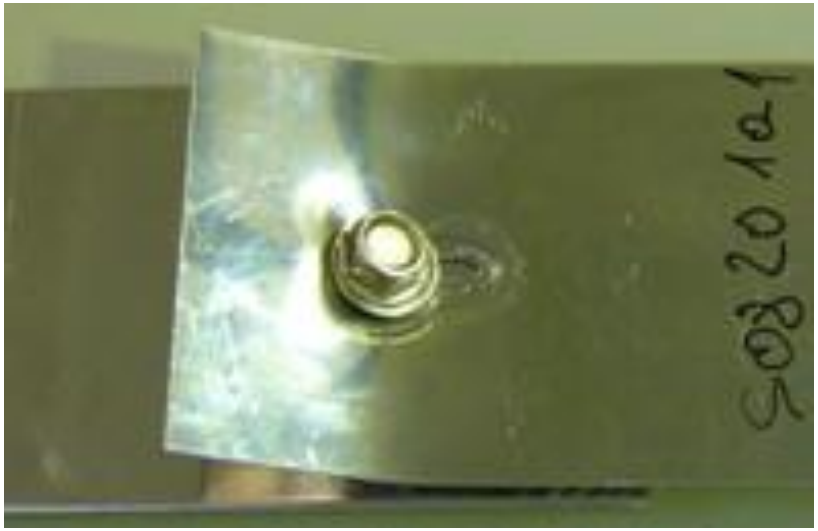
EN 1.4509 (ASTM 441)

A2 Self-drilling screws (EN ISO 1478)

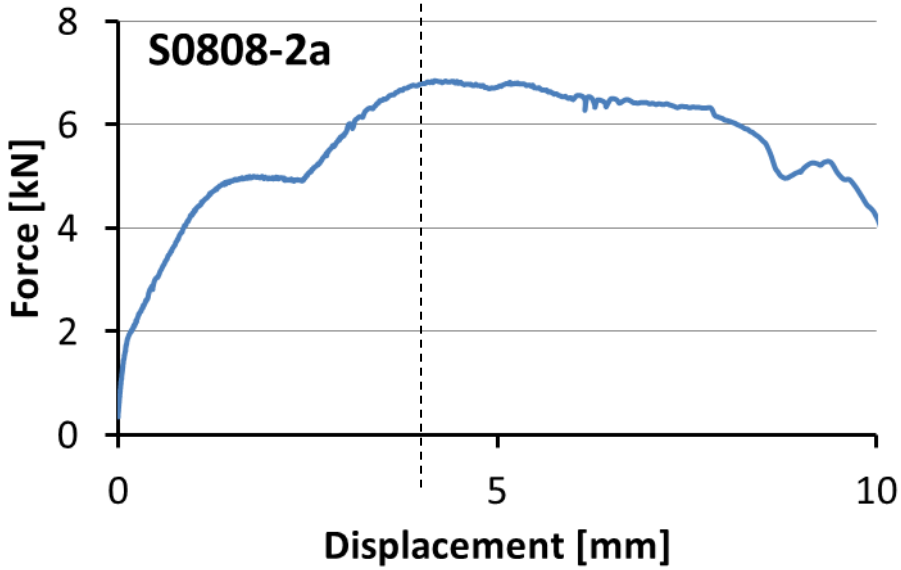
- ✓ nominal diameter: d=5.5 mm
- ✓ outer thread diameter: 5.28–5.46 mm
- ✓ inner diameter: 3.99–4.17 mm
- ✓ thread pitch:1.8 mm
- ✓ clearance hole: 4.0 mm

Bearing & Out-of-plane bending

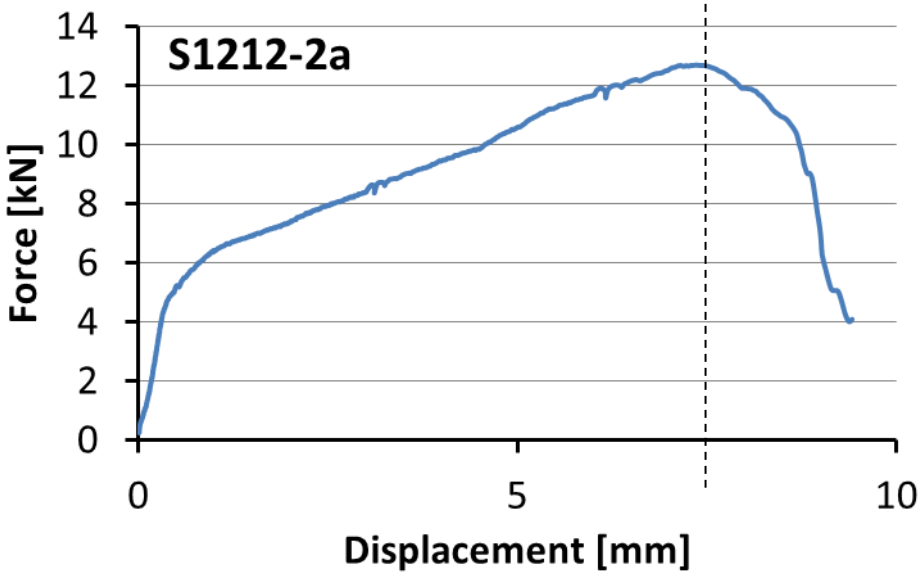




Bearing



Bearing & Pull-out



Eurocode design

Net section resistance

Flats: $N_{u,Rd} = \frac{k_r A_{net} f_u}{\gamma_{M2}}$

EC 1-1: k_r=0.9

EC 1-3= EC1-4

$k_r = [1 + 3r\left(\frac{d_o}{u} - 0{,}3\right)$ ≤1.0

Angles: EC 1-8

$N_{u,Rd} = \frac{\beta_2 A_{net} f_u}{\gamma_{M2}}$

β_2=0.4−0.7

Bearing resistance

EC 1-8: $F_{b,Rd} = \frac{k_1 \alpha_b f_u d t}{\gamma_{M2}}$

Factors k_1 and α_b are depending only on dimensions, not on t

EC 1-3: $F_{b,Rd} = \frac{2{,}5 \alpha_b f_u k_t d t}{\gamma_{M2}}$

Factor α_b is depending on dimensions and k_t is depending on t

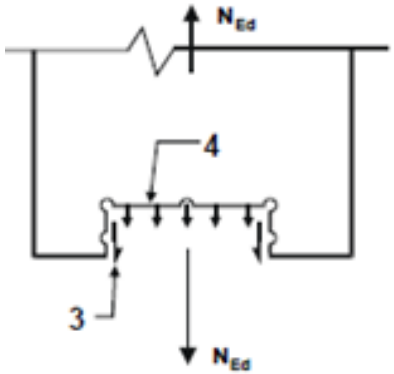
EC 1-4= EC 1-8 but using

$f_{u,red}$=0.5f_y+0.6f_u ≤1.0

Block tearing resistance

EC1-8:

$$V_{eff,1,Rd} = \frac{f_u A_{nt}}{\gamma_{M2}} + \frac{f_y}{\sqrt{3}} \frac{A_{nv}}{\gamma_{M0}}$$



Self-tapping screws

EC 1−3: $F_{b,Rd} = \frac{\alpha f_u d t}{\gamma_{M2}}$; EC 1-4= EC 1-3

$\propto = 3.2\sqrt{t/d}$ ≤2.1 for t=t_1 and for (t_1≥2.5t; t<1.0 mm)

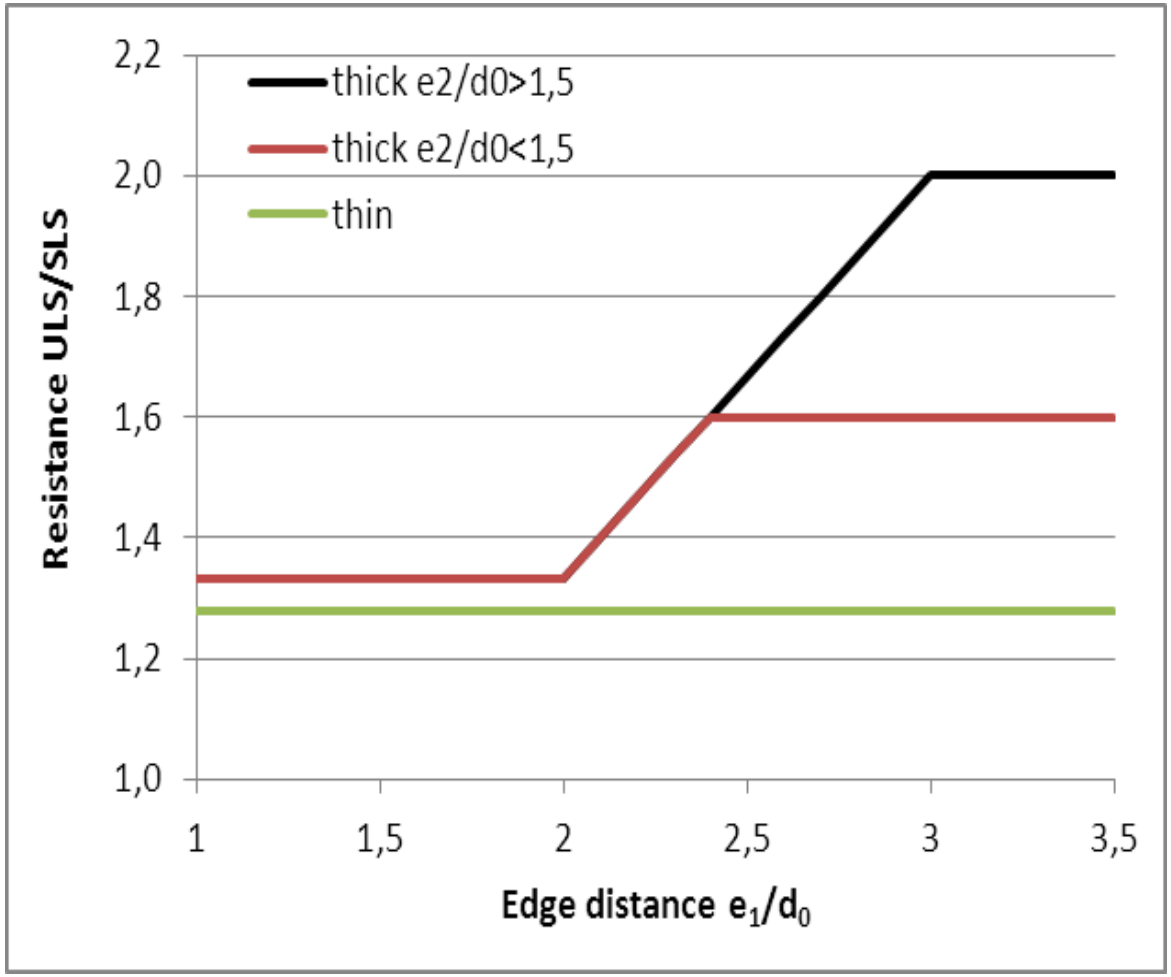
∝ =2.1 for (t_1≥2.5t ; t≥1.0 mm)

∝ for t<t_1<2.5t by linear interpolation

Failure criterion

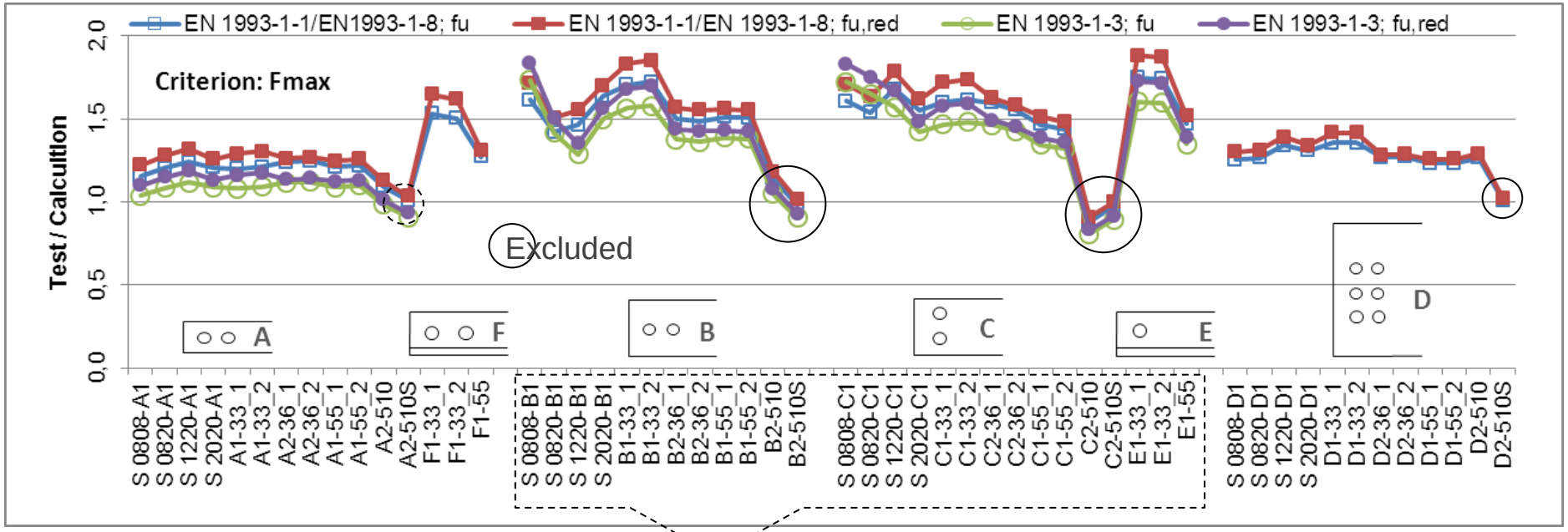
- In the interpretation of the test results it is essential, which criterion is applied to the ultimate limit state.
- The Commentary Part of the Design Manual: Use of $f_{u,red}$ limits the bearing deformation to 3 mm. There is also proposed that a 1.75 mm permanent deformation is acceptable at the serviceability state, and a 5 mm permanent bearing deformation is acceptable at the ultimate limit state.
- AISC Steel Construction Manual: Deformation of 6.35 mm has been adopted in developing design guidance for carbon steel connections (Salih & al. 2011).
- ECCS testing guidance for screwed connections: Failure load is the maximum load, when the corresponding total elongation is less than 3 mm; otherwise the failure load is the load at an elongation of 3 mm.
- Many recent studies has used the maximum load in developing design guidance, although the deformations are large, e.g. 20–25 mm in the case of M12 bolts.
- Two criteria are used here: The first is based on the maximum load without limited deformation (F_{max} criterion) and the second on the elongation (displacement criterion). For bolted connections the elongation is 3 mm per plate and for screwed connections the 3 mm elongation is the total elongation.

Design for ULS vs. SLS



- Salih & al. 2011 propose different design equations for SLS and ULS for bearing resistances of bolted connections .
- The equations for both thick and thin-walled materials base on a parametric FEM study which is verified by test results of stainless steel connections.
- The resistance for SLS is based on a hole elongation of 1.0 mm and the resistance for ULS is based on the maximum load attained in calculation.

Results of bolted connections: F_{max} criterion



Net section resistance

- Plates (N=11):EN 1993-1-1 with f_u and even with modified k_r=1.0, and present EN 1993-1-3, are both safe
- Angles (N=3): 1993-1-8 with f_u is safe

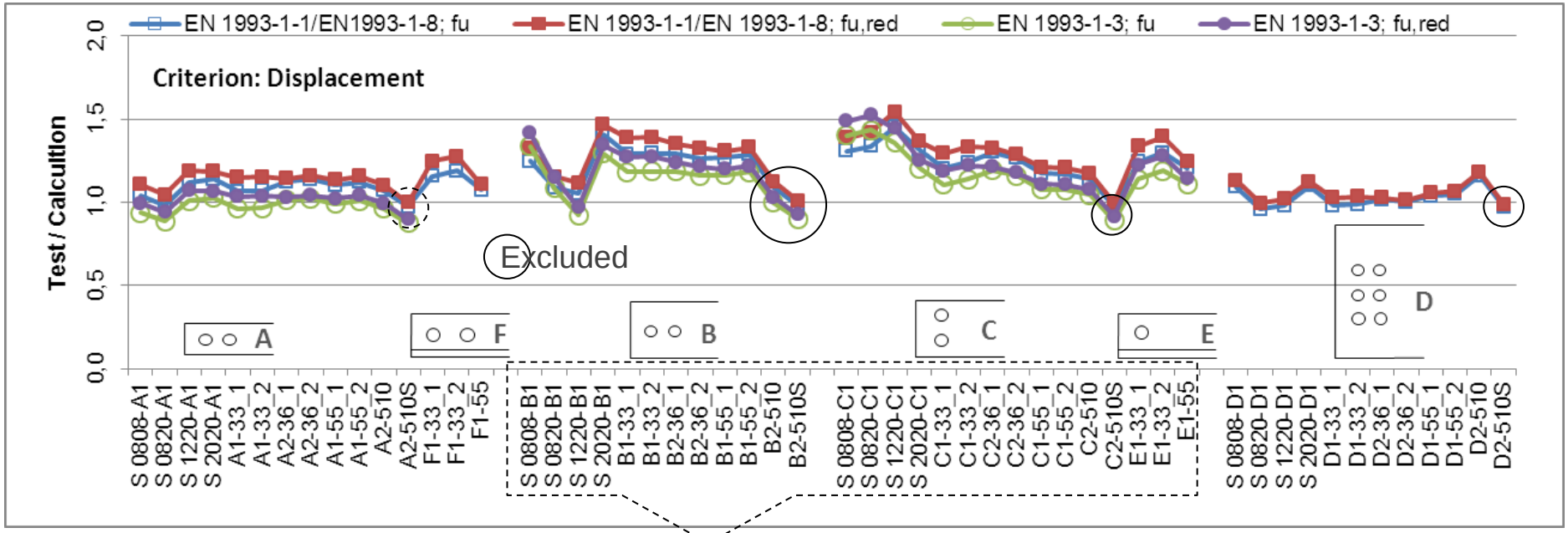
Bearing resistance

- Plates (N=23): EN1993-1-8 and EN 1993-1-3 with f_u are both very safe

Block tearing resistance

- Plates (N=11): EN 1993-1-8 with f_u is safe

Results of bolted connections: Displacement criterion



Net section resistance

- Plates (N=11): EN 1993-1-1 with f_u and existing k_r=0.9 is safe
- Angles (N=3): 1993-1-8 with f_u is safe

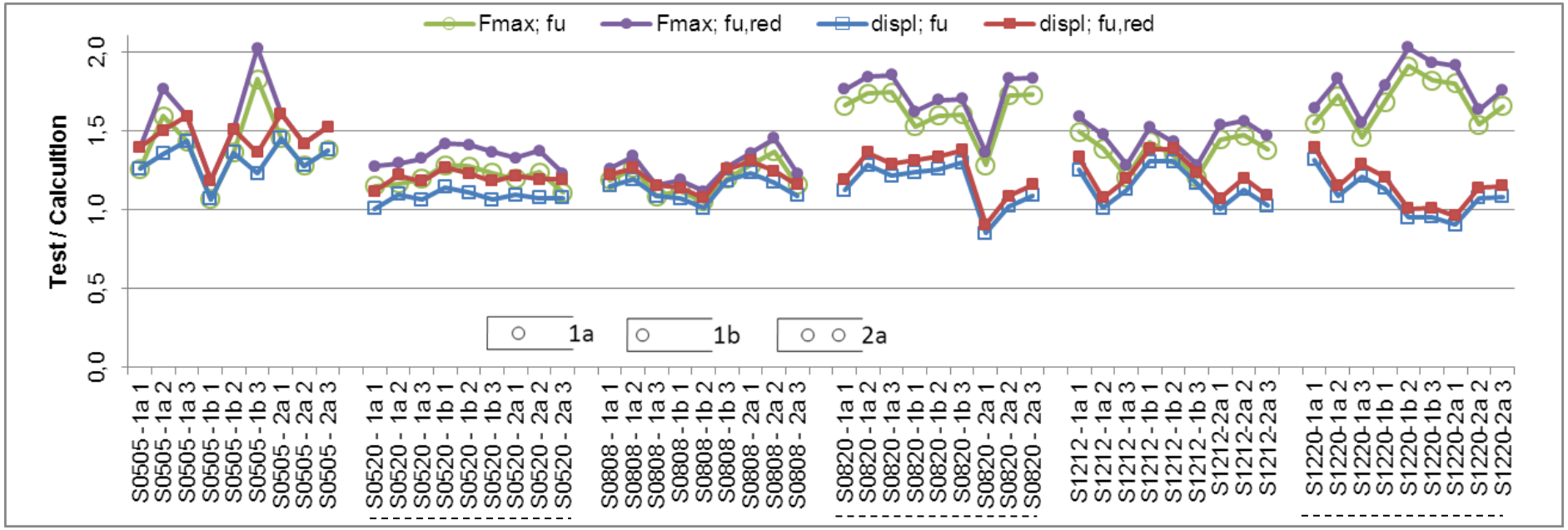
Bearing resistance

- Plates (N=23):EN 1993-1-8 with f_u even with an extra multiplication factor 1.10, and EN 1993-1-3 as it is at the moment, are both safe

Block tearing resistance

- Plates (N=11):EN 1993-1-8 with f_u and with an extra reduction factor 0.9 is safe

Results of screwed connections



- In the case of thick back plates, condition for t>1.0 mm in EN 1993-1-3 is used also for t<1.0 mm, because otherwise the results are too conservative and differ remarkably from other test series.

- N=54
- EN1993-1-3 with f_u results in safe design if the failure criterion is F_{max}.
- If the criterion is displacement, EN 1993-1-3 with f_u and with an extra reduction factor 0.9 is safe.

Conclusions and future research needs

- The design expression of bolted connections can be same for thicknesses of 0.8–4.5 mm. The use of EN 1993-1-1 approach with f_u is recommended for net section resistance and the use of EN 1993-1-8 approach with f_u is recommended for bearing and block tearing resistances.
- The design expressions of screwed connections can be same for thickness 0.5–1.2 mm. EN 1993-1-3 approach with f_u is recommended. Extra condition for t<1 mm is not necessary.
- If the failure criterion is the ultimate load in test, the design expression given in EN1993-1-1, EN 1993-1-3 and EN 1993-1-8 result in a safe outcome.
- In order to ensure that the deformations at the fasteners is limited to about 1 mm in SLS, an extra reduction factor of 0.9 should be considered in design of block tearing resistance of bolted connections and in design of bearing resistance of screwed connections.
- The conclusions above are based on characteristic resistances, which are determined according to Annex A of EN 1993-1-3. In the design based on characteristic values, Annex A recommends the use of same γ_M-values as in the case of normal calculation.
- More favourable results may be achieved, if statistical determination of resistance models according to Annex D of EN-1990 is used. Then the study should also include test results from other sources and other steel grades.

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