Buckling resistance of angle bracing members with one-leg bolted end connections

Sofia Antonodimitraki, M-Z. Bezas, J-F. Demonceau, I. Vayas, J. Maesschalck, M-O. Anwaar, J-P. Jaspart

UEE department, University of Liège, Liège, Belgium
Institute of Steel structures, NTUA, Athens, Greece
Elia, Bruxelles, Belgium
ArcelorMittal, Esch-sur-Alzette, Luxembourg

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UEE Urban & Environmental Engineering

Objectives

- Review of European normative design framework
- Comparison and evaluation of alternative design methods
- Study of the influence of various support conditions on the buckling resistance
- Study of the influence of steel grade on buckling resistance

Studies conducted in the framework of an ongoing research project: “New Steel”

European normative design framework

- Design standards dealing with the design of angle bracings in lattice towers:
  1) prEN 1993-3 (new version of EN 1993-3-1)
  2) EN 50341-1
- Analysis of structures (both standards propose the same approach):
  - Modelling as trusses
  - Linear Elastic Analysis
- Member verification: 2 distinct methodologies
  1) Effective slenderness method (prEN 1993-3- Annex C and EN 50341-1- Annex J)
  2) Interaction formulae method (prEN 1993-3- Annex F)

European normative design framework

Effective slenderness method

- Assumptions:

1) Members assumed as concentrically loaded → subjected exclusively to axial loads
2) Pin-jointed members → buckling length = system length
3) Eccentricities and actual end rotational restraints are considered implicitly through an effective slenderness:

$$\bar{\lambda}_{eff} = k\bar{\lambda} + c$$

k: Reduction coefficient accounting for the beneficial effect of the actual end restraints

c: Constant accounting for the eccentricities

- Verification check: $$\frac{N_{Ed}}{N_{b,Rd}} \leq 1$$

European normative design framework

Interaction formulae method

$$\left[\frac{N_{Ed}}{N_{bu,Rd}} + k_{uu}\frac{M_{u,Ed}}{M_{bu,Rd}}\right]^{\xi} + k_{uv}\frac{M_{v,Ed}}{M_{v,Rd}} \leq 1$$

$$\left[\frac{N_{Ed}}{N_{bv,Rd}} + k_{vu}\frac{M_{u,Ed}}{M_{bu,Rd}}\right]^{\xi} + k_{vv}\frac{M_{v,Ed}}{M_{v,Rd}} \leq 1$$

- The eccentricities at the extremities of the member can be considered explicitly through the resulting bending moments.
- The restraining effects of the actual supports can be accounted for through appropriate buckling lengths.

Evaluation of design methods

General

- Comparison of resistance predictions by normative design methods to experimental results from University of Graz (Kettler et al., 2019)
- Examined members:

  Profile: L80x80x8

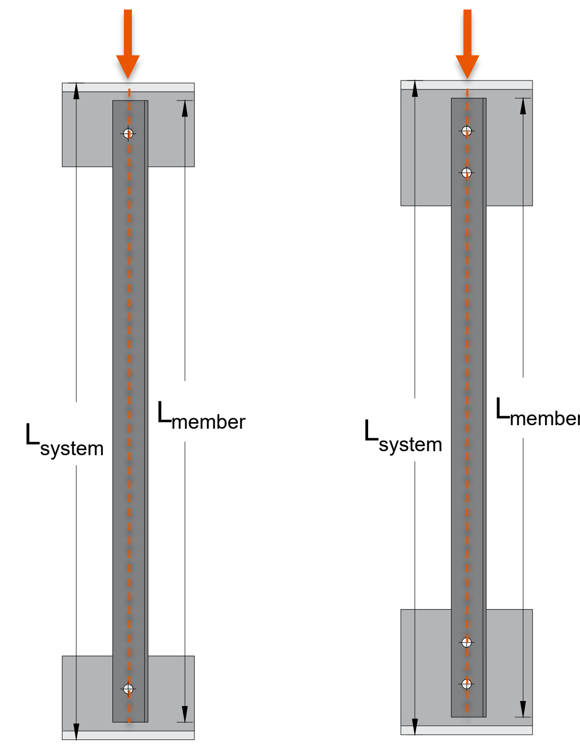
  Steel: S275

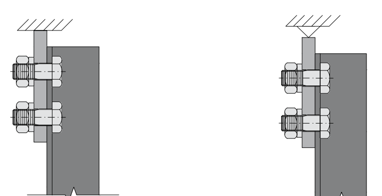
  Length: 210-3290 mm

- End joints:

  Bolted with 1 or 2 bolts

  Support at the external edge of the gusset plates: fixed or knife –edge





Fixed support

Knife-edge support

Evaluation of design methods

Assumptions – prEN 1993-3-F

- Support conditions

  2 Bolts → ϕ_z : fixed

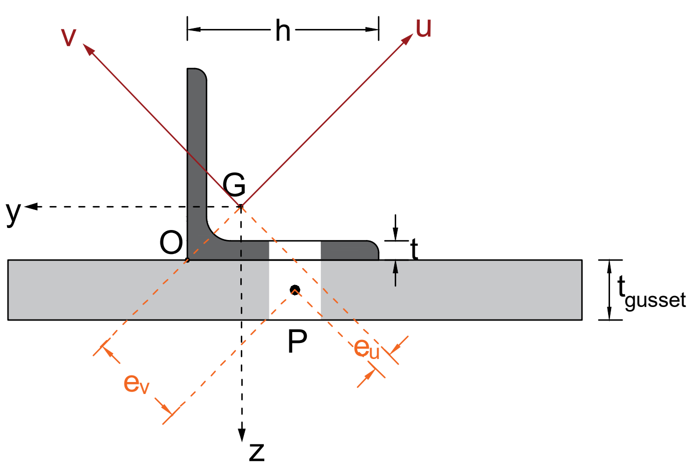
  1 Bolt → ϕ_z : free

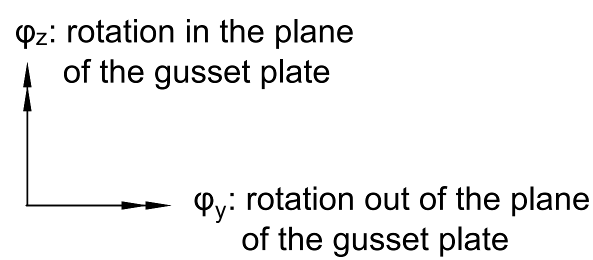
  Fixed gusset plate → ϕ_y : fixed

  Knife-edge supported plate → ϕ_y : free

- Calculation of internal forces ($N_{Ed}+M_u+M_v$) with LEA by SOFiSTiK software

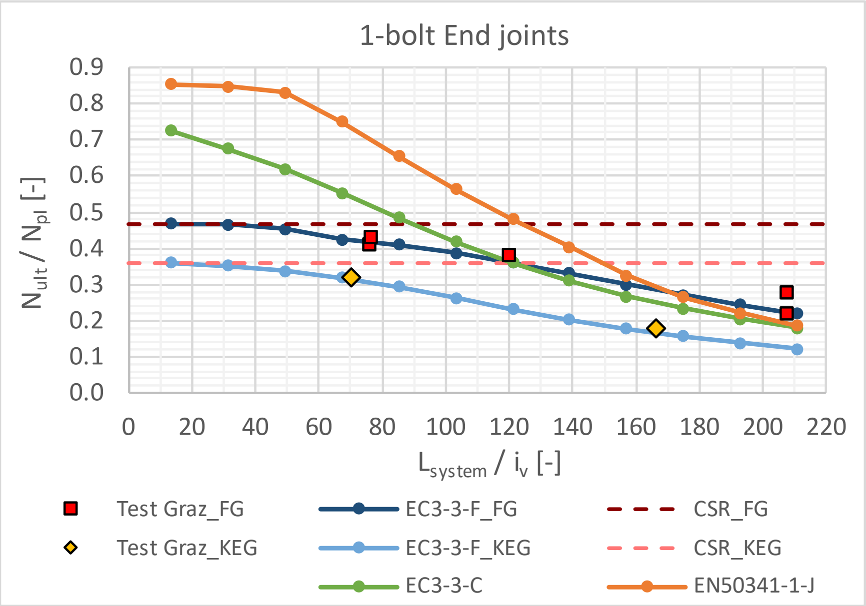
- Buckling length: LBA – 1^{st} $FB_{v\text{-}v}$ mode

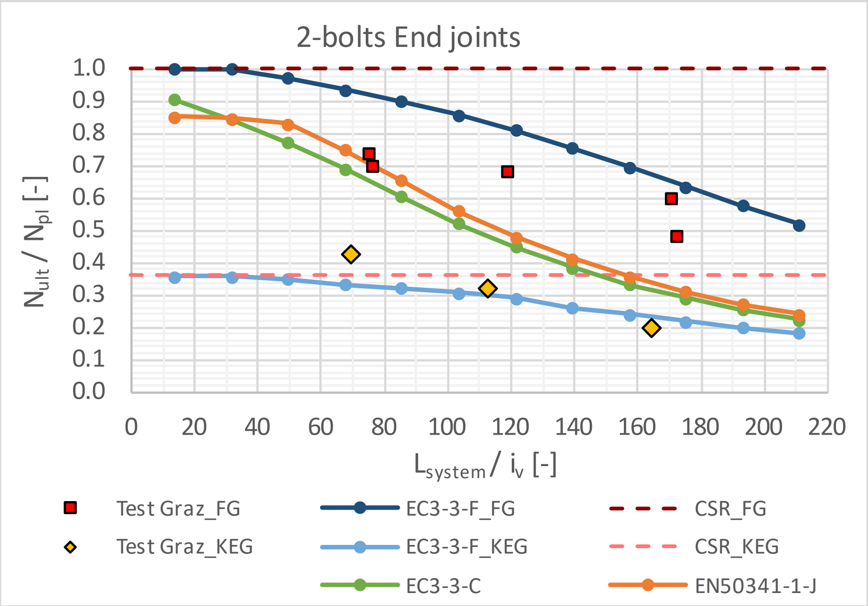




Evaluation of design methods

Results





Notation:

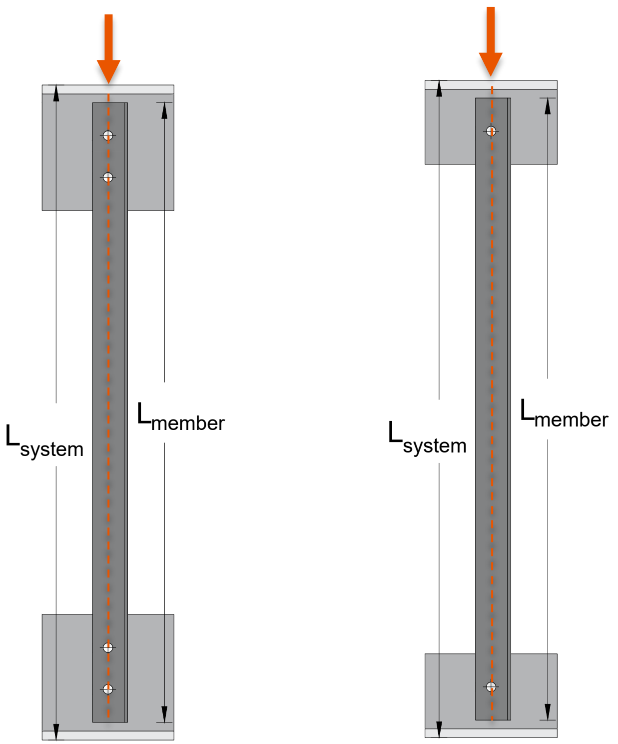
FG: Fixed Gusset plate

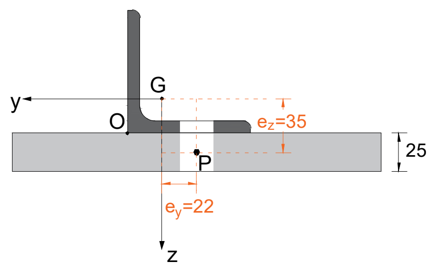
KEG: Knife-Edge type supported Gusset plate

CSR: cross-section resistance

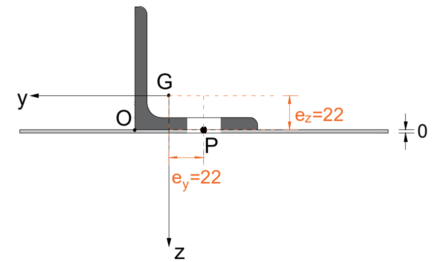
Influence of support conditions

Examined members

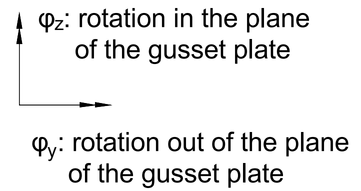




Joint with thick gusset plate

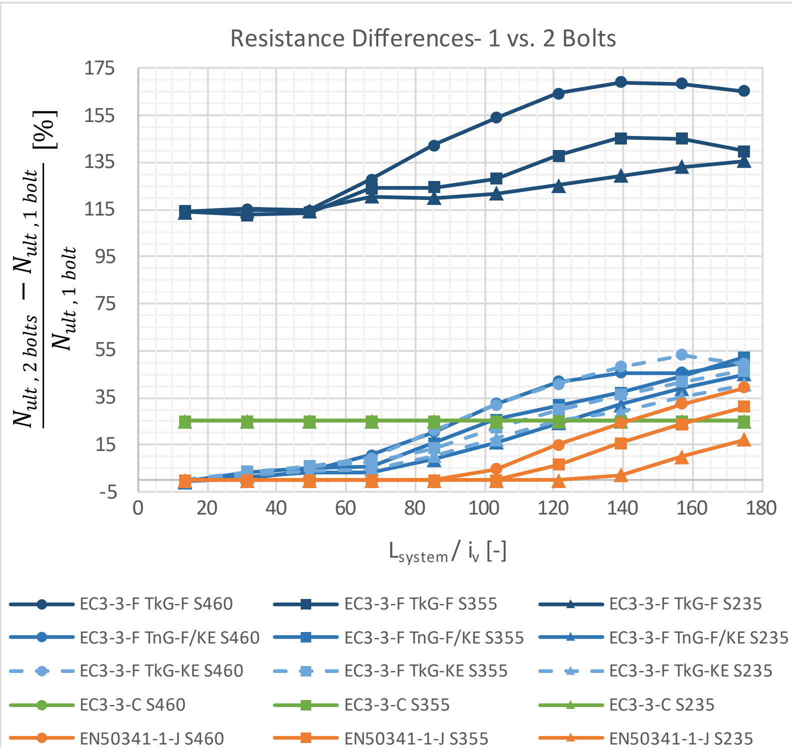


Joint with thin gusset plate



Influence of support conditions

Number of bolts – Rotational restraint in the plane of the gusset plate



<u>Notation:</u>

TkG-F: Fixed Thick Gusset plate

TkG-KE: Thick Gusset plate with Knife-Edge type support

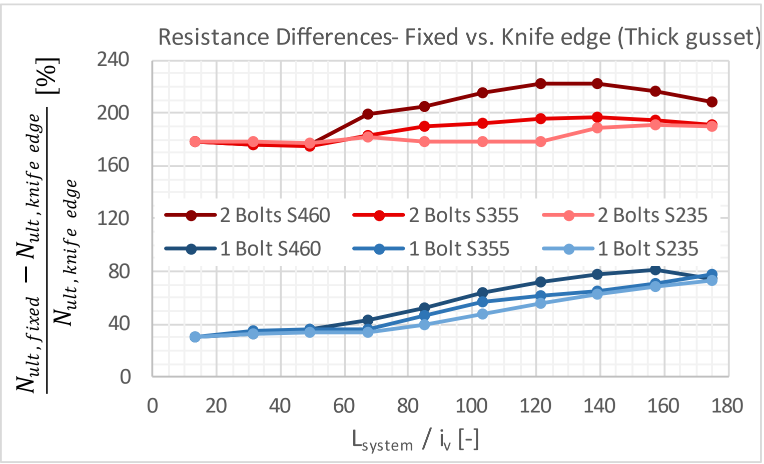
TnG-F/KE: Thin Gusset plate with Fixed or Knife-Edge type support

- The increased stiffness of the rotational restraint affects positively the buckling resistance.
- Factors affecting the beneficial effect:
  1) Member length
     Length ↑ → Benefit ↑ (*)
  2) Stiffness of the gusset plate and its support
     Stiffness ↑ → Benefit ↑
  3) Steel grade
     Grade ↑ → Benefit ↑ (*)

(*) According to prEN 1993-3-Annex C, the benefit of using 2 instead of 1 bolt is independent of the member length and the steel grade.

Influence of support conditions

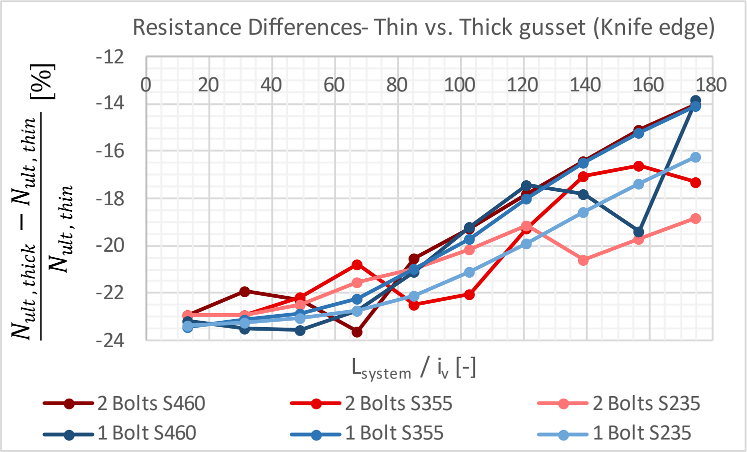
Gusset plate support – Rotational restraint out of the plane of the gusset plate



- The increased stiffness of the gusset plate support affects positively the buckling resistance.
- Factors affecting the beneficial effect:
  1) member length
  2) steel grade
  3) using 2 bolts instead 1

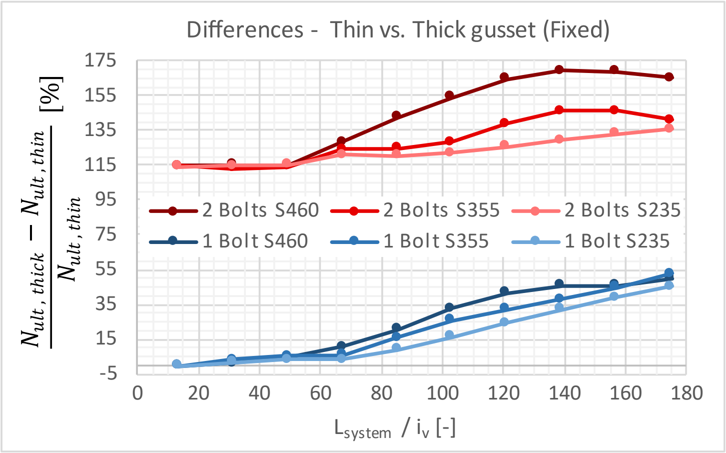
Influence of support conditions

Thickness of knife-edge supported gusset plate – Influence of load eccentricity



- The increased eccentricity affects negatively the buckling resistance.
- The negative effect decreases with the member length.

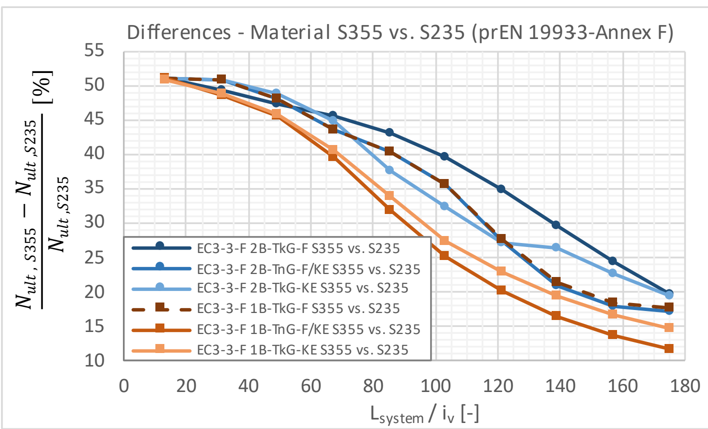
Thickness of fixed gusset plate – Combined effect of load eccentricity and joint stiffness

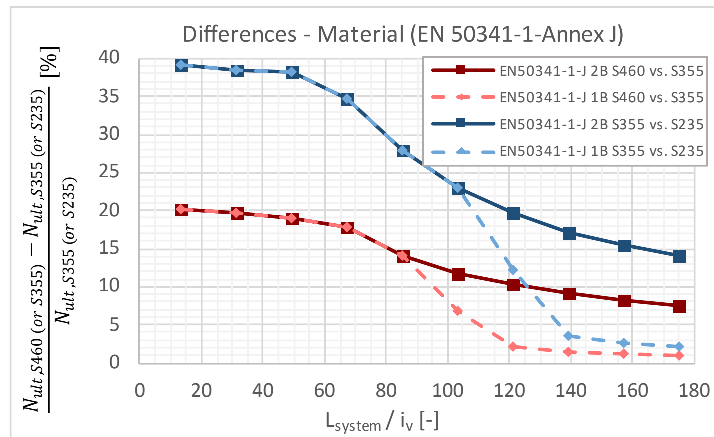


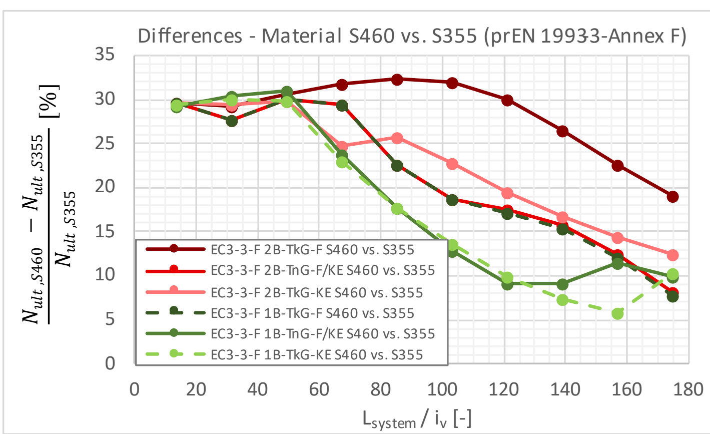
- The beneficial effect of the increased joint stiffness surpasses the negative effect of the increased load eccentricity.

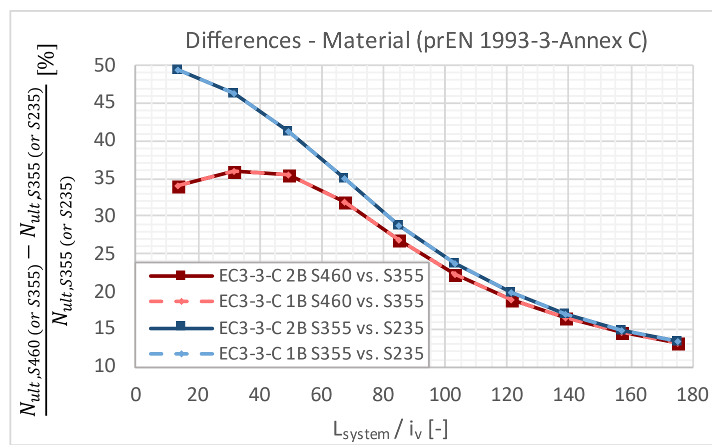
Influence of steel grade

- The benefit from upgrading steel grade reduces with the slenderness of the member.
- The gain in resistance by upgrading steel grade depends on the support conditions of the member. In most cases, the more rigid the end joint the higher the benefit.









Conclusions

- There are 2 distinct design approaches in the European design framework: the effective slenderness method and the interaction formulae method.
- The effective slenderness method is safe but conservative for members connected with 2 bolts on fixed gusset plates. On the opposite, it is mostly unsafe for members connected to fixed gusset plates with 1 bolt. If the support of the gusset plate is not fixed, the effective slenderness method leads to unsafe results.
- The interaction formulae method is safe and accurate for members with 1-bolt end joints. For members with 2-bolts end joints the application of the method needs more refinement, otherwise it leads to inaccurate results which are unsafe in many cases.
- The influence of the support conditions on the buckling resistance is very significant. The positive effect of increasing the stiffness of the end joints is higher for slenderer members and higher steel grades.
- The gain in resistance by upgrading the steel grade depends on the length of the member as well as the stiffness of its supports and it can be negligible for high slenderness members.

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Thank you for your attendance!

santonodimitraki@central.ntua.gr

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