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COMPRESSED STIFFENERS IN STRUCTURAL CONNECTIONS

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INTRODUCTION

Stiffeners in connections are triangular or rectangular plates with different types of support (free edge, partially stiffened, clamped). Three typical beam-to-column connections with different reinforcement degree are shown in *Fig. 1*. Triangular stiffeners are used on the compression side of beam-to-column connections to increase the design resistance of the beam flange and web in compression. This paper is focused on the effect of the stiffener on connection resistance and stiffness and on the resistance of the stiffener according to boundary conditions.

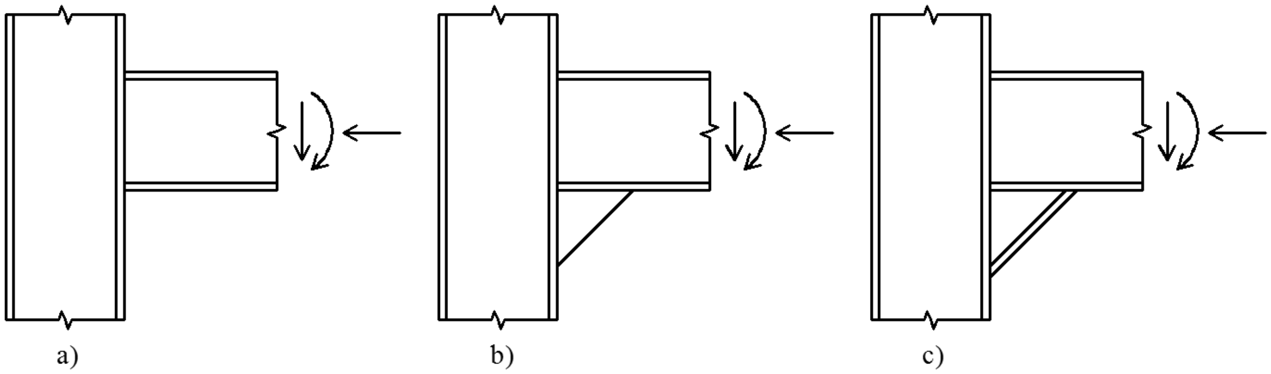

Fig. 1. a) Beam-to-column joint without stiffener; b) Beam-to-column joint with gusset (free edge); c) Beam-to-column joint with haunch (partially stiffened or clamped edge)

The design procedure for stiffener in standard EN1993-1-8 [1] is not detailed neither for resistance nor for stiffness and recommends only the flange and web thickness and maximal angle between flanges.

Many works have focused on the design of triangular stiffeners in the past 30 years. First method published by *Martin* [2], which is based on the post-critical strength of strips parallel with the free edge, was later improved by *Shakya and Vinnakota* [3] to comply with AISC specifications. The other design method based on the theory of plasticity, namely yield line theory, was presented by *Laustsen* [4]. In first step is estimated the failure mechanism and the deflected form and based on the equilibrium of internal forces is determined the post-buckling strength. The method was verified on the experiments done by *Robinson* [5]. Both methods are difficult to use in numerical calculations, because the estimation of failure mechanism is the key part of the design and can not be automated and will hardly work for haunches.

European standard EN1993-1-5 [6] provides two design approaches for slender plates – effective width method and reduced stress method. Reduced stress method has some advantages, which makes it convenient for numerical calculations, for example one step procedure, correct stiffness and unaffected FE formulation. The method is based on the von-Mises yield criterion and seems to be complex and effective dealing with biaxial compressive stresses and shear stress. Research in plates under biaxial compression by *Braun* [7] shows that the method is giving very good results, but should be further studied especially the interaction verification.

1 EFFECT OF STIFFENER ON BEAM-TO-COLUMN CONNECTION

To investigate the effect of a stiffener on the resistance are designed three beam-to-column connections, which geometry is shown in *Fig. 2*. The only difference is in the use of gusset or haunch. To design the unstiffened connection is used component method to assure that the critical component is beam flange and web in compression.

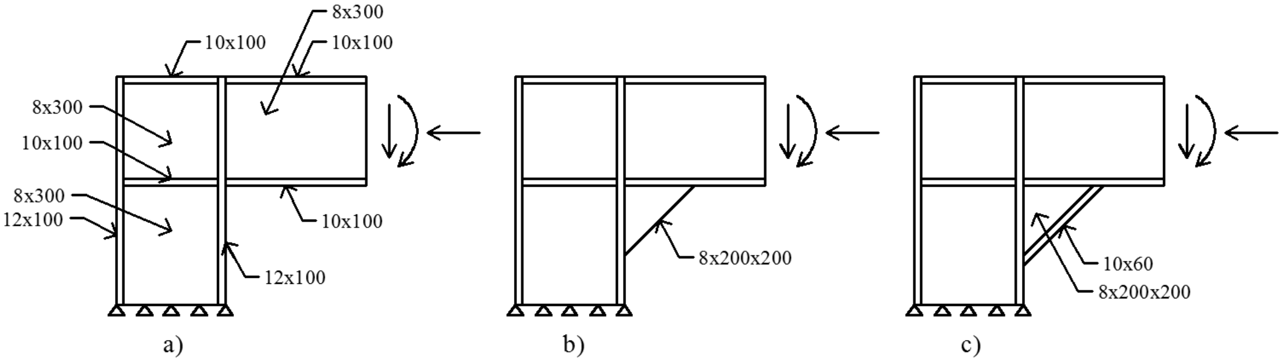

Fig. 2. a) Beam-to-column joint without stiffener; b) Beam-to-column joint with gusset; c) Beam-to-column joint with haunch

FEM simulation is done in RFEM [8], using shell elements and linear-plastic material model. Ultimate resistance is determined by geometrical and material nonlinear analysis with imperfections (GMNIA), which are modelled in the shape of first buckling mode with appropriate initial deflection. The location of applied bending moment, axial and shear force is shown in *Fig. 2.*
Results obtained from the simulation have proved, that stiffeners can significantly increase the resistance and stiffness of the connection. In *Fig. 3* is shown von-Mises stress distribution for the three types of connection for the same loading combination (M = 130 kNm, N = 65 kN, V = 65 kN), which is ultimate for the unstiffened connection. Adding a stiffener causes that plastic stresses in beam flange and shear panel are redistributed, specifically to gusset plate in *Fig. 3b)* and to haunch flange and beam flange in *Fig. 3c)*. Although the criteria in EN1993-1-8 for gusset plate thickness have been fulfilled the plasticization in gusset is significant. The gusset plate has become the critical component in the connection, therefore should be paid more attention to its design.

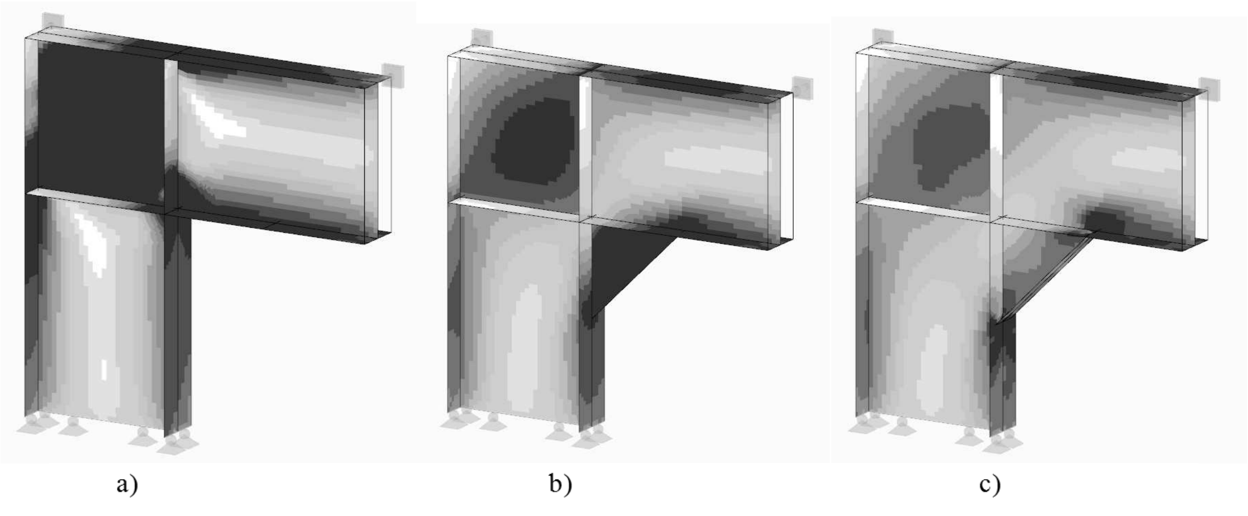

Fig. 3. Von-Mises stress distribution for the joint a) without stiffener; b) with gusset; c) with haunch

Simulation results of the stiffened and unstiffened connections are compared and are shown in *Fig. 4* on the moment-rotation curve. Horizontal axis shows the rotation and vertical axis the maximal bending moment. The increase of the resistance reaches up to 25% what makes the stiffener a very good component for increasing the resistance and stiffness of connections.

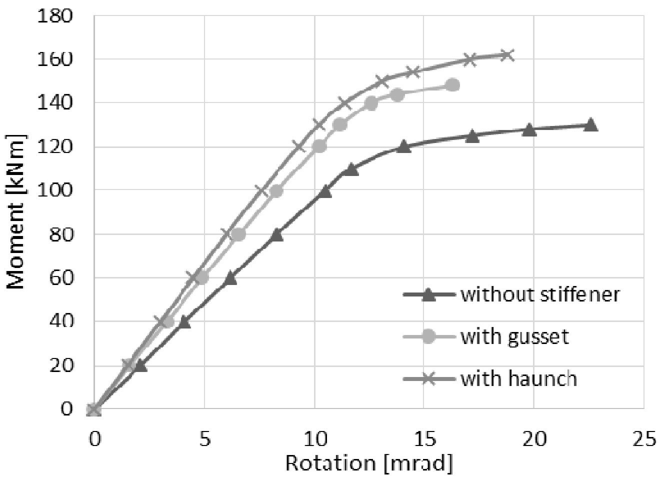

Fig. 4. Moment-rotation curve for different type of stiffening

2 PROPOSED DESIGN METHOD

2.1 Reduced stress method

The proposed design method for triangular stiffeners is the reduced stress method. The verification given in *Eq. (1)* is based on the von-Mises yield criterion and sums up the load effects of normal and shear stresses shown in *Fig. 5*.

$$\left(\frac{\sigma_{x,Ed}}{\rho_x \cdot f_y / \gamma_{M1}}\right)^2 + \left(\frac{\sigma_{z,Ed}}{\rho_z \cdot f_y / \gamma_{M1}}\right)^2 - \left(\frac{\sigma_{x,Ed}}{\rho_x \cdot f_y / \gamma_{M1}}\right) \cdot \left(\frac{\sigma_{z,Ed}}{\rho_z \cdot f_y / \gamma_{M1}}\right) + 3 \cdot \left(\frac{\tau_{Ed}}{\chi_w \cdot f_y / \gamma_{M1}}\right)^2 \leq 1 \qquad (1)$$

where σ_{Ed}, τ_{Ed} are the design load values,

ρ_x is the reduction factor for longitudinal stresses,
ρ_z is the reduction factor for transverse stresses,
χ_w is the reduction factor for shear stresses,
f_y is yield strength,
γ_{M1} is partial safety factor.

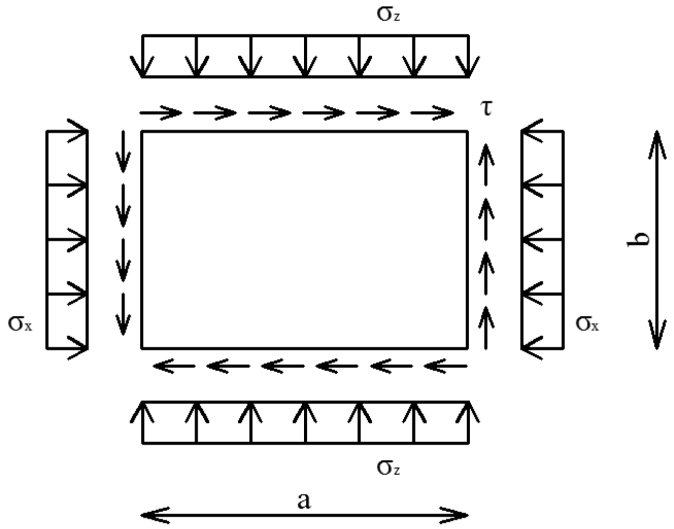

Fig. 5. Rectangular plate loaded by normal and shear stresses

The reduction factors ρ_x, ρ_z and χ_w depend on the boundary condition and slenderness and are chosen from EN 1993-1-5 section 4.5. or Annex B for plate buckling taking into account column-like behaviour where relevant and section 5.3. for shear buckling. For triangular stiffeners is chosen the formula from Annex B given in *Eq. 2*.

$$\rho = \frac{1}{\phi_p + \sqrt{\phi_p^2 - \overline{\lambda}_p}} \tag{2}$$

where $\overline{\lambda}_p$ is the modified plate slenderness,

$$\phi_p = \frac{1}{2}\left(1 + \alpha_p\left(\overline{\lambda}_p - \overline{\lambda}_{p0}\right) + \overline{\lambda}_p\right)$$

where α_p is 0,13 for hot rolled and 0,34 for welded or cold formed sections,

$\overline{\lambda}_{p0}$ is 0,7 for direct stress and 0,8 for shear and transverse stress buckling mode.

The modified plate slenderness may be obtained from *Eq. 3*.

$$\overline{\lambda}_p = \sqrt{\frac{\alpha_{ult,k}}{\alpha_{cr}}} \tag{3}$$

where α_{cr} is the elastic critical load factor of the plate,

$\alpha_{ult,k}$ is the characteristic resistance load factor.

The characteristic resistance load factor may be determined from *Eq.4*.

$$\frac{1}{\alpha_{ult,k}^2} = \left(\frac{\sigma_{x,Ed}}{f_y}\right)^2 + \left(\frac{\sigma_{z,Ed}}{f_y}\right)^2 - \left(\frac{\sigma_{x,Ed}}{f_y}\right) \cdot \left(\frac{\sigma_{z,Ed}}{f_y}\right) + 3 \cdot \left(\frac{\tau_{Ed}}{f_y}\right)^2 \tag{4}$$

2.2 Numerical model

The elastic buckling factor α_{cr} may be obtained from FE-calculation and depends on boundary conditions, stress distribution and plate geometry. The following boundary conditions are considered for buckling calculation:

1. *Simply supported edge (S)*
2. *Clamped edge (C)*
3. *Free edge (F)*

Two models are created in MIDAS [9] to determine the buckling factor α_{cr} using linear buckling analysis. The boundary conditions are chosen CCF and CCC, which correspond to gusset plate and haunch with clamped edge from the previous chapter. The applied stresses on the edges are uniform compression stress and shear stress, as shown in *Fig. 6*. Values of normal and shear stress applied on the edge are taken from the numerical model in the previous chapter, but the analysis is geometric linear without imperfections.

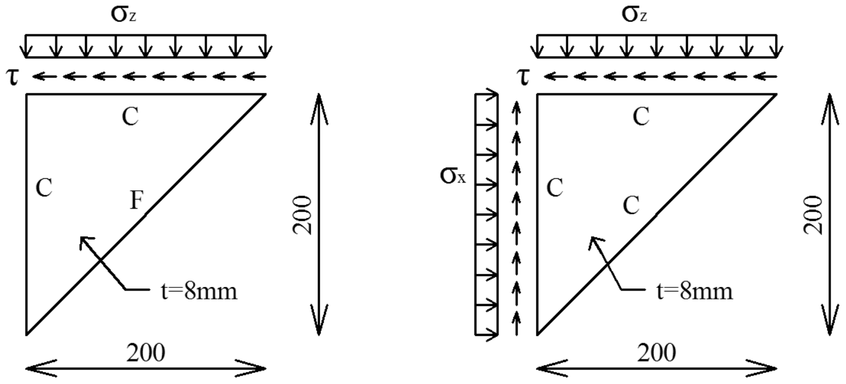

Fig. 6. Boundary conditions and applied stresses for gusset plate and haunch

2.3 Verification

Buckling shapes are shown in *Fig. 7* and the obtained elastic buckling factors α_{cr} are summarized in *Table 1*. Last column in *Table 1* shows the stiffener plate verification calculated according to the proposed design procedure in part 2.1.

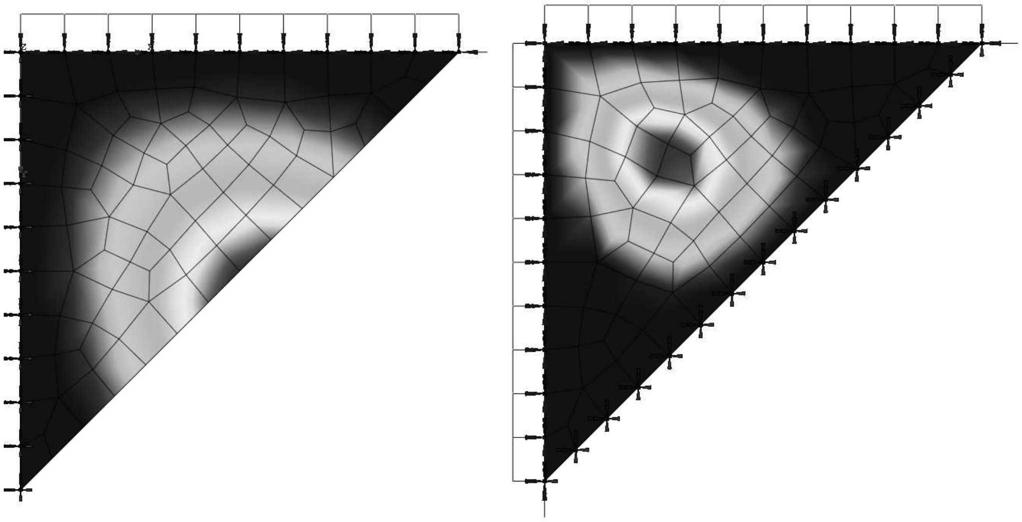

Fig. 7. Buckling shape in first mode for CCF and CCC stiffener

Table 1. Loading, buckling factor and verification for CCF and CCC stiffener

	σ_x	σ_z	τ	α_{cr}	verification
	[MPa]	[MPa]	[MPa]	[-]	[-]
CCF	0	200	190	5,04198	0,969 < 1,0
CCC	110	150	120	48,3154	0,371 < 1,0

It can be seen in the last column that the gusset plate (CCF) is close to failure, although it is designed according to recommendations in the standard EN 1993-1-8. Probably in the next load step the resistance of the gusset will be depleted and it will collapse before reaching the ultimate load of the connection.

Reduced stress method may become very useful design tool for compressed stiffeners. The results will be validated on planned experiments of triangular stiffeners with free, partially stiffened and clamped edge as shown in *Fig. 8*.

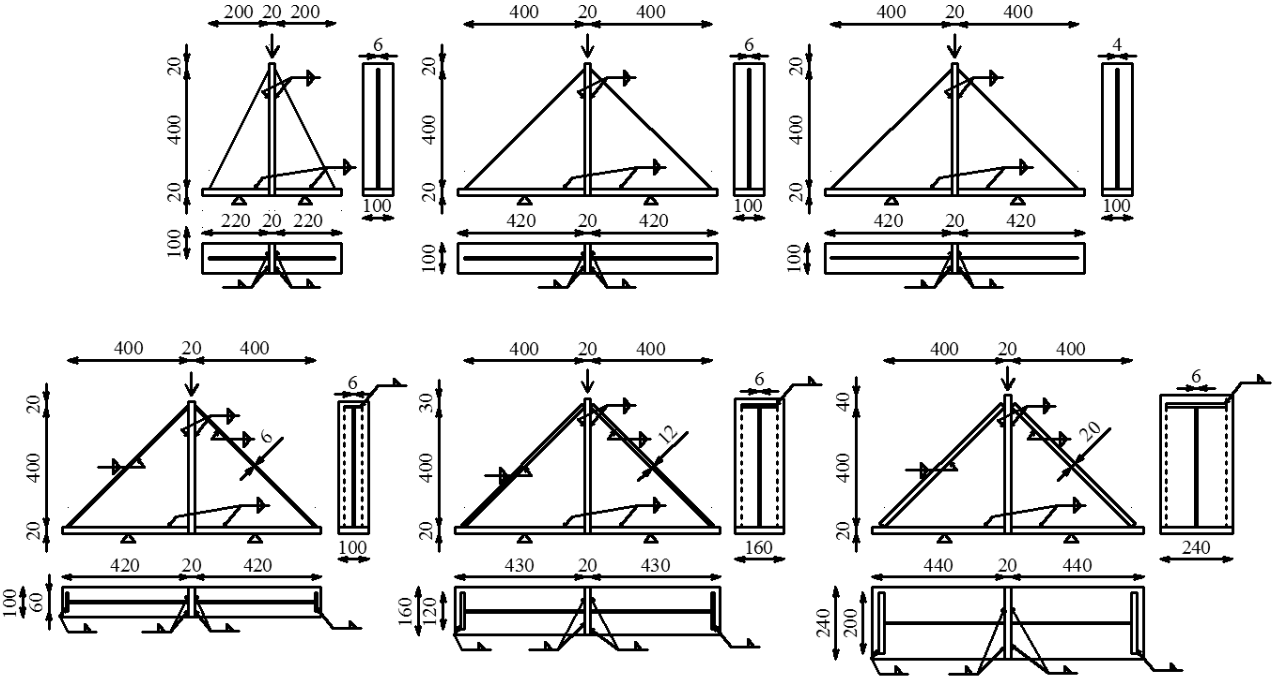

Fig. 8. Planned experiments of triangular stiffeners

3 SUMMARY AND ACKNOWLEDGMENT

The effect of stiffener on beam-to-column connection is investigated. Results indicated that using gusset plate or haunch could be interesting way for increasing resistance and stiffness of the connection.

It is proposed to use the reduced stress method for verification of gusset plate and haunch. The verification shows good results and will be validated on planned experiments of stiffeners with different types of support (free edge, partially stiffened and clamped). By adding linear stress distribution instead of uniform compression will be improved accuracy and suitability for more types of connection.

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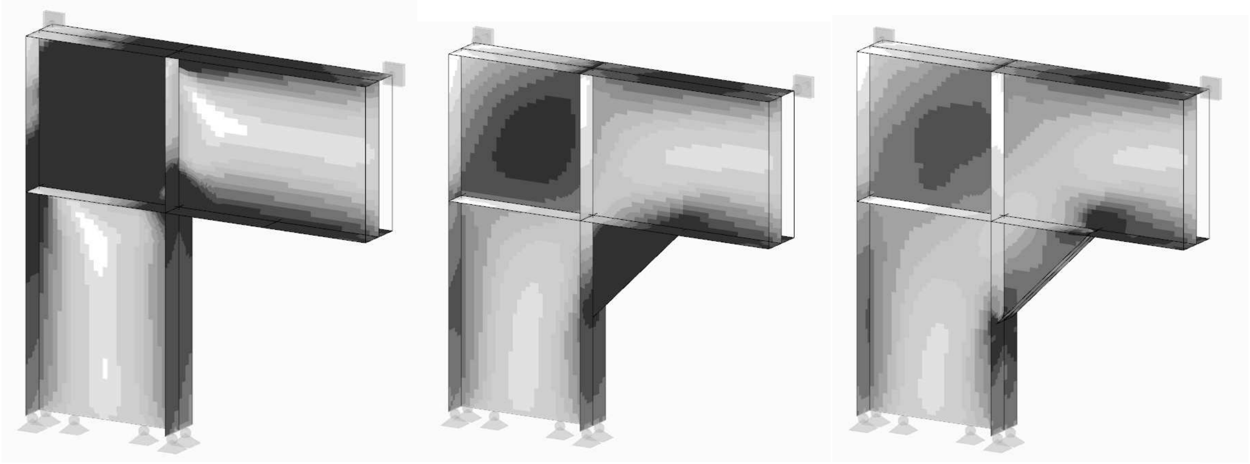
KEYWORDS: triangular stiffener, gusset plate, haunch, reduced stress method

ABSTRACT

Stiffeners in connections are triangular or rectangular plates with different types of support (free edge, partially stiffened, clamped). Triangular stiffeners are used on the compression side of beam-to-column connections to increase the design resistance of the beam flange and web in compression. This paper is focused on the effect of the stiffener on connection resistance and stiffness and on the resistance of the stiffener according to boundary conditions.

CONCLUSION

To investigate the effect of a stiffener on the resistance are designed three beam-to-column connections. FEM simulation is done in RFEM [1], using shell elements and linear-plastic material model. In *Fig. 1* is shown von-Mises stress distribution for the three types of connection for the same loading combination, which is ultimate for the unstiffened connection. Adding a stiffener causes that plastic stresses that occurred in beam flange and shear panel are redistributed, specifically to gusset plate in *Fig. 1b)* and to haunch flange and beam flange in *Fig. 1c)*. Although the criteria in EN1993-1-8 [2], for gusset plate thickness have been fulfilled the plasticization in gusset is significant. Results obtained from the simulation have proved, that stiffeners can significantly increase the resistance and stiffness of the connection.



a) b) c)

Fig. 1. Von-Mises stress distribution for the joint a) without stiffener; b) with gusset; c) with haunch

The proposed design method for triangular stiffeners is the reduced stress method provided in EN 1993-1-5 [3]. The verification given in *Eq. (1)* is based on the von-Mises yield criterion and sums up the load effects of normal and shear stresses.

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χ_w is the reduction factor for shear stresses,
f_y is yield strength,
γ_{M1} is partial safety factor.

Reduction factors depend on the buckling factor α_{cr}. Two models are created in MIDAS [4] to determine the buckling factor α_{cr} using linear buckling analysis. The boundary conditions are chosen CCF (clamped, clamped, free) and CCC (clamped). The normal and shear stress values are taken from RFEM results.

Buckling shapes are shown in *Fig. 2* and the obtained elastic buckling factors α_{cr} are summarized in *Table 1.*

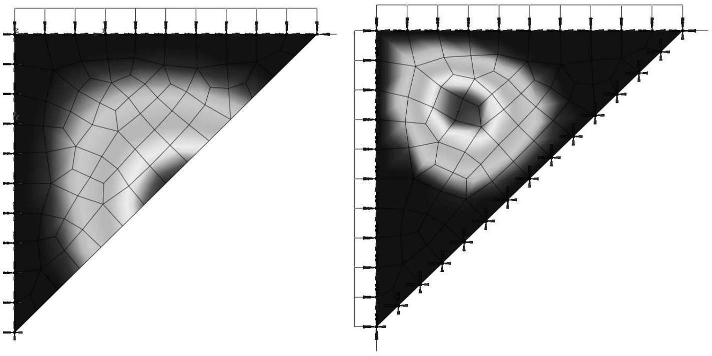

Fig. 2. Buckling shape in first mode for CCF and CCC stiffener

Last column in *Table 1* shows the stiffener plate verification calculated according to the proposed design procedure given in *Eq. (1).* It can be seen that the gusset plate (CCF) is close to failure, although it is designed according to recommendations in the standard EN 1993-1-8. The proposed design method gives very good results, may be useful for resistance verification of triangular slender plates and will be validated on the experiments of triangular stiffeners with different types of support (free, partially stiffened and clamped edge).

Table 1. Loading, buckling factor and verification for CCF and CCC stiffener

	σ_x	σ_z	τ	α_{cr}	verification
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