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TEST OF ECCENTRICALLY CONNECTED GUSSET PLATES IN COMPRESSION

Bartůšek P.[1], Jandera M.[2], Cábová K.[3], Feber N. [4]

Abstract: *An Experimental study of twelve bolted single-brace eccentric gusset plate connections in compression was carried out. Ten experiments were made of steel S355 and two experiments made of steel S690. The specimens varied also in their geometry, namely the geometry of the plate, namely the connection plate length, tapering, thickness, weld on one or two sides, and the slenderness of the connected member itself. The results were compared with the predictions of existing analytical models. The observed resistances demonstrate the influence of the plate slenderness on a compressive resistance of the connection. The influence of basic parameters of connection and the accuracy of existing design procedures is shown.*

Keywords: Gusset plate connection, Compressive resistance, Experiment, Numerical model, Buckling

1. Introduction

Gusset plates are key structural elements that connect multiple members using bolted, riveted or welded joints. Since their introduction in the 19th century, they have played a crucial role in structural engineering. Despite advancements in sensor technology, material engineering, and computational methods since the late 1980s, the behavior of gusset plates, particularly their connections, remains and complex issue requiring further research.

Under axial loading, gusset plates experience planar stresses with localized stress concentrations near connections. In compression, stability issues arise, including local buckling and local buckling, complicating the design of these elements. In addition to evaluating the plate stability, it is necessary to consider the load-bearing capacity of bolts and welds, as well as the behavior of the connected member, which may influence the plate through its own buckling. Under tensile loading, assessing the weakening of the cross-section and the potential for bolt group tear-out is critical.

This article focuses on eccentrically loaded gusset plates in compression, where bending moments occur due to the eccentricity of the member, including both first- and second-order effects. Twelve experiments were conducted on specimens with various gusset plate geometries—ten using standard steel and two with high-strength steel. The connections were assembled with four bolts arranged in two rows. The results provide valuable insights into the behavior of gusset plates under eccentric compressive loading.

2. Existing analytical methods

The Whitmore Method (Whitmore, 1952) from 1952 is based on the assumption that stress in the gusset plate is transmitted through a plane stress state. This transmission occurs at an angle of 30° from the center of each row of bolts or rivets. Based on this principle, the stress transfer is limited to the so-called effective width, which encompasses the portion of the plate most heavily loaded by the forces transmitted through

[1] Ing. Pavel Bartůšek: Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 2077/7, 16629 Praha 6, CZ, pavel.bartusek@fsv.cvut.cz

[2] Prof. Ing. Michal Jandera, Ph.D.: Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 2077/7, 16629 Praha 6, CZ, Michal.Jandera@fsv.cvut.cz

[3] Doc. Ing. Kamila Cábová, PhD.: Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 2077/7, 16629 Praha 6, CZ, kamila.cabova@fsv.cvut.cz

[4] Ing. Nina Feber: Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 2077/7, 16629 Praha 6, CZ, nina.feber@fsv.cvut.cz

the gusset plate. The effective width thus represents the actual portion of the plate actively involved in load transfer. The remaining part of the plate is considered either unloaded or minimally loaded.

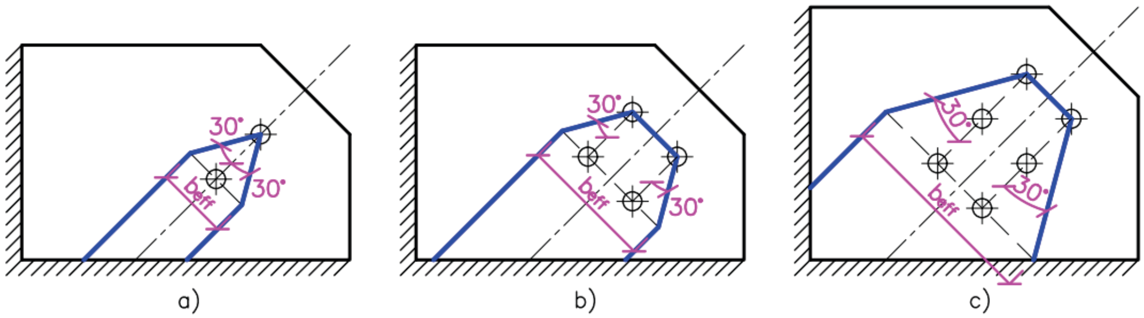

Fig. 1: Effective width according to Whitmore method

As shown in Figure 1, this effective cross-section is obtained by drawing 30-degree lines from the first row of bolts, extending to intersect with the second line passing through the last row of rivets.

Thornton (1984) proposed an update to Whitmore's method in 1984 to account for the effect of buckling in the corner gusset plate. Today, this update is known as Thornton's method. Based on Whitmore's width, it defines three nominal lengths of the gusset plate: L_1, L_2 and L_3, which are illustrated in Figure 2.

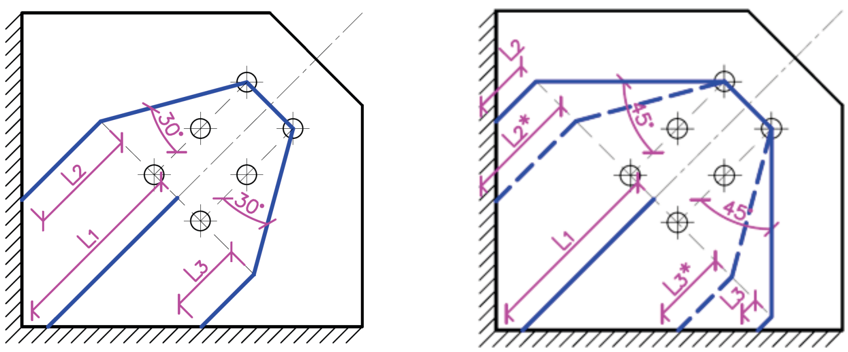

Fig. 2: Nominal lengths, Left: Thornton method, Right: Modified Thornton method

Depending on the specific configuration of the joint, either one of these lengths or their average value are used in the calculation, which is calculated as:

$$L_{avg} = \frac{L_1 + L_2 + L_3}{2} \tag{1}$$

The assignment of individual lengths was modified by Dowswell (2006) in his study. The calculation of the relative slenderness is performed:

$$\bar{\lambda} = \frac{\beta_{cr} \cdot L_O}{\pi \cdot i} \cdot \sqrt{\frac{f_y}{E}} \tag{2}$$

Where, β_{cr} is critical length factor and L_0 is nominal length by Dowswell (2006).

In 2002, M.C.H. Yam and J.J.R. Cheng conducted an analytical study (Yam and Cheng, 2002) focused on the behavior and strength of steel gusset plates under compression. In this research, they concluded that the distribution angle from the original Thornton method could be increased from 30° to 45°. This can be seen in Figure 2. This adjustment is feasible due to the plastic deformation of the gusset plate. This modification results in an increase in the effective width and a reduction in the nominal lengths L_2 and L_3. The most significant impact of this change is observed in connections with a single row of bolts.

In 2009, Khoo, Perera, and Albermani (2010) (KPA method) introduced a completely new method for calculation of gusset plates buckling capacity, which fundamentally differs from all previous approaches. Unlike traditional methods that rely on stress distribution angles and effective width, this new method is based on a collapse mechanism, in which two plastic hinges form within the gusset plate. This mechanism is evident from Figure 3.

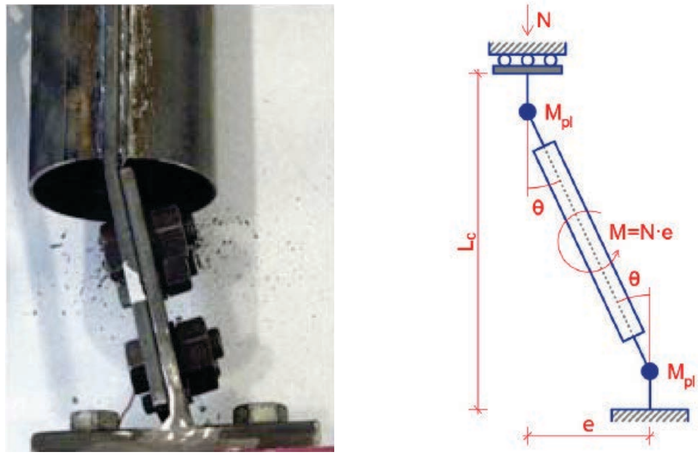

Fig. 3: Interactive failure of a gusset and slice plate, Left: Detail of the gusset plate after the experiment (Khoo et al., 2010). Right: Proposed collapse mechanism (redrawn and modified from (Khoo et al., 2010))

The new calculation procedure utilizes the principle of virtual work, with a key step being the determination of the normal force that induces the formation of the kinematic mechanism—i.e., the two plastic hinges. This force is then compared with the critical buckling force, considering that part of the capacity of the plastic hinges has already been exhausted, which affects the required force for the kinematic mechanism to develop. This model represents a significant advancement in the design of gusset plates; however, it still does not account for:

- double stiffness at overlap regions
- actual rotational stiffness at the connection point of the compressed member
- effect of second-order bending moment

This model will be extended in subsequent research.

3. Proposed experiments

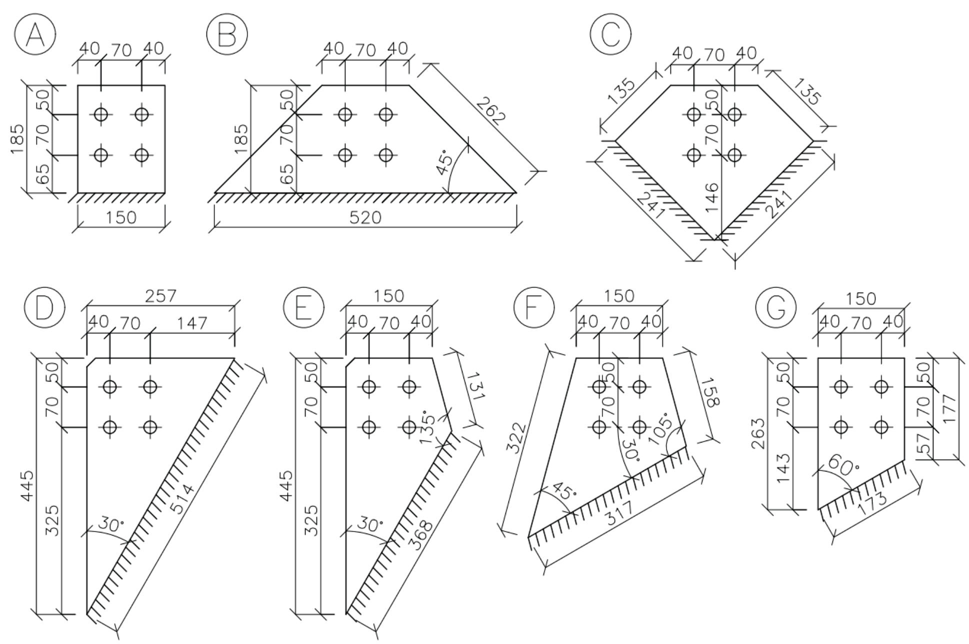

Fig. 4: Plate geometries of the specimens

Behavior of connections under compression has been investigated on twelve full-size experimental specimens, representing bracing member connected on both sides by cleat and gusset plates. Seven types of specimens were prepared. Geometry is shown in Figure 4. During the loading process, measurements were also conducted using the DIC method, and out-of-plane displacements were measured using sensors. The measurements of these methods will be evaluated later.

Using the analytical models described in the previous section, the predicted ultimate load was calculated for all twelve specimens. For the Thornton method, βcr and L_0 were considered according to Downswell's recommendations (Dowswell, 2006). For the KPA method, the buckling length factor was set as $\beta cr = 1.20$ according to (Khoo et al., 2010), and the nominal length was taken as the connection length $L_0 = Lc$. All calculations are preliminary and do not take actual material properties into account. Table 1 summarizes and compares the obtained results.

Tab. 1: Comparison of measured and predicted ultimate loads of the specimens

Specimen	Design			Test	Whitmore		Thornton		KPA	
	Plate	Tube	Shape	$N_{u,W}$	$N_{u,W}$	ρ	$N_{u,T}$	ρ	$N_{u,KPA}$	ρ
	[mm]	[-]	[-]	[kN]	[kN]	[-]	[kN]	[-]	[kN]	[-]
S355.1	8	TR 102x6,3	A	120,6	426,0	3,53	414,3	3,44	97,8	0,81
S355.2	8	TR 102x6,3	B	187,3	428,8	2,29	417,0	2,23	119,1	0,64
S355.3	6	TR 102x6,3	B	105,1	321,6	3,06	306,1	2,91	57,4	0,55
S355.4	8	TR 76x5	B	186,2	428,8	2,30	417,0	2,24	119,1	0,64
S355.5	8	TR 102x6,3	D	247,2	427,4	1,73	328,4	1,33	49,8	0,20
S355.6	8	TR 102x6,3	E	147,1	427,4	2,91	328,4	2,23	47,9	0,33
S355.7	8	TR 102x6,3	F	129,2	428,8	3,32	366,0	2,83	89,3	0,69
S355.8	8	TR 102x6,3	G	114,5	426,0	3,72	396,1	3,46	77,8	0,68
S355.9	8	TR 102x6,3	C	232,2	428,8	1,85	415,7	1,79	58,2	0,25
S355.10	10	TR 102x6,3	C	358,7	536,0	1,49	525,5	1,47	106,3	0,30
HSS.1	8	TR 102x6,3	A	181,6	828,0	4,56	784,4	4,32	122,8	0,68
HSS.2	8	TR 102x6,3	B	242,9	833,5	3,43	789,6	3,25	138,0	0,57

4. Conclusions

From Tab. 1, it is clearly evident that the KPA method best captures the behavior of the gusset plates. In all cases, it provides values lower than the actual load capacity, making it a safe approach. However, this method only provides results with sufficient accuracy for practical application in certain cases and is generally overconservative. For this reason, further evaluation of the tested results will be conducted, along with a numerical study. It is therefore necessary to revise and modify the calculation method for specific types of connections.

Acknowledgement

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