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RESISTANCE OF TENSION BRACE IN PLUG & PLAY N SHAPE RHS TRUSS CONNECTION

The paper presents concept of RHS truss with N-shape connections in the plug & play form, made in non-welded technology. The procedure of calculating the resistance of tension brace truss connection was presented, using the component method. The results of obtained resistance of joint was compared with the tension bracing RHS strut resistance and the usefulness of the concept considered was determined.

Keywords: steel truss N shape RHS joints, non-welded plug &play connections

1. Introduction

The subject of the paper is a new plug & play connection in application to a steel truss made of rectangular hollow section (RHS). The resistance of such a joint was the subject of previous works [2 and 3]. In this paper, a study was carried out on the resistance modified in relation to the tension brace shown in [2].

The use of modern 3D laser cutting technology enables easy and precise cutting in steel elements, here closed RHS profiles, of openings of any and often very complex shapes.

It was an inspiration to develop plug & play non-welded joints. Tests of this type of joints were previously presented in [2 and 3], where forces were transferred only by bearing and shearing stresses in the elements in contact with each other, the key (bracing elements) and the lock (holes in the truss chord).
For this purpose, a "lock" was made in the truss chord, in which a "key" strut was inserted. A tension brace made of double plate bar is attached to the chord. It covering the chord on both sides and it is fixed to the chord with a bolt. This solution led to a quick ovalization of the hole in the RHS profile of the chord. To remedy this, a steel square bar was placed under the chord, see Fig. 1 [5].

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This bar has significantly reduced the ovalization of the hole in the side walls of the chord, because the load is also transferred by the stress to the lower RHS chord face plate with a much larger contact area than previously.

The combination of this type eliminates the need for welds in the joint. The publications [3 and 4] present the results of experimental research, as well as the theoretical estimation of the resistance capacity of T-shape truss joints, made of RHS profiles, in non-welded technology in the plug & play form [3]. The theoretical resistance, calculated by means of a developed yield lines model with experimental studies, was also compared [4].

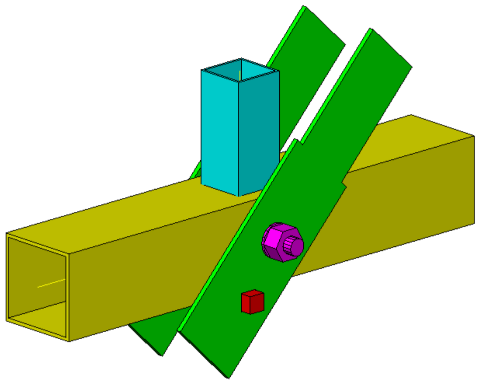

Fig. 1. Plug & play N-shape connection, 3D model [5]

In this paper, a modified concept of connecting the tension brace to the chord in the N-shape connection was considered. The tension brace is made not from flat bars as before [5], but from the RHS profile with special "teeth" and meshes against the chord walls. A "lock" is made in the truss chord, which allows inserting a "key" or a tension brace into it. The vertical strut is also inserted in the "lock" made in the chord, but after the tension brace is mounted, which causes it to jam in the connection. The combination of this type eliminates the need to use welds to connect the bracing with the chord, In concept No. I, Fig. 2, the resistance of the lock was small. So, this was improved by developing concept no. II, where the surface of the "teeth" was changed, which allowed the increase of the resistance of the connection. The scheme of such a solution is shown in Fig.3.

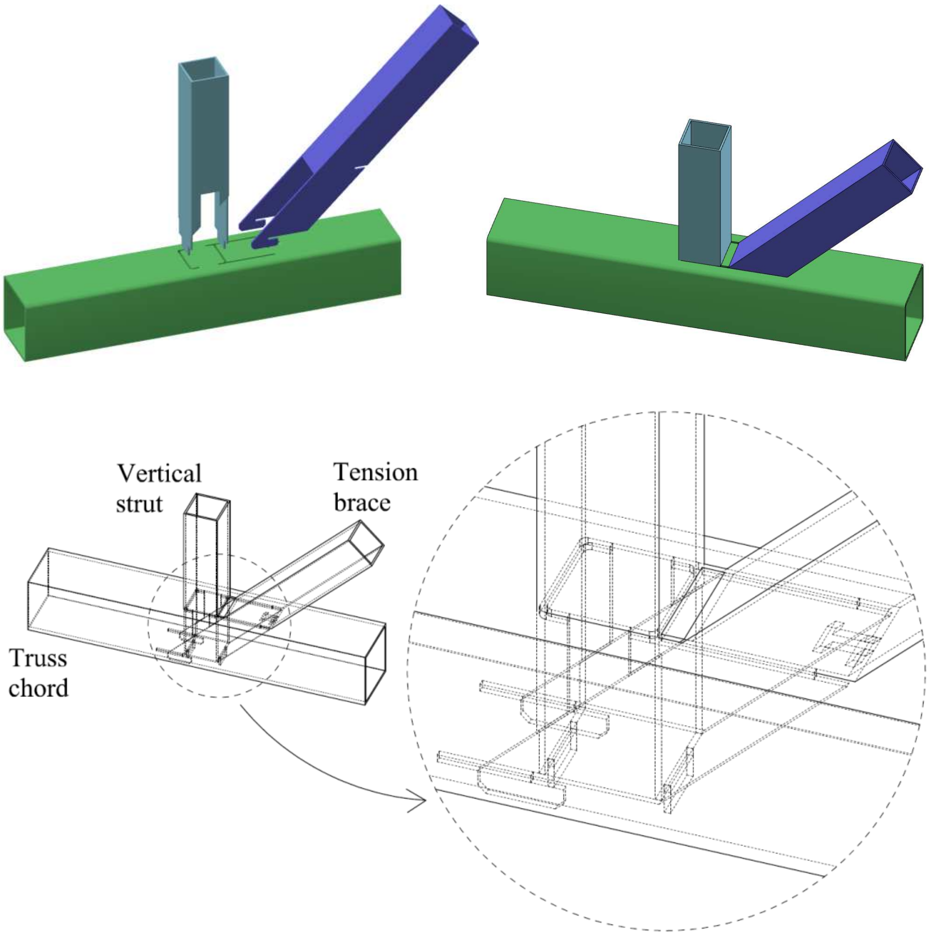

Fig. 2. Concept no. I –plug & play N-shape connection, 3D model

Structures made in non-welded technology can be used successfully in construction, for example for production facilities, warehouses, etc. Easy transport of this type of construction in single elements allows for the construction of permanent or temporary halls. Due to the lack of permanent connections between the elements, such structure can be dismantled and reassembled elsewhere.

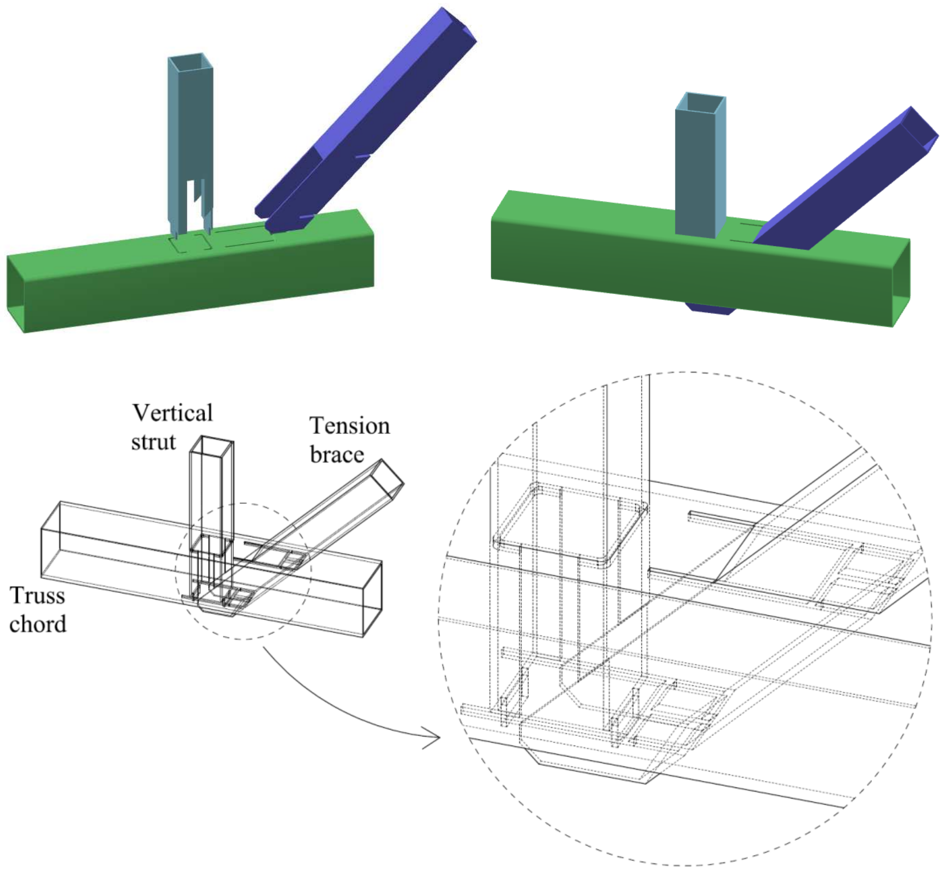

Fig. 3. Concept no II – plug & play N-shape connection, 3D model

2. Theoretical estimation of the resistance of tension brace

The resistance of the tension brace connection with the chord was calculated using the component method. The theoretical model of failure was presented (model I - upper connection, model II - lower connection). The tension brace loaded with axial force N, distributed over the horizontal N_x and vertical N_z components, the load diagram and the theoretical plane of failure was shown in Figure 4. Also, the 3D model of the tested tension brace made of RHS where the contact of individual planes surfaces is indicated, is shown in this Fig. It is assumed that the element is deformation resistant (compact).

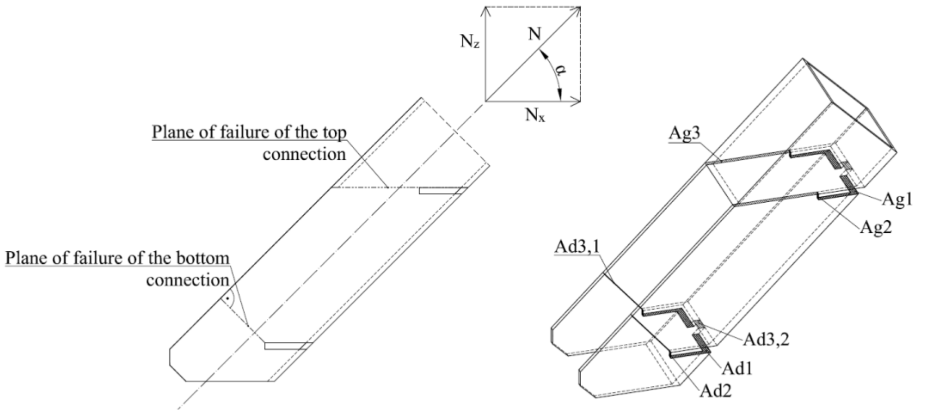

Fig. 4. Tension brace side view and 3D view, where: A_{g1}, A_{d1} – stress area perpendicular to N_z force, A_{g2}, A_{d2} – stress area perpendicular to N_x force, A_{g3} – area of failure of the top connection, $A_{d3,1}$ – area of failure of the bottom connection (subjected to tension), $A_{d3,2}$ – area of failure of the bottom connection (subjected to shear and tension)

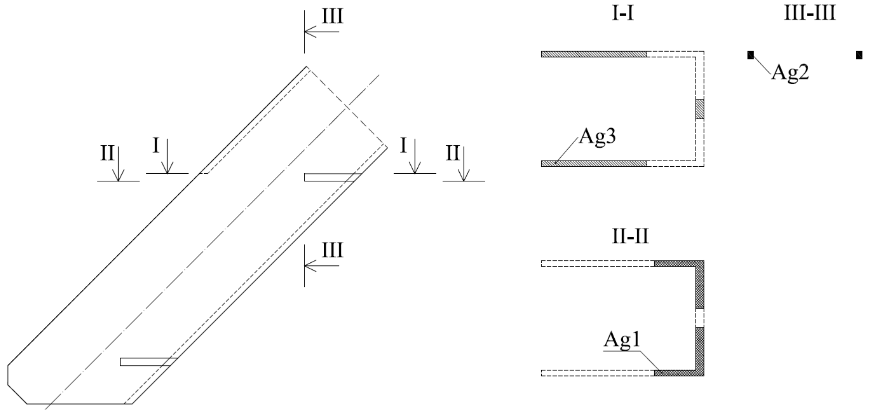

Fig. 5. Tension brace view – top connection

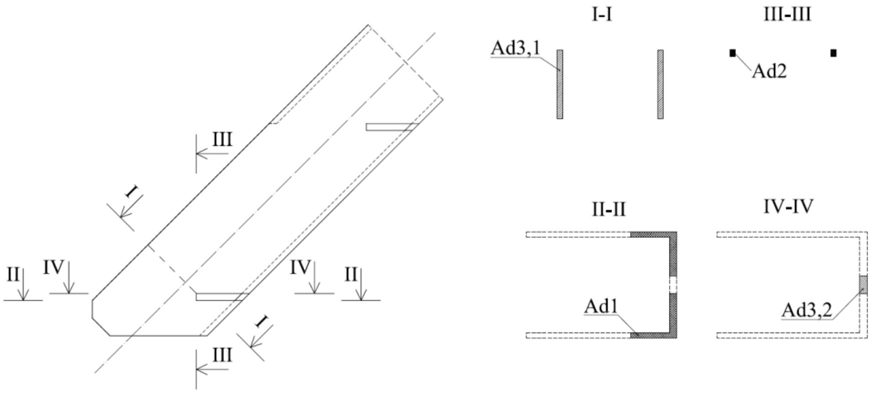

Fig. 6. Tension brace view – bottom connection

2.1. Model I – tension brace top connection

2.1.1. Resistance of connection („teeth") to Hertz contact stress

$$f_{dbH} = 3.6 \times f_d \tag{1}$$

where: f_{dbH} – resistance of connection (Hertz contact stress),
f_d – design resistance of steel according to PN-B-90-03200.

So, the force on the stress surface is estimated as

$$N_{\mathrm{z(x),g}} = \frac{f_{dbH} \times A_{g1}(A_{g2})}{\gamma} \tag{2}$$

where: A_{g1} – stress area perpendicular to the direction of N_z force,
A_{g2} –stress area perpendicular to the direction of N_x force,
γ – safety factor.

The resistance of the connection is calculated as bellow

$$\frac{N_z(N_x)}{N_{z(x),g}} \le 1.0 \tag{3}$$

2.1.2. Block tearing

Resistance of the connection subjected to shear and tension is equal

$$\frac{N_x}{\frac{1}{\sqrt{3}} \times \frac{f_y \times A_{g3}}{\gamma}} + \frac{N_z}{\frac{f_u \times A_{g3}}{\gamma}} \le 1.0 \rightarrow N \le \frac{1}{\frac{\cos\alpha}{\frac{1}{\sqrt{3}} \times \frac{f_y \times A_{g3}}{\gamma}} + \frac{\sin\alpha}{\frac{f_u \times A_{g3}}{\gamma}}} \tag{4}$$

where: f_y – yield strength of steel,
f_u – tensile strength of steel,
γ – safety factor.

2.2. Model II – tension brace bottom connection

2.2.1. Resistance of connection („teeth") to Hertz contact stress

Proceedings is analogous to the procedure in pt. 2.1.1.

2.2.2. Block tearing

The condition of resistance of the connection subjected to shear and tension is analogous to the procedure in pt. 2.1.2.

Tensile strength of the connection is calculated as bellow

$$N_{u,Rd} = \frac{A_{d3,1} \times f_u}{\gamma} \tag{5}$$

where: $A_{d3,1}$ – area of the connection subjected to tension,
f_u – tensile strength of steel,
γ – safety factor.

Condition for the resistance of the connection subject to tension

$$\frac{N}{N_{u,Rd}} \leq 1.0 \rightarrow N \leq N_{u,Rd} \tag{6}$$

So, the total resistance of the bottom connection to block tearing

$$N \leq \frac{1}{\dfrac{\cos\alpha}{\dfrac{1}{\sqrt{3}} \times \dfrac{f_y \times A_{g3}}{\gamma}} + \dfrac{\sin\alpha}{\dfrac{f_u \times A_{g3}}{\gamma}}} + \frac{A_{d3,1} \times f_u}{\gamma} \tag{7}$$

where: f_y – yield strength of steel,
f_u – tensile strength of steel,
γ – safety factor,
α – the inclination angle of the tension brace to the horizontal surface

2.3. Resistance of the connection

The connection resistance is equal to the sum of the resistance on the top and bottom connection, both on the x and z direction

$$N_{\mathrm{z(x),gd}} = N_{\mathrm{z(x),g}} + N_{\mathrm{z(x),d}} \tag{8}$$

where: $N_{z(x),g}$ – resistance of top connection,
$N_{z(x),d}$ – resistance of bottom connection.

2.4. Tension brace resistance [1]

$$N_{pl.Rd} = \frac{A \times f_y}{\gamma_{M0}} \tag{9}$$

where: A – tension brace cross-section area,
γ_{M0} – safety factor.

3. Resistance calculations

The resistance of connection between the tension brace and the chord was compared with the resistance of the bracing profile RHS in order to assess the efficiency of such connection. The cross-section of the profiles and their properties is presented below. Due to the lack of experimental research and reliable other data, a safety factor was assumed ($\gamma = 1.0$).

Table 1. Data of the considered tension brace

Concept	**Geometric dimensions [mm]**		**Yield strength [MPa]**	**Design resistance of steel [MPa]**	**Tensile strength [kN]**	**α [°]**
	b×h	t				
II	60×60	3	355	305	235	45

Results of the theoretical resistance of the components and the tension brace strut are shown in Table 2.

Table 2. Results of resistance of particular components of the tension brace

Resistance condition	**Symbol**	**Resistance [kN]**
Block tearing connection	A	198.4
Stress on x direction	B	61.3
Stress on z direction	C	849
Resistance of the tension brace strut	D	235

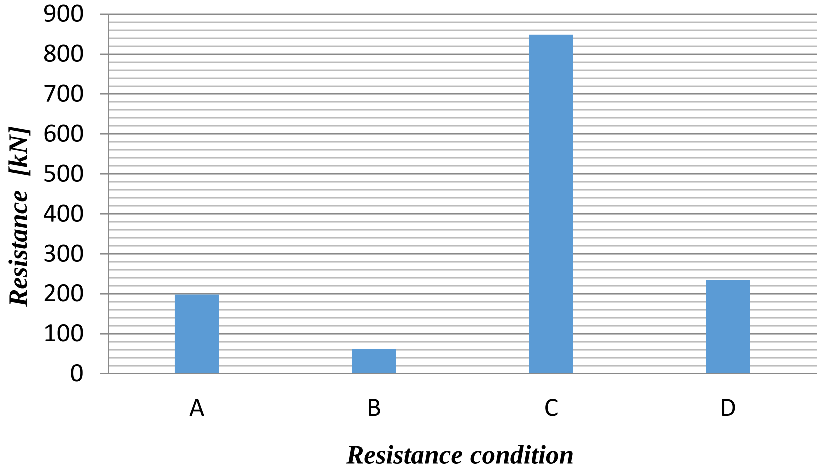

Fig. 7. Diagram of the resistance of the individual components of the tension brace connection

The connection is characterized by a high resistance to stress in the z-direction (C) equal to 849 kN, due to the large contact area to the chord. However, the resistance in the x-direction (B) is only 61.3 kN, due to the small wall thickness of RHS member, what decides about too small contact area. The resistance for block tearing (A) is satisfactory and it is equal to 198.4 kN (sum bottom and top resistance of connection).

4. Summary

Follow the performed above calculations, it can be concluded that:

- it is possible to eliminate the welding of the bracing connections with the chord,
- resistance of the tension brace connection with the chord is highly variable depending on the resistance of the individual components,
- the connection under consideration is characterized by a high resistance to stress in the z-direction, due to the large contact area to the chord. However, the resistance in the x-direction is only 26% of the resistance of the tension brace. Another weak component was the top connection with the chord, where the resistance for block tearing is only 32% of the resistance of the tension brace.

Generally, after carrying out the above analyzes, the authors concluded that presented here connection between the tension brace and the chord does not offer great possibilities to obtain a significant resistance in the x-direction (B), comparable to the resistance of the tension brace. For that much bigger wall thickness of RHS members is needed, which is not necessary for the resistance of chord and branch members.

So, the summarized conclusions from the advantages, and especially the disadvantages of the presented here N-shape connection, leads to a new solution of such joints, characterized by a much higher resistance of the contact stress area. The results of the research of these new innovative connections will be presented in the subsequent works of the authors.

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