Research Article

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Resistance of plug & play N type RHS truss connections

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Abstract: The article presents concept of II generation N type RHS plug & play truss connection made in non-welded technology. Three connections of the representative truss are analyzed. Resistance calculations of these truss joints, using the component method, are shown. Test results and the theoretical resistance of these connections are compared.

Keywords: RHS steel truss, plug & play connections, N type non-welded joints, laser and AM manufacturing, component method, theoretical static resistance

1 Introduction

Modern techniques introduced by AM (Advanced Manufacturing), such as: cutting metals with laser 3D, CNC laser cutter, 3D printers, and automation of production processes lead to the need to reconsider again the current methods and techniques of connecting elements in steel structures. In this paper, a new concept of plug & play, non-welded N type joint for the rectangular hollow section (RHS) steel trusses is presented. A “lock” was made by laser cut in the truss RHS chord appropriate slots, in which it is inserted a “key”, which is branch compressed RHS member with special slots and ends prepared by laser cutting. Tension bracing was fixed to chord member by anchor blocks manufactured by AM technology and they have been twisted on their treaded ends by nuts. Assembly of these elements eliminates the need to use welds to connect the bracing members with the chord what is the typical technology used so far [1]. Loads from bracings to the chord are transferred only by squash and shear. The component method which is frequently used for the resistance

estimation of the open section joints [1] has been recently used for the RHS truss T joints welded [2] and no welded developed as plug & play [3]. This method is also used for resistance estimation of studied herein plug & play N type RHS joints. However, it is necessary to include some different components, compare to that which are introduced before [3].

Figure 1: Laser cutting of chord lock (the top). Elements of II generation N type RHS truss joint (bottom)

2 Concept of II generation joints

New concept of non-welded N type RHS II generation joint is different of non-welded N RHS I generation one [4]. The tension bracing is not made with two flat bars as before, but with single round rod threaded at the ends which allows to be screwed. Sometimes when the compressive force could be present in a usually tensile bracing then it could be made with RHS, however in its ends should be welded threaded round bars to be screwed as in case of full length round rods. The anchor block consists of two

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parts. The first have special “teeth” fixed this part to truss chord member and the second part through the cylindrical surface enables transfer the load stress from different inclination angle and simultaneously it is a support for washer and nut. The branch with RHS as a “key” is inserted in the slots of “socket” made in the chord member and also it has its own slots in which are fixed “teeth’s” of top and bottom anchor blocks. This limits the deflections of chord flanges. The “teeth” in upper anchor block put into the branch allows the better merging the branch to chord member. Sections of the joint are shown in Figure 2.

Figure 2: Section views of N type RHS joint with its details

3 Component approach for resistance calculation

The failure phenomena of studied joint and components N_i using in component method to describe its resistance are as follows:

1. Chord inelastic failure of the face and bottom flange caused by compressed branch– N_1 - under research
2. Chord inelastic failure of bottom flange caused by anchor block – N_2 - under research
3. Chord webs failure under compression – N_3

4. Chord socket and “teeth” of anchor block punching shear failure – located on the face flange and loaded in the place of contact with the branch member – N_4
5. Chord punching shear failure of the bottom flange – loaded in the place of contact with the anchor block – N_5
6. Chord socket bearing stress failure – loaded in the place of contact with the “teeth” of anchor block – N_6
7. Branch member failure under compression – inside the chord between the face and bottom flange of chord – N_7
8. “Teeth” anchor block punching shear failure – N_8
9. Tension bracing failure – N_9

Figure 3: Load scheme of the joint (branch and bracing)

The resistance of each component developed so far are presented as bellow.

Figure 4: View of the laser made holes in upper flange of chord

Figure 7: Static scheme of the RHS steel truss

Table 1: Specimen geometric dimensions and mechanical properties

Specimen	Geometric dimensions					Yield stress				Parameters		
	RHS chord $b_0 \times h_0$ [mm]	RHS branch $b_n \times h_n$ [mm]	Chord wall thick. t_0 [mm]	Branch wall thick. t_n [mm]	Brace d [mm]	Chord f_{y0} [MPa]	Branch f_{yn} [MPa]	Tension bracing f_{yb} [MPa]	Anchor block f_{yp} [MPa]	β $=b_n/b_0$	η $=h_n/b_0$	λ_0 $=b_0/t_0$
WN1	100x100	40x40	5.0	4.0	16	338	360	415	229	0.40	0.40	20.0
WN2	100x100	60x60	5.0	3.0	25	338	400	407	229	0.60	0.60	20.0
WN3	100x100	80x80	5.0	3.0	30	338	335	381	229	0.80	0.80	20.0
WN4	100x100	40x40	3.0	4.0	16	281	470	415	229	0.40	0.40	33.3
WN5	100x100	40x40	4.0	4.0	16	305	470	415	229	0.40	0.40	25.0
WN6	100x100	60x60	3.0	3.0	25	281	353	407	229	0.60	0.60	33.3
WN7	100x100	60x60	4.0	3.0	25	305	353	407	229	0.60	0.60	25.0
WN8	100x100	80x80	3.0	3.0	30	281	334	381	229	0.80	0.80	33.3
WN9	100x100	80x80	4.0	3.0	30	305	334	381	229	0.80	0.80	25.0

resistance of the top and bottom anchor block “teeth”. The resistance of this component which considering the slope angle of tension brace is equal to:

$$V_{pl,Rd} = A_v(f_{yp}/\sqrt{3})/\cos \alpha \quad (6)$$

where:

A_v - shear area of “teeth” in bottom and upper anchor block.

3.6 Tension bracing under tension – component N9

When the parameter β is small, and chord member has high rigidity e.g. thick flanges, this could involve failure of tension bracing. The resistance of his component is equal to:

$$N_{t,Rd} = A_s \cdot f_{yb} \quad (7)$$

where:

A_s – sectional area of tension bracing

4 Experimental tests

In Table 1 the geometry of the nine tested specimens and their mechanical properties are given. From 24 meter double-grate RHS truss, Figure 7 has been selected 3 different representative connections. Because truss has have constant spacing of nodes equal to 2 m tension diagonals in tested joints have a different angles of inclination to chord member. The vertical branch was loaded and unloaded several times by a 200 kN hydraulic jack and in the same time the tension brace by a 500 kN one. The chord was loaded by constant longitudinal force equal to 200 kN for stabilization of it during the test procedure. LVDT gauges and ARAMIS system were used to measure the dis-

Table 2: Theoretical resistances of joints

Specimen	Theoretical component resistance [kN]							Minimum theoretical resistance [kN]	Mode of failure
	N1+N2	N3	N4	N6	N7	N8	N9		
WN1	102,6	-	142,6	318,9	86,0	244,8	65,9	65,9	N9
WN2	148,3	-	182,6	374,4	125,6	371,1	137,2	137,2	N9
WN3	248,5	226,0	287,8	511,6	145,5	626,1	205,4	145,5	N7
WN4	30,7	-	74,1	191,3	112,3	244,8	65,9	30,7	N1
WN5	59,2	-	104,6	255,1	112,3	244,8	65,9	65,9	N9
WN6	44,4	-	120,5	224,6	110,8	371,1	137,2	44,4	N1+N2
WN7	85,7	-	166,5	299,5	110,8	371,1	137,2	85,7	N1+N2
WN8	85,7	62,0	162,1	307,0	145,0	626,1	205,4	62,0	N3
WN9	164,3	125,6	218,0	409,3	145,0	626,1	205,4	125,6	N3

Figure 8: Load-deflection diagram for joint WN4 ($\beta = 0,4$) **Figure 9:** Load-deflection diagram for joint WN5 ($\beta = 0,4$)

Figure 10: Load-deflection diagram for joint WN6 ($\beta = 0,6$)

Figure 11: Load-deflection diagram for joint WN7 ($\beta = 0,6$)

placements of samples. The load and displacements of vertical compressed branch and tension

bracing were continually registered during the loading and unloading process until failure. In Table 2 the theoretical resistances of the joint are given. These predictions of the joint resistances have been estimated from all components and its minimum value is finally provided. The components N1+N2, N3, N4, N7, described failure phenomena causes by vertical force in compressed brace while

components N6, N8 and N9 from force in tension bracing. In Figure 8 to Figure 13 are presented test results and also the theoretical estimations obtained from the decisive components of the joint resistance. Components N1+N2 are adopted from estimation done for T RHS joints [2].

Figure 12: Load-deflection diagram for joint WN8 ($\beta = 0,8$)

Figure 13: Load-deflection diagram for joint WN9 ($\beta = 0,8$)

5 Conclusions

1. Main advantage of joints under research is that they bring the top and bottom flange of truss chord into load transfer, while commonly used welded joints only the top flange
2. However main drawback of such joints is weakness of chord member due to its slots and holes which could decrease resistance of this member in joint section
3. Tests results confirm that it is possible to eliminate the welding in connections between bracing and chord in studied herein N type RHS plug & play joints and reach resistance not less than welded ones.
4. The resistance of non-welded N RHS joint II generation is similar to face and bottom flange failure for non-welded T type RHS joint [2]. However N type joint of II generation has smaller deformations because of positive influence of the anchor blocks.

5. Specimens WN1-WN3, when chord is made with the compact section ($\lambda_0 = 20$) reached full resistance and displacements of their chord flanges are small.
6. The anchor blocks ensure the transfer of force from the tension bracing to the chord with limited deflections and better integrate whole joint.
7. The theoretical estimations show that the anchor blocks have high resistance, exceeding other components.

6 Practical applications and future prospects

1. Non-welded N type RHS II generation joint are easy to manufacturing automation.
2. However the real manufacturing tolerances of the RHS members could be a problem to make the slots and holes in proper places. More advanced preparation of such operations will be needed.
3. These joints may bring closer the truss steel structures with large spans and oversized dimensions for their delivery in elements. They could be easy to make and cheap in transport and could significantly reduce the overall costs.
4. It is suggested to apply hot dip galvanizing as the corrosion protection of structures with such joints.
5. Structures with such joints can be mounted as temporary because they are easy to assemble and disassemble

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