RESISTANCE OF NON-WELDED RHS CONNECTIONS

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Summary:
Aim of the study: These days creation a new type of connection such as non-welded joints can be useful. It allows save money and time. Idea of push-pull type joints in application to steel truss made with RHS is the base to this research.
Research methods: Experimental evidence of such joint behavior tested in natural scale is described. Geometry and material properties of the tested connections are given. Axial-deflection curves are presented. Yield line local push mechanism on front wall and as the alternative front and bottom wall chord section is used to the theoretical estimation of the failure load. Numerical model of “plug & play” type T and N joints for calculation and a prediction of joints resistance is proposed.
Results: Theoretical and experimental results of joints resistance are shown. Eleven T RHS laser made joints in natural scale were tested here up to failure. Typical joint failure was the inelastic deformation of the loaded top & bottom flange of chord..
Eight joints of N-type grid of a natural scale were tested. Two selected joints of the chord thickness 3.0 mm (WTLN5 and WTLN6) were selected. The numerical model mapped the load method used during experimental studies.
In both case(T RHS joints and N-type joints) computation model to a large extent reflects the real work of a joint, assuming reasonable time of numerical calculations.

Keywords: non-welded joints, RHS T joints, numerical model of “plug & play” type T and N joints

Introduction

Welding is extensively used in modern production of steel. Above-mentioned technique of merging steel elements is not complicated, but requires a highly qualified staff to make the whole process done accurately. Because of the variety of construction designs it is not possible to fully robotisethe automatic welding machines at the current stage of its development.

Due to the rising cost of steel structures welding, it is expected to search for new methods of connecting sections, which will involve a small labour input, as well as eliminate the need to pursue professional certification.

The new idea RHS made of joints uses the internal forces in the bars to make them merged (uses share and friction forces). This can be achieved by using a specific type of connections without welding employment.

Joints made of RHS selections review

Shaping RHS joints made of RHS sections significantly differs from other hot-rolled sections. A closed hollow intersection causes a number of handicaps, both at the design and manufacturing stages. Compared to traditional solutions (joints made of open profile - (such as H-shape, T-shape, L-shape, C-shape) closed hollow structure shave much lower stiffness due to their thinner walls (causing susceptibility of the designed joints). They have a lower carrying capacity for pressure and shear as well. Popularisation of welding technique let the pipes to be widely used in steel structures.

Welded connections aren't demountable. They occur in the following forms: joints without shear plate, with shear plate and with spacers. The most commonly used joints solution of T RHS truss joints are joints without shear plates (Bródka, Broniewicz 2001).

Forming of the joints, computation methods and models of damage of classic welded connections have been thoroughly discussed in the paper 'Hollow sections in structural applications' (Wardnier i in., 2010). The model proposed by the standard EN 1993-1-8 (Eurocode 3) is based on yield line theory. Carrying capacity calculation of RHS joints can also be done by applying other models. These models are often more accurate in describing the work of the joint, but because of the fact they aretime-consuming, they are not widely used (Szlendak 2007).

Brief history of RHS joints

The first calculation formulas (joints K and N) were published by W. Estwood and A.A. Wood in the late 60 and 70 (United Kingdom). Calculation formulas were later developed by J. Davies and T. W. Giddings.

In the 60's, to estimate the carrying capacity of the welded type T joint, R.G. Redwood and J. E. Jubb used a yield line model. This method, developed by Johansen (1962) was used in the construction of reinforced concrete to determine the bearing capacity of the plates.

In 1973, the research team was formed in the Netherlands, which took up the issue of carrying capacity of welded RHS joints. The leading role was played by prof. J. Wardnier.

In Canada, in the 80'sA. Packer and S. S. Haalem were engaged in the joints made of steel RHS topic.

In Poland, behavior of welded RHS joints was taken by a research team at COBPKM "Mostostal" under the guidance of prof. J.Bródka in the 80's. A. Czechowski, J. Życiński, J.K. Szlendak, J. Kordjak were the members of a team.

Classification of the links

Links in steel structures can be divided into several types:

<u>1) Depending on the type of connector</u>

a) Welded

b) Screw

<u>2) Manufacturing venue</u>

a) Workshop

b) Assembly plant

3) Type
a) fixed
b) demountable
4) Stiffness
a) Rigid
b) articulated
c) susceptible

The new type connection in the form of push-pull joint should be classified depending on the type of connector as the innovative joint with adopted screws . Nevertheless the screw parts should be considered secondary and the primary feature is the possibility to transfer the forces with the employment of pressure. The joint is fully demountable and susceptible. It can be made either in the workshop or on the construction site (during assembly).

Modern technologies of steel cutting

Using modern methods for cutting the steel components like the industrial laser, you canmake desired types and shapes of slots with high accuracy. Similar methods of steel processing were used only in the machinery industry.

Fig. 1. Laser cut of lock.

Laser cutting technology is used for the metal processing. Laser cutting processing can be used for all types of metals such as carbon steel, structural steel, stainless steel, nonferrous metal. Laser technology can achieve precise cut of 0.1 mm. Adequate process control of cutting and shaping the slots and the ends of the profiles are fully automated. Thereby it allows to avoid the need to prepare the templates used in older technologies. Machines are responsible for proper cutting of the parts. They collect cutting data (nc files) from the files included in the drawings .dwg in electronic form .dstv. Until recently a steel was cut only in one plane (2D). Along with a development of technology, lasers can cut profiles in 3D (cut in one plane, but they can freely rotate the workpiece, without human intervention). Technology mentioned above eliminates the considerable investment of human labour who don't have to merge the structure by means of welding anymore.

Concept of non-welded joint

Extended rods of truss are attached with a single bolt, and compressed parts will carry the load by means of local shear and pressure. For this purpose, the chord rods were suitably prepared (in the form of locking slots), and the ends of the truss branches (in the form of keys). Inserting the key (branch) in the lock (chord) creates a non-welded connection of plug & play / push-pull capable of transferring shear and compression (by pressure).

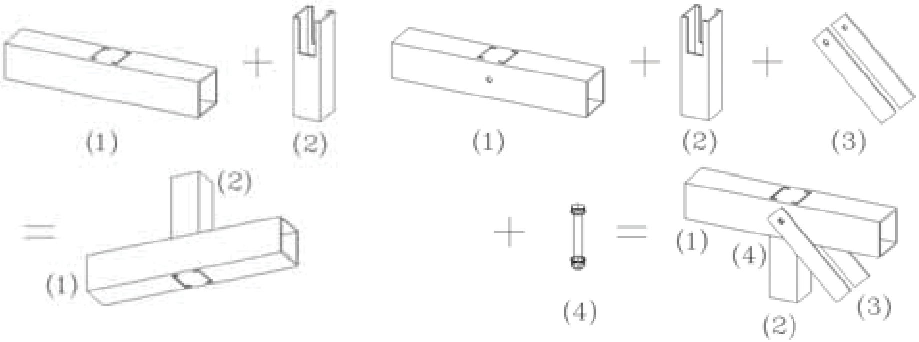

Fig. 2. The type T joint, and type N joint

Non-welded joint application

Structures made in technology that does not require welding can be successfully used in the construction industry e.g. for manufacturing facilities, warehouses, sheds, etc. This type of construction is easy to carry in separate parts and don't have to be fixed with the ground so that it can be built as temporary or permanent hall. There are demountable connections between the construction parts so it can be removed and re-building elsewhere.

Advantages and disadvantages of non-welded joint

Advantages of using the non-welded joint:
- Little experience required
- Possibility to assembly directly on the construction site
- Full demountability of the structure
- The possibility of typification of the parts
- Full automation in the production of the structure

Disadvantages of non-welded joint:
- Production of the construction requires sophisticated cutting machines
- High precision in manufacturing required
- Branch does not carry the tensile force

The T joints

The proposed non-welded joints in the form of a “plug & play” can only transfer a force through the pressure of the branch to the chord. This joint can be designed in the way the external loadis carried by the top chord. With the proper design of cut the bottom chord can also be employed. In this case, the clamping force is distributed on the top and bottom chord of the RHS.

The computation model

Based on the theory of yield line the model of this type of joint destruction was developed. In the paper (Oponowicz 2011) the issues of T joint using only the top chord were discussed. In the joint being discussed, both chords were used. Model I describe the joint plastic failure of the upper wall of chord, model II describes the plastic failure of the bottom wall of chord.

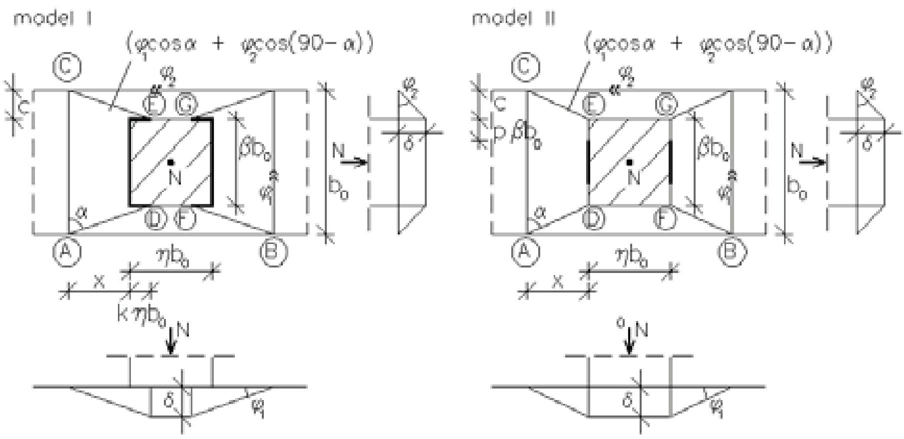

Fig. 3. One & double side yield line model of T THS joint plastic failure.

The energy of external force N:

$$Z = N \cdot \delta \tag{1}$$

Non-welded joints -upper wall of chord [only Model I]

From geometry of mechanism occurs:

$$AD = \sqrt{\left(x + k\eta b_0\right)^2 + c^2}\ ;\ c = \left(\frac{1-\beta}{2}\right)b_0\ ;\ \varphi_1 = \frac{\delta}{x + k\eta b_0}\ ;\ \varphi_2 = \frac{\delta}{c}$$

The energy dissipated in the yield lines is as follows, [3]:

$$D = \sum D_{ij} = \left[4\eta b_0 \cdot (1-2k)\cdot\frac{\delta}{c} + 8\cdot\left(x + k\eta b_0\right)\cdot\frac{\delta}{c} + 2\cdot\left(b_0 + 2c\right)\cdot\frac{\delta}{x + k\eta b_0}\right]\cdot m_{pl} \tag{2}$$

After assumption that a shape of the laser cut hole on the face of chord is constant the coefficient k = const. When and because (1) could be equal to (2) so

$$\frac{N}{m_{pl}} = 4\eta b_0 \cdot (1-2k) \cdot \frac{1}{c} + 8 \cdot z \cdot \frac{1}{c} + 2 \cdot (b_0 + 2c) \cdot \frac{1}{z} \tag{3}$$

For the minimum

$$\frac{\partial N}{\partial z} = 0 = 0 + 8 \cdot \frac{1}{c} - \frac{2}{z^2} \cdot (b_0 + 2c) \bigg| \cdot \frac{cz^2}{8} \tag{4}$$

$$z^2 = \frac{c(b_0 + 2c)}{4} \tag{5}$$

Because and after substituting value of c:

$$x + k\eta b_0 = \frac{b_0}{2}\sqrt{10\frac{3}{2}\beta + \frac{\beta^2}{2}} \Rightarrow x = \frac{b_0}{2}\sqrt{10\frac{3}{2}\beta + \frac{\beta^2}{2}} - k\eta b_0 \tag{6}$$

Finally, when values x, c and m_{pl} are given, formula (3) is given as:

$$N = f_0 \cdot t_0{}^2 \cdot \left[\frac{2 \cdot \eta \cdot (1-2k) + 2 \cdot \sqrt{1 - \frac{3}{2}\beta + \frac{\beta^2}{2}}}{1-\beta} + \frac{2-\beta}{\sqrt{1 - \frac{3}{2}\beta + \frac{\beta^2}{2}}} \right] \tag{7}$$

Non-welded joints-bottom wall chord [only Model II]

From geometry of mechanism occurs:

$$AD = \sqrt{x^2 + c^2}\ ;\ c = \left(\frac{1-\beta}{2}\right) b_0\ ;\ \varphi_1 = \frac{\delta}{x}\ ;\ \varphi_2 = \frac{\delta}{c}$$

The energy dissipated in the yield lines is as follows, [3]:

$$D = \sum D_{ij} = \left[4\eta b_0 \cdot \frac{\delta}{c} + 8 \cdot \frac{\delta x}{c} + 2 \cdot b_0 (1 + 2p\beta) \cdot \frac{\delta}{x} + 4 \cdot \frac{c}{x} \right] \cdot m_{pl} \tag{8}$$

After assumption that a shape of the laser cut hole on the face of chord is constant the coefficient k = const and because (1) could be equal to (8) so:

$$\frac{N}{m_{pl}} = 4\eta b_0 \cdot \frac{1}{c} + 8 \cdot \frac{x}{c} + 2 \cdot b_0 (1 + 2p\beta) \cdot \frac{1}{x} + 4 \cdot \frac{c}{x} \tag{9}$$

For the minimum

$$\frac{\partial N}{\partial z} = 0 = 0 + 8 \cdot \frac{1}{c} - 2 \cdot b_0 \cdot (1 - 2p\beta) \frac{1}{x^2} - 4 \cdot \frac{c}{x^2} \bigg| \cdot \frac{cx^2}{8} \tag{10}$$

After substituting value of c:

$$\ddot{u} = \frac{b_0}{\ddot{u}}\sqrt{1-\beta\left(\quad -\frac{3}{}\right)+\beta^2\left(\quad -\frac{1}{}\right)} \tag{11}$$

Finally, when values x, c and m_{pl} are given, formula (9) is given as:

$$N = f_0 \cdot t_0^{\,2} \cdot \left[\frac{\eta + \sqrt{1-\beta\left(p-\frac{3}{2}\right)+\beta^2\left(p-\frac{1}{2}\right)}}{1-\beta} + \frac{2+2p\beta-\beta}{\sqrt{1-\beta\left(p-\frac{3}{2}\right)+\beta^2\left(p-\frac{1}{2}\right)}} \right] \tag{12}$$

Non-welded joints-the upper and bottom wall of chord work [Model I + Model II]

To compute the carrying capacity of the joint with the upper and bottom wall of chord work you should add up calculations for the bottom and top chord.

Final formula (7+12):

$$N = f_0 \cdot t_0^{\,2} \cdot \left[\frac{2\cdot\eta\cdot(1-2k)+2\cdot\sqrt{1-\frac{3}{2}\beta+\frac{\beta^2}{2}}}{1-\beta} + \frac{2-\beta}{\sqrt{1-\frac{3}{2}\beta+\frac{\beta^2}{2}}} \right]$$
$$+ f_0 \cdot t_0^{\,2} \cdot \left[\frac{\eta + \sqrt{1-\beta\left(p-\frac{3}{2}\right)+\beta^2\left(p-\frac{1}{2}\right)}}{1-\beta} + \frac{2+2p\beta-\beta}{\sqrt{1-\beta\left(p-\frac{3}{2}\right)+\beta^2\left(p-\frac{1}{2}\right)}} \right] \tag{13}$$

The experimental joints “plug&play” type T

Eleven T RHS laser made joints in natural scale were tested here up to failure. Three of them have been one side joints, where only face wall of RHS chord has been loaded - WTL (i), the remaining eight joints utilized top and bottom wall of chord of T RHS to carry the force - WT2L (i). In several steps the branch was loaded up to reachthe failure load. After each loading step, the joint was unloaded to measure the permanent deformations of the tested specimen. Typical joint failure was the inelastic deformation of the loaded top & bottom flange of chord. LVDT gauges were used to measure the displacements. Registrations of the results were made permanently during the full loading and unloading process, up to failure. In Table 1 and 2 the geometric parameters were showed along with the mechanical features of investigated joints.

Tab.1. Geometrical dimensions and mechanical properties WTL joints

Geometrical dimensions					Yield stress	Parameters		
No specimen	Profile RHS chord $b_o x h_o$ mm	RHS branch $b_n x h_n$ mm	Chord wall thickness t_0 mm	Branch wall thickness t_n mm	Chord f_{y0} MPa	β	η	$\lambda_0 = b_0/t_0$
WTL1	100x100	40x40	3,0	3,0	334	0,40	0,40	33,3
WTL2	100x100	60x60	3,0	3,0	343	0,60	0,60	33,3
WTL3	100x100	80x80	3,0	3,0	335	0,80	0,80	33,3

Tab.2. Geometrical dimensions and mechanical properties WT2L joints

Geometrical dimensions					Yield stress	Parameters		
No specimen	Profile RHS chord $b_o x h_o$ mm	RHS branch $b_n x h_n$ mm	Chord wall thickness t_0 mm	Branch wall thickness t_n mm	Chord f_{y0} MPa	b	h	$\lambda_0 = b_0/t_0$
WT2L1	100x100	40x40	3.0	3.0	335	0.40	0.40	33.3
WT2L2	100x100	60x60	3.0	3.0	335	0.60	0.60	33.3
WT2L3	100x100	80x80	3.0	3.0	335	0.80	0.80	33.3
WT2L4	100x100	40x40	4.0	3.0	335	0.40	0.40	25.0
WT2L5	100x100	60x60	4.0	3.0	335	0.60	0.60	25.0
WT2L6	100x100	80x80	4.0	3.0	335	0.80	0.80	25.0
WT2L7	100x100	40x40	5.0	3.0	335	0.40	0.40	20.0
WT2L8	100x100	60x60	5.0	3.0	335	0.60	0.60	20.0

where:

b_0,h_0,t_0- width, height, thickness wall of chord

b_n,h_n,t_n- width, height, thicknesswall of RHS branch

f_{ey0} –yield stress chord

$\beta=b_n/b_0$, $\eta=h_n/b_0$ – dimensionless width, height of RHS branch

$l_0=b_0/t_0$ – slenderness wall of chord.

Numerical model of “plug & play” type T joints

The numerical model mapped the load method used during experimental studies. Nets with a mesh size of 16mm were usedin secondary zones, and in the areas witha threat of maximum deformation the grid was concentrated to 4mm. The model uses finite element of ‘tetrahedrons’ type with the intermediate joints. The backlash offset (0.3 mm), inaccuracies in the production of steel profiles, (including stitches on RHS) were not included.

Using the dual symmetry the joint quadrant was modeled. In the computation model carried in ANSYS system, base of RHS branch- modeld as one-way contact of preassure force (without extension), additionallyin some joints used offset size 0,05mm to included imperfections production specimen.

This computation model to a large extent reflects the real work of a joint, assuming reasonable time of numerical calculations.

Results and numerical calculations for the T RHS joints

To compute joints carrying capacity with the work of the upper and bottom wall of chords we have to add up.

Tab.3. Theoretical and experimental resistance of joints WTL(i)

Specimen No	Theoretical resistance (7+12)* N_{teo} [kN]	Experimental resistance (elastic) N_{exp} [kN]	MES software resistance (elastic) N_{num} [kN]	N_{teo} / N_{exp}
WTL1	15,88	10,03	21,18	1,58
WTL2	20,96	18,01	31,49	1,16
WTL3	32,94	28,01	35,31	1,18

*Theoretical resistance has been calculated from formula (7) for joints, where parameter k=0.25, p=0.25 was used.

Tab.4. Theoretical, experimental and analytical resistance of joints WT2L(i)

Specimen No	Theoretical resistance (7+12)* N_{teo} [kN]	Experimental resistance (elastic) N_{exp} [kN]	MES software resistance (elastic) N_{num} [kN]	N_{teo} / N_{exp}	N_{num}/ N_{exp}
WT2L1	34.7	30	25	1.16	0.83
WT2L2	48.7	37.4	37.4	1.30	1.00
WT2L3	82.7	64	64	1.29	1.00
WT2L4	61.8	45	45	1.37	1.00
WT2L5	86.5	70	70	1.24	1.00
WT2L6	146.9	110	93	1.34	0.85
WT2L7	96.5	75	75	1.29	1.00
WT2L8	135.2	112	96	1.21	0.86

*Theoretical resistance has been calculated from formula (7+12) for joints, where parameter k=0.25, p=0.25 was used.

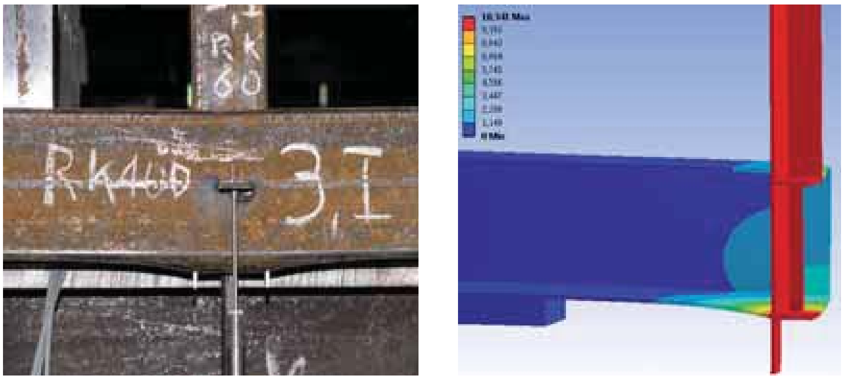

Fig. 4. Joint WT2L2 (β= 0,6) during test with numerical model

Fig. 5. Joint WT2L4 after test (detail of face wall failure in right corner).

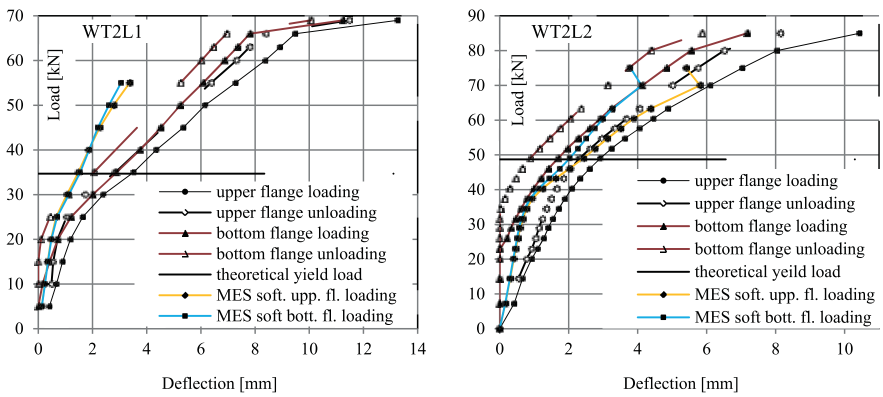

Fig. 6. Load-deflection diagram for joint WT2L1 (β= 0,4) &WT2L2 (β= 0,6)

N-type joints

In the N type joints two forces are involved, compressive force that influences the branch and the tensile force carried by the diagonal strut. Non-welded the N type joints plug & play connections work only by pressure and shear contact of key parts (grid) and lock (the hole in the chord truss).

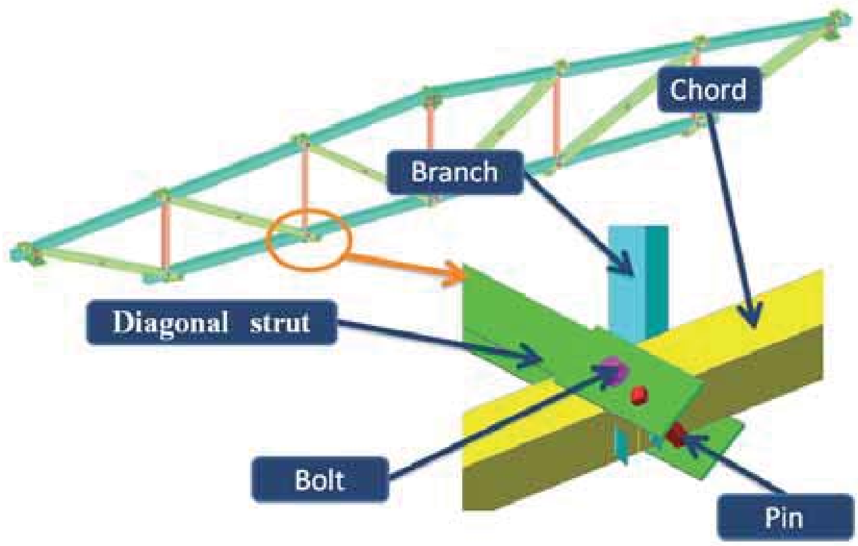

Fig. 7. View one selected joint (with pin) type N from non-welded truss.

In order to transfer the load of the internal forces in the chord of truss the "lock" (slot) is made, which allows the insertion of a "key" branch. Dual diagonal strut (it is possible to use plates, L-shapesor C-shapes) comprising the chord, is attached to the chord via a pin inserted through the openings in the rods of the diagonal strut and side walls of the chord. Diagram of the grid and N type joints are shown in Figure 6. Chord and branch are made of RHS. As diagonal strut used plate, which include mutually chord, in the middle of the dual diagonal strut we put C-shape profile to reduce buckling. Because in extended diagonal strut are considerable forces, which contribute to the ovalisation hole of RHS chord in fast way, additionally introduced stiffening pin. This pin to a large degree limit ovalisation hole in side walls of the chord, cause pin carries part of load from the bold to walls. The connection of this type eliminates the need to use seams in the joint. In previous publications and in the last chapter the results of experimental and theoretical estimation of carrying capacity of T RHS truss joints, made in non-welded technology, in the form of plug & play (Szlednak, Oponowicz 2011) were presented. The theoretical carrying capacity calculated using the yield line model was compared to the experimental studies (Szlednak, Oponowicz 2013).

The experimental joints"plug & play" N

The study was carried out at the Technical University of Bialystok in 2009-2012 under a grant PR/WBiIŚ/1/09/NCBR on designed for this purpose bench.

Eight joints of N-type grid of a natural scale were tested. Two selected joints of the chord thickness 3.0 mm (WTLN5 and WTLN6) were selected. For those numerical models were developed. In Table 5 the joints geometry and mechanical properties of the steel are shown.

Tab.5. Geometrical dimensions and mechanical properties of joints

Geometrical dimensions RHS members					Yield stress	Parameters		
No specimen	Chord b_0xh_0 mm	Branch b_nxh_n mm	Chord wall thick t_0 mm	Branch wall thick t_n mm	Chord f_{y0} MPa	β	η	$\lambda_0 = b_0/t_0$
WTLN5	100x100	60x60	3.0	3.0	335	0.60	0.60	33.3
WTLN6	100x100	40x40	3.0	3.0	335	0.40	0.40	33.3

where:

b_0,h_0,t_0- width, height, thickness wall of chord

b_n,h_n,t_n- width, height, thickness wall of RHS branch

f_{ey0} –yield stress chord

$\beta=b_n/b_0$, $\eta=h_n/b_0$ – dimensionless width, height of RHS branch

$l_0=b_0/t_0$ – slenderness wall of chord .

A numerical model for "plug & play" type N joints.

The numerical model mapped the load method used during experimental studies. Nets with a mesh size of 20mm were used in secondary zones, and in the areas with a threat of maximum deformation the grid was concentrated to 5mm. The model uses finite element of "tetrahedrons" type with the intermediate joints. The backlash offset (0.3 mm), inaccuracies in the production of steel profiles, (including stitches on pipes) were not included. Using the symmetry the joint half was modeled.

In the computation model carried in ANSYS system the following assumptions were made:

- branch base on walls of chord- one-way contact of preassure force (no extension), additionally in some joints used offset size 0,05mm to included imperfections production specimen was modeled
- contact between the diagonal strut and the chord- only one-way contact of pressure force (no extension) was modeled
- contact between the screw (bolt) and the chord- only one-way contact of pressure force (no extension) was modeled
- contact between the screw (bolt) and the diagonal strut - only one-way contact of pressure force (no extension) was modeled
- contact between the pin and the bottom wall of chord - modeled as a frictional contact with a coefficient of 0.3

- contact between the diagonal strut and the nut - modeled as a frictional contact with a coefficient of 0.3
- contact between the diagonal strut and the pin - modeled as a frictional contact with a coefficient of 0.3

This computation model to a large extent reflects the real work of a joint, assuming reasonable time of numerical calculations.

Results and numerical calculations for the N type joints

For the graphs following abbreviation were used: PD -bottom chord, PG-top chord;

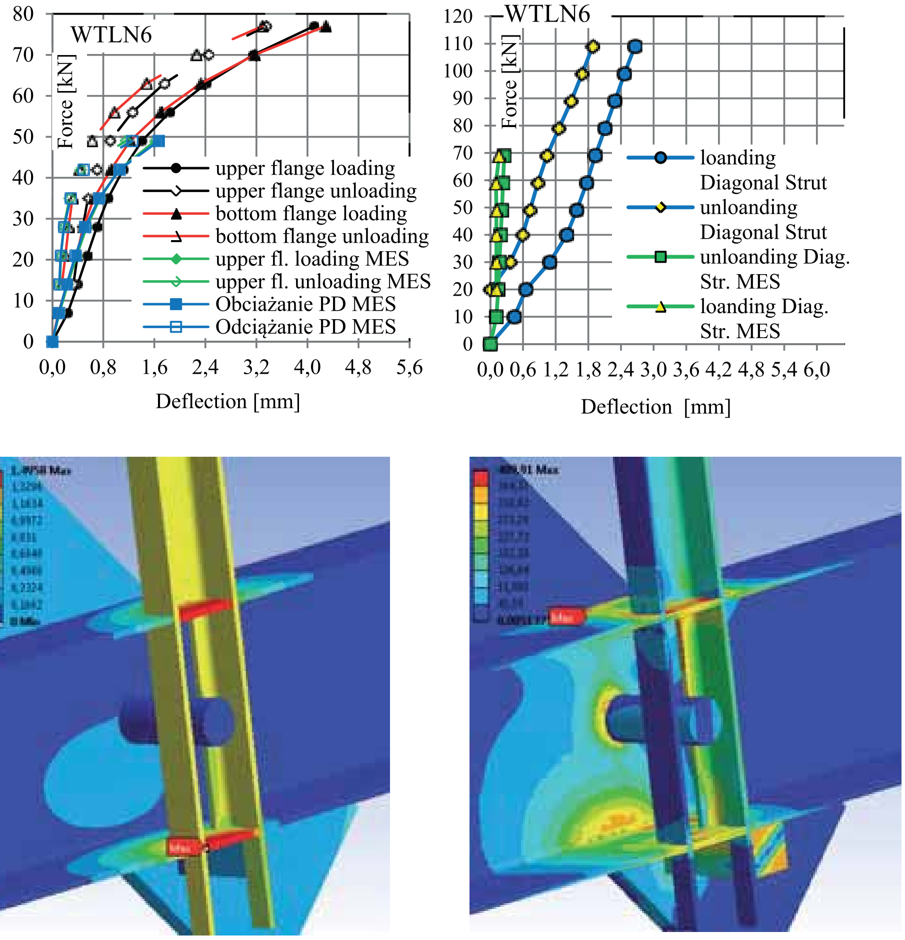

Fig. 8. Charts force – displacement of the WTLN 6 joint (beta = 0.4) respectively: branch, diagonal strut and deformation and stress for the WTLN 6 joint (beta = 0.4)

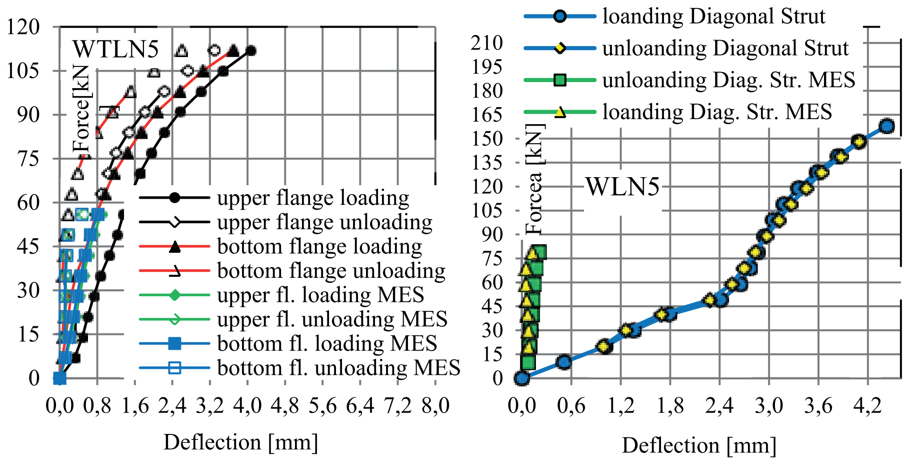

Fig. 9. Charts force - displacement WTLN 5 joint (beta = 0.6), respectively: branch, diagonal strut

The results with the numerical analysis for the rest of the N type joints (with different thicknesses) are currently being developed and will be presented at a scientific conference Krynica 2013 (Szlendak, Oponowicz 2013)

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