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Behaviour K-Joint Truss Connection with Rectangular Hollow Section

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Keywords

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Lattice girder,
Hollow rectangular section.

Abstract

This study is concerned with the study of the plastic behaviour of overlapped K-joint of lattice girders, made up of elements of rectangular hollow section with very thin walls. An experimental study was carried out on three full-scale truss girders with the same sections and different geometry. According to studies, the main parameters which have defined the strength of overlapped K-joints are the ratio between the width of the diagonals and that of the chord, the ratio between the width of the chord and that of its thickness and the angle of the diagonal with the chord. The latter was the parameter taken in this work. A numerical investigation was combined in order to draw up a comparative assessment of the behaviour. This study will certainly make it possible to better apprehend one of the main parameters governing the behavior of the joints of beams of hollow rectangular sections and to define the analytical model appropriate to this type of beam. It appears that in this study the very thin-walled sections exhibit a different behaviour compared to the trusses with more or less thick or thin sections. Plasticization of the face and walls of the chord was the type of failure observed in this study.

1. Introduction

Eastwood & Wood (1970)[1] investigated the plastic behaviour of the joints of the trusses of rectangular hollow section and the various modes of failure , among these last only the following cases are to be taken:

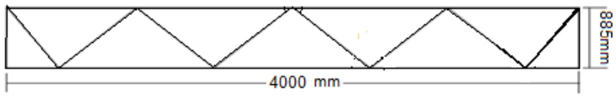
J. Wardenier (2001) [2] describes the behaviour of the plasticization of the face of the chord, ruin of the walls of the chord, punching of the chord, chord shear and ruin of the diagonal. Therefore the modes by buckling of the compressed diagonal and by plasticization of the face of the chord are generally observed in overlapped joints with relatively thin walls. Philiastides A (1988)[3] and Saidani M (1991) [4] most of their experimental and theoretical research was conducted out on this type of trusses, the major part of their program was carried out on sections of 100x100 mm and of different thicknesses of 4 and 5 mm and more. Thus, on the basis of these investigations, a comparative and crossed contribution by the present study on rectangular hollow sections with very thin walls relative to the sections cited above, will certainly allow a better understanding of the mode of ruin appropriate to this type of section and calculate the capacity of the node.

Thus, the three trusses have tested and allowed for a comparative and comprehensive study of their behaviour and followed by a numerical analysis (Abaqus) for validation.

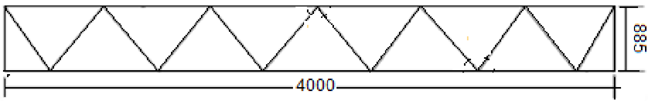
2. Experimental work

Analytical models are used by Wardenier J., Stark J.W.B (1978) [5] to describe the behaviour of the joint and to determine the paramount parameters with regard to its strength. Sometimes the behaviour of the assembly is too complex to take into account all the influencing parameters. A total of three full-scale trusses with full overlap of the diagonals at the joints (P1, P2 and P3) made of S 235 steel were used and tested. These trusses are supplied by a company. By virtue of their shape, which was part of a symmetrical system, these three trusses had a different geometry while keeping the same sections of the chord and the bracing. The experiment was carried out on a test slab with a maximum loading capacity of 20 tonnes.

Truss P1 with 7 nodes



Truss P2 with 11 nodes



Truss P3 with 9 nodes

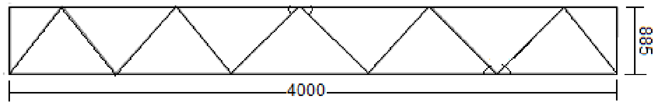


Figure 1.. Finite element model of truss

(a) Truss P1

(b) Truss P2

(c) Truss P3

Figure 2. (a), (b) and (c). Overall view of testing arrangement

This study examines the plastic behaviour and the mode of failure of the joints, in particular the various elements constituting the joints, by observing the deformations, the stresses as well as the forces measured following the experiment, followed by a numerical analysis for validation.

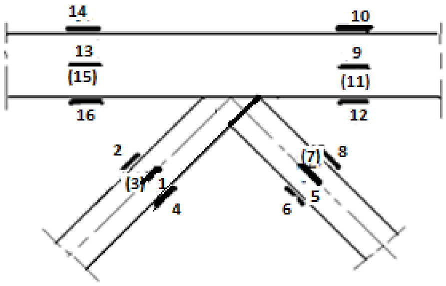


Figure 3. Positioning and numbering of gauges

Table 1. Dimensions of trusses and sections of elements

Parameters	Unit
Length	4m
Height	0.885m
Chord&vertical	70x50x2.5 (mm)
Diagonal	60x30x2 (mm)

The instrumentation considered is made up of electrical gauges to measure the deformations at the joints and the comparators placed in the middle of the trusses to measure the central deflection. The deformations are acquired by a measuring chain.

Table 2. Different parameters of the joint

Trusses	Joint Type	θ_1	β	b_o/t_o	b_1/t_1	b_2/t_2	b_1/b_2
P1	100% Overlapped	60.6	0.9	20	15	15	1.0
P2	100% Overlapped	65.7	0.9	20	15	15	1.0
P3	100% Overlapped	69.4	0.9	20	15	15	1.0

$$\beta = \frac{b_1 + b_2 + h_1 + h_2}{4b_0}$$

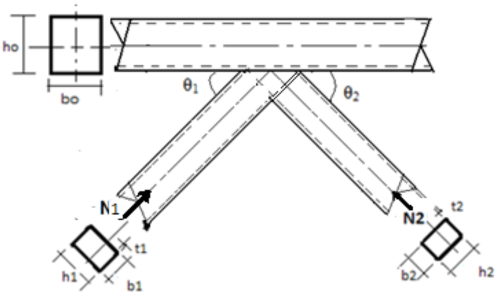
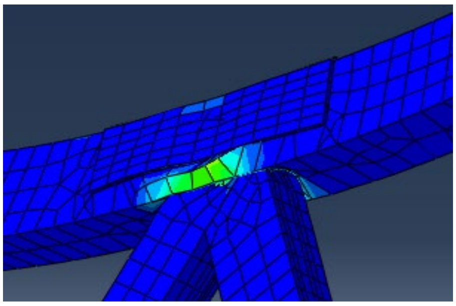


Figure 4. Parameters of the joint

3. Results

The objective is to analyze and study the behaviour of the central joint at the point of application of the load. This is the node where the chord is most solicited by the reactions of the diagonals. Following the experiment and from the intensity of the load equal to 20 KN, the deformations at the level of the elements constituting the joint increase and reach their maximum values at loading of 80 KN. At this critical value, this joint has completely plasticized. There was chord face plasticization and chord side wall yielding. Moreover, this plasticization which occurred at the level of the central joint affected the distribution of the load, thus causing a lateral buckling of the truss.

This mode of ruin has been observed on trusses with very thin walls. Moreover, this mode has been observed both through the experimental study and the numerical one, giving the same deformation at the levels of the walls and the face of the chord (Fig.5).



(a) Numerical

(b) Experimental

Figure 5. (a) and (b). Plasticization of the members at the point of application of the load

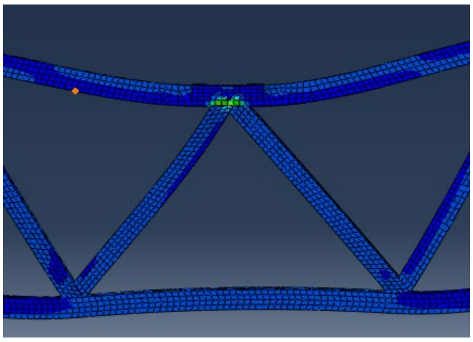


Figure 6. Deformation of the truss

3.1. Stress and deformations in the diagonals

Using the notations of Fig. 4. the axial force in the element i may be written as follows:

$$\text{Axial force } N_i = \sum_{i=1}^{n=4} \varepsilon_i * E.A = \frac{(\varepsilon_1+\varepsilon_2+\varepsilon_3+\varepsilon_4)}{4} * E.A \qquad (1)$$

E: Modul of elasticity, A: Diagonal section,

ε_i: Strain

Figures 7, 8 and 9 show the stress-strain diagram in compressed diagonals of trusses P1, P2 and P3 of the central joint.

Table 3. Stress, Strain in the diagonal of the central joint (Truss P1)

Load (kN)	σ_n (MPa)	ε_n (x10^{-6}) experimental	σ_{exp} (MPa) experimental	ε_{exp} (x10^{-6}) experimental	Per. Stress	Per. Strain
0	0	0	0	0	0	0
10	15.62	22.2	17.8	32.5	12%	30%
20	31.32	42.8	33.5	44.5	6.5%	4.5%
30	47.07	64.2	49.1	66.7	4.1%	3.7%
40	62.51	85.8	64.7	89.6	3.3%	4.2%
50	78.14	106.9	80.7	111.2	3.2%	3.8%
60	94.14	127.6	96.5	129.8	2.4%	16%
70	109.4	147.9	112.5	155.7	2.7%	5%
80	125.1	171.3	128.0	177.7	2.3%	3.6%

Percentage error $= \frac{(\sigma_n - \sigma_{exp})}{\sigma_{exp}} 100\%$ (stress), $= \frac{(\varepsilon_n - \varepsilon_{exp})}{\varepsilon_{exp}} 100\%$ (strain)

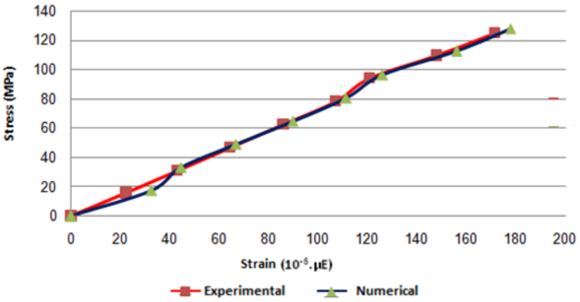


Figure 7. Diagram stress/strain in the diagonal (Truss P1)

Table 4. Stress, Strain in the diagonal of the central joint (Truss P2)

Load (kN)	σ_n (MPa)	ε_n (x10^{-6}) experimental	σ_{exp} (MPa) experimental	ε_{exp} (x10^{-6}) experimental	Per. Stress(%)	Per. Strain (%)
0	0	0	0	0	0	0
10	13.5	18.9	18.5	20.1	27	6
20	27.11	38.1	33	45	17.8	15
30	40.67	57.2	45	65	9.6	12
40	54.23	76.3	59	77	8	1
50	67.77	95.4	75	107	9.6	10
60	80.40	115	87	122	7.5	5.7
70	94.46	134.2	105	147	10	8.7
80	108.5	152.7	115	166	5.6	8

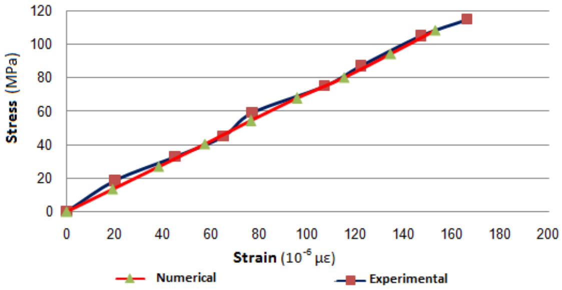


Figure 8. Diagram stress/strain in the diagonal (Truss P2)

Table 5. Stress, Strain in the diagonal of the central joint (Truss P3)

Load (kN)	σ_n (MPa)	ε_n (x10^{-6}) experimental	σ_{exp} (MPa) experimental	ε_{exp} (x10^{-6}) experimental	Per. Stress (%)	Per. Strain (%)
0	0	0	0	0	0	0
10	13.8	19.9	15	21	8	5.2
20	27.6	39.9	29.3	42	5.8	5
30	41.5	59.8	43.5	62	4.6	3.5
40	55.2	79.8	58.9	83	6.2	3.8
50	69.1	99.8	72.5	103.4	4.6	3.4
60	86.4	120.2	90	124.5	4	3.4
70	97.8	140.2	104	146.3	5.9	4.2
80	10.4	160	114	164	3.2	2.4

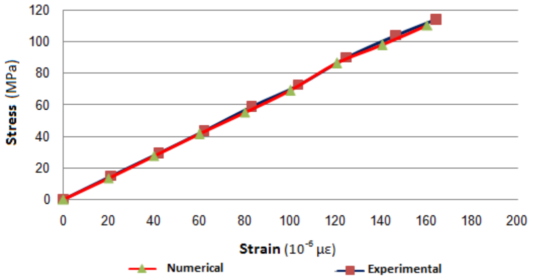


Figure 9. stress / strain variation in joint diagonal

The Stress / Deformation diagrams in the diagonals of the different types of Trusses were characterized by linear curves. This elastic and similar behavior does not induce irreversible apparent deformations in these elements. It was noted that the strains in the elements constituting the nodes of the truss P1 are higher than those obtained in the trusses P2 and P3. This difference is mainly and probably due to the slenderness of the diagonals of truss P1 compared to those of other trusses.

3.2. Deformations in the chord at the joint of application of the load.

The values of the stresses and strains in the chord obtained by the experimental and numerical analysis are deferred on the following table VI.

Table 6. Stress, Strain in the chord of the central joint

Load	σ_n (x10^{-3}.ɥε)	ε (x10^{-3}.ɥε) numerical	σ_{exp} (MPa) experimental	ε (x10^{-3}.ɥε) experimental
0	0	0	0	0
10	137	0.56	114	0.57
20	201	1.18	210	1.25
30	201.9	2.16	212	1.25
40	205.2	5.08	218	5.2
50	214	11.9	221	12.6

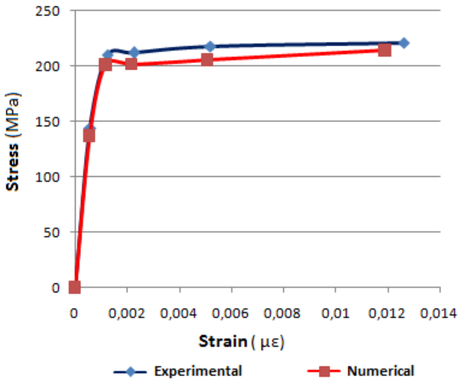


Figure 10. Diagram Stress/Strain in the chord

Figure 10 shows the distribution of stress and strain in the chord and after reaching the ultimate strain. Therefore, the ultimate load capacity must therefore be defined by the strain limit for the limit load. However and following the results obtained on the truss P1, the capacity of the joint is limited to the load of 30KN.

4. Analytical models and failure modes

Packer J.A.(1978) [6] are proposed different analytical models to describe the failure mode of this type of assemblage. The ruin model which was observed following the experimental study and the numerical analysis was indeed the plasticization of the face and buckling of the walls of the member. The mechanical and geometrical parameters of the three models are shown in (Fig. 4) and used to calculate the force N1 in the diagonal.

Yield line model is frequently used for assemblies between rectangular hollow profiles and more precisely for overlapped K-joints where membrane stresses, shear stresses and work hardening are neglected. J.Wardenier (2001) [2] describe the principle of the yield line method, consisting in equalizing the external energy caused by the external force N1, for a displacement δ, with the internal energy of the plastic hinges which is a function of their length l and an angle of rotation φi.

$$\mathrm{N_1.\sin\theta_1.= \sum l_i.\varphi_i.m_p} \tag{1}$$

$$\mathrm{m_{p=\frac{1}{4}}.t_0^2.f_{y0}} \tag{2}$$

The energy dissipated by the different plastic hinges is also shown in (Fig. 12). Equalizing the sum of internal work with external work gives us:

$$N_1\,.\sin\theta = \frac{2f_{y0}.t_0^2}{1-\beta}\left(\tan\alpha + \frac{(1-\beta)}{\tan\alpha} + \frac{\eta}{\sin\theta}\right) \tag{3}$$

With a minimum for:

$$\frac{dN_1}{d_\alpha} = 0\ \ ou \tag{4}$$

$$\tan\alpha = \sqrt{1-\beta} \tag{5}$$

Substituting (5) in (3) gives a capacity of:

$$N_1\ = \frac{2f_{y0}.t_0^2}{1-\beta}\left(\frac{2\eta}{\sin\theta} + 4\sqrt{1-\beta}\right)\frac{1}{\sin\theta} \tag{6}$$

$\mathrm{f_{yo}}$, $\mathrm{f_{y1}}$: Elasticity limits of steel

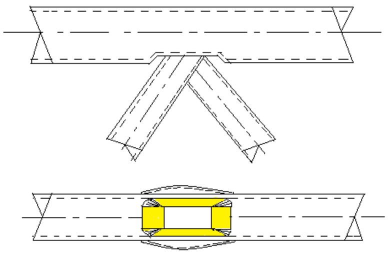


Figure 11. Plasticization of the face and walls of the chord

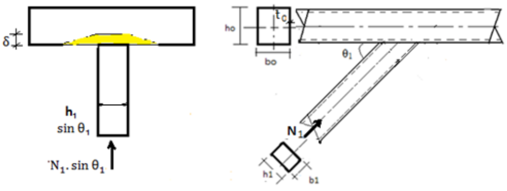
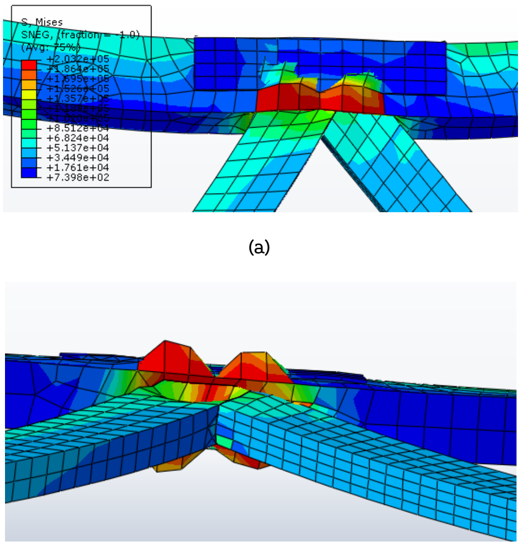


Figure 12. Yield line model of joint



(a)

(b)

Figure 13. (a) and (b). Plastification of the joint on Abaqus

The (Table 7) identifies the three models chosen for comparison, the joint capacity quantization equations, and the calculated values for each truss.

Table 7. Analytical models

Analytical models	Joint capacity(KN) P1	P2	P3	Trusses
Yield line $N_1 = \frac{f_{y_0}.t_0^2}{(1-\beta)}\left(\frac{2\eta}{\sin\theta_1} + 4\sqrt{1-\beta}\right)\frac{1}{\sin\theta_1}$	43,2	39,8	48	model
Brace effective $N_1 = f_{y1}.t_1(2h_1 - 4t_1 + b_1 + b_{e(ov)})$	76,4			
Width model $b_{e(ov)} = \frac{10}{b_j/t_j}.\frac{f_{yj}}{f_{yi}}.\frac{t_j}{t_i}.b_i$				
Chord side wall bearing Or $N_1 = 2.f_{y_0}.t_0\left(\frac{h_1}{sin\theta_1} + 5t_0\right).\frac{1}{sin\theta_1}$ buckling model	110	101	97	

Load	N₁	P₁ (kN)	N₁ (in)	P₂ (kN)	N₁ (in)	P₃ (kN)
kN	in	Num.	Exp.	Num.	Exp.	Num.
0	0	0	0	0	0	0
10	5.8	5.4	5.2	4.8	4.5	4
20	10.5	10.28	11.2	10.2	9.2	8.2
30	15.3	14.9	15.4	14.8	13.1	12.3
40	18.9	17.2	20.1	19.7	17.2	16.5
50	25.3	22.2	25.9	24.7	23.5	20.6
60	28.9	26.2	31.2	30.9	26.1	24.6
70	35.2	33.2	36.1	35.8	31.2	28.7
80	41.2	38.6	43.1	39.4	34.3	32.8

Exp: Experimental; Num: Numerical

The experimental and theoretical axial forces values (for the diagonals of trusses P1, P2 and P3) are compared in the table 8. The results showed that the two approaches converge and the error percentage is minimal. Moreover, and compared to the values of the capacity of the joint obtained by the yield line model, the diagonals can withstand a load of up to 70 KN, this value gives axial forces for the different trusses in the vicinity of the capacity of the joint of 39.8 KN (see table 7). On the other hand, the chord cannot withstand a load exceeding 30 KN (see Figure 10).

5. Conclusion

The experimental behaviour of a large-scale overlap-jointed RHS truss, with very thin walls has been compared with the numerical analysis. The joint at the point of application of the load exhibits a different behavior with respect to more or less thick trusses sections. Experimentation and numerical analysis have clearly shown this.

The following conclusions can be deduced:

- The effect of the angle ɵ has a considerable influence on the behavior of trusses. In particular, on the values of the deformations of the elements constituting the joint, and on the central deflection of the trusses.

- Reinforcement with a U-profile of the node at the point of application of the load could not prevent buckling of the walls of the chord. It is better to reinforce the section of the chord at the level of the joint under loading.

- The yield line model proved to be the most suitable model for determining the capacity of the joint for this type of section and for the overlapped K-joint.

- In the plastic behavior of trusses, the chord was the weakest among the elements that constitute the joint.

- The experimental and numerical approaches converge on average with an error rate of around 5%.

Declaration of Conflict of Interests

The 50authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1.] Eastwood W., A., "Welded joints in tubular structures involving rectangular hollow sections," Proc., Joints in Structures, Sheffield, England, 1970.
[2.] Prof.dr.J. Wardenier., Hollow Sections in Structural Applications, Delft University of technology, The Netherlands, December 2001.
[3.] Philiastides A., "Fully overlapped rolled hollow section welded joints in trusses" PhD thesis, department of civil engineering, The University of Nottingham, United Kingdom, 1988 .
[4.] Saidani M., The effect of the flexibility of the joints on the behavior of RHS trusses. PhD thesis, department of civil engineering, The University of Nottingham, United Kingdom, 1991.
[5.] Wardenier J., Stark J.W.B, "The static strength of welded lattice girder joints in structural hollow sections. Parts 1-10. CIDECT Final Report 5Q/78/4. Delft University of Technology, Delft, Netherlands, 1978.
[6.] Packer J.A., "Theoretical Behaviour and Analysis of Welded Steel Joints with RHS Chords, CIDECT, Final Report 5U-78/19.

[7.] Packer J.A., Wardenier J., Kurobane Y., Dutta D., Yeomans N., Hendersen J.E., “ Design Guide for Rectangular Hollow Sections (RHS) Joints under predominantly static loading, Ed. by CIDECT, Verlag TÜV Rheinland, Cologne, 1992.

[8.] Strength of Welded T-Joint Truss Connections between Equal Width Cold-Formed RHS. Research Report No R831

[9.] Packer, J.A. and Henderson, J.E.: Hollow Structural Section Connections and Trusses - A Design Guide. Canadian Institute of Steel Construction, Toronto, Canada, 1997. ISBN 0-88811-086-3.

[10.] Eurocode3, "Design of Steel Structures" - Annex K: Hollow Section Lattice Girder Connections, ENV 1993-1-1, CEN, 1992.

[11.] Rondal J., Wurker K.G., Dutta D., Wardenier J., Yeomans N, : Structural Stability of Hollow Sections., Ed. by CIDECT, Verlag TÜV Rheinland, Cologne, 1992

[12.] Packer J.A., “Theoretical Behaviour and Analysis of Welded Steel Joints with RHS Chords, CIDECT, Final Report 5U-78/19.

[13.] Abaqus., (Version 6.10), User’s manual. Hibbitt, Karlsson and Sorensen Inc., Pawtucket, Rhode Island, USA. 2010