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Original Research Article

Behaviour of Top-Set with Double-Web Angle Steel Connections under Applied load

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Abstract

The present work is dedicated to the study the effect of the applied loads on the behavior of top-set angle with double web angle bolted metal beam-to-column (TSA-DWA) connection. A numerical study of finite elements for the characterization of the nonlinear behavior of metal connections types carbon steel ASTM A36 mild steel with screw fasteners. The numerical analysis is based on a three-dimensional model with 3D solid brick element, each element consists of eight nodes using the software of finite elements ABAQUS. The model takes into account material and geometric nonlinearities (contact, plasticity, large displacements). This model has calibrated on the basis of experimental results two connections with different geometric configurations. In addition, to validate the model developed.
Keywords: column-beam connection; semi-rigid, linear analysis; Moment-rotation; finite elements Model; ABAQUS.

INTRODUCTION

Currently, Bolted connections of the angle are widely used in steel structures, due to the simplicity of its realization, its economic manufacturing, as well as the ease of it's implementation [1-5]. However, its behavior and analysis are extremely complex due to the variation in the number of rows of bolts, the spacing between bolts, dimensions of the parts of connection that may be overflowing or without overflowing, dimensions of posts and beams, the prestressing force on the bolts, the properties mechanical properties of steel and contact surfaces, as well as the presence of reinforcements [6]. Research work [7-12] that have been carried out over the past decade to study the details of the connections in their behavior provide only limited information and, in particular, about the behavior of steel beam-to-column connections used in world as shown in Figure-1. These connections are used in steel structures to hardens the joints and ensures the continuity of the beam core for to increase the rigidity of steel [13].

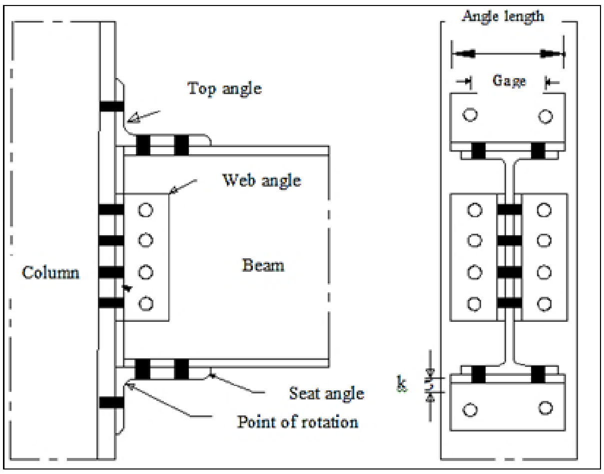

Fig-1: Top and seat angles with double-web angles connections

Currently, the component method of Eurocode 3 is the procedure used for the Characterization of the behavior of bolted connections. However, this the method l does not indicate how the components of the joints are deformed. For this purpose, a better understanding of the behavior of this type of assemblies it is of the utmost importance [14]. The research work on the influence of approximately on the behavior of TSA-DWA connections reports in the literature show that connection with simi-rigid of TSA-DWA connection exhibit better behavior compared to non-rigid connection, particularly in terms of resistance in regions with high seismic intensity [8, 15, 2]. In fact, these connections can limit the deformations of the stop angle connection more than others type of angle connections. This article first presents a brief description of the experimental program used at the base of the calibration of the numerical model that constitutes its main contribution. The results of the test are presented in the form of moment-rotation curves. In addition, a numerical model by finite elements, three-dimensional and non-linear, to characterize the real behavior of the TSA-DWA connections from start to the damage. The results obtained from the models numerically in terms of the moment of rotation are compared with the experimental results to verify and calibrate the proposed approach. Once the model is validated, it is used to simulate the distorted assemblies. This information provides a database to develop models for angle bolts connection.

Description of the Experimental Program

To examine the reliability of the model, two bolted steel connections have been chosen assemblies. They have been tested experimentally at Azizinamini and Radziminski [16]. Figure-2 shows the detailed diagrams of the assemblies of the different specimens. The first (IS41) is an angles connection with three rows of bolts. The second (IS4) is an angles connection with two rows of bolts. For all tested assemblies, made from A36 steel section was used for the beams, column and angles and A325 for bolts. The geometric details and characteristics can see from Table 1, 2 & 3. The connection mounting test is performed in 3-point bending. The applied load is of the type increasingly monotonous with full charge-discharge cycles to track the evolution of the rigidity of each assembly for different load levels. The tests were done in controlling the movements to be able to follow the descending parts in the displacement curves. The means of measurement used to consist of inclinometers, force sensors, and displacement sensors.

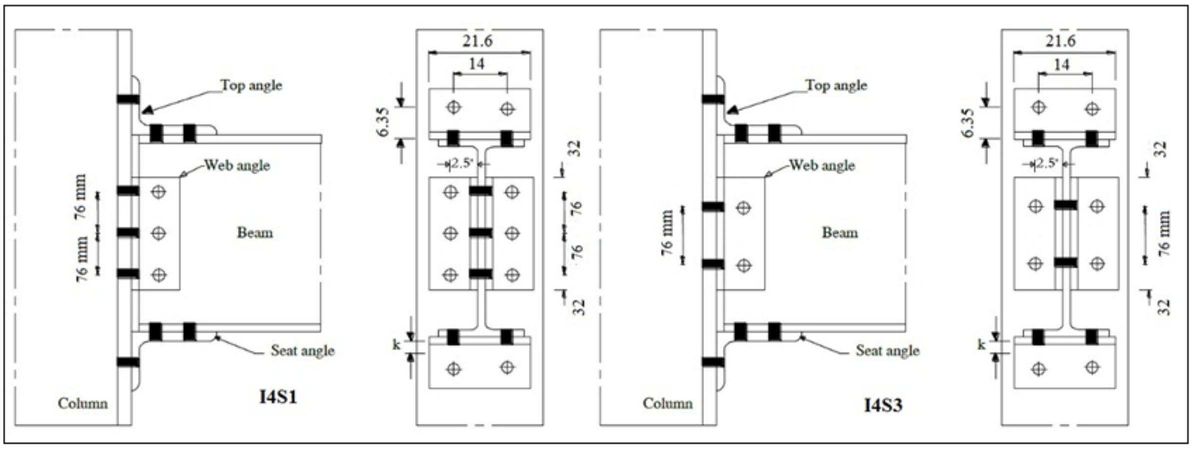

Fig-2: Detail of beam to column connections

Table-1: Summary of the geometries of angles and bolts

Test Ref	Beam size) mm*kg/m	Column size mm*kg/m	Gage mm	Flange-Angle size mm	Web-Angle size mm	Fastener mm
14S1	W360x58	W310x143	63.5	152.4x102x9.5x203.2	102.4x88.9x6.35x216	A325-19.1
14S3	W360x58	W310x143	63.5	152.4x88.9x7.94x152.4	102.4x88.9x6.35x139.7	A325-19.1

Table-2: Summary of the Columns geometric dimensions and yield stresses

Test Ref	d mm	b_f mm	t_w mm	t_f mm	A mm	L mm	F_y MPa
14S1	323	309	14	22.9	18190	572	248
14S3	323	309	14	22.9	18190	572	248

Table-3: Summary of the Beams geometric dimensions and yield stresses

Test Ref	d mm	b_f mm	t_w mm	t_f mm	A mm	L mm	F_y MPa
14S1	358.1	172	7.9	13.1	72200	1200	248
14S3	210.3	133.9	6.4	10.2	3970	1200	248

Description of the Finite Element Models

The finite element modeling of the experimentally tested connection was carried out with the ABAQUS software using iso-parametric hexahedral volume elements in 8 nodes called C3D8. Figure-3 provides a general description of the 3D mesh of the to steel assemblies connection. In our model, the bolt consists of a head screw and a nut. The head screw is modeled by a rod of constant cylindrical diameter equal to that of the non-threaded portion. The head of the bolt is modeled by a solid cylinder having a thickness equal to the thickness of the bolt head. The model is characterized by an elastoplastic behavior of the materials and takes into account the non-linearity generated by contact, plasticity and large displacements. The beam, column, and angles are modeled in such a way that there is a concordance between their nodes to take into account the contact between each pair of neighboring nodes.

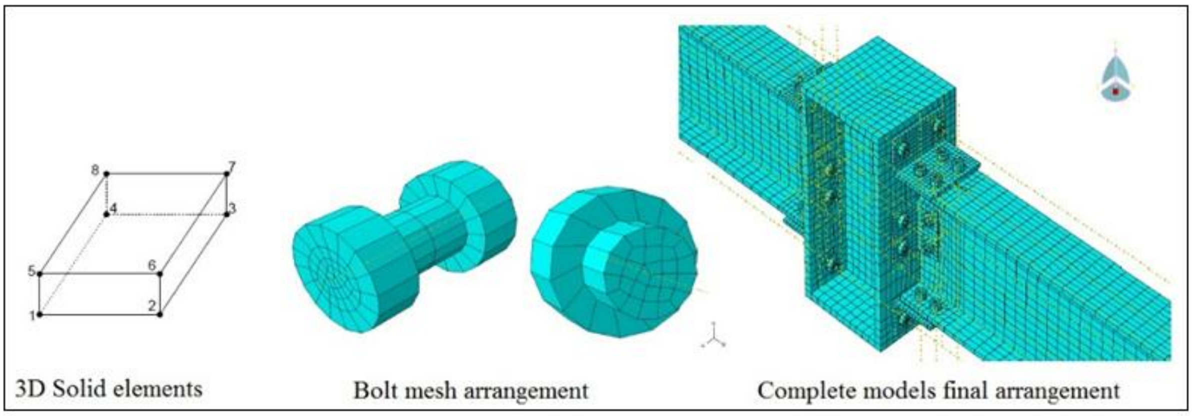

Fig-3: Types of elements and final arrangement of mesh

The boundary conditions considered in the models are a blocking of displacements along the Y direction, a blocking of displacements according to the X direction, as well as define the friction between surfaces of Figure-4. The applied load is of the type increasingly monotonous, applied at the centre of the model at 1.2 m from support as shown in Figure-4.

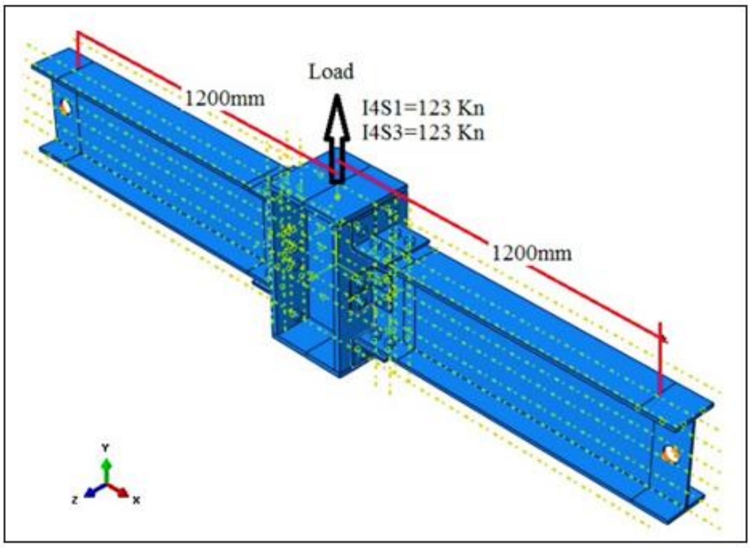

Fig-4: Boundary conditions and loads

Results of the Numerical Model

Calculations of Moment, Displacement and Rotation

To study the behaviour of a connection, a node n_1 and n_2 were selected on the top and bottom surface of the beam to find the displacement and stresses at this node". "Furthermore, the selected a node n_1 and n_2 were positioned at the top surface of the beam at L from the end support, as shown in Figure-5. These plots are used in calculating the beam and column rotation."

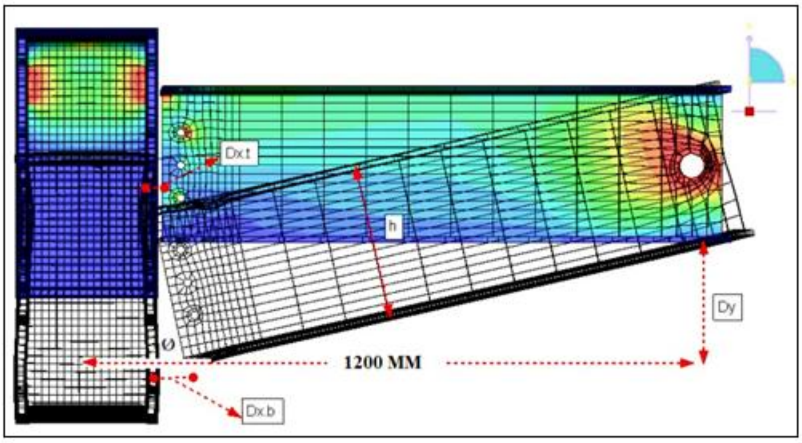

Fig-5: Calculation Rotation of DWA Connection

To measure the rotation of connections, use the equation [1]:

$$\text{Ø} = \tan^{-1}\left[\frac{\Delta x}{h}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ (1)}$$

$$\Delta x = [D_{xt} - D_{xb}]$$

"Where Δx is the Change in the horizontal displacement between D_{xt} and D_{xb} , Ø is the relative rotation of connection and (h) is the beam depth."

The applied moment is calculated by using the equation 2:

$$\text{M} = Load\ factor \times 0.5 \times L \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ (2)}$$

Where (M) is applied moment in kN.m acting $L\ mm$ from the support, L is length of beam.

Load-Displacement Curves

The load displacement curves at ambient temperature of all samples are shown in Figure-6.

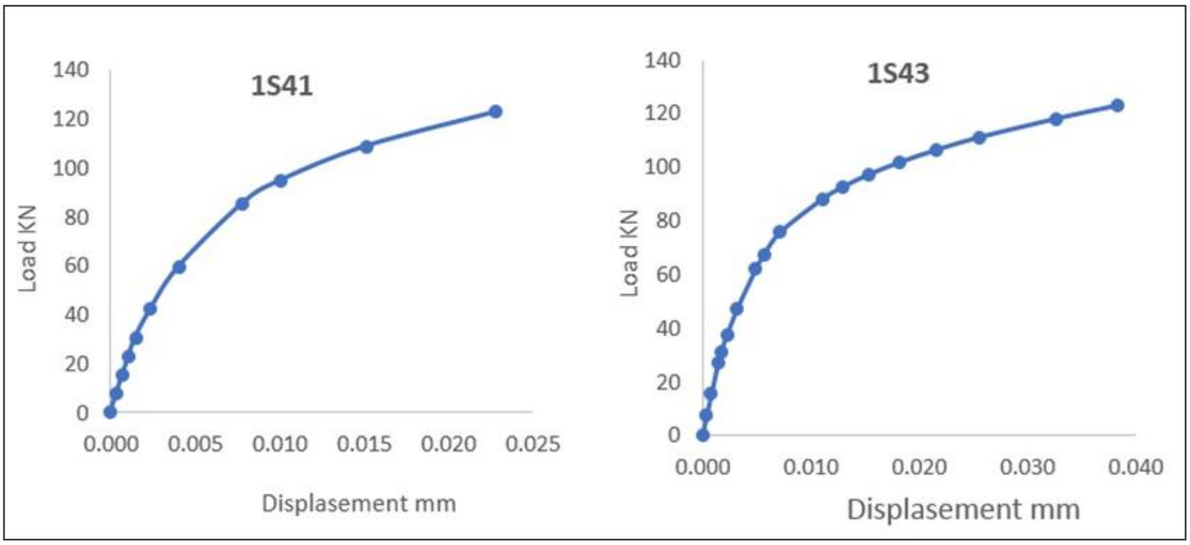

Fig-6: Load - Displacement of TSA-DWA connections

Validation of the Model

To validate the non-linear model, the results of the numerical simulation are compared with experimental results available in terms of moment-rotation curves. With the same definitions of moment-rotation curves used in the experimental tests. The moment rotation curves of the numerical simulation and the experimentally obtained for the two models are shown in Figure-7 and the main results are summarized in Table-4. In general, for all tests, these curves show that the models Numerical results give satisfactory results both in the elastic domain and in the plastic field of behavior. In relation to the characteristics of the moment-rotation behavior of the connection, know how resistant, the initial rigidity and the rotation capacity can make comments following:

- The evaluation of the initial rigidity given by the numerical model is very close to the experimental value as shown in Table-4. In fact, of the two tests, the average ratio of experimental and numeric yield moments is 0.99 is very close to 1.
- The simulation adopted is satisfactory in terms of the resistant moment. In fact, in the two tests, the average proportion of experimental and numerical Ultimate moment is 0.98 which is very close to 1.
- With respect to the capacity of rotation of the sets, the numerical model provides results that satisfactorily evaluate the rotations obtained experimentally with a minimum difference from 6 % to 8%.

The differences that are seen between the results of the numerical model and the model experimental may be due to:

- Errors associated with the approximation of the stress-strain curve of the material.
- Imperfections present in the experimental assembly.
- Errors associated with adjusting the experimental curve.

Therefore, the results obtained show that the 3D finite element model is a very useful tool. powerful for the study of steel connections.

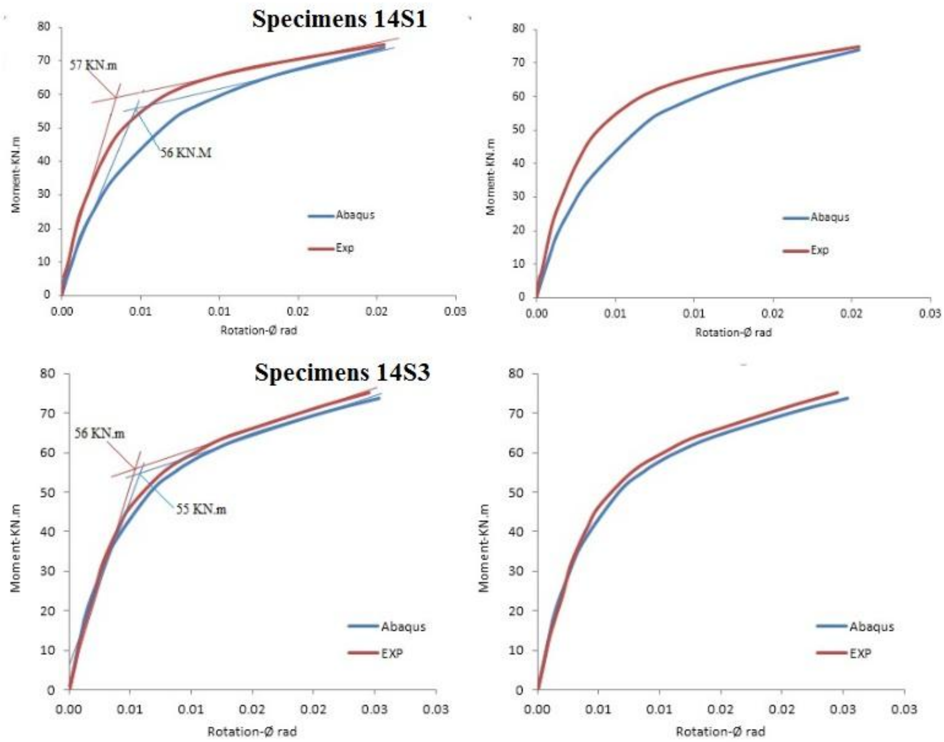

Fig-7: Moment-Rotation (M-Ø) curve

Table-4: Summary of the results for specimens 14S1 and 14S3

Test Ref	Yield moment(KN.m)			Ultimate moment (KN.m)			Rotation (rad)		
	FEM	Exp	$\frac{Exp - FEM}{Exp}$	FEM	Exp	$\frac{Exp - FEM}{Exp}$	FEM	Exp	$\frac{Exp - FEM}{Exp}$
14S1	56	57	1.75%	73.8	74.7	1.20%	0.022	0.021	4.76%
14S3	55	56	1.78%	73.8	75	1.60%	0.027	0.025	8.00%

Connections Deformation

Von-Misses Stress contour plots are shown in Figure-8. This figure shows the stress contours on solid elements such as angles, beam flanges, bolt head, and connecting column flanges. In addition, shows a different deformation and Von-Misses stress, specifically at the web and top angles, particularly at the bottom bolts contacts to column flange for specimens I4S1and I4S3, where it is subjected to the highest tensile stresses. This is due to the high tensile stresses on angle used in the specimen I4S3. Furthermore, the thickness of the small angle led to the inability of the bolts to use their strength. As a result of these reasons, the angles used in the web angle of the upper tensile pressures were exposed and failed. At the same time, in I4S1, this deformation was less due to increased angle thickness, which made the bolts help in carrying capacity for connection.

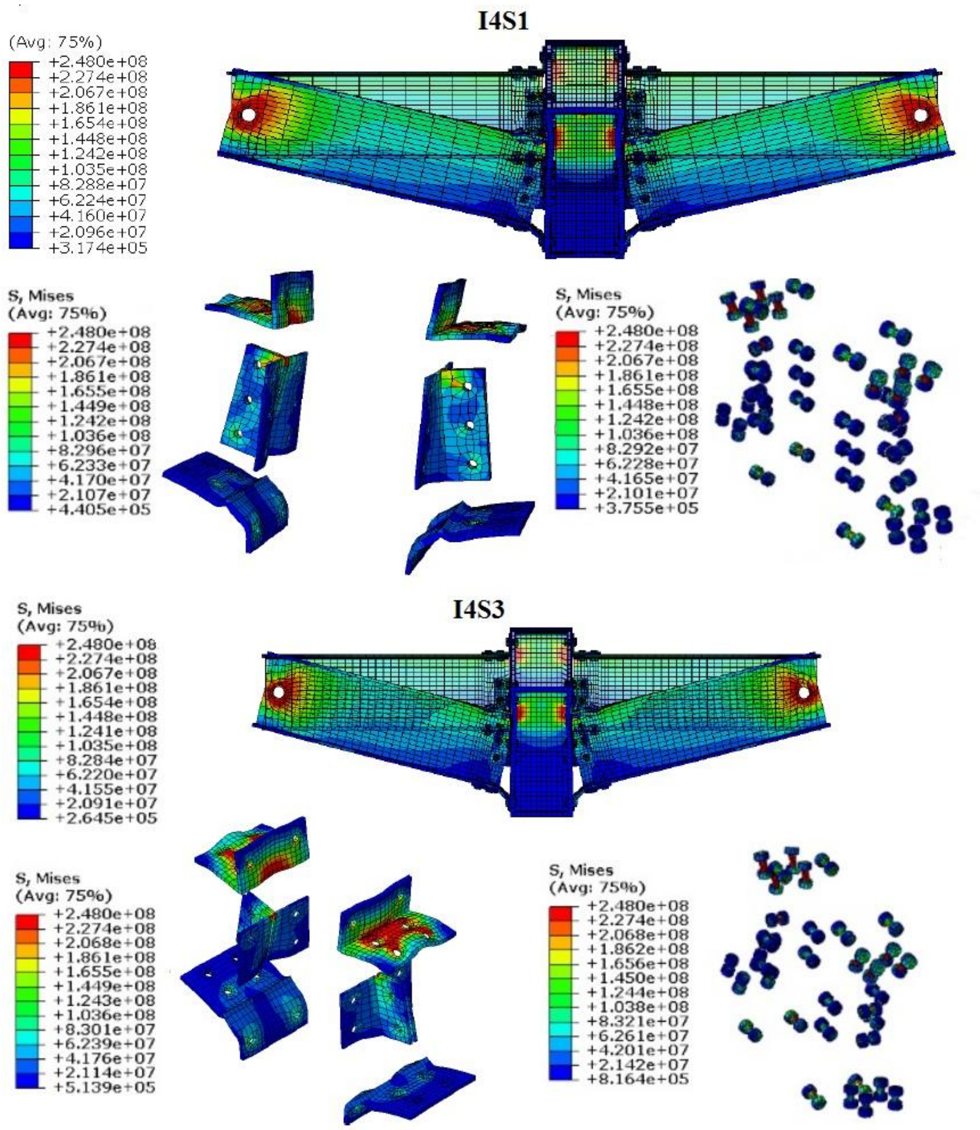

Fig-8: Von-Misses stress and deformation at elevated temperatures

Models of Connections Failure

The rigidity and deformation of the connection can be controlled by controlling the possibility of breaking the parts of connection. This is done through controlling the diameter, the number of bolts and the thickness of the angle of the connection. The possible Faults of the screws are a stress break, the thread of the screw and the thread of the nut and thickness of angle. The bolts are designed so that the stress fracture occurs before the start of the threads on screw and nut. It was then considered that the ultimate strength of the tension bolts was controlled by the fracture of these. So, for this element, a fracture condition can be always considered when the last deformation is reached in the sections criticism of the different elements. To avoid this failure, increased the diameter of the bolts of the specimen I4S1 and I4S3 connection, which fails in the fault mode at the angles connection, can be increased from 19 mm to 22 mm. This solution increases the strength of communication, especially since the rest of the elements of connection did not collapse and has the ability to withstand longer. Moreover, the angular thickness of the connection, which fails in the fault mode at the top angle and web angle, can be increased.

CONCLUSION

In this study, two configurations of beam-column connection experimentally and numerically are tested to study their behavior. The behavior analysis of connections revealed the following conclusions: The bolted connections with the TSA-DWA connection can have better behavior with respect to the set of the angle connection. In addition, the values given by the experimentally show a slightly higher stiffness compared to the rigidity obtained numerically for the two connections (I4S1 and I4S3). On the other hand, the results obtained show that the resistance moments calculated by the numerically are still lower than those obtained experimentally for the two connections. Furthermore, the comparative study carried out between the numerical model and the tests showed that the numerical modelling satisfactorily represented the general behavior of rotation at the moment as well as the deformations of the assemblies from beam to the column.

In general, load-bearing capacity, as well as the rotation capacity of TSA-DWA connections, is dependent on the strength of bolts, numbers and diameter of bolts and the thickness of angle.

RECOMMENDATIONS

The results, recommendations, conclusions, and opinions contained in this document show that the results of the analysis compared with experimental data available from the literature lead to the Abaqus simulation program can be used to represent steel connections**.**

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REFERENCES

1. Trahair, N. S., Bradford, M. A., Nethercot, D., & Gardner, L. (2007). The behaviour and design of steel structures to EC3. CRC Press.
2. Danesh, F., Pirmoz, A., & Daryan, A. S. (2007). Effect of shear force on the initial stiffness of top and seat angle connections with double web angles. *Journal of Constructional Steel Research*, *63*(9), 1208-1218.
3. Owens, G. W., & Cheal, B. D. (1989). Structural Steelwork Connections, Butterworth, 1st Edition, London.
4. Wang, Y. C., Dai, X. H., & Bailey, C. G. (2011). An experimental study of relative structural fire behaviour and robustness of different types of steel joint in restrained steel frames. *Journal of Constructional Steel Research*, 67(7), 1149-1163.
5. Kulak, G. L., Fisher, J. W., & Struik, J. H. A. (1987). Guide to design of semi-rigid frames.
6. Maggi, Y. I., Gonçalves, R. M., Leon, R. T., & Ribeiro, L. F. L. (2005). Parametric analysis of steel bolted end plate connections using finite element modeling. *Journal of Constructional Steel Research*, *61*(5), 689-708.
7. Prabha, P., Rekha, S., Marimuthu, V., Saravanan, M., Palani, G. S., & Surendran, M. (2015). Modified Frye–Morris polynomial model for double web-angle connections". *International Journal of Advanced Structural Engineering (IJASE)*, *7*(3), 295-306.
8. Ghindea, M., Catarig, A., & Ballok, R. I. (2015). Semi-rigid behaviour of bolted connections using angle cleats part 1. Development of 3-d finite element model. *Buletinul Institutului Politehnic din lasi. Sectia Constructii, Arhitectura*, *61*(4), 53.
9. Ahmed, A., & Hasan, R. (2015). Effect and evaluation of prying action for top-and seat-angle connections. *International Journal of Advanced Structural Engineering (IJASE)*, *7*(2), 159-169.
10. Sulong, N. R., Elghazouli, A. Y., Izzuddin, B. A., & Ajit, N. (2010). Modelling of beam-to-column connections at elevated temperature using the component method. *Steel and Composite Structures*, *10*(1), 23-43.
11. Abolmaali, A., Kukreti, A. R., & Razavi, H. (2003). Hysteresis behavior of semi-rigid double web angle steel connections. *Journal of Constructional Steel Research*, *59*(8), 1057-1082.
12. Xinwu, W. (2007). Experimental Research on Hysteretic Behavior of top-seat and web Angles Connections. In *5th WSEAS International Conference on Environment, Ecosystems and Development, Tenerife, Spain*, 14-16.
13. Shi, G., Shi, Y., Wang, Y., & Bradford, M. A. (2008). Numerical simulation of steel pretensioned bolted end-plate connections of different types and details. *Engineering Structures*, *30*(10), 2677-2686.
14. Shi, G., Shi, Y., & Wang, Y. (2007). Behaviour of end-plate moment connections under earthquake loading. *Engineering structures*, *29*(5), 703-716.
15. Kishi, N., Ahmed, A., Yabuki, N., & Chen, W. F. (2001). Nonlinear finite element analysis of top- and seat-angle with double web-angle connections. *Structural Engineering and Mechanics*, *12*(2), 201-214.
16. Azizinamini, A., & Radziminski, J. B. (1989). Static and cyclic performance of semirigid steel beam-to-column connections. *Journal of Structural Engineering*, *115*(12), 2979-2999.

