IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 18, Issue 1 Ser. IV (Jan. – Feb. 2021), PP 06-21
www.iosrjournals.org

Parametric Studies and Investigation of Stiffener Effects on Bolted Beam-To-Column Connections

Ahmad Arash Baheej[1], Ahmad Waheed Rayea Khatibi[2],
Parisa Mohandespoor[3], Abdullah Anis[4], Sayed Abdul Baset Mododi[5]
Fatimah Samim[6]

1- Civil Engineering Department, Herat University Associated Professor
2- Civil Engineering Department, Herat University Associated Professor
3- Architecture Engineering Department, Herat University Associated Professor
4- Civil Engineering Department, Herat University Associated Professor
5- Civil Engineering Department, Herat University Associated Professor
6- Civil Engineering Department, Herat University Associated Professor

Abstract:
Steel structures are considered the most common structures in the world. In these structures, joints play an essential role in evaluating performance and seismic behavior. Therefore, achieving optimal design criteria that have the ability to use the maximum capacity of connections, has always been considered. In this research, numerical studies have been performed to evaluate the seismic performance of bolted beam-to-column joints with endplates and also the effect of stiffeners on the seismic performance of connections. In this regard, by considering 3 main parameters (column stiffener, endplate stiffener, and bolt diameter), 8 models of beam-to-column bolted connections have been created in Abaqus finite element software. In order to validate the numerical model, the outputs were compared with the results of the experimental model, which indicated an error of less than 4% for the numerical model. The results of this study show that the use of beam and column stiffeners without increasing the bolt resistance has a negative effect on the seismic performance of the joint, but with the application of both stiffeners and increasing the bolt resistance, the seismic performance of the joint increases up to 2 times. The results also show that increasing the thickness of the endplate stiffener reduces the seismic performance of the joint.
Keywords: Joints, Stiffness, Endplate, Bolts, Stiffeners, Seismic performance, Beam-to-column connection

---

Date of Submission: 10-02-2021 Date of Acceptance: 24-02-2021

I. Introduction

Steel structures are one of the most widely used structures in the world, which due to the distinctive features of this structure, the demand for its use is increasing day by day[1-4]. In these structures, joints are considered as one of the key parts in the performance and efficiency of the structure. Today, most of the joints created in steel structures are semi-rigid connections due to the optimal and characteristic performance against seismic loading [5,6].

One of the most common types of semi-rigid joints is the beam-to-column bolted connection. In general, the performance of bolted connections can have a direct effect on parameters such as the stiffness, stability, deformation capacity, bearing capacity, and seismic performance of structures [7].

Therefore, the study and evaluation of the seismic performance of bolted connections are considered as one of the main parameters in the analysis of steel structures.

This issue has become more and more considered by designers and engineers with the occurrence of large earthquakes such as (Norwich 1994 in the United States and Kobe 1995 in Japan) and improper seismic behavior of structures.

Due to the poor performance of traditional bolted joints under seismic loads, various numerical and experimental studies to achieve the optimal and ideal design of this type of joints began and continue to this day [8-10].

One of the types of bolted joints is the connection of the beam to the column with the endplate. In this connection usually, the endplate is bolted to the column by several rows of bolts, and the beam is connected to the endplate by welding.

This connection has improved the behavior of the structure in these conditions due to its semi-rigid performance against seismic loads and is widely used in steel structures.

To date, various numerical and analytical studies have been performed on the semi-rigid performance of joints as well as their seismic performance [11], the evolution of which can be classified as follows:

Most of the studies on the performance of bolted connections to date, in all three numerical, analytical, and experimental approaches have been focused on predicting and investigating the moment-rotation behavior and consequently evaluating the rigidity of bolted joints.

In the numerical studies approach, we can refer to the research of Krishnamurthy et al.,[12-14] who for the first time presented the numerical modeling procedure using the finite element method (FEM) in three-dimensional space to evaluate the behavior of bolted connections.

Ismail et al. [15] In a numerical study, a stiffened single-sided connection was subjected to parametric studies focusing on the geometry of its components. The results of this study showed that the presence of hardener in the end plate increases the flexural strength of the connection as well as its rotation.

Shi et al. [16,17] performed an experimental study on the performance of bolted connections with endplates, with or without stiffeners. In their studies, the focus was on parametric evaluation and assessment of connection performance under variables such as endplate thickness, endplate and column web stiffeners as well as bolt diameter.

Abidelah et al. [18,19] Extensive experimental and numerical studies were performed to investigate the stiffening effect on the performance of beam-to-column joints.

Merad et al. [20] Parametric studies were performed to evaluate the performance of bolted beam-to-column joints, in which parameters such as flange and endplate stiffness and pre-stressing of bolts in a tension zone were evaluated.

Researchers have conducted various numerical and experimental studies to evaluate the seismic performance of joints. In this regard, Zhang et al. [21] by conducting studies on a beam-to-column joint with T-shaped cast-steel energy-dissipating members examined the performance of the joint under cyclic loading. it should be noted that these members easily It has the ability to be repaired and replaced.

Zhang et al. [21] succeeded in designing a pre-stressed self-centering beam-to-column joint based on their researches using numerical and experimental methods. In this research, experiments performed on this connection in the form of cyclic loading showed that this connection can be adjusted after the earthquake and has the ability to withstand aftershocks.

In this paper, a finite element numerical model based on Abaqus software has been developed to evaluate the performance of the beam-to-column bolted connection and investigate the effect of stiffeners on the seismic behavior of the joint.

In order to match the numerical model with the nature of performing beam-to-column bolted connections, all details including nonlinear material and geometric behavior, bolt pre-stressing force, contact between model parts have been defined and implemented. Also, in order to evaluate the accuracy and validation of the model, the outputs of the numerical model have been compared with the results of the experimental research of Shi et al. [16].

II. Specification of studied joints

In this research, 8 numerical models have been defined and studied to investigate the effect of stiffeners on the seismic performance of beam-to-column bolt connections. Dimensions and geometric characteristics of all models, as well as the details of the beam-to-column connection design, have been selected based on the experimental research of Shi et al. [16].

The defined models represent the bolt connection of the beam to the column with the endplate where the endplate is bolted to the flange column with 4 rows of bolts, also the beam is connected to the column by welding.

The main purpose of this study is to evaluate the effect of stiffeners on the seismic performance of beam-to-column bolt joints. Accordingly, the variable parameters in the definition of the considered models are: Endplate stiffener, column stiffener, endplate thickness and bolts specifications.

Based on the considered parameters, 8 scenarios have been defined for conducting parametric studies and evaluating the seismic behavior of joints under the influence of stiffeners. Table 1 shows the specifications of 8 modeling scenarios.

Table 1: Research Modeling Scenarios

scenarios	Bolt diameter (mm)		Column stiffeners		Endplate stiffeners			Endplate thickness	
	20 mm	24 mm	Yes	NO	No	thickness 8mm	thickness 16mm	20 mm	25 mm
Model 1									
Model 2									
Model 3									
Model 4									
Model 5									
Model 6									
Model 7									
Model 8									

According to Table 1, the main variables of the study included bolt diameter in two cases of 20 mm and 24 mm. Also, in order to evaluate the effect of stiffeners, two general conditions of presence and absence of column and endplate stiffeners have been examined. The four general cases of the created models that indicate the presence and absence of stiffeners are described in Fig.1.

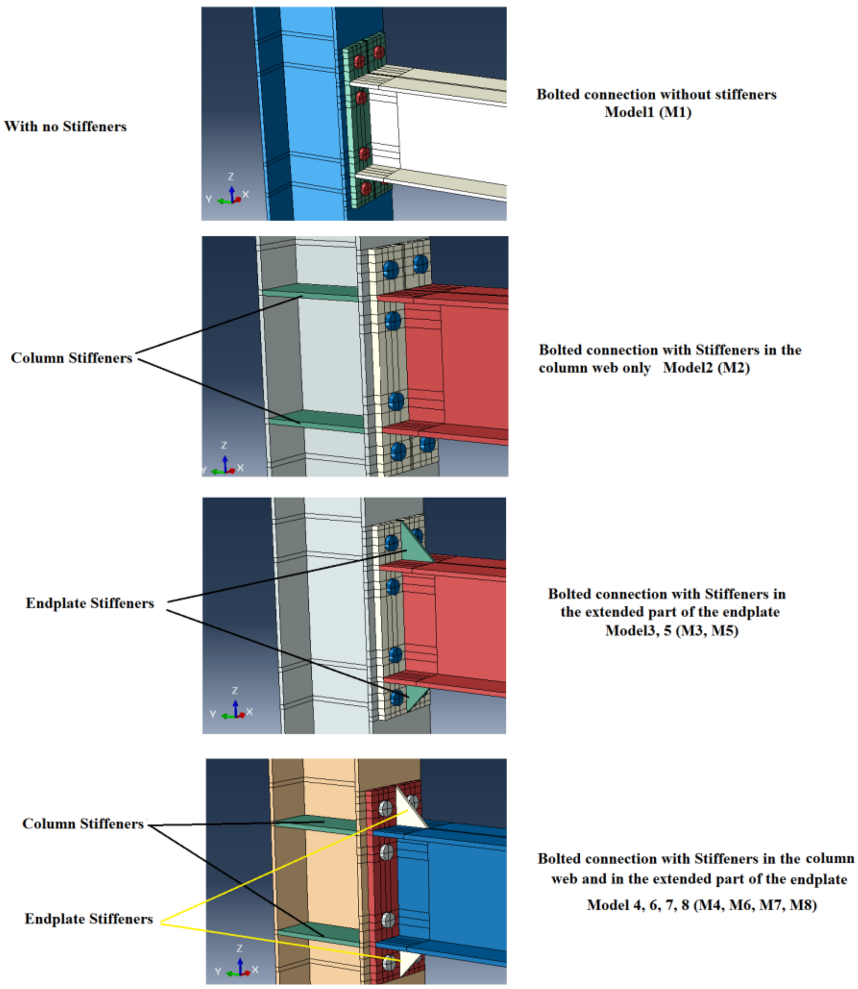
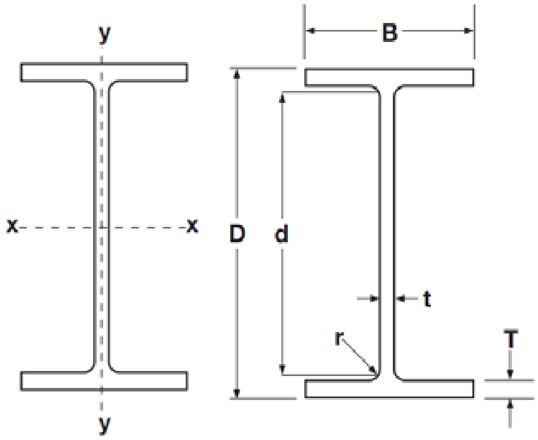


Fig. 1. Configurations of the modeled specimens.

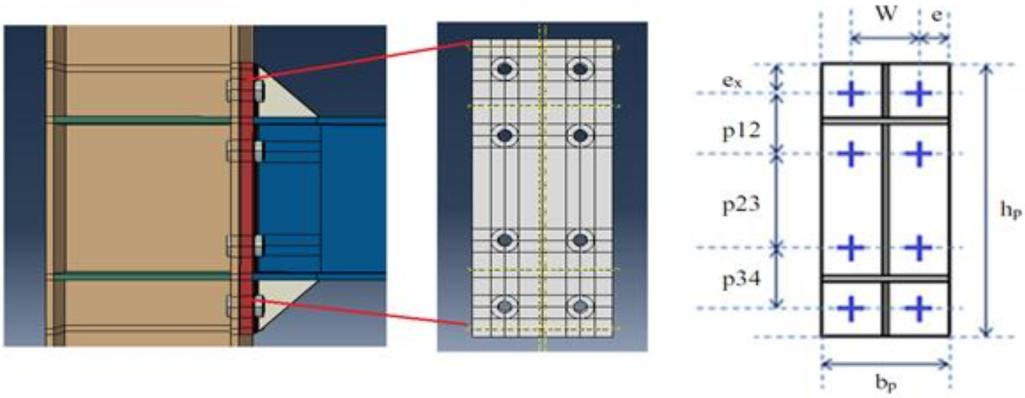
To evaluate the effect of the thickness of the stiffeners, two conditions with a thickness of 8 mm and 16 mm were considered for the endplate. The last parameter is the thickness of the endplate which is examined in two cases of the endplate thickness of 20 mm and 25 mm. In all models, the geometric specifications of the beam and column are considered the same, in Fig. 2, the dimensions of profiles of the beams and columns of the models are shown.



	Column	Beam
Height D (mm)	300	300
Width B (mm)	250	200
Web thickness t (mm)	8	8
Flange thickness T (mm)	12	12

Fig. 2. Dimensions of profiles used in the models connections

In bolted connections, dimensions and geometric details have been one of the most important and influential parameters in the connection performance. Fig. 3 shows the geometric details of the connection and the endplate of the models.



Dimentions (mm)	W	e	ex	p12	p23	p34	bp	hp
	108	46	50	112	176	112	200	500

Fig. 3. Geometrical details of the models

III. Numerical Modeling Details

In this research, in order to implement numerical studies, 8 models are introduced in Abaqus finite element software and the details of the finite element numerical model are as follows.

3-1 Selection of elements and meshing

One of the main steps in numerical modeling in Abaqus software is to define the element type and mesh size. In this study, in order to investigate the seismic behavior of the semi-rigid bolted connection, the C3D8R element has been selected for all components of the joints (including columns, beams, plates, and bolts).

The C3D8R element has 8 nodes as well as 3 degrees of freedom for each node, which has the ability to easily operate and behave different parts of the connection.

3-2 Material properties

To define the material properties of different parts of the joint, the nonlinear model of material behavior is used. To define the elastic and plastic performance of the material, the vonMises yield criterion is used with isotropic hardening. Fig. 4 shows the material stress-strain curve of the various connection parts (Profiles, plates and bolts), which is based on the results of laboratory tests.

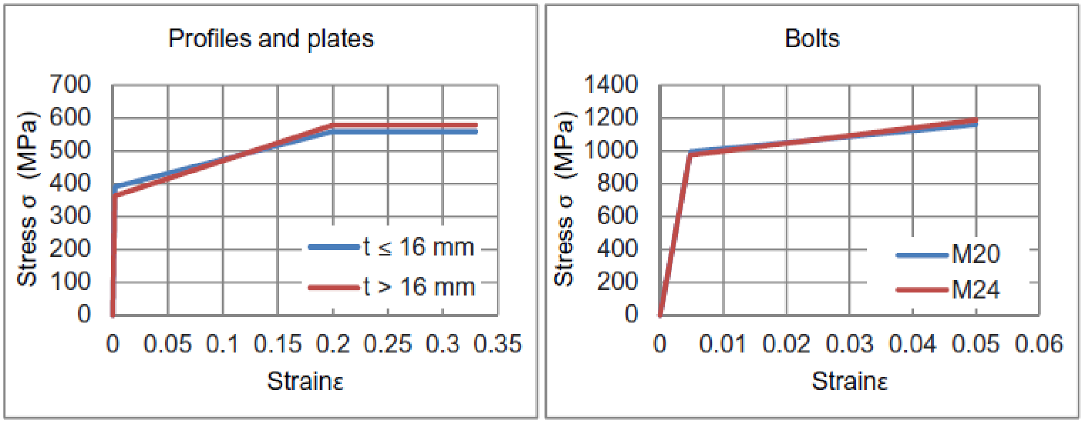


fig. 4. Stress-strain curves (Profiles, plates and bolts), [23]

Also, The elastic limit fy, the ultimate strength fu, Young's modulus E of the different components of the joint, as well as the bolt pre-stressing, are obtained from the experimental tests, previously carried out by Shi et al.[16]. Mechanical characteristics of the materials are shown in Table 4.

Table 2. Mechanical characteristics of the materials

Material	Elastic limit fy (N/mm2)	Ultimate strength fu (N/mm2)	Young's modulus E (N/mm2)	Poisson coefficient ν	Prestressing (KN)
Steel	391	559	190,707	0.3	-
Bolt M20	995	1160	206,000	0.3	185
Bolt M24	975	1188	206,000	0.3	251

3-3 Defining contacts & connections in the numerical model

The principal step of modeling beam-to-column joints is the definition of contacts & connections between different parts of the joint. In order to achieve efficient results from the created numerical model, the contacts between different parts must be correctly identified and defined from a numerical point of view in Abaqus software.
In the created models, the main contacts & connection between different parts of the connection can be categorized as follows:

1- Connection between the endplate and the beam
In the defined models, the connection between the beam and the endplate is welding, so in Abaqus software, using the Tie constraint, we tied the column connection surface to the endplate connection surface and limit all their degrees of freedom to each other. This feature correctly models the welding connection between the two parts.

2- Connection between stiffeners and column, stiffeners and beam, stiffeners and endplate
Due to the connection of the beam to the column and considering the welded connection between the stiffeners and different parts of the model, the Tie constraint has been used to define these connections.

3- Contact between nut and column flange, between bolt head and endplate, between bolt shank and hole
The contacts between the mentioned parts are of frictional contact type, which is defined by using surface-to-surface contact and considering the coefficient of friction equal to 0.44 in Abaqus software.
Fig. 5 shows all the connections and contacts in the numerical models created, along with the description.

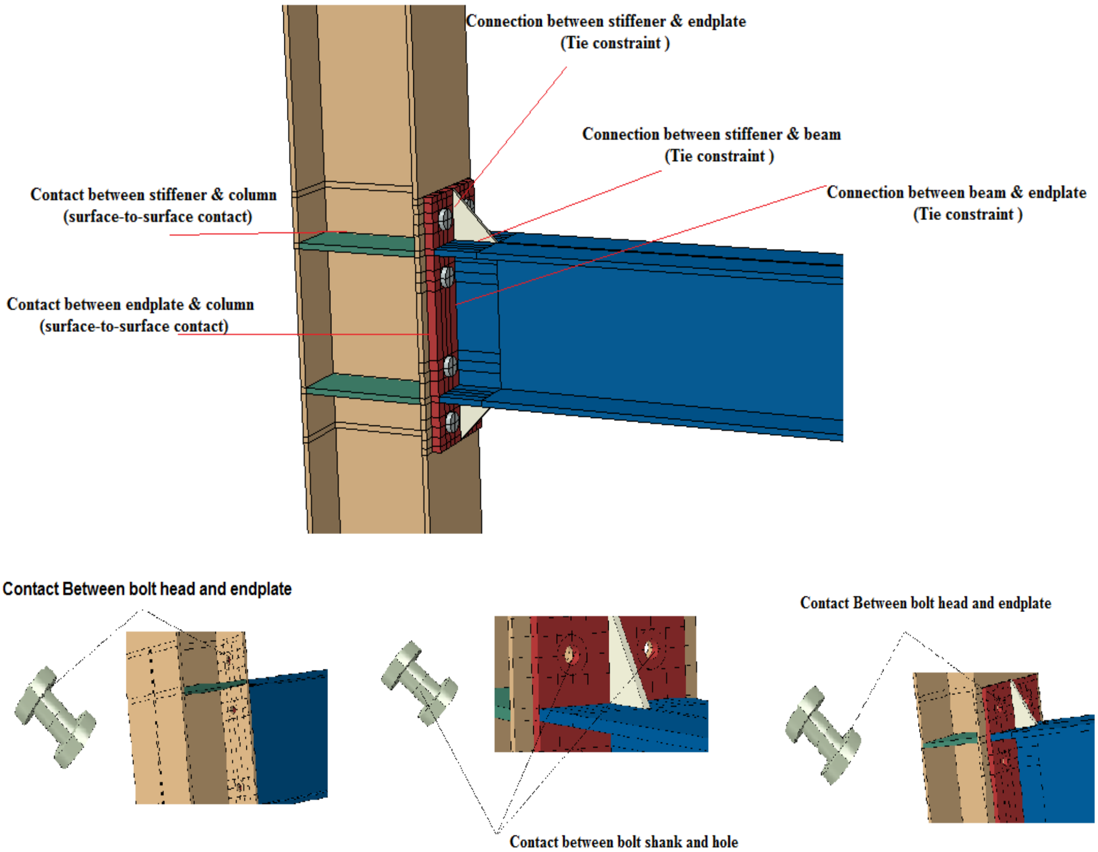


Fig. 5. Connection & contact parts in models

3-4 Boundary conditions and loading

The boundary conditions used in the numerical models of this research are shown in Figure 6.
In this research, the main purpose is to investigate and evaluate the performance of beam-to-column bolted connections under seismic loads. The applied load is modeled according to the ATC-SAC guideline (Figure 7) and by applying this cyclic displacement at the free end of the beam.

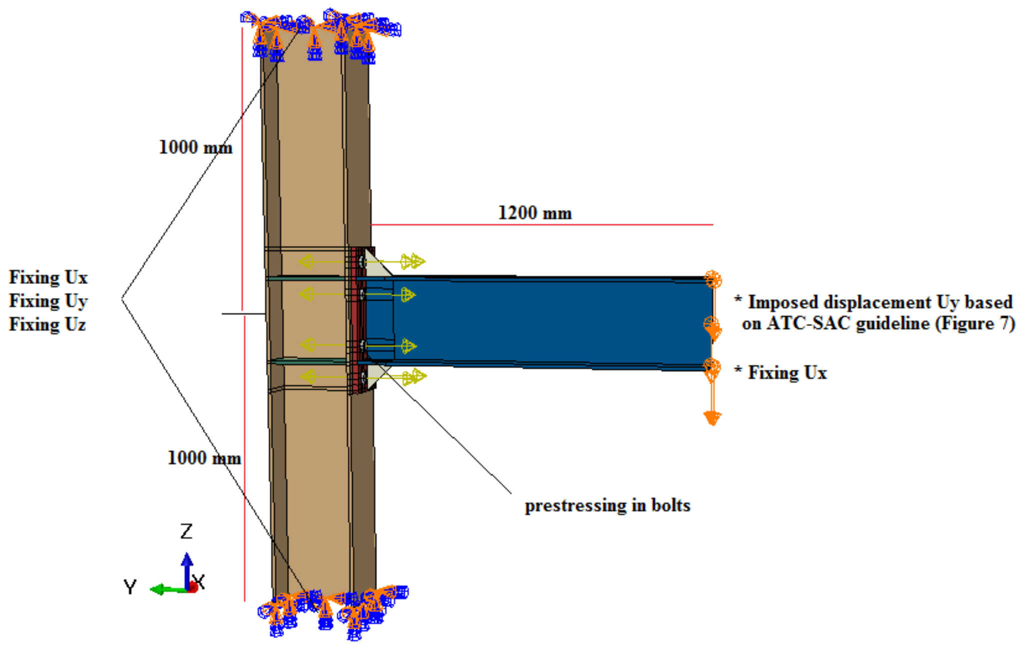


Fig. 6. Boundary conditions and loading in numerical models

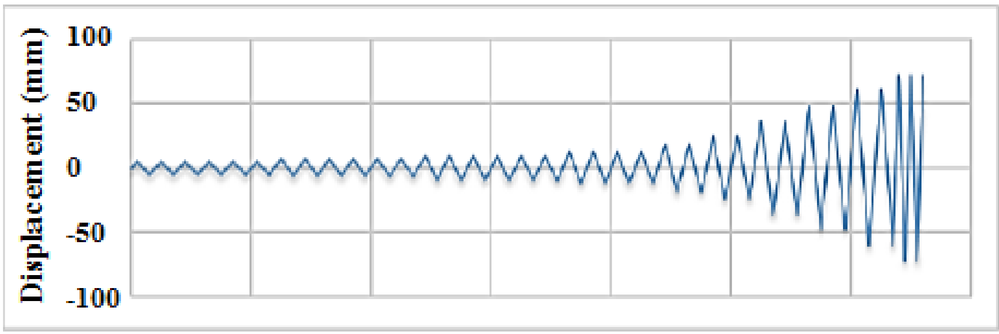


Fig. 7. Displacement Amplitude based on ATC-SAC guideline

IV. Results

In this section, the results of numerical modeling and parametric studies performed according to research scenarios (Table 1) are presented. Also, the results of comparisons between the performance of the numerical model and the experimental model based on shi. et al. [16].

The results presented in this section can be categorized as follows:

1. Numerical model validation and evaluation of Moment-Rotation curve
2. Investigation of seismic performance of joints in 8 models based on the von Mises stress
3. Investigation of hysteresis curve of joints in 8 research models
4. Evaluation of stress and strain in the main part of joints including (endplate and bolts) in each of the models
5. Investigating the amount of energy dissipation in 8 models

4-1 Model validation and evaluation of Moment-Rotation curve

To validate the created numerical model, the moment-rotation curve of the M2 model with the experimental test results performed by shi. et al. [16] has been compared (Figure 8). Also, for more accurate evaluation, two statistical tests, RMSE and MSE, were applied between the results of the numerical model (M2) and the experimental test, the output of which are shown in Table 4.

Table 4. Numerical model error statistical test

RMSE	MSE	Average error %
39.37	6.28	3.37%

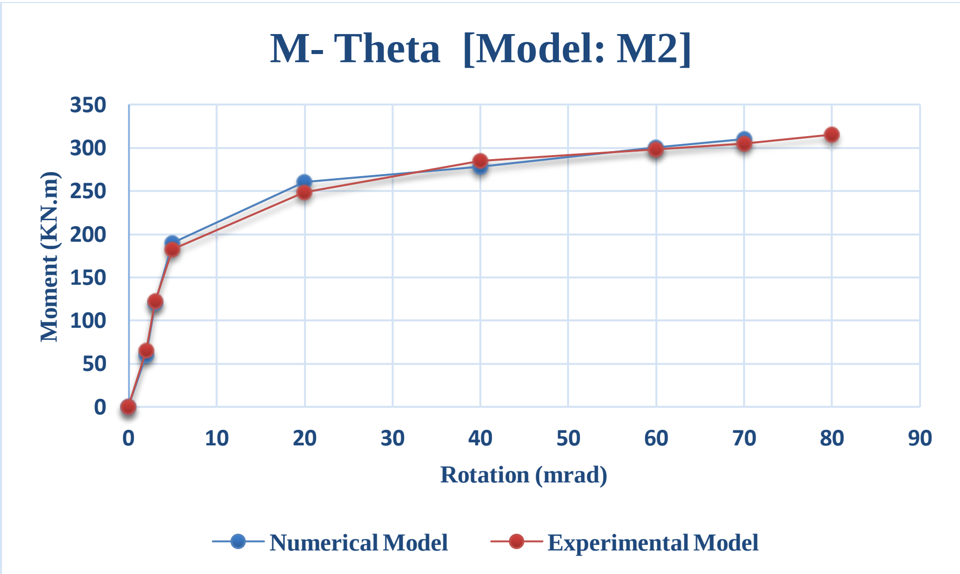


Fig. 8. Comparison of the experimental and numerical moment-rotation curves

Figure 7 shows a comparison between the results of the numerical model (for the M2 model) and the laboratory test.
Also in Table 4, the percentage of modeling error and the values of two statistical tests RMSE and MSE are presented. The results show the high accuracy of the numerical model and the average error of the moment-rotation curve is less than 4%.

4-2 Investigation of seismic performance of joints based on the von Mises stress

In this research, in order to evaluate the seismic performance of beam-to-column bolted joints, various numerical models have been created and subjected to cyclic loading. One of the effective parameters in the investigating of seismic behavior of joints is the amount of stresses created in different parts of the connection under seismic loading. Accordingly, Figure 8 shows the von Mises stresses in 8 numerical models and in the last step of cyclic loading.

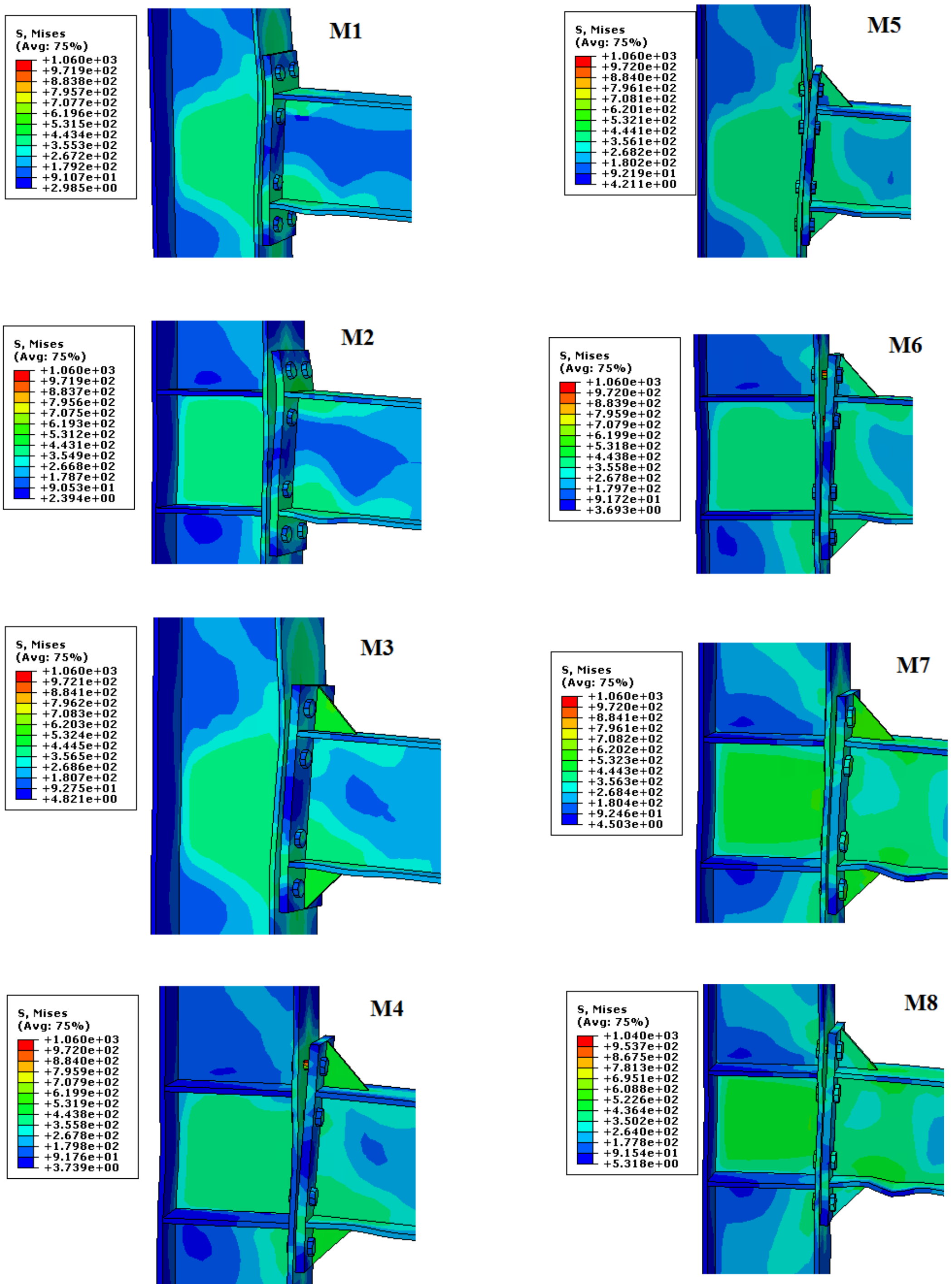


Fig. 9. von Mises stresses in 8 numerical models and in the last step of cyclic loading

Figure 9 shows the von Mises stresses in 8 models of beam-to-column connections. According to the results, it is clear that in M1 model due to the lack of column & endplate stiffener and in M3 and M5 models due to the lack of column stiffeners, the most deformations were created in the column. Also, based on the comparison between the amount of stresses created, it becomes clear that in the models with stiffeners the amount of stresses created in different parts of the connection had larger values, which indicates an increase in the connection stiffness parameter.

Comparing the M3 and M5 models, which have the same modeling details and only the endplate stiffeners thickness is different, it is clear that changing the column stiffeners thickness has little effect on the stress values but changes the stress patterns created in different parts of the connection. In the M5 model, which had thicker stiffeners (16mm), the stress values in the stiffeners were lower than the M3 model.

Comparing the M4 model with the M6 model, which both had an endplate and column stiffeners and the only difference is the thickness of the endplate stiffeners, it is clear that the model with thicker stiffeners experienced greater stresses and consequently had more stiffness.

Comparing between the models with column stiffener and the models without it, shows that in the models with column stiffener, the concentration of stress in the column was in the area between the two column stiffeners.

Comparing the M7 and M8 models with the M4 and M6 models, which have variable bolts parameters, it is clear that increasing the bolt diameter causes larger stresses, which increases the joint stiffness, as well as the displacement of the endplate in Models with bigger diameter bolts were less than models with smaller diameter bolts.

4-3 Investigation of hysteresis curve of joints

In the study of seismic performance of the structure, the concept of displacement of structural components for a certain amount of force was one of the most basic criteria for seismic behavior. The hysteresis curve is presented as one of the main performance outputs of numerical models in Figure 10.

In the investigation of seismic performance of joints, the hysteresis curve indicates the amount of displacement based on the applied forces. In cyclic loadings, this curve helps to assess the seismic behavior of the connection, so that besides showing the amount of displacement based on changes in the applied load in the load cycles, it also examines the amount of bearing capacity and energy dissipation.

According to the description, the higher the stretch of the hysteresis curve (the area enclosed between the curves), the higher the energy dissipation and the better the connection performance against seismic loading. According to the results (Figure 10), it is clear that the M7 model has the best seismic performance among 8 models based on cyclic loading, also according to the results, the M6 model has the weakest performance. As a general conclusion, it can be mentioned that the application of stiffeners increases the connection difficulty and thus reduces the bearing capacity. It should be noted that by increasing the diameter of the bolt and the use of column and endplate stiffeners, we have witnessed the optimal and proper connection performance against seismic loading. Another important point is the effect of the thickness of the endplate stiffeners, which has reduced the proper seismic performance.

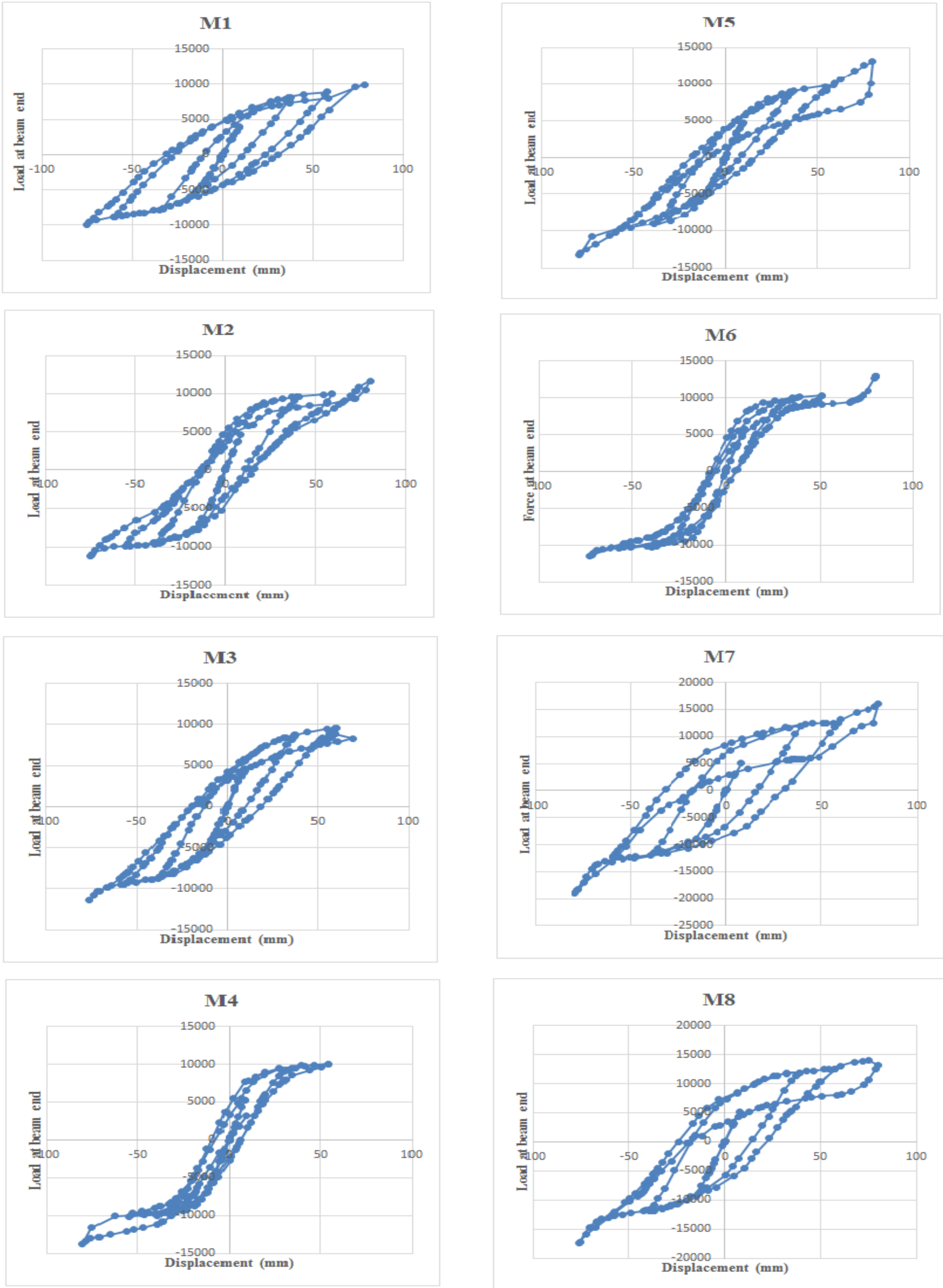


Fig. 10. Hysteretic curves

4-4 Evaluation of stress and strain in the main part of joints including (endplate and bolts)

In joints under seismic loading, stress, and strain in different parts of the connections have been of special importance due to the use of maximum connection capacity. In beam-to-column connection, endplates and bolts are considered as the main elements of the connection. Therefore, the amount of stress and strain created in the numerical models has been investigated and the values of these parameters for the endplates and the bolts are examined.

Figure 11 shows the amount of stress and plastic deformation (strain) introduced in Abaqus software with PEEQ parameter, for the endplates in models M1 to M4 and also in Figure 12 for models M5 to M8.

The amount of stress and plastic deformation in the bolts is shown in Figures 13 (for models M1 to M4) and Figure 14 (for models M5 to M8).

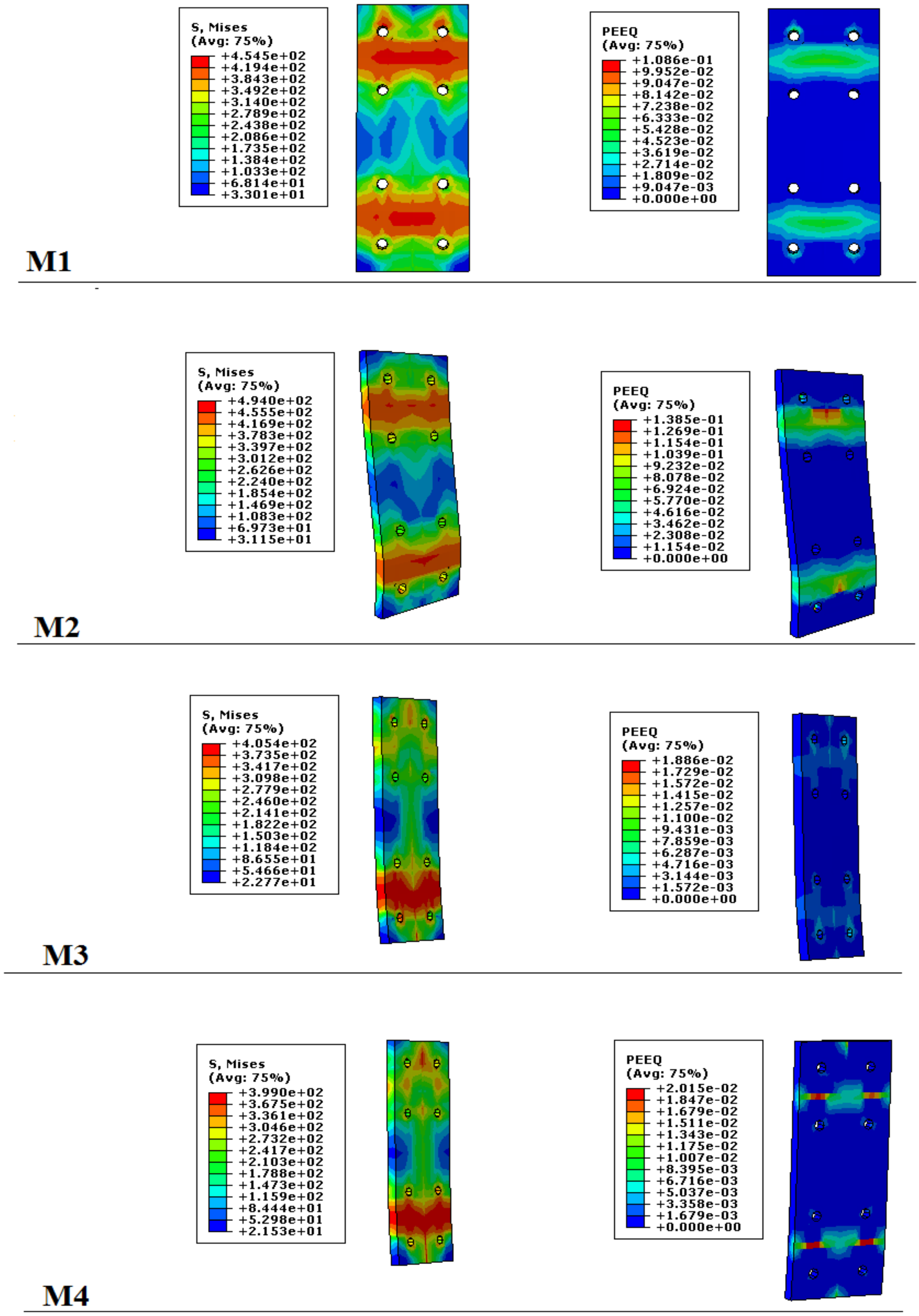


Fig. 11. Stress and plastic deformation on the endplate of M1 to M4 models

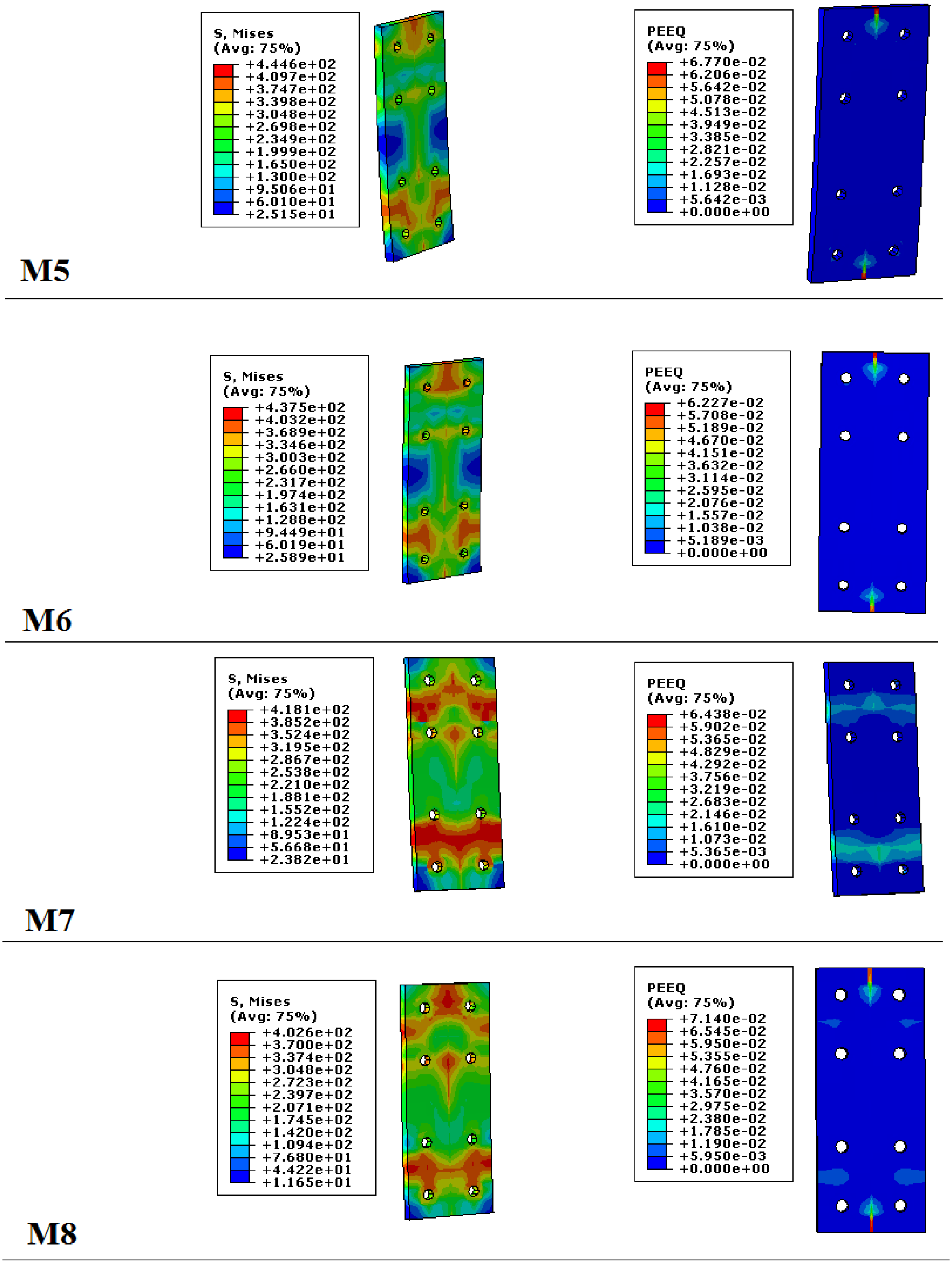


Fig. 12. Stress and plastic deformation on the endplate of M5 to M8 models

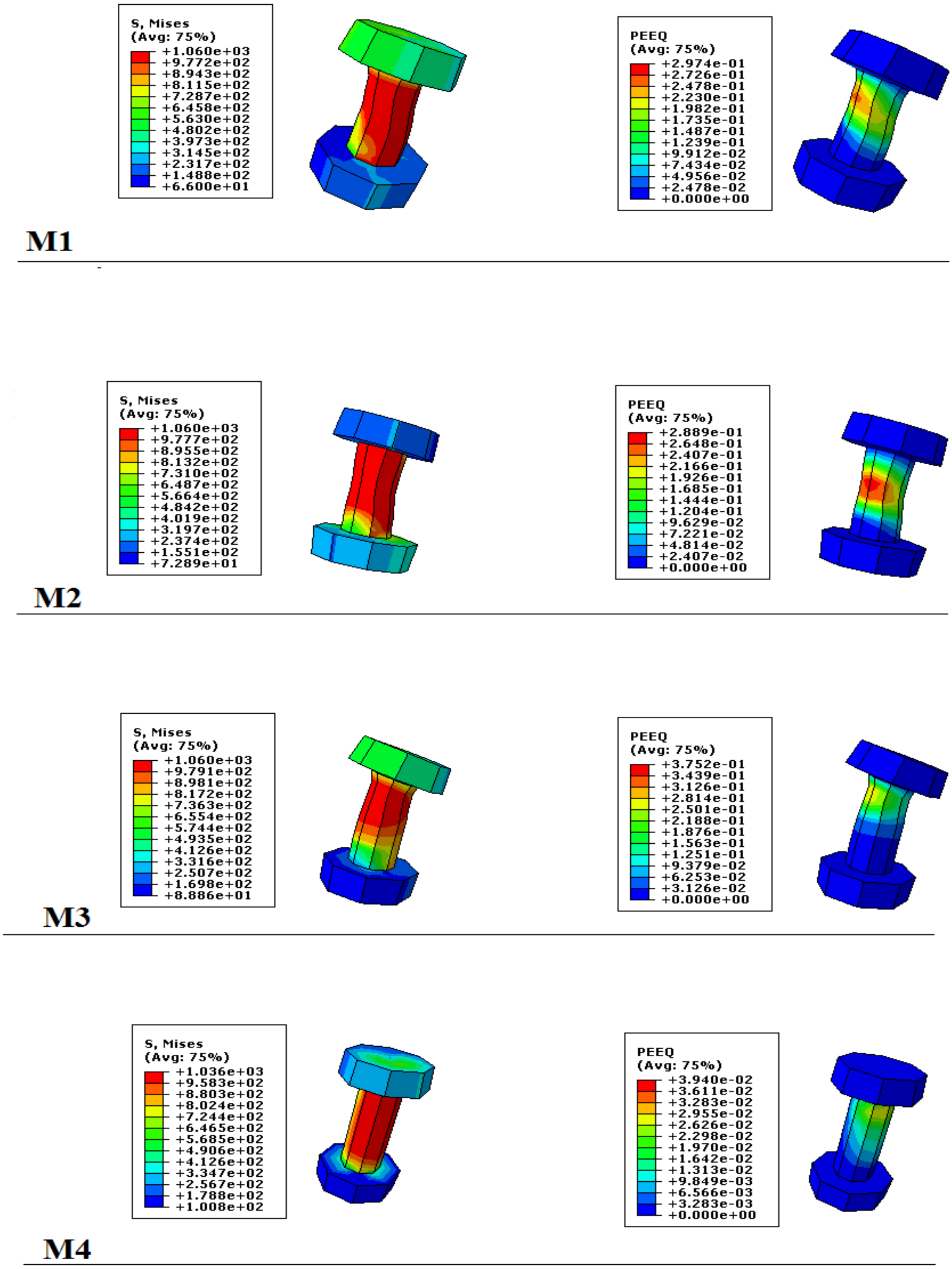


Fig. 13. Stress and plastic deformation on the bolts of M1 to M4 models

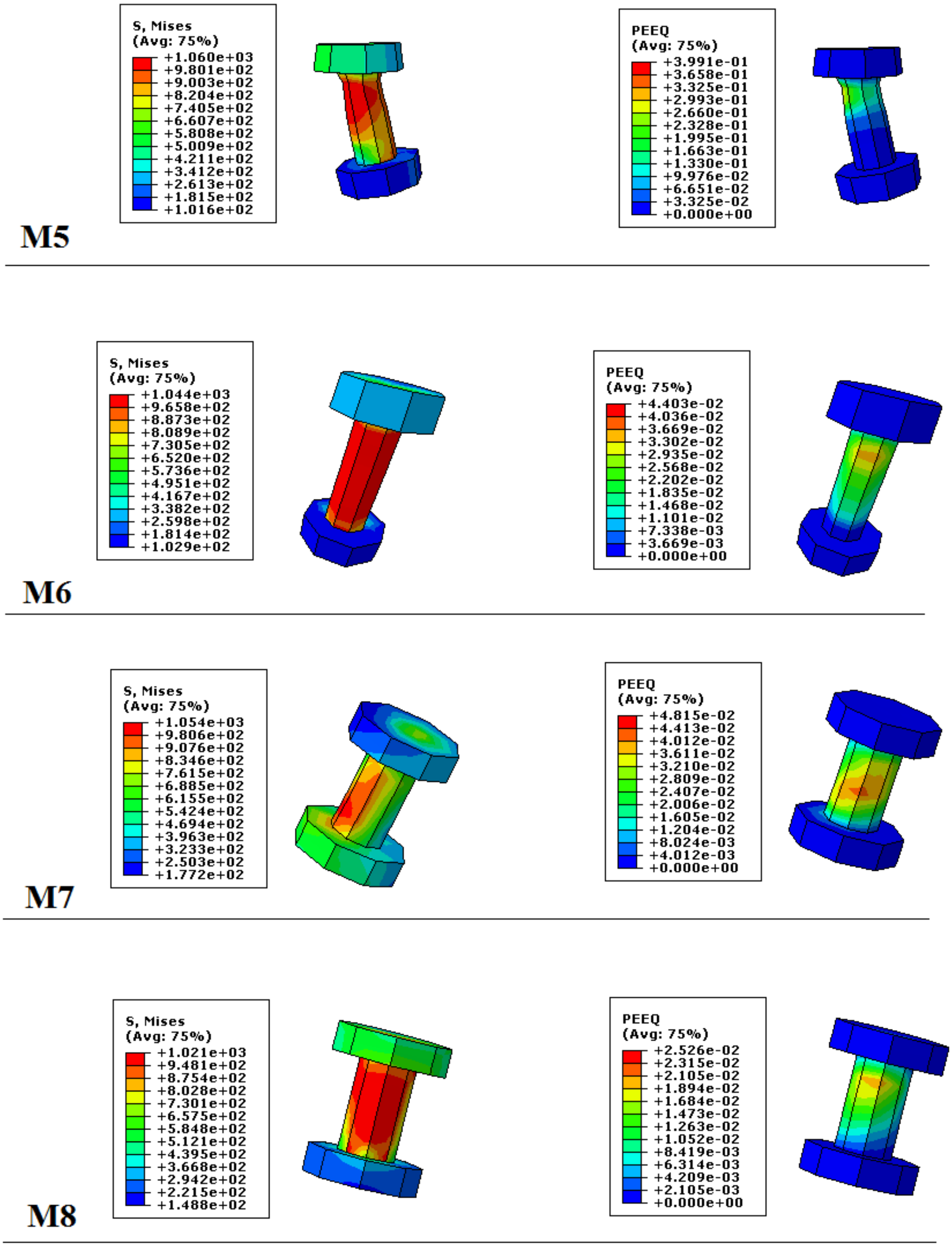


Fig. 14. Stress and plastic deformation on the bolts of M5 to M8 models

4-5 Investigating the amount of energy dissipation in 8 models

One of the main criteria in evaluating the seismic behavior of the connection is the amount of kinetic energy dissipation.

Energy dissipation in the structure takes place in the form of elastic and plastic deformations. It is clear that the higher the energy dissipation of connection, the better performance under the seismic loading.

Figure 15 shows the amount of energy dissipation for the 8 models of connections under cyclic loading.

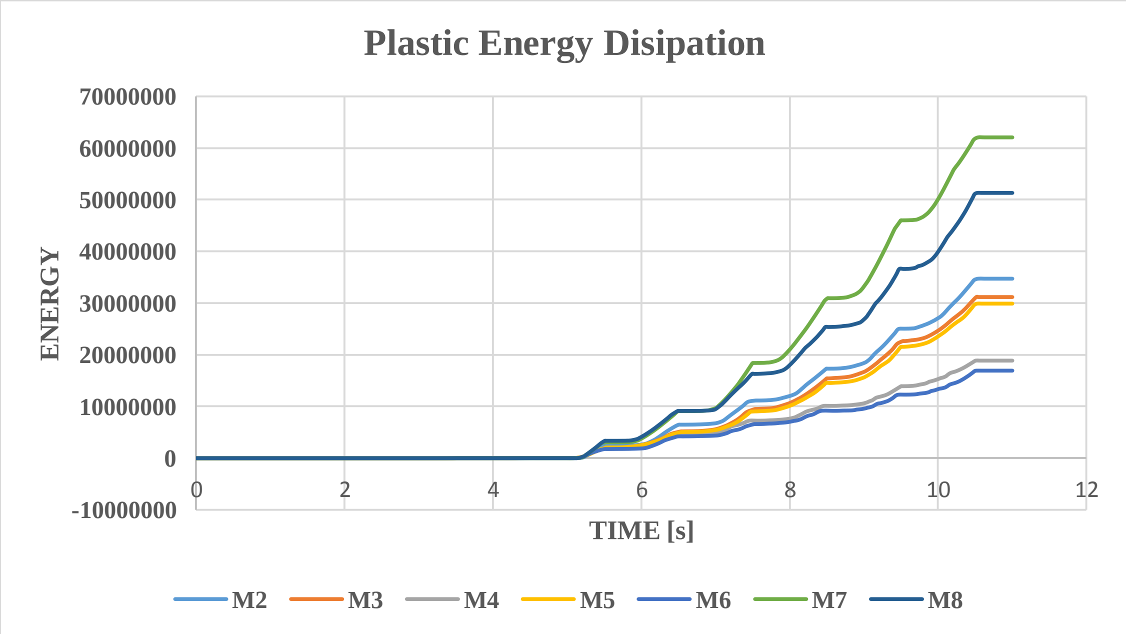


Fig. 15. The amount of energy dissipated by the model joints

According to the results of energy dissipation in the connections of 8 numerical models (Figure 15) and also the explanations provided in the previous section, it is clear that the M7 model has the best seismic performance against cyclic loading and the M6 model has the weakest seismic behavior.

Based on the obtained results, it is clear that the use of stiffeners in beam-to-column joints with endplates without increasing the bolt resistance (increasing the diameter) does not increase the efficiency and improve the seismic behavior of the joints.

It is also found that increasing the thickness of the endplate stiffeners does not improve the seismic performance of the joint and only changes the patterns of plastic deformation and stress propagation. Also, increasing the joint stiffness reduces the bearing capacity against seismic loads.

V. Conclusions

In this research, the seismic performance of beam-to-column bolted connections with endplates under seismic loading has been evaluated. The effect of using stiffeners on the seismic behavior of these joints has also been studied.

In this regard, parametric studies have been performed by considering the variables of bolts diameter, column stiffener, endplate stiffener, and also the effect of endplate stiffener thickness.

To conduct studies, 8 models of beam-to-column bolted connections with endplate have been defined and numerically modeled in Abaqus finite element software. The general results of this research can be classified as follows:

- In this research, studies have been done using numerical modeling and finite element software. In order to check the validity of the modeling, the results of numerical modeling of M2 model have been compared with the results of its laboratory test. The results showed that the error of the numerical model was less than 4% compared to the experimental test.
- Comparing the results of numerical modeling, it was found that the use of column stiffener reduces the elastic and plastic deformations of the column. Also, in these conditions, the stress concentration is located in the area between the two column stiffeners.
- Based on the results of stress and strain contours in different parts of numerical models, it was found that the use of stiffener increases the joint stiffness and increases its rigidity. It was also observed that the use of thicker endplate stiffener did not cause significant changes in the stress created in the joint, but caused a change in the stress propagation pattern and plastic deformation.
- Examining the hysteresis curve of 8 modeled connections, it was found that the M7 model had better seismic performance than other connections, and the M6 model had the weakest seismic behavior against cyclic loading.
- As mentioned, one of the main criteria in the assessment of seismic performance of joints was the amount of energy dissipation of the joint. Considering the energy dissipation of 8 connections (Figure 14), it was found that M8 connection had the best seismic behavior against cyclic loading.

- Based on the results and evaluating the effect of the parameters (end plate stiffener, column stiffener, screw diameter) it was observed that the use of column and endplate stiffeners increases the joint stiffness and rigidity of connection, that is inappropriate for seismic performance of joints. Increasing the bolts resistance (increasing the diameter) with the use of stiffeners has a significant effect on the seismic performance of the joint, so it doubles the amount of energy dissipation (comparing the seismic behavior of the M7 model with the M1 model). Also, increasing the thickness of endplate stiffeners has a negative effect on seismic behavior.

References:

[1]. G.W. Owens, B. Cheal, Structural Steelwork Connections, Butterworth-Heinemann, 1989.

[2]. N.S. Trahair, M. Bradford, D. Nethercot, L. Gardner, The Behaviour and Design of Steel Structures to EC3, CRC Press, 2007.

[3]. X.C. Liu, F.Y. Cui, Z.Q. Jiang, et al., Tension-bend-shear capacity of bolted-flange connection for square steel tube column, Eng. Struct. 201 (2019) 439–460.

[4]. X.C. Liu, X.J. Zhou, A.L. Zhang, et al., Design and compilation of specifications for a modular-prefabricated high-rise steel frame structure with diagonal braces. Part I: Integral structural design, Struct. Des. Tall Spec. 27 (2) (2018) 1–20e1415.

[5]. X.C. Liu, X.N. He, A.L. Zhang, et al., Design and specification compilation of a modular-prefabricated high-rise steel frame structure with diagonal braces part II: Elastic-plastic time-history analysis and joint design, Struct. Des. Tall Spec. 27 (2) (2018) 1–18e1414.

[6]. H.B. Liu, L.L. Xie, Y.Y. Shao, The earthquake damage of steel frame buildings and the causes of brittle facture, World Earthq. Eng. 22 (04) (2006) 47–51(In Chinese).

[7]. A. Colson, R. Bjorhovde, Intérêt économique des assemblages semi-rigides, Construction Métallique 29 (1992) 37–41.

[8]. S.J. Chen, C.H. Yeh, J.M. Chu, Ductile steel beam-to-column connections for seismic resistance, J. Struct. Eng. 122 (11) (1996) 1292–1299.

[9]. M. Nakashima, K. Inoue, M. Tada, Classification of damage to steel buildings observed in the 1995 Hyogoken-Nanbu earthquake, Eng. Struct. 20 (4) (1998) 271–281.

[10]. E. Paul Popov, T. Yang, S. Chang, Design of steel MRF connections before and after 1994 Northridge earthquake, Eng. Struct. 20 (12) (1998) 1030–1038.

[11]. M. Ivanyi, Semi-Rigid Joints Instructural Steelwork, 2000 https://doi.org/10.1007/ 978-3-7091-2478-9.

[12]. N. Krishnamurthy, Modelling and prediction of steel bolted connection behavior, Comput. Struct. 11 (1980) 75–82, https://doi.org/10.1016/0045-7949(80) 90148-0.

[13]. N. Krishnamurthy, L.K. Avery, P.K. Jeffrey, H.-T. Huang, Analytical M-θ curves for end-plate connections, J. Struct. Div. 105 (1979) 133–145.

[14]. N. Krishnamurthy, D.E. Graddy, Correlation between 2-and 3-dimensional finite element analysis of steel bolted end-plate connections, Comput. Struct. 6 (1976) 381–389, https://doi.org/10.1016/0045-7949(76)90016-X.

[15]. R.E. Ismail, A.S. Fahmy, A.M. Khalifa, Y.M. Mohamed, Numerical study on ultimate behaviour of bolted end-plate steel connections, Lat. Am. J. Solids Struct. 13 (2016) 1–22, https://doi.org/10.1590/1679-78251579.

[16]. G. Shi, Y. Shi, Y. Wang, F. Bijlaard, Monotonic loading tests on semi-rigid end-plate connections with welded I-shaped columns and beams, Adv. Struct. Eng. 13 (2010) 215–229, https://doi.org/10.1260/1369-4332.13.2.215.

[17]. G. Shi, Y. Shi, Y. Wang, M.A. Bradford, Numerical simulation of steel pretensioned bolted end-plate connections of different types and details, Eng. Struct. 30 (2008) 2677–2686, https://doi.org/10.1016/j.engstruct.2008.02.013.

[18]. A. Abidelah, A. Bouchaïr, D. Kerdal, Experimental and analytical behavior of bolted end-plate connections with or without stiffeners, J. Constr. Steel Res. 76 (2012) 13–27, https://doi.org/10.1016/j.jcsr.2012.04.004.

[19]. A. Abidelah, A. Bouchaïr, D. Kerdal, Influence of the flexural rigidity of the bolt on the behavior of the T-stub steel connection, Eng. Struct. 81 (2014) 181–194, https://doi .org/10.1016/j.engstruct.2014.09.041

[20]. S.B.Merad Boudia, C.M. Benyelles, N. Boumechra, A.Missoum, A. Bouchaïr, "Comportement Mécanique d'un Tronçon en Té d'Assemblage Boulonné avec et sans Précontrainte," Presented at the Rencontres Universitaires de Génie Civil RUGC'2018, Saint Etienne, 2018.

[21]. A.L. Zhang, Y.X. Zhang, R. Li, et al., Cyclic behavior of a prefabricated self-centering beam-column connection with a bolted web friction device, Eng. Struct. 111 (2016) 185–198.

[22]. Boudia, S. B. M., Boumechra, N., Bouchair, A., & Missoum, A. (2020). Modeling of bolted endplate beam-to-column joints with various stiffeners. Journal of Constructional Steel Research, 167, 105963.

[23]. Liu, X. C., Wang, Y., Cui, X. X., Yu, C., & Bai, Z. X. (2020). Seismic performance of bolted beam-to-column connection with rib-stiffened splicing plate. Journal of Constructional Steel Research, 174, 106300.

Ahmad Arash Baheej, et. al. "Parametric Studies and Investigation of Stiffener Effects on Bolted Beam-To-Column Connections." *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, 18(1), 2021, pp. 06-21.