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Influence of Geometric Parameters on The Performance of Welded Angle Seat Connections Under High-temperature loading

Vahid Saberi [1]*, Hamid Saberi [1], Mohammadali Mastari Farahani [2], Abbasali Sadeghi [3]

[1] Assistant Professor, Department of Civil Engineering, Eyvanekey University, Semnan, Iran.
[2] M.Sc, Department of Civil Engineering, Eyvanekey University, Semnan, Iran.
[3] PhD, Department of Civil Engineering, Mashhad Branch, Islamic Azad University, Mashhad, Iran.

*Correspondence should be addressed to Vahid Saberi, Assistant Professor, Department of Civil Engineering, Eyvanekey University, Semnan, Iran. Tel: +989366671575 ; Email: saberi.vahid@eyc.ac.ir

ABSTRACT

The prevalence of various types of experimental and numerical uses in this area is mostly due to the significance of welded connections in the behaviour of steel moment-resisting frames (SMRFs). The most effective conditions that aggravates the undesirable performance of welded connections is high-temperatures. With regard to conduct analytical research, three types of welded angle seat connections will be selected for finite element modeling (FEM) in ABAQUS software to investigate the performance of them under high-temperature loading. The parameters of increasing thickness, length of welded angle seat connection, and simple connection with angle by adding stiffener are assessed. For this aim, a flexible angle seat connection is used to help the web angle. The characteristics of the web angles and seats are determined based on the features of the beam. Based on the results, the sample COL-ST10-L50-SP15 has the best performance versus other samples. In this sample, beam to column connection is welded angle seat with dimensions such as 10 mm thickness, 50 mm length and 15 mm thickness of stiffener. The displacement of this sample is 502.52 mm under heat conditions. It means that the displacement ratio of the mentioned sample is 18.25% versus reference sample. Therefore, the results showed that by increasing the heat, two important factors should be suggested in the design of steel connections. These factors such as increasing the force due to longitudinal expansion and decreasing the strength and stiffness are considered.

Keywords: Geometric parameter, Connection performance, Welded angle seat connection, High-temperature loading, finite element modeling (FEM)

1. INTRODUCTION

Steel moment-resisting frames (*SMRF*s) are commonly used in earthquake-prone locations because of their great energy dissipation capabilities. In order to maintain the structure's lateral stability, the aim of seismic design of *SMRFs* is to place a plastic hinge in the beam and avoiding its occurrence in the column. With respect to *SMRFs* must have a strength to transmit the shear and bending forces among the elements such as beams and columns, the welded-flange connection was recommended as a connection whose functioning is proper under lateral loading such as wind or seismic excitations. It was discovered that the behavior of this kind of connection was inadequate after a prone earthquake. The welded angle seat connectors were the preferred option. Because this sort of connection was welded in the factory, with adequate supervision and under proper conditions, high-quality welding was achieved [1-3]. Steel structures must protect people and buildings against fire, which is a potential threat. Because of the internal pressures generated by thermal expansion, the material's' reduced strength and nonlinear behaviour at elevated temperatures, more noticeable displacements, and other variables, structural design is done under fire circumstances, resulting in a high level of complexity. Structures can be upgraded in numerous ways. Because the adjustments used in the implemented connections are complicated, one of their characteristics might be the enhancement of stiff connections in *SMRFs*. Another feature is the increasing the dissipated energy of *SMRFs* by considering simple connections, which are likely to have two neighboring buildings with relatively significant displacements [4].

Steel buildings must now be resistant to the lateral loads, such as fire, blast, and vehicle impact. To estimate and evaluate the strength of *SMRF* connections to elevated temperatures or thermal stress has been a key applied subject for engineers and researchers in recent years. As a result, much researches have been performed to conceive the performance of structures under elevated temperatures conditions exactly and the design recommendations are provided for specifying the amount of fire strength in buildings. As a result, exact design criteria have been developed. These criteria are presented in the Eurocode standard, *ISO 834* code [5, 6], and *AISC* [7]. In the following, by using a numerical technique in *ABAQUS* software, this study explores the influence of geometric parameters on the behavior of welded angle seat connections in *SMRFs* under elevated temperature loads. A number of experimental and numerical researches on related themes have been conducted [8]. In the following, some researches about performance of *SMRFs* under high- temperatures are presented. Memari and Mahmoud [9] studied the behavior of *SAC SMRFs* with reduced beam section (*RBS*) under high-temperatures. As their results, the design limit state of the *SMRF* beams reached during the heating phase at high-temperatures ranging from *400* to *600 °C*. Furthermore, the beams met the tensile axial force limit requirement throughout the cooling phase at temperatures ranging from *400* to *600 °C*. The experimental research about *SMRF* under fire loading was conducted on eight flange-welded/web-bolted steel *I*-beam to hollow tubular column connections by Song et al. [10]. The research problem of buckling of *SMRF* subjected to natural fire was investigated by Silva et al. [11]. They conducted a research to check strength estimations of *SMRF* in two different calculations: basic and complex. Their findings showed that basic design approaches were more conservative than complexity of finite element methods (*FEM*). Fischer and Varma [12] conducted parametric research to create *SMRF* structures that have an ability against fire loads with simple connections. Their findings showed that considering slab continuity increased the performance of composite beams under elevated temperatures. In recent decade, there has been a lot of focuses on the influences of high-temperatures on structural elements of *SMRF* such as beams and columns. [13-26]. Rahnavard and Thomas [13] evaluated various numerical modelling methodologies for bolted and welded connections subjected to high-temperature loading. Cai and Young [14] evaluated the performance of single bolted shear connections with cold-formed stainless steel numerically. Jabotian and Hantouche [15] assessed the effect of thermal creep of *SMRF* on shear tab beam-column connectors under high temperatures loading. Their findings revealed that creep must be taken into account when evaluating shear tab connector response to high-temperature loading. Zhu and Li [16] studied the behaviour of welded *SMRF* connections under high temperature stresses. Heating and cooling effects on welded *SMRF* connections were checked. Wald et al. [17] checked and compared experimental models for stiff end-plate connections with considering an emphasis on failure mechanisms and beam center displacement. Also, Yu et al. used an artificial neural network (*ANN*) to explain the stress-strain correlations of *SMRF* connections under elevated temperatures [18]. Sagiroglu [19] investigated bolted *T*-connections under high-temperature loading in an experimental research. Early breaking was clearly evident under high temperature loads. Venkatesh et al. [27] investigated the effect of fire on the structural elements such as beams and columns with varied cover widths, and slabs with varying thicknesses at high temperatures using *3D* nonlinear transient thermomechanical *FEM*. Saberi et al. [28] evaluated the influences of bolt number and material under fire loadig. Six steel stiff bolted connection specimens with end plates were modelled in *ABAQUS* software as *A490* and *A300* and tested under fire loading by using nonlinear dynamic analysis. The results showed that the material *A300* created the maximum stress in the bolt. This was due to the *A300* bolts having a lower yield stress than the *A490* bolts because they were yielded at lower stresses. Saberi et al. [29] studied the geometrical parameters of *T*-connection under elevated temperatures loading. The obtained results showed that by increasing the bolt diameter of the *COL. M16-N4-TST15* and *COL.M20-N4-TST15* samples, the displacement value is reduced *10%* and *14%*, respectively, compared to the reference sample. Haghighat et al. [30] evaluated the behavior of *SMRF* with *RBS* connections under fire conditions. Then, four types of steel frame connections including *RBS* with radial, rectangular, triangular and trapezoidal cuts were modeled in *ABAQUS* software. The results of this study showed that by increasing temperature of the heated area, the transferring of plastic hinge is conducted better. Meanwhile, based on the obtained outputs of displacement-time coefficients, *Frame-RBS-01* sample had the most ultimate strength compared to other samples up to *748.34 ° C* temperature and the least ultimate strength is related to the *Frame-RBS-Rectangle-02* sample up to *526/90 ° C* temperature.

The purpose of this research is to examine the performance of welded angle seat connections in a fire scenario while taking different geometrical aspects into account. In the other word, the analytical study is done to evaluate the influence of changing geometric parameters on the behavior of welded angle seat connections, so considering the three types of models in *ABAQUS* software to evaluate the performance of them by increasing the thickness, length of welded angle seat connection, and simple connection with angle seat connections by adding stiffener. In this connection, two corners are welded from one side to the end of the beam and from the other side to the column. It is not possible to connect even beams to the column due to the high support reaction only by using the web angle. For this goal, a flexible angle seat connection is used to help the web angle. The properties of the web angles and seats are governed by the beam attributes. The presented findings will provide useful information on the comparative statues of various welded angle seat connection kinds, which will assist structural engineers and designers in selecting connections that will conduct the best performance under high-temperature loading.

2. MATERIALS AND METHODS

2.1. STATUS OF STEEL STRUCTURES UNDER HIGH-TEMPERATURE LOADING

Steel structure protection has increased in recent years at airports, supermarkets, parking lots, the oil and gas and petrochemical sectors, and power factories. Steel structures will lose rigidity as a result of the extreme heat, and the specified structures will collapse. A building code's primary goal is to provide a fire-resistant designed environment [5]. The need to protect the structure from fire should be regarded as the most critical part of passive defense by designers. The application of fire protective coating to steel buildings is one of the most significant and practical methods of structural retrofitting in the field of fire engineering [6]. Structure retrofitting as one of the cornerstones of building fire safety can be approached in a variety of ways. In other words, in the event of a structure fire, the capacity of people to evacuate is vital, followed by the possibility of relief by firemen and rescue teams, and finally, the building's stability as a national asset should be safeguarded. The rehabilitation of steel structures against fire is one of the needed categories in the construction industry. It can protect the building's safety while also providing fire alarm and extinguishing systems. If the fire extinguishing system fails to extinguish the fire for any reason, the modified structure will remain stable and provide respite time. In this method, the rescue forces provide persons surrounded by fire enough time to evacuate, allowing the fire to be quenched before the structure collapses. When firefighting facilities are unavailable in high-rise structures, the severity of this issue becomes evident [7]. Although structural steel has the advantage of being non-combustible, its allowable yield strength and modulus of elasticity are reduced at high temperatures.

2.2. FINITE ELEMENT MODELLING (FEM)

The FEM is utilized in this work to model welded angle seat connections by taking into account variations in angle seat length and thickness as well as the addition of stiffener. In this research, all prototypes with geometrical and material nonlinearity were simulated in ABAQUS software. In the following, the steps of research method are presented step by step.

2.2.1. MODELING VERIFICATION

Figure 1 depicts the geometry of the experimental model investigated by Wald et al. [17]. The sample assembly consists of an IPE300 beam with a 5.7 m concrete slab and a HEA300 column linked at mid-height with 2.4 m. This geometry was replicated numerically, except that only half of the length of the beam was modeled. The bearing capacity and behavior of beam-to-column connections were examined in this study by varying the connection parameters against fire stress. Beam-to-column connections, which serve as the interface between the two major sections, are one of the most significant forms of connections.

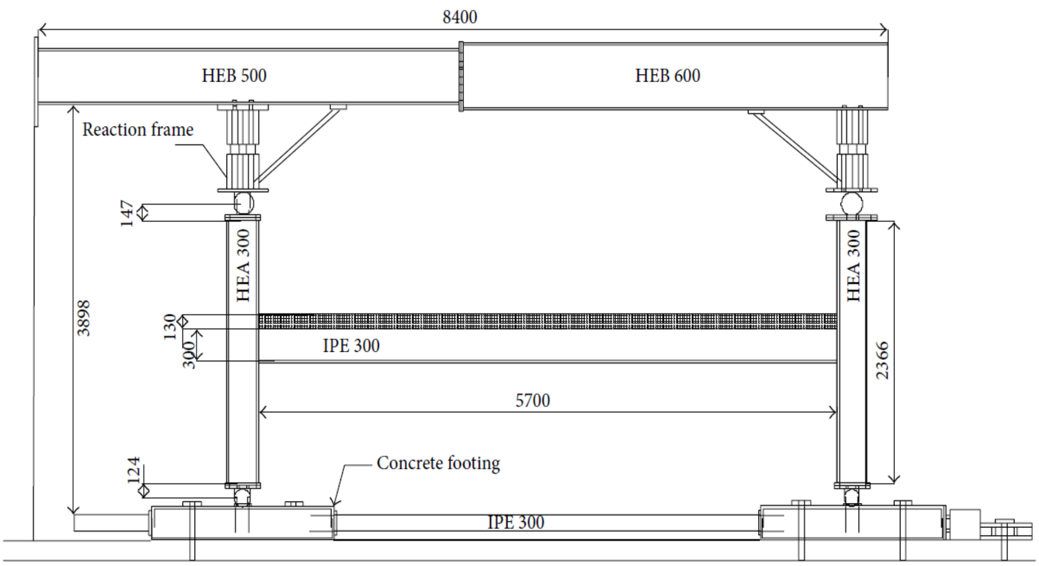
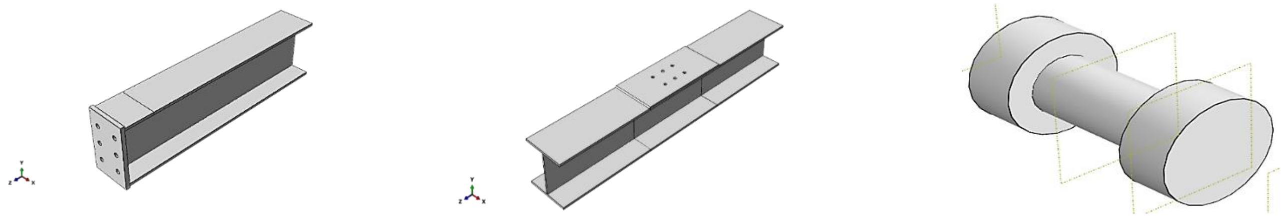
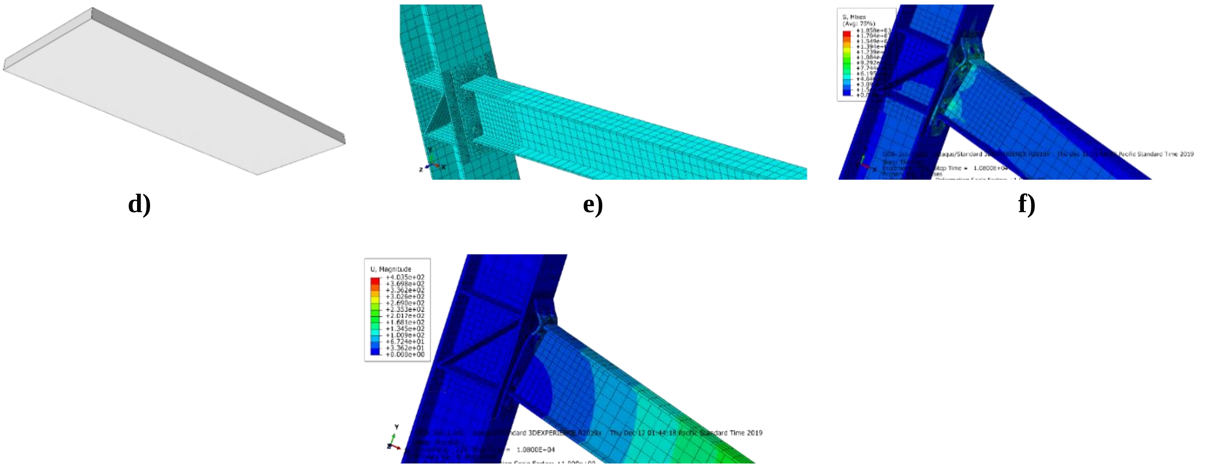


Figure 1. A schematic of an experimental setup of beam-column connection [17]

The findings are obtained in comparison with the results of the reference paper [17] at the conclusion of the verification stage. The visualization module must be used to extract the findings. Figure 2 (a) to **(d)** indicates structural elements such as beam, Column, bolt, and stiffener, respectively. In the following, the mesh of model, von-mises counter, and displacement counter are shown in Figure 2 (e) to **(g)**, respectively.



a) **b)** **c)**



d) e) f)

g)

Figure 2. Numerical inputs of finite element models such as beam, column, bolt, and stiffener and also numerical outputs of finite element analysis

According to the verification model, by increasing the temperature of the attenuated area moved the plastic hinge away from the column, causing the longitudinal strain in these areas to increase considerably outside of the heated parts. The experimental and numerical results are shown based on the displacement curve over time in Figure 3. In the elastic and plastic zones, the displacement-time curve for connection is found to correspond well with the finite element modeling results. The ratio of accuracy in numerical modeling is more than *90%* and the error ratio is *10%* among experimental and numerical modeling approaches.

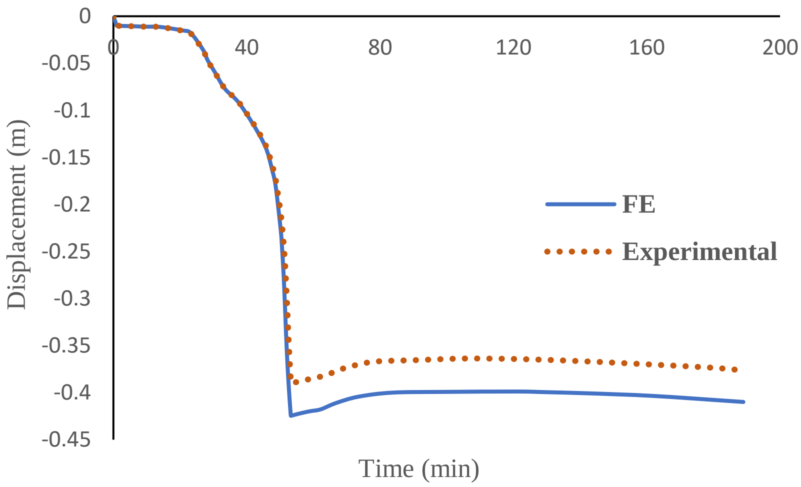


Figure 3. Comparison of numerical and experimental results.

2.2.2. MODELLING PROCEDURE

The analytical study conducted in this research focuses on the effect of changing geometric parameters on the behavior of welded angle seat connections, so considering the three types of models in *ABAQUS* software to evaluate the performance of them by increasing the thickness, length of welded angle seat connection, and simple connection with angle by adding stiffener according to Table 1. Based on Figures 4, 5, and 6, in this connection, two angle seats are welded from one side to the end of the beam and from the other side to the column. The width of the angle seat of it should not be less than *5.7 cm* (*10 cm* is considered in the regulations). To keep the beam in place and provide a transverse support and prevent the beam from rolling, another auxiliary corner is installed and welded on top of it, and the dimensions of this corner are delicate and only the two end edges of its wings are wide. The wings have been shown solely to give a sense of proportion. In this research, the cross section of beam and column is *IPE300x150* with a length of *2 m*. Meanwhile, the kind of weld is Complete Joint Penetration (*CJP*). In this research, a number of mesh studies were carried out during this procedure to test the sensitivity of simulation results for various finite element mesh sizes. According to the findings of this sensitivity analysis, the optimal mesh size for bolts, angles, or end-plates should be *5 mm*, and *10 mm* for beam and column elements. Bolt thread was not explicitly modeled since it would be exceedingly time consuming. Because quantifying the first stress in bolts is challenging, no pre-stress was applied to the bolts. Based on the effective cross-sectional area of one bolt, an *M20* bolt was reproduced by an analogous diameter. In static simulations, "contact controls" were described to solve the convergence difficulty produced by transitory instabilities of rigid body movements in contact and fracture situations.

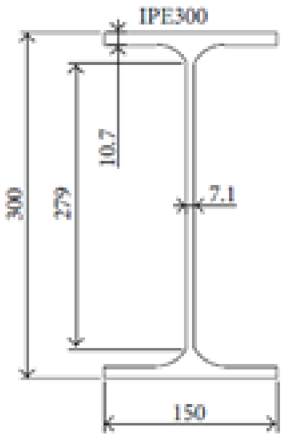


Figure 4. The characteristics of beam and column sections

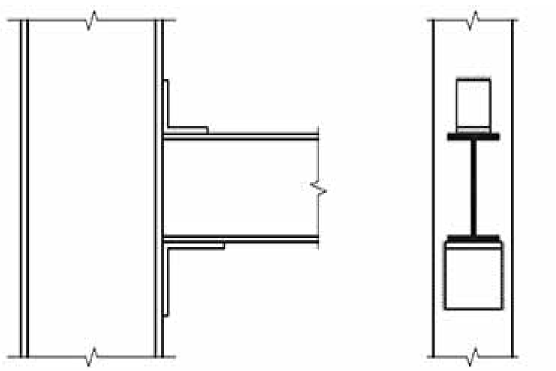


Figure 5. The schematic of beam-to-column connections with welded angle seat

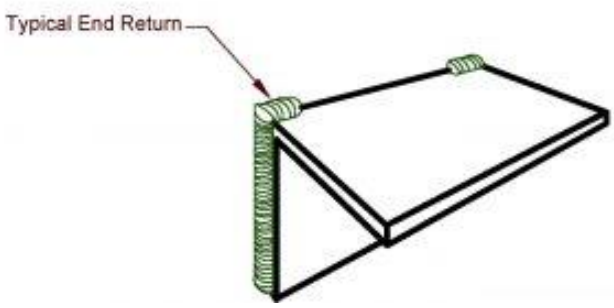


Figure 6. The schematic of welded angle seat connection

Table 1. The features of the mentioned samples in this study

Group	Sample	Weld	Angle seat length (*mm*)	Angle seat thickness (*mm*)	Stiffener (*mm*)
Angle seat connection reinforced by increasing thickness	COL-ST10-L50	CJP	50	10	-
	COL-ST15-L50	CJP	50	15	-
	COL-ST20-L50	CJP	50	20	-
Angle seat connection reinforced by increasing length	COL-ST10-L55	CJP	55	10	-
	COL-ST10-L60	CJP	60	10	-
	COL-ST10-L65	CJP	65	10	-
Simple connection with angle seat and adding stiffener	COL-ST10-L50-SP5	CJP	50	10	5
	COL-ST10-L50-SP10	CJP	50	10	10
	COL-ST10-L50-SP15	CJP	50	10	15

In accordance with *EUROCOD3* standard [6], the values of specific heat capacity and thermal expansion of steel are shown in Figures 7, and 8, respectively. Also, the ratio of modulus of elasticity at different temperatures to modulus of elasticity at *20 ° C* and also the ratio of yield stress at different temperatures to yield stress at *20 ° C* are shown in Figure 9.

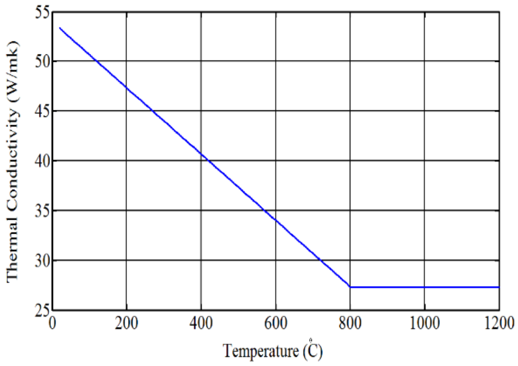


Figure 7. The amount of specific heat capacity of steel material at various temperatures [6]

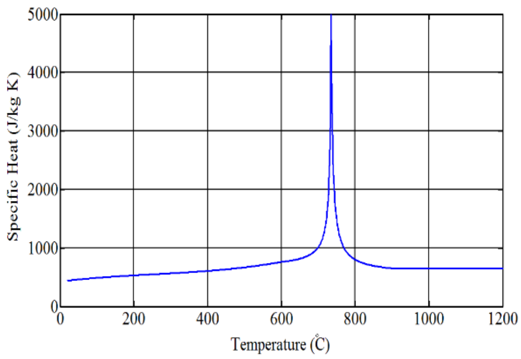


Figure 8. The amount of specific thermal conductivity of steel material at different temperatures [6]

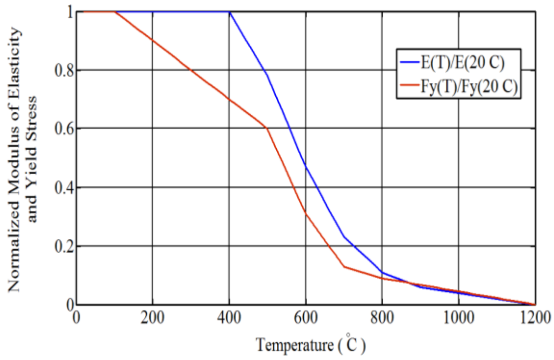
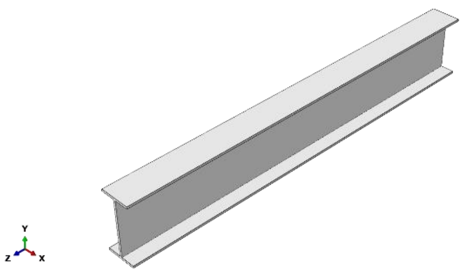


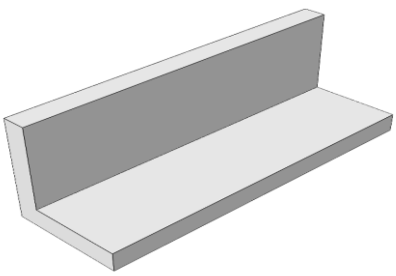
Figure 9. Changes in modulus of elasticity and yield stress of steel material at different temperatures compared to *20 ° C* [6]

2.3. MATERIAL CHARACTERISTICS

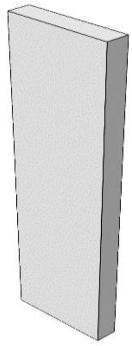
By changing the material features, the structural elements of a beam-to-column connection, such as the beam, column, angle seat, and stiffener, are depicted in Figure 10 (a) to (d). Figure 11 also depicts the model's setup. In the Mesh module, the *C3D8T* element was chosen to model the components of beams, columns, stiffeners, and welding. This element is a three-dimensional, eight-node element that has degrees of freedom of movement as well as temperature. The *C3D8T* element is used to model structural elements in combined mechanical-thermal analysis. Figure 12 depicts the prototype mesh.



a)



b)



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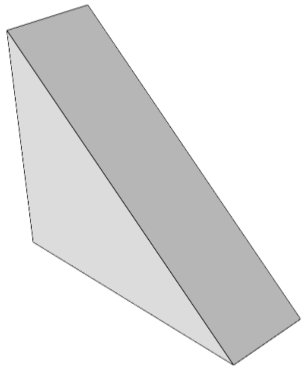
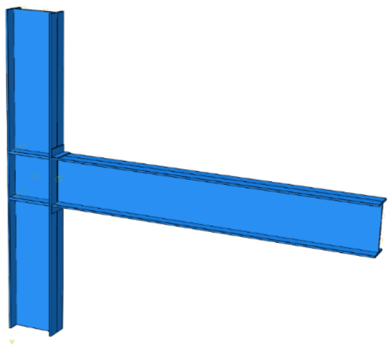


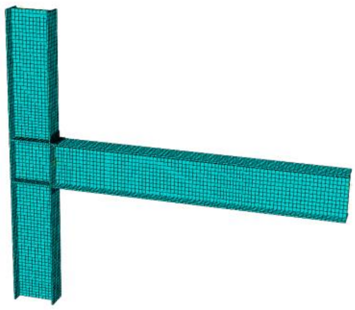
d)

Figure 10. Numerical inputs of finite element models such as a) beam section, b) column section, c) angle seat, and d) stiffener

Also, the configuration of *SMRF* in *ABAQUS* software is presented according to Figures 11 (a) and (b). Based on this figure, in the mesh control section, the shape of all meshes is considered as rectangular and the "Structured" mesh method is considered; only in the partitioned part of the *RBS* sample flanges, the meshing method is considered as "Free". Because the degree of freedom of the elements must be such that the simultaneous effects of temperature and displacement are taken into account, the "*S4RT*" element is used.



a)



b)

Figure 11. a) Configuration of finite element model. b) Mesh of finite element model.

In the following, the various fire curves (temperature-time curve) have a considerable effect on the structure's reaction to fire load. Based on Figure 12, temperature-time curve is extensively employed to analyze the structural behavior of beam-to-column connections by using *ISO 834* code [6]. In *ABAQUS* software, the geometry of steel frames is drawn. Fire analysis is considered as coupled temp-displacement. In order to study the behavior of the studied frames, nonlinear static analysis method is used as lateral displacement application based on reference paper [17]. The type of analysis is defined as "Static General". The distributed load is exerted to the surface of the beam in the frame as a compression of *60 kN*, then gradually, over a period of time, a fire load is applied to the structure. Since the strain stress curves entered in the software are a function of temperature, it is necessary to apply the initial temperature of *20 ° C* to the structure from the initial step based on Figure 12.

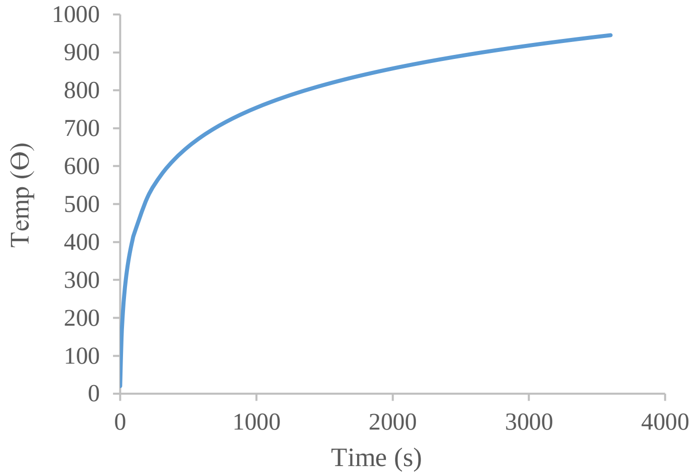
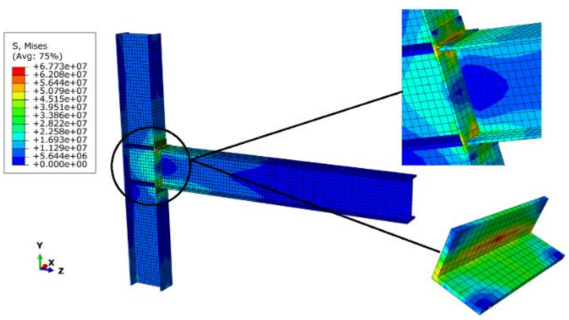


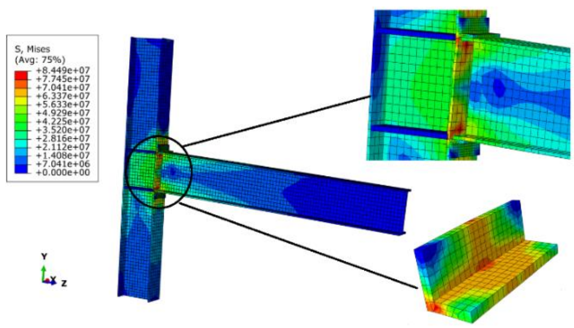
Figure 12. The fire loading curve used in nonlinear analysis

3. RESULTS AND DISCUSSION

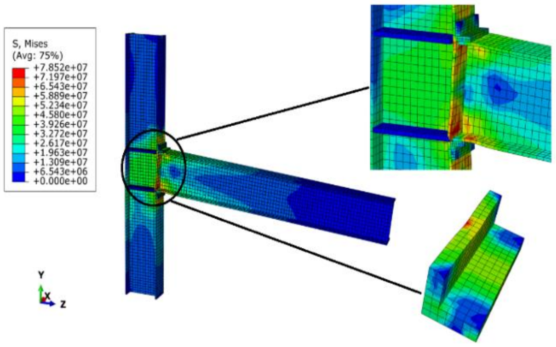
In this section, the results of samples analysis including Von-Mises stress and displacement contours and finally the displacement-time curves are evaluated and compared. According to Figures 13, 14, and 15 (a) to (i), the mentioned values of these samples at the end of fire analysis are also examined and finally the effects of displacement, and stress of members are assessed. In the following, for instance, *COL-ST10-L50* sample is selected for more evaluation. This beam-to-column connection example is represented by an angle seat with dimensions of *10 mm* thickness and *50 mm* length. Following an examination of the samples' displacement values, the phonemic stress arising from their outputs is explored up to the permitted displacement limit. The indicated values in the ultimate loading moment of these samples at the end of fire analysis were then analyzed, and finally, the effects of displacement, stress, and residual strain of members resulting from sample analysis outputs were evaluated. According to Figure 13 (a), the maximum stress in the permitted load range is *673.3 MPa*. According to Figure 14 (a), displacement values in the connecting spring grew dramatically with rising temperature, with the amount of vertical displacement in the middle of the bay reported to be *150.3 mm*. The position of local buckling rises with connection temperature. Meanwhile, the angle seats are discovered to be in the tensile range of the joint to the point of rupture in the compression section in connection with the column, which strengthens the joint. According to Figure 15 (a), displacement has occurred from the start of fire loading. According to the data, the *COL-ST10-L50* sample can tolerate up to *819.29 ° C* before collapsing, which is caused by increasing the load or fire exposure for a period of time, which causes an increase in the temperature of the structural parts and eventually ruptures totally.



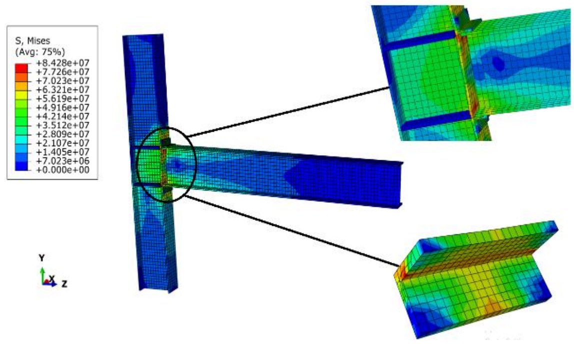
a) COL-ST10-L50 Sample



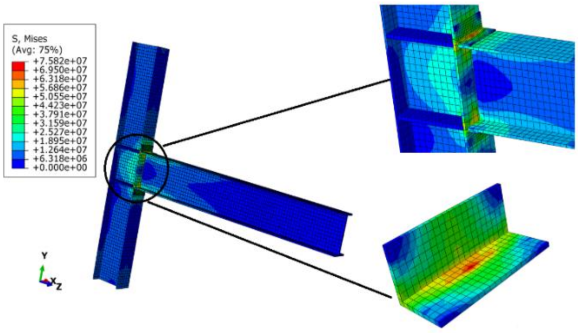
b) COL-ST15-L50 Sample



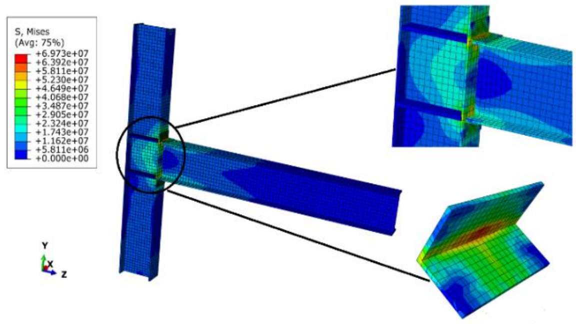
c) COL-ST20-L50 Sample



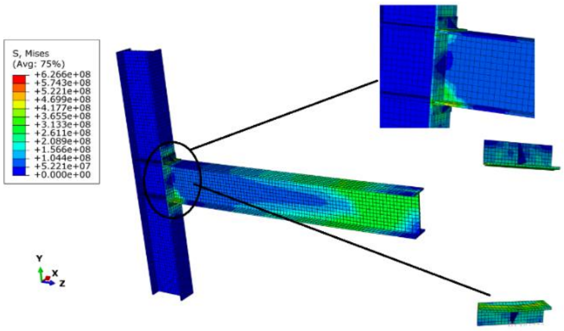
d) COL-ST10-L55 Sample



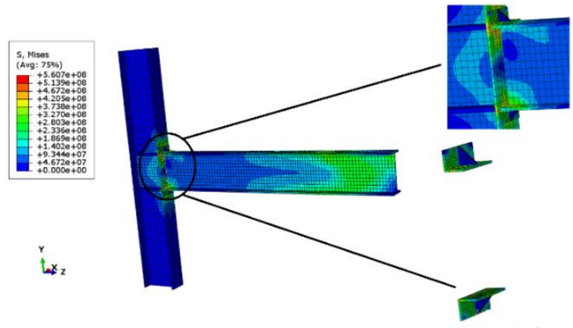
e) COL-ST10-L60 Sample



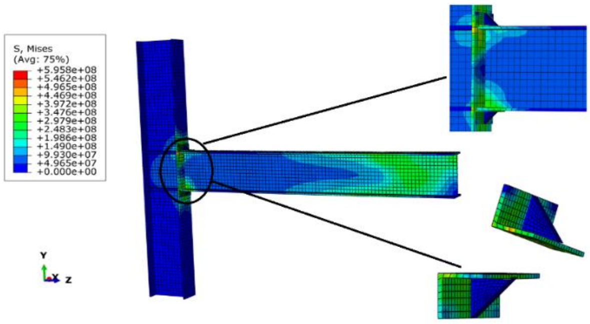
f) COL-ST10-L65 Sample



g) COL-ST10-L50-SP5 Sample

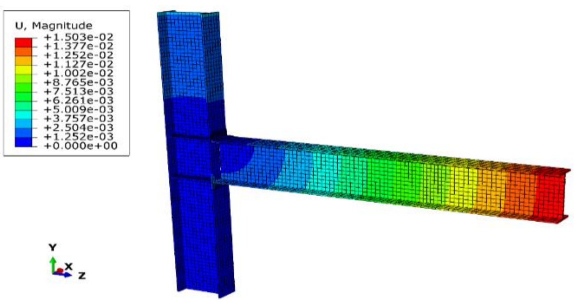


h) COL-ST10-L50-SP10 Sample

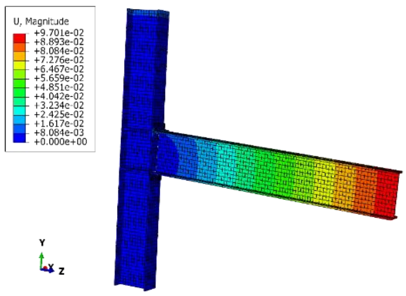


i) COL-ST10-L50-SP15 Sample

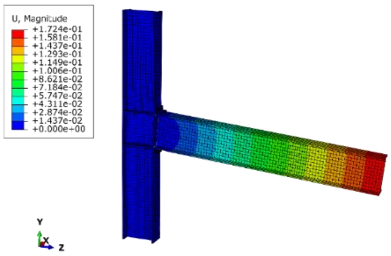
Figure 13. The counter of Von-Mises stress of studied samples.



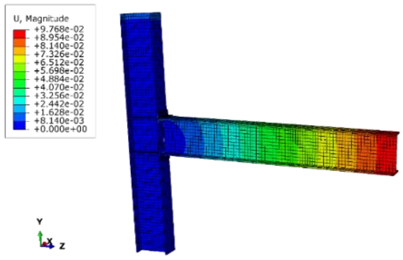
a) COL-ST10-L50 Sample



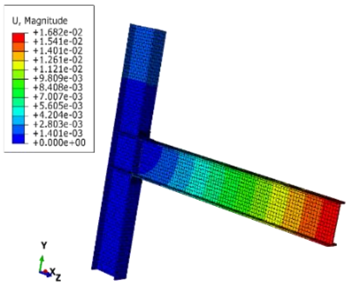
b) COL-ST15-L50 Sample



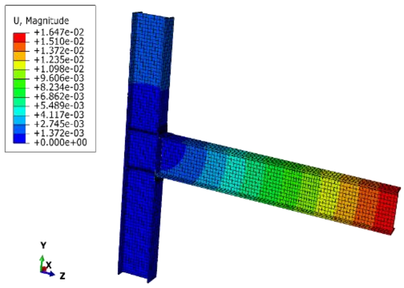
c) COL-ST20-L50 Sample



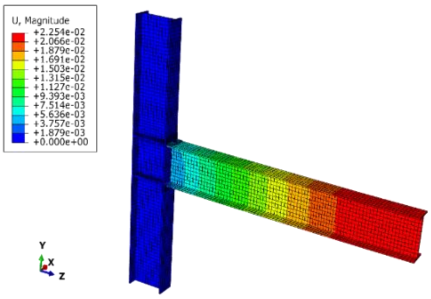
d) COL-ST10-L55 Sample



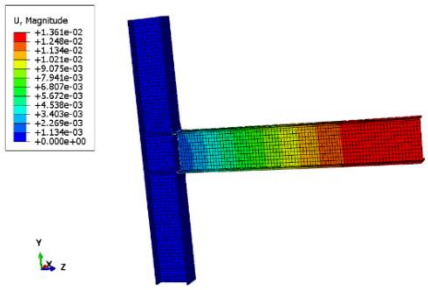
e) COL-ST10-L60 Sample



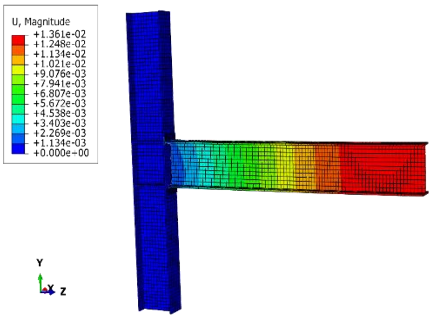
f) COL-ST10-L65 Sample



g) COL-ST10-L50-SP5 Sample

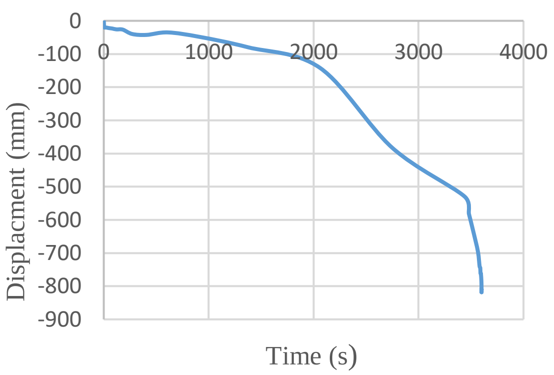


h) COL-ST10-L50-SP10 Sample

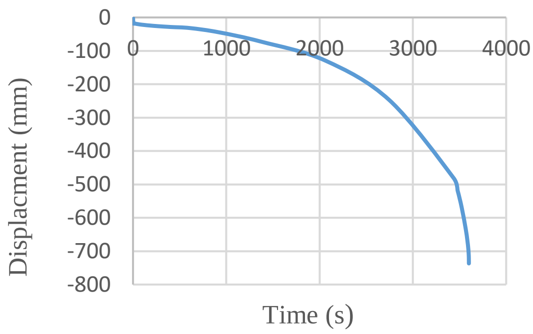


i) COL-ST10-L50-SP15

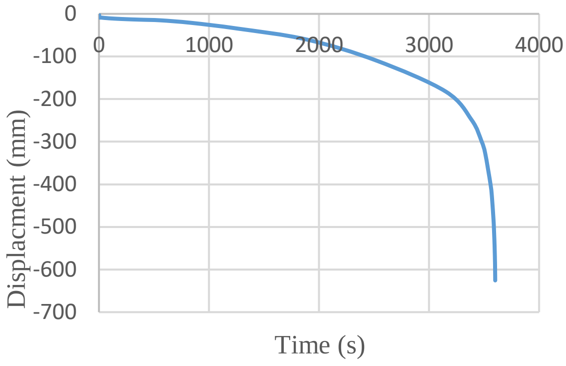
Figure 14. The counter of displacement of studied samples



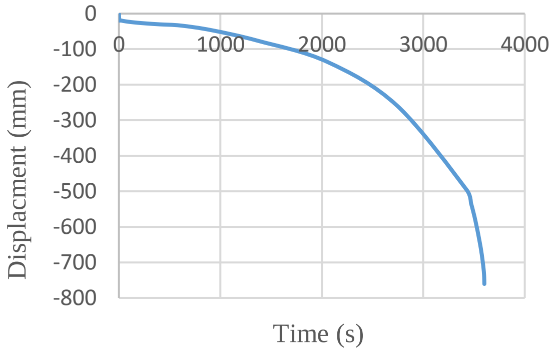
a) COL-ST10-L50 Sample



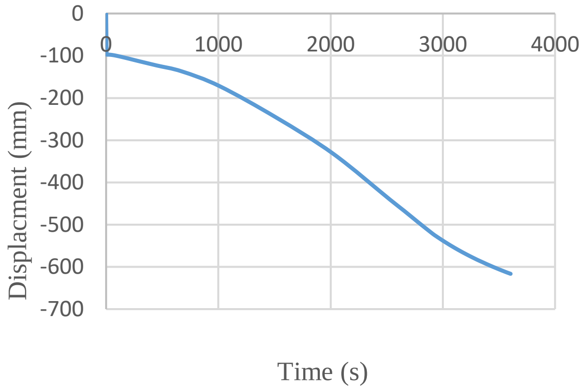
b) COL-ST15-L50 Sample



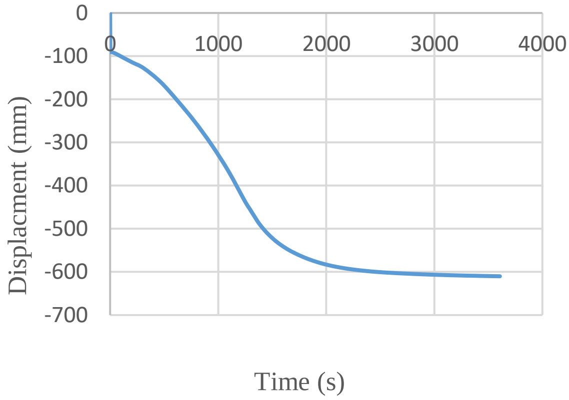
c) COL-ST20-L50 Sample



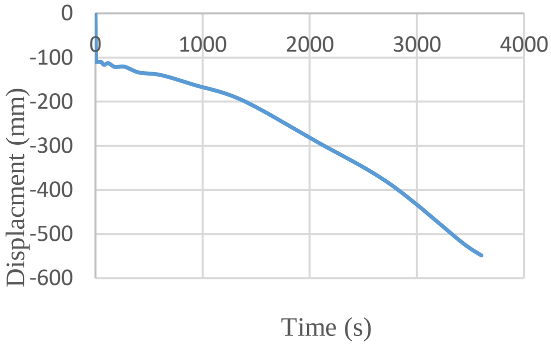
d) COL-ST10-L55 Sample



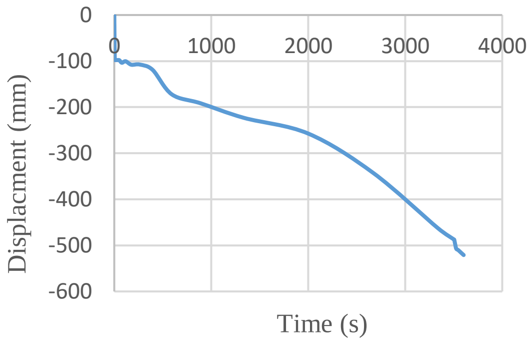
e) COL-ST10-L60 Sample



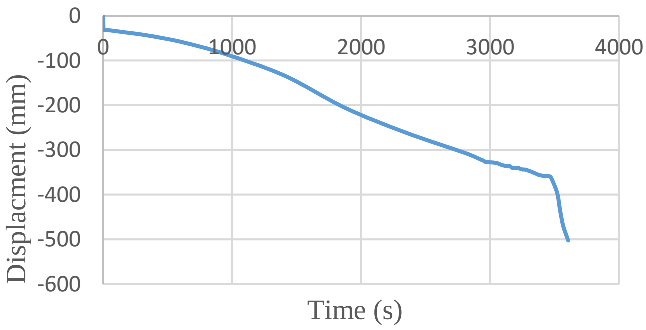
f) COL-ST10-L65 Sample



g) COL-ST10-L50-SP5 Sample



h) COL-ST10-L50-SP10 Sample



i) COL-ST10-L50-SP15

Figure 15. The displacement-time curve of studied samples

A simple shear connection with the help of an angle seat is used to connect a beam to a beam or a beam to a column. In this type of connection, the angle seat should be as flexible as possible. In this simple connection of the beam to the beam, two angle seats are welded to one end of the beam and connected to the column or beam with a spot on the other side. In these three samples, the reinforced angle seats are evaluated by increasing length based on Figure 16.

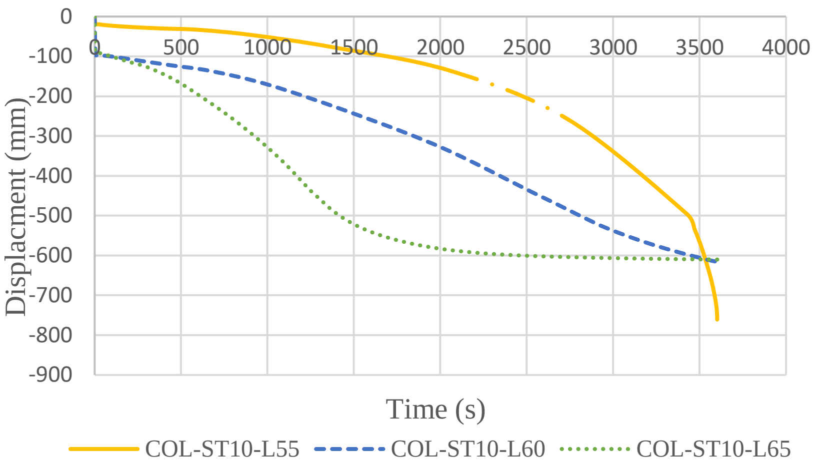


Figure 16. The displacement-time curve for three samples by increasing length of an angle seat connection.

Connections in any structure are considered as the most important parts of the structure, which if the design points are observed in them, and the strength of the structure and if the designer is not careful in their design, the weaknesses of the structure are considered. This is especially important in *SMRF* joints, as part of the lateral load is borne by the joint. In these three samples, the reinforced angle seats are assessed by increasing the ratio of thickness. For a better comparison, all three examples of displacement-time curves are shown based on Figure 17.

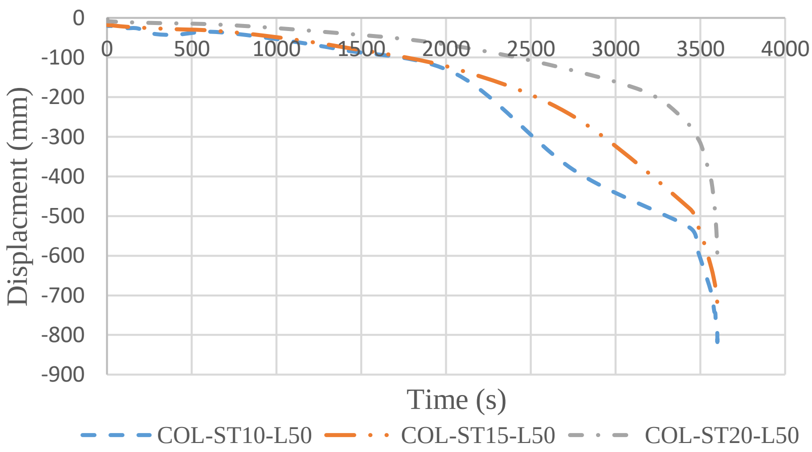


Figure 17. The displacement-time curve for three samples by increasing thickness of an angle seat connection

The connection with the angle seat is used only to transmit the reaction of the vertical support. Therefore, the connection should not cause significant entanglement at the end of the beam. In this type of connection, the beam is placed on an angle seat in which no reinforcement has been made. The angle seat facilitates the installation and adjustment of the beam. This type of an angle seat is usually welded to the column at the required height in the factory or in the workshop, and after installing the column, the beam is mounted on it and welded to it. In this connection, another auxiliary angle seat is installed and welded on top of the beam, which does not participate in vertical bearing and is used only to keep the beam in place and prevent it from rolling. When the vertical reaction at the abutment is greater than the tolerance of a simple seat, we should use a reinforced angle seat. The thickness of the seat plate is sometimes selected around the thickness of the beam wing and the reinforcing plates under the seat are used in a rectangular or triangular (elastic) manner (triangular hardening plate is more difficult to connect than rectangular hardening plate). In these three examples, the performance of simple connection by an angle seat and addition of stiffener is investigated according Figure 18 by considering displacement-time curve.

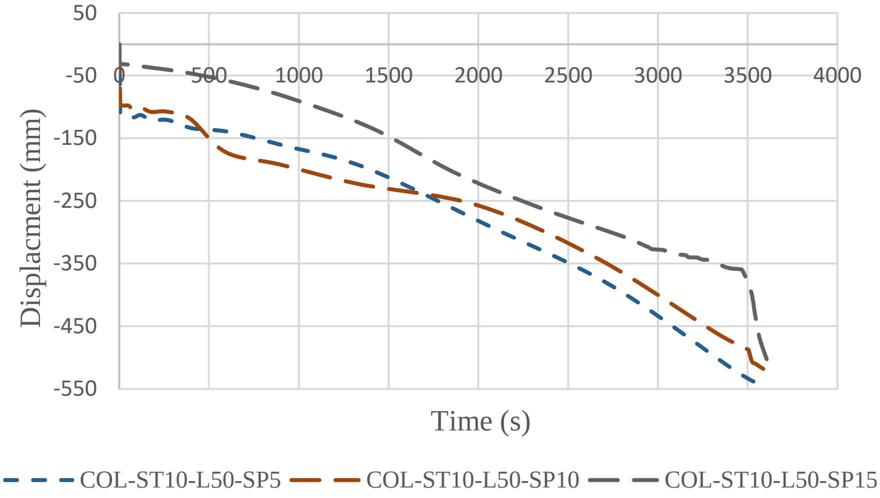


Figure 18. The displacement-time curve for three samples of simple connection with angle seat by adding stiffener

Beam connections transmit a set of internal forces (axial, shear, flexural, and torsional). In structural frame joints, axial, shear and torsional deformations are usually negligible compared to flexural deformations and are omitted for design purposes. In order to compare the behavior of the joints with the welded angle seat under fire loading, the displacement-time curve of all the studied samples is presented according to Figure 19.

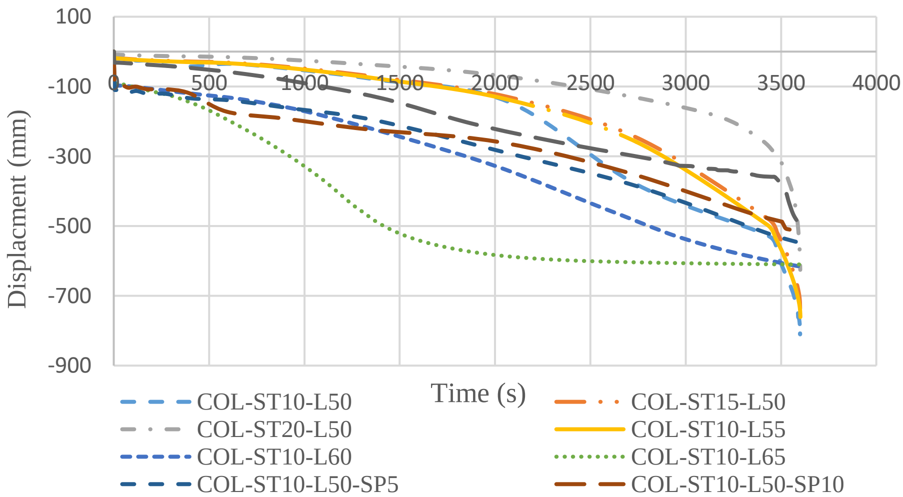


Figure 19. The displacement-time curve for all samples

The displacement values of all samples are indicated in Table 2. According to this table, sample *COL-ST10-L50-SP15* of beam-to-column connection with *10 mm* thickness angle seat, *50 mm* length, and *15 mm* thickness of stiffener has the best performance under fire loading. Therefore, based on the obtained results from the nonlinear dynamic analyses, it is observed that by increasing temperature, two important factors in the design of steel structures should be considered: **a)** To enhance in force due to longitudinal expansion due to increasing temperature, and **b)** To decrease the strength and stiffness of steel material due to increased heat are important results of this research.

Table 2. The values of displacement for all samples

Group	Sample	Angle seat length (*mm*)	Angle seat thickness (*mm*)	Stiffener (*mm*)	Displacement (*mm*)	Displacement ratio versus reference sample
Angle seat connection reinforced by increasing thickness	COL-ST10-L50	50	10	-	819.29	53.45%
	COL-ST15-L50	50	15	-	734.63	38.09%
	COL-ST20-L50	50	20	-	625.49	40.47%
Angle seat connection reinforced by increasing length	COL-ST10-L55	55	10	-	760.74	47.61%
	COL-ST10-L60	60	10	-	616.37	45.23%
	COL-ST10-L65	65	10	-	610.13	42.80%
Simple connection with angle seat and adding stiffener	COL-ST10-L50-SP5	50	10	5	548.42	23.80%
	COL-ST10-L50-SP10	50	10	10	520.92	21.20%
	COL-ST10-L50-SP15	50	10	15	502.52	18.25%

4. CONCLUSION

Fire has always been a serious threat to all aspects of human life and it is one of the most damaging environmental factors for structures. Every year in most countries, heavy casualties and heavy financial losses to residential and commercial buildings. Despite the many advantages of steel structures, the sensitivity of steel material to temperature is one of its major weaknesses. The mechanical properties of steel material are significantly reduced at high temperatures, therefore the bearing capacity of this type of structure is greatly decreased in the event of a fire. Due to the weakness of steel material against increasing heat, simulating the effects of fire in steel structures is of the particular importance. Therefore, in the last two decades, the issue of design and retrofitting of structures against fire has been studied and considered, and in the design regulations of structures, special criteria have been considered for this purpose. One of the most important components of steel structures that are responsible for transmitting the forces of the members to each other and to the supports are the connections between the members. Therefore, the performance of the whole steel structure is affected by the behavior of the joints, which should be considered in the analysis of the overall performance of the structure. It is clear that poor connection can be a very determining factor in the failure of steel structures and the occurrence of progressive collapse. According to the obtained results and the discussed samples, the *COL-ST10-L50-SP15* sample is a beam-to-column connection with a welded angle seat with a thickness of *10 mm*, a length of *50 mm* and a stiffener with considering a thickness of *15 mm* has the best behavior against high temperatures.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

ONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

5. REFERENCES

[1] Sadeghi A, Kazemi H, Samadi M. Probabilistic seismic analysis of steel moment-resisting frame structure including a damaged column. InStructures 2021 Oct 1 (Vol. 33, pp. 187-200). Elsevier. [View at Google Scholar]; [View at Publisher].

[2] Sadeghi A, Kazemi H, Samadi M. Single and multi-objective optimization of steel moment-resisting frame buildings under vehicle impact using evolutionary algorithms. Journal of Building Pathology and Rehabilitation. 2021 Dec;6:1-3. [View at Google Scholar]; [View at Publisher].

[3] Sadeghi A, Kazemi H, Samadi M. Reliability and reliability-based sensitivity analyses of steel moment-resisting frame structure subjected to extreme actions. Frattura ed Integrità Strutturale. 2021 Jun 22;15(57):138-59. [View at Google Scholar]; [View at Publisher].

[4] Zhu MC, Li GQ. Behavior of beam-to-column welded connections in steel structures after fire. Procedia engineering. 2017 Jan 1;210:551-6. [View at Google Scholar]; [View at Publisher].

[5] CEN, Eurocode 3: Design of Steel Structures, Part 1.2: General Rules – Structural fire design, European Committee for Standardization, Brussels 2005. [View at Publisher].

[6] Eurocode 3, prEN-1993-1-8: 20, Part 1.8: Design of joints. Eurocode 3: Design of steel structures, draft2 rev, European Committee for Standardization, Brussels, Belgium 2000. [View at Publisher].

[7] Muir L, Duncan CJ. The AISC 2010 specification and the 14th edition steel construction manual. InStructures Congress 2011 2011 (pp. 661-675). [View at Google Scholar]; [View at Publisher].

[8] Bradford MA, Luu KT, Heidarpour A. Numerical studies of a steel beam in a frame sub-assembly at elevated temperatures. Electronic Journal of Structural Engineering. 2007 Dec 1(2):1-7. [View at Google Scholar]; [View at Publisher].

[9] Memari M, Mahmoud H. Multi-resolution analysis of the SAC steel frames with RBS connections under fire. Fire Safety Journal. 2018 Jun 1;98:90-108. [View at Google Scholar]; [View at Publisher].

[10] Song QY, Heidarpour A, Zhao XL, Han LH. Post-earthquake fire performance of flange-welded/web-bolted steel I-beam to hollow column tubular connections. Thin-Walled Structures. 2017 Jul 1;116:113-23. [View at Google Scholar]; [View at Publisher].

[11] Silva T, Carić M, Couto C, Real PV, Lopes N, Skejic D. Buckling analysis of steel frames exposed to natural fire scenarios. InStructures 2017 May 1 (Vol. 10, pp. 76-88). Elsevier. [View at Google Scholar]; [View at Publisher].

[12] Fischer E.C Varma A.H. Fire resilience of composite beams with simple connections: parametric studies and design, J. Constr. Steel Res., 2017; 128: 119-135. https://doi.org/10.1016/j.jcsr.2016.08.004

[13] Rahnavard R, Hassanipour A, Siahpolo N. Analytical study on new types of reduced beam section moment connections affecting cyclic behavior. Case Studies in Structural Engineering. 2015 Jun 1;3:33-51. [View at Google Scholar]; [View at Publisher].

[14] Cai Y, Young B. Fire resistance of stainless steel single shear bolted connections. Thin-Walled Structures. 2018 Sep 1;130:332-46. [View at Google Scholar]; [View at Publisher].

[15] Jabotian HV, Hantouche EG. Thermal creep effect on the behavior of shear tab connections due to fire temperatures. Fire safety journal. 2018 Mar 1;96:74-92. [View at Google Scholar]; [View at Publisher].

[16] Zhu MC, Li GQ. Behavior of beam-to-column welded connections in steel structures after fire. Procedia engineering. 2017 Jan 1;210:551-6. [View at Google Scholar]; [View at Publisher].

[17] Wald F, Da Silva LS, Moore DB, Lennon T, Chladna M, Santiago A, Beneš M, Borges L. Experimental behaviour of a steel structure under natural fire. Fire Safety Journal. 2006 Oct 1;41(7):509-22. [View at Google Scholar]; [View at Publisher].

[18] Yu H, Burgess IW, Davison JB, Plank RJ. Numerical simulation of bolted steel connections in fire using explicit dynamic analysis. Journal of Constructional Steel Research. 2008 May 1;64(5):515-25. [View at Google Scholar]; [View at Publisher].

[19] Sagiroglu M. Experimental evaluation of the post-fire behavior of steel T-component in the beam-to-column connection. Fire safety journal. 2018 Mar 1;96:153-64. [View at Google Scholar]; [View at Publisher].

[20] Kang H, Kim J. Progressive collapse of steel moment frames subjected to vehicle impact. Journal of Performance of Constructed Facilities. 2015 Dec 1;29(6):04014172. [View at Google Scholar]; [View at Publisher].

[21] Rahgozar N, Pouraminian M, Rahgozar N. Reliability-based seismic assessment of controlled rocking steel cores. Journal of Building Engineering. 2021 Dec 1;44:102623. [View at Google Scholar]; [View at Publisher].

[22] Rahnavard R, Thomas RJ. Numerical evaluation of the effects of fire on steel connections; Part 1: Simulation techniques. Case Studies in Thermal Engineering. 2018 Sep 1;12:445-53. [View at Google Scholar]; [View at Publisher].

[23] Endait M, Wagh S. Effect of elevated temperature on mechanical properties of early-age concrete. Innovative Infrastructure Solutions. 2020 Apr;5(1):4. [View at Google Scholar]; [View at Publisher].

[24] Salgar PB, Patil PS. Temperature effect on behavior of structural light weight concrete filled steel tube (LWCFST) column. Journal of Building Pathology and Rehabilitation. 2020 Dec;5(1):6. [View at Google Scholar]; [View at Publisher].

[25] Leiras AB, Rodrigues JP, Meacham BJ. A performance-based fire risk analysis for buildings. Architecture, Structures and Construction. 2021 Dec;1:143-75. [View at Google Scholar]; [View at Publisher].

[26] Santiago IB, Rodrigues JP, Rodrigues FC, de Oliveira RL. Numerical analysis of cold-formed steel sigma-shaped beams in fire conditions. Architecture, Structures and Construction. 2021 Nov;1:53-63. [View at Google Scholar]; [View at Publisher].

[27] Venkatesh C, Sonali Sri Durga C, Durga S, Muralidhararao T. Evaluation of fire impact on structural elements using ANSYS. Journal of Building Pathology and Rehabilitation. 2021 Dec;6(1):22. [View at Google Scholar]; [View at Publisher].

[28] Saberi H, Saberi V, Javan S, Sadeghi A. Evaluation the Effect of Number, Material and Configuration of Bolts on Rigid Bolted Connections under Fire, Journal of Structural and Construction Engineering 2021. (In Persian). [View at Google Scholar]; [View at Publisher].

[29] Saberi H, Saberi V, Khodamoradi N. et al. Effect of detailing on performance of steel T-connection under fire loading. J Build Rehabil 2022; 7(7). https://doi.org/10.1007/s41024-021-00147-w

[30] Haghighat S, Saberi H, Saberi V, Sadeghi A. Numerical Investigation of Steel Moment-Resisting Frame with RBS Connections under Fire Conditions. Journal of Civil Engineering & Materials Application. 2022 Dec 1;6(4).[View at Google Scholar]; [View at Publisher].