

**Research Paper**

Using Damage Indices for Investigating the Effect of Hole Distance in Seismic Behavior of Drilled Flange Connections

Hamed Asgaran¹, Mohammad Qasem Vetr^{2*}  and Hamid Reza Ebrahimizadeh³

1. Ph.D. Candidate, International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran
2. Associate Professor, Structural Engineering Research Center, International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran, *Corresponding Author; email: vetr@iiees.ac.ir
3. Ph.D. Candidate, International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran

Received: 28/08/2024

Revised: 22/03/2025

Accepted: 06/04/2025

Keywords:

Drilled flange connections, Damage index, Seismic behavior, Numerical analysis

ABSTRACT

The Drilled Flange connection is a reduced cross-section beam connection that has been suggested by creating holes in the beam flange instead of a flange cut. In these connections, for quantifying the damage of a component, the damage index can be used as a factor for parametric comparison of results from software modeling. This index includes pressure index, von Mises index, Equivalent Plastic Strain, triaxial strain, and rupture. In this article, the Mises and Equivalent Plastic Strain damage indices have been used in order to quantify the seismic behavior of the DF connection. To better explain the concept of these indices, it can be said whenever the von Mises stress is higher than the yield stress, failure will occur and the equivalent plastic strain will be greater than zero in the area that has been plasticized. According to these concepts, in the twenty four DF connections that have been modeled in ABAQUS software based on proposed patterns and parameters in FEMA, numerical analysis of damage to these connections considering the effect of hole distance from the edge of the beam flange was investigated, and the optimized model for transferring the maximum stress and plastic strain from the edge of the column has been determined.

How to cite the article:

Asgaran, H., Vetr, M. Q. & Ebrahimizadeh, H. (2025). Using damage indices for investigating the effect of hole distance in seismic behavior of drilled flange connections. *Journal of Seismology and Earthquake Engineering*, 27(3), 45-55, <https://doi.org/10.48303/jsee.2025.2037960.1118>



1. Introduction

The extensive damages and failures in welded unreinforced flange (WUF) connections in steel moment resisting frames (MRF) during the Northridge (1994) and Kobe (1995) earthquakes highlighted the weakness of the seismic performance of these connections. Even though special steel moment resisting frames were mainly used in seismic areas in the United States before the 1994 earthquake in Northridge, after that the general approach to the connection of these frames has changed. Various studies were conducted to find the best method for improving the seismic behavior of steel connections. After the Northridge earthquake, two general concepts were proposed to achieve high deformation and reliable performance of these connections:

- Increasing the strength of connections by using stiffeners and properly welding to prevent the connection failure.
- Weakening of the beam section at a distance away from the column means that a plastic hinge without any failure in the column is formed in the reduced section.

Increasing the strength of connections was developed by using stiffener plates, continuity plates, etc. Reduced beam section connections were also considered as promising options for weakening connections in steel moment frames. One of the methods for weakening the beam section and removing the stresses and plastic strains from the edge of the column as well as the beam to column connections are drilling holes on the beam flanges. Drilled flange connections are made by drilling a series of holes on the top and the bottom of the beam flange to create a weak region for transferring non-linear deformations, A.I.O.S.

Construction (2010) (Figure 1).

The drilled flange connections were proposed in 1996 for the first time by Popov et al. in order to eliminate the effect of heat due to flame cut of the beam section, reduce production costs in comparison with RBS connections that were made with radius cut, and improve the existing buildings. In a report presented by Anderson and Duan (1998) and Anderson (1997), a connection with reduced section by using holes on the beam flange was examined that did not reach a suitable rotation for applying in special moment resisting frames with considering a fuse in beam and a strong panel zone, fragility in the connection happened again from the welding area. Farrokhi et al. (2009) proposed a connection with a reduced section to move the stress concentration from the beam to the column connection area. His study showed that the DF connections can improve the WUF and RBS ductility capacity. Asgaran et al. (2024) investigated the seismic behavior of drilled flange connection in a similar study. They modeled several patterns of beam-column connection and showed that when the distance of the hole from the top flange of the beam increases, the values of stress and plastic strain decrease. In another study by Atashzaban et al. (2015), to show the optimum efficiency of DF connections, compared their maximum equivalent plastic strain, triaxial stress ratio, and rupture index with DF connections with WUF and RBS connections.

The results of this comparison showed that DF connections can be a suitable replacement for WUF and RBS connections in seismic areas, due to their favorable performance compared to RBS connections.

In this study, the seismic behavior of connection

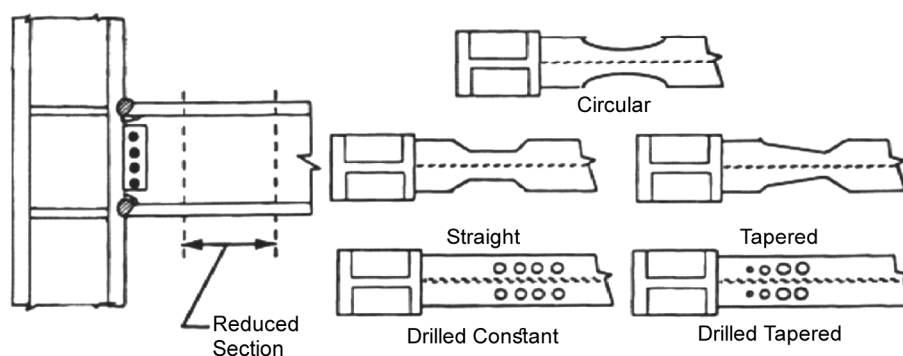


Figure 1. Types of RBS connections.

with changing the distance of holes from the edge of the flange by making four statues that are created by changing the distance from the edge of the column and changing the length of the reduced area has been investigated. In each state, six models created in ABAQUS software based on proposed patterns and parameters in FEMA. With parametric comparison on maximum stresses and equivalent plastic strains, we will find an optimum arrangement for connection. For this purpose, we use the Mises and equivalent plastic strain damage indices in order to parametric comparison on the results of analysis of the models.

2. Mises and Equivalent Plastic Strain Damage Indices

According to plasticity theory, when the section of an element becomes completely plastic due to the bending moment, any attempt to increase the moment could create a plastic hinge in the section. In this plastic hinge, large rotations can occur in steel moment resisting frames without any significant change. In severe motion of earth, plastic hinges are intended to form at the end of the beam in steel moment resisting frames. In fact, the plastic hinges are formed away from the edge of the column when the connection is reinforced. In such cases, stress in the connection is reduced. Subsequently, when the stresses are removed from the beam to column connections, large rotations happen in plastic hinges. The reduced sections allow the strength of connection to exceed the strength of the beam without the need of reinforcing them. As stresses move away from the beam to column connection, yielding occurs in the reduced section and brittle failure potential in connection is decreased.

In order to the parametric comparison between the obtaining results from models analysis, damage indices are used. Damage indices include pressure index (PI), Mises index (MI), equivalent plastic strain index (PEEQI), triaxial strain index (TI) and rupture index (RI) that have been proposed by El-Tawil et al. (1998). The mentioned indices are obtained from Equations (1) to (5).

$$PI = \frac{\sigma_n}{\sigma_y} \quad (1)$$

$$MI = \frac{\sigma_v}{\sigma_y} \quad (2)$$

$$PEEQI = \frac{PEEQ}{\varepsilon_y} \quad (3)$$

$$TI = \frac{\sigma_m}{\sigma_v} \quad (4)$$

$$RI = \frac{PEEQ}{\exp(-1.5 \frac{\sigma_m}{\sigma_y})} \quad (5)$$

where σ_m and σ_y , are hydrostatic and yielding stresses, PEEQ is equivalent plastic strain, ε_y and σ_v , are yielding strain and Mises stresses.

In this research, in order to quantify the seismic behavior of DF connection, two damage indices of Mises and equivalent plastic strain are used.

2.1. Mises Damage Index (MI)

In relation to von Mises stress definition, it can be said that failure happens when the obtained von Mises stress is larger than yielding stress (Figure 2).

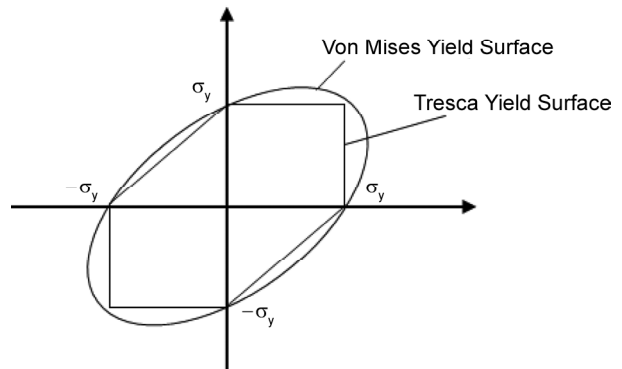


Figure 2. Von Mises and Tresca yielding criteria in two-dimensional modal.

2.2. Equivalent Plastic Strain Damage Index (PEEQ)

Equivalent plastic strain (PEEQ) is a scalar parameter that is introduced as one of the damage indices. This parameter is used for distinguishing the structure's plasticity. In an area that has been plasticized, the quantity of PEEQ is larger than zero. The difference between this parameter and plastic strain (PE) is that the plastic strain is a symmetric tensor with six independent components. There are three normal strain components and

three shear strain components, unlike the equivalent plastic strain that is a numerical parameter.

3. Model Validation

In order to ensure the results obtained from finite element analysis in ABAQUS, verification should be done by using existing information from experimental activities. For this purpose, in this article, the experimental study of Vetr et al. (2012) that has been used in relation to DF connections and the results obtained from the experimental and numerical study have been evaluated and compared.

In this test, a reduced beam section to column connection that has a double plate in 8 mm thickness in the panel zone was applied. The H220 section is used for the column, and the IPE270 is used for the beam. In order to reduce the beam section, three couples of holes with diameter in 19, 25 and 30 mm were drilled in each top and bottom beam flange. The setup detail of the experimental model is shown in Figure (3).

The material of the beam is ST37 and for the column's material, steel SM400 was applied. In order to apply stress and strain specifications, the Japanese Industrial Standard (JIS) that is about hot rolled steel, has been used for steel type SM400 (Japanese Industrial Standard, 1995). The specifications of materials are shown in Table (1).

The loading record has been chosen from the proposed standard pattern by ATC24 code and applied according to Table (2) (ATC, 1992).

The result of the test done by Vetr et al. (2012) showed that in 17.5 mm displacement, the plastic hinge was completely formed in reduced beam

Table 1. The specifications of materials.

Mass Density	7850
Young's Modulus	210×10^9
Poisson Ratio	0.3
Beam-ST37	
Yield Stress	Plastic Strain
240754285.7	0.21266045
Column-SM400	
Yield Stress	Plastic Strain
290000000	0
59	0.165

Table 2. Connection loading record.

Loading Stages	Rotation (Rad)	Number Cycle
1	0.005	3
2	0.0075	3
3	0.01	3
4	0.0125	3
5	0.015	3
6	0.0176	3
7	0.02	2
8	0.025	2
9	0.03	2
10	0.035	2
11	0.04	2
12	0.045	2
13	0.05	2

flanges area, and in 30 to 35 mm displacement, the plastic hinge is transferred to the beam web. It was also shown that in 40 mm displacement, deformation occurs in the beam, and in 45 mm displacement, the plastic hinge is fully extended to the beam web.

In Figure (4), the formation of plastic hinges in the flange and web of the beam can be identified

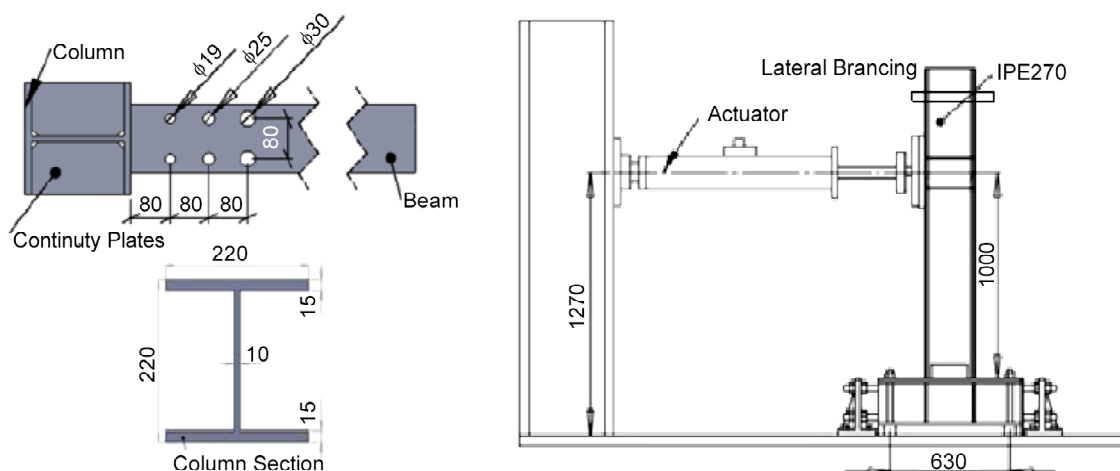


Figure 3. Specified details for reduced section.

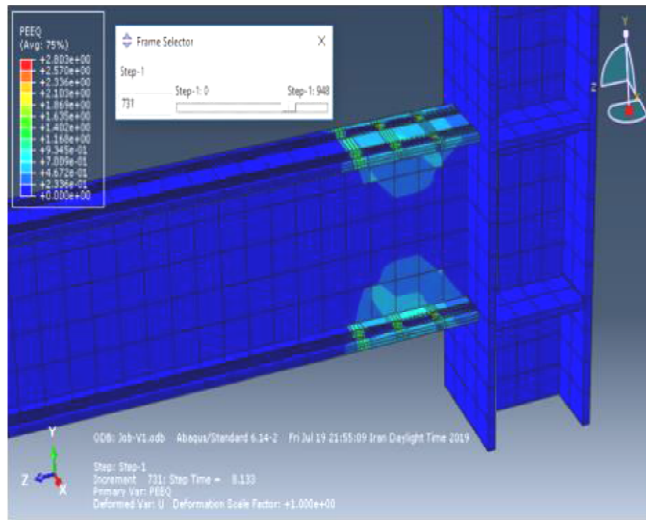


Figure 4. Formation of plastic hinges in experimental and numerical samples.

in both experimental and numerical samples.

In order to compare the result of experimental and numerical samples, the seismic response push curves of models were shown in Figure (5). The hysteresis curves of steel connection is obtained by connecting the maximum points of lateral resistances to each other.

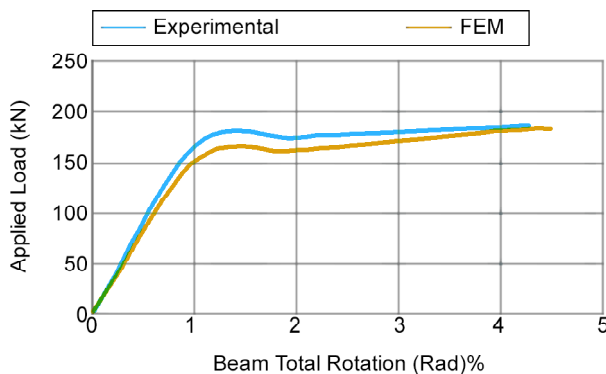


Figure 5. The seismic response push curves of numerical and experimental models.

4. Introducing the Models

The specified details for reduced area in this article are considered based on FEMA-350 code (Federal Emergency Management Agency, 2000b) and Figure (6).

Equations (6) and (7) have been used to determine the values of a and b . Parameter a is the distance of column edge and b is the length of reduced area.

$$a = (0.5 \text{ to } 0.75)b_f \quad (6)$$

$$b = (0.65 \text{ to } 0.85)d_b \quad (7)$$



Figure 6. Proposed connection details for reduced area.

Four states are considered for a and b values, according to the maximum and minimum of a and b . In The first state $a = 100$ mm and $b = 220$ mm, the second state $a = 70$ mm and $b = 180$ mm, the third state $a = 70$ mm and $b = 220$ mm and the last one $a = 100$ mm and $b = 180$ mm. Six models were created for each state. In the first model of each state, the distance between the center of each hole from the flange edge is 17.5 mm and in the other following state is 22.5 mm, 27.5 mm, 32.5 mm, 37.5 mm and 42.5 mm, respectively. The number of considered holes on each flange are 10 and the diameter of all holes are 25 mm. The geometry of the model is the same as the model in the validation article, a cantilever beam to column connection with the same specifications of beam and column and using the same codes. Yielding and ultimate stresses for the beam are 241 and 515 MPa and for the columns are 290 and 590 MPa, respectively.

Also, for modeling ABAQUS CAE ver. 6.14 has been used. Modeling has been done as a solid in 3D space. The type of chosen element is C3D8R (eight-node brick element with reduced integration). The loading was applied with reciprocating motion on the top flange and at a distance of 1 m from column edge. As previously mentioned the loading record has been chosen from the proposed standard pattern by ATC24 code, as shown in Figure (7). All specimens have loaded to 0.05 radians. According to AISC regulations, American Institute of Steel Construction, Inc. (AISC, 2002; 2010) loading up to 0.04 radians is sufficient.

5. Parametric Comparison of Mises and PEEQ Indices for Models

According to the mentioned model in each state, six models have been studied. For the first state of samples to the last one, S1~S6, S7~S12, S13~S18, S19~S24 have been modeled res-

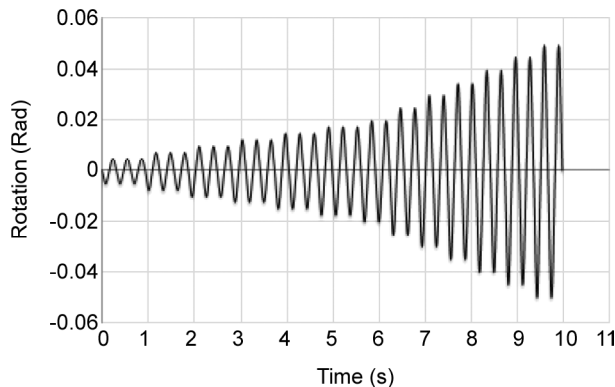


Figure 7. Loading Protocols.

pectively. To control the Mises damage index, models have been studied based on the maximum stress at distance 0 to 50 mm from column edge. For all the four mentioned states, the maximum stress from the edge column has been shown in Table (3).

As it can be seen in the models of all states, the maximum stress value on the column edge is reduced with the distance of hole from the flange beam, so the lowest stress has happened in the last model of each state. Among the last model of the four states, the maximum stress of the S12 model has a value lower than the yield stress, which is 241 MPa and this issue shows that no failure has occurred on the column edge based on Mises's damage index. Therefore, it can be concluded that the optimum model in order to move the maximum stresses from the column edge is the S12 model among S6, S12, S18 and S24 models. In Figure (8), the von Mises stress distribution contour of models S6, S12, S18 and S24 has been shown.

In order to control the equivalent plastic strain, the plastic strain values on the column edge shown in Table (4), was calculated from the ABAQUS software data in the four proposed states. In all models, except S14 and S15 from the third state, the equivalent plastic strain on the column edge has been reduced, which shows the plastic strain transfers to another part of the beam that is called the reduced area. The plastic strain in the column edge has decreased the most in the second state among the other states. As can be seen in Table (4),

Table 3. The maximum stress at distance 0 to 50 mm from the column edge.

Parameter	First State						Second State					
	S ₁	S ₂	S ₃	S ₄	S ₅	S ₆	S ₇	S ₈	S ₉	S ₁₀	S ₁₁	S ₁₂
Hole distance from the flange edge (mm)	17.5	22.5	27.5	32.5	37.5	42.5	17.5	22.5	27.5	32.5	37.5	42.5
Maximum stress at distance 0 to 50 mm from the column edge (MPa)	278	267	260	256	258	255	271	270	253	253	253	237
Parameter	Third State						Fourth State					
	S ₁₃	S ₁₄	S ₁₅	S ₁₆	S ₁₇	S ₁₈	S ₁₉	S ₂₀	S ₂₁	S ₂₂	S ₂₃	S ₂₄
Hole distance from the flange edge (mm)	17.5	22.5	27.5	32.5	37.5	42.5	17.5	22.5	27.5	32.5	37.5	42.5
Maximum stress at distance 0 to 50 mm from the column edge (MPa)	283	280	278	278	277	259	276	270	263	259	258	252

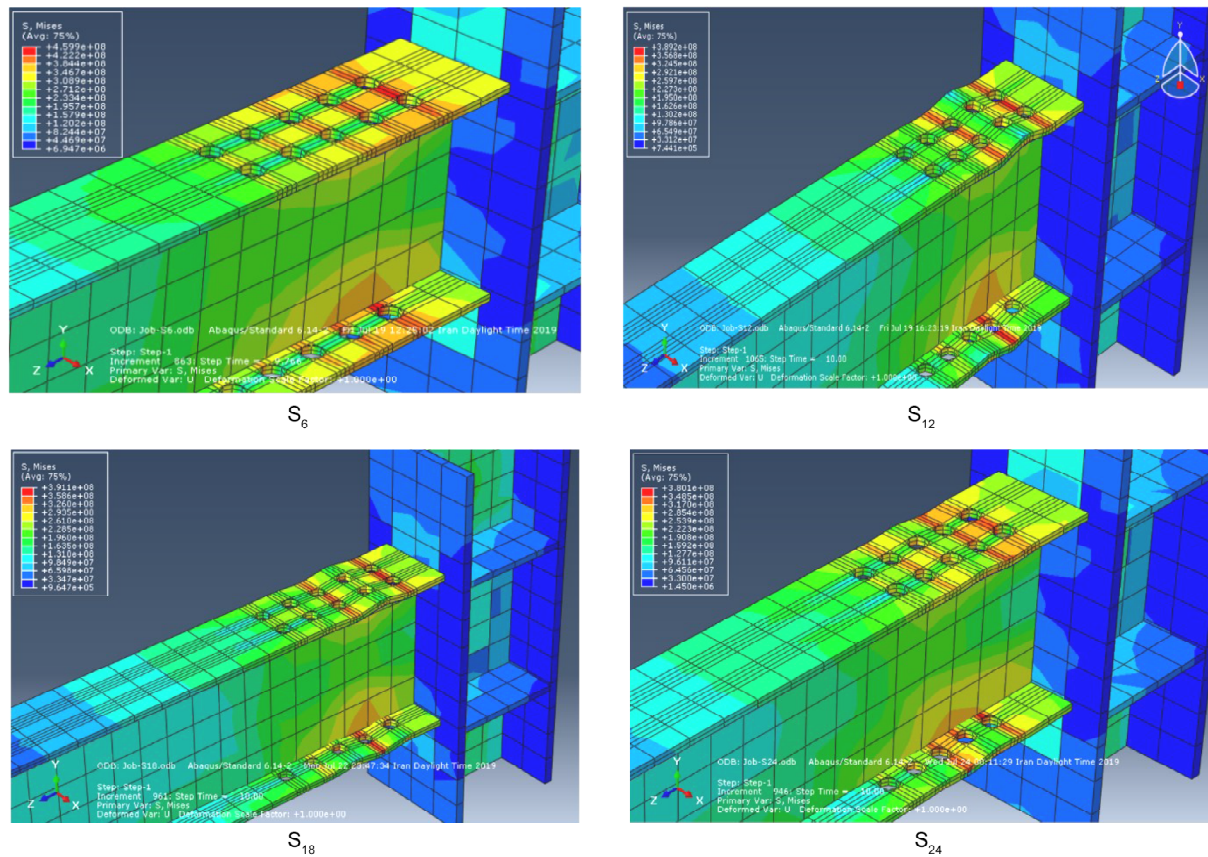


Figure 8. Von Mises stress distribution contour of models S6, S12, S18 and S24.

Table 4. The equivalent plastic strain on the column edge for the first state to forth state.

Parameter	First State								Second State			
	S ₁	S ₂	S ₃	S ₄	S ₅	S ₆	S ₇	S ₈	S ₉	S ₁₀	S ₁₁	S ₁₂
Hole distance from the flange edge (mm)	17.5	22.5	27.5	32.5	37.5	42.5	17.5	22.5	27.5	32.5	37.5	42.5
Plastic Strain in column edge	0.46	0.43	0.41	0.4	0.39	0.38	0.7	0.69	0.65	0.61	0.55	0.48
Parameter	Third State								Fourth State			
	S ₁₃	S ₁₄	S ₁₅	S ₁₆	S ₁₇	S ₁₈	S ₁₉	S ₂₀	S ₂₁	S ₂₂	S ₂₃	S ₂₄
Hole distance from the flange edge (mm)	17.5	22.5	27.5	32.5	37.5	42.5	17.5	22.5	27.5	32.5	37.5	42.5
Plastic Strain in column edge	0.7	0.72	0.71	0.68	0.61	0.54	0.48	0.45	0.43	0.42	0.4	0.39

the value of PEEQ has reached from 0.7 in model S7 to 0.48 in model S12, which shows that the second state models have performed better in transferring the equivalent plastic strain.

The equivalent plastic strain distribution contour of models S6, S12, S18 and S24 has been shown in Figure (9).

As can be seen in Table (5), the reduction percentage of equivalent plastic strain was obtained for the first model of each state to the last one. In Figure (10), the equivalent plastic strain diagrams have been drawn for optimum models of each state.

6. Examining the Obtained Result by Using the Basic Relations

In order to achieve a simultaneous plastic hinge, the reduce section in the beam flange must reach a specific percentage of the plastic moment of the beam. This can be obtained using Equation (8).

$$\frac{M_1}{Z_1} = \frac{M_2}{Z_2} = \frac{M_3}{Z_3} = \dots = \frac{M_i}{Z_i} \quad (8)$$

In Equation (8), M_i is a reduced moment for designing holes in the considered section for creating fuse in the beam that is obtained through

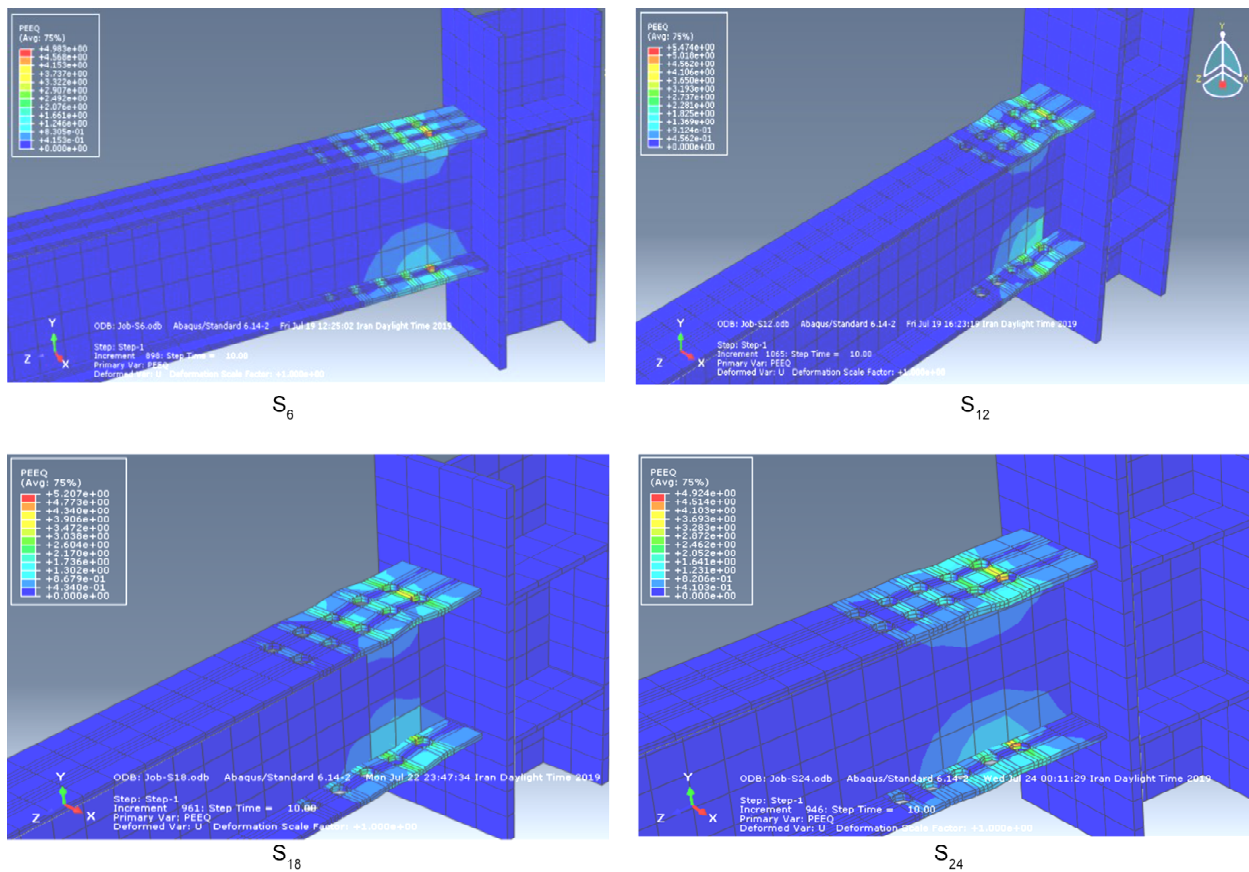


Figure 9. Von Mises stress distribution contour of models S6, S12, S18 and S24.

Table 5. The reduced percentage of equivalent plastic strain on the column edge.

States	Model	Equivalent Plastic Strain from the Column Edge	Reduced Percentage of Equivalent Plastic Strain (%)
First State	S ₁	0.46	17.39
	S ₆	0.38	
Second State	S ₇	0.7	31.43
	S ₁₂	0.48	
Third State	S ₁₃	0.7	22.86
	S ₁₈	0.54	
Fourth State	S ₁₉	0.48	18.75
	S ₂₄	0.39	

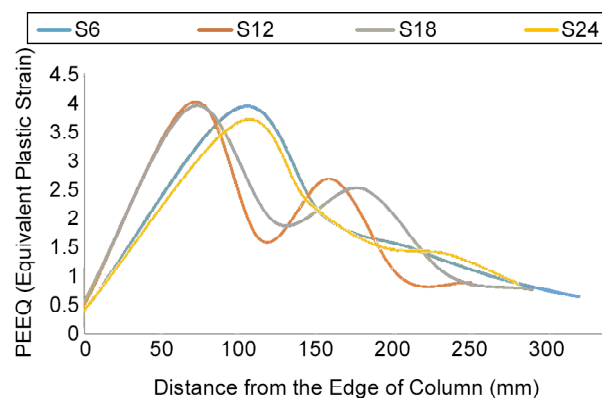
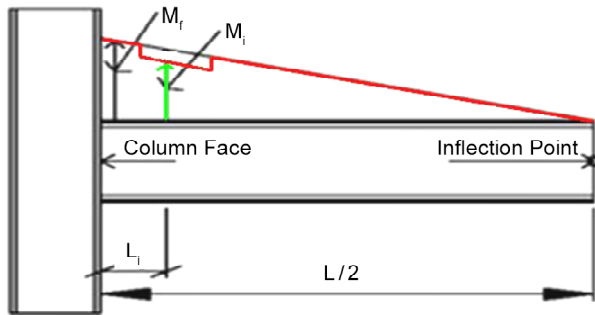


Figure 10. Equivalent plastic strain from the column edge for models S6, S12, S18 and S24.

Table 6. The equivalent plastic strain on the column edge for the first state to forth state.

Parameter	First State						Second State					
	S ₁	S ₂	S ₃	S ₄	S ₅	S ₆	S ₇	S ₈	S ₉	S ₁₀	S ₁₁	S ₁₂
M _i (kN.m)	150.07	148.76	147.64	147.53	147.11	145.72	144.95	144.06	143.38	141.62	136.12	130.92
Z _i (mm)	0.835	0.831	0.827	0.822	0.818	0.814	0.835	0.831	0.827	0.822	0.818	0.814
Parameter	Third State						Fourth State					
	S ₁₃	S ₁₄	S ₁₅	S ₁₆	S ₁₇	S ₁₈	S ₁₉	S ₂₀	S ₂₁	S ₂₂	S ₂₃	S ₂₄
M _i (kN.m)	143.76	144.43	143.02	144.01	136.53	135.79	148.54	148.04	147.41	147.56	146.04	145.93
Z _i (mm)	0.835	0.831	0.827	0.822	0.818	0.814	0.835	0.831	0.827	0.822	0.818	0.814

**Figure 11.** Reduced section profile seismic moment.

Equations (9) and (10), Figure (11). Z_i is the basis of the beam's plastic cross-section in the reduced region, which is obtained through Equation (11).

$$M_i = \alpha M_{pr} \left(\frac{L/2 - L_i}{L/2} \right) \quad (9)$$

$$M_{pr} = C_{pr} R_y Z_b F_y \quad (10)$$

$$Z_i = Z_b - 2D_i b_f (d_b - b_f) \quad (11)$$

In Equation (9), α is the coefficient of transfer for the plastic hinge with a recommended value of 0.85 to 0.9. Considering the applied momentum in the non-reduced section in the face of the column (Equation 10), and the basis of the beam's section in the reduced region, and the slope of the seismic moment applied to the beam, the holes can be designed based on Equation (12).

$$D_i = \frac{Z_b \left[1 - \alpha \left(\frac{L/2 - L_i}{L/2} \right) \right]}{2b_f (d_b - b_f)} \quad (12)$$

In the above equations, L is the beam's span length, and L_i is the considered section's distance for drilling and reduced section from the column's face, D_i is the hole diameter in the considered location for reduced section, and d_b is the beam height, while b_f is the beam flange width (Vetr et al., 2012).

In this study, the above parameters can be seen in Table (6).

By checking the values in the table, it can be seen that Equation (8) has been established with a good approximation in most cases.

7. Conclusion

- By increasing the hole distance from the edge of the flange, the values of maximum stresses and plastic strains, which have been studied in Mises and equivalent strain damage indices, have been reduced and transferred to the area that was intentionally created for forming the plastic hinge.
- Given that the amount of yield stress at zero plastic strain is 241 Mpa, yielding of the beam will occur when the stress exceeds this value. As can be seen in Table (3), the maximum stress at a distance of 0 to 50 mm from the column edge of all samples except S12 exceeds 241 Mpa, which states that in all the mentioned samples, the beam yielding has occurred on the edge of the column. Also, considering that the maximum ultimate stress is 515 Mpa, if the maximum stress exceeds this value, failure will occur. None of the samples have such conditions and failure does not occur in them. The yield and ultimate stress values for the beam are shown in Table (1).

- The reduction percentage of equivalent plastic strain on the column edge for the first model compared to the last one in the second state has the maximum value among other states, which shows the optimum model for transferring equivalent plastic strain for model S12.
- Model S12 from the second state ($a = 70$ mm and $b = 180$ mm) has the best performance in transferring the maximum stresses from the column edge.

Acknowledgment

The seismic tests were performed at the International Institute of Earthquake Engineering and Seismology (IIEES) in Tehran, and this study was supported financially by the IIEES under Grant No. 13.554. The assistance of the structural engineering laboratory personnel is also gratefully acknowledged.

Grant No. 7152-p15-19 and their contribution is highly appreciated.

Study of drilled flange connection in moment resisting frames.

References

- A.I.O.S. Construction, (2010). *Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications*, Chicago, Illinois
- American Institute of Steel Construction. (2002). *Seismic Provisions for Structural Steel Buildings (ANSI/AISC 341-02)*. <https://www.aisc.org/aisc/publications/current-standards/aisc-341>
- American Institute of Steel Construction. (2010). *Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications (ANSI/AISC 358-10)*. <https://www.aisc.org/globalassets/aisc/publications/standards/A358-10-s1-11-s2-14.pdf>
- Anderson, J. C. (1997). *A Welded Moment Connection for Low-Rise Steel Frames (Report No. UCB/EERC-97/05)*. Earthquake Engineering Research Center, University of California, Berkeley.
- Anderson, J. C., & Duan, X. (1998). *Repair/Upgrade Procedures for Welded Beam to Column Connections (PEER Report 1998/03)*. Pacific Earthquake Engineering Research Center, University of California, Berkeley. https://apps.peer.berkeley.edu/publications/peer_reports/reports_1998/9803.pdf
- Asgaran, H., Vetr, M., Ebrahimizadeh, H., Khaleghi, A., Tayeri, F., & Zolfagharzadeh, M. (2024). Investigating the effect of hole distance from the edge of the beam flange in seismic behavior of drilled flange connection by damage indices. *9th International Conference on Seismology and Earthquake Engineering (SEE9)*, Tehran, Iran.
- Atashzaban, A., Hajirasouliha, I., Jazany, R. A., & Izadinia, M. (2015). Optimum drilled flange moment resisting connections for seismic regions. *Journal of Constructional Steel Research*, 112, 325-338. <https://doi.org/10.1016/j.jcsr.2015.05.013>
- Applied Technology Council. (1992). *Guidelines for Cyclic Seismic Testing of Components of Steel Structures (ATC-24)*. <https://www.atcouncil.org/files/ATC-24TOC.pdf>
- El-Tawil, S., Mikesell, T. D., Vidarsson, E., & Kunnath, S. K. (1998). *Strength and Ductility of FR Welded-Bolted Connections (Report No. SAC/BD-98/01)*. Applied Technology Council.
- Farrokhi, H., Danesh, F., & Eshghi, S. A. (2009). Modified moment resisting connection for ductile steel frames (Numerical and experimental investigation). *Journal of Constructional Steel Research*, 65(10-11), 2040-2049. <https://doi.org/10.1016/j.jcsr.2009.06.002>
- Federal Emergency Management Agency. (2000a). *A Policy Guide to Steel Moment-Frame Construction (FEMA 354)*. <https://www.nehrp.gov/pdf/fema354.pdf>
- Federal Emergency Management Agency. (2000b). *Recommended Seismic Design Criteria for New Steel Moment-Frame Buildings (FEMA 350)*. <https://www.govinfo.gov/content/pkg/GOVPUB-FEM1-PURL-LPS117732/pdf/GOVPUB-FEM1-PURL-LPS117732.pdf>
- Japanese Industrial Standards Committee. (1995). *Rolled Steels for Welded Structure (JIS G 3106:1995)*.

Popov, E. P., Blondet, M., & Stepanov, L. (1996). *Application of Dog-Bones for Improvement of Seismic Behavior of Steel Connections* (Report No. UCB/EERC-96/05). Earthquake Engineering Research Center, University of California, Berkeley.

Vetr, M. G., Miri, M., & Haddad, A. (2012, September 24-28). Seismic behavior of a new reduced beam section connection by drilled holes arrangement (RBS_DHA) on the beam flanges through experimental studies. In *Proceedings of the 15th World Conference on Earthquake Engineering (15WCEE)*, Lisbon, Portugal. https://wcee.nicee.org/wcee/article/WCEE2012_5061.pdf