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Numerical Analysis Method for Evaluating the Response of Steel Structures Equipped with Different Friction Dampers Configuration: A Case Study

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ABSTRACT

Earthquakes can be catastrophic phenomena that cause casualties, injuries, and significant damage to buildings. The damage magnitude to individuals and assets caused by earthquakes is mostly determined by the performances of buildings to withstand seismic forces. The current study investigates the performance of friction damper under different earthquake loads considering different configuration using three-dimensional finite element software ETABS. The friction damper was represented by Bouc–Wen model and location optimization was studied. The investigation was carried out to explore the impact of damper optimum placement and configuration. The result showed that using the friction damper in the ten-story building reduced both maximum displacement and the maximum acceleration occurs during the earthquakes events. Also, the result showed the behavior of the diagonal, chevron and the upper toggle friction damper as the location of the damper change across the stories. Finally, the results demonstrate that upper toggle friction dampers significantly reduce seismic-induced displacements and accelerations include up to a 36% reduction in overall displacements and a 35% reduction in peak accelerations compared to undamped structures. Additionally, using a diagonal friction damper (DFD) resulted in a maximum displacement reduction (MTDR) of 30% and a maximum acceleration of 18%. Furthermore, the implementation of a chevron friction damper led to a 29% decrease in maximum displacement and an 23% increase in maximum acceleration.

1. INTRODUCTION

Passive control systems involve using dampers in structures. Passive control systems are a commonly used method to reduce the impact of dynamic loads in civil engineering, which include earthquakes, wind, and vibrations. Dampers are devices specifically engineered to absorb, dissipate, or decrease the energy produced by dynamic forces. This helps to improve the stability and safety of buildings and other structures. Installing passive energy dissipation in a building aims to absorb a portion of seismic energy and minimize damage to the primary structural elements. There are many types of passive energy dissipation systems: friction, viscoelastic, viscous, and others [1]. Friction dampers have several advantages over other passive dampers, including an efficient mechanism, affordable, and requires only minor maintenance, and a strong ability to dissipate energy. Friction dampers prove to be effective not only in seismic design but also in repairing and fortifying existing structures [2]. In order to improve the structure's performance under earthquake excitation, the researcher introduces a variety of friction dampers and configurations. Based on the studies conducted, Filiatrau and Cherry [3] proposed a new simple numerical design method for braced friction dampers. The novel numerical approach is significantly more cost-effective compared to DRAIN-2D and is highly valuable for the practical development of friction-damped braced frames. The new method is compatible with computer programs. The method is both simple and accurate, making it significant for effectively determining the optimal slip load distribution of buildings with friction devices. Mualla and Belev [4] designed a new friction damper mechanism to protect buildings from earthquakes. The researchers assessed the damper's effectiveness using both numerical and experimental methods. The research results indicated that the device can be made and put in structural frames in an affordable way to protect buildings from both physical damage to their structure and other types of damage during earthquakes of moderate and severe intensity. López-Almansa et al. [5] performed an experimental study on a scaled steel frame structure with one and two stories using a unidirectional shaking table test. Each level of the frames contains a pair of parallel friction dissipators. The research findings revealed that the dissipators successfully reduce resonance peaks, with the majority of cases exhibiting twisting effects. Monir and Zeynali [6] carried out a test on a prototype of the redesigned friction damper using a universal machine. The results show that the implementation of this redesigned energy absorber significantly reduced the multi-story building's lateral displacements and base shears. Moghadam et al. [7] carried out an investigation into the performance of a resistance building under the San Fernado earthquake record, designed at the Design Basis Earthquake Level. The SAP200 finite element program was used to analyze the steel structure of four stories. The seismic isolation system appears to be able to reduce the base shear to the greatest extent possible, and the friction damper appears to be more effective in terms of energy dissipation. Quintana and Petkovski [8] proposed a new semi-active control method that focuses on adjusting the slip-loads by using a both of local and global response factors. Using specially built software, the experiment involved simulating the behavior of a low-rise steel frame. The semi-active system effectively reduced the structural response to values comparable to the optimal passive control, while also achieving more evenly distributed storey drift. Armali et al. [9] developed a forward design optimization strategy for determining the ideal quantity and location of friction dampers in a model. The analysis has used two different structural systems: the shear wall system and the shear wall system with dampers, respectively. The reduction in roof displacement, storey displacements, roof acceleration, and storey accelerations is achieved by optimizing the quantity and positioning of the dampers. A design approach for friction dampers was developed by Taiyari et al. [10]. The purpose of this approach was to determine the ideal range of design parameters for friction dampers in multistory chevron-braced steel frames. The analysis indicates that the situation with the larger slip force and the lower stiffness ratio corresponds to the case with the highest damage probability in each structural model. For the purpose of modelling and designing the brace steel frames, they have utilized the OpenSees application. Ghorbani and Rofooei [11] introduced a double slip load (DSL) friction damper, which contains two levels of slippage. The OpenSees software has been used for modelling purposes. The findings demonstrated an improvement in the seismic performance of the moment resistance frame models, resulting in a more uniform distribution of maximum reactions among the floors in the building models equipped with DSL dampers.

The performance of friction dampers was studied analytically by using finite element software and the efficiency was determined by obtaining the maximum deflection, story drift, base shear, dissipated energy of structures, and storey accelerations [12-17].

Paronesso and Lignos [18] carried out 62 experimental tests on five non-metallic friction pads. Couch et al. [19] conducted an experimental test that involved the design, detailing, fabrication, and testing of a full-scale dual system frame on a uniaxial shake table subjected to sixteen scaled ground motions of various intensities and amplitudes, as well as eight artificially generated sinusoidal, sweep, and step functions.

Previous numerical studies have mostly examined the issue using a two-dimensional technique, and further study is required to have an understanding of this relationship between the seismic response of buildings and the damper configurations. This study used ETABS v21 to employ a three-dimensional finite element model of the case study. The building and the dampers were modelled, and a nonlinear time history analysis was conducted. Furthermore, the analysis includes the optimum damper location for three configurations. The evaluation of the damper configuration performance was studied by the mean of maximum displacement and the maximum acceleration of the model during the earthquake excitation.

The purpose of this study is to analyze the behavior of the friction damper when subjected to seismic loads and gain insight into the seismic performance of various damper configurations. This work aims to enhance the understanding of friction damper behavior and damper configuration in the seismic design method. Subsequently, this understanding can be utilized to develop improved design principles.

2. BUILDING GEOMETRY AND MATERIAL

The building used in this study is a hotel located in Basrah Iraq. The building consists of steel members shown in Table 1. The building has 10 story shown in Figure 1. The building total height of 36 m. There are 6 bays in the x direction and 4 bays in the y direction as shown in Figure 2. A shear wall where the elevator is available. The building was modeled using ETABS software as shown in Figure 3. The material uses in this study is steel for the column, primary beams and secondary beams. Concrete for the slabs. The concrete had a young modulus of 21.718 kN/mm^2, Poisson s ratio 0.17 and density of 2400 kg/m^3. For the steel structure members, the young s modulus is 205 000 MPa, Poisson ratio of 0.3 and a density of 7830 kg/m^3. In this study the earthquakes data were represented as time-acceleration. The acceleration was applied in the x-direction at the base of structure. The base condition was restrained against translation in X, Y, Z direction. The detailed procedure and the specified assumptions ensure that the nonlinear time history analysis in ETABS accurately captures the dynamic response of the structure under seismic loading. Proper definition and calibration of material properties, load cases, damping devices, and analysis parameters are crucial for obtaining reliable results.

Table 1. Building sections

	Exterior Column	Interior Column	X-Direction Beams	Y-Direction Beam
Story 1 5.25 m	HEB 340	HEB400	IPE 220 IPE 270	H300*150*6.5 H396*199*7
Story 2 4.45 m	HEB 340	HEB400	IPE 220 IPE 270	H300*150*6.5 H396*199*7
Story 3-10 3.4 m	HEA 340	HEA400	IPE 220 IPE 270	H300*150*6.5 H396*199*7

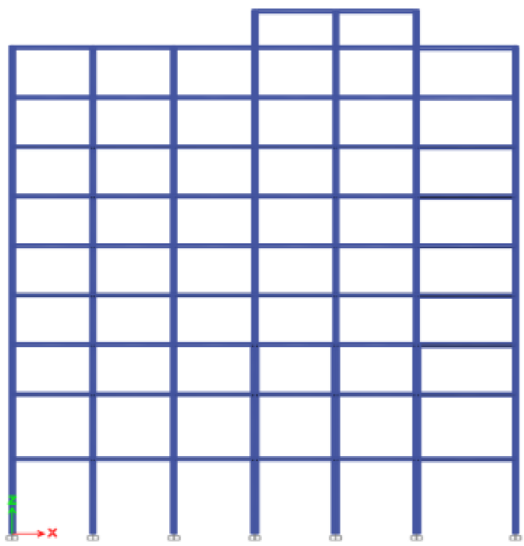

Figure 1. Story layout

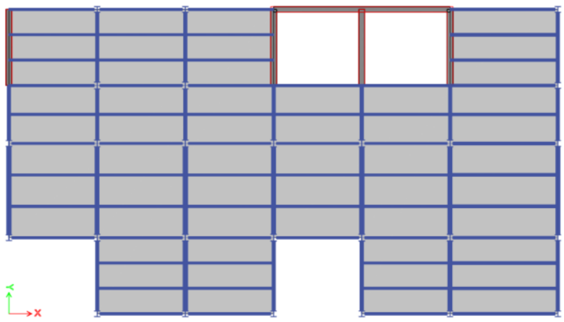

Figure 2. Floor layout

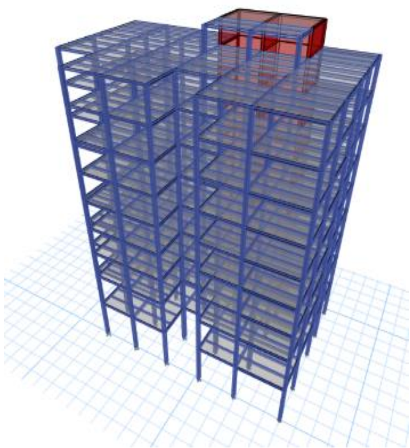

Figure 3. ETABS model

3. APPLIED LOADS AND GROUND MOTIONS

3.1 Applied loads

The building is subjected to its self-weight and imposed dead load, live load and earthquake time history load. The loads are defined in accordance with the International Building Code 2021 [20].

The load is applied:

1. Dead load:
- Self weight of the building
- Floor finish material 0.5 kN/m^2
- Concrete slab load 2.5 kN/m^2
- Suspended ceiling 0.3 kN/m^2
- Movable partitions load 1 kN/m^2
- Roof construction load 1 kN/m^2

2. Live load: the hotel building, the live load is taken as (4 kN/m^2) IBC [Table 1607.1].

3.2 Ground motions

For the purpose of this research, five earthquakes were selected based on their historical significance and their known effects on buildings similar to the one under study. Table 2 presents a list of the earthquakes. The data for those earthquakes was obtained from the U.S.G.S. and the I.M.O.S. [20, 21]. The location of a building at the epicenter of an earthquake significantly affects the extent of seismic damage it suffers. Buildings that are close to the epicenter exhibit more intense shaking and ground acceleration than those located farther away. This leads to greater and more extensive harm to the structure due to the strong and rapid imposition of seismic forces. The chosen earthquakes are known for their destructive impact on the structure.

Table 2. Seismic input data

Earthquake	Year	Place	Magnitude (Richter)	PGA	Intensity (Mercalli)
Ali Algarbi	2012	Iraq	4.9	0.102g	V (Moderate)
Bam	2003	Iran	6.6	0.727g	IX (Violent)
Iraqi-Iranian border	2017	Iraq	7.3	0.098g	IX (Violent)
El Centro	1940	USA	6.95	0.28g	VIII (Severe)
İzmit	1999	Turkey	7.6	0.282g	X (Extreme)

4. FRICTION DAMPER AND ITS CONFIGURATION

Passive control systems involve using dampers in structures. Passive control systems are a widely used method to reduce the impact of dynamic loads in civil engineering. This study employs the friction damper (FD) as the passive control system. Figure 4 illustrates the placement of the damper in three configurations: diagonal, chevron, and upper toggle [22]. The selection of diagonal, chevron, and upper toggle bracing dampers is dependent on achieving a balance between cost, ease of construction, and aesthetic influence while also meeting the performance criteria of the project. Diagonal bracing provides a cost-effective and convenient alternative; however, it may have a minor impact on the overall appearance. Chevron bracing offers a more substantial visual impact at a higher cost while maintaining better function. Upper toggle systems provide exceptional performance at a higher cost and require intricate construction. However, the damper can be engineered to minimize any negative impact on aesthetics.

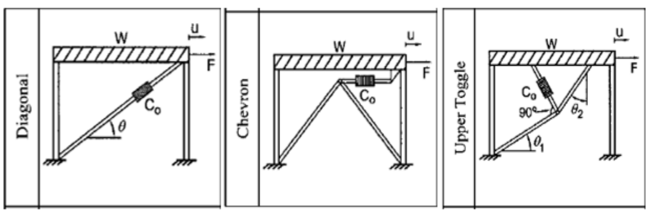

Figure 4. Damper friction configuration

The friction damper was modelled as a Bouc–Wen model to accomplish this project. The Bouc-Wen model is a widely used mathematical model to describe hysteretic behavior in structures, especially for simulating the response of friction dampers as shown in Figure 5. This model is particularly popular due to its ability to capture a wide variety of hysteretic behaviors by adjusting its parameters. The Bouc-Wen model's governing equation is given by Eq. (1). The boundaries of this approach were illustrated in Figure 4. The Bouc–Wen model was generated using the ETABS software.

$$F(t) = \alpha k x(t) + (1-\alpha) k z(t) \quad (1)$$

where, $F(t)$ is the restoring force, α is a parameter ($0 \leq \alpha \leq 1$) that determines the balance between linear and nonlinear behavior, k is the stiffness of the system, $x(t)$ is the displacement, $z(t)$ is the hysteretic component.

For the friction damper used in this study, the stiffness of the damper was calculated using the question of the effective stiffness. The mass of the link equal to the mass of bracing plus the mass damper. The weight of the damper is the mass divided by 9.81. The slip load range was from 2 kN up to 1200 kN according to QuakeTek Seismic Products [23]. The natural frequency of the model with damper vary from 0.827 to 1.09 Cyc/sec and the natural frequency of the undamped structure is 0.827 Cyc/sec. The effective stiffness used for the analysis is $10*10^7$ N/m. The length of the damper varies according to the bay installed in.

To determine the optimal placement of the damper, genetic algorithms were used. This method was implemented by placing the damper in sixteen different locations within the building. The first set of dampers was placed only in one story and denoted by S1, S2, S3, S4, S5, S6, S7, S8, and S9. The second set was placing the damper in two stories, denoted by S12, S34, S56, and S78. The last set was placing the damper in three stories, denoted by S123, S456, and S789. Two dampers are placed on each side of the building.

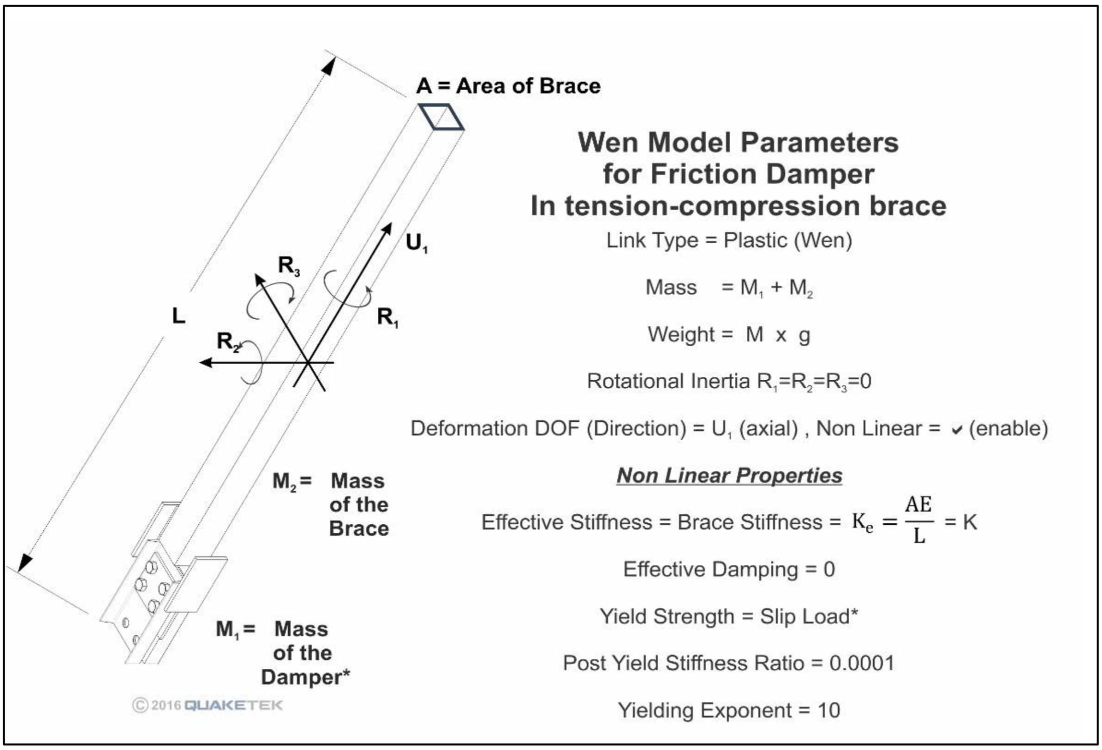

Figure 5. Bouc–Wen model [23]

5. RESULTS AND DISCUSSION

The undamped structural model was developed with the purpose of comparing its results with those of the structure that was supplied with damping systems and three different bracing configurations.

Maximum displacement and maximum acceleration of this structure were measured and displayed in the Table 3.

Table 3. Undamped structure maximum displacement and maximum acceleration

	Ali Algarbi	Bam	El Centro	Iraqi-Iranian	Izmit
Maximum displacement (m)	0.0891	0.3773	0.1665	0.0598	0.1389
Maximum acceleration (m/s^2)	3.91	16.503	5.167	3.661	9.398

5.1 Maximum displacement reduction

5.1.1 Diagonal friction damper (DFD)

The percentage of reduction in maximum value of the displacement experienced by the building model with diagonal Friction damper fitted in nine different locations when subjected to five earthquakes are in Figure 6. As it can be observed from the figure, the diagonal Friction damper exhibit exceptional performance when subject to the Algarbi, Bam, Iraqi-Iranian border, and El Centro earthquakes. On the other hand, the performance of the damper when subject to Izmit was obviously very poor. The best performance of this damper was occurred when subject to El Centro Earthquake with an average maximum displacement reduction of 14%. From the figures below, it can be obvious that the maximum displacement reduction found when subject to Izmit earthquakes have unfavorable increase in the maximum displacement. The reason of this increment due to the effect that the damper has on the natural frequency of the model. The negative value of the acceleration is due to the resonance effects.

Figure 7 shows the maximum displacement reduction results of the same structure in term of damper location. As shown in figure the damper was at the best performance when the damper embedded in the seventh story. The reduction when the damper located in seventh story is up to 18%. For El Centro and Iraqi-Iranian border, the optimal location was in the seventh story with reduction in the maximum displacement up to 18%. The reduction of the friction damper is more significant at the top because the vibrational amplitude is generally higher there, leading to a larger reduction in displacement.

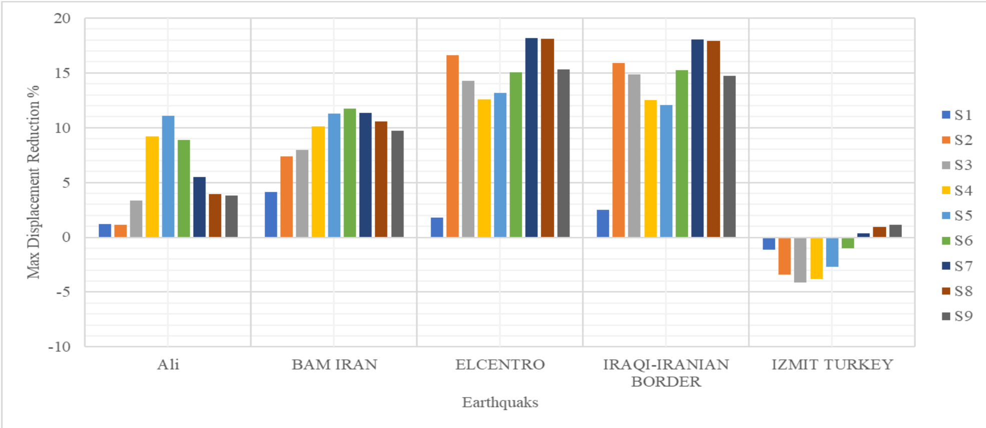

Figure 6. DFD located in one story for different earthquakes

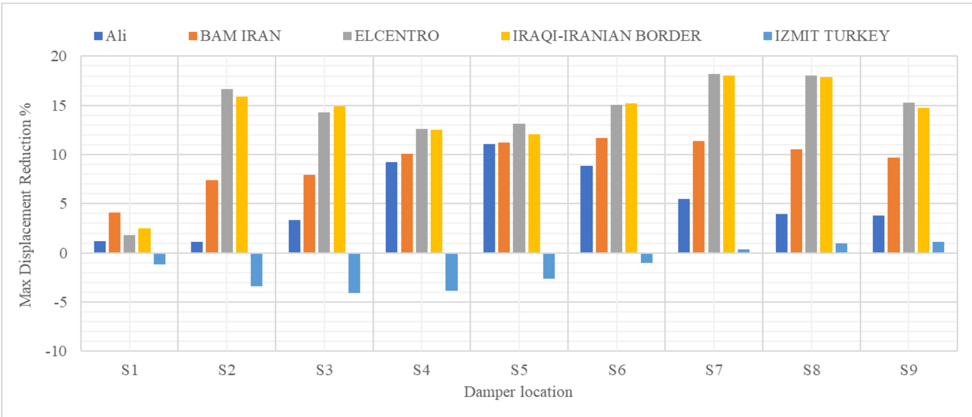

Figure 7. DFD located in one story for different damper location

The maximum displacement reduction for the structure when the Friction damper in two stories for different location is shown in Figure 8. The result in general showed that there was no increase in maximum displacement reduction of the structure was obtained as compared to the result from the analysis of structure damper embedded in one story. Where the highest average maximum displacement reduction of 19% was obtained when the structure subject to Bam earthquake, the lowest average maximum displacement of 1% when subject to the Izmit earthquake. The maximum displacement reduction for Izmit has unfavorable increase in the maximum displacement. The reason of this increment due to the effect that the damper has on the natural frequency of the model.

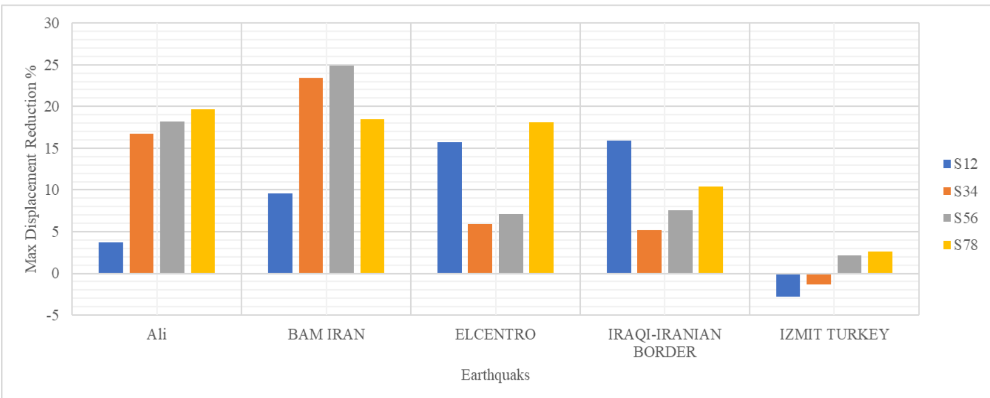

Figure 8. DFD located in two stories for different earthquakes

Figure 9 demonstrates the maximum displacement reduction in the term of damper placement. The best performance of friction damper was occurred when the friction damper located in the mid stories. The highest average displacement reduction of 25% under Bam earthquake. The highest maximum joint displacement reduction occurs at the mid-stories where the value of story drift tends to have high values.

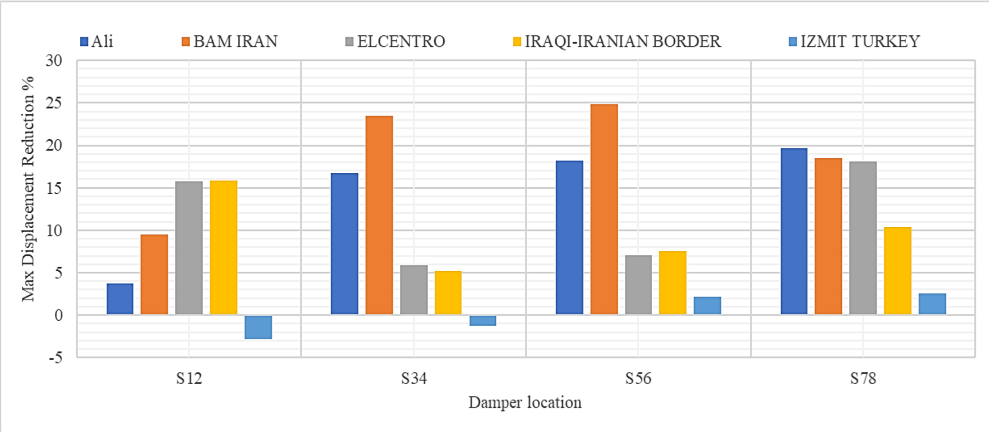

Figure 9. DFD located in two stories for different damper location

The maximum displacement reduction for the structure when the Friction damper in three stories with different location is shown in Figure 10. The result in general showed as was as expected, an increase in maximum displacement reduction of the structure was obtained. Where the highest average maximum displacement reduction was obtained when subject to Iraqi-Iranian border earthquake. The highest average reduction in the maximum displacement was 25% obtain when subject to Bam earthquake.

Figure 11 illustrates the maximum displacement reduction of the structure model in the term of damper placement. The most effective performance of the damper was obtained when the damper is place in the building mid stories. The highest maximum displacement reduction in this position was 30%.

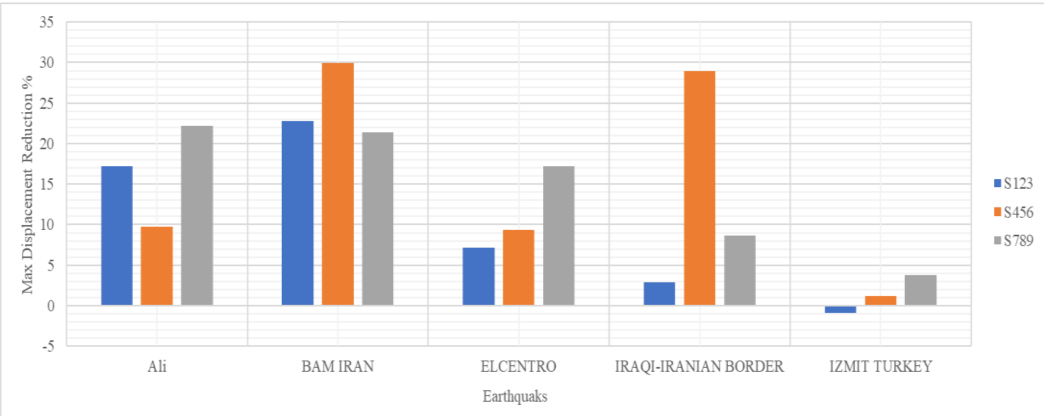

Figure 10. DFD located in three stories for different earthquakes

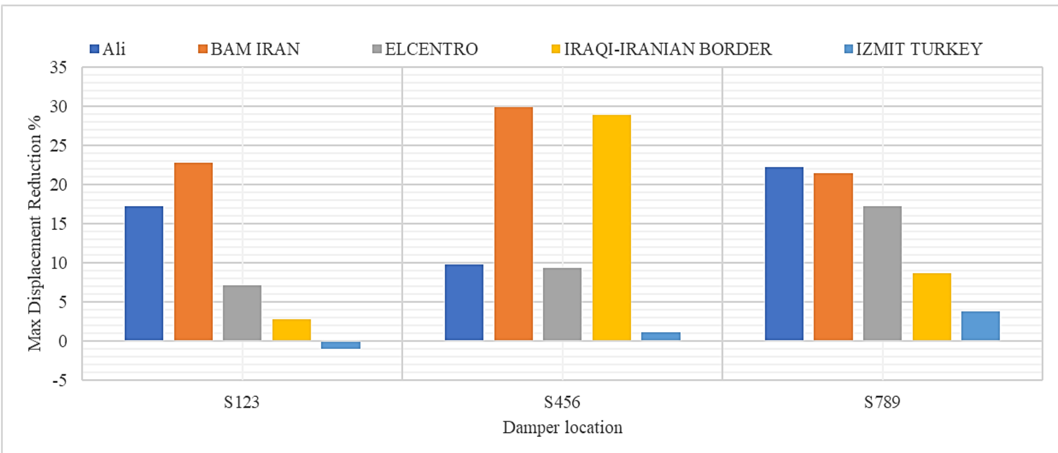

Figure 11. DFD located in three stories for different damper location

5.1.2 Chevron friction damper (CFD)

As it can be observed in Figure 12, the highest average maximum displacement reduction of 13% occurs under El Centro earthquake. The average maximum displacement reduction occurs under Iraqi-Iranian border earthquake was adequately high. While the average maximum displacement reduction when the model subjected to Izmit earthquake was inconsistent.

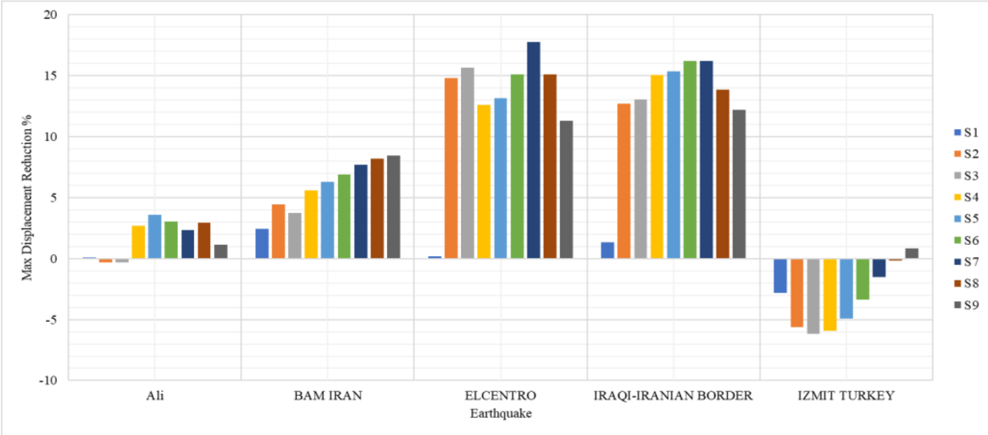

Figure 12. CFD located in one story for different earthquakes

The highest maximum displacement reduction of 18% occurs when the damper located in the seventh story as illustrated in Figure 13. The maximum displacement reduction occurred where the maximum story drift occurred.

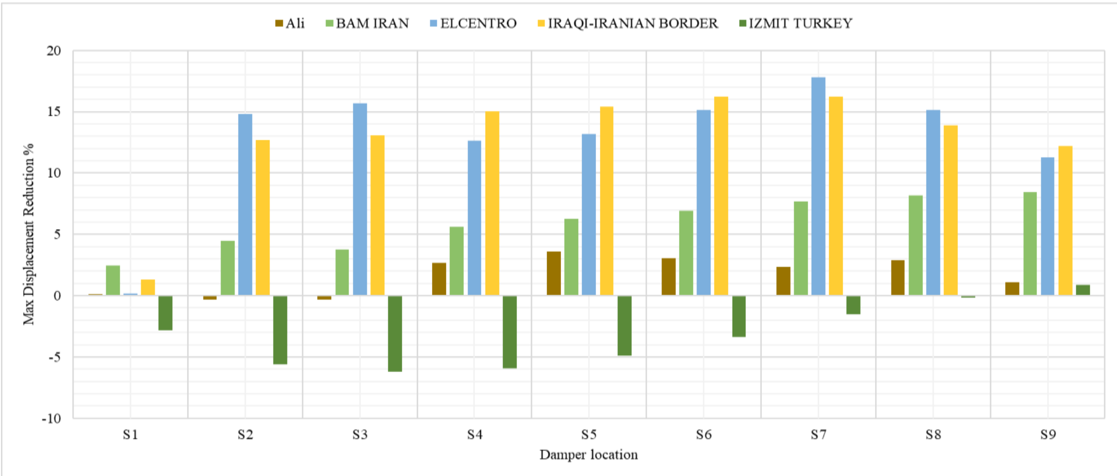

Figure 13. CFD located in one story for different damper location

The maximum displacement reduction of the structure with Chevron Friction damper located in two stories was represented in Figure 14. The highest average maximum displacement reduction of 17% occurred when subject to bam earthquake. The average maximum displacement reduction of Ali Algarbi, and El Centro earthquakes were also high. The maximum displacement reduction occurs when subject to Izmit earthquake were insufficient and inconsistent.

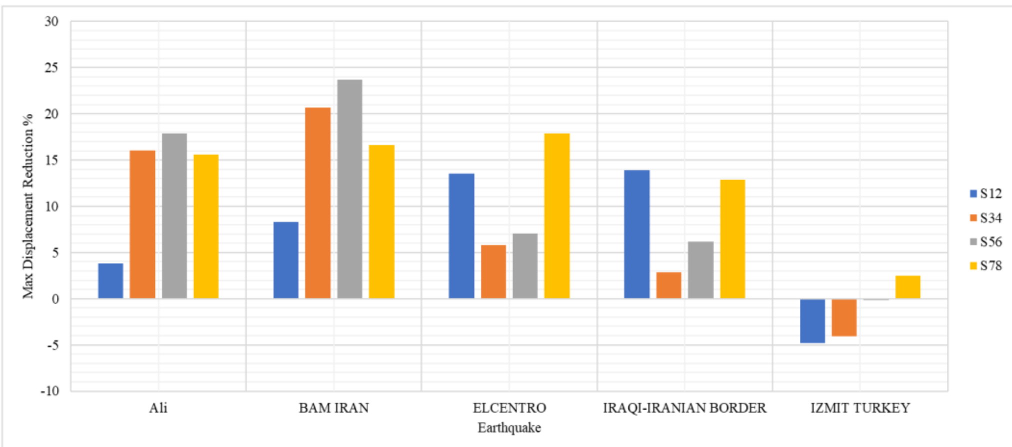

Figure 14. CFD located in two stories for different earthquakes

Figure 15 shows the maximum displacement of the structure when the Chevron Friction damper located in nine different stories. The highest maximum displacement reduction of 23% was occur when the damper located in the 5th and 6th story. The effectiveness of the damper in the other location was slightly lower in reduction value. The maximum displacement reduction occurred when subject to El Centro earthquake increased as the dampers moves from the bottom to the upper stories of the structure. For maximum displacement reduction of Izmit behave in the same manner changing from negative value to the positive. While the maximum displacement reduction for Iraqi-Iranian border earthquake was the highest at mid-stories where the maximum drifts occur.

The highest average maximum displacement reduction of 24% occurs under bam earthquake shown in Figure 16. While the average maximum displacement reduction obtained under Ali Algarbi, and El Centro was high. The average maximum displacement reduction under Izmit earthquake was inconsistent.

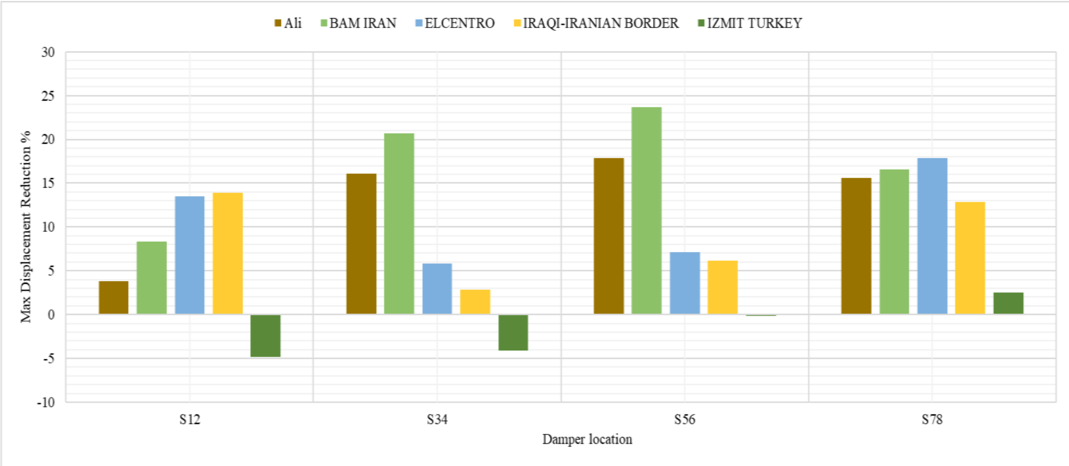

Figure 15. CFD located in two stories for different damper location

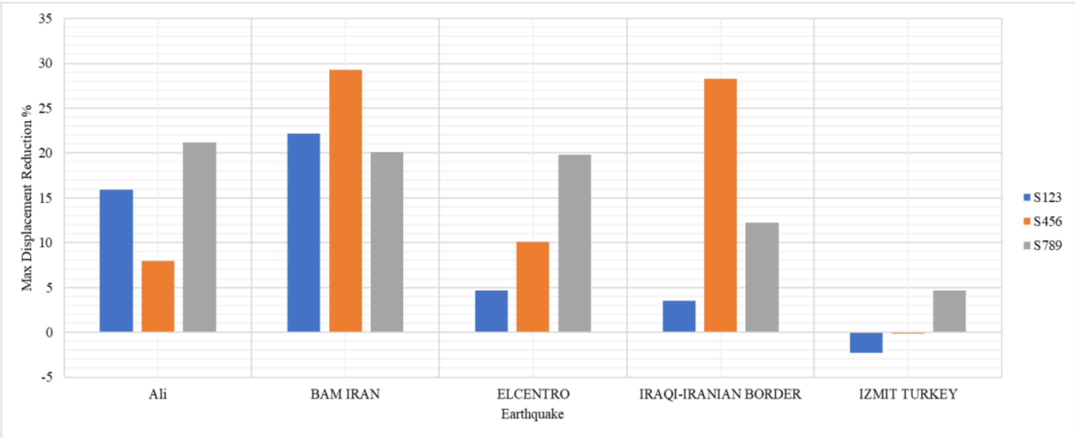

Figure 16. CFD located in three stories for different earthquakes

As it can be seen from Figure 17 the maximum displacement reduction of 29% occurred when subject to Bam earthquake. For Iraqi-Iranian border, and El Centro earthquake, the maximum displacement reduction was sufficiently high. While the lowest reduction occurred when subject to Izmit Earthquake.

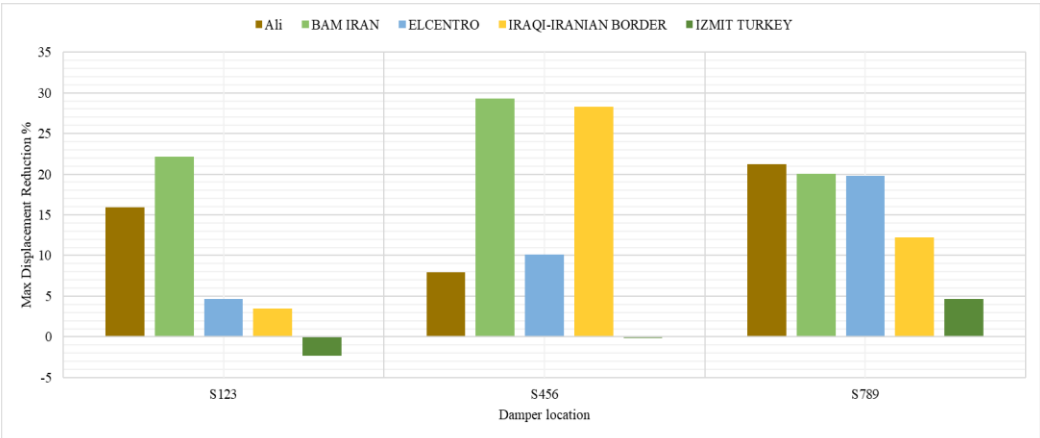

Figure 17. CFD located in three stories for different damper location

5.1.3 Upper toggle friction damper (UTFD)

As it can be seen in Figure 18, the highest average maximum displacement was obtained when subject to El Centro earthquake was 13%. While the reduction of the maximum displacement occurred when subject to bam, Iraqi-Iranian border earthquakes were considerably high value. On the other hand, the maximum displacement reduction obtained when subject to Izmit was noticeably low and inconsistent.

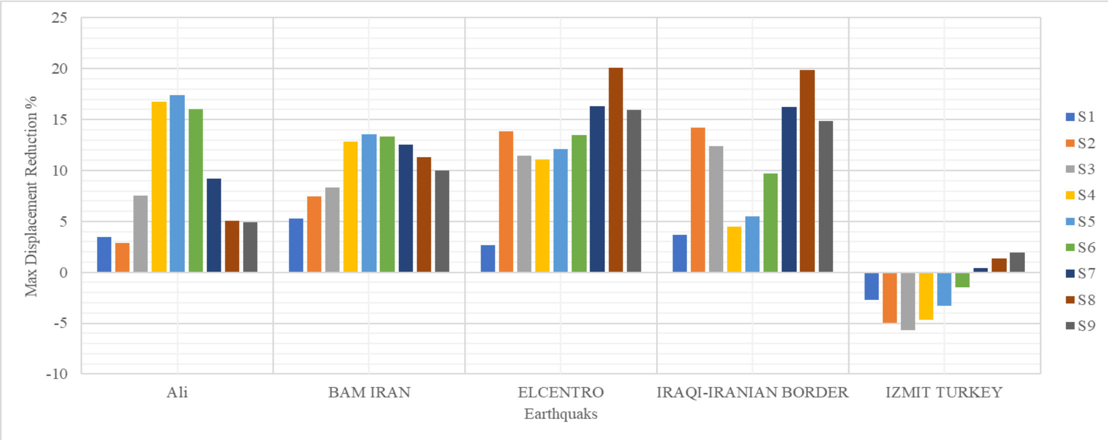

Figure 18. UTFD located in one story for different earthquakes

Figure 19 shows the maximum displacement of the structure when the upper toggle Friction damper located in nine different stories. The highest maximum displacement reduction of 20% was occur when the damper located in the 8th story. The effectiveness of the damper in the other location was slightly lower in reduction value. The maximum displacement reduction occurred when subject to El Centro and Iraqi-Iranian border earthquake increased as the dampers moves from the bottom to the upper stories of the structure. While for Ali Algarbi, Bam earthquake the maximum displacement increased when the damper located in the mid-story. For maximum displacement reduction of Izmit behave in the same manner changing from negative value to the positive.

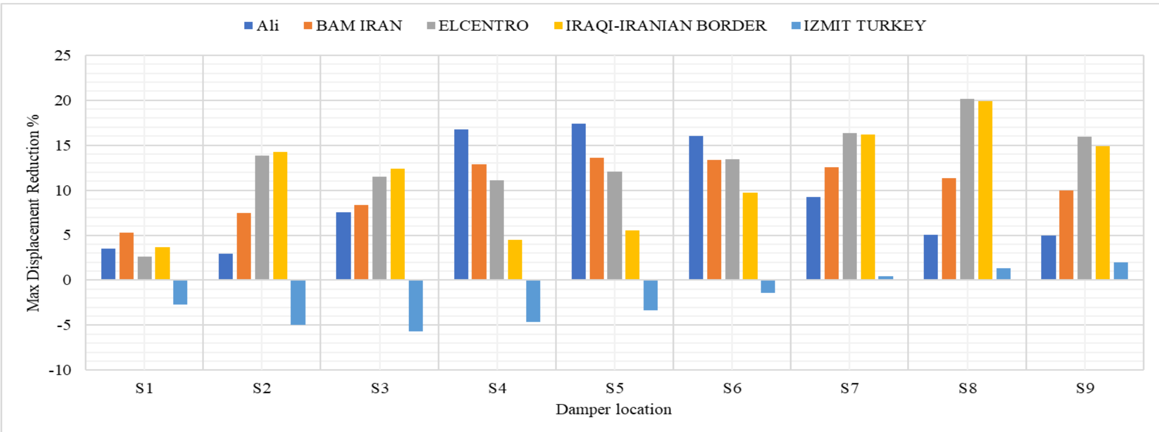

Figure 19. UTFD located in one story for different damper location

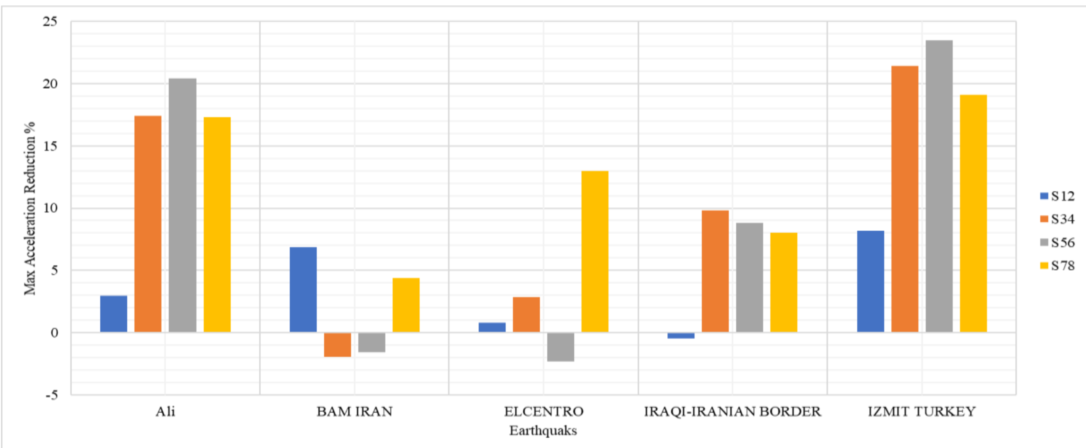

Figure 20. UTFD located in two stories for different earthquakes

The maximum displacement of the structure with upper toggle Friction damper located in two stories was represented in Figure 20. The performance of the damper was very sufficient. The highest average maximum displacement reduction of 23% occurred when subject to Bam earthquake. The average maximum displacement of Ali Algarbi, El Centro, and Iraqi-Iranian border earthquakes were also high. The maximum displacement reduction occurs when subject to Izmit earthquake were insufficient and inconsistent.

Figure 21 shows the maximum displacement reduction of structure with respect to damper location. The highest maximum displacement of 28% was occur when the damper is located in the mid-story. The reduction when subject to Bam and El Centro were adequately high when the damper place in the mid story.

As it can be seen from Figure 22 the damper showed a very good performance in reducing the maximum displacement similar to structure model fitted with upper toggle Friction damper in three stories. The average maximum displacement reduction of 28% occurred when subject to Bam earthquake. For Ali Algarbi, El Centro and Iraqi-Iranian border earthquakes, the average maximum displacement reduction was sufficiently high. While the lowest reduction occurred when subject to Izmit Earthquake.

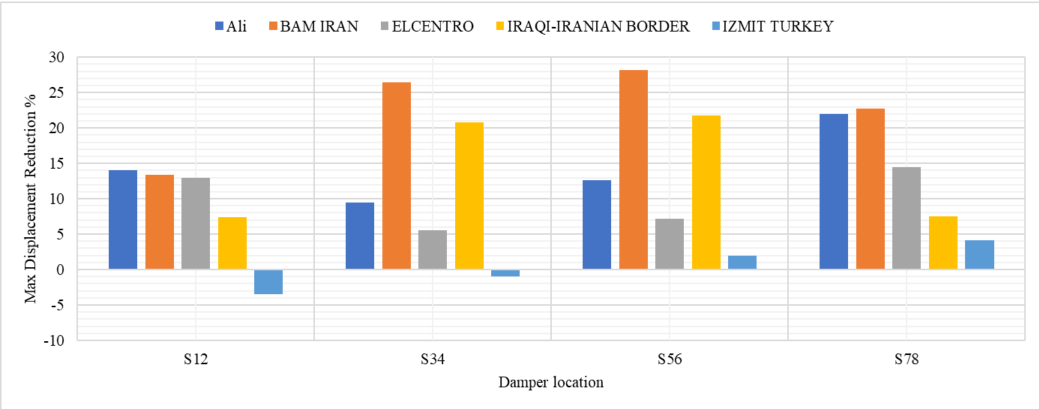

Figure 21. UTFD located in two stories for different damper location

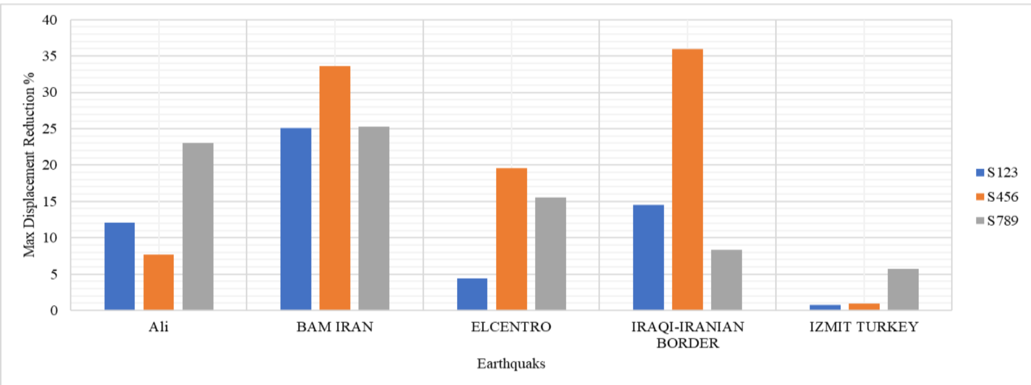

Figure 22. UTFD located in three stories for different earthquakes

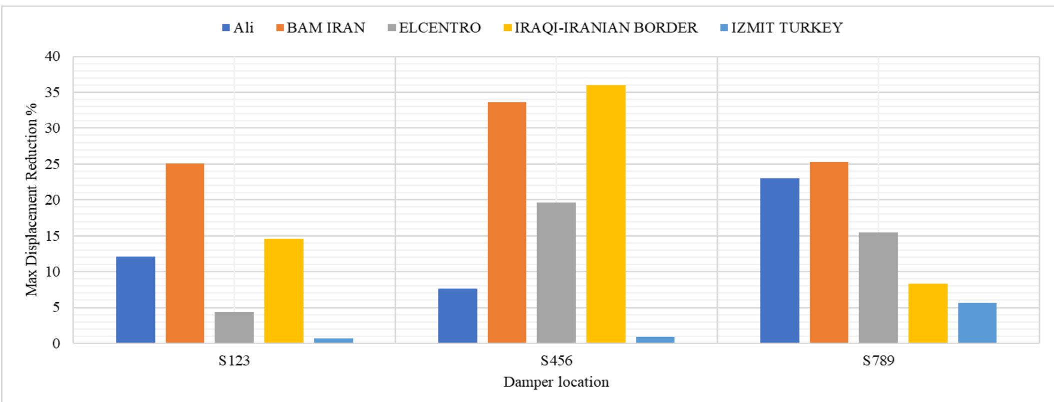

Figure 23. UTFD located in three stories for different damper location

The result of the maximum displacement reduction of the structure, where the friction damper located in three stories was represented in Figure 23. The highest maximum displacement of 36% was obtain as the damper located in fourth, fifth and sixth story when subjected to Iraqi-Iranian border earthquake.

5.2 Maximum acceleration reduction

5.2.1 Diagonal friction damper

The maximum acceleration reduction of the structure varies in wide range of values. The highest average of maximum acceleration reduction was 5% when subject to Izmit earthquake in Figure 24. The maximum acceleration reduction for Ali Algarbi was adequately high. While the maximum acceleration reduction of El Centro, and Bam earthquakes were inconsistent. The negative value of the acceleration is due to the resonance effects.

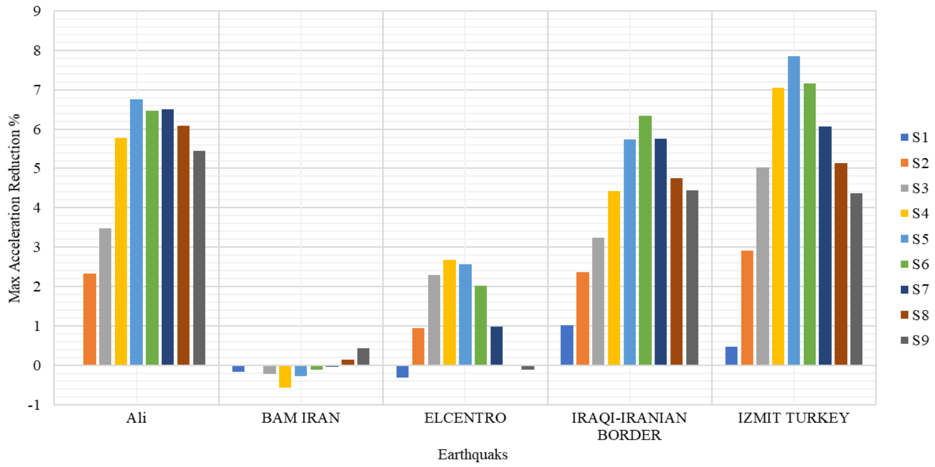

Figure 24. DFD located in one story for different earthquakes

The result of the maximum acceleration of the structure when the damper in one story in term of its location was illustrated in Figure 25. The highest maximum displacement reduction occurs at the mid-stories where the story drift tends to be higher. The maximum acceleration reduction occurs at fifth story was 8% under Izmit earthquake.

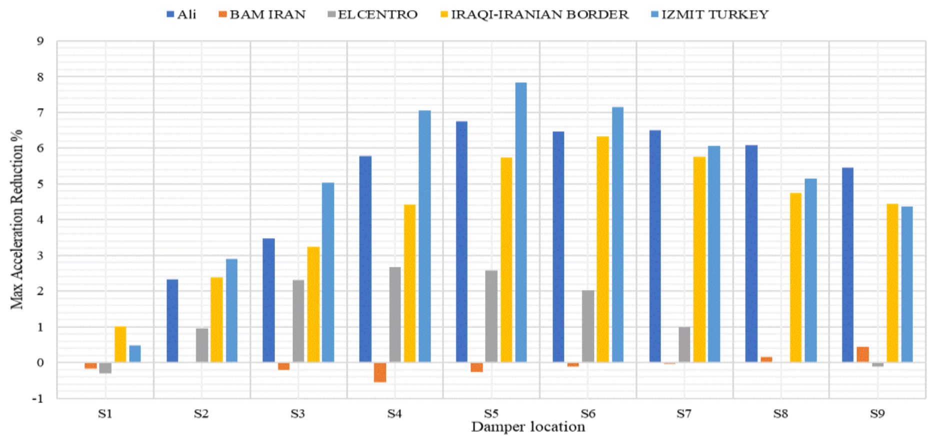

Figure 25. DFD located in one story for different damper location

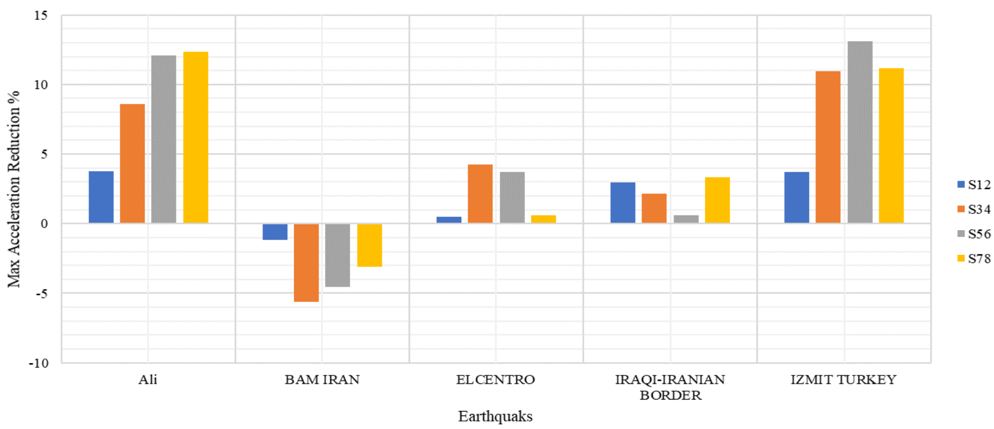

Figure 26. DFD located in two stories for different earthquakes

The average maximum acceleration reduction in this case is almost twice the reduction of the damper located in a one story. The highest average maximum acceleration reduction occurs when subject to Izmit earthquake was 10% in Figure 26. In the meantime, the reduction when subject to both El Centro and Iraqi-Iranian earthquake were insignificant.

In term of maximum acceleration reduction at different damper location in Figure 27, the highest maximum acceleration reductions occur when subject to Izmit earthquake was at the mid stories. The maximum reduction occurs at the fifth-sixth story was 13% under Izmit earthquake.

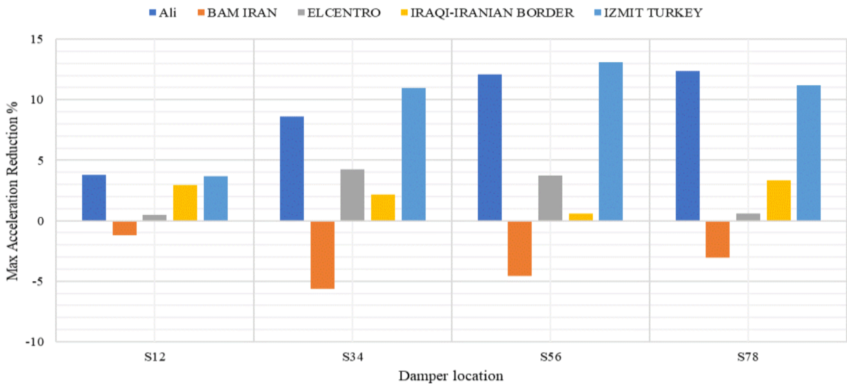

Figure 27. DFD located in two stories for different damper location

The average highest maximum acceleration reduction was 14% obtained when subject to Izmit earthquake. While the lowest occur when subject to El Centro earthquake showed in Figure 28. This pattern was consistent with the previously analyzed structure with diagonal friction damper located in two stories.

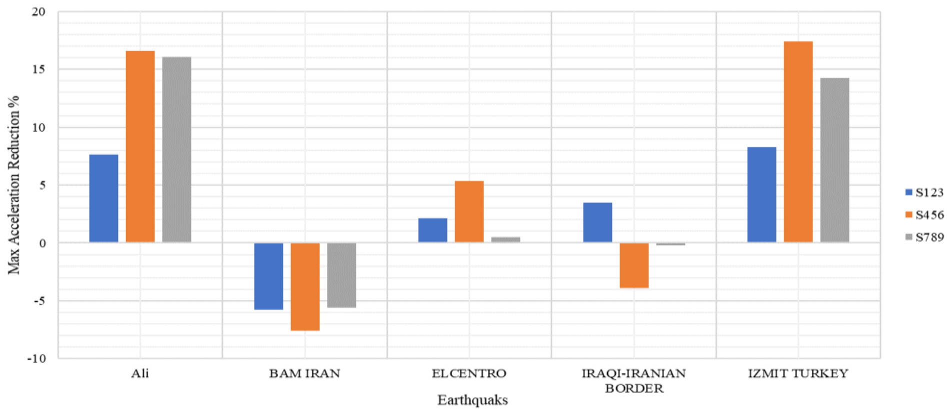

Figure 28. DFD located in two stories for different earthquakes

The maximum acceleration reductions experienced by the structure fitted with Friction damper located in three stories are shown in Figure 29. In general, the same behavior continued as the highest average maximum acceleration reduction was obtained in the mid-stories of the structure. As mentioned, previously the maximum reduction happen where max story drift occur. The maximum acceleration reduction was 18% under Izmit earthquake.

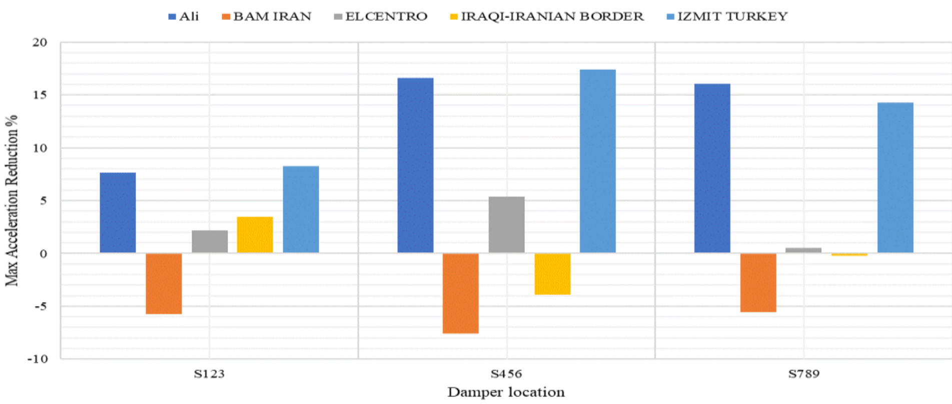

Figure 29. DFD located in two stories for different damper location

5.2.2 Chevron friction damper

Figure 30 presents the reduction in maximum acceleration of the structure when the chevron friction damper located in one story. The highest average maximum acceleration reduction of 8% occurs when subject to Izmit earthquake. While the average maximum acceleration reduction under Ali Algarbi, and El Centro was high. The reduction when subject to Iraqi-Iranian border was inconsistent.

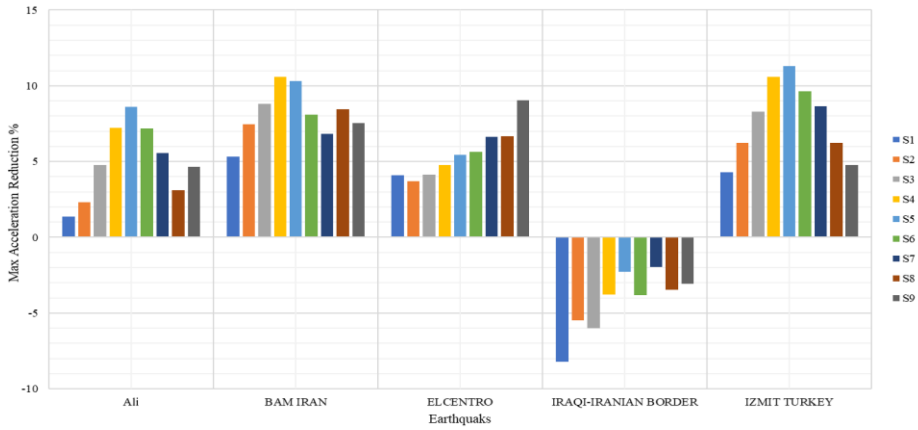

Figure 30. CFD located in one story for different earthquakes

The maximum acceleration reduction of 11% obtained when the damper located in fifth story under Izmit earthquake showed in Figure 31. While the maximum acceleration reduction obtained under El Centro increased as the damper moved toward top stories. There was increased in the maximum acceleration under Iraqi-Iranian earthquake.

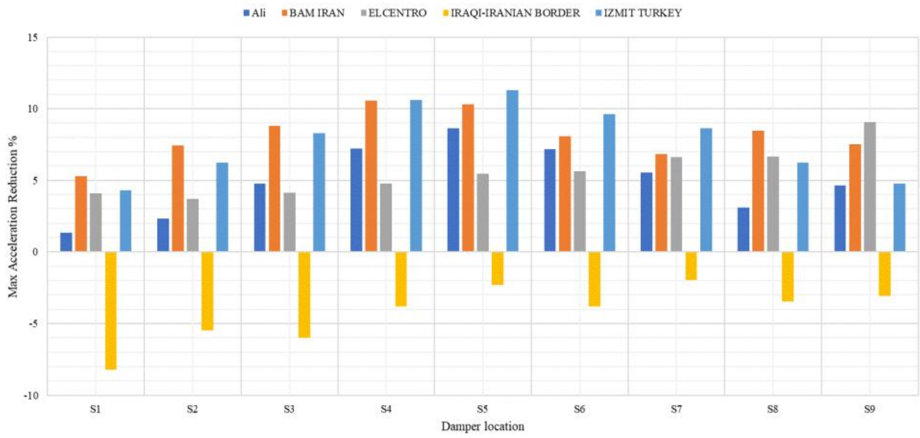

Figure 31. CFD located in one story for different damper location

Figure 32 illustrates the maximum acceleration reduction of the structure with dampers located in two stories. The average maximum acceleration reduction of 13% obtained when subject to Izmit earthquake. The maximum acceleration reduction under Iraqi-Iranian border was inconsistent.

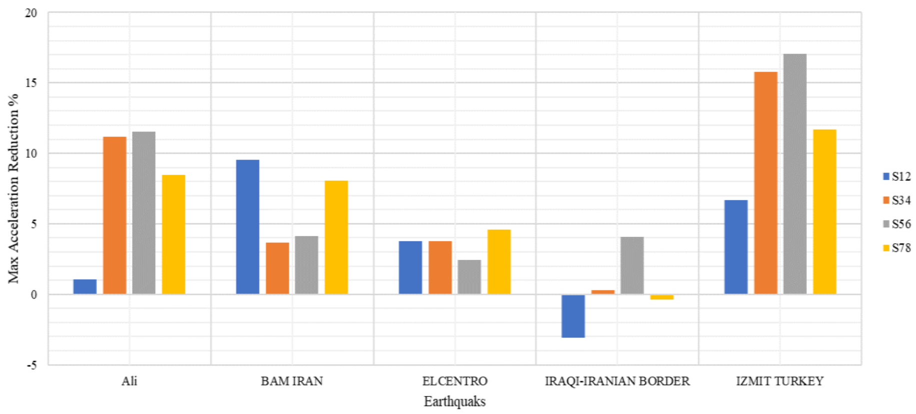

Figure 32. CFD located in two stories for different earthquakes

The highest maximum acceleration reduction of 17% obtained when the damper located in the fifth and sixth story under Izmit earthquake shown in Figure 33.

Figure 34 illustrates the maximum acceleration reduction of the structure with dampers located in three stories. The average max acceleration reduction of 15% obtained under Izmit earthquake. While maximum acceleration reduction obtained under El Centro and Iraqi-Iranian border was inconsistent.

In term of damper location, the highest max acceleration of 23% occur when the damper located in the stories 4th to 6th stories as shown in Figure 35. The reduction when the damper located in stories 7th to 9th stories was adequately high.

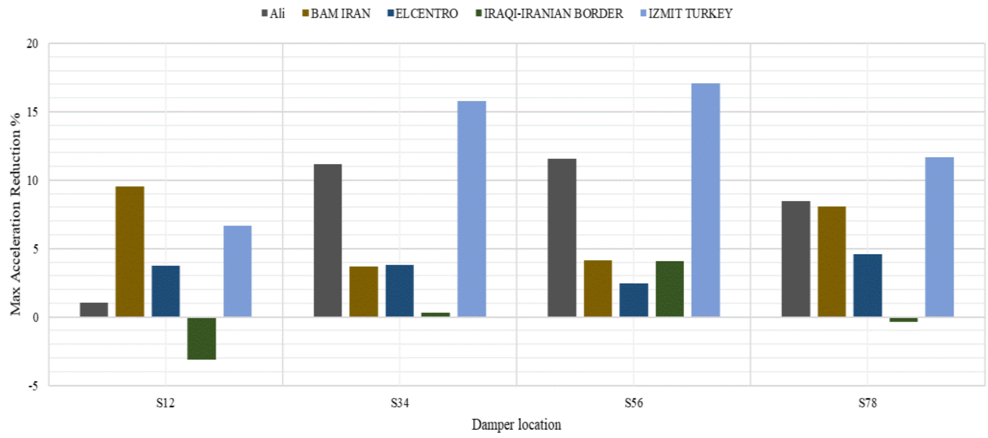

Figure 33. CFD located in two stories for different damper location

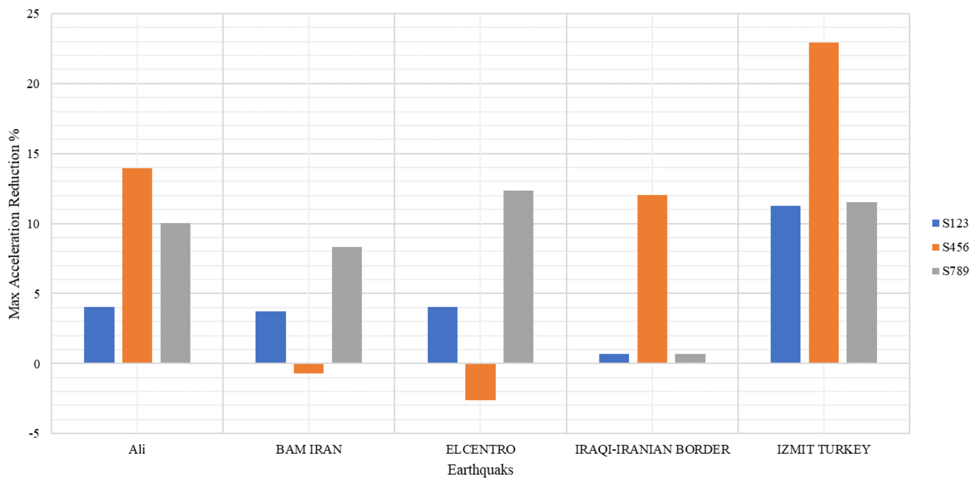

Figure 34. CFD located in two stories for different earthquakes

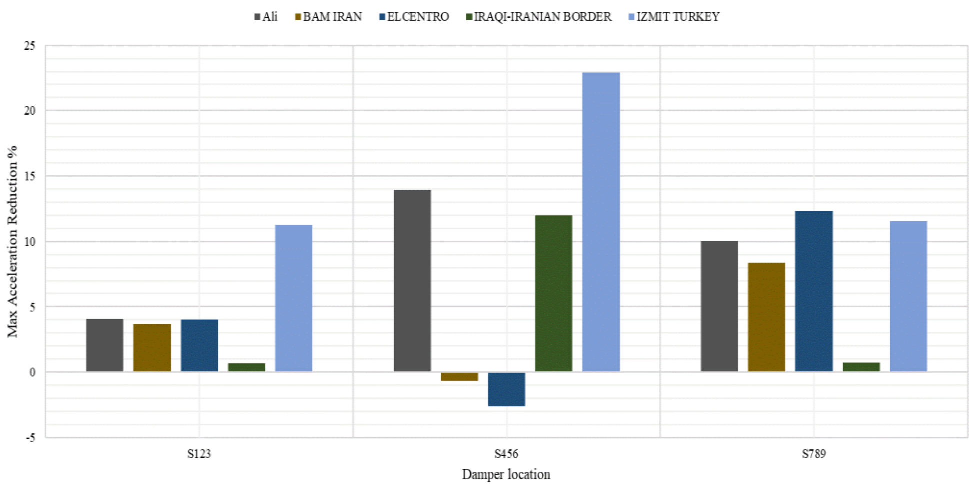

Figure 35. CFD located in two stories for different damper location

5.2.3 Upper toggle friction damper

Figure 36 presents the reduction in maximum acceleration of the structure when the upper toggle Friction damper located in one story. The highest average maximum acceleration reduction of 10% occurs when subject to Izmit earthquake. The reduction obtained when subject to Ali Algrabi was also adequately high While the reduction when subject to Iraqi-Iranian border was inconsistent.

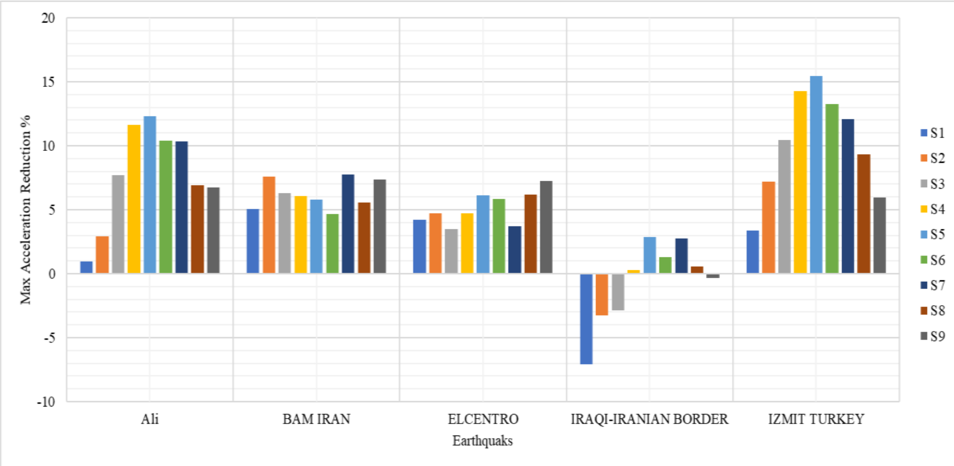

Figure 36. UTFD located in one story for different earthquakes

The results of the maximum acceleration reduction of the structure model when the upper toggle friction for different damper location in Figure 37. The highest maximum acceleration reduction of 16% obtained when the damper located in the fifth story of the structure. As the damper located to the up or down the fifth floor, a slight decrease in the maximum acceleration reduction was noticed. The maximum acceleration reduction was obviously high in all damper's locations when subject to Izmit earthquake. The reduction when subject to Iraqi-Iranian border were inconsistent.

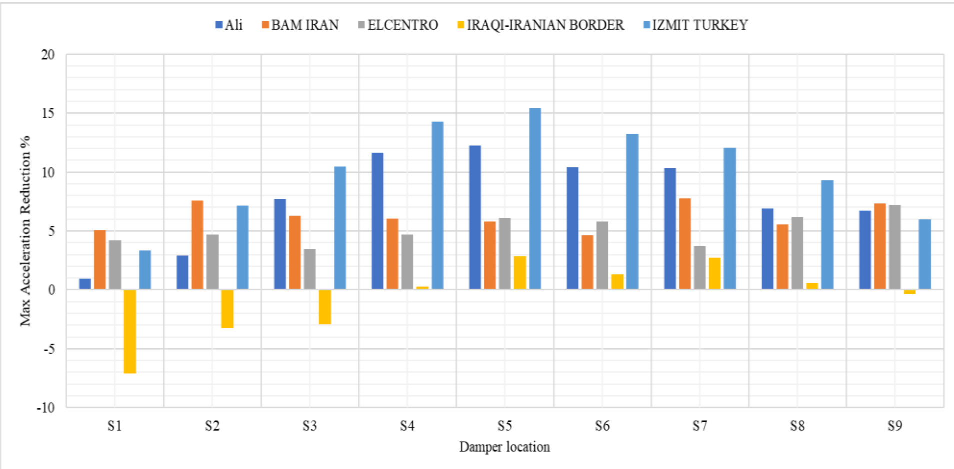

Figure 37. UTFD located in one story for different damper location

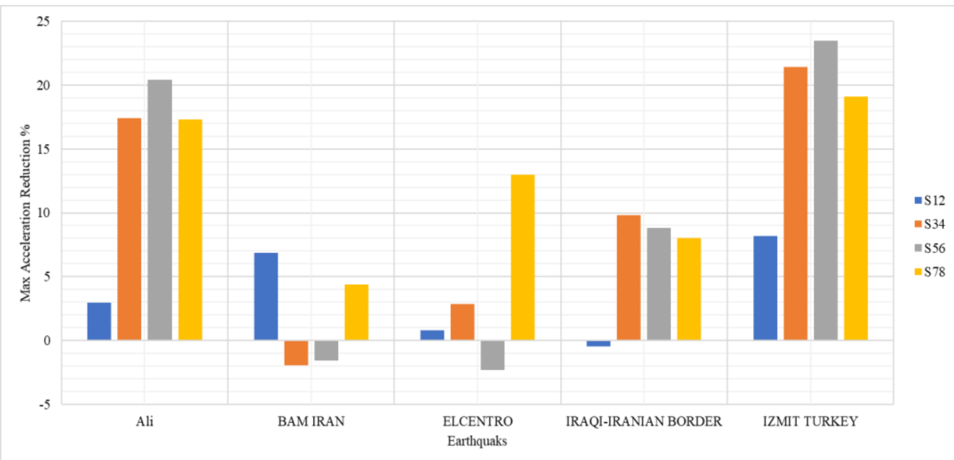

Figure 38. UTFD located in two stories for different earthquakes

The highest average maximum acceleration of 18% occurs when subject to Izmit earthquake illustrated in Figure 38. While the average maximum acceleration reduction obtained when subject to Ali Algarbi was significantly high. The reduction when subject to Iraq-Iranian border and El Centro were low and inconsistent.

In term of maximum acceleration reduction for structure when the damper with upper toggle friction for different damper location in Figure 39. The highest maximum acceleration of 24% obtained when the damper located in the fifth and sixth story. The same behavior obtained from the previous case of placing the damper in one story.

Figure 40 illustrates the maximum acceleration reduction of the structure with dampers located in three stories. The average maximum acceleration reduction of 21% obtained when subject to Izmit earthquake. The maximum acceleration reduction occurs when subject to Ali Algarbi and Kobe was adequately high. While maximum acceleration reduction obtained when subject to Bam, El Centro and Iraqi-Iranian border was inconsistent.

In term of damper location, the highest maximum acceleration of 30% occur as the damper located in the stories 4th to 6th story as shown in Figure 41. The reduction when the damper located in stories 7th to 9th was adequately high.

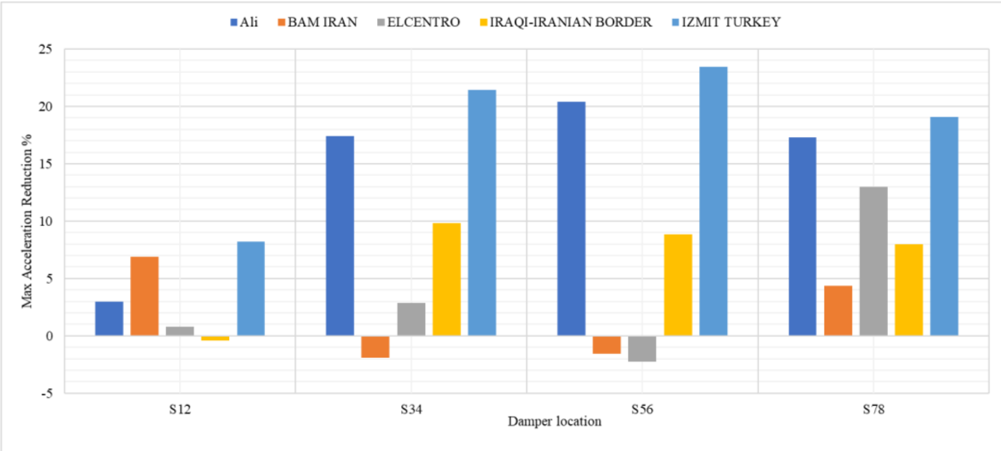

Figure 39. UTFD located in two stories for different damper location

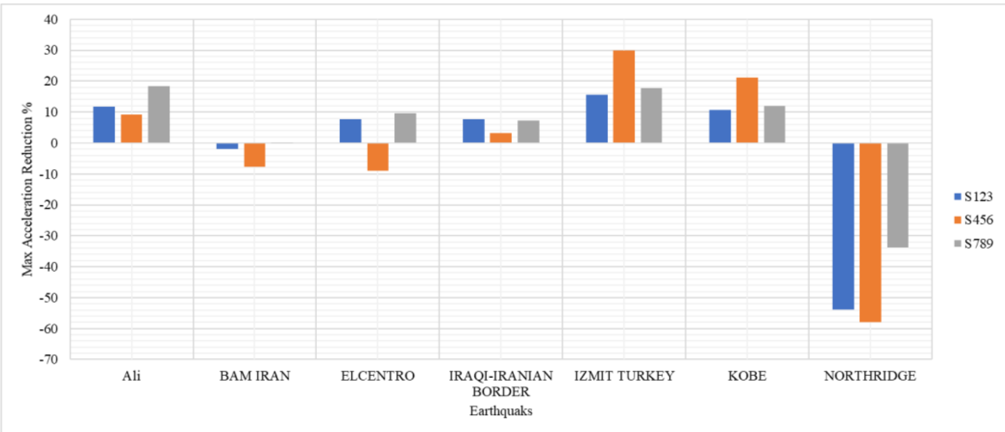

Figure 40. UTFD located in two stories for different earthquakes

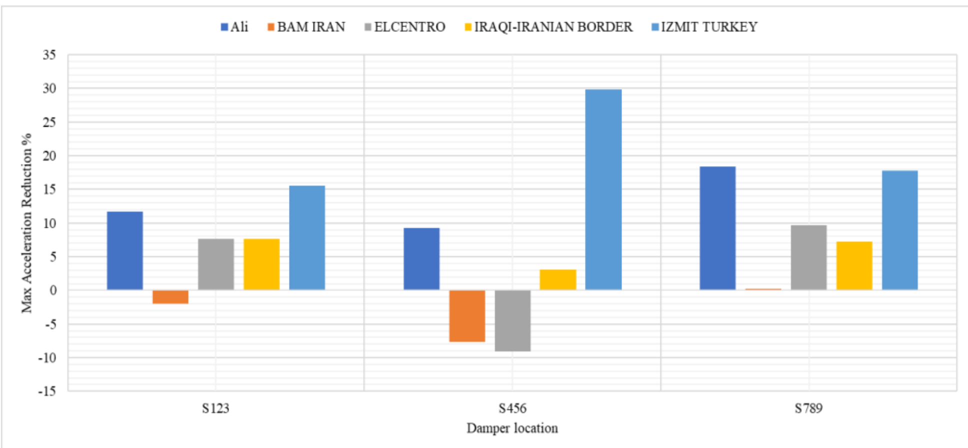

Figure 41. UTFD located in two stories for different damper location

Table 4. Maximum displacement reduction in term of damper location and damper configuration

Damper Location	S1	S2	S3	S4	S5	S6	S7	S8	S9	S12	S34	S56	S78	S123	S456	S789
Diagonal friction	2.51	16.64	14.88	12.61	13.15	15.22	18.20	18.08	15.32	15.89	5.89	7.53	18.14	7.15	28.93	17.24
Chevron friction	1.34	14.83	15.68	15.05	15.38	16.22	17.78	15.14	12.21	13.88	5.83	7.09	17.90	4.68	28.26	19.82
Toggle friction	3.68	14.21	12.37	11.11	12.07	13.45	16.34	20.12	15.98	12.91	20.74	21.74	14.47	14.55	35.95	15.50

Table 5. Maximum displacement reduction in term of configuration and earthquakes records

	Diagonal Friction	Chevron Friction	Upper Toggle Friction
Ali	22.22	21.21	23.01
BAM IRAN	29.92	29.26	33.63
ELCENTRO	18.20	19.82	20.12
IRAQI-IRANIAN BORDER	28.93	28.26	35.95
IZMIT TURKEY	3.82	4.68	5.69

Table 4 and Table 5 show that the maximum displacement reduction is in terms of damper placement; the reduction under the Izmit earthquake needs further study of different arrangements to reduce the maximum displacement.

6. CONCLUSIONS

In this study, the building is model by the use of ETABS v21. The model investigated the behavior of multistory building under seven earthquakes. The configurations are diagonal, chevron and upper toggle. Each of the damping system performed in different way with a variety of results. The study led to the following conclusions:

i. The highest maximum displacement reduction was obtained when using upper toggle friction damper. The reduction result show that this type of damper has outstanding performance when located in all location.
ii. The maximum displacement reductions in diagonal friction damper were adequately high When, placing the damper in top stories of the structure. The efficiency of the damper reduced when move to the bottom was reduced.
iii. The highest maximum displacement reduction of diagonal friction damper occurs when the damper placed in the mid stories where the story drift was the highest value.
iv. The highest maximum displacement reduction obtained when the damper is located in mid story. The behavior of the chevron friction damper is similar to diagonal friction damper.
v. In term of highest maximum acceleration reduction was obtained when using upper toggle friction damper. The reduction result show that this type of damper has outstanding performance when located in all location.
vi. The maximum reduction of acceleration when using the upper toggle friction damper occurs when the damper located at mid stories.
vii. The maximum reduction of acceleration of chevron friction damper also occurs when the damper located in mid-stories. While the diagonal friction damper has the same behavior with lower values of reduction.

The study demonstrates that friction dampers significantly reduce seismic responses in 3D structures. The reduction in displacement, acceleration, across various seismic events showcases the dampers' efficacy. Different configurations of friction dampers provide varying levels of performance improvement, indicating the importance of optimal placement and orientation within the structure. The study found that friction dampers are particularly effective in mitigating responses under medium to high seismic intensities. This indicates their potential utility in regions prone to significant seismic activity. Engineers can leverage the insights on configuration-specific performance to develop customized damper solutions tailored to individual building designs. This approach ensures that each structure receives the optimal level of damping based on its unique characteristics.

6.1 Limitations

This research faced several significant limitations, which include:

- The building is not symmetric.
- The building was designed for no seismic zone.
- The effect of seismic excitation on the foundation was ignored.
- The study was limited to one building and one type of damper.

6.2 Future work

For the future study suggestion:

- The study includes more toggle configurations.
- Extend the study to include the use of other types of dampers (viscous, viscoelastic, metallic, etc.).
- Extend the study to include the use building with different heights.
- Extend the study to include the use of wide range of synthesized excitation.
- Studying economical methods of damping historical buildings from seismic hazards.

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