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Investigating Effect of Friction-yielding Top Plate of Rigid Connections on Seismic Response of Special Moment Frames

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ABSTRACT

Acceptable seismic performance, ease and low cost in design and implementation are advantages of passive dampers, but fixed performance parameters corresponding to the type and amount of input energy reduce their efficiency. In this research, a new two-level passive damper in rigid connections with variable stiffness, strength, and energy absorption capacity is introduced and its seismic performance in 5, 10, and 15-story steel frames is evaluated with nonlinear dynamic analysis using SAP2000 software. The results show that, despite the different dynamic parameters in the selected seismic records, such as the frequency content and duration of ground motions, the performance of the structures under all earthquakes has improved significantly, which confirms the effectiveness of the proposed damper in rigid connections on improving the seismic performance structures. Besides, results prove the proposed damper effectiveness on decreasing the structural response such as maximum displacement and base shear. The average displacements reduced by 61%, 51% and 16% compared to those of BSEEP-4ES connections for the 5, 10 and 15-story frames, respectively. Besides, maximum base shear forces reduced by average of 29% and 15% compared to those of BSEEP-4ES connections for the 5 and 10-story frames, respectively.

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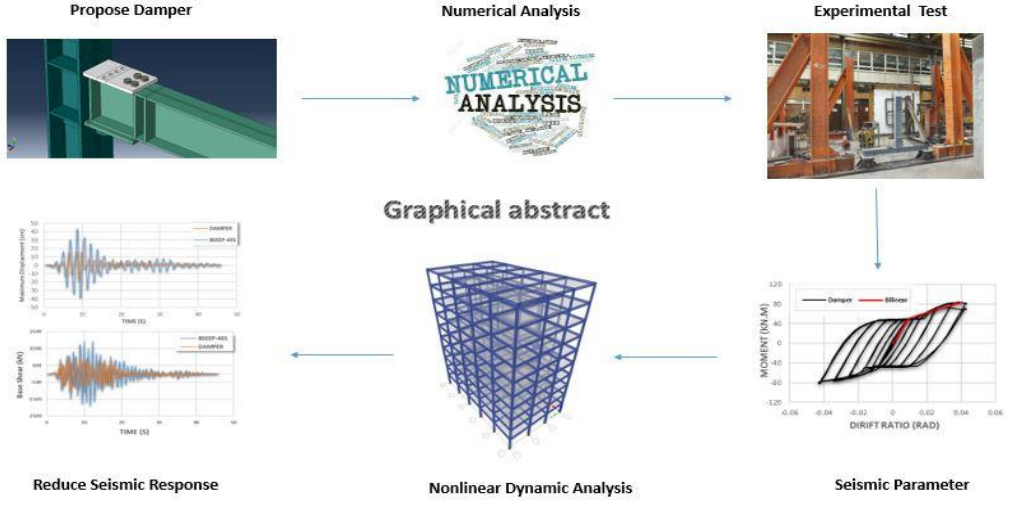
Graphical Abstract



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1. INTRODUCTION

In previous earthquakes, many steel frames suffered damage at their ordinary rigid moment beam-to-column connections. The research conducted on the damaged structures showed that the welded areas in the beam-to-column connections can be damaged against the seismic movement of the structure during an earthquake. Considering these widespread damages, it was tried to find solutions to increase the ductility of bending connections. The design of moment connections by creating a plastic hinge in the beam at a suitable distance from the column or in additional members such as dampers in beam-to-column connection, is the main approach in such ductile ideas. In addition to creating the required rotation in the connection, the strength and stiffness are also maintained at a proper level. The approaches carried out so far to create a plastic hinge in the beam are based on the intentional reduction of the beam section at a short distance from its connection to the column; mainly by cutting part of the flange or web of the beam (1, 2). Also by cutting a part of the beam flange and separating the flange and web in that part (3), drilling the flange of beam (4), drilling the flange of beam and separation of the flange and web (5), replacing flat beam web by corrugated plate and replacing flat beam web by a tubular segment in an area near to the column (6, 7), as well as reducing the yield stress in the beam, in the near of its connection to the column by heating the section (8). Gjukaj et al. (9) investigated the numerical behavior of extended end-plate bolted connection under monotonic loading. Also Pawanithiboworn et al. (10) evaluated the parameters affecting rotational behavior of cold-formed steel connection. Kaveh et al. (11) presented an optimization-based record selection approach for incremental dynamic analysis and estimation of fragility curves.

The use of ideas based on strengthening the beam-to-column connection area or deliberately weakening the beam relative to the column leads to proper performance and damage control in the structure, but during an earthquake, the damage is still concentrated in the main member of the structure.

One of the most effective and practical solutions to prevent these problems is to use dampers in connections. Passive control methods are usually used as retrofit methodologies and seismic rehabilitation for existing structures. These dampers are classified into several groups: hysteretic, frictional, viscoelastic and viscous. The use of yielding dampers in the connection is one of the proposed ideas to reduce damage in structural members against earthquake energy, so that the majority of energy is dissipated by these dampers and as a result, damage to the main members is reduced. Oh et al. (12) suggested the use of yield dampers in the beam-to-column rigid connection. In their study, full-scale specimens of two slit steel dampers were tested and compared. Also, Saffari et al. (13) introduced the slit steel damper in the beam-column connection and analyzed its cyclic behavior with the finite element method. Vasdravellis et al. (14) investigated the cyclic behavior of the pre-tensioned moment connection, equipped with yielding dampers placed in the beam web, experimentally and numerically. Sivandi-Pour et al. (15) evaluated a new type of yielding dampers in steel moment frame joints, numerically and experimentally. The results of the laboratory tests showed the optimal performance of the proposed damper in the connections. Molavi et al. (16) evaluated the cyclic behavior of a new type of beam-to-column connection including a yield damper with a circular pattern in the depth of the beam.

The design criteria used by the codes in recent years are based on resistances, which the general objective in these methods is to dissipate energy by applying plastic deformation, in specific deformable areas in the structure. However, social and economical problems have recently pushed researchers towards systems that can dissipate energy in the level of the earthquake with low damage. Structures equipped with friction rotational connections provide a suitable solution for steel structures, which have good seismic performance with high strength and damage reduction (17-21).

Grigorian et al. (22) conducted the first study on the beam-to-column rigid connection equipped with friction dampers, which investigated slotted bolt connection with friction interfaces of mill scale steel and brass. Later, comprehensive and specialized studies on friction connections with friction dampers in the lower flange of the beam, called sliding hinge connections, were conducted by New Zealand researchers (23, 24). Research groups in this country developed design methods for friction connections, allowing structural engineers to use them in a number of new buildings in New Zealand (17, 20, 24, 25). The seismic behavior of sliding hinge connections is mainly based on the asymmetric friction mechanism, which is converted into various types of dampers with shims made of mild steel, brass, aluminum and abrasion-resistant steel (23, 24). Due to the seismic behavior and proper performance, this type of friction connections has been studied and used in seismic countries such as Japan (26, 27). In Europe, the use of friction dampers in the beam-to-column rigid connection is newer with a different mechanism, so that the connection schematic is different and based on the symmetrical friction mechanism (19-21). The schematic and layout of the European friction connections is not as simple as the New Zealand connections, but the design of these connection is such that it can be installed as a separate damper. Therefore, the main difference between European and New Zealand friction connections is the friction mechanism. New Zealand connections are based on asymmetric friction, while European connections are designed based on a symmetrical friction mechanism. New Zealand asymmetric friction connections subjected to strong earthquakes in the laboratory and in the real building have been extensively analyzed and tested, and as a result, they show good seismic performance with good hysteretic behavior (17, 18, 25). In the asymmetric friction mechanism, the phenomenon of pinching has been observed on the hysteresis curves during load transfer, but in the symmetric friction mechanism, this problem was less (28, 29). The symmetric friction connections were determined by compact hysteretic behavior (29). Whatever different type of symmetry mechanism is considered, beam-to-column rigid connections are designed as partial resistance because their design resistance is usually set equal to friction of the connected beam resistance. According to the standard EN1998-1 (30), partial strength connections can be used in the seismic area only if their rotation capacity is shown. Research on traditional partial strength connections in the last few years has shown that, if appropriate local hierarchies are applied, their performance can meet code requirements that allow plastic deformation in ductile connection sub-components (31-35). Recently, in Europe, two types of frictional connections with symmetric friction mechanism have been prequalified for seismic designs (28). Corresponding numerical and experimental analyzes showed rigid preslip behavior and obtained strength close to design values, resulting in a good cyclic response (29). Also, frictional connections showed ideal behavior under impact loads (36, 37).

The use of two-level control systems in structures is among the systems that have attracted the attention of researchers in the last decade. The design idea of the mentioned systems is to combine two separate control systems in series with different stiffness and strength, which creates dual seismic behaviors due to energy dissipation at different levels of the earthquake. Cheraghi and Zahrai (38) investigated the dual system using a combination of vertical beam and knee elements. damage on the vertical link at low forces increases energy dissipation, and plastic deformation of the knee increases ductility and energy absorption during high forces to improve seismic performance. Zahrai and Vosooq (39) proposed a two-level passive control system using friction and yielding dampers. Also, Cheraghi and Zahrai (38) investigated the use of multi-level dampers with concentric pipes along braces. The experimental and numerical results show high energy absorption along with concentration of failure in the pipes.

Some researchers have conducted studies to improve the seismic performance and ductility of structural systems through two-level control systems. However, the use of such systems in rigid connections has not been proposed and studied so far. In this research, the seismic performance of a proposed two-level control system is investigated using friction-yielding top plate in the beam-to-column rigid connection. It seems that the proposed hybrid damping system in beam-to-column connection, despite its practicality, simplicity, and low cost, shows a good performance and is so effective in reducing the seismic vibrations of moment frames.

2. PROPOSED TWO-LEVEL CONTROL SYSTEM

Considering that it is necessary to increase the ductility and energy dissipation of structures in seismic areas, in this study a two-level passive control system with ability to change dynamic behavior parameters like stiffness, strength and damping ratio for energy absorption at different earthquake levels in beam-to-column rigid connection is discussed. This system consists of a combination of two friction and yielding dampers at the top plate of beam-to-column rigid connection that absorb energy during moderate to severe earthquakes.

In slight lateral relative displacement under the slight seismic loads, the friction damper as a first fuse with sliding force, reduces a large part of the resistance required for loads and with an increase in the displacement range of the vibrations due to strong earthquakes, the yielding damper also comes into action and with the plastic deformations, the level of energy dissipation of the system significantly increases. With proper design and accurate placement of damper parts in the rigid connection, the dissipation of a large part of earthquake energy can be allocated to these parts, as a result, the damage to the main members is reduced. The main idea of the proposed damping system is schematically shown in Figure 1.

As shown in Figure 1, the proposed damper consists of a combination of two friction and yielding dampers. In this system, the friction damper is activated in the first level and due to the dominance of the sliding force over the friction between the top plate and the beam upper flange, it causes energy dissipation. Subsequently, the second level damper or the yielding plate comes into action and with axial yielding, it causes energy dissipation. It should be noted that the dimensions of yielding damper are theoretically not limited and by increasing or decreasing their modularity, one can design the two-level passive control system, where the displacement gap is estimated based on the drift limit considered by the codes and damper geometry. Therefore, the displacement gap was appraised as being equal to the drift value. It is assumed that before this limit is reached, the friction damper can participate in determining the required stiffness and damping. Next, the yielding damper controls the dynamic properties of the structure when the story drift exceeds the specified drift limit.

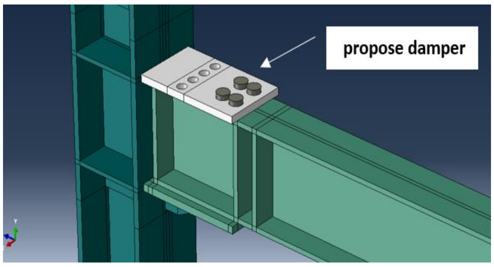


Figure 1. Innovative idea of this research using friction yielding top plate in beam-to-column rigid connection.

3. DAMPER COMPONENTS

3. 1. Friction Damper As shown in Fig. 2, this part of the damping system has four horizontal slotted holes. There is no additional plate between the top plate and the upper flange beam and only the friction of steel on steel is considered. Also, as shown in Fig. 2, four bolts with the diameter of 16 mm were used in connect the friction part to the beam. The diameter and number of bolts are considered according to the required resistance. In order to prevent the concentration of stress in the bolts and their non-yielding, as well as the simplicity of the work, the bolt heads are made slightly larger than the actual size to act as a washer.

3. 1. 1. Theory of Friction Dampers The frictional force can be calculated using the following equation:

$$F = \mu . N \tag{1}$$

In the above equation, F and N represent the friction force and normal force, respectively. The μ is friction coefficient. The value of this coefficient depends on the material of the surfaces that are in contact with each other. Also, in most surfaces, it is slightly dependent on other variables such as the contact surface and temperature. Friction grooved screw connections in concentric bracing frames are linear sliding and rotational sliding. Also, in moment frames, these connections are used in beam-to-column rigid connection as rotational sliding. These connections create the ability to provide the number of cycles of energy dissipation through the pre-tensioning force of the screws. A sliding bolt connection used as an energy-dissipating element in a structure must withstand repeated displacement cycles without loss of strength and perform energy dissipation well. The important factors that have an effect on the satisfactory performance of screw sliding joints are: 1. Keeping the connection pressure constant between the sliding plates 2. Keeping the sliding coefficient constant between the sliding plates 3. Avoiding the failure of the connection components. In friction grooved screw connections, according to the number of sliding surfaces, the following equation is used:

$$F = n * T_b * N * \mu \tag{2}$$

where F is the slip force , n is the number of slip surface, N is the number of bolts, T_b is the tensile force in a bolt, and μ is the friction coefficient. According to the above formula, changing the number and tensile force of screws leads to a wide range of sliding forces. Finally, the optimal sliding force for the friction damper is considered to be 90 kN.

3. 2. Yielding Damper As shown in Figure 2, the yielding part of the proposed system is the same top plate in the beam-to-column rigid connection which is used as a second fuse with axial yielding. The top plate was drilled to weaken its axial strength at a suitable distance from the column at the rate of 0.3 of plate length (0.3L), which can cause damage in the plate before forming in the beam by reducing the plate stiffness.

To better determine the behavioral mechanism of the proposed damper in rigid connection, its full view is drawn in Figure 3. At first, two dampers are completely independent from each other and by applying displacement to the connection only the friction part will come into action after the force in the top plate exceeds the friction between the steel surfaces of the top plate and the upper flange beam and the friction between the mentioned surfaces will cause energy dissipation. An increase in displacement and as a result the longer connection rotation causes the bolts to completely cover the length of the slotted holes and further the yielding damper causes more energy dissipation by creating plastic hinge in itself. The important point is to determine the proper slip length on the friction level and the weakening cross-section on the yielding level, in the proper behavior range of each of the dampers so that the yielding part should be activated before major damage occurs in the beam flange and with increasing stiffness and finally with the composite behavior of both dampers, the occurrence of plastic strains in the yielding plate causes energy dissipation.

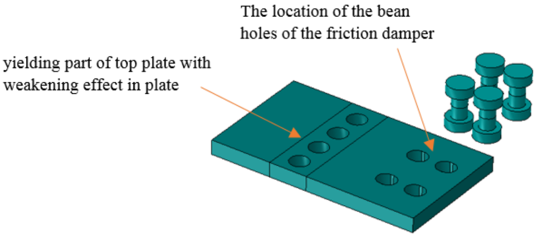


Figure 2. Details damping parts of the two-level control system

4. NONLINEAR DYNAMIC ANALYSIS

In order to evaluate the performance of the proposed damper in multi-story frames, dynamic nonlinear

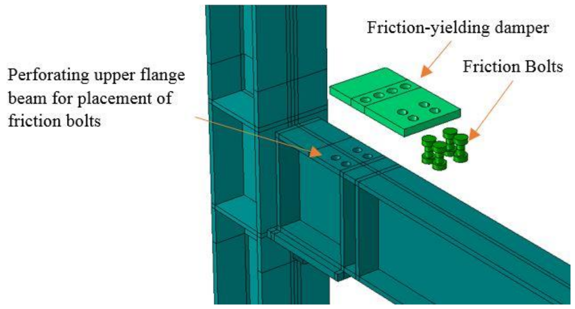
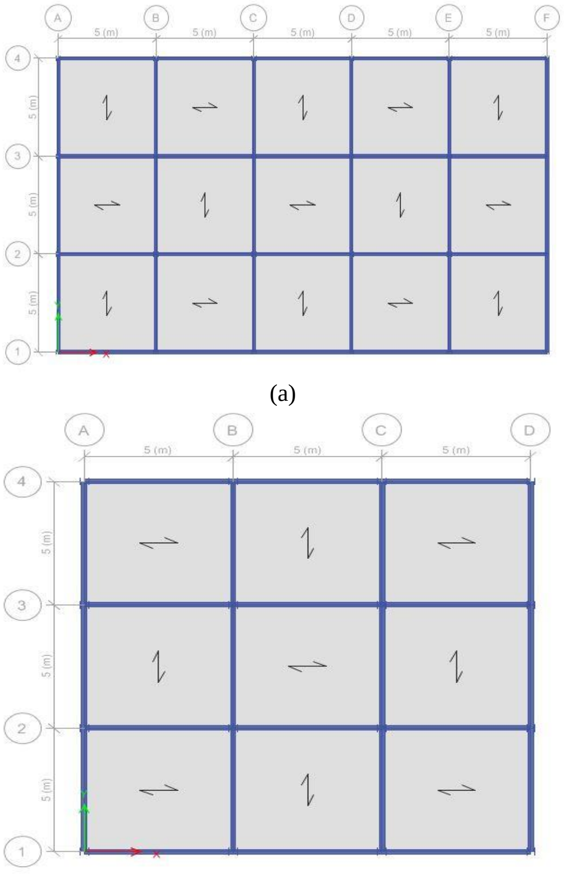


Figure 3. Full view of the proposed two-level damping system in the rigid connection

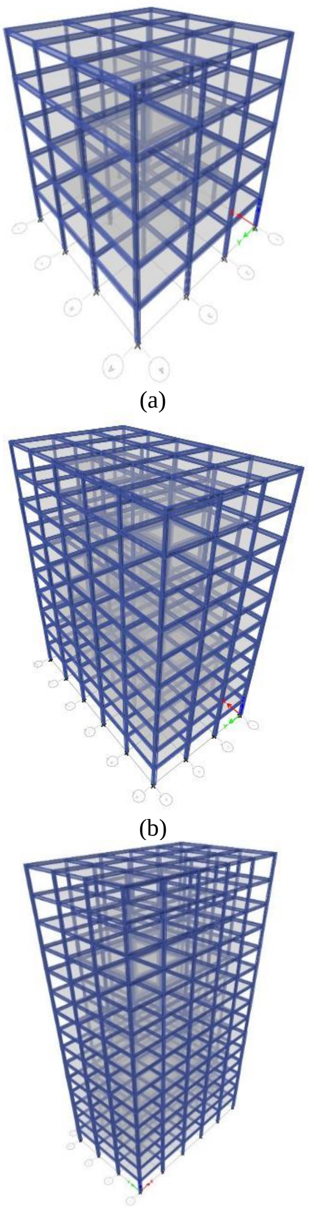
analyses were performed. For this purpose, three 5, 10 and 15-story steel moment resisting frames with the plan shown in Figure 4, as representatives of low-rise, mid-rise and high-rise buildings, respectively, are designed in accordance with Iranian standard 2800 code, and their seismic responses under various earthquakes records are assessed using dynamic nonlinear analysis by SAP2000 software. The story height is selected 3.2 m for all Special Moment Resisting Frame (SMRF). Seismic and gravity loading are selected based on the Iranian seismic national code. The live and dead load are selected 200 kg/m^2 and 500 kg/m^2, respectively. Frames are considered with medium importance on type I soil built in the high risk zone. In order to compare the performance of the proposed connection, BSEEP-4ES connection (40) was designed in (SMRF) based on 2800 code. The steel used is St37 with the yield stress, modulus of elasticity and Poisson's ratio of 240 MPa, 200 GPa and 0.3, respectively. Also, IPB sections are used for columns while IPE sections are used for beams. 3D view of the structure models is shown in Figure 5.



(a)

(b)

Figure 4. Plans of the structure models: a) 10 and 15-story b) 5- story structures



(a)

(b)

(c)

Figure 5. 3D view of the structure models: a) 5- story structures, b) 10- story structures, c) 15- story structures

4. 1. Selected Earthquake Records

In order to check the performance of the proposed damper during seismic loading, 7 accelerograms with differences in maximum acceleration (41), duration and frequency content have been used according to Table 1.

The response spectra of each of the mentioned accelerograms were drawn in Figure 6. According to code 2800, applied accelerometers are first scaled to their maximum value, so that the maximum acceleration of all of them is equal to 1g. Then the combined response spectra were compared to the standard design spectrum, in the time range of 0.2 to 1.5 times the period of the structure. Finally, the scale factor should be selected in such a way that the values of the earthquake spectra are not less than 1/4 times the values of the standard design spectrum.

4. 2. Numerical Modeling

Since it is difficult to accurately model the nonlinear behavior of elements in computer programs, it is usually tried to use a model with two or multi linear behaviors. To introduce the behavior of the proposed damper to the SAP2000 software and for ease of work, its bilinear performance curve was extracted according to the hysteresis curve of experimental specimens (42). The bilinear behavior model of the proposed damper is shown in Figure 7.

After preparing the equivalent bilinear curves of the model, the seismic parameters including the yield drift, ultimate drift, yield moment, ultimate moment, effective stiffness was derived and behavior of the proposed damper including plastic link was defined in SAP2000 software based on the mentioned parameters. The seismic characteristics of model are presented in Table 2.

TABLE 1. Specifications of the records used

Earthquake	Year	Station	PGA (g)	Duration (s)
Hollister	0.198	USGS 1028	0.19	39.8
Kujali	1999	YARIMCA	0.35	35
Northridge	1994	CDMG-24278	0.57	40
Imperial Valley	1979	USGS 5115	0.33	39
chi-chi	199	TCU045	0.36	53
kobe	1995	Kakogawa	0.34	41
Loma Prieta	1989	CDMG -47381	0.37	39.9

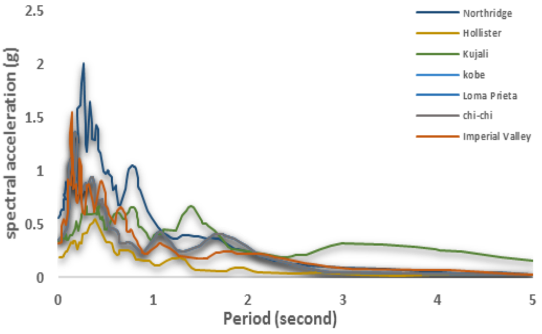


Figure 6. Response spectrum of acceleration

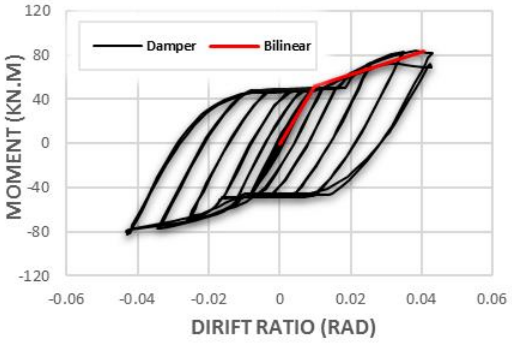


Figure 7. Bilinear behavior model of proposed damper

Effective stiffness of the model is calculated using Equation 2:

$$K_e = M_y/\theta_y \tag{2}$$

TABLE 2. Seismic specifications of the model

M_y (kN.m)	M_u (kN.m)	θ_y (Rad)	θ_u (Rad)	K_e (kN/Rad)
51.72	84.57	0.0098	0.0404	5277.55

5. RESULTS OF TIME-HISTORY ANALYSIS

5. 1. Period of Strcture

Period is one of the most influential parameters in the behavior of the structure during dynamic loading. Therefore, firstly to investigate the effect of the proposed damper on changing the dynamic characteristics of the structure, the periods of the first and second modes were recorded using modal analysis. As shown in Table 3, the results show the noticeable effect of the damper in reducing the period of the structure, and its effectiveness will also be affected by the technical specifications of the damper.

Also, with the reduction of the height of the structure, the effect of the proposed damper on reducing the period of the structure is greater. Therefore, with an increase in the height of the structure, its effectiveness in reducing the period decreases.

5. 2. Maximum Displacment

Based on the results obtained from the modal analysis, the maximum displacement of the structure was calculated in all three steel moment resisting frames of 5, 10 and 15-story frames. The results of the analysis show the noticeable effect of the proposed damper on reducing behavioral parameter of maximum displacement.

It should be mentioned that the change in the period of the structure, as an effective parameter in the amount of force applied to the structure during seismic loading, according to the standard design spectrum, should always be considered in the seismic design and rehabilitation of the structure.

Based on the results obtained from the modal analysis according to Table 3, the use of the proposed damper in the rigid connections compared to the pre-qualified connection (BSEEP-4ES) (40) has reduced the period in all three of 5, 10 and 15-story steel moment resisting frames, in the first and second modes.

According to the results of Table 4, maximum displacement of the structure in the 5-story frame with the proposed damper in rigid connections compared to the pre-qualified connection (BSEEP-4ES) (40) has a ratio between 0.18-0.59 and this amount in the 10 and 15-story frames has reached values between 0.37-0.61 and 0.67-1, respectively. Therefore, it seems that the effectiveness of the proposed damper on reducing the maximum displacement parameter would be greater in low-rise and mid-rise structures than in high-rise structures. As an example, the curves of maximum displacement changes under the Kobe earthquake record in all three 5, 10 and 15-story steel moment resisting frames are shown in Figure 8.

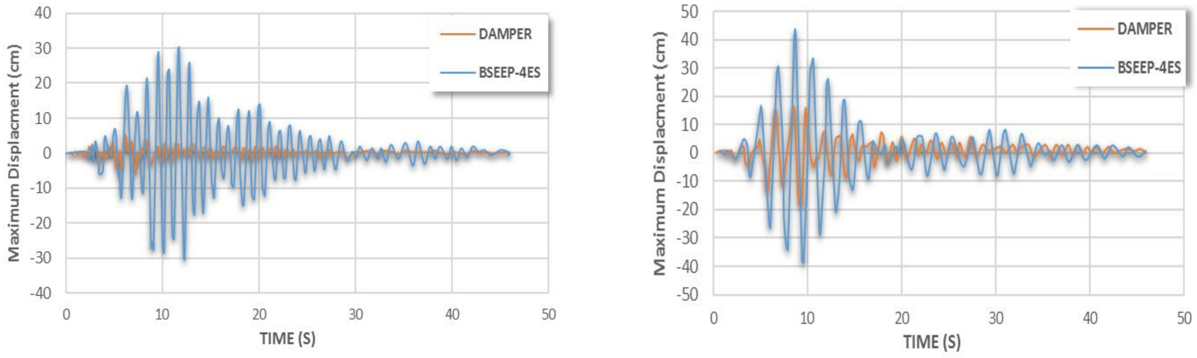
As shown in the curves of the maximum displacement changes in the Kobe earthquake record in Figure 8, the proposed damper has a positive impact, but this effect does not have a constant trend. In other words, in low-rise and mid-rise structures, it has a more severe decreasing trend but in high-rise structures it has a decreasing trend with a milder slope and sometimes it has

TABLE 3. Effect of the proposed damper on the perio

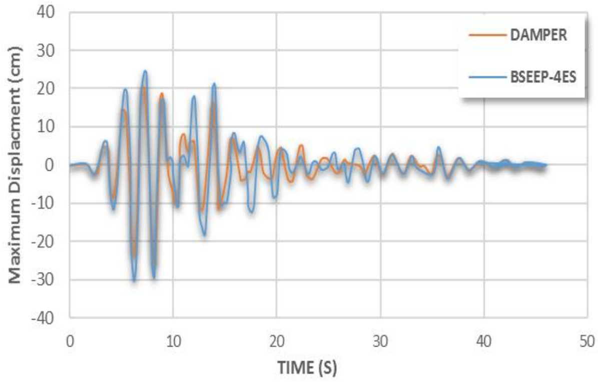
FRAME	**5-STORY**			**10-STORY**			**15-STORY**		
PERIOD (S)	**BSEEP-4ES (B)**	**Damper (D)**	**D/B**	**BSEEP-4ES (B)**	**Damper (D)**	**D/B**	**BSEEP-4ES (B)**	**Damper (D)**	**D/B**
MODE 1	1.11	0.76	0.68	2.01	1.58	0.78	2.54	2.22	0.87
MODE 2	0.68	0.43	0.63	1.13	0.96	0.84	1.41	1.08	0.76

TABLE 4. Damper effect in reducing maximum displacement

Mximum displacement [cm]									
15-story frame			**10-story frame**			**5-story frame**			**Earthquake record**
D/B	**Damper (D)**	**BSEEP-4ES (B)**	**D/B**	**Damper (D)**	**BSEEP-4ES (B)**	**D/B**	**Damper (D)**	**BSEEP-4ES (B)**	
0.76	30.03	39.1	0.44	14.12	31.97	0.48	10.06	20.87	Imperial Valley
0.67	20.51	30.21	0.37	16.52	43.65	0.18	5.57	30.27	kobe
1	14.89	14.21	0.57	8.67	15.05	0.44	7.65	17.34	chi-chi
0.88	17.46	19.81	0.61	11.54	19.22	0.59	7.86	13.56	Hollister
0.73	11.23	15.21	0.42	8.26	19.25	0.56	8.56	15.35	Kujali
0.81	19.41	24.18	0.51	11.56	22.76	0.59	10.45	17.48	Northridge
0.77	32.45	42.4	0.52	19.24	36.8	0.43	9.87	22.87	Loma Prieta



(a) (b)



(c)

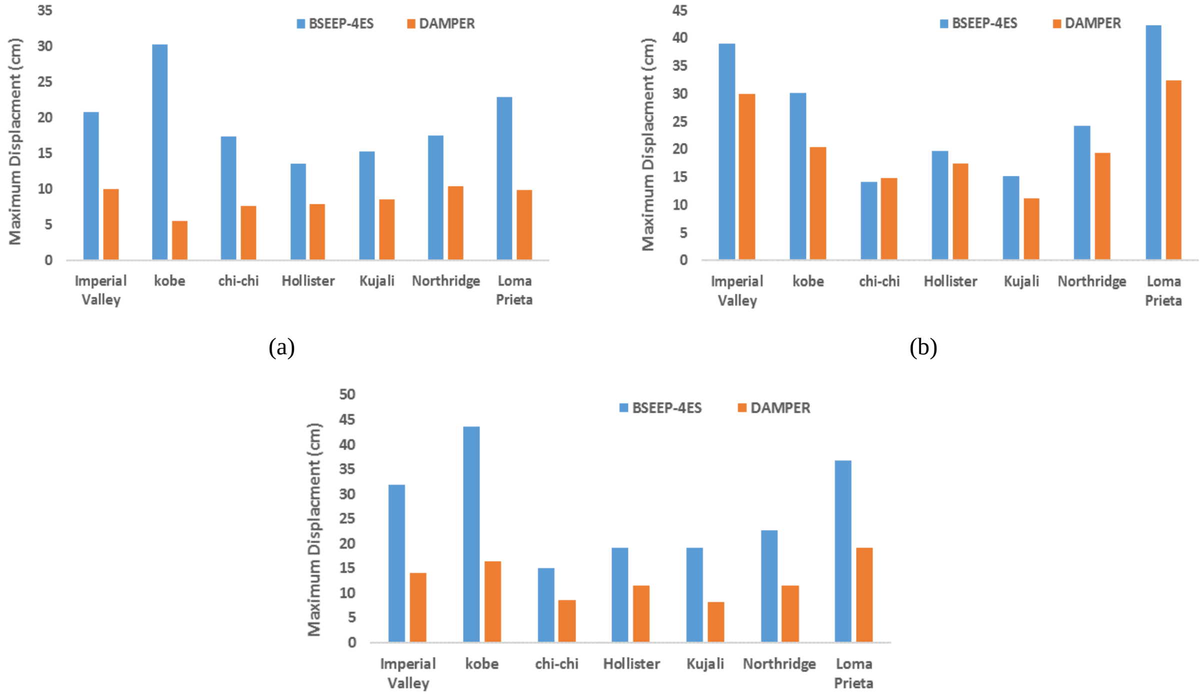
Figure 8. Maximum displacement of the structure under the Kobe earthquake record: a) 5-story, b) 10-story, c) 15- story

also increased the responses. It seems that reducing the period of such structures according to standard design spectrum has caused an increase in responses.

Therefore, paying attention to the standard design spectrum as well as the frequency content of earthquakes is very important in design that if attention is not paid, it will reduce the efficiency of the damper. In order to better compare the results, the maximum displacement is presented in bar charts. As shown in Figure 9, in all seven applied accelerograms, the response of the structure equipped with a damper is lower compared to that of the pre-qualified connection (BSEEP-4ES) [42].

5. 3. Maximum Base Shear

According to the results obtained from the nonlinear dynamic analysis, the base shear was calculated for 5, 10 and 15-story steel



(a)

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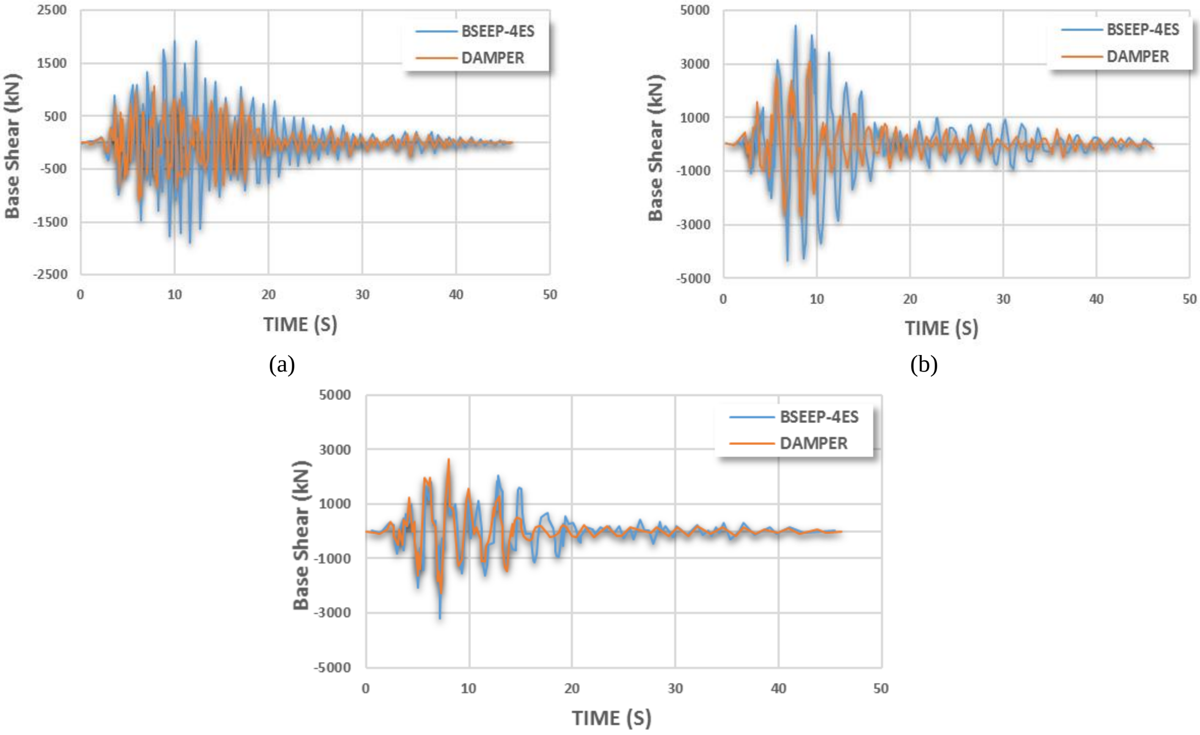
Figure 9. Comparison diagram of the maximum displacement of the structures under different earthquake record: a) 5-story, b) 10-story, c) 15- story



(a)

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(c)

Figure 10. Base shear under the Kobe earthquake record: a) 5-story, b) 10-story, c) 15- story

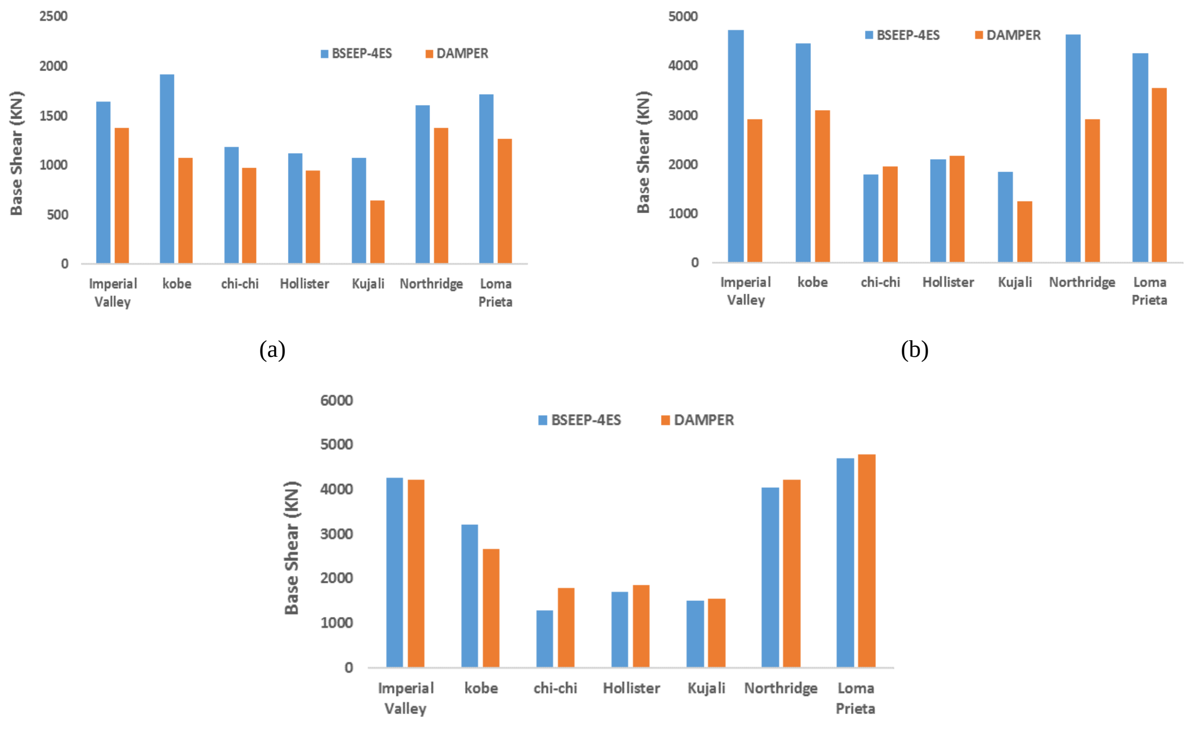
moment resisting frames. The results of the evaluation show the optimal performance of the two-level damper in beam-to-column rigid connection, in a way that significantly reduces the base shear in the structures. According to the results of Table 5, the maximum base shear in the 5-story structure equipped with proposed damper in beam-to-column rigid connections compared to that of the pre-qualified connection (BSEEP-4ES) [42] has a ratio between 0.56-0.85 and this amount in the 10 and 15-story structures has reached values between 0.62-1.08 and 0.82-1.39, respectively.

In some cases, due to the noticeable increase in stiffness and reduction in the period of the structure, the base shear has increased slightly, which indicates the need to pay attention to the standard design spectra in the design of structures. According to the obtained results, it seems that the effect of the proposed damper in reducing the maximum base shear parameter is greater in low-rise and mid-rise than that in high-rise structures. The diagram of base shear changes in the Kobe earthquake record for all structures is shown in Figure 10.

As shown in the curves of the maximum base shear changes in the Kobe earthquake record in Figure 10,

TABLE 5. Damper effect in reducing base shear

Maximum base shear [kN]									
15-story frame			**10-story frame**			**5-story frame**			**Earthquake record**
D/B	**Damper (D)**	**BSEEP-4ES (B)**	**D/B**	**Damper (D)**	**BSEEP-4ES (B)**	**D/B**	**Damper (D)**	**BSEEP-4ES (B)**	
0.98	4220.86	4260.33	0.62	2924.57	4729.16	0.84	1380.73	1642.19	Imperial Valley
0.82	2653.92	3220.33	0.69	3098	4457.03	0.56	1076.7	1921.91	kobe
1.39	1792.5	1286.5	1.08	1961.01	1803.12	0.82	973.2	1183.12	chi-chi
1.08	1846.17	1700.72	1.03	2168.69	2095.77	0.84	944.98	1117.98	Hollister
1.03	1541.81	1495.02	0.67	1253.74	1855.53	0.63	647.66	1072.38	Kujali
1.04	4210.12	4049.89	0.62	2917.11	4635.57	0.85	1377.21	1609.69	Northridge
1.02	4796.58	4692.88	0.83	3561.21	4257.92	0.73	1266.19	1717.19	Loma Prieta



(a)

(b)

(c)

Figure 11. Comparison diagram of the maximum base shear of the structures under different earthquake records: a) 5-story, b) 10-story, c) 15- story

same as maximum displacement changes, the proposed damper in rigid cinnections, has a positive effect, but this effect does not have a constant trend. Base shear in low-rise and mid-rise structures has a more decreasing trend than that of high-rise structures and even in high-rise structures, sometimes the response of the structure has also increased. It can be concluded that reducing the period of such structures according to standard design spectra has caused an increase in responses. As mentioned before, it is very important to pay attention to the standard design spectrum as well as the frequency content of the earthquake in the design [43, 44].

In order to better compare the results of Table 5, the maximum base shear is presented in bar graphs. As shown in Figure 11, in all the seven applied accelerograms, the response of the structure equipped with a damper is lower compared to that of the pre-qualified connection (BSEEP-4ES) [42].

6. CONCLUSION

In this study, the impact of the friction- yielding top plates damper in beam-to-column rigid connections on improving the dynamic response of special moment frames in multi-story steel structures was investigated using nonlinear dynamic analysis. The results were as follow:

-Despite the different dynamic parameters in the selected seismic records, such as the frequency content and duration of ground motions, the performance of the structures under all earthquakes was improved significantly, which confirms the effectiveness of the proposed damper in rigid beam-to-column connections on improving the seismic performance.

-Based on the results obtained from the modal analysis, the use of the proposed damper in the rigid connections compared to the pre-qualified connection (BSEEP-4ES) has reduced the period in all three steel moment resisting frames of 5, 10 and 15-story structures, in the first and second modes.

-The average displacements reduced by 61%, 51% and 16% compared to those of BSEEP-4ES connections for the 5, 10 and 15-story frames respectively.

-Maximum base shear forces reduced by average of 29% and 15% compared to those of BSEEP-4ES connections for the 5 and 10-story frames respectively.

-According to the obtained results, the effect of proposed damper on reducing the maximum base shear and maximum displacement parameters is greater in low-rise and mid-rise structures than in high-rise ones.

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Persian Abstract

چکیده

عملکرد لرزه ای قابل قبول، سهولت و هزینه پایین در طراحی و اجرا از مزایای میراگرهای غیرفعال می باشد، اما عدم امکان تغییر در مشخصات سیستم متناسب با نوع و مقدار انرژی ورودی، کارایی آنها را کاهش می دهد. در این تحقیق یک میراگر غیرفعال دوسطحی جدید در محل اتصال گیردار تیر به ستون با سختی، مقاومت و ظرفیت جذب انرژی انتخابی معرفی شده و عملکرد آن در سه قاب ۵، ۱۰ و ۱۵ طبقه با تحلیل دینامیکی غیرخطی با استفاده از نرم افزار SAP2000 مورد ارزیابی قرار گرفته است. نتایج نشان می دهد، علیرغم پارامترهای دینامیکی متفاوت در رکوردهای لرزه ای منتخب، ازجمله محتوای فرکانس و مدت زمان حرکات زمین، عملکرد سازه تحت زلزله های مختلف به طور چشمگیری بهبود یافته است که موید اثربخشی میراگر پیشنهادی در اتصالات گیردار تیر به ستون، در بهبود عملکرد لرزه ای سازه ها می باشد. علاوه بر این، نتایج کسب شده نشان از اثربخشی میراگر پیشنهادی در کاهش پاسخ های سازه مانند برش پایه وحداکثر جابجایی دارد. میانگین حداکثر جابجایی در مقایسه با اتصالات از پیش تایید شده گیردار از نوع BSEEP-4ES ، برای قاب های های ۵، ۱۰ و ۱۵ طبقه به ترتیب ٦١، ۵۱ و ١٦ درصد کاهش یافته است. علاوه بر این، حداکثر برش پایه نسبت به اتصالات از پیش تایید شده مذکور برای قاب‌های ۵ و ۱۰ طبقه به‌ترتیب ۲۹ درصد و ۱۵ درصد کاهش یافت.