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Sensitivity Analysis of Behavior of Simple Trapezoidal Steel Plates to Introduce a New Yielding Damper

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ABSTRACT

Over years, the energy absorption process against different kinds of loading has always been one of the most important issues in the engineering science. To address this, many kinds of dampers such as viscoelastic, friction, yielding, mass, and liquid dampers have been invented. Among all these dampers, steel yielding dampers are one of the most economic, available, suitable, and best choices for the long return period of seismic cyclic loading on structures. However, it seems that there are not sufficient studies on these dampers to convince the designers to use them widely. This research tries to show the effects of geometrical parameters on the energy absorption and cyclic behavior on a specific simple trapezoidal steel yielding damper using the finite element method, then the effect of using a new steel damper on base shear and roof acceleration responses of a three storey building studied by nonlinear time history analysis. According to the results, there are some effective and less effective parameters whose variation such as geometrical parameters can seriously change the total energy absorption level and improve the damper hysteresis loops as well as ductility under specific cyclic loading and showed that using a new steel damper will result in the significant decreasing in base shear and roof acceleration of the building.

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NOMENCLATURE

E	Steel module of elasticity (kN/mm^2)	PGA	Peak ground acceleration of ground motion (m/S^2)
F_y	Steel yielding strength (kN/mm^2)	PGV	Peak ground velocity of ground motion (m/S^2)
P_n	Yielding plate nominal yielding load (kN)	α	Trapezoidal plates angle (deg)
K_{eff}	Yielding plate elastic stiffness (kN/mm)	θ	Brace angle (deg)
V_s	Soil shear wave velocity (m/s)	β	Effective damping
b	Yielding plate width (mm)	t_0	Yielding plate thickness (mm)
t_1, t_2	Moving & fixed support plates thickness (mm)	A	Hysteresis loop area (kN.mm)

1. INTRODUCTION

Controlling and damping the structural seismic energy at the time of an earthquake has always been an important issue for structural earthquake researchers. Nowadays, codes allow designers to take account of plastic hinges in some parts of structures. In addition, they offer some sections and connections to concentrate on the damaged area such as reduced beam sections. However, it is a fact that some parts of the structure will get damaged and should be replaced after a major shock. Thus, researchers are trying to find damage control approaches to reduce the damaged area and increase the energy dissipation of structures. The use of dampers is one of the most considerable ways to achieve this goal. Dampers can dissipate the input earthquake energy without any significant damage to the main parts of the structure. Among all dampers, steel yielding dampers are the most available, economic, and easy to construct. Concerning the energy absorption process of steel, it should yield due to shear force and bending moment, so steel yielding dampers should be embedded such that they deform due

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to the lateral force of structures during an earthquake. ADAS dampers are one of these useful dampers. They are made of many yielding plates, placed above a chevron brace and yield together; meanwhile, it seems they can also be used in many other places of structure such as base plates, beam-to-column connections, and diagonal braces. The related history and evolution of these kinds of dampers are expressed further. Since 1976, many researchers have been trying to find a way to use steel yielding dampers in structures. In 1976, Kimura et al.[1] and in 1980 Mochizuki et al. [2] began their studies on dampers by researching non-buckling braces. The first type of this type of brace was introduced by Wanatabe et al. [3] in 1988. In 1990, Fujimoto et al. [4] installed them on 10- to 15-storey office buildings in Japan after conducting several experiments on non-buckling braces and preparing a numerical model. Extensive research has been conducted on various types of dampers since then. In 2019, Daniel et al. [5] studied seismic mitigation of Magnetorheological dampers. In 2019, Del Gobbo and Marcantonio [6] also evaluated the seismic performance of three types of four-, eight- and sixteen-story buildings by installing viscous dampers. He concluded that the use of dampers could significantly reduce the cost of repairing a structure once it occurred if any of the methods of placing the dampers were considered and an optimal design was achieved. Elsewhere, dealing with friction dampers, Taiyari et al. [7] in 2019 evaluated the seismic performance of two real four- and ten-storey structures using friction dampers. They concluded that the use of this type of damper plays an effective role in reducing the seismic parameters of the structure. Various yielding dampers have always been considered by researchers due to their optimal performance and energy absorption, stable cycle diagram, and ease of construction, as well as the flexibility of their shape and design. In 2018, Gerami and Kafi [8] conducted studies on the effect of the presence of yielding dampers at predetermined points on the seismic performance of convergent bracing frames. They proved that by using theoretical foundations and numerical modeling if the sections of the bracing members are properly reduced at certain points, the seismic behavior of the braced frame will be significantly improved. The use of a variety of ring and U-shaped elements has also been one of the favorite fields of damping researchers due to the high energy absorption process; among them, we can mention in 2014 Kafi et al. [9] and Zahraei and Cheraghi [10] in 2016. Yielding slit dampers are also a type of yielding damper that has recently been researched for use. In 2008, Chan and Albermani [11] examined the use of slit dampers in braced frames and performed several laboratory tests. They concluded that due to yielding of this type of damper in small rotations, it quickly enters the process of energy absorption during an earthquake. Also, considering the re-hardening after yielding, the ultimate strength of the fuse increases to twice its yielding rate. The use of parallel yielding plates in the design of yield dampers is a method considered in recent years due to its many advantages. In 2020, Maleki et al. [12] studied the effect of Curved-TADAS dampers on seismic response of moment resisting steel frames. The parallel triangular and trapezoidal plates used in XADAS[2] and TADAS[3] dampers have also been considered by researchers due to the high uncertainty of the part and the wide energy absorption in the entire yielding surface. In 1995, Soong et al. [13] considered a yielding damper using triangular parallel plates for the use on the upper part of Chevron braces. In 2009, Chan et al. [14] used shear steel plates to absorb energy in Chevron braces. After nineteen monotonic and cyclic laboratory tests, they concluded that the system had a completely stable behavior and that a large amount of energy was absorbed. In 2011, Krawinker et al. [15] performed experiments on the rhombic slit dampers. Indeed, the geometry of this damper was designed to better distribute the yielding and energy absorption process of the steel on its surface. In 2011, Akula [16] tested a type of yielding damper using U-shaped components. By designing a kind of connecting piece, he was able to arrange the U-shaped pieces in such a way that it would deform suitably by absorbing axial force and absorbing energy. In 2012, Hosseini and Noroozinejad [17] along with Hosseini and Alavi [18] in 2014 proposed the idea of telescopic columns when the rocking motion of the structure by using parallel yielding plates in the side columns. After experimental studies and nonlinear analysis, they proved that the use of parallel steel plates as interchangeable yielding dampers can provide desirable results in the behavior of the structure during an earthquake. In 2013, Li et al. [19] investigated the use of parallel yielding plates in series in the upper part of Chevron braces in reinforced concrete frames. They also installed and tested a prototype of this type of system in a reinforced concrete building. Finally, they concluded that the stiffness of this system subjected to small earthquakes and the possibility of yielding in large earthquakes provided a good opportunity for the seismic resistance and energy absorption. After several numerical analyses, they concluded that the use of this system in a reinforced concrete structure understudy will reduce seismic responses. In 2016, Aghakouchak et al. [20] investigated the effect of using a new type of damper called a sawtooth steel yielding damper to improve the cyclic behavior of steel frames. The results of finite element modeling as well as the conducted experiments showed that the designed damper produced responses by the design objectives. The tested specimens also revealed

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[2] X-Shaped Plate Added Damping and Stiffness

[3] Triangular-Shaped Plate Added Damping and Stiffness

a completely stable hysteresis loop curve before tooth fracture while tolerating significant cumulative displacement. Gray et al. [21-24] introduced a yielding damper using parallel triangular pieces from 2012 to 2017. During several years of research, he built his damper by casting. Finally, after doing a few tests on the damper, he tested it by installing on a real-size frame. The experimental results indicated the optimal behavior of the bracing frame equipped with dampers. Also in 2019, Zibasokhan et al. [25] introduced a new type of yielding damper with parallel plates to improve the seismic performance of braced structures. After conducting several experimental studies, they concluded that the frame containing the proposed damper had a stable and desirable cyclic behavior. As mentioned in the literature, the constituent component of the damper, the trapezoidal plate, can be used as a part of new dampers. However, there is no perfect research on this field and it seems that a sensitivity analysis is required on the effective parameters of this important component. This research tries to show the sensitivity of the steel trapezoidal fuse due to changing geometrical specifications then a nonlinear time history analyses done on a three-story building which has been equipped by the new steel yielding damper made by trapezoidal plates and the base shear and roof acceleration responses were comprised using OpenSees. The model is made of two parallel and one simple trapezoidal fuse (Figure 1). Considering the function of the damper, two parallel plates move across each other so the fuse part yields and energy absorption process begins. The small sideway of the fuse part can be easily moved into the embedded gap where the large one is welded into another plate. The gap seize is so that pieces can be easily made but the extra gap can have some negative effects on the function of the damper and hysteresis loops. Eventually, this small simple model can act as a small part of a large damper.

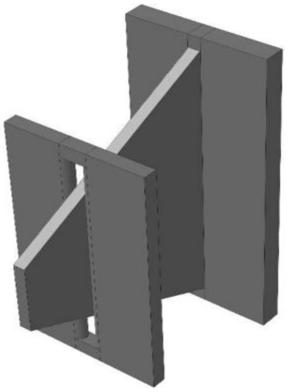


Figure 1. General shape of the damper element

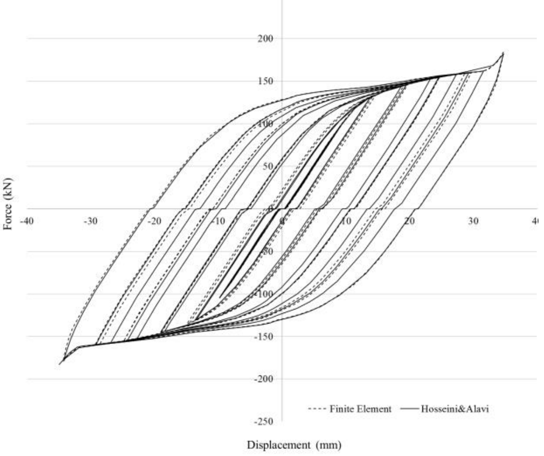


Figure 2. Modeling Verification

2. MODELING VERIFICATION

To ensure that the analytical results are reliable, the finite element modeling procedure and results should be controlled with a similar experimental model. Hosseini and Alavi [18] tested a kind of energy dissipation device, whose hysteresis loops could be the modeling reference. Figure 2 shows the hysteresis loops verification.

3. ANALYSIS

The model behavior was measured by 28 finite element analyses by ABAQUS software. For this purpose, the three main effective parameters were selected. The first is material properties including yielding and ultimate strength, the module of elasticity and ductility effect on the damper behavior. since yielding dampers are usually made of structural steel (ST37), so the related effective parameters obtained from the laboratory test of structural steel by Hosseini and Alavi [18], which is shown in Figure 3. The friction coefficient is considered 0.3.

The second analysis setting is related to the software which involves loading speed, size of meshing, and the solution method affecting the results. For the second category of the parameters, the model hysteresis loops

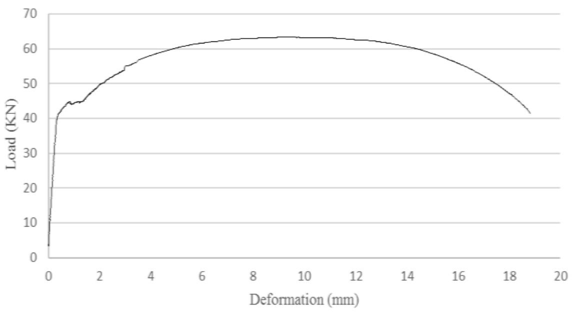


Figure 3. The Hosseini & Alavi Stress-Strain Diagram [18]

are verified against experimental test results. loading protocol (Figure 4) and loading speed, analysis method, the element type of meshing, and size of meshing fall in this category. The static nonlinear method was used to calculate the results. For this purpose, the maximum 45 mm displacement at 1.8 s was applied to the model according to Figure 4 loading diagram. The first step of the analysis was supposed to be 5e-5 and the maximum step time was described as 0.01 s. It should say that according to the model verification, the chosen analytical parameters are correct and can be fixed.

Due to sensitivity and excessive distortion of the fuse part, the element C3D10 was selected for this part and the element C3D8R was selected for the other parts of the damper. Figure 5 reveals the shape of these elements.

Figure 6 indicates the meshing size and element assignment and arrangement of the parts. As stated earlier, the fuse part meshing assignment is different from the other parts due to its excessive distortion. Due to the support condition of the fuse part, the bending moment will decrease from the large sideway of the plate to the small sideway, but the shear force of the fuse will not change along with the plate. This, for obtaining a good yielding distribution and maximum energy absorption, the trapezoidal shape of the plate was chosen. The small sideway of the fuse support is prepared in a way that the fuse plate can slide inside the gap. This feature will not cause any tension to the fuse plate as well as connections welding. Also, the total displacement domain of the damper will increase.

3. 1. Geometrical Effective Parameters

Distance of two parallel plates, fuse plate thickness, fuse thickness to parallel plates ratio, fuse shape angle, and the gap between fuse plate and the support plate fall in this category with each being disused individually further. The response of the fuse plate can be predicted using simple equations [7]; Equations (1) and (2) predict the fuse nominal yield load, P_n, and fuse elastic stiffness, $K_{eff.}$

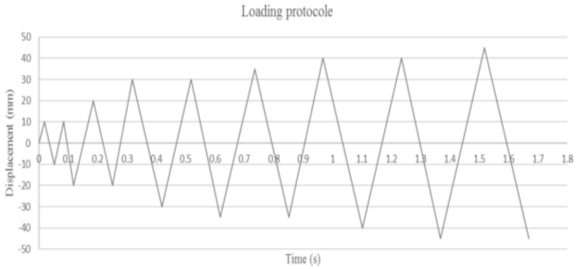


Figure 4. Loading protocol

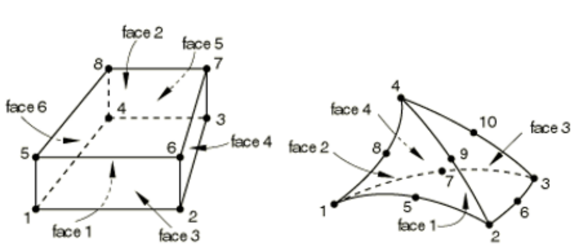


Figure 5. The shape of elements C3D8R (Left) & C3D10 (Right)

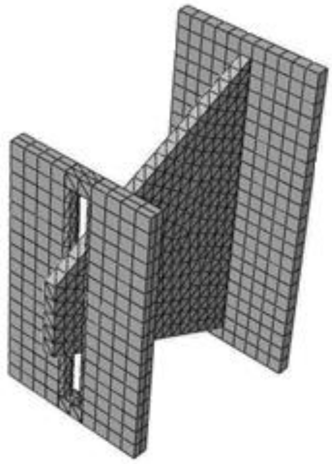


Figure 6. Meshing assignment of the damper model

$$P_n = \frac{bt^2}{4L} F_y \tag{1}$$

$$K_{eff} = \frac{bt^3}{6L^3} E \tag{2}$$

where, b is the width of the fuse plate at its base, t represents the effective thickness, L is the length of the fuse plate, F_y denotes the yielding strength of the selected construction steel, and E is the module of its elasticity.

3. 1. 1. Two Parallel Plates' Distance

One of the most important effective parameters on the damper behavior is the distance of two parallel plates. According to the analyses, as the distance increases, so does the displacement domain of the damper and hence the fuse yielding distribution. On the other hand, upon reduction of the distance of the two parallel plates, more stiffness will result. On the other hand, the ultimate strength of the damper will increase. Figure 7 shows the hysteresis loops of 7 to 13 centimeters, distances of two parallel plates, which prove the above points. Note that there are two yielding mechanisms in this situation: first, the bending mechanism, which occurs in large distances and second the shear mechanism, which occurs in small distances. In the first mode, the energy dissipation of the fuse is not considerable and as the distance increases, the shear yielding mechanism will be associated with the bending mode where the absorbing energy will grow. On the other hand, in small distances, the energy dissipation will decline again because of the small yielding area. Thus, there is an optimum distance between two parallel plates where both the bending and shearing yielding

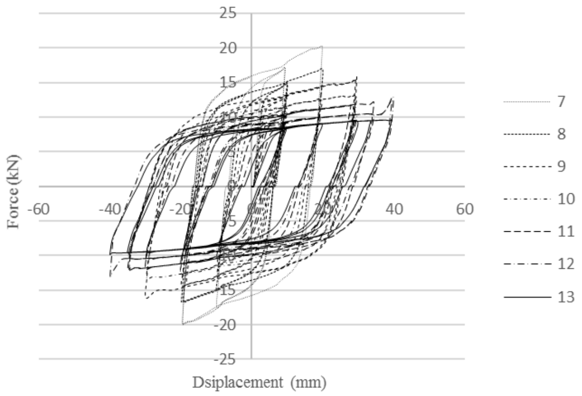


Figure 7. 7 to 13 centimeters analyses result of the two parallel plates distance

mechanisms maximize the energy absorption on the fuse plate. In addition, because of major rotations in the fixed end of the plate, the connection should withstand the cyclic moments and yielding rotations.

3. 1. 2. Yielding Plate to Parallel Plate's Thickness Ratio

One of the other effective geometrical parameters in the damper behavior is the ratio of the fuse plate thickness to any of the parallel plate's thickness. To examine it, by changing the large plate thickness and fixing the other parameters, six analyses were performed as shown in Table 1. Further, for the second condition, these analyses were conducted for the small plate as detailed in Table 2. The ratio was supposed to be between zero and two and then this domain was divided into six conditions, which can show a good index in the analysis results.

Figure 8 reveals the hysteresis loops obtained from the first condition analyses. According to the results and obtained hysteresis loops, as the ratio decreased, so did the energy absorption and the damper displacement domain while the stiffness of the device increased. No change was observed in the ultimate strength and it seems that the total shape of the loops was acceptable and stable. Note that although at large thickness ratios, the dissipated energy increases, but as the large plate thickness drops, the welding will be more sensitive and less reliable in cyclic loading. On the other hand, the thick plate will increase the weight of the device, so the aftershock replacement will be hard. Thus, it seems the designer should choose an economic functional ratio for his design goals. The results of the second analysis conditions show that as the ratio decreased, the displacement domain of the damper would increase, but the energy absorption of the damper would not change significantly. It seems that because of the small contact between the fuse plate and the small plate due to the inner curvature of the support gap, the small plate thickness will not affect the results considerably. Figure 9 displays the hysteresis loop of these analyses. Note that the S1A11 and S2A12 analyses could not be completed because of excessive distortion and fracture of the small support plate.

TABLE 1. Geometrical specification of models for the first situation sensitivity analyses

Analysis	t_0	α	Distance	Gap	t_2	t_1	t_0/t_1
S1A1	8	65	130	0.5	10	24	0.33
S1A2	8	65	130	0.5	10	12	0.67
S1A3	8	65	130	0.5	10	8	1.00
S1A4	8	65	130	0.5	10	6	1.33
S1A5	8	65	130	0.5	10	4.8	1.67
S1A6	8	65	130	0.5	10	4	2.00

TABLE 2. Geometrical specification of models for the first situation sensitivity analyses

Analysis	t_0	α	Distance	Gap	t_1	t_2	t_0/t_2
S1A7	8	65	130	0.5	15	24	0.33
S1A8	8	65	130	0.5	15	12	0.67
S1A9	8	65	130	0.5	15	8	1.00
S1A10	8	65	130	0.5	15	6	1.33
S1A11	8	65	130	0.5	15	4.8	1.67
S1A12	8	65	130	0.5	15	4	2.00

3. 1. 3. The Angle of Yielding Plate

The other effective geometrical parameter is the fuse angle (Figure 10).

The condition of the fuse plate is such that it should withstand the bending moment and shear force on the large side fixed end and only the shear force on the free small side. Thus, for better uniform yielding in the fuse plate area, its geometry should be trapezoidal. The extent of dissipated energy is dependent on the plate angle; as

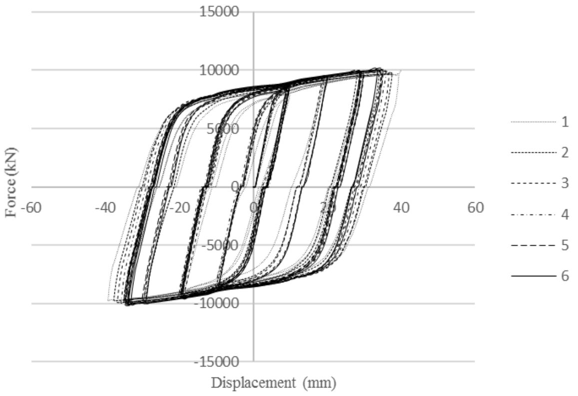


Figure 8. Hysteresis loops obtained from S1A1 to S1A6 analyses

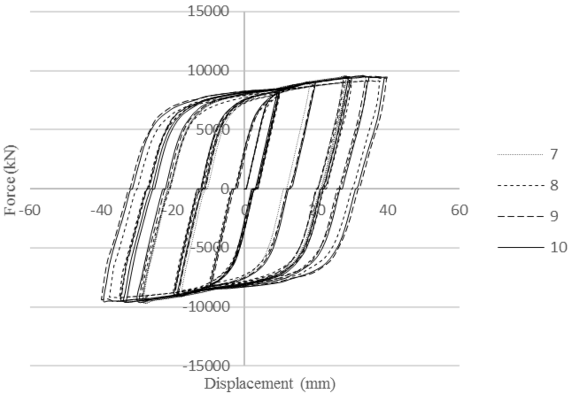


Figure 9. Hysteresis loops obtained from S1A7 to S1A10 analyses

the fuse angle rises, the distance between the two parallel plates can be enlarged and then the steel yielding surface and energy absorption increases. Also, when the distance between two parallel plates increases, the displacement domain of the damper will grow. On the other hand, as the fuse angle diminishes, the steel yielding uniform extension will improve. Also, the distance between two parallel plates will decline and so will its displacement domain. The condition of the fuse plate is such that it should withstand the bending moment and shear force on the large side fixed end and only the shear force on the free small side. Thus, for better uniform yielding in the fuse plate area, its geometry should be trapezoidal. The extent of dissipated energy is dependent on the plate angle; as the fuse angle rises, the distance between the two parallel plates can be enlarged and then the steel yielding surface and energy absorption increases.

When the distance between two parallel plates increases, the displacement domain of the damper will grow. On the other hand, as the fuse angle diminishes, the steel yielding uniform extension will improve. Also, the distance between two parallel plates will decline and so will its displacement domain. Table 3 shows the considered analyses to capture the effects of this parameter. For this purpose, four angles between 60 to 75 degrees were considered according to previous studies.

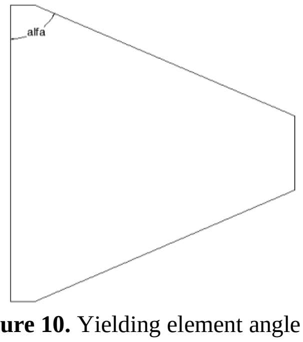


Figure 10. Yielding element angle (α)

Figure 11 displays the hysteresis loops obtained from these analyses. As shown in this figure, as the fuse angle rises, the stiffness of the damper will increase, but the displacement domain of the damper will drop and there is no significant change in its ultimate strength. It seems that the plates with smaller angles have better tolerance against the cyclic deformation and yielding.

3. 1. 3. The Gap Between the Yielding Plate and Support Plates

The other effective parameter is the gap between the fuse plate and the support plates. If the fuse thickness is 8 mm, the gap between the fuse and the support should not be less than 0.5 mm for damper easy construction. On the other hand, selecting large gaps can affect the damper behavior and degree of energy absorption. Meanwhile, use of large gaps makes the device have small free movements to obtain the fuse stiffness. Therefore, this issue causes a kind of a shock to the damper in real loading, which is not optimal. Choosing the minimum size of the gap will enhance the stiffness of the damper and augment the end moment as well as rotation of the fuse plate. Table 4 reports the considered analyses to capture the effect of this geometrical parameter. Figure 12 shows the hysteresis loops of these analyses. As shown in this figure, the displacement domain and amount of energy absorption of the damper increased due to increasing gap distance, but the stiffness and ultimate strength of the device decreased in large displacements. It seems the total shape of the

TABLE 3. Considered analyses to discover the yielding element angle effects

Analysis	t_0	α	Distance	Gap	t_2	t_1
S2A1	8	60	80	0.5	10	15
S2A2	8	65	80	0.5	10	15
S2A3	8	70	80	0.5	10	15
S2A4	8	75	80	0.5	10	15

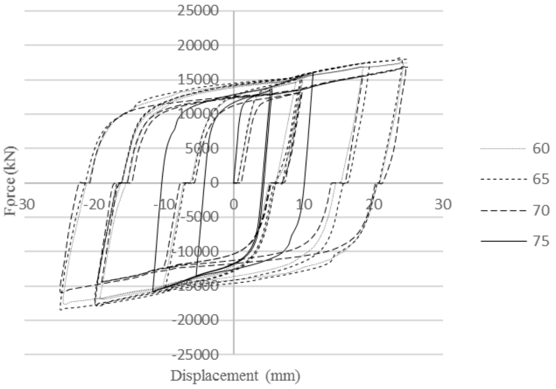


Figure 11. Hysteresis loops of changing yielding element angle

TABLE 4. The supports gap sensitivity analyses

Analysis	t_0	α	Distance	Gap	t_2	t_1
S3A1	8	65	80	0.5	10	15
S3A2	8	65	80	1.0	10	15
S3A3	8	65	80	2.0	10	15

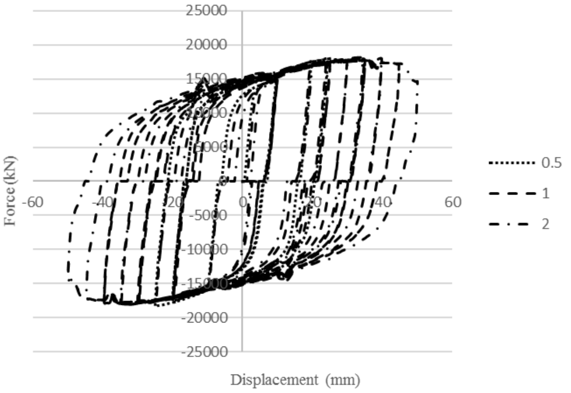


Figure 12. Hysteresis loops of changing fuse and support gap

hysteresis loops is stable and no significant change has occurred in the hysteresis shapes by altering the gap distance; however, the large gap models can dissipate more cyclic energy.

3. 1. 4. Yielding Plate Thickness

The fuse plate thickness is another effective parameter on damper behavior; elevation of this value will increase the shearing rule in the energy absorption process. It will also boost the ultimate strength and stiffness of the damper. Table 5 provides the analyses considered for the sensitivity of this parameter.

As shown in Table 5, four analyses were considered to discover the damper sensitivity of the fuse thickness between 5 and 20 mm. According to the results and hysteresis loops are shown in Figure 13, Increasing the fuse thickness will cause augmented fuse end moment; so, the risk of damper fracture will increase. On the other hand, a reduction of this value will cause a reduction in the shearing and bending yielding extension and hence the energy absorption. In addition, as the fuse thickness increases, so do the stiffness and the energy absorption of the damper, but the ultimate displacement domain of the damper decreases due to the fuse fixed end fracture risk.

TABLE 5. Analyses considered for yielding plate thickness

Analysis	t_0	α	Distance	Gap	t_2	t_1
S4A1	**5**	65	130	0.5	10	15
S4A2	10	65	130	0.5	10	15
S4A3	15	65	130	0.5	10	15
S4A4	20	65	130	0.5	10	15

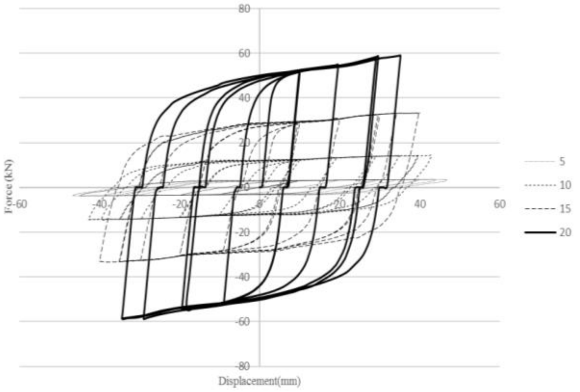
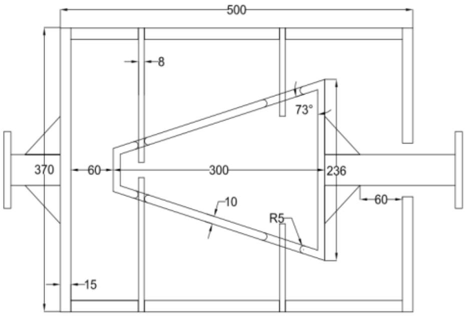


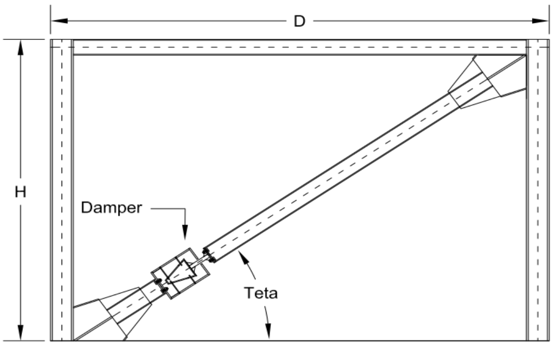
Figure 13. Hysteresis loops obtained from analyses S4A1 to S4A4

4. TWO-LEVEL DAMPER

To assessment the application of the studied plates, a two-level performance damper was designed for use in the building's brace frames. The design of the damper is in such a way that in small displacements the two taller plates with smaller stiffness bear the force and absorb energy but as the displacement increases, the other (shorter) plates help the taller ones. The outer box restricts the damper displacement to exceeds a specific value. Figure 14 shows the damper dimension details and its placement in the frame. Figure 15 displays the hysteresis loops obtained from finite element analysis in terms of force capacity and damper deformation. As shown in the figure, the resulting diagram has stable cycles and two-level performance. The damper capacity for deformation of 60 mm was 870 kN in one direction and 550 kN in the other. The asymmetry in the diagram is due to the pyramidal geometry of the inner part, which though has little effect on the overall performance of the damper.



(a) Damper configuration



(b) Damper placement in the frame

Figure 14. The location of the new designed damper in the frame and its details

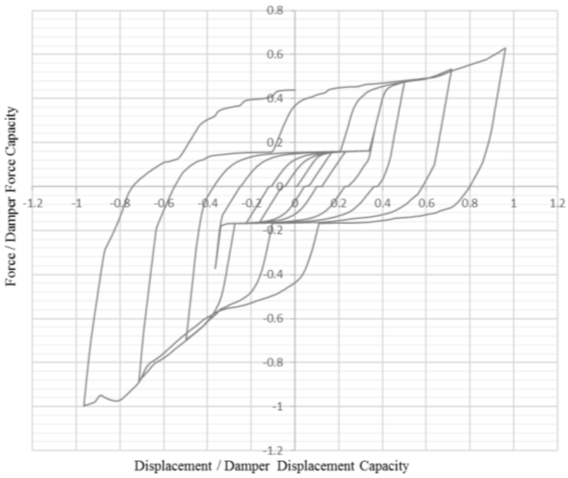


Figure 15. Hysteresis loops obtained from finite element analyses

In general, as the number of yielding plates increases, the angle of the pyramidal section decreases and the asymmetry in the graph diminishes due to the increase in the length of the pyramidal section. Table 6 also outlines the parameters of effective stiffness, effective damping, and confined area calculated in each loading cycle for the finite element model.

TABLE 6. Calculated parameters for each loading cycle

Cycles	Displacement Ratio	Force Ratio	K_{eff}	β	A
1, 2	0.17, 0.17	0.16, 0.15	1.40	0.182	154
3, 4	0.24, 0.24	0.17, 0.16	1.04	0.288	346
5, 6	0.38, 0.38	0.37, 0.26	1.26	0.206	780
7, 8	0.52, 0.52	0.7, 0.47	1.71	0.173	1663
9, 10	0.74, 0.74	0.89, 0.53	1.45	0.228	3800
11, 12	1, 1	1, 0.63	1.23	0.278	7162

In general, as the number of yielding plates increases, the angle of the pyramidal section decreases and the asymmetry in the graph diminishes due to the increase in the length of the pyramidal section. Table 6 also outlines the parameters of effective stiffness, effective damping, and confined area calculated in each loading cycle for the finite element model.

5. TIME HISTORY ANALYSIS

An OpenSees code was developed to comprise the nonlinear time history analyses responses of a three storey three span CBF frame. Figure 16 shows the frame configuration and sections. the frame was designed based on the AISC 360-10 [26] criteria. Seven far field earthquakes based on the soil and fault condition selected from the FEMA P-695 [27] suggested ground motions for the time history analyses. Table 7 shows the

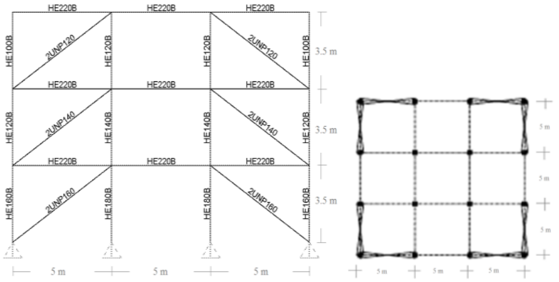
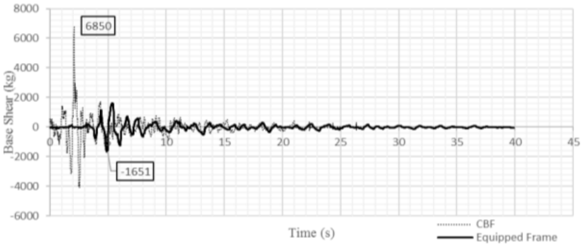


Figure 16. Frame configuration

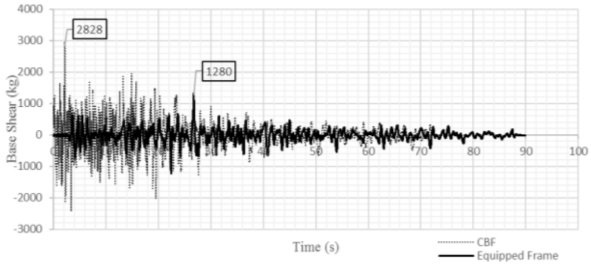
TABLE 7. Ground motions characteristics [27]

ID No.	Record Seq. No.	Name	Magnitude	Site-Source Distance (km)	Vs	PGA	PGV
1	1602	Duzce	7.1	12.4	326	0.82	62
2	169	Imperial Valley	6.5	22.5	275	0.35	33
3	174	Imperial Valley	6.5	13.5	196	0.38	42
4	1116	Kobe	6.9	28.5	256	0.24	38
5	1158	Koceaeli	7.5	15.4	276	0.36	59
6	900	Landers	7.3	23.8	354	0.24	52
7	848	Landers	7.3	20	271	0.42	42

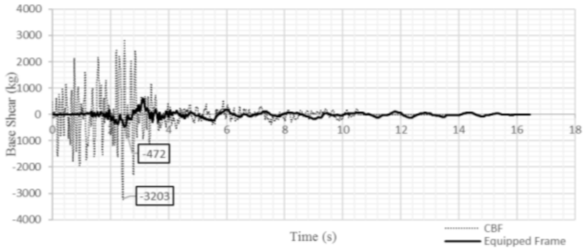
specifications of the selected ground motions. To prevent buckling of the brace members, dampers with the capacity of 90% of brace members capacity designed to use at any story and the maximum displacement capacity of dampers are adjusted to the maximum allowable drift of the building stories. to understand the effect of dampers on the building seismic behavior the base shear and roof acceleration responses were studied. Figure 17 and Figure 18 respectively show the base shear and roof acceleration comparative diagrams.



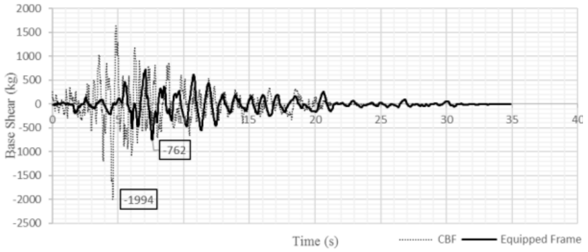
(a) Duzce (1602) comparative response diagram



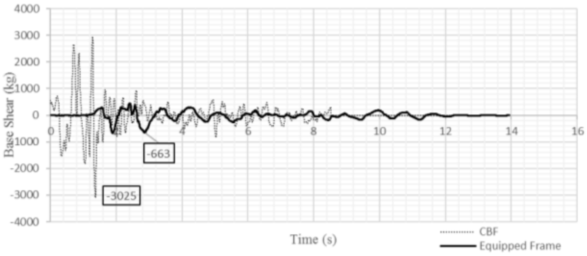
(b) Imperial Valley (169) comparative response diagram



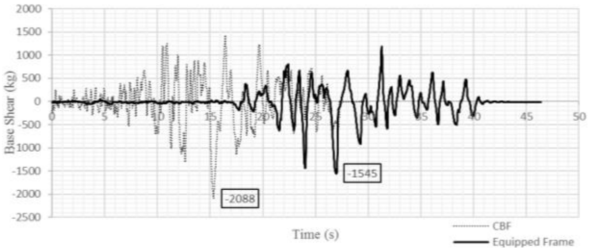
(c) Imperial Valley (174) comparative response diagram



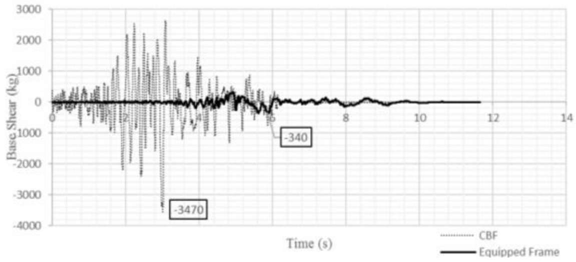
(d) Kobe (1116) comparative response diagram



(e) Kocaeli (1158) comparative response diagram

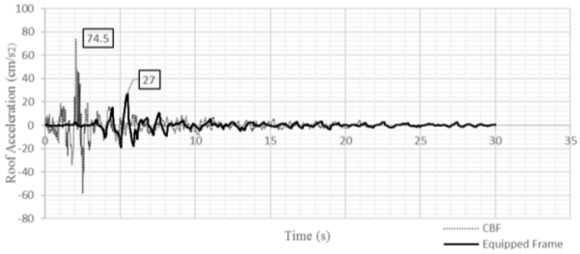


(f) Landers (900) comparative response diagram

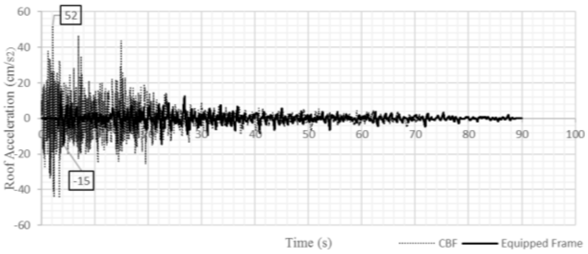


(g) Landers (848) comparative response diagram

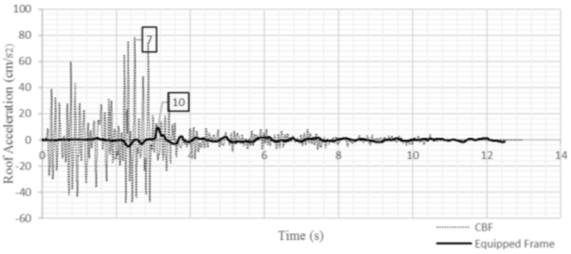
Figure 17. Base shear comparative time history response diagrams



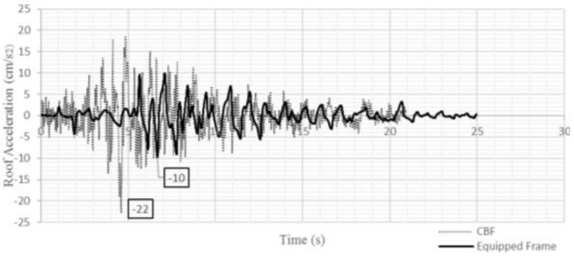
(a) Duzce (1602) comparative response diagram



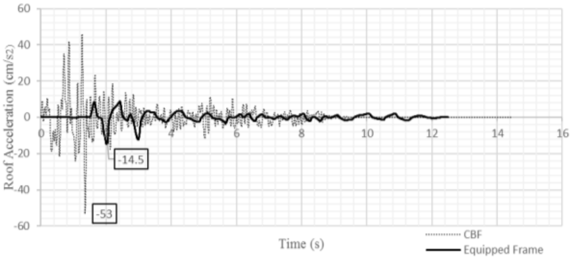
(b) Imperial Valley (169) comparative response diagram



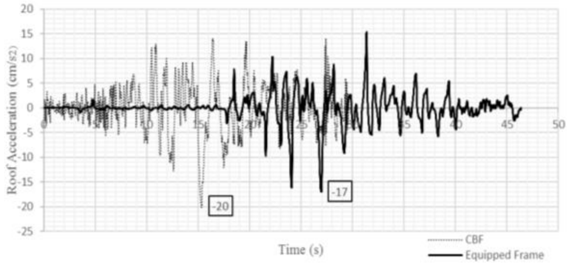
(c) Imperial Valley (174) comparative response diagram



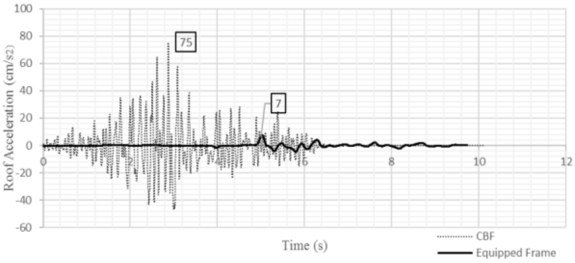
(d) Kobe (1116) comparative response diagram



(e) Kocaeli (1158) comparative response diagram



(f) Landers (900) comparative response diagram



(g) Landers (848) comparative response diagram

Figure 18. Roof acceleration comparative time history response diagrams

6. CONCLUSION

According to the analyses performed for the damping device, the conclusions are presented as follows:

1. Trapezoidal plates as a fuse in steel yielding dampers can give steady reliable hysteresis loops and their shape will cause better yielding extension and energy absorption.
2. Among the sensitivity analyses performed for the geometrical parameters, the distance of two parallel plates and fuse plate thickness parameters had the most substantial effects on the damper analysis result. Elevation of the distance of two parallel plates will cause enhanced dissipated energy and damper cyclic moving domain, but adequate free length should be prepared for the fuse plate to withstand the shear force and not to exit the gap.
3. The rise of the fuse thickness might cause permanent shear deformation on the plate, which makes the fuse cyclic moving difficult.
4. Although small angles of the fuse plate can give a good uniform yielding, but the smaller the angle, the lower the length of the fuse and so the smaller the distance of the two parallel plates is. On the other hand, the large fixed side of the fuse plate can have an interaction with the architectural part of the structure.
5. As shown in the comparative diagrams, using the two-level performance damper had a significant decreasing effect on the base shear and roof acceleration response of the CBF frame under the seven time history far field ground motion analyses.

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Persian Abstract

چکیده

فرآیند جذب انرژی برای کاهش نیروهای وارده همواره یکی دغدغه‌های علم مهندسی سازه بوده است. بدین منظور انواع مختلفی از میراگرها همچون میراگرهای اصطکاکی، جرمی و تسلیمی ابداع شده اند؛ از این میان میراگرهای فلزی تسلیم شونده جزو میراگرهای اقتصادی و کاربردی بوده که عملکرد مناسبی را در عمل و در آزمایشات به نمایش گذاشته‌اند. لکن هنوز مطالعات کافی برای استفاده‌ی گسترده‌ی آنها در طراحی و مقاوم‌سازی سازه‌ها صورت نگرفته است. در این تحقیق سعی شده است تا با استفاده از روش اجزای محدود، تحلیل‌های حساسیت ابعاد هندسی بر روی جز موثر میراگرهای فلزی با ورق موازی انجام شده و سپس با استفاده از نتایج به دست آمده یک نوع میراگر تسلیمی دو سطحی جدید طراحی و ارائه گردد. در نهایت عملکرد میراگر مذکور با استفاده از مقایسه نتایج تحلیل‌های تاریخچه زمانی غیر خطی، در یک قاب فرض شده مورد بررسی قرار گیرد. نتایج به دست آمده نشان داد، تغییر در برخی پارامترهای هندسی تاثیر زیادی بر روی عملکرد و میزان جذب انرژی میراگر داشته و برخی از پارامترهای دیگر تاثیرات اندکی بر روی این دو مولفه دارند. همچنین استفاده از میراگر جدید توانست کاهش موثری را در پاسخ‌های لرزه‌ای قاب مورد نظر ایجاد نماید.