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Investigating the effect of using Multi-Level Yielding Pipe Damper dampers in steel structures under earthquake force in the horizontal direction

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Abstract

Multi-level Pipe Damper (MPD) recently proposed by the authors is a passive control device to reduce the seismic vibration. In this research, seismic response of steel structures equipped with MPD is studied. To evaluate the effects of the proposed damper, typical 8 story steel buildings are modeled and their seismic responses under three earthquake excitations are investigated using dynamic nonlinear time-history analyses by ETABS program. Results show the effectiveness of MPD to altering the seismic response of the structures. Moreover, using MPD decreases the structural and nonstructural damages noticeably by limiting the inter story drifts because of the secondary hardening branch of force-displacement respectively proving the effectiveness of the proposed damper as a retrofitting technique for structures at high seismic risk areas. © 2017 Journals-Researchers. All rights reserved. (DOI:**https//doi.org/10.52547/JCER.5.1.10**)

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1. Introduction

Severe earthquakes impose noticeable amount of input energy to structures and cause structural and non-structural damages. Besides, most structural elements show stiffness and strength degradation and low inherent damping ratio during the first cycles of a seismic excitation. So, utilization of new tools and equipment is inevitable to avoid these defects by concentrating on the plastic deformation in some controlled locations in building structures. Using metallic yielding dampers is one of the effective and economical manners to improve the seismic performance of structures by limiting the seismic forces like a fuse and dissipating a major part of input seismic energy. At first Kelly et al. (1972) proposed yielding damper as an effective passive control device. After that many metallic dampers have been suggested by others such as ADAS device (Bergman and Geol 1987), TADAS device (Tsai et al., 1993), and Shear-Panel Damper (Nakashima et al., 1994). The numerical and experimental research proved that the above mentioned devices result in seismic input reduction, increase in the equivalent viscous damping

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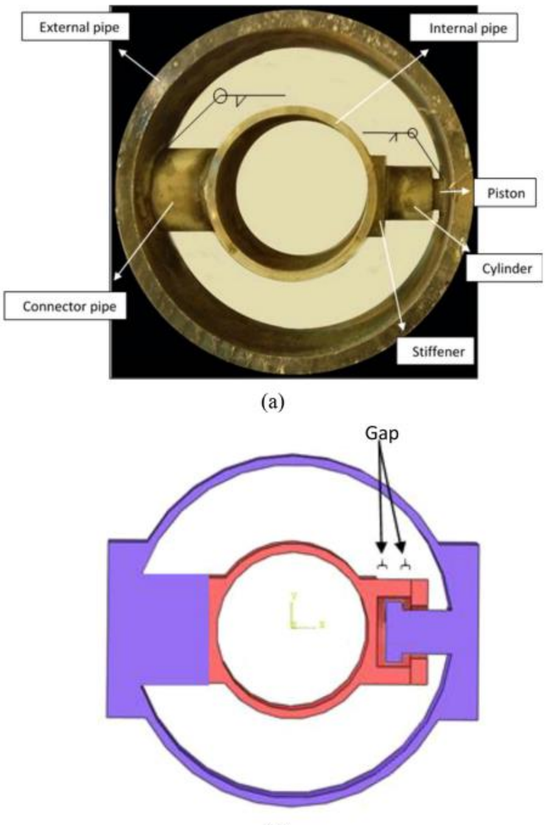
ratio and damage decrease. Curadelli and Riera (2004) conducted research on steel and concrete frames equipped with metallic dampers. Fragility curves of the structures show that the failure probability of the structures may be decreased to 20% of the initial value by adding external metallic dampers for the cases studied. In another work, Oviedo et al. (2010) studied the seismic response of structure with metallic dampers. Results proved that buildings with low yield story drift ratio show the largest reduction in the inelastic demand. Slit damper is one of the other metallic dampers. Shape optimization of the slit damper has been widely investigated by researchers (Ghabraie et al., 2010; Houng Xu et al., 2011). In addition, Saffari and Hedayat (2013) offered suitable setting relationships to achieve proper behavior using several cyclic testing on 8 samples. In recent years, steel pipes are widely used to improve seismic behavior of Concentrically Braced Frames, CBFs. Kafi (2009) conducted research on the effects of steel pipe to improve seismic behavior of CBFs. The numerical and experimental results showed main influence on the frames ductility and delay in brace buckling. Hollow steel pipes filled with concrete were suggested by Maleki andBagheri (2010a) as hysteresis dampers under shear stresses. According to their results, stiffness and strength of the pipe increased linearly with increasing the length but nonlinearly with increasing the thickness and reducing the diameter. Steel pipes filled with concrete showed no ductile behavior caused by concrete failure while hollow steel pipes had stable hysteresis behavior and high equivalent viscous damping ratios. Also, they used pipe damper to improve the seismic performance of a bridge (Maleki and Bagheri 2010b). Their numerical results presented a proper energy dissipation and reduction in the forces transferred to the foundations of bridges. Another pipe damper proposed by Maleki and Mahjoobi (2013) was Dual Pipe Damper (DPD). This damper consisted of two pipes, welded to the upper part of chevron or diagonal bracing under the lateral loading to increase energy dissipation. The results of the cyclic tests on four samples indicated stable hysteresis curves with a significant increase in ductility and energy dissipation. Besides, seismic performance evaluation and design of steel structures equipped with dual-pipe dampers were investigated (Mahjoubi and Maleki, 2016). Some steel moment frames of 5, 10 and 20 stories were modeled and their seismic responses under seven earthquake excitations were investigated using dynamic nonlinear analyses. The results showed that the DPD is so effective in dissipating a considerable amount of the input seismic energy and reducing the damage. Using two-level control systems is one of the new methods that attracted the researchers in the recent years. The significant idea of these systems is to combine several control systems with various amounts of strength and stiffness resulting desirable energy dissipation in various earthquake intensity levels. Balendra et al. (2001) proposed two-level passive control system consisting of a knee brace and a slotted connection. In service loads, slit connection would create energy dissipation by friction damping, while in severe earthquakes, energy dissipation through plastic behavior of knee member is provided. The concept of multi-level control system was proposed and improved by many researchers during the last decade (Hosseini Hashemi & Alirezai 2010; Zahrai & Rousta 2013). Moreover, Zahrai and Vosoogh (2013) suggested the dual system using a combination of vertical link beam and knee elements. Plastic hinge on the vertical link within low forces, increased energy dissipation while plastic deformation of the knee increased the ductility and energy absorption during extreme forces to improve seismic performance. Cheraghi and Zahrai (2016) recently proposed the innovative Multi-level Pipe Damper (MPD) using two steel pipes. As shown in Fig. 1, the proposed damper consists of a combination of nested pipes that could change dynamic behavior parameters like strength, stiffness and damping ratio for energy absorption at different earthquake levels from moderate to severe conditions. They first investigated numerical study of the innovative damper and then performed experimental quasi-static cyclic tests on two samples showing suitable hysteresis curves up to relatively large displacements and high ductility. Figure 2 displays the deformed shape of a MPD specimen at the end of the cyclic test. Hysteresis diagrams show multi-level behavior with variable strength and stiffness as expected that can dissipate seismic energy in different earthquake levels. In other word, at large deformations, increasing the stiffness was observed that seems this behavior can prevent large drifts and P-Δ moments in structures subjected to severe earthquakes. Besides, achieving equivalent viscous damping ratio of about 19-38% without use of sophisticated tools is noticeable. In this paper, the seismic responses of 8 story steel buildings equipped with proposed dampers are obtained using nonlinear dynamic time-history analyses by ETABS program. In addition, IDA analyses are performed to evaluate the damper effects on promoting the performance capacity of the frames. Finally, the results are compared with each other to find the new dampers efficacy to alter seismic behavior and energy dissipation.

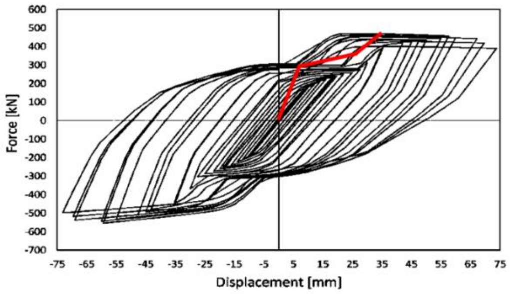


(a)

(b)

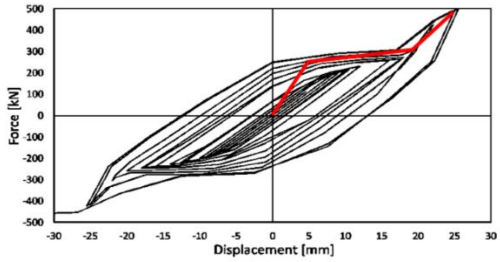
Figure1 :(a) Assembled damper (b) Cross section of the damper (Cheraghi and Zahrai, 2016).

(a) sample1 (b) sample 2



(a) sample 1

Figure 2: Failure details of the test samples (Cheraghi and Zahrai, 2016)



(b) sample 2

Figure3. Simplified tri-linear model representing nonlinear behavior of the MPD according to the experimental hysteresis curves (Cheraghi and Zahrai, 2016)

2.Numerical Modeling and Analysis

In this paper, to obtain the seismic performance of steel structures equipped with proposed dampers, 8 story moment resisting steel building are modeled and their seismic responses under three earthquake excitations are investigated using dynamic nonlinear analyses.

First, In order to evaluate the vulnerability of MDOF structures (multiple degrees of freedom) under the effect of earthquake and aftershock sequences, an 8-story building in Tehran of medium steel bending frame type and type 3 soil by LRFD method based on the 10th topic of the National Building Regulations and the 4th edition 2800 standard was designed. These structures have three 5-meter openings in each direction, and the height of the floors is 3.2 and the height of the parking lot is 2.7. First, the design of this building according to the residential use and located on the area with very high relative risk according to the definition of standard 2800 with the help of software Etabs done. And then in the A and D frames, Multi-Level Yielding Pipe Damper ((a) sample 1) was used.

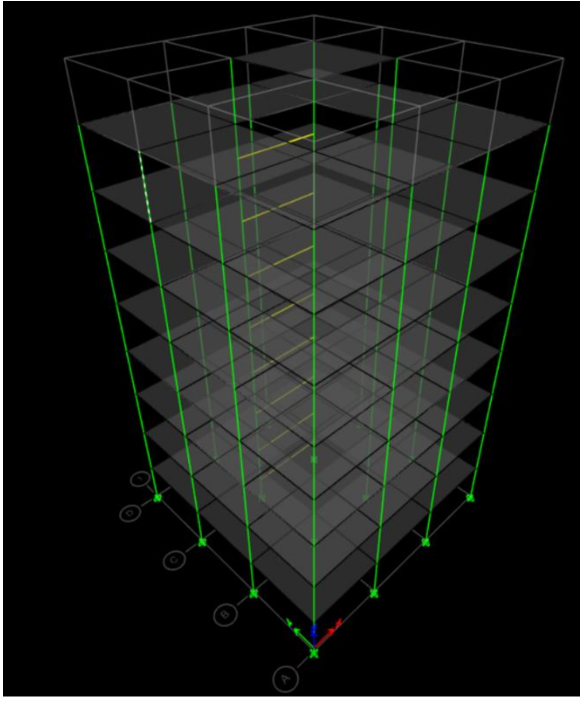
List of designed column sections

Box180x8
Box200x8
Box200x10
Box200x12
Box240x10
Box240x12
Box240x15
Box240x20
Box300x20

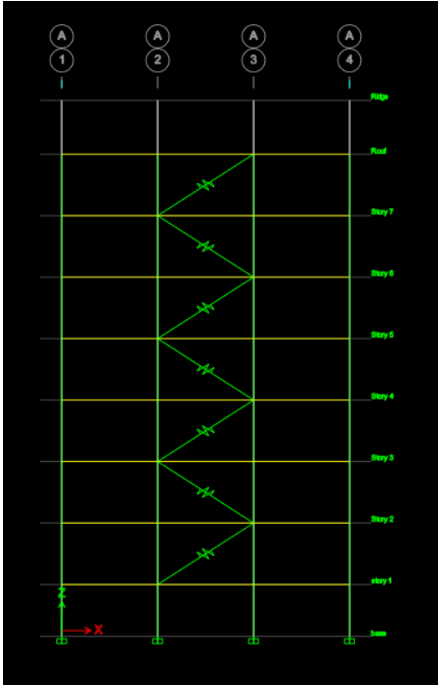
List of designed beam sections:

PG-W180x6-F150x8
PG-W180x6-F150x15
PG-W300x6-F150x10
PG-W300x6-F150x12
PG-W300x6-F150x15
PG-W300x6-F150x20

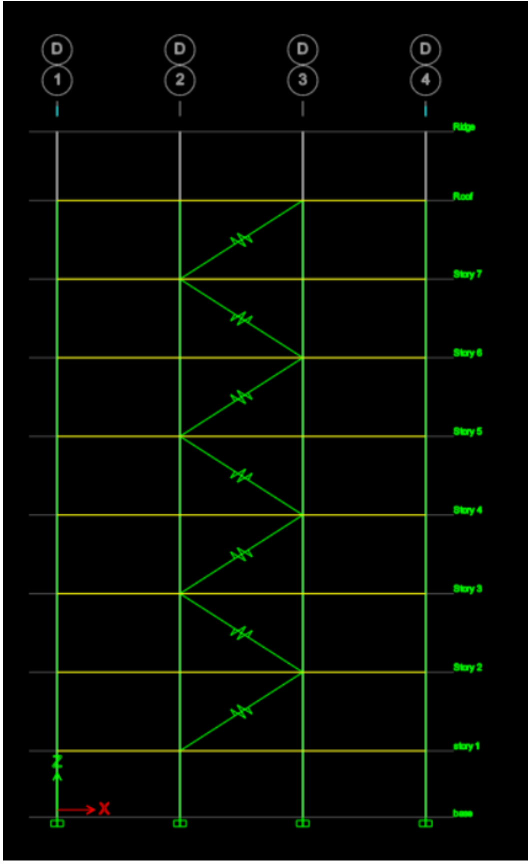
3D view without damper:



2D view designed with damper:frame A:



2D view designed with damper:frame D:

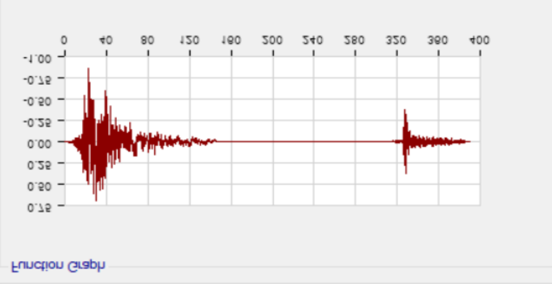


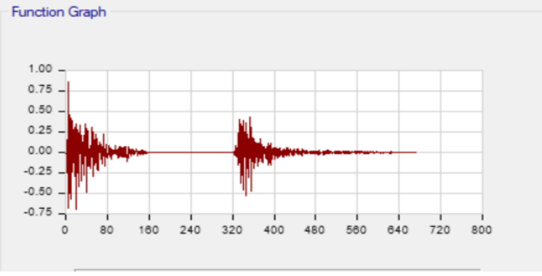
Past studies have shown that in order to achieve a suitable seismic behavior, the records must be scaled to the desired risk level. In this research, from 3 The raw accelerometer that is suitable for the type of soil is extracted from the data of the PEER site and according to the instructions of the fourth edition of the 2800 peer-based standard andscaled and used And comparisons based on HOLISTER earthquake were shown in this article.

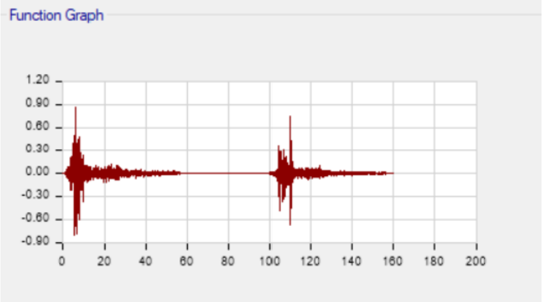
In Table 1, the characteristics of each of the earthquake accelerometers and their corresponding aftershocks are given.

Table No. 1 - Characteristics of earthquake and aftershock acceleration maps

The name of the earthquake	Station	Great Earthquake	great aftershocks	spead shear wave
1.HOLISTER	HOLISTER	5.6	5.5	198
2.Imperial Valley	Holtvile	6.53	5.01	202
3.Northwest	Jiashi	6.1	5.8	240







1.Holister earthquake
2.Imperial Vallay earthquake
3.Northwest earthquake

3.Comparison of the drift distribution of floors

The mentioned building has been exposed to the seismic sequences of accelerometers introduced in Table 1 under time history analysis and the changes The drift of floors is shown in tables 2 and 3. As can be seen from the graphs related to the drift of the floors, the use of damper leads to the reduction of the drift of the structure.

Table2. Relative displacement of floors under earthquake 1 without using damper

Story	Output Case	Step Type	Dir.	Drift
Story 7	EQ1	Max	X	0.097923
Story 7	EQ1	Max	Y	0.018276
Story 7	EQ1	Min	X	0.081789
Story 7	EQ1	Min	Y	0.018133
Story 6	EQ1	Max	X	0.123716
Story 6	EQ1	Max	Y	0.032681
Story 6	EQ1	Min	X	0.107888
Story 6	EQ1	Min	Y	0.032492
Story 5	EQ1	Max	X	0.122161
Story 5	EQ1	Max	Y	0.02962
Story 5	EQ1	Min	X	0.108304
Story 5	EQ1	Min	Y	0.029583
Story 4	EQ1	Max	X	0.121894
Story 4	EQ1	Max	Y	0.028441
Story 4	EQ1	Min	X	0.108955
Story 4	EQ1	Min	Y	0.028424
Story 3	EQ1	Max	X	0.119638
Story 3	EQ1	Max	Y	0.028189
Story 3	EQ1	Min	X	0.107224
Story 3	EQ1	Min	Y	0.02817
Story 2	EQ1	Max	X	0.103495
Story 2	EQ1	Max	Y	0.024689
Story 2	EQ1	Min	X	0.091843
Story 2	EQ1	Min	Y	0.024668
story 1	EQ1	Max	X	0.049083
story 1	EQ1	Max	Y	0.011208
story 1	EQ1	Min	X	0.043623
story 1	EQ1	Min	Y	0.011197

4- Comparison of structure periodicity time and frequency in different modes of the structure

The 8-story building has 24 modes, which are shown in tables 4 and 5 of the periodicity and frequencies of the structure in different modes. The comparison of the above tables shows that the use of the damper reduces the period of the structure in different modes.

Table3. Relative displacement of floors under earthquake 1 in the case of using a damper

Story	Output Case	Step Type	Dir.	Drift
Story 7	EQ1	Max	X	0.067256
Story 7	EQ1	Max	Y	0.015419
Story 7	EQ1	Min	X	0.056153
Story 7	EQ1	Min	Y	0.015257
Story 6	EQ1	Max	X	0.080806
Story 6	EQ1	Max	Y	0.02132
Story 6	EQ1	Min	X	0.090603
Story 6	EQ1	Min	Y	0.021276
Story 5	EQ1	Max	X	0.096639
Story 5	EQ1	Max	Y	0.021438
Story 5	EQ1	Min	X	0.085519
Story 5	EQ1	Min	Y	0.021409
Story 4	EQ1	Max	X	0.091282
Story 4	EQ1	Max	Y	0.020917
Story 4	EQ1	Min	X	0.096086
Story 4	EQ1	Min	Y	0.020921
Story 3	EQ1	Max	X	0.099637
Story 3	EQ1	Max	Y	0.022223
Story 3	EQ1	Min	X	0.095368
Story 3	EQ1	Min	Y	0.022305
Story 2	EQ1	Max	X	0.0874
Story 2	EQ1	Max	Y	0.019855
Story 2	EQ1	Min	X	0.09113
Story 2	EQ1	Min	Y	0.019906
story 1	EQ1	Max	X	0.046417
story 1	EQ1	Max	Y	0.011494
story 1	EQ1	Min	X	0.05629
story 1	EQ1	Min	Y	0.011486

Table4.The periodicity of the structure and the frequency due to the earthquake in the state without using a damper in different modes of the structure

TABLE: Modal Periods And Frequencies				
Mode	**Period**	**Frequency**	**CircFreq**	**Eigenvalue**
	sec	cyc/sec	rad/sec	rad²/sec²
1	1.905	0.525	3.2976	10.8742
2	1.753	0.571	3.5852	12.8537
3	1.629	0.614	3.8564	14.8721
4	0.648	1.544	9.6998	94.0859
5	0.627	1.595	10.0201	100.4028
6	0.564	1.774	11.1454	124.2196
7	0.384	2.604	16.3628	267.741
8	0.366	2.729	17.1446	293.9359
9	0.331	3.019	18.9695	359.8415
10	0.278	3.591	22.5627	509.0765
11	0.264	3.789	23.8071	566.777
12	0.247	4.051	25.4509	647.75
13	0.227	4.407	27.6876	766.6035
14	0.217	4.617	29.0126	841.7308
15	0.214	4.67	29.3405	860.8638
16	0.184	5.423	34.074	1161.0359
17	0.182	5.498	34.5476	1193.535
18	0.173	5.786	36.3535	1321.5794
19	0.139	7.18	45.1137	2035.2478
20	0.138	7.225	45.3936	2060.5804
21	0.133	7.533	47.3312	2240.2443
22	0.109	9.205	57.8366	3345.0668
23	0.107	9.306	58.4685	3418.5632
24	0.104	9.597	60.2992	3635.994

Table 5. Period of the structure and frequency due to earthquake in the mode of using the damper in different modes of the structure

Mode	**Period**	**Frequency**	**CircFreq**	**Eigenvalue**
1	1.752	0.571	3.5853	12.8546
2	1.377	0.726	4.5617	20.8088
3	1.219	0.82	5.1552	26.5761
4	0.627	1.595	10.0215	100.4305
5	0.459	2.177	13.6805	187.1571
6	0.411	2.434	15.2937	233.8976
7	0.366	2.731	17.1568	294.3571
8	0.278	3.596	22.5955	510.5558
9	0.264	3.789	23.807	566.7731
10	0.248	4.035	25.3553	642.8924
11	0.228	4.382	27.535	758.1781
12	0.223	4.492	28.2254	796.6725
13	0.214	4.669	29.3386	860.753
14	0.182	5.486	34.4688	1188.0975
15	0.182	5.506	34.5934	1196.7002
16	0.172	5.821	36.5722	1337.529
17	0.145	6.893	43.3101	1875.7675
18	0.138	7.224	45.3922	2060.456
19	0.134	7.447	46.7885	2189.1634
20	0.114	8.744	54.9376	3018.1452
21	0.109	9.193	57.7599	3336.208
22	0.107	9.306	58.4687	3418.5889
23	0.094	10.671	67.046	4495.1643
24	0.089	11.178	70.2352	4932.9782

5. Comparison of the shear force of floors under the effect of earthquake 1 in the horizontal direction in the state without dampers

Tables 6 and 7 show that the use of this type of damper increases the shear force of floors.

6.Conclusions

Results show that the proposed Multi-Level Yielding Pipe Damper damper is so effective to improve the seismic behavior of the structures under all three selected earthquakes. It seems that having a specific secondary hardening portion in force displacement shows multi-level behavior with variable strength and stiffness that can dissipate seismic energy in different acting as a two-level damping system.

In this article, two-frame attenuators were used in the horizontal direction of an 8-story steel building, and the shear force of the floors, rotation time, and relative displacement of the floors under the earthquake were studied in the horizontal direction, and the results showed that the use of this type of damper increases the shear force of the floors and reduces the relative displacement of the floors and reduces the period of the structure in different modes.

Table 6. story force due to earthquake in horizontal direction without using damper.

Story	Output Case	Step Type	Location	VX
				tonf
Story 7	EQ1	Max	Top	917.1827
Story 7	EQ1	Max	Bottom	917.1827
Story 7	EQ1	Min	Top	-1081.3662
Story 7	EQ1	Min	Bottom	-1081.3662
Story 6	EQ1	Max	Top	1247.8159
Story 6	EQ1	Max	Bottom	1247.8159
Story 6	EQ1	Min	Top	-1358.3237
Story 6	EQ1	Min	Bottom	-1358.3237
Story 5	EQ1	Max	Top	1511.0533
Story 5	EQ1	Max	Bottom	1511.0533
Story 5	EQ1	Min	Top	-1498.0265
Story 5	EQ1	Min	Bottom	-1498.0265
Story 4	EQ1	Max	Top	1707.3772
Story 4	EQ1	Max	Bottom	1707.3772
Story 4	EQ1	Min	Top	-1664.4234
Story 4	EQ1	Min	Bottom	-1664.4234
Story 3	EQ1	Max	Top	1855.3592
Story 3	EQ1	Max	Bottom	1855.3592
Story 3	EQ1	Min	Top	-1804.9272
Story 3	EQ1	Min	Bottom	-1804.9272
Story 2	EQ1	Max	Top	1916.6557
Story 2	EQ1	Max	Bottom	1916.6557
Story 2	EQ1	Min	Top	-1904.1255
Story 2	EQ1	Min	Bottom	-1904.1255
story 1	EQ1	Max	Top	1937.1745
story 1	EQ1	Max	Bottom	1937.1745
story 1	EQ1	Min	Top	-1940.1856
story 1	EQ1	Min	Bottom	-1940.1856

Table 7. story force due to type 1 earthquake in the horizontal direction in the case of using the damper

Story	Output Case	Step Type	Location	VX
				tonf
Story 7	EQ1	Max	Top	1079.8332
Story 7	EQ1	Max	Bottom	1079.8332
Story 7	EQ1	Min	Top	-1133.6256
Story 7	EQ1	Min	Bottom	-1133.6256
Story 6	EQ1	Max	Top	1473.0102
Story 6	EQ1	Max	Bottom	1473.0102
Story 6	EQ1	Min	Top	-1616.3961
Story 6	EQ1	Min	Bottom	-1616.3961
Story 5	EQ1	Max	Top	1955.2678
Story 5	EQ1	Max	Bottom	1955.2678
Story 5	EQ1	Min	Top	-1973.892
Story 5	EQ1	Min	Bottom	-1973.892
Story 4	EQ1	Max	Top	2040.8156
Story 4	EQ1	Max	Bottom	2040.8156
Story 4	EQ1	Min	Top	-2369.3402
Story 4	EQ1	Min	Bottom	-2369.3402
Story 3	EQ1	Max	Top	2762.5299
Story 3	EQ1	Max	Bottom	2762.5299
Story 3	EQ1	Min	Top	-2374.2996
Story 3	EQ1	Min	Bottom	-2374.2996
Story 2	EQ1	Max	Top	2092.6127
Story 2	EQ1	Max	Bottom	2092.6127
Story 2	EQ1	Min	Top	-2816.1085
Story 2	EQ1	Min	Bottom	-2816.1085
story 1	EQ1	Max	Top	3277.1995
story 1	EQ1	Max	Bottom	3277.1995
story 1	EQ1	Min	Top	-2387.5161
story 1	EQ1	Min	Bottom	-2387.5161

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