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ORIGINAL RESEARCH

Investigating the Effect of Using Multistory Pipe Dampers and their Combination with Braces on Structure Performance

Erfan Jalali[1]; Sayed Behzad Talaeitaba[2]

Abstract

Researchers have combined passive control systems of differing stiffness to provide multistory passive control systems. Each system absorbs and dissipates the applied energy according to its stiffness. The present study seeks to investigate the multistory control system with the modern pipe-in-pipe passive damper and combining them with braces, which can change the stiffness and absorb energy under various loads to reduce seismic structural vibrations. Their performance in 5-, 10-, and 15-story 3D steel structures on type 1, 2, and 3 soils was evaluated with nonlinear time history analysis and referred to as the structure's seismic responses. Results showed that using a combination of dampers and braces in 5, 10 and 15 story steel structures can be a suitable substitute for traditional bracing systems. For example, using pipe-in-pipe dampers instead of dual structures in 5-, 10-, and 15-story structures on type 3 soil reduced base shear by 45%, 51%, and 55%, and roof acceleration by 39%, 35%, and 50%. Compared to dual structures, a combination of dampers in lower stories and braces in higher stories on type 3 soil reduced base shear by 36%, 36%, and 46%, and roof acceleration by 38%, 32%, and 41% in the 5-, 10- and 15-story structures.

Keywords: Pipe-in-pipe damper, Time history analysis, multistory passive control system, Dual system

Introduction

Earthquake is a natural disaster, and structural engineers have presented many approaches for protecting structures against it for years. Passive control is an early structure control system that changes the structure's stiffness and dampening by adding secondary components. An effective approach for protecting structures against earthquakes and improving their seismic performance that was first proposed by Kolli et al. (1972) is to use metallic yielding dampers. Researchers later designed the ADAS (Bergman & Geol, 1987), TADAS (Tsai et al, 1993), and shear panel dampers (Nakashima et al, 1994).

Another type called the ring damper was proposed by Malek et al (2006). This damper is comprised of a ring with a square cross-section of steel sheets and is installed in the cross-section of concentric brace members. It focuses the stress on the braces-damper connection to create local buckling in these areas. In addition, Abbasnia et al. (2006) investigated the use of steel rings to improve the behavior of concentric bracing.

Oh et al (2009) proposed structural connections with slit dampers to strengthen the connection between the beam and the column against earthquakes. In another study, Koken and Garoglo (2012) evaluated a new

Corresponding author: talaeetaba@iaukhsh.ac.ir

1. MSc., Mechanical and Civil Engineering Department, Khomeyni Shahr Branch, Islamic Azad University, Khomeyni Shahr, Isfahan, Iran, Po. Box 81475-119.
2. Assistant Professor, Mechanical and Civil Engineering Department, Khomeyni Shahr Branch, Islamic Azad University, Khomeyni Shahr, Isfahan, Iran, Po. Box 81475-119, Corresponding author.

connection equipped with slit and rubber dampers. The connection's ductile behavior concentrates energy dissipation in itself with plastic deformation to prevent its transfer to the beam and column. Zahraei and Cheraghi (2015, 2016) studied the effect of using steel angles in slit braces before the adjacent connection sheet to prevent its premature buckling, and the results showed improved seismic performance and increased ductility in the concentric brace.

The aforementioned and similar systems are designed for one member (secondary and replaceable) to act as a fuse and dissipate a percentage of seismic energy by entering the nonlinear stage and forming plastic hinges based on its design and technical specification and prevent other members from going into the nonlinear state and the buckling of bracing components.

Researchers have combined two passive control systems to design multi-story passive control systems where each system absorbs and dissipates the applied energy according to its stiffness. Balendra et al (2001) proposed the dual control system comprised of a knee brace and a slit screw connection. Under service loads, the slit screw connection dissipates energy by creating friction damping; and in severe earthquakes, energy is dissipated by the knee member's yielding. The proposed multistory control system has been improved in the last decade by numerous researchers. Another study by Hosseini-Hashemi and Alirezaei (2012) investigated the two-story damper's behavior in combination with eccentric braces and knee elements. The knee element dissipates the energy at lower forces, and the eccentric brace absorbs seismic energy at higher forces. Zahraei and Vosough (2013) also studied two-story systems with a combination of vertical link beams and knee elements. The formation of plastic hinges under minor forces along the vertical link beam increases the energy dissipation systems, and the knee element's plastic deformations increase ductility and improve the system's seismic performance under severe loads.

Zahraei and Cheraghi (2016) recently proposed an innovative multistory piped yielding damper. This damper is comprised of several nested steel pipes that can be used for absorbing the energy of moderate to severe earthquakes by changing behavioral parameters such as strength, stiffness, and the dampening ratio.

Zahraei and Cheraghi (2017) also proposed two solutions for improving the proposed damper's behavioral parameters. The first approach is to use a metal core, such as lead and zinc, inside the internal pipe to increase dampening, and the second approach is to use various slit dampers inside the internal pipe to increase stiffness, strength, and the equivalent dampening.

This study investigates the effect of using pipe-in-pipe dampers in combination with braces in 5-, 10-, and 15-story 3D steel structures in SAP 2000 modeling. The seismic response was analyzed using the nonlinear modal time history analysis under 3 earthquake records. Responses were then compared and reported for the bare moment frame and a braced dual moment frame. The aforementioned structures were modeled on 3type 1, 2, 3 soils, and each structure group included six models. For example, the models for the 5 story structures on type 1 soil are as follows:

The sway intermediate moment frame structure, the pipe-in-pipe damper structure, the brace structure, the hybrid structure with dampers in lower stories and braces in upper stories, and the hybrid structure with braces in lower stories and damper in upper stories.

Methodology

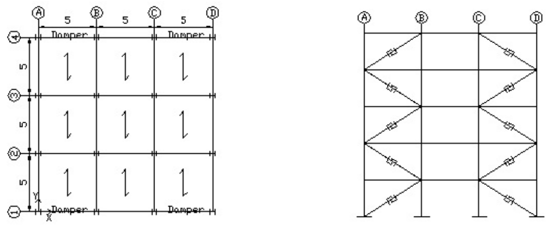
The effect of the damper, brace, and their combination on the 3D steel structure's seismic response was evaluated in this section. In this regard, 5-, 10-, and 15-story structures representing short, medium, and almost tall structures were designed according to clause 10 of the Iranian National Building Code and the fourth edition of standard 2800 IRAN and analyzed using the nonlinear modal time history method. The aforementioned structures were designed on 3type 1, 2, 3 soils with moderate relative hazards for residential use. The steel moment frame lateral load system was used in both X and Y directions in designing all bare frame structures, and the dual moment frame and the special concentric brace was used in the X direction, and the steel intermediate moment frame was used in the Y direction for designing braced and hybrid damper-brace structures.

Structures were classified into nine groups for modeling, each containing six models, and a total of 54 structures were modeled as follows:

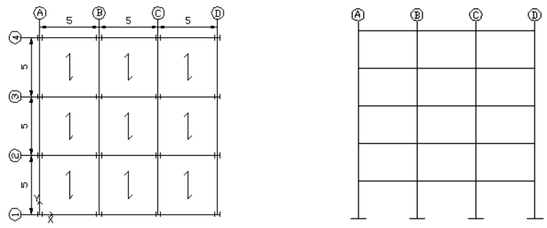
Group 1: In plan regular 5-story steel structures located on type 1 soil;
Group 2: In plan regular 5-story steel structures located on type 2 soil;
Group 3: In plan regular 5-story steel structures located on type 3 soil;
Group 4: In plan regular 10-story steel structures located on type 1 soil;
Group 5: In plan regular 10-story steel structures located on type 2 soil;
Group 6: In plan regular 10-story steel structures located on type 3 soil;
Group 7: In plan irregular 15-story steel structures located on type 1 soil;
Group 8: In plan irregular 15-story steel structures located on type 2 soil;
Group 9: In plan irregular 15-story steel structures located on type 3 soil;

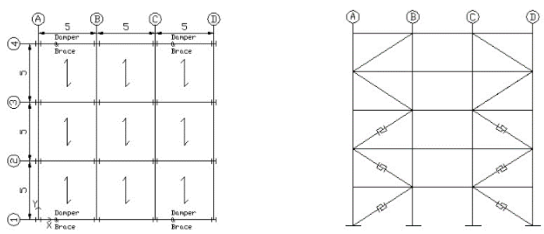
Name of samples contains 4 characters (□□□□);
- The first character on the left represents the number of stories;
- The second character on the left represents the regular (R) or irregular (I) structure;
- The third character represents the type of structure:
 a- The Bf index represents the "bare frame".
 b- The WD index indicates "with damper".
 c- The WB index indicates "with brace".
 d- The CD and CB indexes indicate the combination of damper and brace at height; the letter D following the letter C first indicates that the 3 lower stories in the 5-story structure, the 5 lower stories in the 10-story structure, and the 8 lower stories in the 15-story structure have dampers, while upper stories have braces. The letter B following the letter C first indicates that the 3 lower stories in the 5-story structure, the 5 lower stories in the 10-story structure, and the 8 lower stories in the 15-story structure have braces, while upper stories use dampers.
The structure plan is the same for all three soil types, but the specification of beams and their column differs by design.

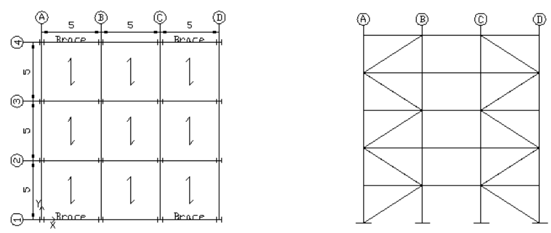
 e- The CP index indicates the composition of the dampers and braces on the floors.
- The fourth character on the left represents the type 1, 2, and 3 soils.
Group I structures are as follows:
Regular 5-story steel structure with sway intermediate bending frame system located on Type I soil (5.R.Bf.1), (Fig. 1).
Regular 5-story steel structure with damper located on Type I soil (5.R.WD.1), (Fig. 2).
Regular 5-story steel structure with diameter bracelet located on Type I soil (5.R.WB.1), (Fig. 3).
Regular 5-story steel structure with a combination of dampers and braces at height, located on type 1 soil (5.R.CD.1) (Fig. 4).
Regular 5-story steel structure with a combination of dampers and braces at height located on type 1 soil (5.R.CB.1), (Fig. 5).
Regular 5-story steel structure with a combination of dampers and braces on the floors located on type 1 soil (5.R.CP.1), (Fig. 6).



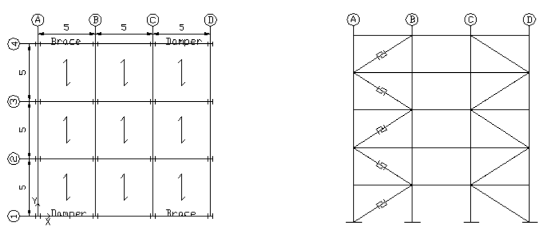
(a) (b)
Figure 2: 5.R.WD.1 plan; b: axis "1" frame


(a) (b)
Figure 1- a: 5.R.Bf.1 plan; b: axis "1' frame

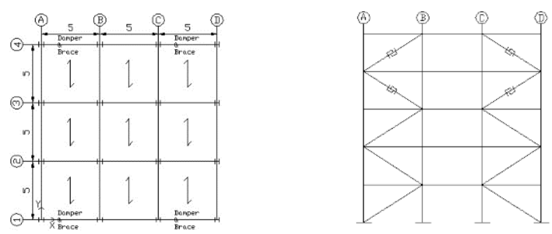

(a) (b)
Figure 4- a: 5.R.CD.1 plan; b: axis "1" frame



(a) (b)
Figure 3- a: 5.R.WB.1 plan; b: axis "1' frame



(a) (b)
Figure 6- a: 5.R.CP.1 plan; b: axis "1" frame


(a) (b)
Figure 5- a: 5.R.CB.1 plan; b: axis "1" frame

The plan of structures are the same for all three types of soils, but the beam and column specifications vary according to the designs.

The 3type 1, 2, 3 soils are defined according to 2800 IRAN (code of practice for the seismic-resistant design of buildings). Type I: the stone and pseudo-rock soil with shear wave speed (v_s) greater than 750 m/sec; Type 2 soil: very dense soil or lose rock ($375<v_s<750$) and Type 3: Dense to medium soil ($175<v_s<375$ m/sec).

Figures 7 to 11 show the plan for 10-story structures.

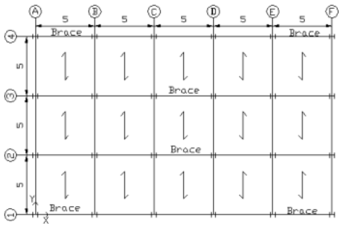


Figure 9- 10.R.WB.1 plan

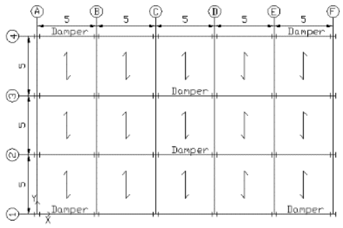


Figure 8- 10.R.WD.1 plan

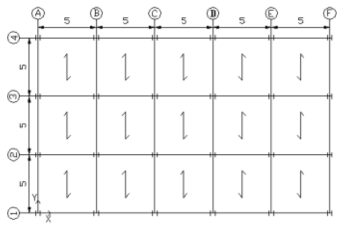


Figure 7- 10.R.Bf.1 plan

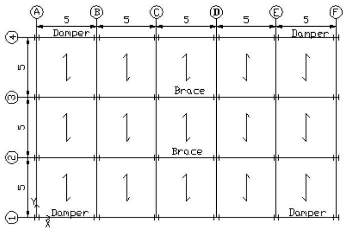


Figure 11: 10.R.CP.1 plan

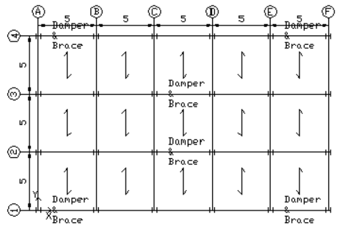


Figure 10- 10.R.CD.1 & 10.R.CB.1 plan

Figures 12 to 16 illustrate the plans of 1A 5-story structures.

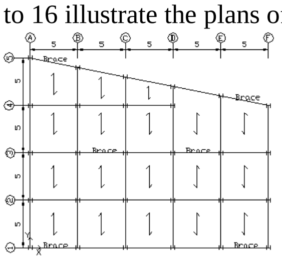


Figure 14- 15.I.WB.1 plan

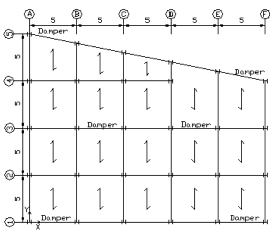


Figure 13- 15.I.WD.1 plan

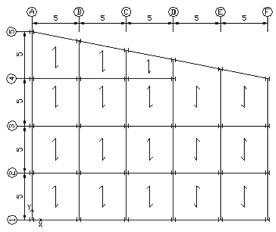


Figure 12- 15.I.Bf.1 plan

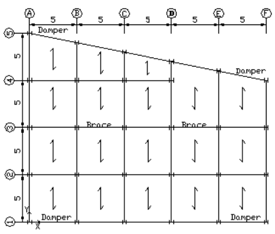


Figure 16- 15.I.Cp.1 plan

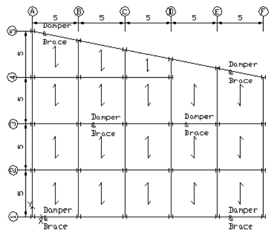


Figure 15- 15.I.CD.1 & 15.I.CB.1 plan

The roof is joist and rib for all specimens and the arrow shows the joist direction in all figures. All stories are 2.3m high and the live and dead loads are 500 and 200kg/m^2. The steel used in steel structures is ST37 with yielding stress of 2400kg/cm^2, elasticity modulus of 2×10^{16} kg/cm^2, and Poisson's ratio of 0.3. The IPE section was selected for modeling beams and the IPB section was selected for modeling columns.

1.2. Selected Earthquake Records

According to table 1, 3 accelerograms were used for maximum acceleration, continuity, and different frequency content in time history analysis, and the response spectrum for each accelerogram was drawn according to figure 17.

The applied accelerograms were scaled according to standard 2800 IRAN and the following method:

First, each accelerogram pair was scaled to the maximum. That is, the maximum acceleration in the largest factor was equated to the gravitational acceleration (g). The acceleration response spectrum was determined for each scaled accelerogram by accounting for 5% dampening. Each accelerogram pair's response spectrum was combined using the square root of the sum of the squares to create a single combined spectrum for each pair. Then, the combined response spectrum was compared with the standard design spectrum in a timeframe equal to 0.2 to 1.5 multiples of the structure's periodic time. Finally, the scale factor was selected so that in the aforementioned range, the square root of the sum of the square spectrum average for all paired factors did not exceed 10% of 1.3 times the corresponding value in the standard spectrum. The aforementioned scale factor of accelerograms was used in time history analysis after multiplication.

Table 1- Specification of used time histories

Earthquake	Date	Station	PGA(g)	Duration (sec.)
Northridge	1994	LaCrescenta - New York	0.221	30
Loma Prieta	1989	UCSC Lick Observatory	0.460	40
Kobe	1995	Kakogawa	0.324	41

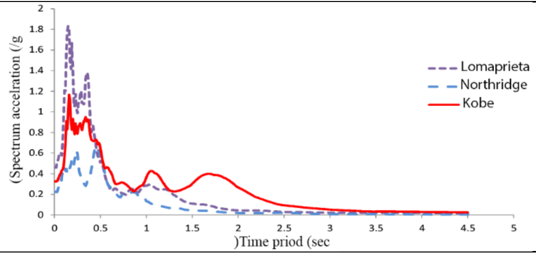


Figure 17- The response spectrum of the non-scaled accelerometers

Table 2- Dimension of two-level damper used (Zahraei and Cheraghi, 2018)

Specimen number	External pipe diameter (mm)	Internal pipe diameter (mm)	External pipe thickness (mm)	Internal pipe thickness (mm)	External to internal pipe diameter ratio	Diameter to thickness ratio for the outer tube	Diameter to thickness ratio for inner tube	Damper length (mm)
1	610	320	30	15	1.88	20.3	21.6	200
2	406	168	20	8	2.44	20.3	21.0	200

Table 3- Main specifications of dampers

Specimen number	Initial stiffness (kN/mm)	Secondary stiffness (kN/mm)	Secondary/Initial stiffness ratio	Yield displacement (mm)	Final displacement (mm)	Ductility index
1	18.57	13.90	0.75	7.35	74.9	10.19
2	19.4	13.43	0.69	5.46	264.39	11.17

2.2. Modeling the Pipe-in-pipe Damper in SAP 2000

To model the pipe-in-pipe damper in SAP 2000, link and then the "multi-linear plastic" link options were selected, and the checkboxes for U1 and the nonlinear option were activated. Then, U1 was selected in change specifications and the force-displacement curve table. The force-displacement curve was extracted from hysteresis curves, and the numerical analysis and lab samples of Zahraei and Cheraghi, shown in tables 2 and 3, were used. The initial stiffness from table 3 was used in the effective linear stiffness section and the kinematic feature was selected.

The hysteresis curve for samples 1 and 2 is shown in figures 18 and 19 according to the results by Zahraei and Cheragi (2018).

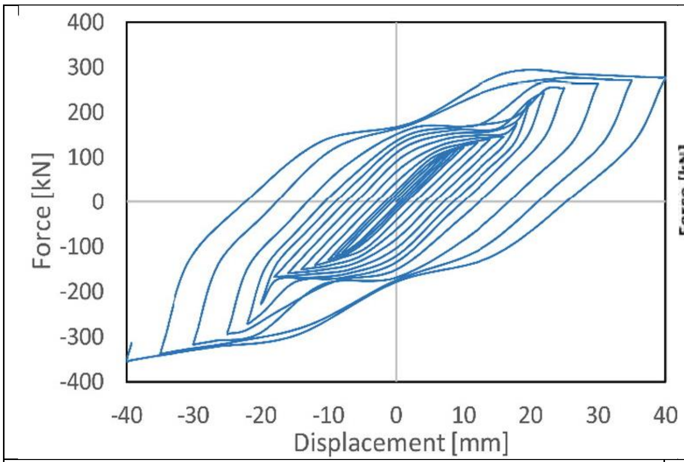


Figure 18- Hysteresis curve of sample 2 (Zahraei & Cheraghi, 2018)

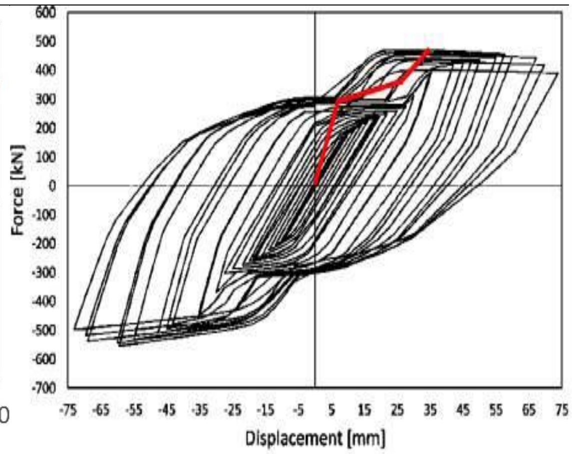


Figure 19- Hysteresis curve of sample 1 (Zahraei & Cheraghi, 2018)

3. Analysis of Results

Tables 4 to 12 show the damper's effect on the base shear of the 5-story 3D steel structures under three earthquake records, namely Northridge, Loma Prieta, and Kobe, on 3type 1, 2, 3 soil. The results presented in the tables indicate that using pipe-in-pipe dampers reduces the structural response, which is affected by technical specifications of dampers, and their number and arrangement in the structure. It's worth mentioning that increasing or decreasing the base shear, acceleration and drift is concerning the moment frame structure state, which is shown in tables with W/B.

Table 4- Effect of the damper on the base shear
A 5-story structure on type I soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Northridge	5.R.Bf.1	190.76	---	---
	5.R.WD.1	166.34	0.87	0.58
	5.R.WB.1	286.02	1.49	1
	5.R.CD.1	207.56	1.08	0.72
	5.R.CB.1	206.22	1.08	0.72
	5.R.CP.1	237.94	1.24	0.83

Table 5- Effect of the damper on the base shear
A 5-story structure on type 2 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Northridge	5.R.Bf.2	295.73	---	---
	5.R.WD.2	216.86	0.73	0.56
	5.R.WB.2	381.24	1.28	1.00
	5.R.CD.2	276.10	0.93	0.72
	5.R.CB.2	262.80	1.88	0.68
	5.R.CP.2	324.28	1.09	0.85

Table 6- Effect of the damper on the base shear
A 5-story structure on type 3 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Northridge	5.R.Bf.3	455.92	---	---
	5.R.WD.3	335.33	0.73	0.54
	5.R.WB.3	617.60	1.35	1.00
	5.R.CD.3	373.17	0.81	0.60
	5.R.CB.3	428.09	0.93	0.69
	5.R.CP.3	490.26	1.07	0.79

Table 7- Effect of the damper on the base shear
A 5-story structure on type 1 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Loma Prieta	5.R.Bf.1	214.55	---	---
	5.R.WD.1	262.14	0.75	0.90
	5.R.WB.1	180.14	0.83	1.00
	5.R.CD.1	153.72	0.71	0.85
	5.R.CB.1	170.12	0.79	0.94
	5.R.CP.1	171.75	0.80	0.95

Table 8- Effect of the damper on the base shear
A 5-story structure on type 2 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br

Loma Prieta	5.R.Bf.2	282.36	---	---
	5.R.WD.2	212.75	0.75	0.89
	5.R.WB.2	238.75	0.84	1.00
	5.R.CD.2	270.46	0.95	1.13
	5.R.CB.2	251.52	0.89	1.05
	5.R.CP.2	208.91	0.73	0.87

Table 9- Effect of the damper on the base shear
A 5-story structure on type 3 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Loma Prieta	5.R.Bf.3	375.51	---	---
	5.R.WD.3	264.96	0.70	0.60
	5.R.WB.3	434.66	1.15	1.00
	5.R.CD.3	292.22	0.77	0.67
	5.R.CB.3	316.13	0.84	0.72
	5.R.CP.3	325.28	0.86	0.74

Table 10- Effect of the damper on the base shear
A 5-story structure on type 1 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Kobe	5.R.Bf.1	259.81	---	---
	5.R.WD.1	215.25	0.82	0.58
	5.R.WB.1	365.05	1.40	1.00
	5.R.CD.1	273.46	1.05	0.74
	5.R.CB.1	237.30	0.91	0.65
	5.R.CP.1	294.49	1.13	0.80

Table 11- Effect of the damper on the base shear
A 5-story structure on type 2 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Kobe	5.R.Bf.2	435.51	---	---
	5.R.WD.2	351.67	0.79	0.73
	5.R.WB.2	479.68	1.08	1.00
	5.R.CD.2	442.24	0.99	0.92
	5.R.CB.2	347.78	0.78	0.72
	5.R.CP.2	367.09	0.82	0.76

Table 12- Effect of the damper on base shear
A 5-story structure on type 3 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Kobe	5.R.Bf.3	648.21	---	---
	5.R.WD.3	437.03	0.67	0.52
	5.R.WB.3	827.12	1.27	1.00
	5.R.CD.3	553.64	0.85	0.66
	5.R.CB.3	456.49	0.7	0.55
	5.R.CP.3	595.35	0.91	0.71

The W/Br columns in tables indicate the ratio of structure response (base shear, acceleration, and drift) to the dual system of intermediate moment frame and special concentric brace.
According to tables, the base shear average for the 5.R.WD structure has decreased by 19%, 25%, and 30% in 3type 1, 2, 3 soils compared to the 5.R.Bf structure.

Figures 20 and 21 show the average base shear bar graph of W/B and W/Br ratios of three earthquakes on 3type 1, 2, 3 soils. According to the following tables and diagrams, using dampers or combining dampers and braces in structures reduces base shear compared to the dual structure. The base shear ratio for the 5.R.WD structure decreased by 31%, 27%, and 45% on 3type 1, 2, 3 soils compared to the 5.R.WB structure. The base shear was reduced in the hybrid 5.R.CD structure by 23%, 8%, and 36% on all three soil types compared to 5.R.WB. The hybrid 5.R.CB structure reduced base shear by 23%, 18%, and 35% compared to 5.R.WB, and the 5.R.CP structure reduced the base shear by 14%, 17%, and 25% compared to 5.R.WB on 3type 1, 2, 3 soils.

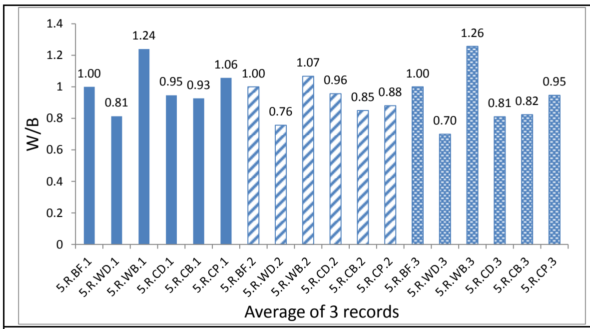


Figure 20- Diagram of the mean W/B ratio of the base shear of three earthquakes, on type 1, 2 & 3 soils

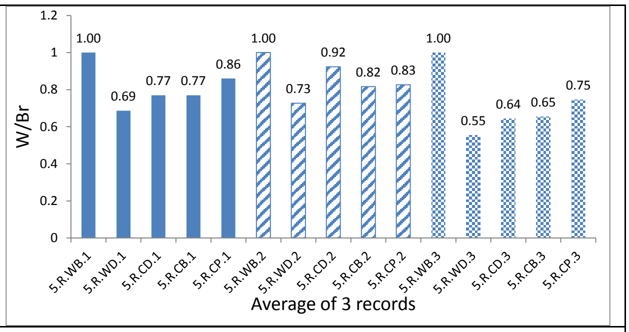


Figure 21- Diagram of the mean W/Br ratio of the base shear of three earthquakes, on type 1, 2 & 3 soils

As shown in tables 13 to 21 regarding the effect of pipe-in-pipe damper on roof acceleration, using structures with dampers (5.R.WD) reduced roof acceleration by 15%, 28%, and 26% on average compared to the moment frame structure (5.R.Bf) on type I, II and 3 soil. Furthermore, using the 5.R.WD structure instead of 5.R.WB reduced average acceleration by 31%, 39%, and 39% on 3type 1, 2, 3 soils. All hybrid structures reduced roof acceleration compared to 5.R.WB, and the 5.R.CD structure had the biggest acceleration reduction by 24%, 32%, and 38%.

Table 13- Effect of the damper on roof acceleration
A 5-story structure on type 1 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Northridge	5.R.Bf.1	6.79	---	---
	5.R.WD.1	4.38	0.64	0.49
	5.R.WB.1	8.85	1.30	1.00
	5.R.CD.1	4.43	0.65	0.50
	5.R.CB.1	5.56	0.81	0.62
	5.R.CP.1	6.85	1.01	0.77

Table 14- Effect of the damper on roof acceleration
A 5-story structure on type 2 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Northridge	5.R.Bf.2	10.66	---	---
	5.R.WD.2	6.13	0.57	0.54
	5.R.WB.2	11.16	1.04	1.00
	5.R.CD.2	5.86	0.54	0.52
	5.R.CB.2	7.20	0.67	0.64
	5.R.CP.2	9.36	0.87	0.83

Table 15- Effect of the damper on roof acceleration
A 5-story structure on type 3 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Northridge	5.R.Bf.3	12.06	---	---
	5.R.WD.3	9.84	0.81	0.58
	5.R.WB.3	16.85	1.39	1.00
	5.R.CD.3	9.76	0.8	0.57
	5.R.CB.3	15.17	1.25	0.90
	5.R.CP.3	15.69	1.30	0.93

Table 16- Effect of the damper on roof acceleration
A 5-story structure on type 1 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Loma Prieta	5.R.Bf.1	5.42	---	---
	5.R.WD.1	5.91	1.09	0.93
	5.R.WB.1	6.33	1.16	1.00
	5.R.CD.1	6.73	1.24	1.06
	5.R.CB.1	6.56	1.21	1.03
	5.R.CP.1	6.09	1.12	0.96

Table 17- Effect of the damper on roof acceleration
A 5-story structure on type 2 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Loma Prieta	5.R.Bf.2	6.67	---	---
	5.R.WD.2	5.59	0.83	0.64
	5.R.WB.2	8.67	1.29	1.00
	5.R.CD.2	7.81	1.17	0.90
	5.R.CB.2	9.75	1.46	1.12
	5.R.CP.2	7.26	1.08	0.83

Table 18- Effect of the damper on roof acceleration
A 5-story structure on type 3 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Loma Prieta	5.R.Bf.3	14.30	---	---
	5.R.WD.3	10.53	0.73	0.79
	5.R.WB.3	13.22	0.92	1.00
	5.R.CD.3	10.89	0.76	0.82
	5.R.CB.3	11.29	0.78	0.85
	5.R.CP.3	10.79	0.75	0.81

Table 19- Effect of the damper on roof acceleration
The A 5-story structure on type 1 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Kobe	5.R.Bf.1	6.67	---	---
	5.R.WD.1	5.44	0.81	0.66
	5.R.WB.1	8.16	1.22	1.00
	5.R.CD.1	5.85	0.87	0.71
	5.R.CB.1	6.57	0.98	0.80
	5.R.CP.1	7.46	1.11	0.91

Table 20- Effect of the damper on roof acceleration
A 5-story structure on type 2 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Kobe	5.R.Bf.2	11.39	---	---
	5.R.WD.2	8.66	0.76	0.66
	5.R.WB.2	12.98	1.13	1.00
	5.R.CD.2	8.21	0.72	0.63
	5.R.CB.2	8.33	0.73	0.64

5.R.CP.2	10.51	0.92	0.80

Table 21- Effect of the damper on roof acceleration

A 5-story structure on type 3 soil				
Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Kobe	5.R.Bf.3	14.63	---	---
	5.R.WD.3	9.86	0.76	0.66
	5.R.WB.3	21.76	1.48	1.00
	5.R.CD.3	10.28	0.70	0.47
	5.R.CB.3	16.43	1.12	0.75
	5.R.CP.3	14.43	0.98	0.66

Figures 22 to 24 show the average acceleration change at height diagram according to time history analysis of three earthquakes on 3type 1, 2, 3 soils. As shown, using the damper and the damper-brace combination reduces average acceleration at height on all three soil types. All average acceleration at height change diagrams were in "g"

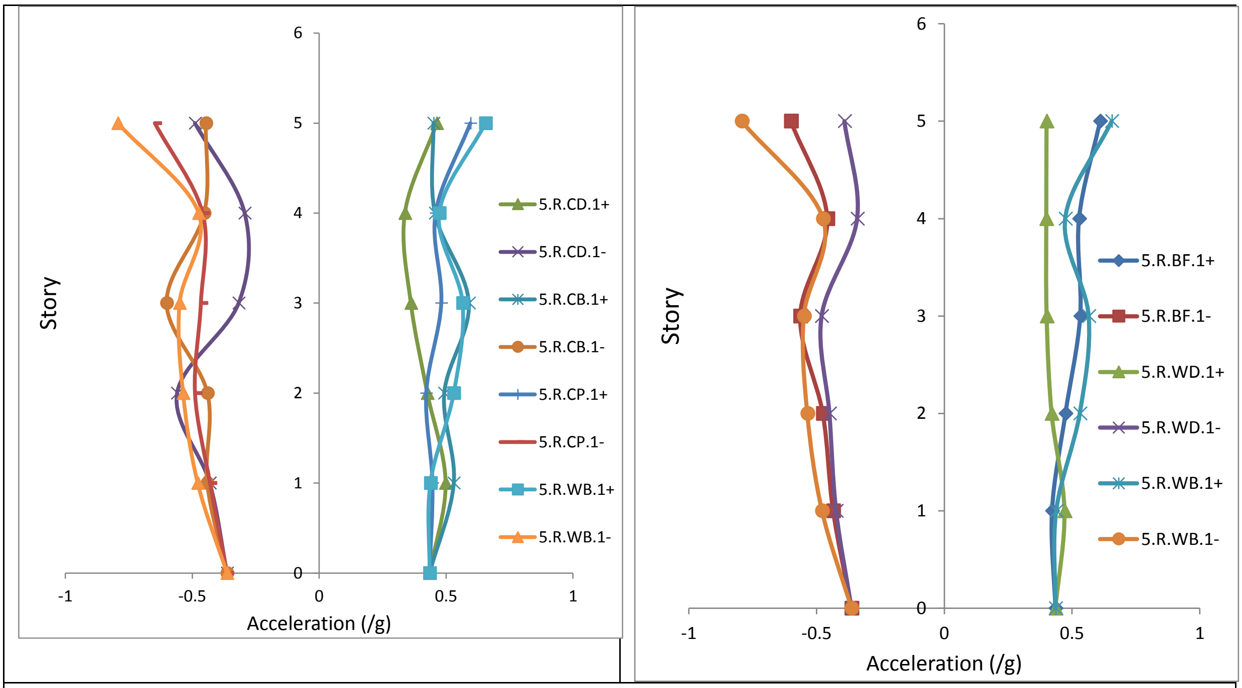


Figure 22- Average acceleration variation in height under time history analysis of three earthquakes on type 1 soil

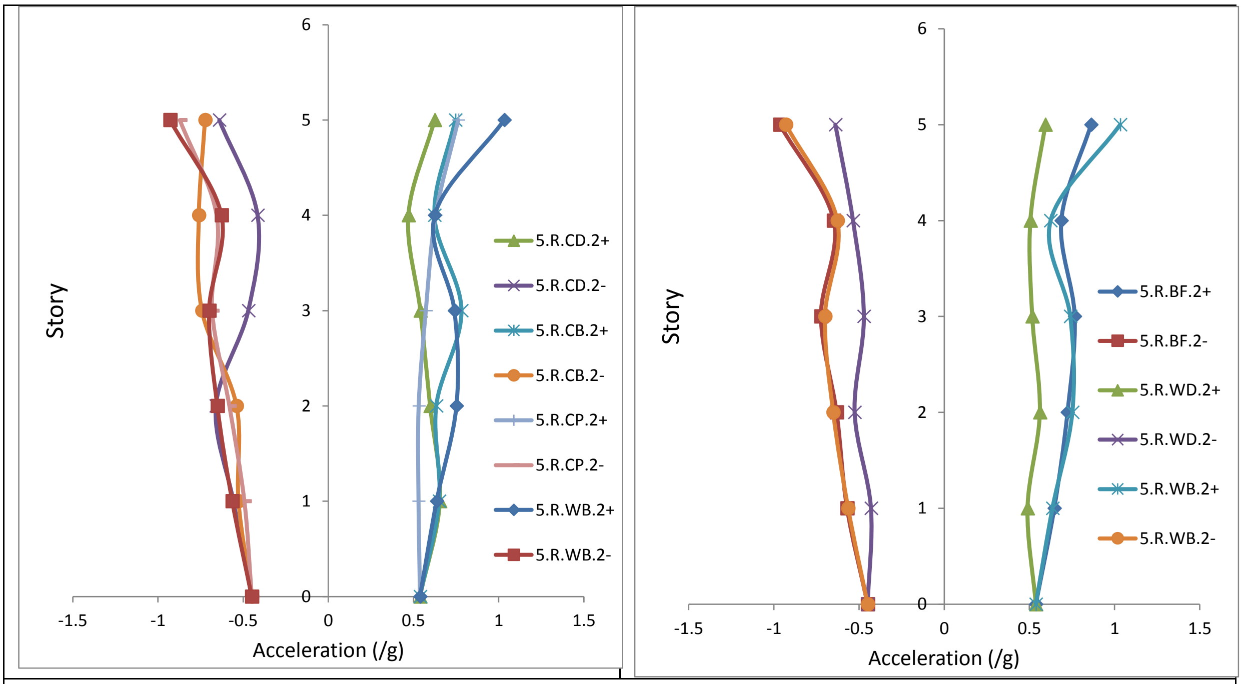


Figure 23- Average acceleration variation in height under time history analysis of three earthquakes on type 2 soil

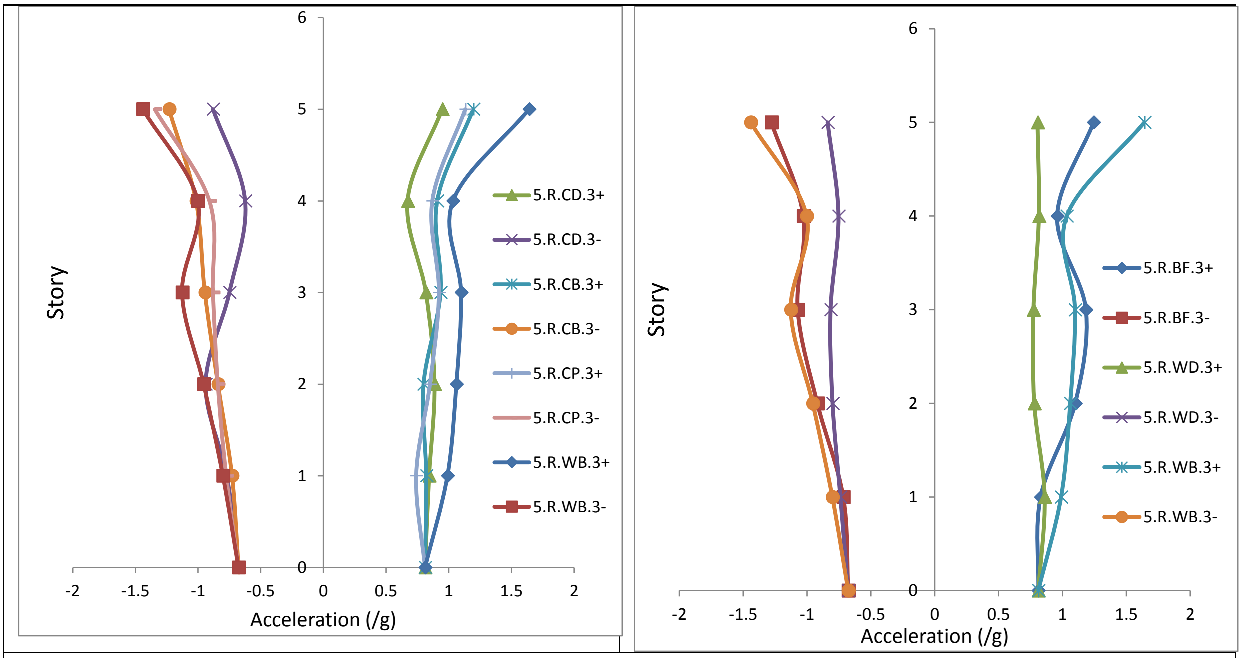


Figure 24- Average acceleration variation in height under time history analysis of three earthquakes on type 3 soil

According to tables 22 to 30 in regards to the damper's effect on a structural drift, using the 5.R.WD structure reduces average drift by 42%, 27%, and 45% compared to the 5.R.Bf structure on 3type 1, 2, 3 soils.

Figure 25 shows structural drift on the three soil types. The drift of all structures has tangibly decreased compared to 5.R.Bf on type 3 soil, and are very close to each other. Due to the use of dampers and braces at stories, the 5.R.CP structure's drift diagram is between the 5.R.WB and 5.R.WD structures.

Table 22- Effect of the damper on average floor drift

A 5-story structure on type 1 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Northridge	5.R.Bf.1	1.33	---	---
	5.R.WD.1	1.12	0.84	1.06
	5.R.WB.1	1.05	0.79	1.00
	5.R.CD.1	1.04	0.78	0.99
	5.R.CB.1	0.98	0.74	0.93
	5.R.CP.1	1.24	0.93	1.18

Table 23- Effect of the damper on average floor drift

A 5-story structure on type 2 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Northridge	5.R.Bf.2	2.04	---	---
	5.R.WD.2	1.54	0.74	1.10
	5.R.WB.2	1.38	0.67	1.00
	5.R.CD.2	1.42	0.69	1.02
	5.R.CB.2	1.63	0.79	1.17
	5.R.CP.2	1.54	0.76	1.13

Table 24- Effect of the damper on average floor drift

A 5-story structure on type 3 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Northridge	5.R.Bf.3	3.5	---	---
	5.R.WD.3	2.14	0.61	1.00
	5.R.WB.3	2.12	0.60	1.00
	5.R.CD.3	1.91	0.54	0.90
	5.R.CB.3	1.81	0.51	0.85
	5.R.CP.3	1.90	0.54	0.89

Table 25- Effect of the damper on average floor drift

A 5-story structure on type 1 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Loma Prieta	5.R.Bf.1	3.16	---	---
	5.R.WD.1	0.78	0.36	1.27
	5.R.WB.1	0.61	0.28	1.00
	5.R.CD.1	0.81	0.37	1.32
	5.R.CB.1	0.53	0.24	0.86
	5.R.CP.1	0.64	0.29	1.04

Table 26 - Effect of the damper on average floor drift

A 5-story structure on type 1 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Loma Prieta	5.R.Bf.2	2.02	---	---
	5.R.WD.2	1.57	0.77	2.06
	5.R.WB.2	0.76	0.37	1.00
	5.R.CD.2	1.21	0.59	1.59
	5.R.CB.2	1.08	0.53	1.42
	5.R.CP.2	0.77	0.38	1.01

Table 27- Effect of the damper on average floor drift

A 5-story structure on type 3 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Loma Prieta	5.R.Bf.3	2.59	---	---
	5.R.WD.3	1.23	0.47	1.24
	5.R.WB.3	0.99	0.38	1.00
	5.R.CD.3	1.00	0.38	1.01
	5.R.CB.3	1.03	0.39	1.04
	5.R.CP.3	1.23	0.47	1.24

Table 28- Effect of the damper on average floor drift

A 5-story structure on type 1 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Kobe	5.R.Bf.1	3.14	---	---
	5.R.WD.1	1.67	0.53	1.49
	5.R.WB.1	1.12	0.35	1.00
	5.R.CD.1	1.29	0.41	1.15
	5.R.CB.1	1.22	0.38	1.08
	5.R.CP.1	1.23	0.39	1.09

Table 29- Effect of the damper on average floor drift

A 5-story structure on type 2 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Kobe	5.R.Bf.2	4.86	---	---
	5.R.WD.2	3.36	0.69	2.5
	5.R.WB.2	1.34	0.27	1.00
	5.R.CD.2	2.27	0.46	1.69
	5.R.CB.2	1.64	0.33	1.22
	5.R.CP.2	1.54	0.31	1.14

Table 30- Effect of the damper on average floor drift

A 5-story structure on type 3 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Kobe	5.R.Bf.3	3.74	---	---
	5.R.WD.3	2.14	0.57	0.92
	5.R.WB.3	2.31	0.61	1.00
	5.R.CD.3	2.01	0.53	0.87
	5.R.CB.3	1.94	0.51	0.83
	5.R.CP.3	1.98	0.52	0.85

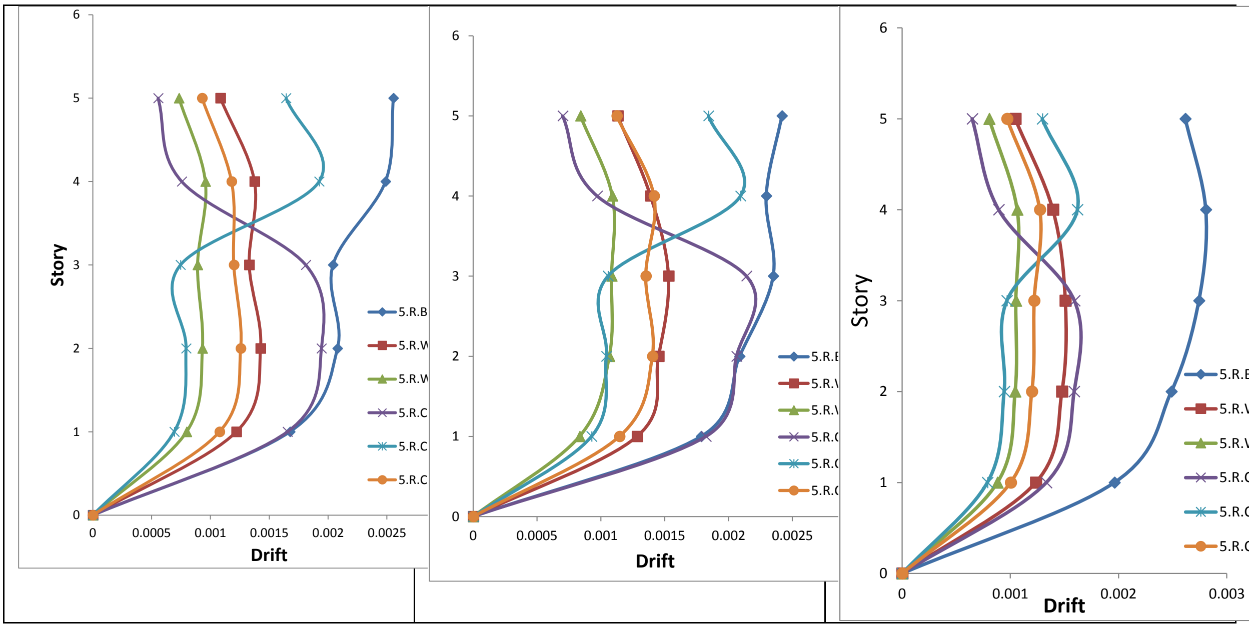


Figure 25- Diagram of relative displacement changes in height for a 5-story building under spectral analysis on type 1, 2, and 3 soils

Using the pipe-in-pipe damper in the 5-story 3D steel structure reduces the base shear, acceleration, and displacement by 19%, 15%, and 43% on soil type I, while in the results by Zahraei and Cheraghi (2018), it has decreased by 26%, 16%, and 54%. Results are close to the base article and are marginally different due to many reasons, including the damper's technical specification, analysis, earthquakes, etc. According to the results from tables 31 to 39 and figures 26 and 27 in regards to the damper's effect on the base shear of 10-story structures on 3type 1, 2, 3 soils, the average base shear has decreased by 18%, 6% and 3% in the structure with the pipe-in-pipe damper compared to the 10.R.Bf structure, and by 52%, 47% and 51% compared to the dual 10.R.WB structure on type I, II and 3 soils. The average base shear of the 10.R.CD structure has decreased by 35%, 29%, and 36% compared to the 10.R.WB structure, 33%, 36%, and 13% for the 10.R.CB compared to 10.R.WB, and 29%, 22%, and 12% for the 10.R.CP structure compared to the 10.R.WB structure on soil types I, II and 3. It indicates that hybrid structures can be a suitable substitute for structures that use traditional bracing system construction.

Table 31- Effect of the damper on the base shear
10 Stories structure on type 1 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Northridge	10.R.Bf.1	264.40	---	---
	10.R.WD.1	184.55	0.96	0.32
	10.R.WB.1	574.87	2.17	1.00
	10.R.CD.1	294.76	1.11	0.51
	10.R.CB.1	337.16	1.27	0.58
	10.R.CP.1	461.36	1.74	0.80

Table 32- Effect of the damper on Base shear
10 Stories structure on type 2 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Northridge	10.R.Bf.2	255.58	---	---
	10.R.WD.2	251.23	0.98	0.37
	10.R.WB.2	677.08	2.64	1.00
	10.R.CD.2	476.48	1.86	0.70
	10.R.CB.2	537.18	2.10	0.79
	10.R.CP.2	776.48	2.03	1.14

Table 33- Effect of the damper on the base shear
10 Stories structure on type 3 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Northridge	10.R.Bf.3	586.73	---	---
	10.R.WD.3	631.18	1.07	0.55
	10.R.WB.3	1137.22	1.93	1.00
	10.R.CD.3	789.63	1.34	0.69
	10.R.CB.3	328.13	2.26	1.16
	10.R.CP.3	1204.52	2.05	1.05

Table 34- Effect of the damper on base shear
10 Stories structure on type 1 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Loma Prieta	10.R.Bf.1	181.36	---	---
	10.R.WD.1	155.43	0.85	0.23
	10.R.WB.1	660.31	3.64	1.00
	10.R.CD.1	277.84	1.53	0.41
	10.R.CB.1	344.49	1.89	0.52
	10.R.CP.1	235.63	1.85	0.50

Table 35- Effect of the damper on base shear
10 Stories structure on type 2 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Loma Prieta	10.R.Bf.2	339.82	---	---
	10.R.WD.2	282.70	0.83	0.33
	10.R.WB.2	832.97	2.45	1.00
	10.R.CD.2	394.32	1.16	0.47
	10.R.CB.2	467.40	1.37	0.56
	10.R.CP.2	524.09	1.54	0.62

Table 36- Effect of the damper on base shear
10 Stories structure on type 3 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Loma Prieta	10.R.Bf.3	642.96	---	---
	10.R.WD.3	607.88	0.94	0.37
	10.R.WB.3	1609.10	2.50	1.00
	10.R.CD.3	939.69	1.54	0.61
	10.R.CB.3	1381.37	2.14	0.85
	10.R.CP.3	1391.39	2.16	0.86

Table 37- Effect of the damper on base shear
10 Stories structure on type 1 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Kobe	10.R.Bf.1	910.36	---	---
	10.R.WD.1	839.29	0.92	0.90
	10.R.WB.1	929.36	1.02	1.00
	10.R.CD.1	1118.36	1.22	1.20
	10.R.CB.1	753.39	0.82	0.81
	10.R.CP.1	764.27	0.83	0.82

Table 38- Effect of the damper on base shear
10 Stories structure on type 2 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Kobe	10.R.Bf.2	1235.12	---	---
	10.R.WD.2	1222.98	0.91	0.89
	10.R.WB.2	1366.77	1.02	1.00
	10.R.CD.2	1084.80	0.81	0.79
	10.R.CB.2	891.68	0.66	0.65
	10.R.CP.2	801.04	0.59	0.58

Table 39- Effect of the damper on base shear
10 Stories structure on type 3 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Kobe	10.R.Bf.3	1486.87	---	---
	10.R.WD.3	1350.28	0.90	0.54
	10.R.WB.3	2456.08	1.65	1.00
	10.R.CD.3	1509.62	1.01	0.61
	10.R.CB.3	1474.74	0.99	0.60
	10.R.CP.3	1819.67	1.22	0.74

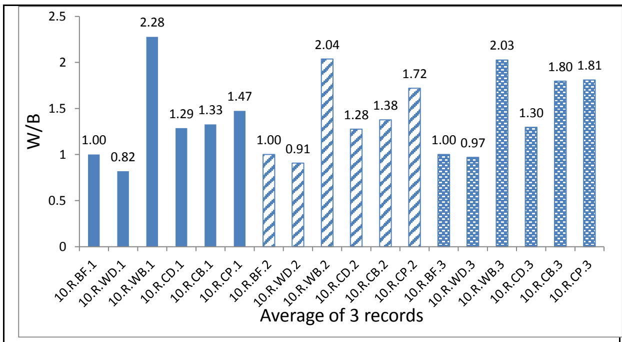


Figure 26- Diagram of the mean W/B ratio of the base shear of three earthquakes, on type 1, 2 & 3 soils

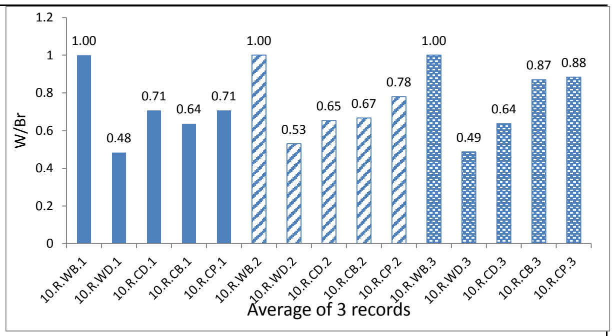


Figure 27- Diagram of the mean W/Br ratio of the base shear of three earthquakes, on type 1, 2 & 3 soils

According to the results from table 40 to 48 in regards to the effect of dampers on roof acceleration on three soil types, the 10.R.WB structure has reduced roof acceleration by 14%, 15%, and 19% on average compared to 10.R.Bf, and the 10.R.WD structure has reduced roof acceleration by 36%, 42%, and 45% compared to 10.R.WB on type I, II and 3 soils.

Table 40- Effect of the damper on roof acceleration 10 Stories structure on type 1 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Northridge	10.R.Bf.1	5.21	---	---
	10.R.WD.1	4.26	0.81	0.54
	10.R.WB.1	7.82	1.50	1.00
	10.R.CD.1	5.86	1.12	0.74
	10.R.CB.1	5.29	1.01	0.67
	10.R.CP.1	7.56	1.46	0.97

Table 41- Effect of the damper on roof acceleration 10 Stories structure on type 2 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Northridge	10.R.Bf.2	5.66	---	---
	10.R.WD.2	5.27	0.93	0.56
	10.R.WB.2	9.37	1.65	1.00
	10.R.CD.2	7.40	1.30	0.78
	10.R.CB.2	8.82	1.55	0.94
	10.R.CP.2	9.97	1.76	1.06

Table 42- Effect of the damper on roof acceleration 10 Stories structure on type 3 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Northridge	10.R.Bf.3	12.75	---	---
	10.R.WD.3	11.60	0.9	0.72
	10.R.WB.3	15.97	1.25	1.00
	10.R.CD.3	10.28	0.80	0.64
	10.R.CB.3	19.43	1.52	1.21
	10.R.CP.3	15.27	1.19	0.95

Table 43- Effect of the damper on roof acceleration 10 Stories structure on type 1 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Loma Prieta	10.R.Bf.1	4.83	---	---
	10.R.WD.1	4.26	0.88	0.57
	10.R.WB.1	7.47	1.54	1.00
	10.R.CD.1	4.37	0.90	0.58
	10.R.CB.1	4.75	0.98	0.63
	10.R.CP.1	5.44	1.12	0.72

Table 44- Effect of the damper on roof acceleration 10 Stories structure on type 2 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Loma Prieta	10.R.Bf.2	6.68	---	---
	10.R.WD.2	5.27	0.78	0.4
	10.R.WB.2	12.97	1.94	1.00
	10.R.CD.2	6.78	1.01	0.52
	10.R.CB.2	7.73	1.15	0.59
	10.R.CP.2	8.51	1.27	0.65

Table 45- Effect of the damper on roof acceleration 10 Stories structure on type 3 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Loma Prieta	10.R.Bf.3	13.58	---	---
	10.R.WD.3	9.76	0.71	0.48
	10.R.WB.3	20.06	11.47	1.00
	10.R.CD.3	11.87	0.87	0.59
	10.R.CB.3	11.66	0.85	0.58
	10.R.CP.3	11.31	0.83	0.56

Table 46- Effect of the damper on roof acceleration 10 Stories structure on type 1 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Kobe	10.R.Bf.1	9.42	---	---
	10.R.WD.1	8.36	0.88	0.80
	10.R.WB.1	10.41	1.10	1.00
	10.R.CD.1	8.35	0.88	0.80
	10.R.CB.1	8.52	0.90	0.80
	10.R.CP.1	9.06	0.96	0.87

Table 47- Effect of the damper on roof acceleration

10 Stories structure on type 2 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Kobe	10.R.Bf.2	12.11	---	---
	10.R.WD.2	10.38	0.85	0.79
	10.R.WB.2	13.11	1.08	1.00
	10.R.CD.2	11.61	0.95	0.88
	10.R.CB.2	9.58	0.79	0.73
	10.R.CP.2	13.44	1.10	1.02

Table 48- Effect of the damper on roof acceleration

10 Stories structure on type 3 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Kobe	10.R.Bf.3	18.56	---	---
	10.R.WD.3	15.33	0.82	0.75
	10.R.WB.3	20.35	1.09	1.00
	10.R.CD.3	16.41	0.88	0.80
	10.R.CB.3	17.48	0.94	0.85
	10.R.CP.3	17.33	0.92	0.84

Similar to 5-story structures, hybrid 10-story structures reduce the average roof acceleration. The 10.R.CD structure has decreased roof acceleration on type 1, 2 and 3 soils by 27%, 29% and 32% compared to the 10.R.WB structure, 30%, 25% and 12% compared to the 10.R.CB structure, and 9%, 15% and 22% compared to the 10.R.CP structure.

As shown in figures 28 to 30, the use of dampers and combining them with braces can reduce average roof acceleration in stories compared to the 10.R.WB structure.

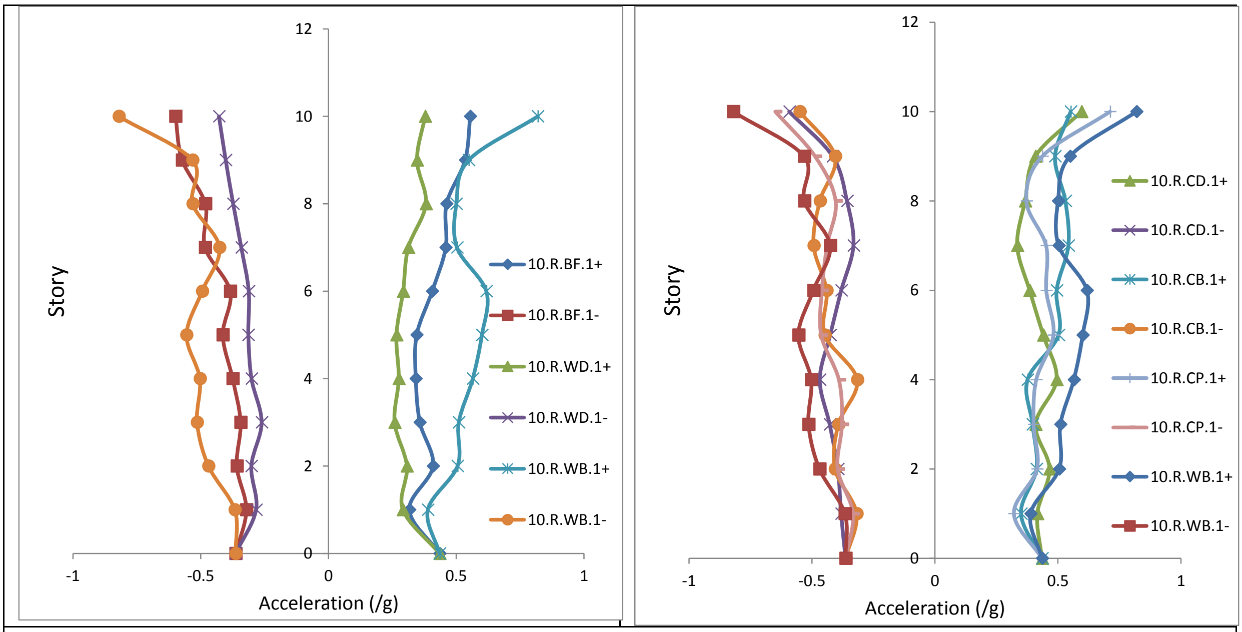


Figure 28- Average acceleration variation in height under time history analysis of three earthquakes on type 1 soil

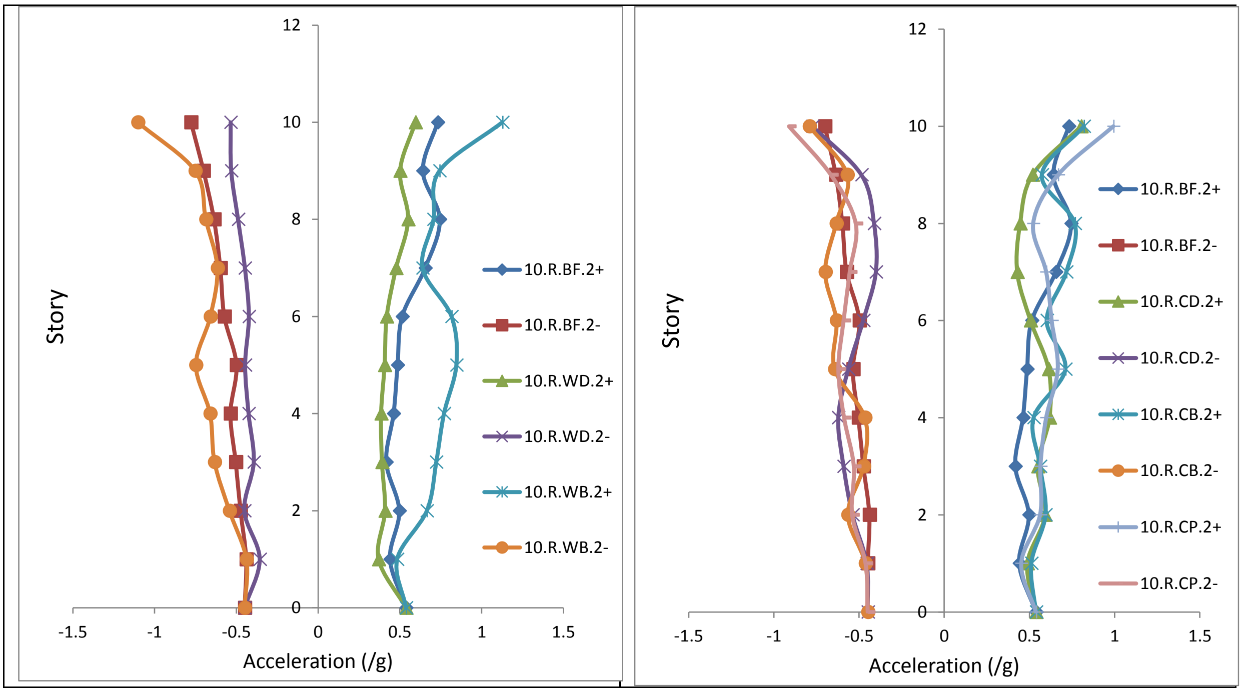


Figure 29- Average acceleration variation in height under time history analysis of three earthquakes on type 2 soil

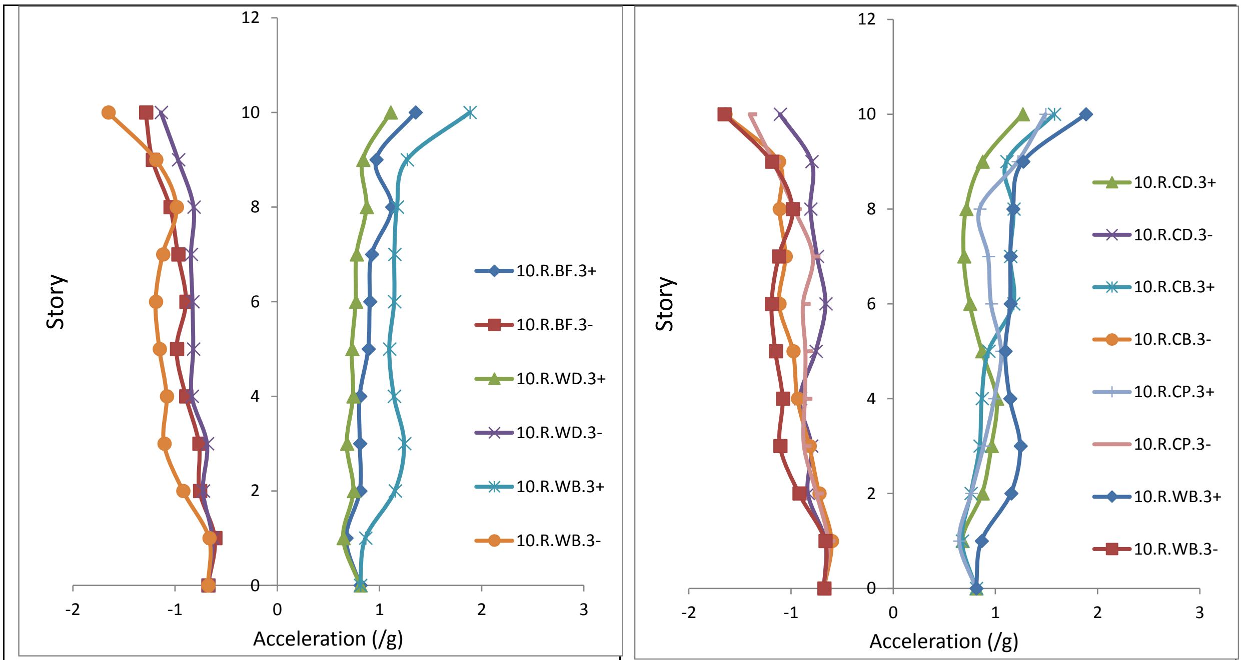


Figure 30- Average acceleration variation in height under time history analysis of three earthquakes on type 3 soil

Tables 49 to 57 show the effect of using dampers on a structural drift. They indicate that the 10.R.WB structure has reduced drift by 22%, 29%, and 13% compared to 10.R.Bf. Compared to the 10.R.WB structure, the average structural drift in certain earthquakes and soils has decreased in some cases and increased in others.

Table 49- Effect of the damper on average floor drift 10 Stories structure on type 1 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Northridge	10.R.Bf.1	0.93	---	---
	10.R.WD.1	0.64	0.68	0.77
	10.R.WB.1	0.83	0.89	1.00
	10.R.CD.1	0.59	0.63	0.71
	10.R.CB.1	0.57	0.61	0.68
	10.R.CP.1	0.71	0.76	0.85

Table 50- Effect of the damper on average floor drift 10 Stories structure on type 2 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Northridge	10.R.Bf.2	0.91	---	---
	10.R.WD.2	0.76	0.83	0.76
	10.R.WB.2	1.00	1.09	1.00

	10.R.CD.2	0.85	0.93	0.85
	10.R.CB.2	0.80	0.87	0.80
	10.R.CP.2	1.00	1.09	1.00

Table 51- Effect of the damper on average floor drift

10 Stories structure on type 3 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Northridge	10.R.Bf.3	1.38	---	---
	10.R.WD.3	1.15	0.83	0.71
	10.R.WB.3	1.60	1.15	1.00
	10.R.CD.3	1.33	0.96	0.83
	10.R.CB.3	1.71	1.23	1.06
	10.R.CP.3	1.55	1.12	0.96

Table 52- Effect of the damper on average floor drift

10 Stories structure on type 1 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Loma Prieta	10.R.Bf.1	0.66	---	---
	10.R.WD.1	0.59	0.89	0.51
	10.R.WB.1	1.14	1.72	1.00
	10.R.CD.1	0.63	0.95	0.55
	10.R.CB.1	0.74	1.12	0.64
	10.R.CP.1	0.74	1.12	0.64

Table 53- Effect of the damper on average floor drift

10 Stories structure on type 2 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Loma Prieta	10.R.Bf.2	1.97	---	---
	10.R.WD.2	0.95	0.48	0.75
	10.R.WB.2	1.26	0.63	1.00
	10.R.CD.2	0.76	0.38	0.60
	10.R.CB.2	1.16	0.58	0.92
	10.R.CP.2	1.24	0.62	0.98

Table54- Effect of the damper on average floor drift

Kobe	10.R.Bf.3	4.72	---	---
	10.R.WD.3	4.15	0.87	1.47
	10.R.WB.3	2.81	0.59	1.00
	10.R.CD.3	2.84	0.60	1.00
	10.R.CB.3	3.85	0.81	1.37
	10.R.CP.3	3.72	0.78	1.32

Figure 31 shows the structural drift on all three soil types.

10 Stories structure on type 3 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Loma Prieta	10.R.Bf.3	1.44	---	---
	10.R.WD.3	1.42	0.91	0.87
	10.R.WB.3	1.63	1.13	1.00
	10.R.CD.3	2.00	1.38	1.22
	10.R.CB.3	2.00	1.38	1.22
	10.R.CP.3	1.89	1.31	1.15

Table 55- Effect of the damper on average floor drift

10 Stories structure on type 1 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Kobe	10.R.Bf.1	6.32	---	---
	10.R.WD.1	4.92	0.77	2.46
	10.R.WB.1	2.00	0.31	1.00
	10.R.CD.1	3.35	0.53	1.67
	10.R.CB.1	2.82	0.44	1.41
	10.R.CP.1	2.08	0.32	1.04

Table 56- Effect of the damper on roof acceleration

10 Stories structure on type 2 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Kobe	10.R.Bf.2	6.08	---	---
	10.R.WD.2	5.08	0.83	1.92
	10.R.WB.2	2.64	0.43	1.00
	10.R.CD.2	2.63	0.43	1.00
	10.R.CB.2	2.51	0.41	0.95
	10.R.CP.2	2.13	0.35	0.80

Table 57- Effect of the damper on average floor drift

10 Stories structure on type 3 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br

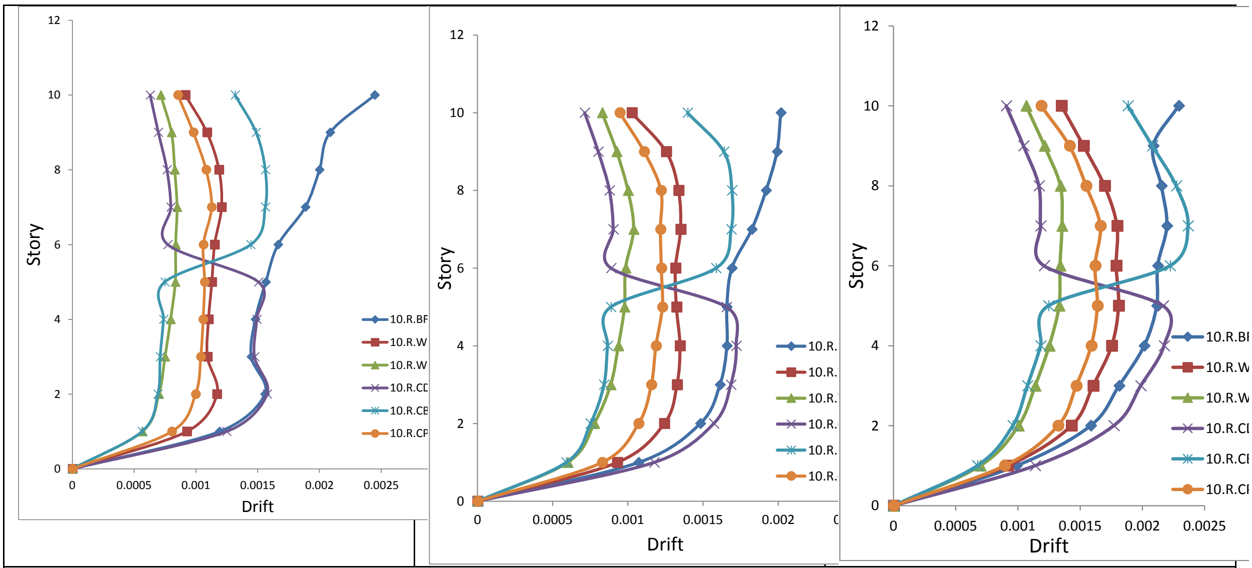


Figure 31- Diagram of relative displacement changes in height for a 10-story building under spectral analysis on type 1, 2, and 3 soils

The study by Zahraei and Cheraghi (2018) reports the average decrease in base shear, acceleration, and displacement for a 10-story damper structure on type I soil to be 20%, 14%, and 52% compared to moment frame, compared to 18%, 14% and 16% in this study. According to tables 58 to 66 and figures 32 and 33, the 15.I.WD structure has reduced the base shear by 48%, 49%, and 55% compared to the 15.I.WB structure on soil types I, II, and 3. Also, the 15.I.CD hybrid structure has reduced base shear on soil types I, II, and 3 by 36%, 43%, and 46%, the 15.I.CB structure by 23%, 28%, and 27%, and the 15.I.CP structure by 19%, 28%, and 15% compared to the 15.I.WB structure.

Table 58- Effect of the damper on base shear 1A 5-story structure on type 1 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Northridge	15.I.Bf.1	906.41	---	---
	15.I.WD.1	768.86	0.84	0.65
	15.I.WB.1	1168.69	1.28	1.00
	15.I.CD.1	567.91	0.62	0.48
	15.I.CB.1	846.50	0.93	0.72
	15.I.CP.1	674.97	0.74	0.57

Table 59- Effect of the damper on base shear 1A 5-story structure on type 2 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Northridge	15.I.Bf.2	894.75	---	---
	15.I.WD.2	814.69	0.91	0.61
	15.I.WB.2	1334.76	1.49	1.00
	15.I.CD.2	794.43	0.88	0.59
	15.I.CB.2	1022.46	1.14	0.76
	15.I.CP.2	948.82	1.06	0.71

Table 60- Effect of the damper on base shear 1A 5-story structure on type 3 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Northridge	15.I.Bf.3	1589.90	---	---
	15.I.WD.3	1288.04	0.81	0.34
	15.I.WB.3	3748.12	2.36	1.00
	15.I.CD.3	1001.25	0.63	0.26
	15.I.CB.3	1749.68	1.10	0.46
	15.I.CP.3	1681.84	1.05	0.44

Table 61- Effect of the damper on base shear 1A 5-story structure on type 1 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Loma Prieta	15.I.Bf.1	640.27	---	---
	15.I.WD.1	567.02	0.88	0.47
	15.I.WB.1	1202.21	1.87	1.00
	15.I.CD.1	780.51	1.21	0.64
	15.I.CB.1	775.68	1.18	0.64
	15.I.CP.1	959.58	1.49	0.79

Table 62- Effect of the damper on base shear 1A 5-story structure on type 2 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Loma Prieta	15.I.Bf.2	871.57	---	---
	15.I.WD.2	686.62	0.78	0.48
	15.I.WB.2	1426.72	1.63	1.00
	15.I.CD.2	1123.14	1.28	0.78
	15.I.CB.2	1169.10	1.34	0.81
	15.I.CP.2	1298.47	1.48	0.91

Table 63- Effect of the damper on base shear 1A 5-story structure on type 3 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
	15.I.Bf.3	1008.53	---	---

Loma Prieta	15.I.WD.3	996.92	0.98	0.37
	15.I.WB.3	2626.10	2.60	1.00
	15.I.CD.3	1204.16	1.19	0.45
	15.I.CB.3	1663.69	1.64	0.63
	15.I.CP.3	1891.23	1.847	0.72

Table 64- Effect of the damper on base shear
1A 5-story structure on type 1 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Kobe	15.I.Bf.1	1649.01	---	---
	15.I.WD.1	1829.77	1.10	0.43
	15.I.WB.1	4159.21	1.52	1.00
	15.I.CD.1	2457.76	1.48	0.59
	15.I.CB.1	3400.49	2.06	0.81
	15.I.CP.1	3372.42	2.04	0.81

Table 65- Effect of the damper on base shear
1A 5-story structure on type 2 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Kobe	15.I.Bf.2	1759.31	---	---
	15.I.WD.2	2321.78	1.31	0.44
	15.I.WB.2	5158.07	2.93	1.00
	15.I.CD.2	2817.28	1.60	0.54
	15.I.CB.2	3863.15	2.19	0.74
	15.I.CP.2	4155.79	2.36	0.80

Table 66- Effect of the damper on base shear
1A 5-story structure on type 3 soil

Earthquake	Sample ID	Base shear (ton)	W/B	W/Br
Kobe	15.I.Bf.3	2076.87	---	---
	15.I.WD.3	2211.98	1.06	0.64
	15.I.WB.3	3420.14	1.64	1.00
	15.I.CD.3	3143.83	1.51	0.91
	15.I.CB.3	3743.49	1.79	1.09
	15.I.CP.3	4727.46	2.27	1.38

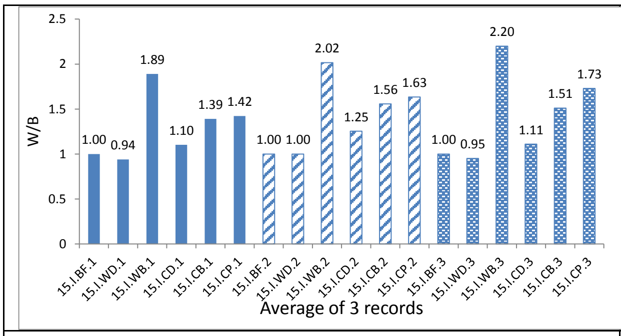


Figure 32- Diagram of the mean W/B ratio of the base shear of three earthquakes, on type 1, 2 & 3 soils

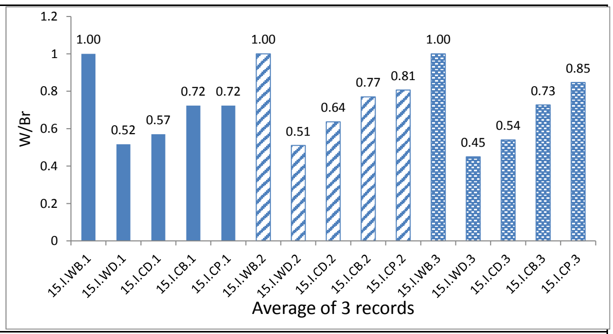


Figure 33- Diagram of the mean W/Br ratio of the base shear of three earthquakes, on type 1, 2 & 3 soils

According to tables 67 to 75 and figures 34 to 36 on the damper's effect on roof acceleration on all three soil types, the 15.I.WD structure has reduced average roof acceleration by 14%, 19%, and 26% on soil types 1 to 3 compared to the 15.I.Bf structure, and the 15.I.WD structure has done the same by 44%, 47% and 50% on all three soil types compared to the 15.I.WB structure.

Table 67- Effect of the damper on roof acceleration
1A 5-story structure on type 1 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Northridge	15.I.Bf.1	13.54	---	---
	15.I.WD.1	9.22	0.68	0.46
	15.I.WB.1	19.63	1.44	1.00
	15.I.CD.1	10.03	0.74	0.51
	15.I.CB.1	10.74	0.79	0.54
	15.I.CP.1	10.52	0.77	0.53

Table 68- Effect of damper on roof acceleration
1A 5-story structure on type 2 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Northridge	15.I.Bf.2	15.53	---	---
	15.I.WD.2	11.43	0.73	0.47
	15.I.WB.2	23.86	1.53	1.00
	15.I.CD.2	11.98	0.77	0.5
	15.I.CB.2	12.73	0.81	0.47
	15.I.CP.2	14.44	0.92	0.60

Table 69- Effect of the damper on roof acceleration
1A 5-story structure on type 3 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Northridge	15.I.Bf.3	28.88	---	---
	15.I.WD.3	19.28	0.66	0.39
	15.I.WB.3	49.41	1.71	1.00
	15.I.CD.3	18.62	0.64	0.37
	15.I.CB.3	29.44	1.01	0.59
	15.I.CP.3	25.98	0.89	0.52

Table 70- Effect of the damper on roof acceleration

1A 5-story structure on type 1 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Loma Prieta	15.I.Bf.1	10.77	---	---
	15.I.WD.1	10.15	0.94	0.62
	15.I.WB.1	16.23	1.50	1.00
	15.I.CD.1	13.00	1.20	0.80
	15.I.CB.1	11.63	1.07	0.71
	15.I.CP.1	14.36	1.33	0.88

Table 71- Effect of the damper on roof acceleration
1A 5-story structure on type 2 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Loma Prieta	15.I.Bf.2	12.95	---	---
	15.I.WD.2	12.95	1.00	0.65
	15.I.WB.2	19.83	1.53	1.00
	15.I.CD.2	16.11	1.24	0.81
	15.I.CB.2	13.77	1.06	0.69
	15.I.CP.2	15.63	1.20	0.78

Table 72- Effect of the damper on roof acceleration
1A 5-story structure on type 3 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Loma Prieta	15.I.Bf.3	24.59	---	---
	15.I.WD.3	17.91	0.72	0.53
	15.I.WB.3	33.47	1.36	1.00
	15.I.CD.3	21.72	0.88	0.64
	15.I.CB.3	22.33	0.90	0.66
	15.I.CP.3	27.18	1.10	0.81

Table 73- Effect of the damper on roof acceleration
1A 5-story structure on type 1 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Kobe	15.I.Bf.1	14.28	---	---
	15.I.WD.1	13.76	0.96	0.60
	15.I.WB.1	22.74	1.59	1.00
	15.I.CD.1	18.33	1.28	0.80
	15.I.CB.1	21.22	1.48	0.93
	15.I.CP.1	21.34	1.49	0.93

Table 74- Effect of the damper on roof acceleration
1A 5-story structure on type 2 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Kobe	15.I.Bf.2	19.03	---	---
	15.I.WD.2	13.16	0.69	0.46
	15.I.WB.2	28.22	1.48	1.00
	15.I.CD.2	20.49	1.07	0.71
	15.I.CB.2	21.42	1.17	0.78
	15.I.CP.2	26.19	1.37	0.92

Table 75- Effect of the damper on roof acceleration
1A 5-story structure on type 3 soil

Earthquake	Sample ID	Roof Accele. (m/s^2)	W/B	W/Br
Kobe	15.I.Bf.3	18.05	---	---
	15.I.WD.3	15.34	0.84	0.58
	15.I.WB.3	26.02	1.44	1.00
	15.I.CD.3	20.28	1.12	0.77
	15.I.CB.3	20.83	1.70	1.18
	15.I.CP.3	24.05	133	0.92

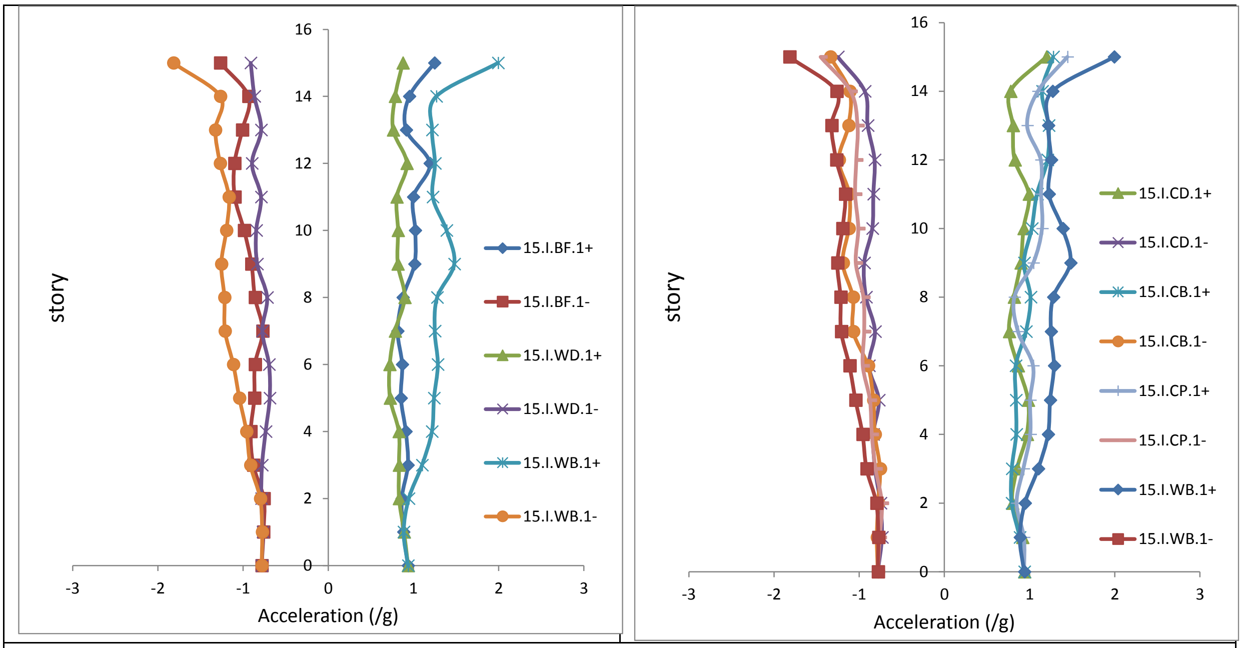


Figure 34- Average acceleration variation in height under time history analysis of three earthquakes on type 1 soil

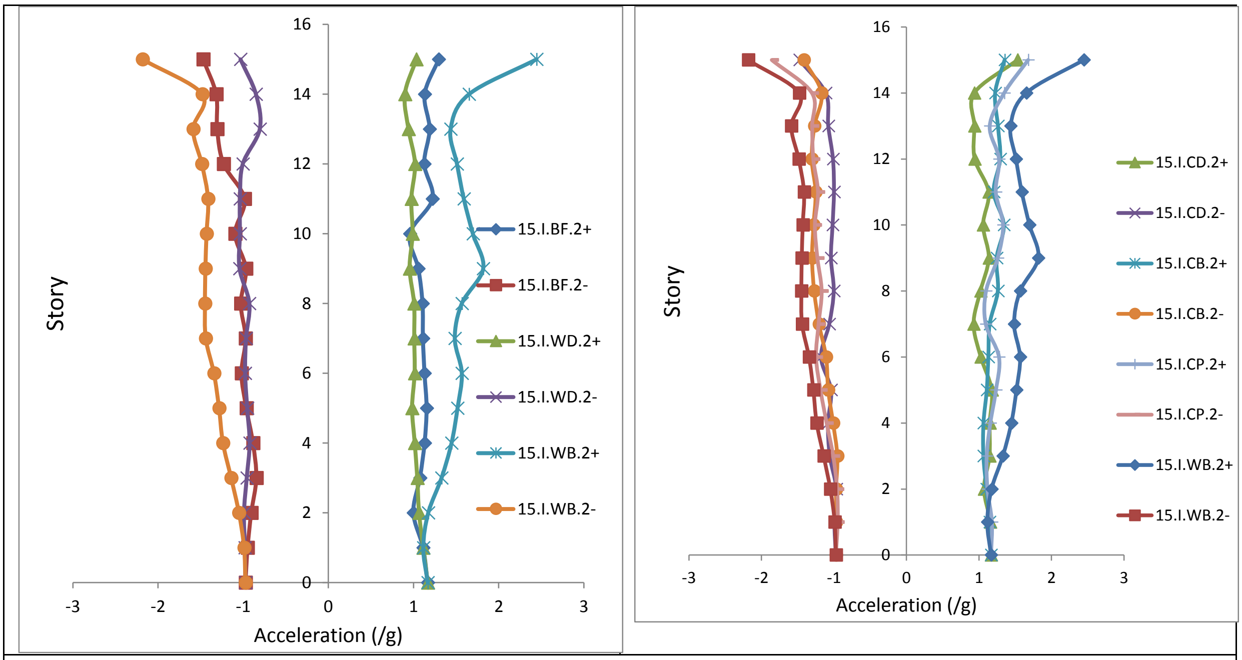


Figure 35- Average acceleration variation in height under time history analysis of three earthquakes on type 2 soil

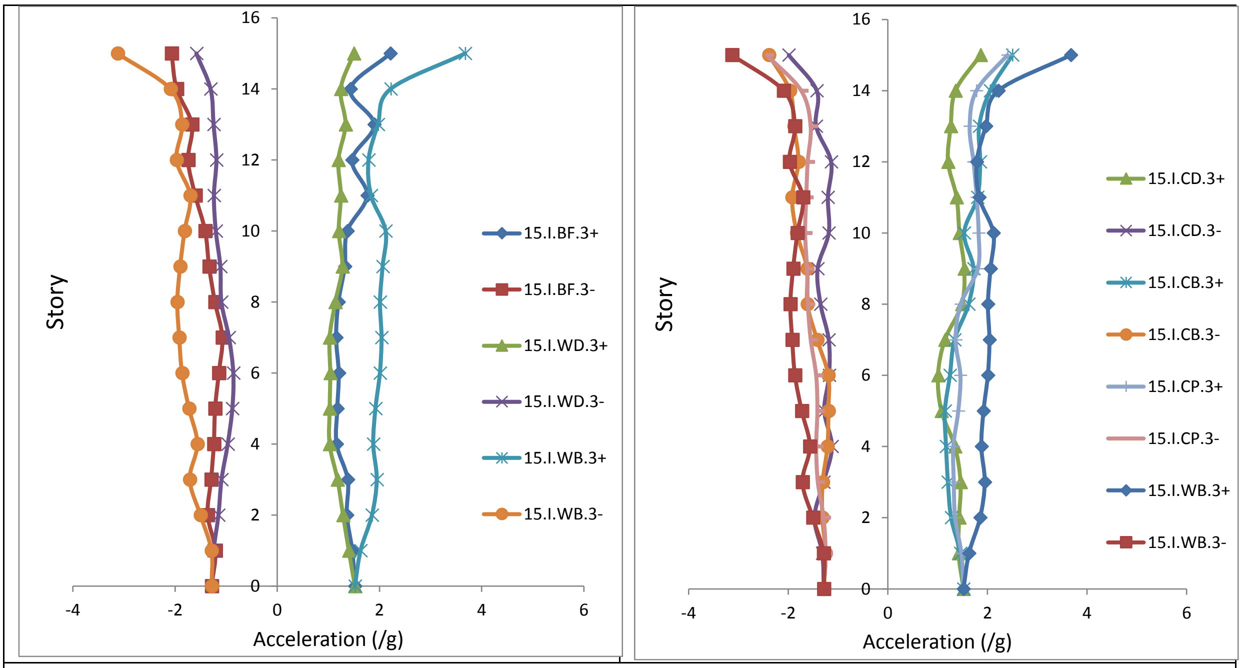


Figure 36- Average acceleration variation in height under time history analysis of three earthquakes on type 3 soil

Similar to the 5-and 10-story structures, using hybrid structures in 15-story structures reduces average roof acceleration. Compared to the 15.I.WB structure, the 15.I.CD structure has reduced roof acceleration by 33%, 30%, and 41%, the 15.I.CB structure by 35%, 27%, and 19%, and the 15.I.CP structure by 23%, 22%, and 25% on type I, II and 3 soils.

As shown in figures 34 to 36, using dampers and combining them with braces can reduce average roof acceleration in stories compared to the 15.I.WB structure.

Tables 76 to 84 show the effect of dampers on structural drift on 3type 1, 2, 3 soils. According to the tables, using the 15.I.WD structure with damper has reduced average drift by 17%, 22%, and 15% compared to the I.Bf.15 structure, and the 15.I.WD structure has reduced structural drift by 27%, 31%, and 12% compared to 15.I.WB on type I, II and 3 soils.

Table 76- Effect of the damper on average floor drift
1A 5-story structure on type 1 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Northridge	15.I.Bf.1	0.94	---	---
	15.I.WD.1	0.66	0.70	0.68
	15.I.WB.1	0.96	1.02	1.00
	15.I.CD.1	0.65	0.69	0.67
	15.I.CB.1	0.98	1.04	1.02
	15.I.CP.1	0.84	0.89	0.87

Table 77- Effect of the damper on average floor drift
1A 5-story structure on type 2 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Northridge	15.I.Bf.2	1.33	---	---
	15.I.WD.2	0.89	0.66	0.67
	15.I.WB.2	1.31	0.98	1.00
	15.I.CD.2	0.91	0.68	0.69
	15.I.CB.2	1.15	0.86	0.87
	15.I.CP.2	1.15	0.86	0.87

Table 78- Effect of the damper on average floor drift
1A 5-story structure on type 3 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Northridge	15.I.Bf.3	1.86	---	---
	15.I.WD.3	1.42	0.76	0.59
	15.I.WB.3	2.38	1.27	1.00
	15.I.CD.3	1.17	0.62	0.49
	15.I.CB.3	1.92	1.03	0.80
	15.I.CP.3	1.84	0.98	0.77

Table 79- Effect of the damper on average floor drift
1A 5-story structure on type 1 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Loma Prieta	15.I.Bf.1	1.05	---	---
	15.I.WD.1	0.82	0.78	0.77
	15.I.WB.1	1.06	1.01	1.00
	15.I.CD.1	0.83	0.79	0.78
	15.I.CB.1	1.03	0.98	0.97
	15.I.CP.1	1.01	0.96	0.95s

Table 80- Effect of the damper on average floor drift
1A 5-story structure on type 2 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Loma Prieta	15.I.Bf.2	1.53	---	---
	15.I.WD.2	1.0	0.65	0.72
	15.I.WB.2	1.37	0.89	1.00
	15.I.CD.2	1.13	0.73	0.82
	15.I.CB.2	1.27	0.83	0.92
	15.I.CP.2	1.34	0.87	0.97

Table 81- Effect of the damper on average floor drift
1A 5-story structure on type 3 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Loma Prieta	15.I.Bf.3	2.01	---	---
	15.I.WD.3	1.67	0.83	0.74
	15.I.WB.3	2.23	1.10	1.00
	15.I.CD.3	1.55	0.77	0.69
	15.I.CB.3	2.04	1.01	0.91
	15.I.CP.3	2.10	1.04	0.94

Table 82- Effect of the damper on average floor drift
1A 5-story structure on type 1 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Kobe	15.I.Bf.1	4.56	---	---
	15.I.WD.1	4.56	1.00	0.75
	15.I.WB.1	6.07	1.33	1.00
	15.I.CD.1	5.47	1.19	0.90
	15.I.CB.1	7.34	1.60	1.20
	15.I.CP.1	7.16	1.57	1.17

Table 83- Effect of the damper on roof acceleration
1A 5-story structure on type 2 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Kobe	15.I.Bf.2	5.56	---	---
	15.I.WD.2	5.74	1.03	0.67
	15.I.WB.2	8.45	1.51	1.00
	15.I.CD.2	6.62	1.19	0.78
	15.I.CB.2	8.82	1.58	1.04
	15.I.CP.2	8.67	1.55	1.02

Table 84- Effect of the damper on average floor drift
1A 5-story structure on type 33 soil

Earthquake	Sample ID	Average drift (cm)	W/B	W/Br
Kobe	15.I.Bf.3	5.20	---	
	15.I.WD.3	5.06	1.31	
	15.I.WB.3	3.86	1.00	
	15.I.CD.3	5.56	1.44	
	15.I.CB.3	6..57	1.70	
	15.I.CP.3	6.98	1.80	

According to figure 37, the structural drift of 15.I.WD and 15.I.CP is almost equal on type 1 and 2 soils, and only stories 2 to 4 are different on soil 3.

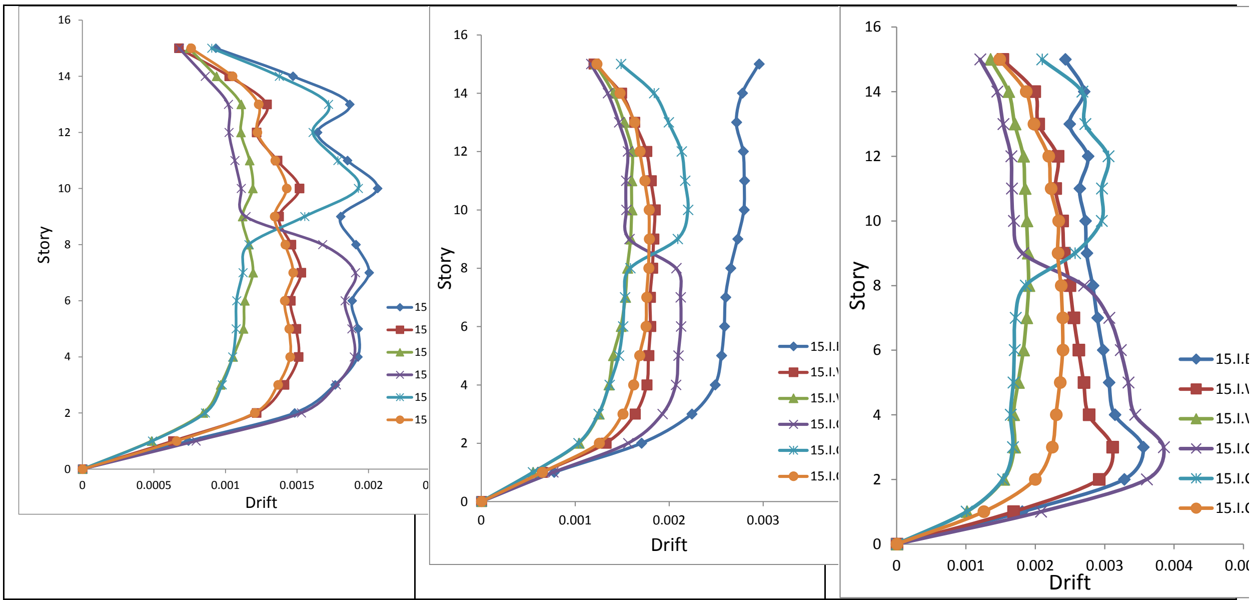


Figure 37- Diagram of relative displacement changes in height for a 10-story building under spectral analysis on type 1, 2, and 3 soils

With regards to the 15-story structure on type I soil, Zahrai and Cheraghi (2018) indicate that average base shear has increased by 4% and roof acceleration and displacement are reduced by 11% and 19%. The average base shear, acceleration, and displacement are reduced by 6%, 14%, and 16% in this study, which is marginally different from the results of Zahraei and Cheraghi (2018).

Figure 38 is the hysteresis curve for the pipe-in-pipe damper (lab sample 1) under the Loma Prieta, Northridge, and Kobe earthquake records in the 15.I.WD structure.

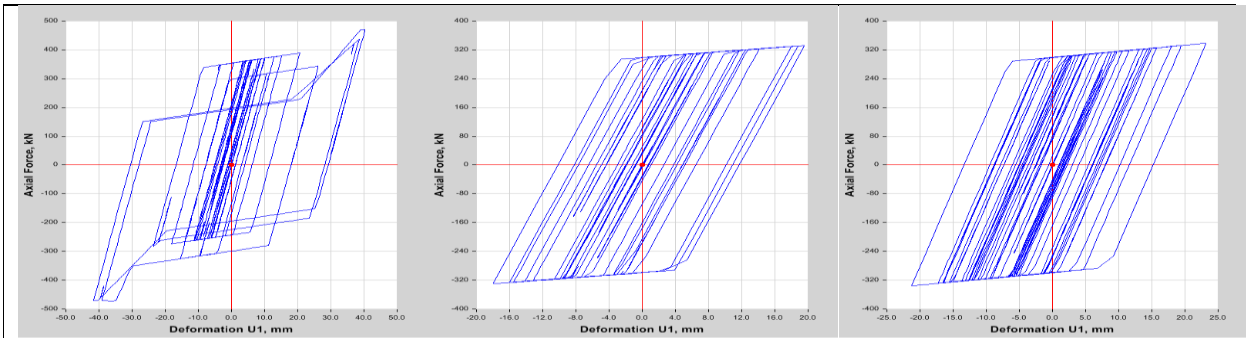


Fig. 38- Pipe-in-pipe damper hysteresis diagram in structure 15.I.WD.1, from left to right, under the Kobe, Northridge, and Loma Prieta earthquakes, respectively.

As shown, only the exterior pipe is activated to dissipate the earthquake's load in the Loma Prieta and Northridge earthquakes, which is due to the displacement on two sides of the damper, and the force applied to the damper is low enough to not activate the internal pipe. In the Kobe earthquake, the exterior pipe has yielded and its capacity is fully utilized before the internal pipe is activated. The two-story behavior of the pipe-in-pipe damper is clearly shown.

1- Conclusion

The present study investigated the effect of multistory piped dampers alone and in combination with braces in 5-, 10-, and 15-story 3D steel structures on 3type 1, 2, 3 soils in SAP 2000 and nonlinear modal time history analysis.

The most important results are as follows:

1. Using pipe-in-pipe dampers in 5-story steel structures (5.R.WD) reduces average base shear by 31%, 27%, and 45%, and roof acceleration by 31%, 39%, and 39% on all three soil types compared to the dual moment frame and the special

concentric steel brace (5.R.WB) structures.

2. Hybrid structures in 5-story structures reduce the base shear and roof acceleration compared to the R.WB.5 structure. The decrease differs according to the damper, brace combination, and soil type. The average base shear of the 5.R.CD structure decreased by 23%, 8%, and 36%, and roof acceleration has decreased by 24%, 32%, and 38% compared to the 5.R.WB structure in type 1, 2, and 3 soils.
3. The hybrid 5.R.CB structure reduced base shear by 23%, 18%, and 35% and roof acceleration by 18%, 20%, and 17% compared to the 5.R.WB structure on type 1, 2, and 3 soils.
4. The 5.R.CP structure reduced base shear by 14%, 17%, and 25% and acceleration by 12%, 18%, and 20% compared to the 5.R.WB structure on type 1, 2, and 3 soils.
5. The 10.R.WD structure on 10-story steel structures reduced base shear by 52%, 47%, and 51%, and average acceleration by 36%, 42%, and 35% compared to the 10.R.WB structure on type 1, 2, and 3 soils.
6. As in 5-story structures, using hybrid structures in 10-story steel structures reduced base shear and acceleration compared to braced structures, and the 10.R.CD structure decreased base shear by 29%, 35%, and 36% and acceleration by 29%, 27%, and 32% on type 1, 2 and 3 soils.
7. The 10.R.CB structure reduced average base shear by 36%, 33%, and 13%, and average acceleration by 30%, 25%, and 12% compared to the 10.R.WB structure on type 1, 2, and 3 soils.
8. The average reduction in shear response and acceleration was slightly lower in 10.R.CP than in the 10-story 10.R.WB structure, and the average base shear was reduced by 29%, 22%, and 12%, and average acceleration was reduced by 15%, 9%, and 22% on type 1, 2 and 3 soils.
9. According to the results, it is recommended to use hybrid systems instead of dual systems in 10-story structures. The optimal approach is to use pipe-in-pipe dampers in lower stories and braces in upper stories.
10. According to the results of the inconsistent 15-story structures, using structures with pipe-in-pipe dampers reduces average base shear by 48%, 49%, and 55%, acceleration by 44%, 47%, and 50%, and average drift by 17%, 22% and 15% on type 1, 2 and 3 soils compared to the dual moment frame structure and the special concentric brace.
11. According to the results, it is recommended to use hybrid systems instead of dual systems in 15-story structures. The 15.I.CD structure reduces average base shear by 43%, 36% and 46%, acceleration by 30%, 33% and 41%, and average drift by 27%, 31% and 12% compared to the 15.I.WB structure on type 1, 2, and 3 soils.
12. The 15.I.CP structure reduced average shear by 28%, 23%, and 27%, and acceleration by 27%, 35%, and 19% compared to the 15.I.WB structure on type 1, 2, and 3 soils.
13. Additionally, the 15.I.CP structure reduced average base shear by 28%, 19%, and 15%, and acceleration by 22%, 23%, and 25% compared to the 15.I.WB structure on type 1, 2, and 3 soils.
14. The best hybrid structures according to the results and the average base shear, acceleration, and drift were CB, CD, and CP. The aforementioned hybrid structures are suitable substitutes for the traditional bracing system.
15. Among the 5-, 10-, and 15-story hybrid structures on all 3 soil types, the 15.I.CP had the highest reduction in average base shear, acceleration, and drift compared to the 15.I.WB structure at 33% for type 3 soil. After that, the 10-story structure reduced average base shear, acceleration, and drift by 27% on type 2 soil and the 5-story structure by 27% on type 3 soil.
16. After the hybrid CP structure, the CB structure had the highest response reduction in average shear, acceleration, and drift compared to the WB structure. Among structures, the 10-story structure on type 2 soil had the highest reduction in average shear, acceleration, and drift by 26%. After that, the 15-story structure reduced average responses by 22% on type 2 soil, and the 5-story structure by 20% on type 3 soil.
17. Using the hybrid CP structure instead of WB will reduce average base shear, acceleration, and drift in 10-story structures and type 1 soil (20%), 15-story structures and type 1 soil (17%), and 5-story structures and type 3 soil (15%)

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