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Study on the Effect of Distribution of Viscous Damper for Steel Frame Structure

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Study on the Effect of Distribution of Viscous Damper for Steel Frame Structure

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Abstract. The main objective of the current study is to reduce the structural response after a steel ten floors building was exposed to earthquakes by using viscous fluid dampers. The building response is studied for two conditions in which the first is without damper and the second by using damper and for tow conditions four seismic excitement earthquakes were selected in this study. Parametric study is employed which include the type of damper, the vertical and horizontal distribution of d, the engineering properties of finder, and the support effect of building. The software used for the analysis is SAP2000 v14 using linear time history analysis. The dampers are installed in the outer frames of the structure and in six different shapes (single one, single two, cross one, cross two, chevron one, chevron two bay damper) and compare between them and choose the best shape, which is a cross two bay damper, which noted a high decrease in seismic response. Then, the number of dampers in the structure is reduced by placing it in five floors, which achieves a decrease in the seismic response as well as a decrease in the cost. The parameters that are used to define the seismic response are the maximum displacement, drift ratio and base shear.

Keyword: Passive energy dissipation, Viscous fluid dampers, Linear time history analysis, Max displacement, Drift ratio, Base shear.

1. Introduction

The concept of damping within a structural system can have different meanings to the various engineering disciplines. To the civil engineer, damping may mean only a reference note on a seismic or wind spectral plot so many new technologies have been deployed to control or change the dynamic behavior of building structures through the use of specific devices and details for a safe seismic design. These devices are widely installed around the world on different structures [1]. The passive control system is one of the best devices used in civil engineering and it does not need an external power source, but it works without any source. This system works when exposed to an earthquake or high winds to efficiently dissipate vibrational energy and there are two ways to achieve this, the first is through a complementary oscillator that absorbs infrastructure vibrations and transfers energy between two or more vibratory modes of construction either. The second method works to convert kinetic energy into heat such as deforming solid materials flexible liquids, metal production, or friction slice execution. Examples of such systems are base isolation, tune liquid damper, and tune mass damper [2].

2. Viscous fluid damper

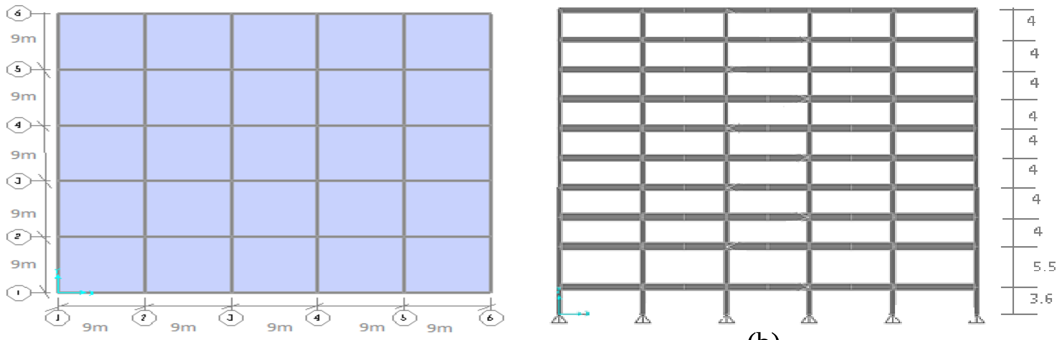
In the 1990s, there was a hypothetical explosion in the use of a new high-tech structural element that dissipated energy with a viscous damper. This type of damping is called synthetic viscous damping or manufactured damping simply because the damper is manufactured in the factory according to stringent quality control standards. The principle of action of viscous fluids is the flow of liquid through nozzles. The stainless-steel piston moves through chambers filled with silicone oil. Silicone oil is inert, non-flammable, non-toxic, and stable for very long periods. The pressure difference between the two chambers causes the silicone oil to flow through a hole in the piston head, and the seismic energy is converted into heat, which is dissipated into the atmosphere [3]. The relationship between force and speed can be described for this type of retarder

$$F = C.V^{\alpha} \qquad \text{.....(1)}$$

Where F is damping force, V is damper velocity, C is the damping coefficient and α is constant damping which it between 0.3 and 1[3]. Soong and Dargush, 1997 [4], studied non-linear viscous dampers that do not need any replacement or repair and are not affected by temperature or stress frequency and remain largely in place when the earthquake occurred. When the dampers are installed on the support of steel elements, hybrid systems viscously damped braced frames (VDBF) are formed. These reduce the dynamic responses from the earthquake and very limited damage with inter-storey drifts between floors and not increase the basic shear as is the case when using traditional reinforcement systems. Uriz and Whittaker, 2001 [5], adopted the FEMA 273 [6] guideline to support a 3-storey steel frame with linear viscous dampers. Use an increase in dampers to obtain a 40% increase in global damping. Because of this, they obtained a significant decrease in the displacement by a factor of two greater compared to the case of non-use of dampers when analyzing the non-linear response history. Colleagues and Behravesh, 2011 [7], evaluated the effect of viscous damper on steel frames under seismic with 3, 6 and 9 floors, respectively. In this way, both structures were examined, once with a damper and without a damper. Structural modeling was implemented using the SAP2000 program. The effect of the seismic on the structure is observed, Once the transformation occurs. The results show the lateral displacement class in the baguette frames has been reduced with more categories, due to the use of viscous dampers. lateral displacement was reduced to about 54% in longer structure.

3. Structural modeling

In this study, steel regular building was used, and the building was supplied with fluid viscous dampers of different and various forms when exposed to different earthquakes. The building used is a ten-story steel frame building (G+9), with five bays of (9m) in X-and Y- direction. The size of the building in plan is (45 m *45 m). The height of the ground floor is (3.6 m) and for the first floor is (5.5m) and the other stories height is (4 m), giving a total height of (41.1 m). All dimensions center to center. A (140 mm) thick concrete deck slab is used for each building resting on the steel beams. Beam and slab structural system is supported on the steel columns. The mass of the structure includes the applied live and dead load in addition to the self-weight. For each member, the mass of the element is divided equally among the nodes, and the mass of the element must be concentrated in the nodes.

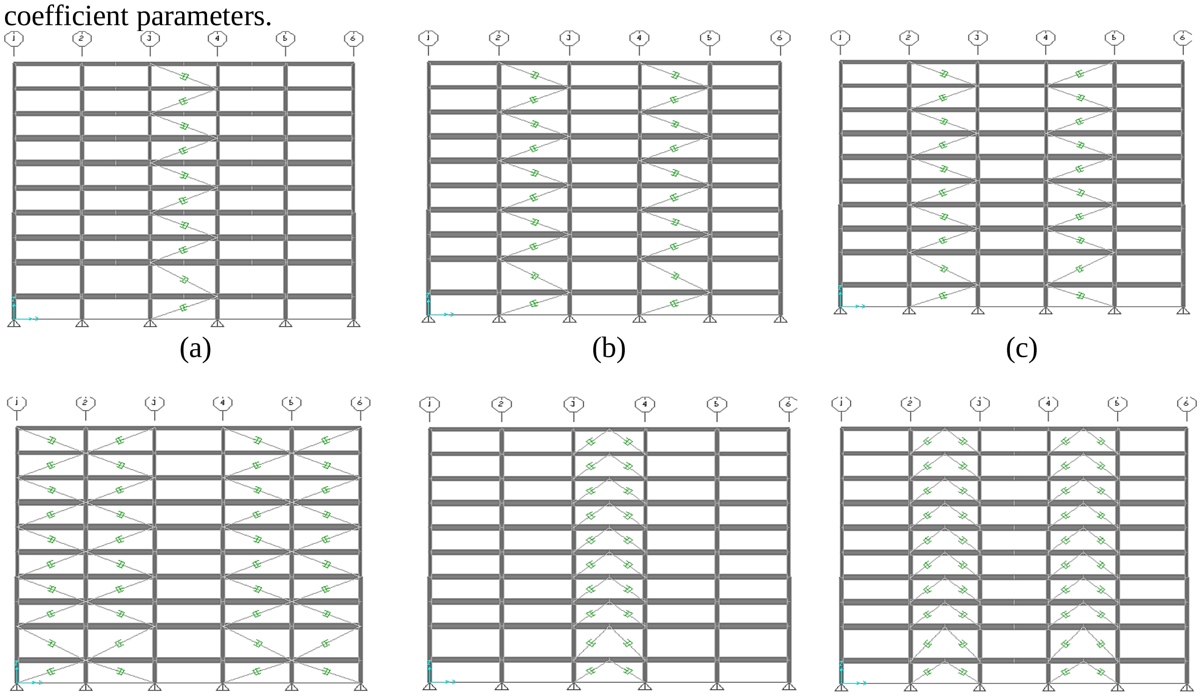


(a) (b)

Figure 1. Schematic of steel building. (a) horizontal. (b) vertical.

3.1. The study plan

The study plan concerned about finding the best damper selection by considering the main parameters influences the structural behavior that include the support condition, the earthquake type, distribution of viscous damper in both vertical and horizontal direction, method of analysis, and finally the damper coefficient parameters.



(a) (b) (c)

(d) (e) (f)

Figure 2. Various forms of dampers placement. (a) single one bay damper. (b) single two bay damper. (c) cross one bay damper. (d) cross two bay damper. (e) chevron one bay damper. (f) chevron two bay damper.

3.2. Applied loads

Live load includes any weight that is added to the structure, whether attached to it or imposed on it (appliances, equipment, people, etc.). According to the IS 875-2 (1987) [8], the roof and floor live load is taken as (1.5 kN/m²) and (3 kN/m²), respectively. When the imposed uniformly distributed floor load is less than or equal to (3 kN/m²) according to the IS 1893-1 (2002) [9], all dead loads are used for seismic analysis in addition to 25% of the live load. According to the IS 875-1 (1987) [10], the roof and floor dead load is taken as (4 kN/m²) and (2 kN/m²), respectively. The dead load includes the self –weight and also all types of equipment, materials, and components that remain constant throughout the life of the structure.

3.3. Earthquake used

Using the acceleration records which representing the expected earthquake a specified duration. All the studied models are El Centro, California in 1940 (magnitude7.1) which is applied for the X direction at the site represent the North-South component of the ground motion [11]. Also, the structure is subjected to other earthquakes obtained through the matching method by the algorithm method proposed by Abrahamson 1992 [12], and Hancock et al. 2006 [13] by the computer software program SeismoMatch 2016 which is an application capable of adjusting earthquake accelerogram by adding waves to the initial time series. Nine records resulted from this matching, and all three were matched with one of the design spectra for Uniform Building Code (UBC 97), International Building Code (IBC 2012) and Iraqi Seismic Code (ISC 2017), one of every three records was used [14].

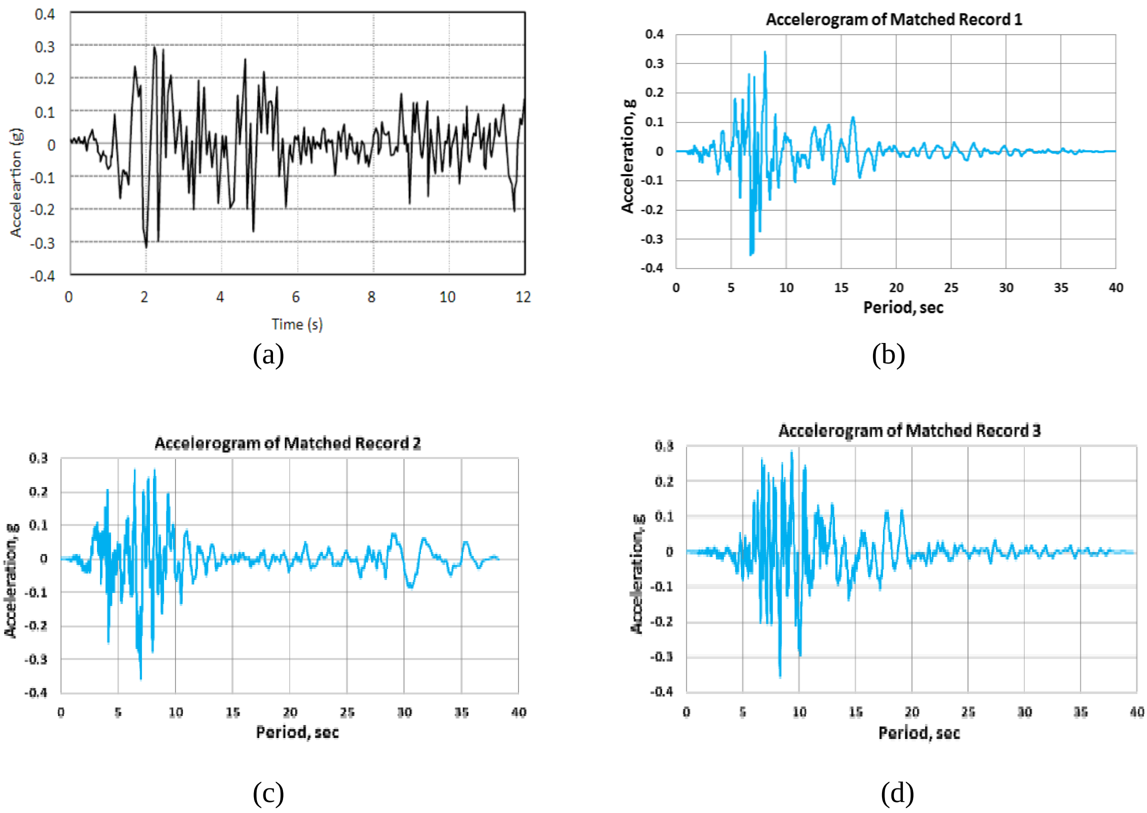


Figure 3. Time-The four earthquakes used in this study. (a) Elcentro. (b) R1.AT2. (c) R2.AT2. (d) R3.AT2

3.4. Member sizes

Indian Standard IS 800: 2007 [15], is used in the design of steel structure. The column and beam section sizes used for the building are shown in Table (1).

Table 1. Column and beam sizes along the buildings

Story	Beam	Outer Column	Inner
1	W36*160	W14*370	W14*500
2	W36*160	W14*370	W14*500
3	W36*160	W14*370	W14*455
4	W36*135	W14*370	W14*455
5	W36*135	W14*233	W14*370
6	W36*135	W14*233	W14*370

7	W36*135	W14*257	W14*233
8	W30*99	W14*257	W14*233
9	W27*84	W14*233	W14*257
10	W27*94	W14*233	W14*257

3.5. Material properties

Reinforced concrete is used for slabs. The size of the mesh that was used is 1 m. Steel is used for beams and columns. The properties of steel and reinforced concrete are described in Tables (2) and (3).

Table 2. Steel properties

Item	Description	Value	Unit
ν_s	Poisson's ratio	0.3	-
E_s	Modulus of elasticity	200000	N/mm^2
ρ_s	Density	77	kN/m^3
f_u	Ultimate tensile stress	400	N/mm^2
f_y	Minimum yield stress	249	N/mm^2

Table 3. Concrete properties

Item	Description	Value	Unit
ν_c	Poisson's ratio	0.2	-
E_c	Modulus of elasticity	25000	N/mm^2
ρ_c	Density	24	kN/m^3
f'_c	Cylinder compression strength	27.5	N/mm^2
fy	Yield stress of steel reinforcement	420	N/mm^2

4. Results and discussion

Linear time history analysis is used to study the various side effects resulting from earthquake movement. The analysis of the history of the dynamic response is the result of when the base of a structure is exposed at a specific time to a ground movement, the resulting increase each time is called "time history analysis".

4.1. Dynamic analysis without dampers

The building was designed on the basis that the support is pinned. The results of the maximum displacement and drift ratio of the building without dampers are illustrated in Table (4). The max displacement of the building without damping ranged from 865.16 mm recorded by the earthquake Matched R2.AT2 to 114 mm recorded by the earthquake El centro. It is considered a very high displacement compared to the height of the building.

Table 4. The maximum displacement and drift ratio for free case

Height	Max displacement (mm)				Inter-storey drift ratio			
	Elcentro	R1.AT2	R2.AT2	R3.AT2	Elcentro	R1.AT2	R2.AT2	R3.AT2
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.6	114.00	147.47	174.95	223.76	3.17	4.10	4.86	6.22
9.1	217.90	276.50	334.08	419.01	1.89	2.35	2.89	3.55
13.1	265.00	330.59	405.96	500.32	1.18	1.35	1.80	2.00
17.1	309.10	375.95	472.41	567.78	1.10	1.13	1.66	1.69
21.1	362.74	424.66	552.47	638.70	1.34	1.22	2.00	1.77
25.1	410.10	462.51	622.25	691.08	1.18	0.95	1.74	1.31

29.1	477.32	514.26	718.16	752.74	1.68	1.29	2.40	1.54
33.1	529.61	566.20	794.44	802.79	1.31	1.30	1.91	1.25
37.1	562.65	605.86	842.30	841.65	0.83	1.00	1.20	0.97
41.1	578.42	626.11	865.16	863.15	0.39	0.51	0.57	0.54

The drift ratio between floors is evaluated by subtracting the displacements from the upper and lower level of the story of any structure that divides it by the height of the story. To determine the level of performance of the structure with FEMA-356, Table (5) shows the permissible inter-story drift ratio. For examples, the value of the inter-story drift ratio for normal case is within (.039-6.22) and it exceeds 2.5%, as in the table, the building becomes vulnerable to collapse.

Table 5. Permissible inter-storey drift ratio [16]

Immediate Occupancy (IO)	Life Safety (LS)	Collapse Prevention (CP)
0.7	2.5%	5%

4.2 Uniform Dampers Distribution

Dampers are placed in six different layout or configuration as shown in Figure (2) and choosing the best structural behavior and economic choice. Table (6) shows the coefficient in addition to damping exponent is equal to 1 that are entered to the SAP 2000 software. The goal was that the sum of the value of the damping coefficient and stiffness of each floor is equal for different forms of distribution and comparing those shapes and choosing the best. Fig. (4) and (5) shows the maximum displacement and drift ratio of the different shapes. In all displacement and drift ratio figures are read from the left main axis, except for earthquake R3.AT2, it is read from the right secondary axis.

Fig.4 and 5 give three important indications which is the one bay damper dingle and two bay damper have the same trend for both items maximum displacements and drift ratio regardless of damper type and the second indication is the chevron one and two bay dampers have a different response for height above 17.1 m (draft ratio began to increasing until height 29.1 m then degreasing) than other damper types (single bay, cross bay) in spite of earthquake pattern. These results can be attributes to the geometric configuration of chevron damper which change the stiffness of whole building than the other damper types. The last matter related to the effect of fixed support condition which can be seen from the large draft ratios for all studied cases in the first floor and then reduced for other floors.

Table 6. Parameters of the dampers for the building

State	Damping coefficient (kN*sec/m)	Stiffness coefficient (kN/m)	Damper Number per each story	Damping coefficient summation per each story	Stiffness coefficient summation per each story
Single One Bay Damper	350	2000000	4	1400	8000000
Single Two Bay Damper	175	1000000	8	1400	8000000
Cross One Bay Damper	175	1000000	8	1400	8000000
Cross Two Bay Damper	87.5	500000	16	1400	8000000
Chevron One Bay Damper	175	1000000	8	1400	8000000
Chevron Two Bay Damper	87.5	500000	16	1400	8000000

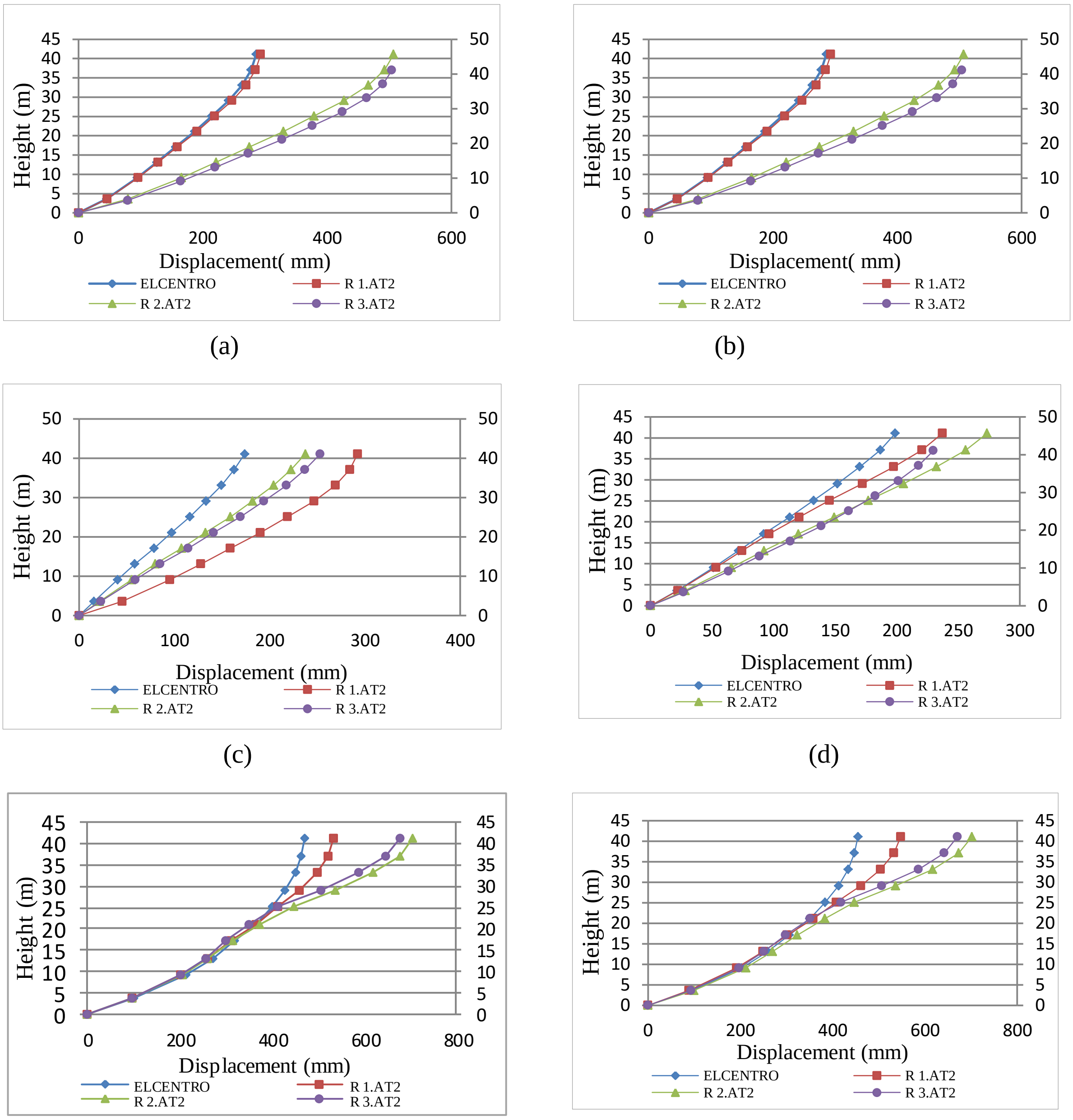


Figure 4. Height-Max displacement for the building. (a) single one bay damper (b)single two bay damper (c) cross one bay damper (d) cross two bay damper (e)chevron one bay damper (f)chevron two bay damper

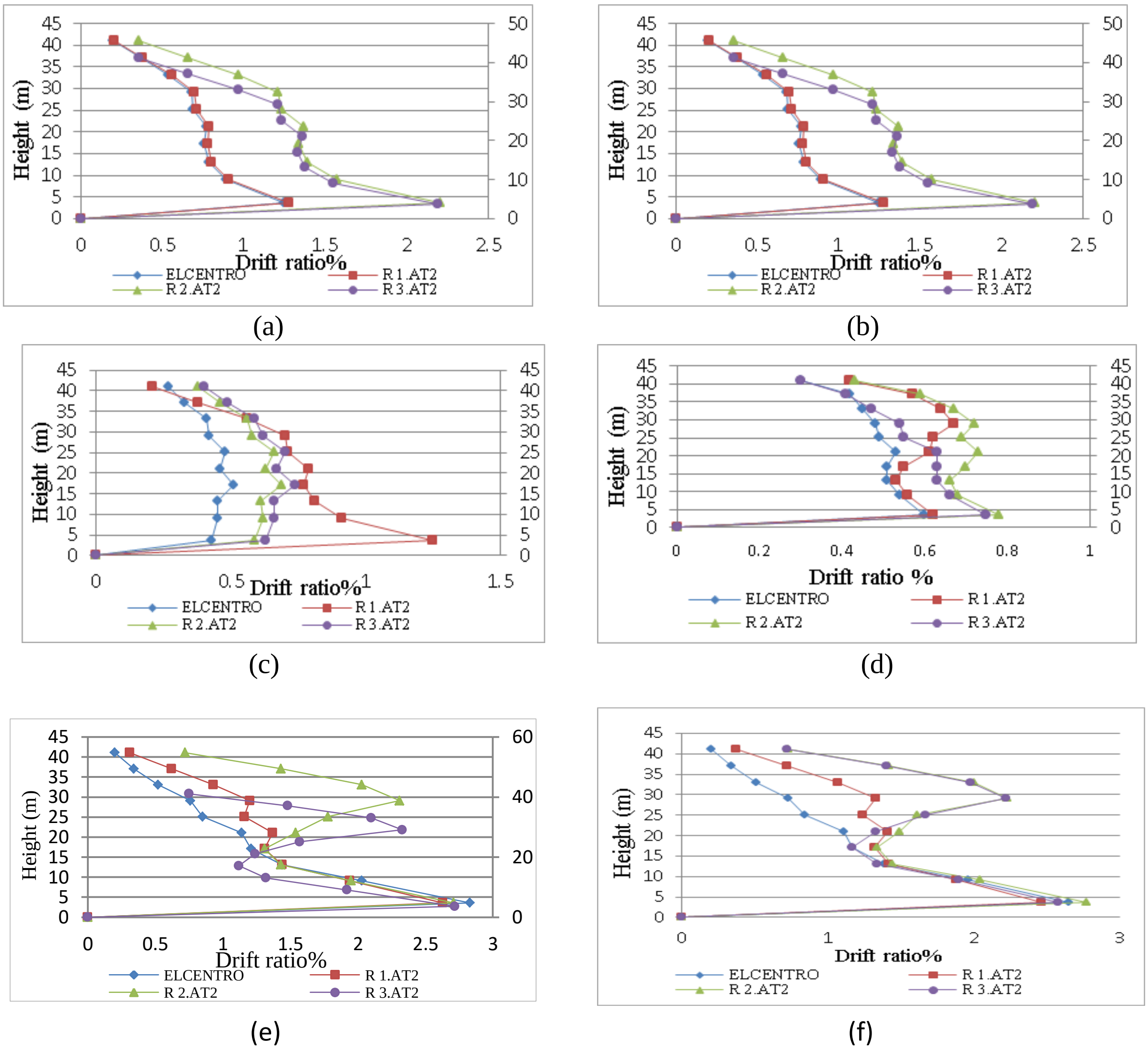


Figure 5. Height-Inter-story drift ratio for the building. (a) single one bay damper (b)single two bay damper (c) cross one bay damper (d) cross two bay damper (e)chevron one bay damper (f)chevron two bay damper

It is clear from figures above that the single damper has the same effect on the drift ratio regardless in the earthquake type but for cross two bay damper produce leaser magnitude of drift ratio in addition to change the pather of drift ratio along the building height for each earthquake type. The same effect is noticed on the chevron damper which chyed the structure response in two bay dampers then the one bay damper. The response of this two-bay effect can be attributed to the gradual transition of forces from the base of the building to the top of other floors. When changing the value of the damping coefficient and stiffness more than once for the same building, it was found that the best shape is the cross two bay damper, which has the least displacement than all other shapes, as its max displacement reaches 273.43 mm at Matched R2.AT2 earthquake, while the inter-story drift ratio is not exceeds the limits permitted by ASCE-10, which assumes that the percentage does not exceed 2.5%. Due to seismic ground motion, maximum lateral force (base shear) occurs at the base of the structure that will depend on soil conditions, level of ductility, a fundamental period of structure vibration, and many different factors. Therefore, the more the building is safe against collapse by using viscous dampers that resist the earthquake, the value of the base shear will decrease and this is observed through the Fig.(6) which shows the base shear of the normal case for the building and (7) when using dampers.

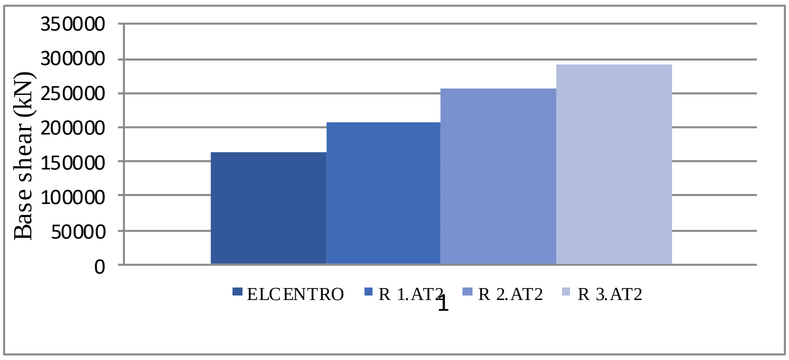
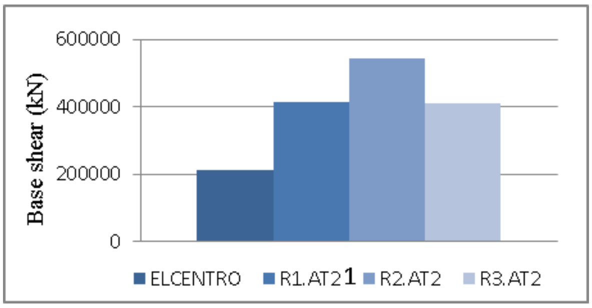
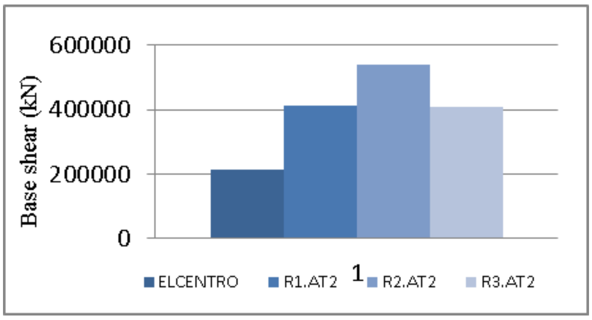


Figure 6. Height-Max base shear for the building without viscous damper



(a)



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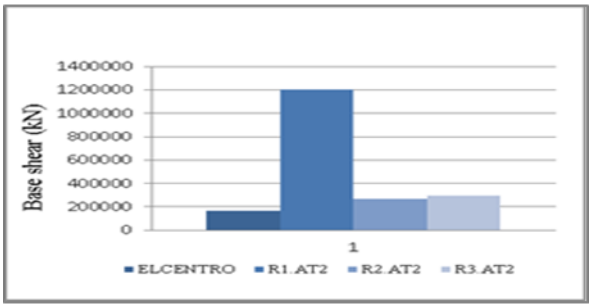

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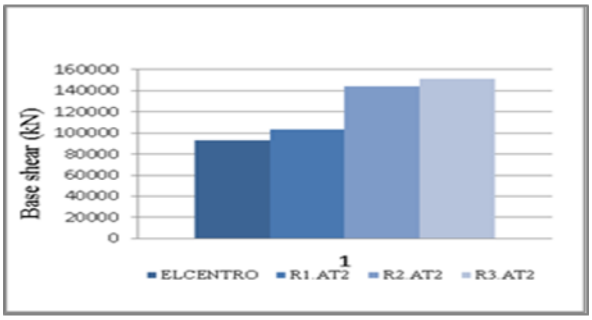

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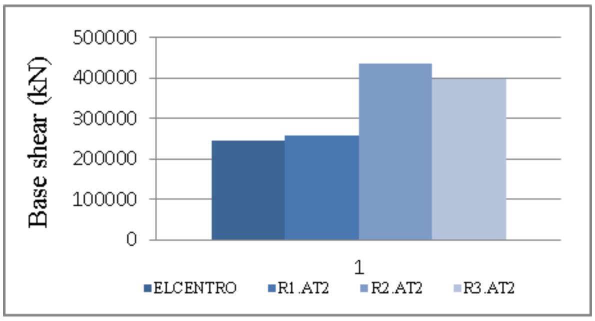

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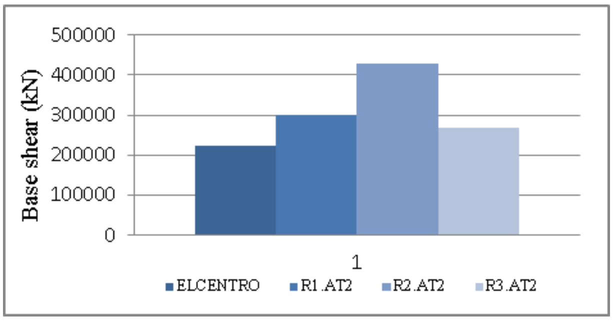
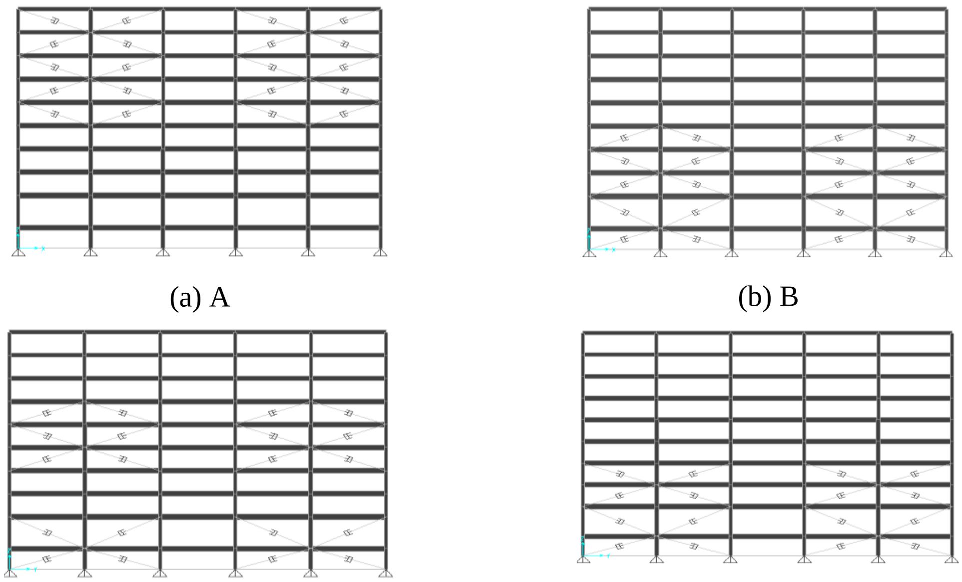


(f)

Figure 7. Height-Max base shear for damper building. (a) single one bay damper (b)single two bay damper (c) cross one bay damper (d) cross two bay damper (e)chevron one bay damper (f)chevron two bay damper

4.3. Vertical damper distribution

An urgent and necessary need arises by reducing the number of dampers in the building in a manner that does not conflict with the construction side, which achieves economic benefit. And because it is difficult to know the sufficient number of dampers for the building without being damaged, so many attempts have been made to distribute the damper on different floors and choosing the best one with doubling the value of the damping coefficient and stiffness (damping coefficient= 175 kN-sec/m, stiffness coefficient = 1000000 kN/m). Figure (8) illustrated distribution dampers for cross two bay damper when placing dampers on a number of floors.



(a) A (b) B (c) C (d) D

Figure 8. Distribution dampers in different floors. (a) A. (b) B. (c) C. (d) D.

Through the figure (8), the idea was to search for the best specifications and distribution of viscous dampers from the economic and construction point of view, the smallest number of dampers allowed and make the building safe is when it is placed in only five floors. When dampers are placed above five floors, it is increased safety, and when placed in less than five floors it is subject to collapse. With different distributions of dampers until the investigation is carried out to the best condition, which is when dampers are placed in the lower five floors with specifications (shape B) (damping coefficient= 175 (kN-sec/m), stiffness coefficient = 1000000 kN/m).

Table 7. Cross two bay damper in different floors

shape	Damper total number	The number of damped floors	Max drift ratio %	Position of max drift ratio
A	80	5	3.07	tenth floor
B	80	5	2.04	eighth floor
C	80	5	3.64	eighth floor
D	64	4	3.60	eighth floor

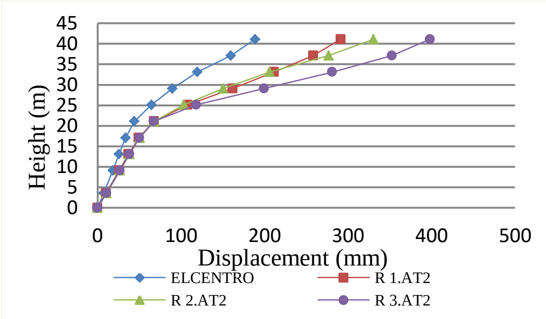


Figure 9. Height- Max displacement when placing damper lower five flower

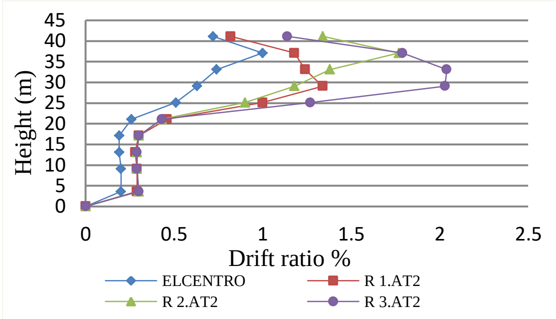


Figure 10. Height- Drift ratio when placing damper lower five flower

4.4. Damper Properties

K is a parameter of Maxwell's viscous damper and must be provided by the damper producer. If the liquid is quite viscous, then K is the stiffness of the damping shaft. The damper in its natural state depends on the damping coefficient, but the stiffness constant is obtained after applying the steel to the damper for installation in the building. In order to study the behavior of the damper in its natural state and without any stiffness, the value of the stiffness coefficient of the damper is entered zero into the SAP2000 program, while the value of the damping coefficient remains the same for the best condition after placing the dampers in the lower five floors of the building. The displacement and drift ratio is very high at zero stiffness and damping coefficient 175 kN-sec/m, so the damping coefficient is increased until a drift ratio of less than 2.5% is obtained. The increase in the damping constant value ranged from 175 until a drift ratio of less than 2.5% was obtained at 120000 kN-sec/m.

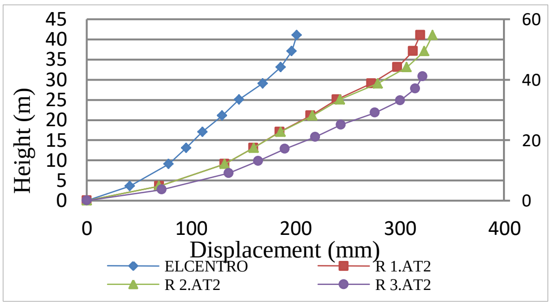


Figure 11. Height- Max displacement when placing damper lower five flower at k=0

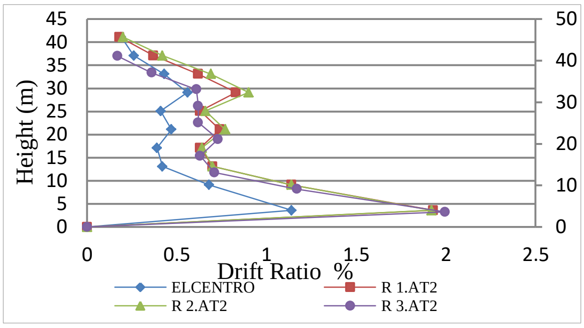


Figure 12. Height- Drift ratio when placing damper lower five flower k=0

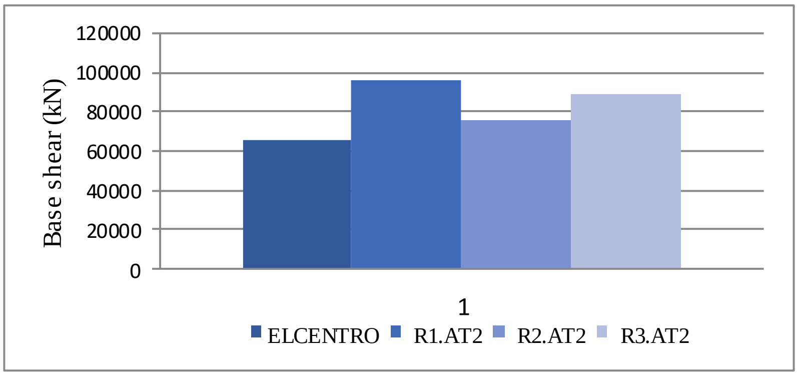


Figure 13. Height- Max base shear when placing damper lower five flower at k=0

It is clear that the presence of viscous dampers of all shapes and locations has increased the safety factor of the building and thus has reduced the maximum displacement value significantly. It is evident that the max displacement obtained when placing the damper on all floors is 38% at MATCHED (R1.AT2) from the displacement in the original condition, while it reached 53% when placing the damper in the lower five floors of the building at (c=120000 and k=0). The best and most economical case is to place dampers in five floors.
An important design factor in all seismic codes is the inter-storey drift ratio. Inter-storey drift ratio for all damped cases was within the limits of (0.1- 2.83) compared to the original condition of the structure which was (0.39- 6.2) so it was noticed that there was a significant decrease in this value upon damping.

The presence of dampers distributed on all floors of the building reduced the value of the base shear to (49.53%), as the base shear when damping reached (127080.46 kN) when the ground movement is Matched R2.AT2, while the highest value for the base shear when not damped 256577.27 kN. The presence of dampers in five floors of the building reduces the base shear to 28%, as the base shear when damping reached 58496.23 kN at Matched R1.AT2.

5. Conclusion

1. Viscous damping is a very effective technique used for civil engineering purposes in minimizing earthquake responses such as maximum displacement, inter-storey drift ratio, and other response parameters.
2. The displacements decreased to a level of 54%-94% when dampers were placed in five floors compared to the normal state of the building, but the value of the decrease reached 51%-68% when changing the stiffness coefficient of the damper to zero and a high increase in the damping coefficient, which reached 120000 kN-sec/m. The analysis also shows a significant reduction in the drift ratio and shear ratio when installing high-damping dampers at 120000 kN-sec/m in five floors was 34%-79% and 24%-70%, respectively.
3. The maximum drift between floors usually occurs at the first floor of a building.
4. Base shear in most cases gradient ascending as follows (Elcentro, MATCHED R1.AT2, MATCHED R2.AT2 and finally MATCHED R3.AT2).

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