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Reducing the torsional behavior in irregular special moment resisting frames with steel dampers

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ABSTRACT

Torsional behavior occurs during the earthquake and it caused displacement on the structure. This study evaluated the used of the metallic damper to the asymmetric three-story building structure in various ground motions scaled to response spectrum. Significant strength and stiffness enhancements were achieved in structure incorporate with damper. Seismic performance evaluation revealed that the used of the damper can potentially reduce lateral displacement approximately 63-69%. The damper could dissipate the energy approximately 28-36%. The used of the damper effectively justified proposed method applicability to seismic structural design.

Keywords: damper; lateral displacement; stiffness; torsional

1 Introduction

One of the irregularities in special moment resisting frame could induce torsional behavior due to unsymmetrical distribution of mass and (or) stiffness. The geometric arrangement or the distribution of mass, stiffness, and/or strength in most structures is irregular to some extent. The lateral resistance of the structure to ground motion is typically unbalanced as a result of these asymmetries. Large displacement amplifications and high force concentrations were caused by this phenomenon within the resisting elements, which can lead to severe damage and occasionally the collapse of the structure [1]–[3]

The structure experienced lateral displacement as well as floor rotation during an earthquake due to the occurrence of torsional behavior, which results in higher member forces and drifts than in a regular structure [4]–[7]. Numerous studies have been done to look into the technique for reducing structural torsion. In study of the effects of supplemental viscous damping on seismic response, Goel [8], [9] discovered that choosing the right supplemental damping parameter could minimize edge deformations in asymmetric systems. A plan-wise distribution of viscoelastic dampers should be used to minimize the torsional responses of an asymmetric structure with one axis of symmetry subject to dynamic motion caused by an earthquake, according to a method put forth by Kim and Bang [10]. Additionally, they discovered that viscoelastic dampers performed better than viscous dampers at controlling a building structure's torsional response. By utilizing modal analysis techniques, Petti and De Iuliis [11] proposed a technique to situate the viscous dampers for torsional response control in asymmetric plan systems. Reducing the structural eccentricity was discovered to lead the optimal damping eccentricity to shift from the flexible edge to the mass center. Hsu, et al [12], [13] examined how innovative braced frame designs performed under cyclic loads and different earthquake ground motions, and demonstrated that higher stiffness in both elastic and inelastic stages to effectively reduce the structural deformation. Kim and Jeong investigated that damper provides additional stiffness and damping of the structure, which can further improve the structural performance includes limiting the lateral displacements [14].

The objective in this study is to evaluate the torsional behavior of the structure under seismic excitation. The energy dissipation capabilities and latera displacement occurred in the structure with and without the strengthening device were compared to evaluate the effectiveness of the proposed method.

2 Data and Methods

2.1 Structure details

The structure is a three-story steel moment resisting frames as shown in Fig. 1. The story height of the structure is 4m for first story and 3m for typical story. The strength of the steel section is 370MPa. The cross section material of the column, beam and support beam are designed with H-beam 350x350cm, 300x150cm, and 250x125cm respectively, with fix-end connection. Fig. 2 show the typical floor plan of the structure, which is rectangular configured with 6m span length of beam. The structure has an inter-story access, stairs with shear wall support located outside of the floor plan.

Structure analysis program was used to create a three-dimensional model both with and without dampers. Damper used in this study is metallic damper. The damper intended to deform when an earthquake causes the building to shake. By installing metallic dampers into the buildings, it is possible to minimize potential structural damage and the structural response to earthquakes. This reduces the demand on the primary structural members for energy dissipation.

The dead and live loads, which were 5 kN/m^2 and 2 kN/m^2, respectively, were used in the structure's design. The structures were created in accordance with the IV risk category and assumed to be built on soft soil (class E). According to SNI 1726:2019 [15], the spectral acceleration for DBE is 0.6g for short period (Ss) and 0.39g for long period (S1). Three various ground motions characteristic were selected from software database ETABS 2017, as listed in Table 1. All earthquake records were scaled to the response spectrum to evaluate the performance during the earthquake and the target of scaled earthquakes depicted in Fig 3.

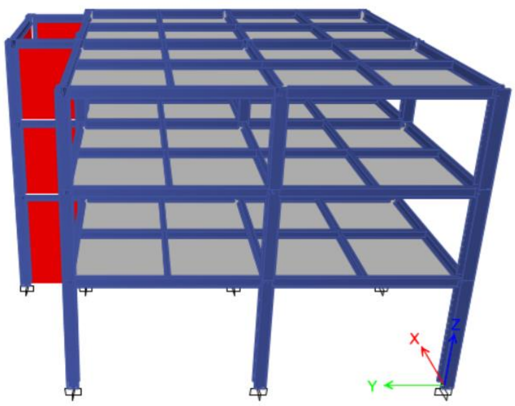


Figure 1. Structure model 3D-view

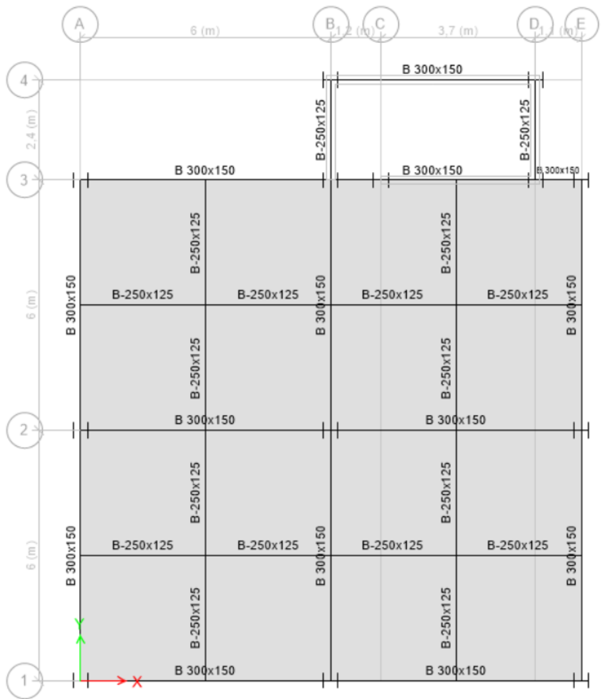


Figure 2. Structure typical floor plan

Table 1. Selected Earthquake Ground Motions

Label	Earthquake	PGA (g)			Duration (s)
		X-Dir	Y-Dir	Z-Dir	
E1	Altadena	0,33	0,17	0,15	3,31
E2	Pomona	0,13	0,19	0,07	3,61
E3	Oakland	0,27	0,26	0,06	14,93

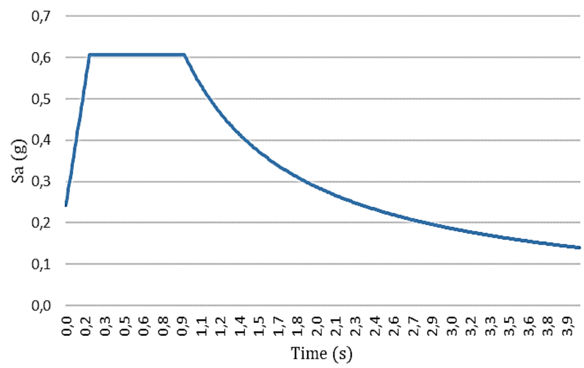


Figure 3. Spectral acceleration for the selected earthquakes

2.2 Torsion reduction using additional dampers

The design of the structure with dampers were described as flowchart in Fig 4. The analysis was first performed on the structure without dampers. The displacement needs to be investigated, whether it fall in safe level or not. If the smaller displacement is preferred, the dampers can be assigned. The locations that required the damper should be defined according to the largest relative displacement.

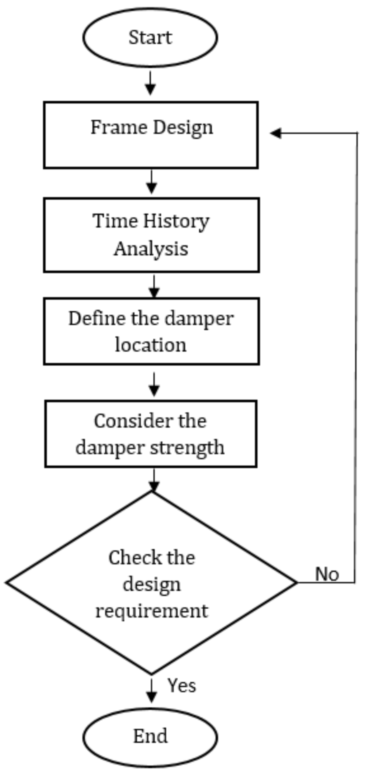


Figure 4. Flowchart for design

The strength of the damper can be assigned based on the primary structure not yield before the damper. The damper used in this study has 161,67 kN required force to yield the damper member and 17.090 kN/m effective stiffness. To determine whether the responses of the structure with the damper meet the design requirements, further non-linear time history analyses were carried out.

3 Results and Discussion

3.1 Torsion effect reductions

Fig. 5 depicts that the center of mass and the center of stiffness were offset each other and the torsional behavior of the structure can be seen in Fig. 6. To carry out the effect of the damper, Fig. 7 depicts the location of the damper used in this study for comparison.

Lateral displacement depicted in Fig. 8. The figure shows that the lateral displacement exhibited by the structure without damper were close to the allowable story drift. According to ASCE 7-13, the allowable story drift for structures in risk category IV was set at 1.5% of the story height as the target inter-story drift [16].

In Table 2 depicted the difference of structure between structure with damper system (w) and structure without damper system (w/o). When the dampers were incorporated with the structure, the lateral displacement were significantly reduced 63% to 69% of moment resisting frames only. Table 3 depicted the rotation angle occurred in the structure with the degree units. It can be shown that the structure incorporated with damper exhibited lower rotation degrees than the structure without damper. Considering this is only a 3 story-building, the amount of rotation angle is substantial and it must be calculated.

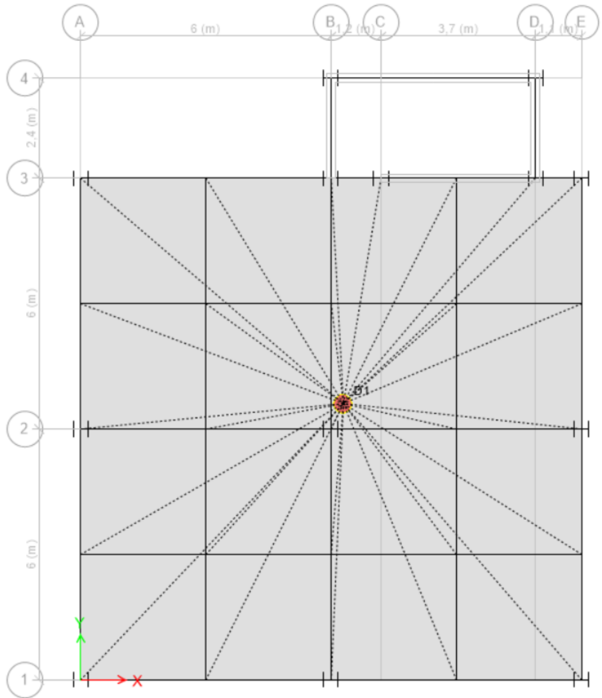


Figure 5. Center of stiffness

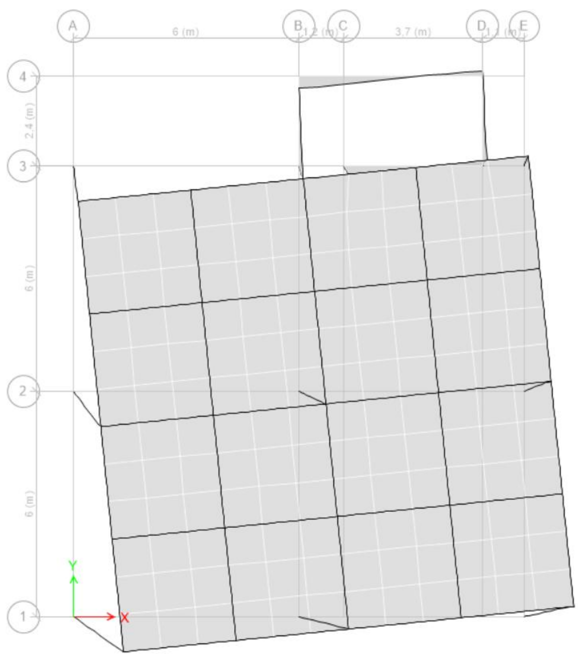


Figure 6. Torsional behavior of the structure

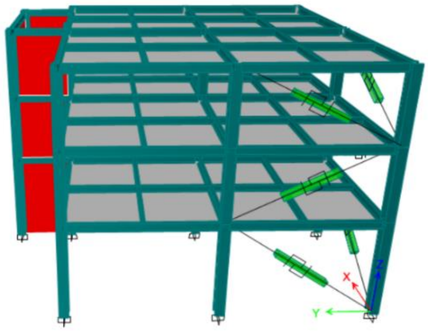
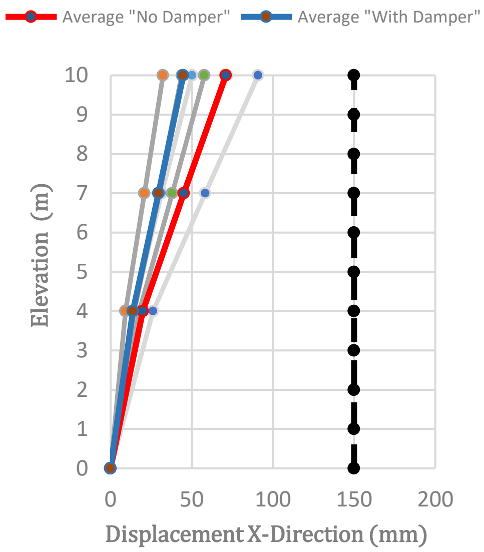


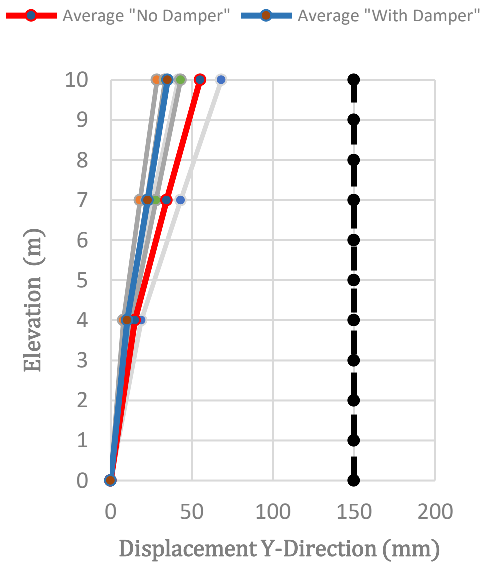
Figure 7. Location of the damper

Table 2. Detailed of lateral displacement

Story	X-direction		
	w/o	w	Ratio
Story 3	70,99	44,79	0,63
Story 2	45,06	29,55	0,66
Story 1	19,90	13,68	0,69
Base	0,00	0,00	-
Story	**Y-direction**		
	w/o	w	Ratio
Story 3	55,12	35,08	0,64
Story 2	34,48	22,75	0,66
Story 1	14,88	10,29	0,69
Base	0,00	0,00	-

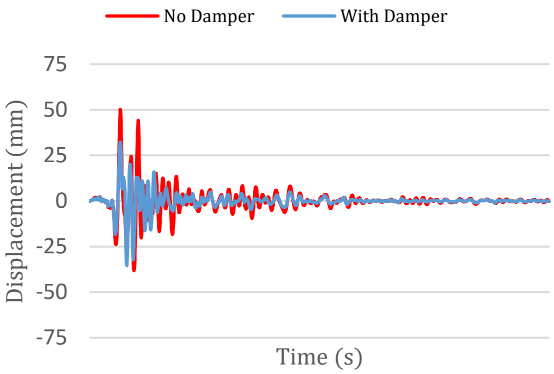


(a) X-Direction

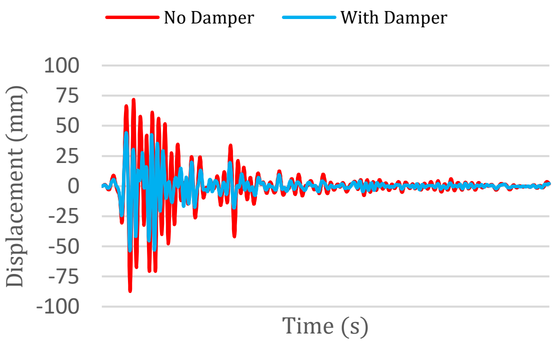


(b) Y-Direction

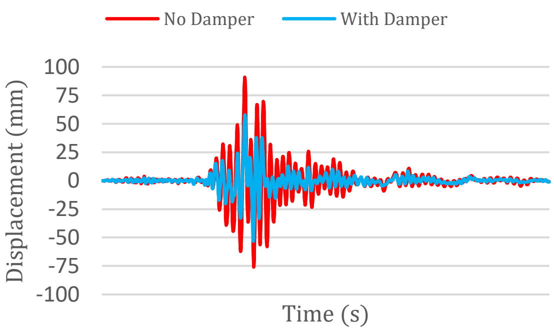
Figure 8. Lateral Displacement



(a) Altadena



(b) Pomona



(c) Oakland

Figure 9. Top displacement during various ground motions

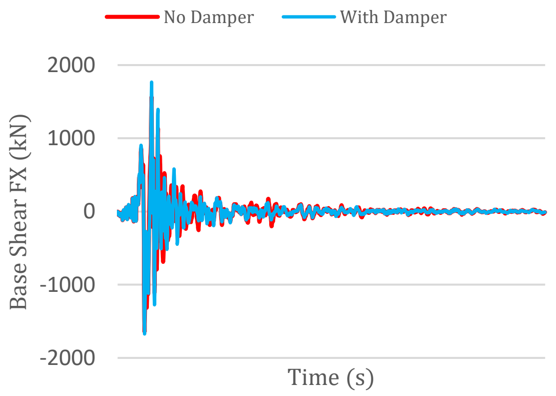
Table 3. Rotation angles occurred in the structure

Story	Rotation Angle	
	w/o	w
Story 3	0,61	0,38
Story 2	0,39	0,25
Story 1	0,17	0,11

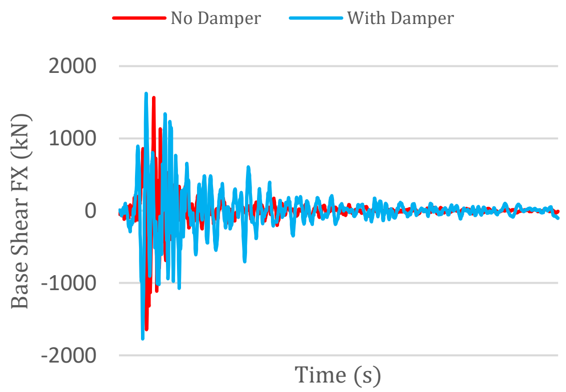
Furthermore, the vibration after the main shock also reduced, which shown in Fig 9. The top displacement which is the third floor of the structure returned to steady state earlier when the dampers integrated with the structure. This phenomenon can be attributed to the additional stiffness and damping provided by the dampers.

3.2 Base shear and energy dissipation

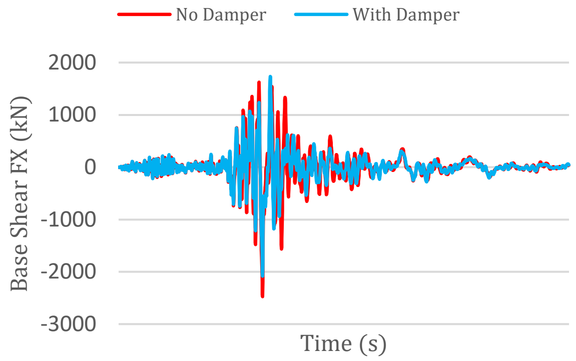
To visualize the damper contribution, the base shear and the energy dissipation capabilities were shown in Fig. 10 and Fig. 11, respectively. The base shear was approximately equal or reduced as the energy dissipation capabilities increase within the structure. This phenomenon indicates the possibility of reducing internal forces of the structure.



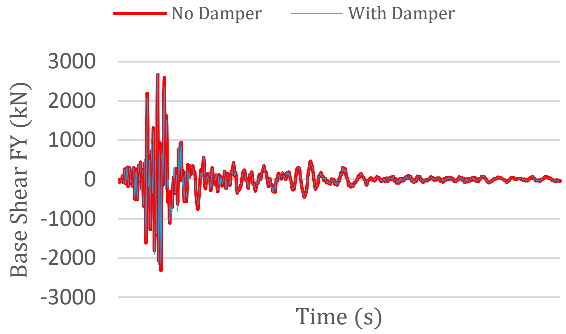
(a) Altadena X-Direction



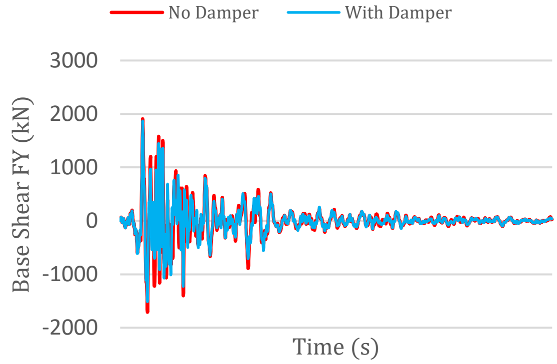
(b) Pomona X-Direction



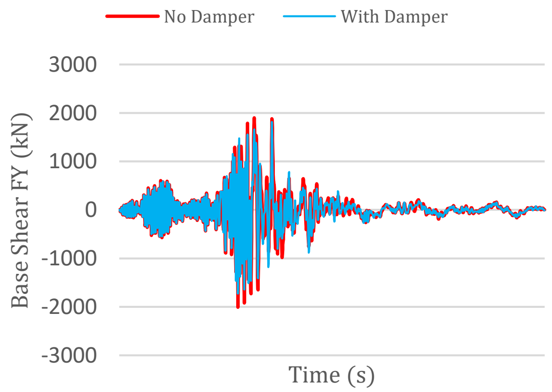
(c) Oakland X-Direction



(d) Altadena Y-Direction



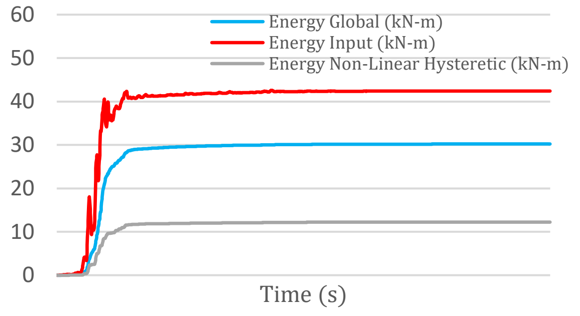
(e) Pomona Y-Direction



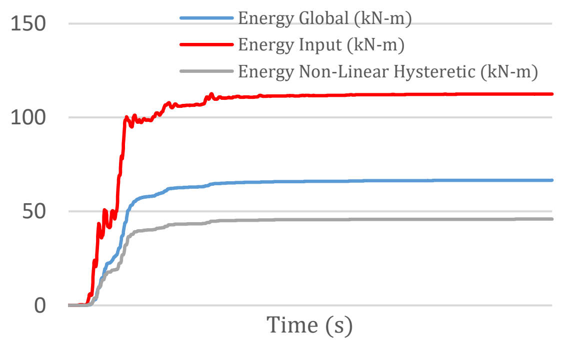
(f) Oakland Y-Direction

Figure 10. Base shear reaction with and without damper

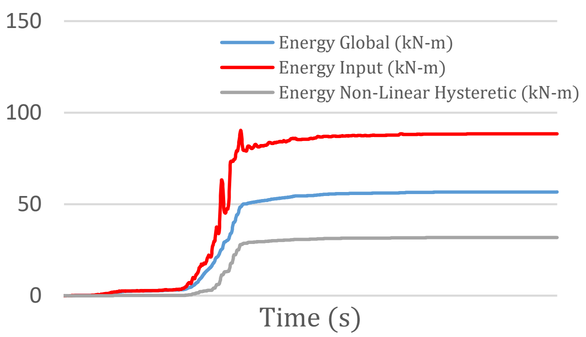
As shown in Fig. 10 the base shear in structure with damper potentially decreased. It is exhibited that a structure incorporated with damper has an enhancement. The damper dissipates the energy when the earthquake happens. Fig. 11 depicts the energy occurred in the structure which is including the total energy named energy global. Part of the input energy will be dissipated through the natural/inherent damping of the structure, and part of it is stored as oscillating elastic energy in the structure as long as the structure is vibrating. The energy non-linear hysteretic is the amount of energy that was absorbed by the damper inelastically. As shown below, the damper could dissipate the energy approximately 28% to 36% of the input energy.



(a) Altadena



(b) Pomona



(c) Oakland

Figure 11. Energy component of the structure

4 Conclusion

In order to reduce the torsion effect in the structure, the installation of dampers can be utilized to provides additional stiffness and damping that limit the lateral displacement.

The time history analyses were conducted to asymmetric three-story building with an eccentric center of mass and stiffness. The evaluations were targeted to structure both with and without dampers. The analyses results exhibit that the torsional behavior can be reduced when the dampers incorporated into the structure. The displacement can be reduced approximately 63% to 69% and the damper can dissipate 28% to 36% of the energy. This scheme validates the effectiveness and applicability of the design.

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