

# Performance of two directional asymmetric buildings in farfield and nearfield earthquakes



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It was identified that the configuration of centers of mass, stiffness and strength has major role in performance of one directional asymmetric single story and multi-story buildings. However, many buildings are asymmetric in both horizontal directions and often haven't any axes of symmetry. The extension of proper configuration of centers as has been determined for unidirectional symmetric models to these more complex types of building needs verification. On the other hand, in some buildings due to design limitations the proper configuration of centers could not be applied to both horizontal directions of building. In this case the designer should know that how the other direction center configuration could affect the proper configuration of centers. In this study, using nonlinear dynamic analysis the bi-directional asymmetric single story models are studied. The asymmetric models are made by changing configuration of centers in both directions. The results of studies on bi-directional asymmetric buildings indicate that the proper configuration of centers can control the torsional responses in bi-direction asymmetric buildings this configuration could be applied in each direction independently; however the direction with the most severe condition of asymmetry has more important role on the torsional responses.

*Keywords: asymmetric building, torsion , eccentricity*

## 1. INTRODUCTION

One of the main factors that affect building performance during earthquake excitations is building asymmetry. Asymmetric buildings often sustain more extensive damage in compare with symmetric ones. The vulnerability of asymmetric buildings has been addressed by building seismic design codes in the form of special torsional provisions. In these provisions design stiffness eccentricity defined as combination of stiffness eccentricity and accidental eccentricity is used to calculate the design torsional moments. The stiffness eccentricity is a good indicator of torsional responses when building behaves in linear range but, majority of buildings have been designed to behave in nonlinear range during moderate and large earthquakes. In this situation stiffness eccentricity is not a good indicator of building responses. The strength eccentricity defined as the distance between center of strength to centre of mass. Center of strength is the centre of yield strength of the LFREs. The strength eccentricity is an appropriate indicator for torsional response of asymmetric building when building is responding in nonlinear range. Subjected to a ground motion, building responses are various ranges of behaviors, from full elastic to elasto-plastic and full plastic. But, in general, some LFREs behave in linear to nonlinear range while the other LFREs remain in linear range. Therefore it can be expected that the torsional responses of a building during moderate and high earthquake intensities depend on both strength and stiffness eccentricities.

It was mainly assumed in past researches that for every lateral force resisting element (LFRE) of a building, the stiffness of element is independent of its strength (K-type). For this type of modeling the location of centre of rigidity can be determined before design procedure. Current design procedures and torsional provisions of seismic codes have been developed based on this assumption. Recent

research (Aschieri 2002, Priestley and Kowalsky 1998) revealed that for many LFREs such as shear walls and moment resisting frames, their stiffness is dependent of their strength and will be modified during strength assignment. These LFREs are called D-type elements. Because the code design procedure is not straight forward in buildings with D-type LFREs and lacks the ability to enforce simultaneous yielding among LFREs, design based on proper configuration of centers could be a good alternative. In the majority of studies before 1998 (e.g. Mittal and Jain 1995, Chandler and Duan 1997-1, Chandler and Duan 1997-2 ) only K-type elements have been considered in identifying proper configuration of centers. In these researches, with the assumption that the location of centre of strength remains unchanged during design procedure, the proper location of centre of strength was examined. For these types of buildings Tso and Ying (1992) suggested that strength eccentricity should be zero or near to zero in order to reduce ductility demand on flexible edge element for buildings that has non-uniform stiffness distribution. Rutenberg (1992) and De Stefano et. al. (1993) tried to find optimum location of centre of strength relative to centre of mass and centre of rigidity for minimizing ductility demand. They concluded that the best location of centre of strength is at the middle of centers of mass and stiffness. Paulay (1997), based on plastic mechanism analysis considered the behavior of single story asymmetric structure with D-type elements. He suggested that an arbitrary strength distribution strategy can be more effective for superior performance of asymmetric structure in ultimate limit state. Similar to Tso and Ying (1992), he proposed that an appropriate location of centre of strength is somewhere near the centre of mass. Myslimaj and Tso (2002, 2004) demonstrated that the response of asymmetric structures during the earthquake excitations depends on the location of both centre of strength and center of stiffness. They proposed that the best configuration of centre of mass, strength and stiffness is a configuration in which the center of mass is between centers of strength and stiffness. This configuration was called as balance configuration. According to their study, balance configuration will improve the interstory drift and diaphragm rotational responses of a building, but it can cause an increase of ductility demand on elements in the stiff side of structure. Based on these findings and to recognize proper configuration of centers Aziminejad and Moghadam (2002, 2008) and Aziminejad et. al. (2006) examined performance of single story and two story shear type buildings. In these studies they tried to identify more accurate configuration of centers which improves the performance of asymmetric buildings to their maximum value, this configuration was called proper configuration of centers. In these studies proper configuration of building for different response parameters and their dependencies to different structural and ground motion parameters were identified. In another study (Aziminejad and Moghadam 2010) to identify proper configuration of centers to improve performance of asymmetric buildings, fragility representation was used. To extend this methodology to multistory buildings (Aziminejad and Moghadam 2008) approximate definitions for center of strength and stiffness based on characteristic of each individual story in building was used. These approximate definitions provide simple methods for determination of the centers location in each story specially when the stiffness of each LFREs is a function of its strength and can change during design cycles. Based on these definitions the strategies for changing centers configuration in building stories were proposed which are capable in controlling undesirable effects of torsional responses (Moghadam and Aziminejad 2008).

Proper configuration of centers of building models with one directional asymmetry was studied, but many of buildings are asymmetric in both horizontal directions. In these cases, it could be unclear for a building designer if the proper configuration found based on unidirectional symmetric models is valid in these types of buildings or not. In the other case, sometimes in one direction due to architectural or other limitations the designer couldn't use proper configuration of centers. In this case the designer should know how the other direction center configuration could affect the proper configuration of centers.

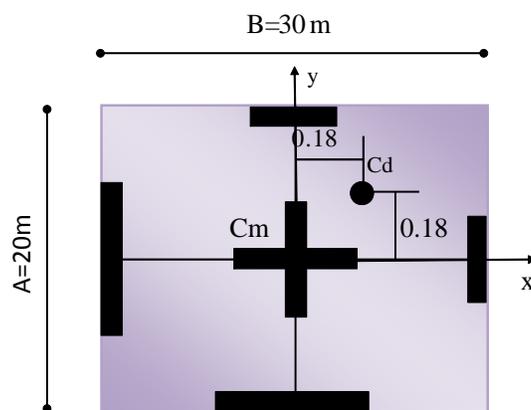
In this study by conducting nonlinear dynamic analysis on groups of single story torsional stiff buildings with variation of centers configuration on both principal direction, proper configuration of centers was recognized. Two groups of ground motion records, one nearfield and the other farfield earthquake were used. A total of 64 building models with different configurations of centers were analyzed using OPENSEES simulation software. These models are made by changing configuration of centers in both directions in form of the eight selected configuration. The larger earthquake record component was applied to x direction.

## 2.ANALYTICAL MODEL

To identify proper configurations of centres of mass, stiffness and strength in different level of hazard, a group of single story buildings with concrete shear walls have been used. The models consist of rigid diaphragms and were asymmetric in both directions. The asymmetry in models is produced by changing width and strength of the two edge walls in each direction; such that the total strength and strength radius of gyration remain unchanged. A symmetric model in both principal directions is also used as a reference torsionally balanced (TB) system. The design gravity loads of the TB system have been determined based on the Iranian standard 519 (Building and Housing Research Center 1999). The design earthquake loads are calculated based on the Iranian standard 2800 earthquake provision (Permanent Committee for Revising the Standard 2800-05, 2005). The lateral strengths of all the torsionally unbalanced (TU) systems are the same and equal to the lateral strength of the TB system. Lateral strengths of the models in the x or y-directions are also the same. For generating TU models, the length of the edge walls in each direction are changed in a way that the models have similar yield displacement eccentricity ( $e_d$ ) equal to 0.1818 of plan dimensions (Fig. 1). In all TU systems the shape and geometry of the walls are similar. Table 1 summarizes the characteristic of the models yield ( $e_d$ ), strength ( $e_v$ ) and stiffness eccentricities ( $e_r$ ) in each direction. By changing these eccentricities in each direction total of 64 TU models were created.

Fifteen two directional (horizontal component) farfield and nearfield earthquake ground motion records have been selected for conducting dynamic nonlinear analyses. All the records are scaled to ten different peak ground accelerations from 0.05g to 0.7g. The characteristic of ground motion records are shown in Table 2 and 3.

Dynamic nonlinear analyses of models are done using OPENSEES (2005) simulation software. A 5% damping ratio for first mode proportional to mass included in the analyses.



**Figure 1.** Configuration of two directional asymmetric basic models

**Table 1.** Main centers configuration in each direction

$e_d$	model	$e_v$	$e_r$	$e_v/e_d$
0.000	1	0.00	0.00	-
0.1818	2	0.182	0.019	1.00
0.1818	3	0.136	-0.035	0.75
0.1818	4	0.091	-0.083	0.50
0.1818	5	0.045	-0.127	0.25
0.1818	6	0.000	-0.167	0.00
0.1818	7	-0.061	-0.214	-0.33
0.1818	8	-0.182	-0.295	-1.00

### 3. ANALYTICAL RESULTS

Using the OPENSEES software, the nonlinear dynamic analyses are performed. All models consist of one TB and TU models analyzed for two group of fifteen, ground motions (Table 2 and 3). As response parameters, diaphragm rotation, maximum interstory drift, plastic rotation of shear walls and edge ductility demand of shear walls were considered.

**Table 2.** Farfield Earthquake ground motion records

	Earthquake	Year	Magnitude (M)	Duration (Sec)	PGA x (g)	Site	Dis. (Km)
1	Cape-Mendocino	1992	7.1m	36	0.229	Shelter Cove Airport	33.8
2	Chi-Chi	1999	7.6m	35	0.413	TCU047	33.01
3	Compano lucano	1980	6.9mw	35	0.14	Mercato san servino	48
4	Manjil	1990	7.4mw	25	0.184	Qazvin	49
5	Imperial Valley	1979	6.5m	40	0.169	Cerro Prieto	26.5
6	Izmit	1999	7.6mw	30	0.208	Gebze-arcelic	38
7	Kern county	1952	7.4mw	25	0.175	Taft	41
8	N. Palm Springs	1986	6m	20	0.228	San Jacinto	32
9	Northridge	1994	6.7m	20	0.256	LA - Century	25.4
10	San Fernando	1971	6.6m	20	0.324	Castaic	25
11	Whittier Narrows	1987	6.0m	20	0.299	Union Oil	25.2
12	Loma Prieta	1989	6.9m	25	0.233	Golden Gate Bridge	85.1
13	Northridge	1994	6.7m	20	0.404	Westmoreland	29
14	Chi-Chi	1999	7.6m	35	0.204	CHY086	35.43
15	N. Palm Springs	1986	6m	11.2	0.240	Hurkey Creek Park	34.9

**Table 3.** Nearfield Earthquake ground motion records

	Earthquake	Year	Magnitude (M)	Duration (Sec)	PGA X (g)	Site	Dis. (Km)
1	Tabas	1978	7.4mw	30	0.836	Tabas	3
2	Landers	1992	7.3m	25	0.412	Coolwater	21.2
3	Loma Prieta	1989	6.9m	20	0.644	Corralitos	5.1
4	Morgan hill	1984	6.2m	20	0.423	Anderson Dam	2.6
5	Northridge	1994	6.7m	25	0.344	Arleta	9.2
6	Cape Mendocino	1992	7.1m	25	0.549	Rio Dell Overpass	18.5
7	Chi-Chi, Taiwan	1999	7.6m	38	0.968	CHY080	6.95
8	Erzincan	1992	6.6mw	22	0.512	Erzincan	1
9	Montenegro	1979	6.9mw	32	0.375	Bar-skupstina	12
10	Kobe	1995	6.9m	20	0.821	KJMA	0.6
11	Superstitt Hills	1987	6.7m	22	0.455	Parachute	0.7
12	South iceland	2000	6.5mw	20	0.610	Kaldarholt	6
13	Montenegro-as	1979	6.2mw	20	0.267	Budva	9
14	Kocaeli	1999	7.4mw	25	0.219	Arcelik	17
15	Palmspring	1986	6mw	20	0.218	Morongo Valley	10

The selected models analyzed in 10 different earthquake intensities from 0.05g to 0.75g. In Fig. 2 the average rotation of diaphragm in different earthquake intensities is shown. In these graphs each curves shows the ratio of  $e_v/e_d$  in y direction. The minimum response happen when models have one

directional proper configuration of centers in both x and y direction when the ratio of  $ev/ed$  is equal to 0.25 in both principal directions. The only exception occurs when PGA is equal to 0.1g, in this case buildings predominantly behave in linear range and proper configurations are the configurations with less stiffness eccentricity. By changing location of centers from the proper configuration, the torsional response increases, but the responses are more sensitive when configuration of centers changes in x direction, the direction with larger width. Similar trend could be identified in nearfield records (Fig.3). in contrast to farfield records, in this case buildings experience more intensive rotation in nearfield records and sensitivity of models to eccentricity was more pronounced.

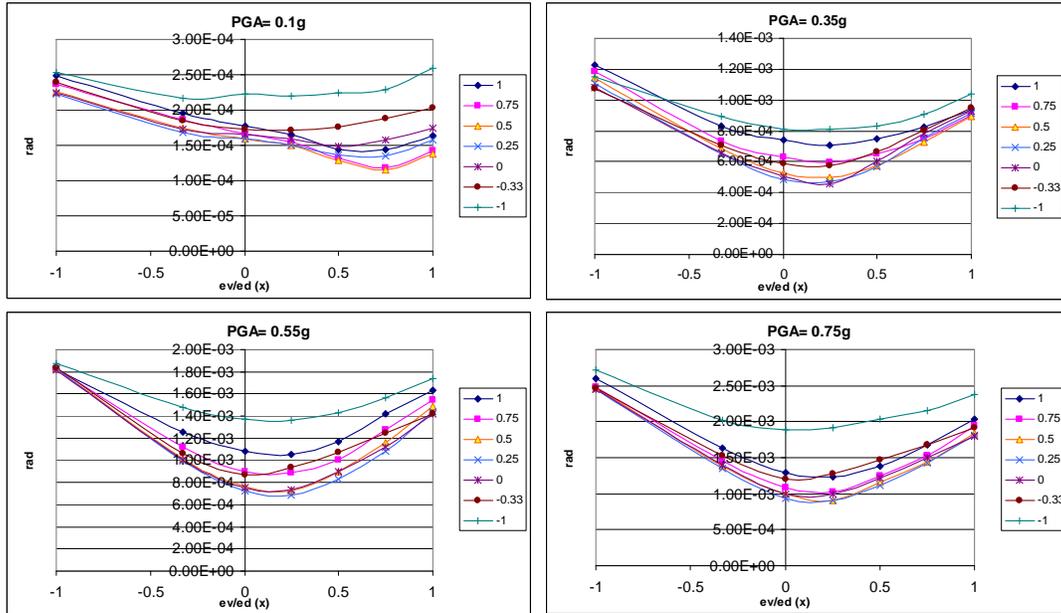


Figure 2: Rotational responses of bi-directional asymmetric building subjected to farfield records

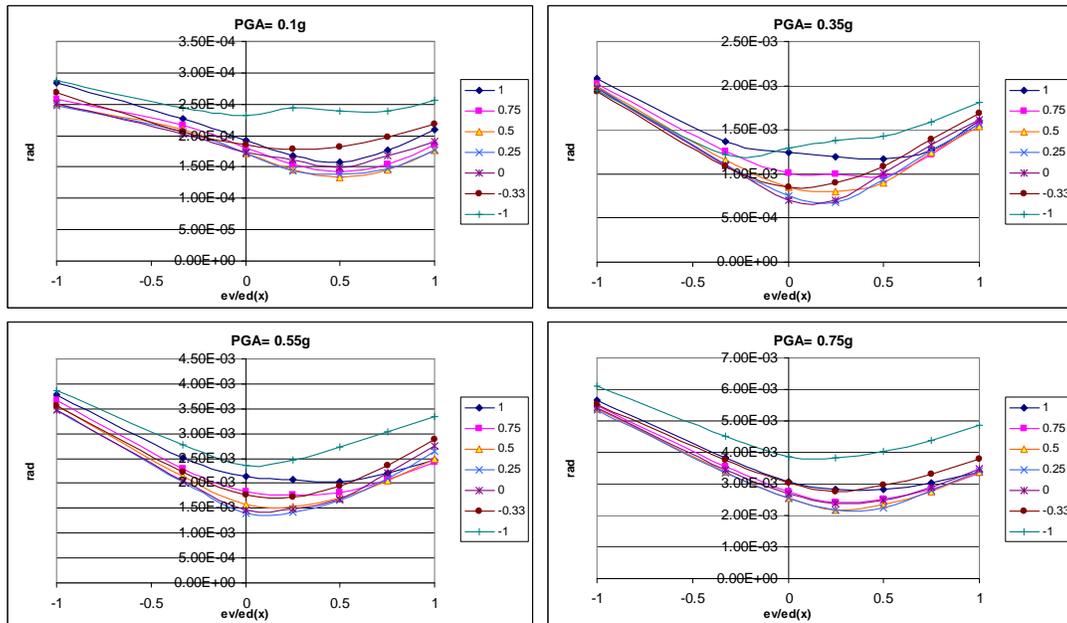
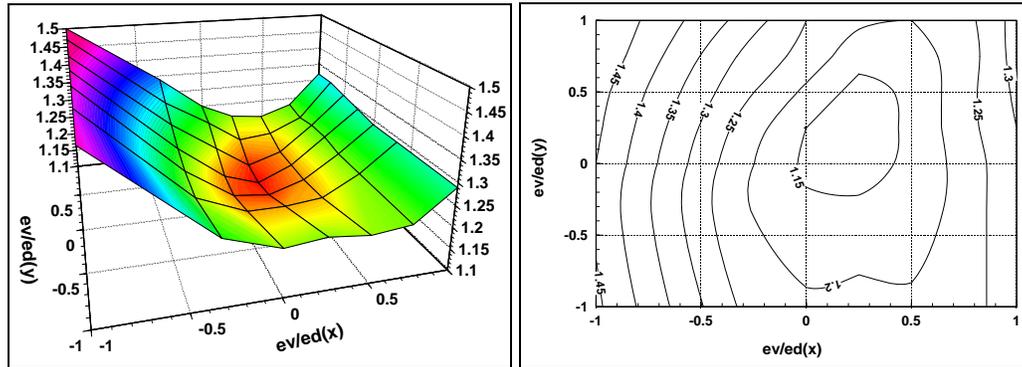


Figure 3: Rotational responses of bi-directional asymmetric building subjected to nearfield records

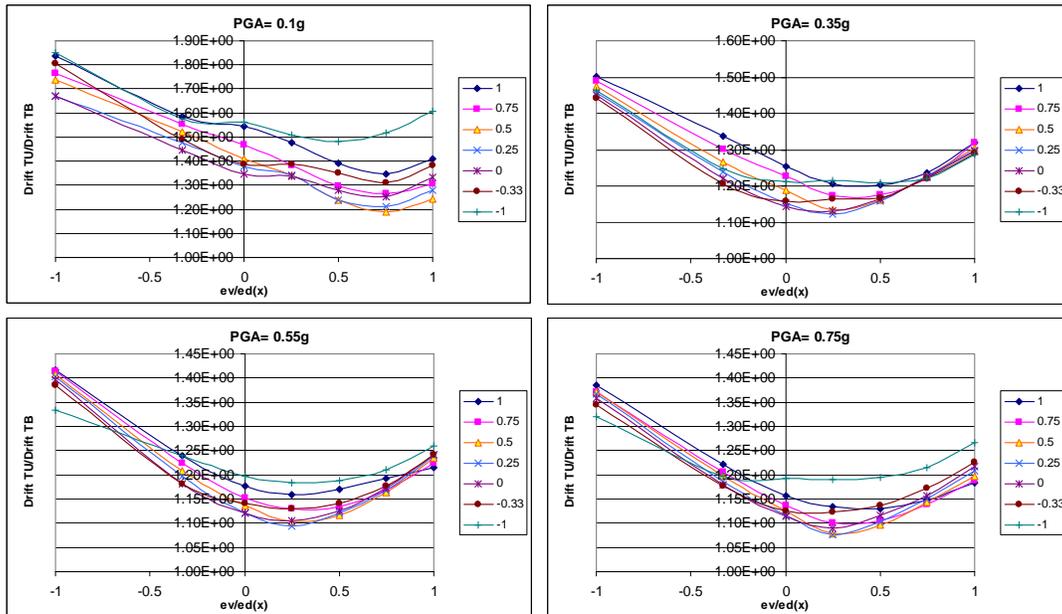
In Fig. 4 normalized drift responses of models for PGA equal to 0.35g are shown. The results are normalized to response of reference symmetric model. Again the proper configuration of centers for

two directional asymmetric building is one-directional proper configuration of centers in x and y direction ( $ev/ed = 0.25$ ). However in drift responses the effect of configuration of x direction on total responses decreases in compare with rotational responses

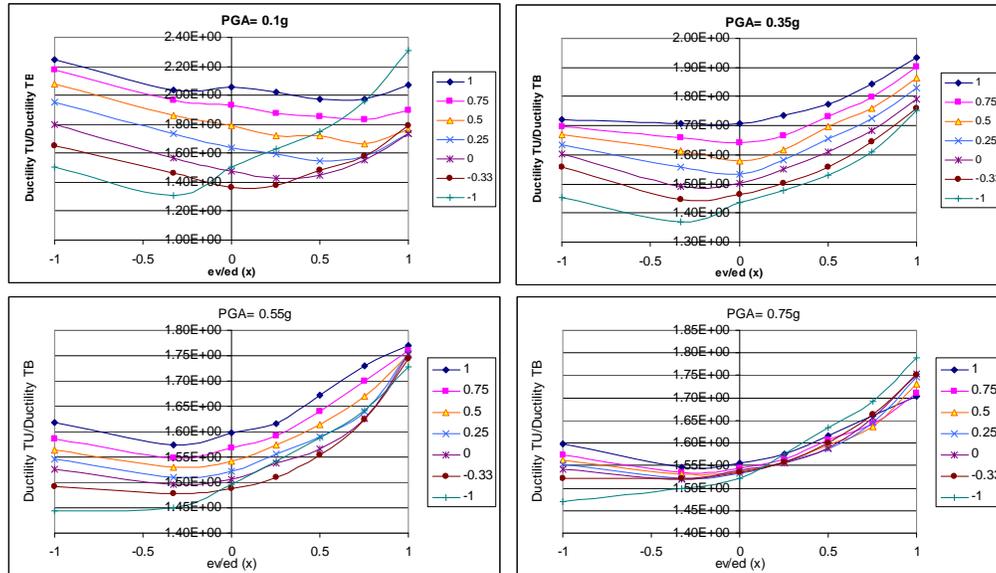


**Figure 4.** Ratio of drift torsional unbalanced to torsional balance responses of bi-directional asymmetric buildings subjected to farfield records (PGA=0.35g)

To examine the results in wider range of earthquake intensities, in Fig. 5 normalized drift response of two directional asymmetric building for some selected earthquake intensities are shown. Different curves in each graph show different center configurations in y direction. As it can be seen in this figure, by increasing earthquake intensity the effect of configuration of x direction decrease more. Again the best configuration of centers is the one directional proper configuration of centers for x and y direction. The similar results can be seen for ductility demand responses (Fig. 6).



**Figure 5.** Ratio of drift for torsional unbalance to torsional balance bi-directional asymmetric buildings subjected to far field records for different earthquake intensities



**Figure 6.** Ratio of ductility for torsional unbalance to torsional balance bi-directional asymmetric buildings subjected to far field records for different earthquake intensities

In models under consideration, the y direction with wider plan width is the main asymmetric direction. Although the earthquake stronger component is applied in x direction, the y direction is the dominant direction in controlling building responses, it means that if building designer couldn't control configuration of centers in y direction because of some limitations the other direction configuration won't be much help in controlling responses.

#### 4. CONCLUSIONS

1. In bi-directional asymmetric buildings, subjected to farfield and nearfield earthquake records, the direction with the higher level condition of asymmetry has the main effect on the torsional responses. The level of asymmetry in a direction could be recognized by comparing parameters such as yield displacement eccentricity or the variation of building period by changing center configurations. In models subjected to nearfield ground motions, sensitivity of models to eccentricity was more pronounced.
2. Drift proper configuration of centers for two directional asymmetric buildings is the configuration, that in both direction centers have proper configuration as identified by, corresponding uni-directional asymmetric building.
3. If designer has some limitation in alignment of drift proper centers configuration in one direction, it could affect the other direction proper centers configuration. In the cases that the configuration of the main asymmetric direction was very different from the proper configuration, changing center configuration in other direction has minor effect on torsional responses.
4. Similar to mono symmetric models, ductility proper configuration of centers is different from drift proper configuration of centers. Ductility proper configuration of centers in each direction has less dependency to the other direction configuration. The proper configuration of centers in each direction is similar to the uni-directional buildings configuration.

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