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PROPER CONFIGURATION OF CENTERS FOR TWO DIRECTIONAL ASYMMETRIC SINGLE STORY BUILDINGS

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ABSTRACT

Proper configuration of centers has been proposed as an effective concept for controlling torsional responses 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 developed based on unidirectional symmetric models to these more complex types of asymmetric 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 those cases the designer should know how the other direction center configuration could affect the proper configuration of centers. In this study, using nonlinear dynamic analysis the bi-directional asymmetric models are studied. The asymmetric models are derived 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 be applied in each direction independently; however the direction with the most severe condition of asymmetry has more effects on the torsional responses.

Introduction

Many buildings are asymmetric in one or both horizontal directions and often haven't any axes of symmetry. The experiences achieved in past earthquakes have shown, 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 a 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 alone is not a good indicator of building responses and strength eccentricity also should be considered. The strength eccentricity defined as the distance between center of strength to center of mass. Center of strength is the center of yield strength of the LFREs. The strength eccentricity is an appropriate indicator of torsional

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responses of asymmetric building when the building is responding in nonlinear range. Subjected to a ground motion, building responses cover 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. Researches in past ten years (i.e., Aschiem 2002, Priestley and Kowalsky 1998) revealed that for many LFREs such as shear walls and moment resisting frames, their stiffness is depended of their strength and will be modified during strength assignment. These LFREs are called D-type elements. Because application of 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 the so-called proper configuration of centers could be a good alternative. In the majority of studies before 1998 (i.e., 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 stiffness 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) also 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, 2001), 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) proposed that the best configuration of centre of mass, strength and stiffness is a configuration in which the centre 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, this configuration was called proper configuration of centers. In these studies proper configuration for different response parameters and their dependencies to different structural and ground motion parameters were identified.

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).

As many of buildings are asymmetric in both horizontal directions, it is unclear if the proper configuration found based on unidirectional symmetric models is valid in these types of buildings or not. There are also cases that 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 analyses on groups of single story torsional stiff buildings with variation of centers configuration on both principal direction, proper configuration of centers was recognized. A total of 64 building models with different configurations of centers were used. 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.

Analytical model

To identify proper configurations of centers of mass, stiffness and strength in different levels of hazard, a main group of single story buildings with concrete shear walls have been used. The models consist of rigid diaphragms and are 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 a total of 64 TU models were created.

Fifteen two directional (horizontal component) far field 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.

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

Analytical results

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

The selected models analyzed in 10 different earthquake intensities from 0.05g to 0.75g. In Fig. 2 the average rotation of diaphragm in earthquake intensities equal to 0.35g is shown. The minimum response happen when models have one directional proper configuration of centers (Aziminejad and Moghadam 2006) in both x and y direction, that is when the ratio of e_v/e_d is equal to 0.25 in both principal directions. 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. This direction can be identified as direction with severe asymmetry condition. By changing configuration of centers for this direction building rotational responses change more intensely.

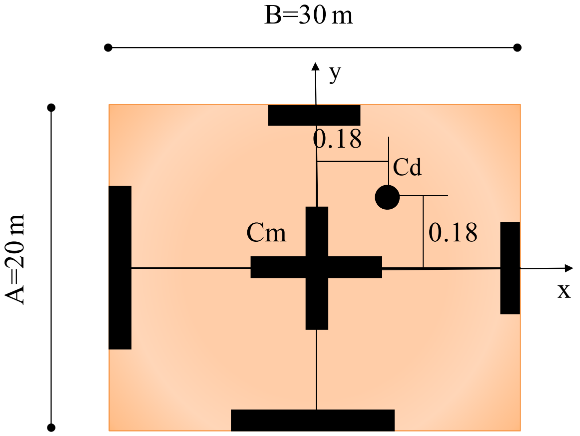

Figure 1: Configuration of two directional asymmetric basic models

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

Table 1. 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

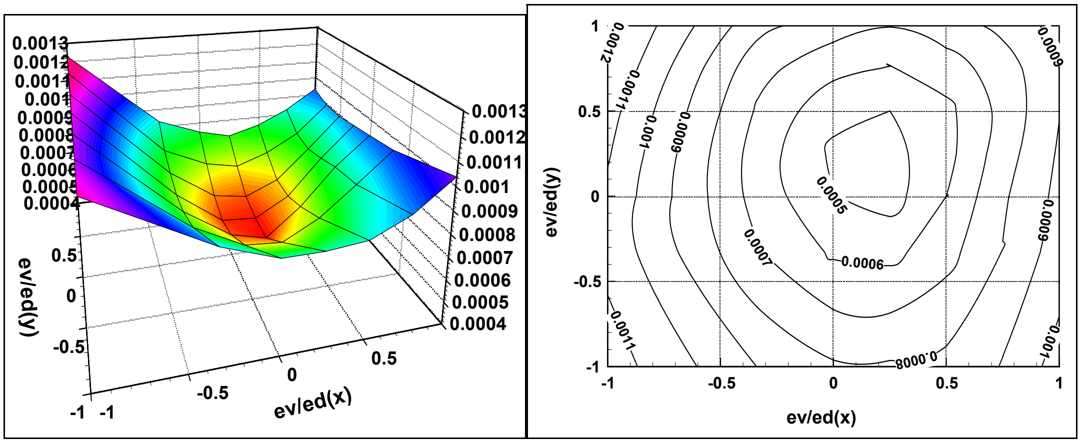

Figure 2: Rotational responses of bi-directional asymmetric building subjected to far field records (PGA=0.35g)

In Fig. 3 normalized drift responses of models for PGA equal to 0.35g are shown. The results are normalized to response of reference symmetric model. Similar to diaphragm rotational responses, the proper configuration of centers for two directional asymmetric building is one-directional proper configuration of centers in x and y direction. However in drift responses the effect of configuration of y direction on total responses decreases in compare with rotational responses. In this case the other direction asymmetry has minor effect in critical drift responses. In fact when the configuration of centers in x direction differ significantly from proper configuration (e_v/e_d = 0.25), change of other direction configuration has negligible effect on building critical drift 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.

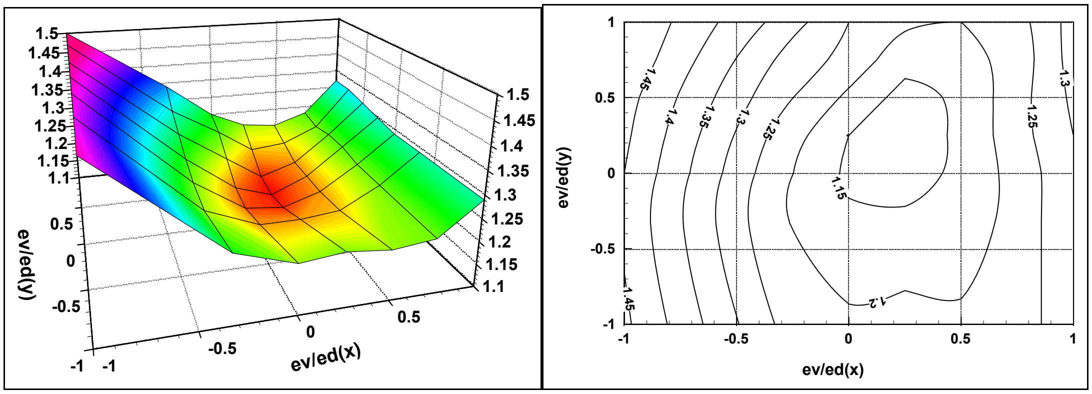

Figure 3: Ratio of torsional unbalanced to torsional balance drift responses of bi-directional asymmetric buildings subjected to far field records (PGA=0.35g)

To examine the results in wider range of earthquake intensities, in Fig. 4 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. The figure shows that by increasing earthquake intensity the effect of configuration in y direction decreases. Again the best configuration of centers is the one directional proper configuration of centers for x and y direction. It is worth to mention here, when configuration of centers in x direction varies significantly from proper configuration, it changes the proper configuration in other direction.

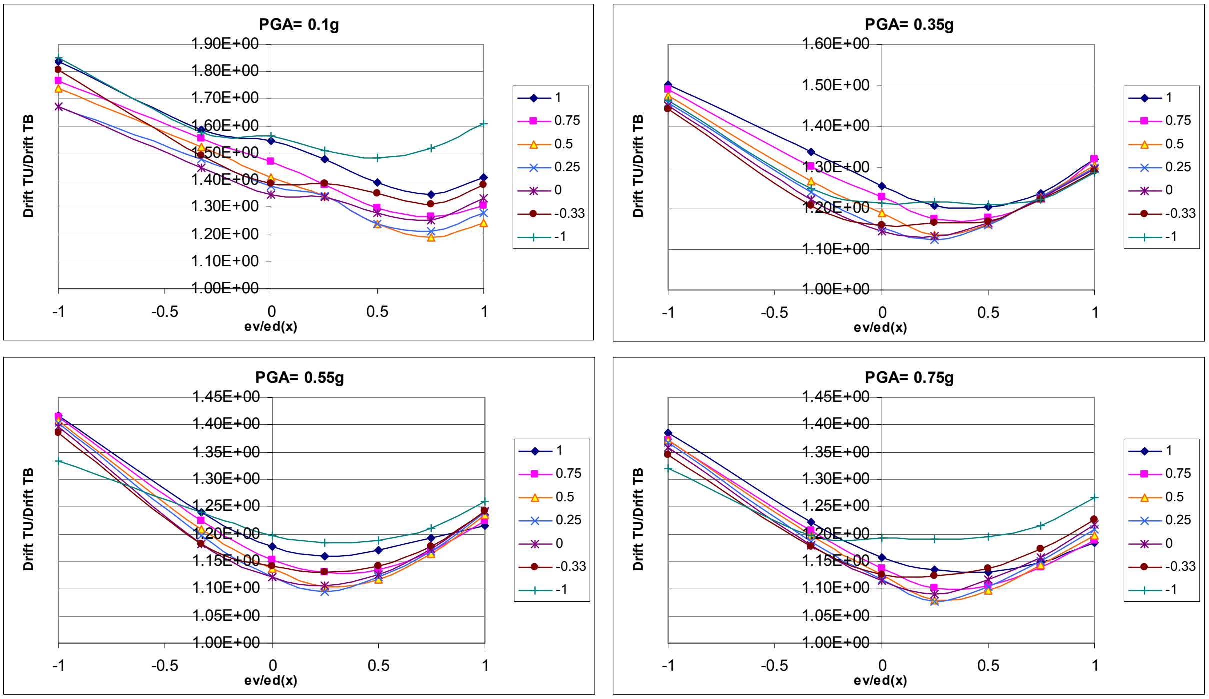

Figure 4. Ratio of drift for torsional unbalance to torsional balance bi-directional asymmetric buildings subjected to far field records for different earthquake intensities

The ductility demand responses for some selected earthquake intensities have been shown in Fig.5. Similar to one directional asymmetric buildings (Aziminejad and Moghadam 2006), the proper configuration of centers for ductility differs from proper configuration of centers for diaphragm rotation and interstory drift. For this response parameter, by increasing earthquake intensity ,and so the amount of nonlinear behavior and ductility demand the proper configuration of centers reaches to stable condition, and models with e_v/e_d ratio around -1 have minimum ductility demand. For models under consideration, the x direction with larger plan length is the main asymmetric direction. Although the earthquake stronger component is applied in x direction (affect asymmetry in y direction), proper configuration in the x direction has the dominant role in controlling building responses. But compare to drift responses, asymmetry in perpendicular direction has more effect in controlling torsion. For this response parameter configuration of each direction is almost independent form configuration of the other direction.

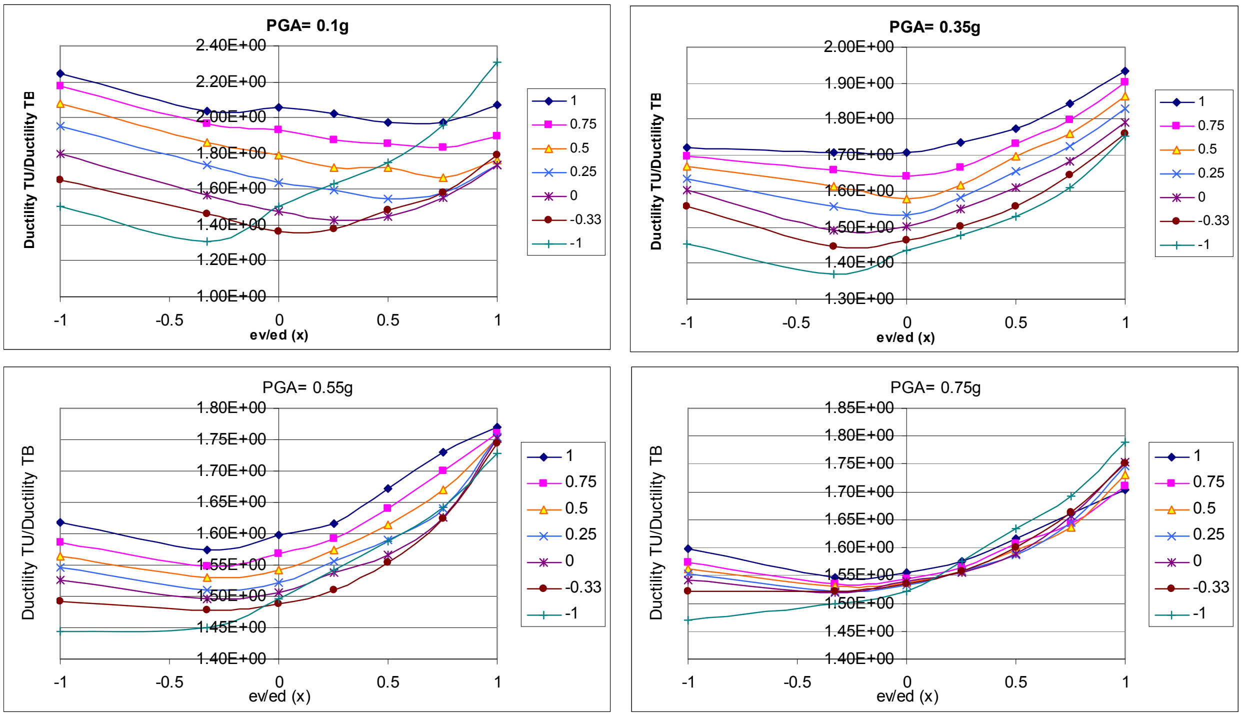

Figure 5. Ratio of ductility for torsional unbalance to torsional balance bi-directional asymmetric buildings subjected to far field records for different earthquake intensities

Conclusions

In this paper the response of bi-directional asymmetric torsional stiff single story models is presented. Diaphragm rotation, interstorey drift and ductility demand were selected as response parameters. Based on the results of this study the following conclusions can be drawn:

1. In bi-directional asymmetric buildings, the direction with larger 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 when center configuration is changed.

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 one 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 is very different from the proper configuration, changing center configuration in the other direction has minor effect on torsional responses.
4. Similar to one directional asymmetric 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 one directional buildings configuration.

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