Effect of Ground Motion Horizontal Definition in Seismic Analysis and RC Moment Frame Structures in Mandalay Region

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Abstract

Since Myanmar is one of the earthquake-prone zones in Southeast Asia, the seismic performance analysis is recommended in this region. Myanmar National Building Code, 2016 which is adapted from ASCE 7-05 is stipulated to examine the analysis by the Federation of Myanmar Engineering Society (Fed. MES). The geometric mean of the two horizontal spectral accelerations is typically used by the earth scientists as the intensity measure for hazard analysis and early effort to account for the seismic design of the structure. Shortcoming of the geomean ground motion intensity definition, the maximum spectral acceleration of the two orthogonal components in any orientation is used in the recent ASCE 7-16 for structural design. In this study, the factors which are the ratio of maximum spectral acceleration ($Sa_{RotD100}$) to median spectral acceleration (Sa_{RotD50}) at discrete period is used to predict the maximum spectral acceleration over all orientations. The objective of the study is to analyze the effect of the two-horizontal definitions in ground motion selection. The comparison of the regular and irregular shaped RC building structural responses is also explored with equivalent lateral force analysis (ELF), response spectrum analysis (RSA) and Linear response history analysis (LRHA). The final response results show the great potential in the performance-based design of the civil system.

Keywords: Geomean Response Spectral Acceleration, Maximum Response Spectral Acceleration, Equivalent Lateral Force Analysis, Response Spectrum Analysis, Linear Response History analysis

1. Introduction

Dynamic structural analysis is commonly used to predict the response of a structure subjected to earthquake ground motions. The different responses of a structure could be resulted by the different ground motions. Thus, ground motion selection become one of the important issues in the seismic performance analysis. There are three orthogonal components of ground motion that accelerogram records: two in the horizontal direction and one in vertical direction. In this study, the two-dimensional intensity of ground motion is taken into account to compute response spectrum by using two orthogonal horizontal components of the ground motion. The geometric mean spectrum is the most widely used horizontal definition to combine the directionally varying two single-component spectral accelerations into a single numerical value [1]. Nevertheless, it doesn't give the values vary with the orientation of horizontal ground motion axes recorded. Due to the shortcoming of the geomean definition, researchers developed the definition of median spectral acceleration (Sa_{RotD50}) and maximum spectral acceleration ($Sa_{RotD100}$) over all orientation [2]. In the seismic design of the structure, $Sa_{RotD100}$ observed all over orientation was deemed more appropriate than the geometric mean horizontal definition. Nowadays, the updated version of seismic provision and ASCE 7-16 [3] provide the maximum direction ground motion instead of geometric mean of two orthogonal components ground motions. Myanmar National Building Code, (MNBC) 2016 [4] is based on the references of Minimum Design Loads for Buildings and Others Structures, ASCE 7-05 [5] and the framework is also similar to the National Earthquake Hazards Reduction Program (NEHRP), 2003 Seismic Design Provision [6]. This study has been performed to figure out how the regional code ground motion definition and the maximum ground motion effects on the reinforce concrete moment frames. The regular and irregular RC moment frame located at Mandalay city which is very close to the major strike slip fault in Myanmar are designed and analyzed by performing permitted analytical procedure.

2. Earthquake Ground Motion

In earthquake engineering, ground motion referred to as the ground acceleration, velocity and displacement. The three amplitude parameters: peak ground acceleration (PGA), peak ground velocity (PGV) and peak ground displacement (PGD) are the particular interests in most cases amplified when transmitted through the structure by ground vibration. The strong motion instruments are used to measure the earthquake ground motion and record the ground acceleration [7]. Moreover, 5% damped spectral acceleration can also be described in either single arbitrary components or the combination of two orthogonal horizontal components. The geometric mean response spectrum computed using two orthogonal ground motion components is the most widely used horizontal definition and it depends on the recording orientation. There are many others proposed orientation independent definitions: $Sa_{GMRotDnn}$ and $Sa_{GMRotInn}$ by Boore et al, 2006 [8] and Sa_{RotDnn} and Sa_{RotInn} by Boore, 2010 [1] to remove the orientation independence. The PEER ground motion database introduced new spectral acceleration to remove the recorded orientation; Sa_{RotD50} (median) and $Sa_{RotD100}$ (maximum) as an intensity measure. Current ground motion prediction equations (GMPE) use median spectral acceleration (Sa_{RotD50}) which is the 84th percentile of the geometric mean response [9]. Shahi and Baker developed the model for maximum direction spectral acceleration ($Sa_{RotD100}$) by using over 3000 ground motions from the NGA West 2 database. The ratio of $Sa_{RotD100}$ to Sa_{RotD50} is evaluated as a multiplicative factor to predict the maximum spectral acceleration of a model at a site. According to Shahi and Baker [10], the polarization of the ground motion referred to the directionality of ground motion which causes the discrepancy among different definitions of response spectra. The ground motion is unpolarized, means the ratio of $Sa_{RotD100}$ to Sa_{RotD50} is close to 1 when it has an approximately equal response spectrum in all orientations at a given period. The 1994 Chi Chi earthquake gives the ratios of 1 for unpolarized case and 1.414 for polarized case at 1 second period. Thus, according to the proposed paper, the ratio of Sa_{Rot100} to Sa_{RotD50} for any ground motion will be within the range of 1 to 1.414 to convert the maximum response ground motion [10]. Huang et al [11] also examined for maximum response with moment magnitude greater than 6.5 and less than 15km site to source distance. The result presented that the maximum response parameters can be obtained by using the factors of 1.1 and 1.3 to short and 1-second 5%damped, spectral acceleration parameters [11].

3. Seismic Hazard Level of Mandalay City

Mandalay city is selected for the site location for the study. It is the second largest city and located very close to the most active dextral Sagaing fault in Myanmar. The Sagaing fault is a major north-trending right lateral strike-slip fault and 8 km away from Mandalay city [12]. Thus, the scale of disaster from seismic excitation will be increased in the cities due to urbanization the vulnerability is increased. MNBC, 2016 brings together the information on the ground motion parameters which are described by the maximum considered earthquake (MCE) spectral response acceleration with 5% damping ratio at short period, S_s (0.2 sec) and at one second period, S_1 (1.0 sec) of Mandalay city are 2.01g and 0.8g respectively [4]. The site class D (stiff soil) and Vs30 ranges from 220m/s to 340m/s is assumed for nearly all of the sites in Mandalay according to the seismic microzonation report of Mandalay city [13]. The response spectrum at design and maximum considered earthquake levels for both geomean and maximum ground motion are illustrated in Fig 1. The geomean code spectra for DBE and MCE are constructed by applying spectral acceleration parameters relative to MNBC, 2016 while the DBE and MCE of $Sa_{RotD100}$ spectra are resulted by provided factors of Shahi and Baker, 2013 [10].

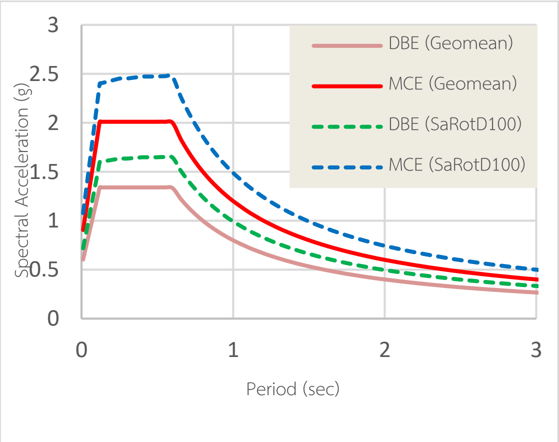

Fig. 1 MCE and DBE of Geomean and SaRotD100 target spectra for Mandalay City

4. Structural Modeling and Analysis

The feature of regular and symmetric building in both plan and elevation enormously affects the building response under static and dynamic loading [14]. Moreover, the structural analysis of the irregular structures is also needed to perform for the adequate behavior of the structures under earthquake excitation [15]. This study focused on 10-story rectangular shaped building (model 1) and L-shaped building with plan irregularity (model 2). The plan of the two office buildings with special concrete moment resisting frame (SMRF) is designed to account for resisting the lateral loads and described in Fig 2 and Fig 3. The story height of 3 m and constant span length of 4.5m in both X-direction and Y-direction is taken for the building design. Minimum load consideration for the loads and the combinations of the loads are adapted from the Myanmar National Building Code, 2016 [4]. The compressive strength of the concrete (f_c') and the yield strength of the steel reinforcement (f_y) used to model these structures are 28 MPa and 413 MPa. The total dead load is supposed to account for the self-weight and additional dead load (super imposed dead load) is 1.5kN/m^2 (typical) and 1kN/m^2 (roof floor). The live load of 2.5kN/m^2 and 1kN/m^2 for typical and roof level is taken into account. The load patterns are added as distributed loads on the slab and all the joints of the structure are assigned as rigid which means fixed support at the base. Moreover, the effective stiffness of the structural components (beams, columns and slabs) are taken into account for the cracked section behavior, according to the American Concrete Institute Code, ACI, 2005 [16]. The response modification factors (R=8), overstrength factor (Ω=3), and deflection amplification factor (C_d=5.5) is considered as code-based parameters for the inelastic behavior of the structure. The models are also checked for the structural irregularities and l-shaped model meets Type-2 horizontal irregularity. The lateral loads to each story by the equivalent lateral force procedure are calculated manually and compared to the ETABS, 2016 [17] results. Moreover, modal response spectrum analysis that is permitted in the MNBC is carried out to check the response of the structure. The sufficient number of modes, at least 90% of the modal participation mass is considered in each of the orthogonal directions of the building. The modal participation mass ratios are summarized in table 1 and table 2 for both models.

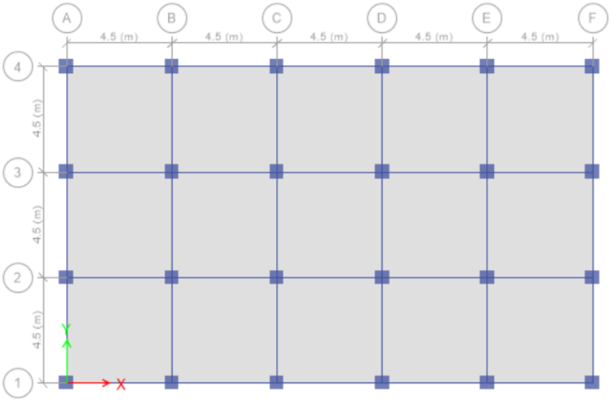

Fig. 2 "2D" view of Model 1

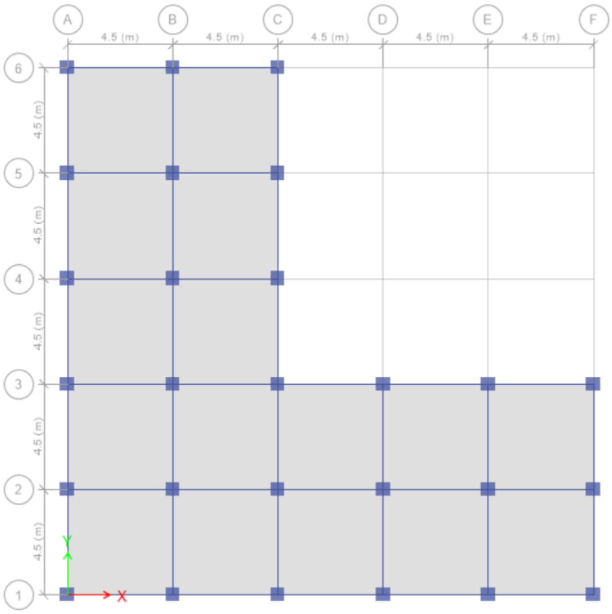

Fig. 3 "2D" view of Model 2

Table 1 Modal participation mass ratio of rectangular building

Case	Mode	Period	UX	UY	RZ
Modal	1	1.542	0	0.7855	0
Modal	2	1.478	0.789	0	0
Modal	3	1.286	0	0	0.7911
Modal	4	0.482	0	0.1029	0
Modal	5	0.464	0.1012	0	0
Modal	6	0.406	0	0	0.0997
Modal	7	0.259	0	0.0425	0
Modal	8	0.252	0.0419	0	0
Modal	9	0.222	0	0	0.0415
Modal	10	0.164	0	0.0246	0
Modal	11	0.161	0.0242	0	0
Modal	12	0.143	0	0	0.024

Table 2 Modal participation mass ratio of L-shaped building

Case	Mode	Period	UX	UY	RZ
Modal	1	1.504	0.3788	0.3788	0.028
Modal	2	1.499	0.3932	0.3932	0
Modal	3	1.331	0.0146	0.0146	0.7602
Modal	4	0.47	0.0498	0.0498	0.003
Modal	5	0.469	0.0513	0.0513	0
Modal	6	0.419	0.0013	0.0013	0.0982
Modal	7	0.253	0.0209	0.0209	0.0006
Modal	8	0.253	0.0212	0.0212	0
Modal	9	0.228	0.0002	0.0002	0.0414
Modal	10	0.161	0.0122	0.0122	0.0001
Modal	11	0.161	0.0123	0.0123	0
Modal	12	0.146	0.000037	0.000037	0.0243

5. Ground motion selection and scaling

The selection of the ground motion is done by using PEER West-2 ground motion database to perform linear response history analysis. At least three time-history of earthquakes must be applied according to the code requirement and average response can be resulted by seven or more earthquakes. In Tall Building Initiative Guideline (TBI), 2010 a minimum of seven ground motions set is selected to conduct time history analysis in this study [18]. According to the PEER website, these ground motions will be selected by tectonic type, magnitude, site to source distance, soil condition of specific site, frequency, scale factor limitation, spectral shape, maximum number of ground motion, considered period range. The magnitude of Mw 5.5 to 8 earthquakes by the source of strike slip fault type, 0km to 5km range of site to source distance and limitation on scale factor (1-4) are criteria to select the ground motions. The ground motion database obtained from the PEER website are scaled by mean square error within the period range of 0.2T to 1.5T and cooperated in ETABs. The seven ground motion records resulted from the PEER ground motion database and scale factors used for the analysis are shown in table 3 and table 4 for geomean response spectrum and $Sa_{RotD100}$ response spectrum. Since, the fundamental periods of both models are nearly the same, they have similar scale factors. Moreover, 2 sets of seven bi-directional ground motion excitations are chosen for three-dimensional analysis according to the code that is illustrated in Fig 4-5 (for rectangular building) and Fig 6-7 (for L-shaped building).

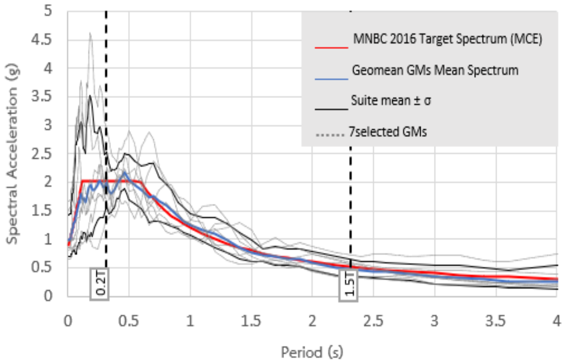

Fig. 4 Geomean ground motions set for rectangular building

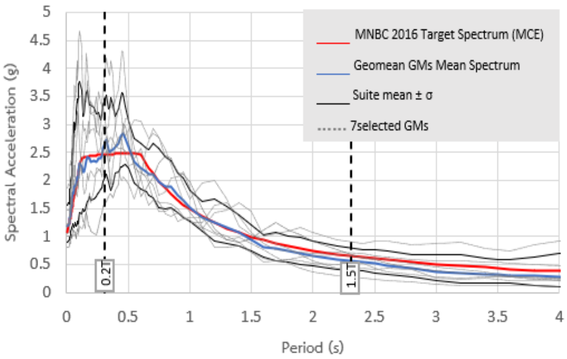

Fig. 5 SaRotD100 ground motions set for rectangular building

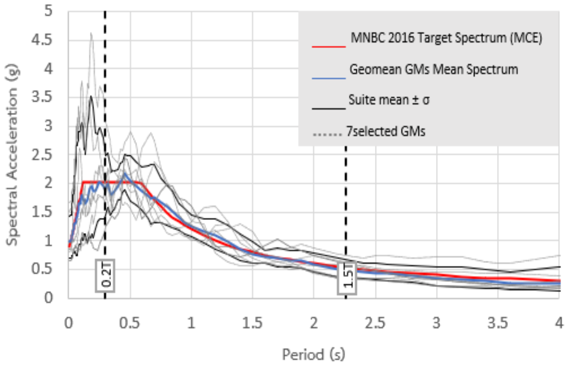

Fig. 6 Geomean ground motions set for L-shaped building

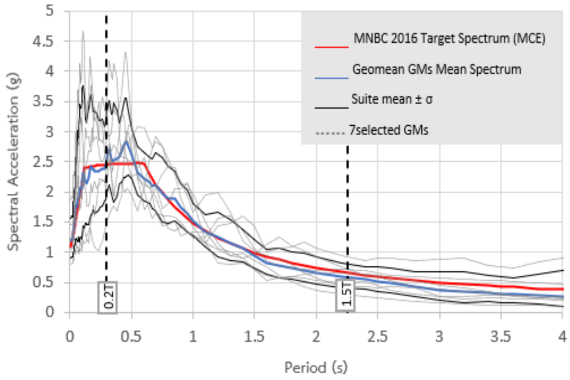

Fig. 7 SaRotD100 Ground motions set for L-Shaped building

6. Results and discussion

The displacement, drift, shear and overturning moment of the irregular and irregular structures are analyzed in ETABS, 2016 by using Equivalent lateral force analysis (ELF), response spectrum analysis (RSA) and linear response history analysis (LRHA). These three analyses are conducted according to MNBC, 2016. The linear response history of three-dimensional analysis is responsible by bi-directional excitation of each ground motion of the geometric mean directionality combination and maximum directionality of ground motions. The two spectra at maximum considered earthquake level are used as target spectra to select seven ground motions from the PEER ground motion database for linear response history analysis. The average responses of both geomean and maximum direction response spectra in each direction (X and Y directions) are calculated and illustrated for two buildings in the following Fig 8-11. The story drift increases from bottom story to the 3rd story and gradually decreases in both models for all analysis. It can be seen that the maximum story drift is observed in irregular model and minimum drift in the regular building respectively. The story displacement in ELF analysis is different around 5-10% from X and Y direction due to its change of moment of inertia. The geomean LTHA overturning moment in Y-direction is slightly lower than that of ELF and higher above 4th story in both structures. The story shear in X direction all over analyses have the same pattern with other responses and have lower difference in the mid-story levels in Y-direction. Moreover, the response of the L-shaped building follows the same pattern as the rectangular building. In general, irregular shaped building shows larger structural responses than the regular structure and the maximum response can be observed that Y-directional response is higher than that of X-direction. The contribution of structural response in ELF overestimates than that of RSA because it ignores the higher mode of the structures. Since the response spectrum of $Sa_{RotD100}$ has larger values than the geomean response spectrum, the selected ground motions also have higher spectral acceleration values for $Sa_{RotD100}$. Based on Huang et al 2008, maximum response spectral acceleration at short and 1 second period have larger values than that geomean response spectral acceleration [11]. Thus, the larger story responses are resulted by $Sa_{RotD100}$ compared with the geometric mean time history analysis in this study. As a result, approximate range of 20%-40% difference is observed in both directions by LRHA for geomean and maximum direction response spectra. Thus, the amount of these differences is significant in performing seismic analysis.

7. Conclusions

In this study, the effect of two horizontal definitions in ground motion selection is investigated by performing static and dynamic analysis on regular and irregular building which is located in Mandalay city, Myanmar. The different ground motions are obtained by different MCE spectra in the selection of ground motions. In general, larger structural responses are controlled by the maximum direction definition compared to the geomean horizontal definition. The results showed the considerable effect on the response of the structure by maximum direction spectral accelerations even though MNBC, 2016 counts for geomean spectral acceleration. On the other hand, using more ground motions could capture all the variability of different characteristics of every single ground motion. Thus, it gave the option to consider the maximum response acceleration in ground motion selection in MNBC code.

Table 3 Selected earthquake ground motions for geomean response spectra

ID	RSN	Earthquake Name	Year	Mw	Rrup (km)	Vs30 (m/sec)	SF
1	6	"Imperial Valley-02"	1940	6.95	6.09	213.44	3.4944
2	165	"Imperial Valley-06"	1979	6.53	7.29	242.05	3.6254
3	183	"Imperial Valley-06"	1979	6.53	3.86	206.08	2.8105
4	864	"Landers"	1992	7.28	11.03	379.32	2.9073
5	1101	"Kobe_ Japan"	1995	6.9	11.34	256	2.1579
6	5825	"El Mayor-Cucapah_ Mexico"	2010	7.2	10.92	242.05	2.9202
7	6893	"Darfield_ New Zealand"	2010	7	11.86	344.02	3.3752

Table 4 Selected earthquake ground motions for $Sa_{RotD100}$ response spectra

ID	RSN	Earthquake Name	Year	MW	Rrup (km)	Vs30 (m/sec)	SF
1	183	"Imperial Valley-06"	1979	6.53	3.86	206.08	3.4712
2	558	"Chalfant Valley-02"	1986	6.19	7.58	316.19	2.8869
3	725	"Superstition Hills-02"	1987	6.54	11.16	316.64	3.919
4	864	"Landers"	1992	7.28	11.03	379.32	3.5908
5	1101	"Kobe_ Japan"	1995	6.9	11.34	256	2.6652
6	5825	"El Mayor-Cucapah_ Mexico"	2010	7.2	10.92	242.05	3.6067
7	5829	"El Mayor-Cucapah_ Mexico"	2010	7.2	13.71	242.05	3.0299

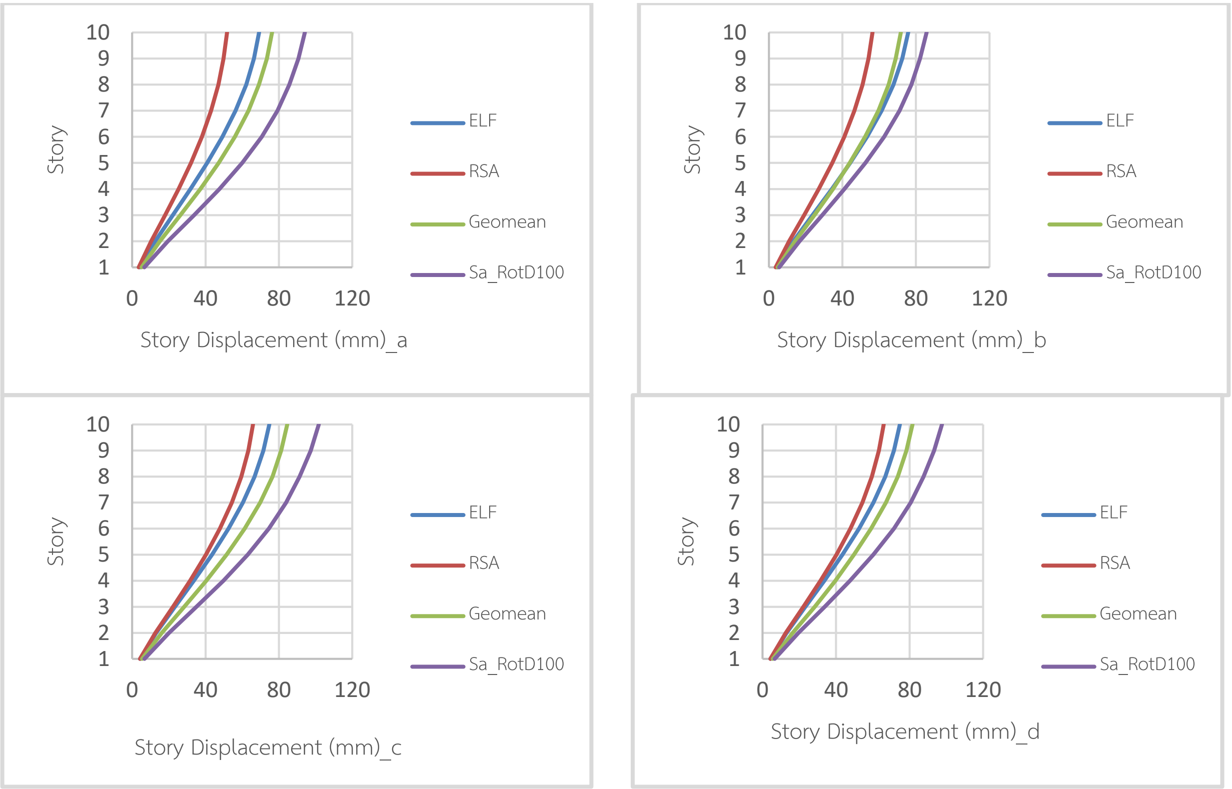

Fig. 8 Story displacement from ELF, RSA and LRHA (geomean and $Sa_{RotD100}$) of model1 (a-X direction, b-Y direction) and model2 (c-X direction, d-Y direction)

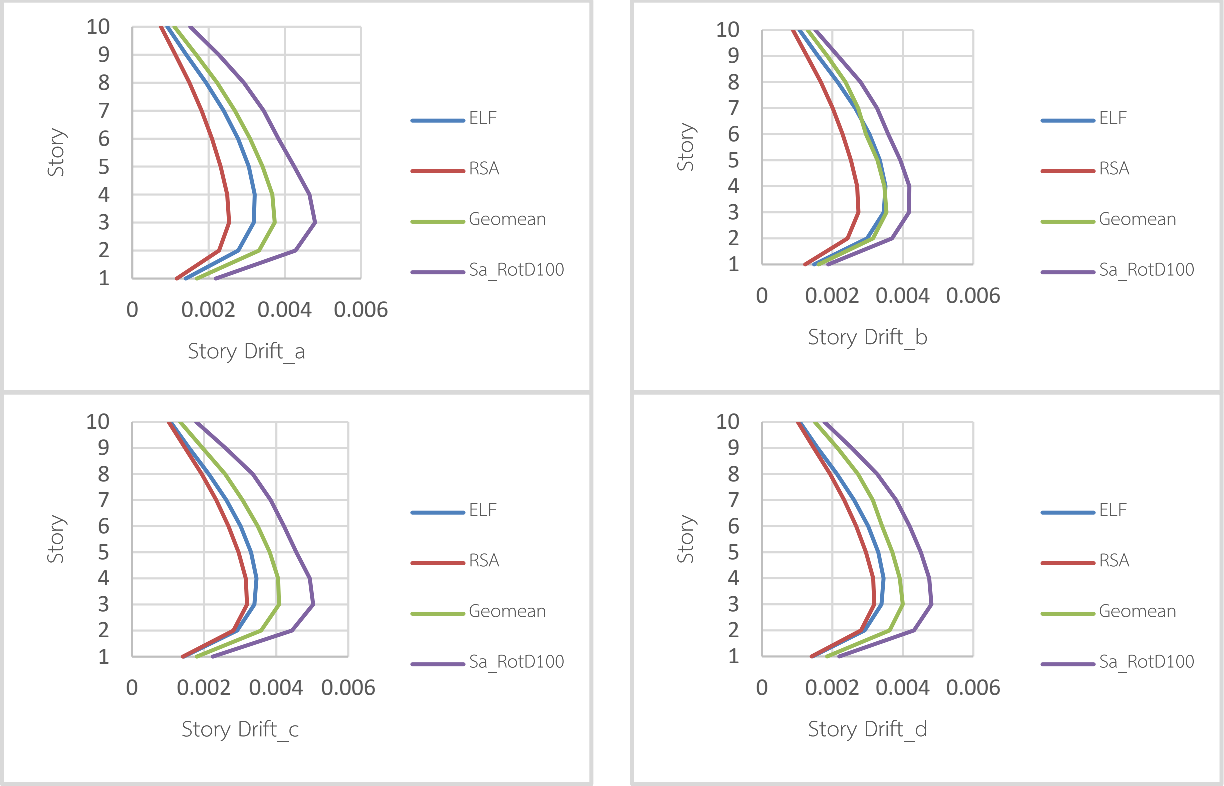

Fig. 9 Story drift from ELF, RSA and LRHA (geomean and $Sa_{RotD100}$) of model1 (a-X direction, b-Y direction) and model2 (c-X direction, d-Y direction)

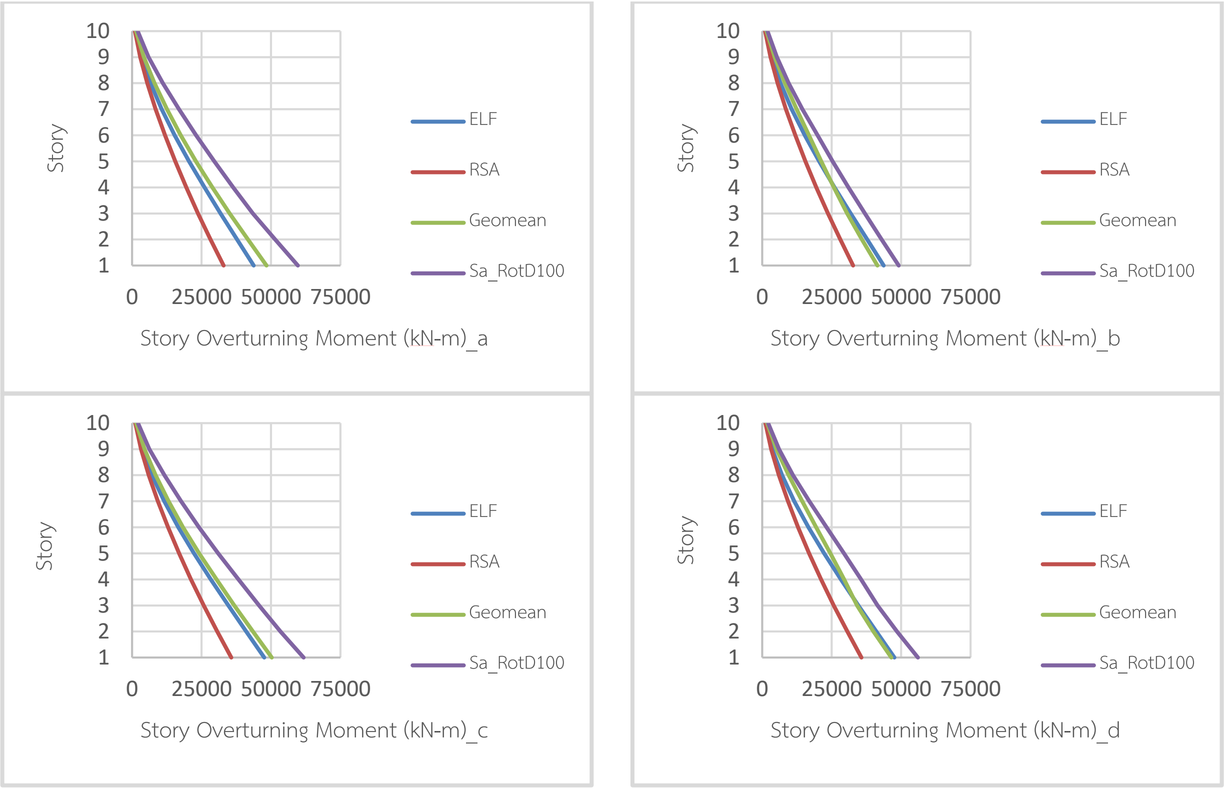

Fig. 10 Story overturning moment from ELF, RSA and LRHA (geomean and SaRoD100) of model1 (a-X direction, b-Y direction) and model2 (c-X direction, d-Y direction)

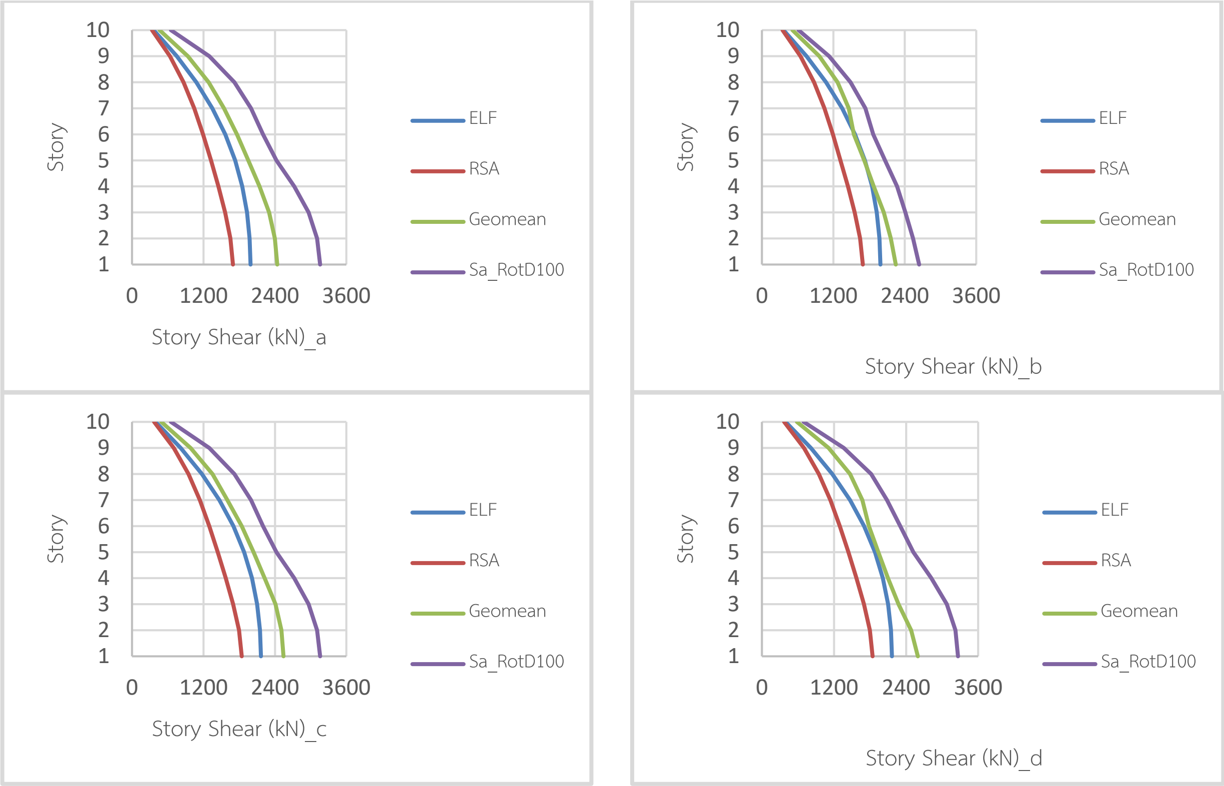

Fig. 11 Story shear from ELF, RSA and LRHA (geomean and SaRoD100) of model1 (a-X direction, b-Y direction) and model2 (c-X direction, d-Y direction)

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