Effect of Scaling Factor in Ground Motion Selection of Seismic Analysis and Design of RC Moment Frame Structures

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Abstract

Selection and Scaling of ground motion plays a major role in designing the structural analysis since the collected data will be applied as seismic load to the structure. Spectrum matching to a smooth target spectrum with the specific input parameters of the scenario; magnitude and source-to-site-distance are focused; is considered in the research. Target spectrum is selected by using the ASCE code guideline. The paper includes three analysis procedures (1) Equivalent lateral force, (2) Response spectrum analysis and; (3) Time history analysis; are applied to the structures which are multi-degree-of-freedom structures with different fundamental periods of vibrations. Seven sets of ground motion suites are collected based on different scale factor ranges from PEER-NGA website. Using scale factor more than limit 4, effect the lateral displacement demand of the structural analysis which lead to bias in some cases. This study indicated that using scale factor less than 1 tend to underestimate the structural response and more cracking than the limit 4 tend to overestimate the demand which is not convenient in practice.

Keywords: Scale factor, ASCE code, PEER-NGA, Ground motion scaling, Magnitude, Source-to-site-distance

1. Introduction

Over the recent years, structural responses are predicted through the various analysis which are dynamic analysis and static analysis by following the respective building codes. There have international building codes like IBC [1], ASCE 7-10 [2] and regional codes like Myanmar National building code (MNBC-16) [3]. For conducting the equivalent static lateral force analysis, response spectrum analysis and time history analysis for both linear and non-linear approach, those codes provide the guidelines for the estimation the structural responses. To analyze the time history response of the structure, ground motions are needed to assign the model analysis. The increased of the complication in selecting, scaling and matching the accelerogram procedure, engineers have been asking how ground motions should be chosen and what factors are needed to consider. It is common in practice to select recorded ground motions and 'scale' them by increasing their amplitude to match a desired earthquake intensity level. The selected suite of ground motions is scaled (normally upward) by using the scale factor to match the target spectrum. By limiting the scale factor range while searching the ground motions suite, the results of site hazard is more accurate. According to the ASCE-7 code, the allowable limit of scale factor is nearly 0.25 to 4. Recent research showed there have some bias in record scaling when the larger scale factor is used (more than 4).

In this study, the multi-story reinforced concrete moment frames are used to check the effect of using large scale factor on the structural responses. Two different shapes and stories of regular shape buildings are analyzed in three-dimensional static analysis by using Etabs software [4] and the research area is located in Mandalay region, Myanmar where the seismic hazard zone is zone V.

2. Modeling of reinforced concrete moment frames

The main components of RCC framed structures are beams, columns, slabs and the foundation inter-connected to each other. Loads transfer process of these structure types is from slabs to beams, from beams to columns and finally columns to foundation. This study adopted two cases of regular reinforced moment frames with different shapes and stories by modeling through the Etabs 2016 version. Both buildings are considered as the high-rise buildings and the modeling standards are based on ACI 318-08[5] and MNBC-2016. 8 story buildings with 3 bays in X-direction and 8 bays in Y-direction while 10 story one has 9 bays in X-direction and 7 bays in Y-direction with the C-shape plan. Each bay is 5m wide with bottom story height 4m and floor to floor height is 3m. 3-dimensional views of those buildings are shown in Fig. 1.

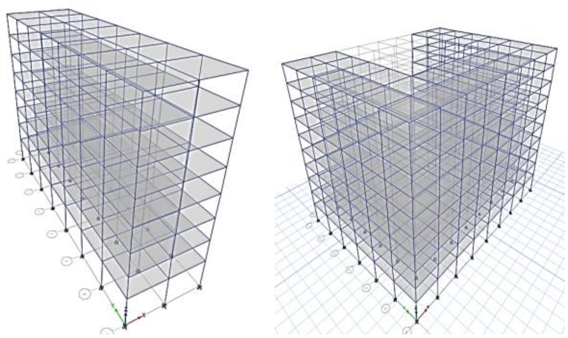


Fig. 1 3-dimensional view of archetype buildings

Table 1 General specification of buildings.

Input properties	Values
Compressive stress, f'c	28 MPA (4000psi)
Modulus of elasticity, EC	24870 MPA
Superimposed dead load	2 kN/m2
Live load	2.4 kN/m2

The first mode or the fundamental mode of the two buildings are 1.366sec for 8-story and 1.628sec for 10-story. Based on those modes, the ground motions are selected and scaled to match the target response spectrum.

3. Seismic hazard level of study area

The study area is located at the Mandalay region, Myanmar with the nearest active fault of Sagaing which is 1200 km long right lateral strike-slip fault [6]. The spectral response acceleration values at short periods Ss and 1 sec period S1 are 2.01 and 0.8 with the long period transition period TL is 6 sec which are taken according to the MNBC-16. The soil type profile is stiff soil (type D) and the shear wave velocity Vs30 is 200-400 m/sec. Maximum considered earthquake (MCE) level hazard spectrum with 2% probability of exceedance in 50 years was developed according to MNBC-16.

4. Ground motion selection and scaling

The selection and scaling of ground motions procedure is based on TBI (2010) [7] approach. From PEER NGA-West2 [8] database, all the earthquake ground motions used in this study are selected. Seven sets of ground motions are used and the scaling method is amplitude scaling within the target period range of interest 0.2T1 to 1.5T1 where T1 is the fundamental vibration of the structure as TBI guideline. When selecting from PEER website, various criteria are needed to restrict according to the study area. The shear wave velocity for the study is 200-400 m/sec with the magnitude range of 6.5 to 7.5 and the fault type is strike-slip fault. Since the main focus of the research is the effect of using larger scale factor than the limit 4 as ASCE code said, two cases are conducted in ground motions selections. Case 1 is selecting scale factor range from 1-4 and the other is range from 10-15. Table 2 illustrate the selection criteria for both cases. The records are scaled to minimize the Mean Squared Error (MSE) with respect to the Target Spectrum. According to TBI (2010) approach, the spectral ordinate is geomean and suite average is considered as geometric mean.

Table 2 Ground motion selections criteria.

Criteria	Case1	Case2
Magnitude	6.5-7.5	6.5-7.5
Range of closet distance Rrup	0.1-10 km	50-100km
Shear wave velocity Vs (m/sec)	200-400	200-400
Scale Factor	1-4	10-15
Spectral ordinate	Geomean	Geomean
Suite Average	Geometric	Geometric
Scaling Method	Minimize MSE	Minimize MSE

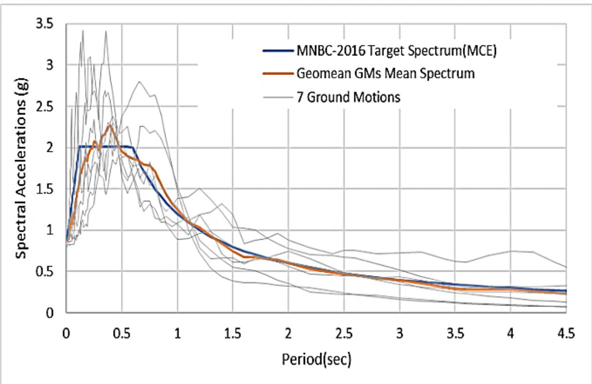


Fig. 2 Case 1 ground motions set for 8-story building

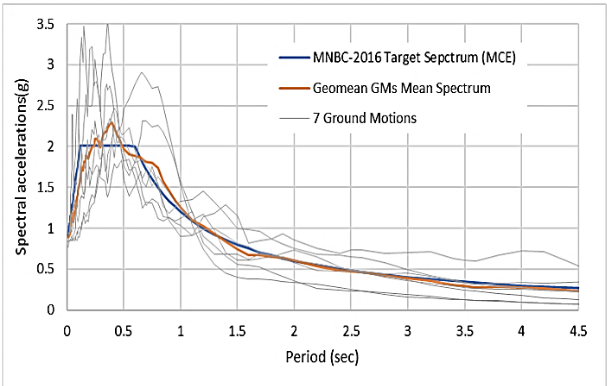


Fig. 3 Case 1 ground motions set for 10-story building

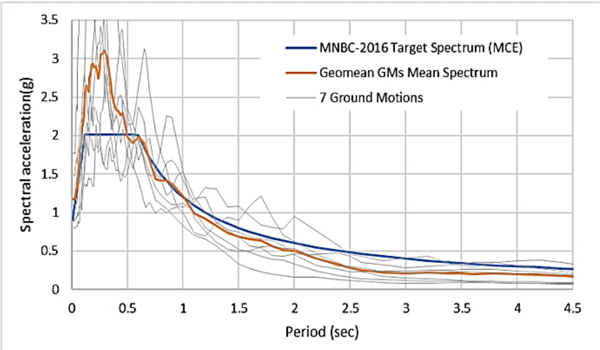


Fig. 4 Case 2 ground motions set for 8-story building

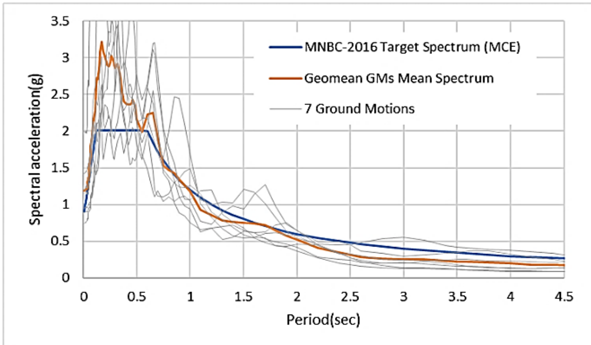


Fig. 5 Case 2 ground motions set for 10-story building

Table 3 Selected ground motions for 8-story building.

Result ID	NG	Earthquake Name	Year	Station Name	Magnitude	Duration (sec)	Rrup (km)	Vs30 (m/sec)	Scale Factor
1	6	"Imperial Valley-02"	1940	"El Centro Array #9"	6.95	24.2	6.09	213.44	3.5314
8	184	"Imperial Valley-06"	1979	"El Centro Differential Array"	6.53	7	5.09	202.26	2.5259
10	723	"Superstition Hills-02"	1987	"Parachute Test Site"	6.54	11	0.95	348.69	1.9451
12	1106	"Kobe_ Japan"	1995	"KJMA"	6.9	9.5	0.96	312	1.127
14	3968	"Tottori_ Japan"	2000	"TTRH02"	6.61	35.3	0.97	310.21	1.0642
15	5825	"El Mayor-Cucapah_ Mexico"	2010	"CERRO PRIETO GEOTHERMAL"	7.2	44.2	10.92	242.05	2.9855
16	6897	"Darfield_ New Zealand"	2010	"DSLC"	7	19.6	8.46	295.74	3.6207
1	280	"Trinidad"	1980	"Rio Dell Overpass - FF"	7.2	12.4	76.26	311.75	13.6071
2	836	"Landers"	1992	"Baker Fire Station"	7.28	25.7	87.94	324.62	10.1817
5	1776	"Hector Mine"	1999	"Desert Hot Springs"	7.13	28.1	56.4	359	11.9096
10	3914	"Tottori_ Japan"	2000	"OKY011"	6.61	16.5	67.34	212.21	10.9854
11	5835	"El Mayor-Cucapah_ Mexico"	2010	"Winterhaven -Sheriff Substation"	7.2	42.6	73.31	229.92	14.385
14	5968	"El Mayor-Cucapah_ Mexico"	2010	"Bombay Beach"	7.2	108.1	77.9	348.77	14.7709
17	6239	"Tottori_ Japan"	2000	"KGW001"	6.61	9.6	99.39	324.85	13.5734

Table 4 Selected ground motions for 10-story building.

Result ID	NG	Earthquake Name	Year	Station Name	Magnitude	Duration (sec)	Rrup (km)	Vs30 (m/sec)	Scale Factor
1	6	"Imperial Valley-02"	1940	"El Centro Array #9"	6.95	24.2	6.09	213.44	3.4837
8	184	"Imperial Valley-06"	1979	"El Centro Differential Array"	6.53	7	5.09	202.26	2.572
9	723	"Superstition Hills-02"	1987	"Parachute Test Site"	6.54	11	0.95	348.69	1.8749
11	1106	"Kobe_ Japan"	1995	"KJMA"	6.9	9.5	0.96	312	1.158
12	3968	"Tottori_ Japan"	2000	"TTRH02"	6.61	35.3	0.97	310.21	1.1031
13	5825	"El Mayor-Cucapah_ Mexico"	2010	"CERRO PRIETO GEOTHERMAL"	7.2	44.2	10.92	242.05	2.8933
14	6897	"Darfield_ New Zealand"	2010	"DSLC"	7	19.6	8.46	295.74	3.7638
1	280	"Trinidad"	1980	"Rio Dell Overpass - FF"	7.2	12.4	76.26	311.75	14.8934
3	836	"Landers"	1992	"Baker Fire Station"	7.28	25.7	87.94	324.62	10.665
5	1766	"Hector Mine"	1999	"Baker Fire Station"	7.13	23.1	64.79	324.62	10.8167
10	1816	"Hector Mine"	1999	"North Palm Springs Fire Sta #36"	7.13	25.7	61.86	367.84	12.1319
12	3914	"Tottori_ Japan"	2000	"OKY011"	6.61	16.5	67.34	212.21	12.3143
13	5835	"El Mayor-Cucapah_ Mexico"	2010	"Winterhaven -Sheriff Substation"	7.2	42.6	73.31	229.92	14.3487
19	6027	"El Mayor-Cucapah_ Mexico"	2010	"Ocotillo Wells - Veh. Rec. Area"	7.2	21.7	67.71	361.22	11.61

5. Conventional seismic design procedures

The equivalent static lateral force analysis and response spectra analysis, the risk category of both buildings is II, the seismic importance factor I is 1, response modification factor R is 8, overstrength factor omega is 3 and deflection amplification factor Cd is 5.5. From the response spectrum analysis, the base shear should not be less than 85 percent of base shear calculated from equivalent lateral force analysis.

6. Result and discussion

Two different models of regular 8 and 10 stories with different plans are developed by using Etabs 2016 software and all the equivalent static lateral force analysis (ELF), response spectrum analysis (RSA) and time history analysis (THA) are performed as linear elastic model. Since there have been divided Case 1 is for scale factor (1-4) range and Case 2 stands for scale factor (10-15) range, linear time history analysis is conducted for both cases. The comparison of interstory drift ratio of 8 story and 10 story for both X and Y axis are shown in Fig. 6.

The interstory drift ratio of 8 story building has 30% larger seismic demand while conducting Case 2 than Case 1 in X direction and for the Y direction, the demand is only 7% greater but still Case 2 produced large demand than Case 1. Not only in 8 story analysis but also in 10 story building, using scale factor range (10-15) (Case 2) gave more seismic demand 3% and 16% for X direction and Y direction. The percentage are slightly different for each building types since they have different plan views and shapes.

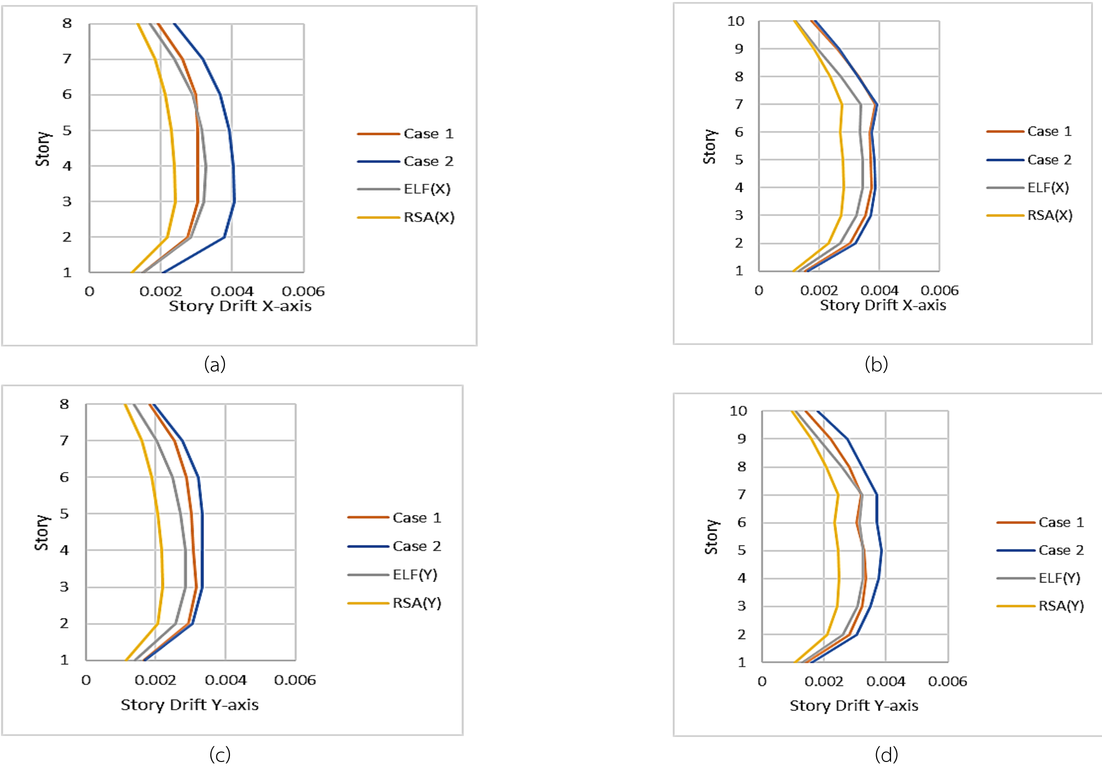


Fig. 6 Story drift ratio calculated from ELF, RSA and LTHA (a) 8story(X-X), (b) 10story(X-X), (c) 8story(Y-Y) and (d) 10story(Y-Y)

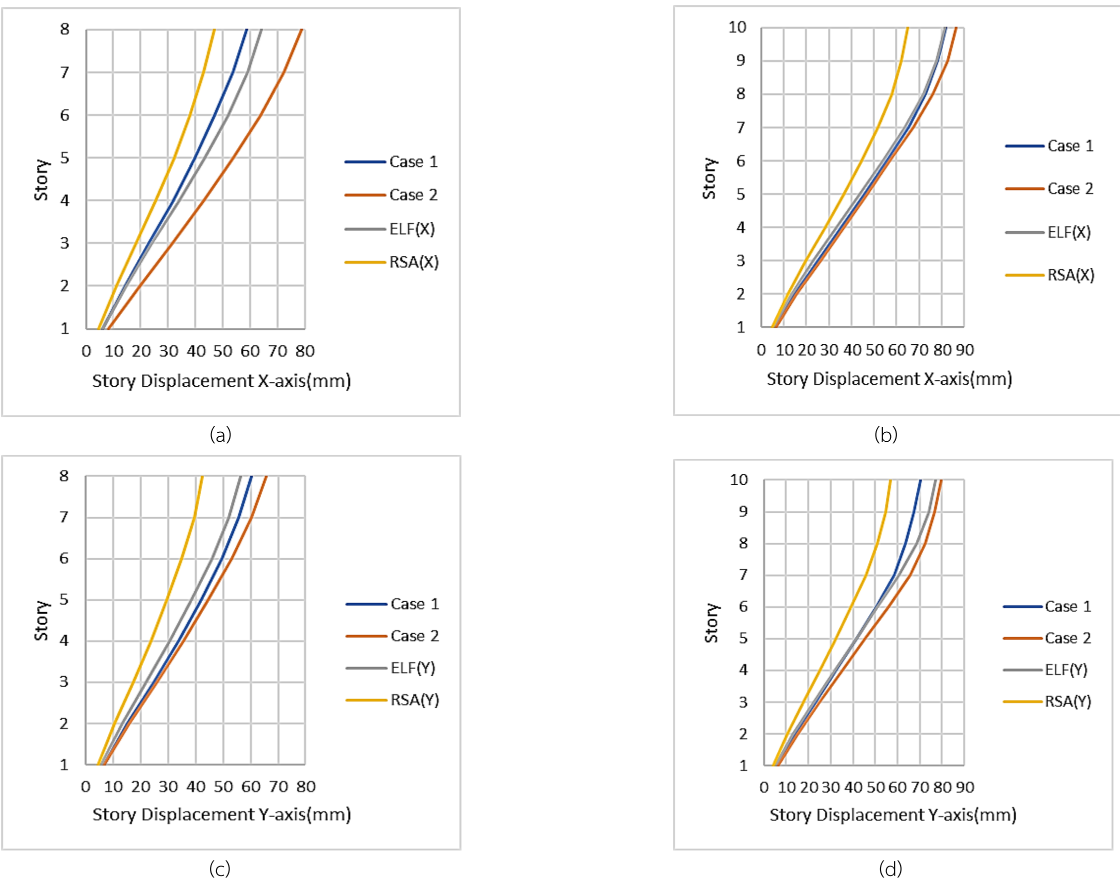
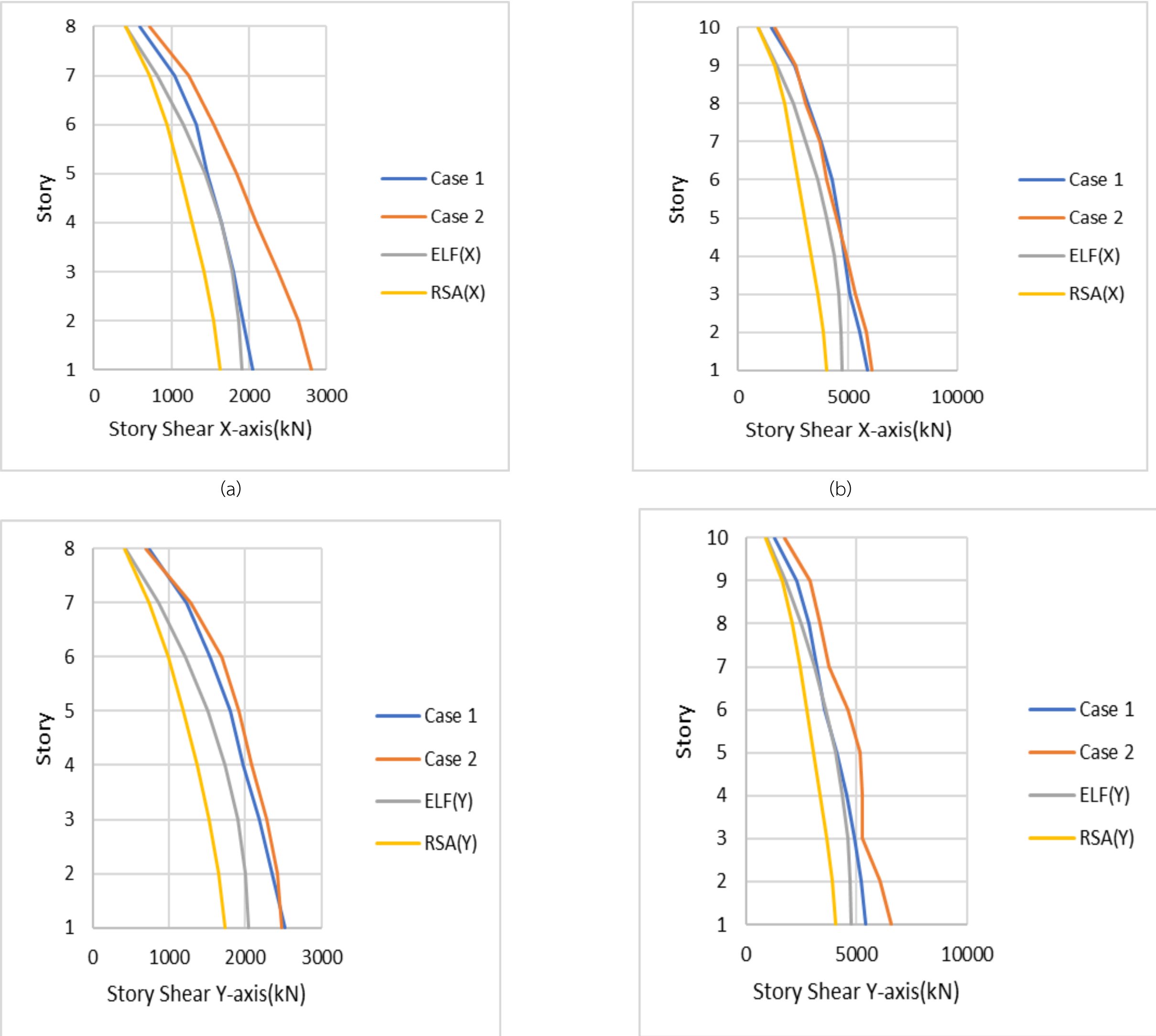


Fig. 7 Story displacement calculated from ELF, RSA and LTHA (a) 8story(X-X), (b) 10story(X-X), (c) 8story(Y-Y) and (d) 10story(Y-Y)



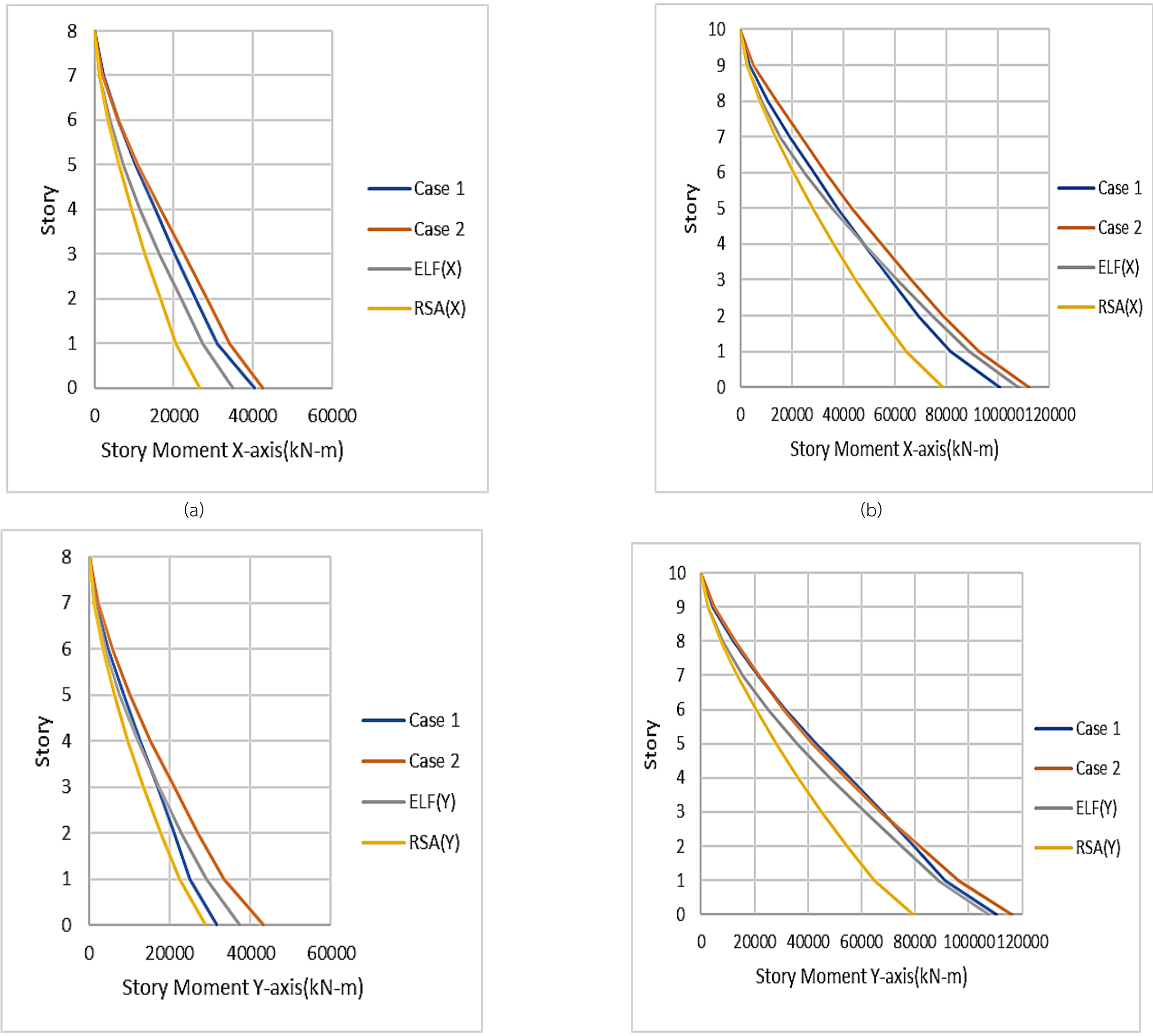
(a) (b) (c) (d)

Fig. 8 Story shear calculated from ELF, RSA and LTHA (a) 8story(X-X), (b) 10story(X-X), (c) 8story(Y-Y) and (d) 10story(Y-Y)

Story displacement computed from RSA got less values compared to LTHA of Case 1 and 2 for both stories. Like the story drift ratio that mentioned above, the displacement for Case 2 is greater demand than Case 1 in both X and Y directions. In 8 story building, ELF produced a more story displacement than Case 1 in X direction while the ELF of 10 story has slightly greater demand than the Case 1 in Y direction.

At the Y direction of the 10-story building, the LTHA of Case 2 can be seen as more fluctuate than the X direction which is 21% greater seismic demand than the Case 1. The elastic base shear demand produced from ELF and RSA found to be smaller than the Case 2. For the conclude of base shear, the demands of LTHA still gave maximum amount for every stories.

The story overturning moment varies inversely with story height. From running the dynamic analysis, it can be pointed out that irregular plans deform more than the symmetrical plans. The moment of 8 story rectangular plan produced more overturning moment than the 10 story with C-shape plane. Fig. 9 represent the story overturning moment of 8 and 10 story for ELF, RSA and LTHA. Computed overturning moments from Case 2 is only 6% greater than the other compared case in X direction of 8 story and 19% in 10 story. Even though the ELF required less seismic demand for two buildings, LTHA is overestimated the demand if the scale factor (10-15) limit is applied to the analysis.



(a) (b) (c) (d)

Fig. 9 Story shear calculated from ELF, RSA and LTHA (a) 8story(X-X), (b) 10story(X-X), (c) 8story(Y-Y) and (d) 10story(Y-Y)

7. Conclusion

Seismic demand of two different reinforced concrete moment frames with different plan views are evaluated by performing the ELF, RSA and LTHA analytical procedure which are following the guideline of TBI (2010) approach through Etabs 2016 version software. The selected seven ground motions site are assigned into linear response history analysis while each pair of ground motions are scaled within the range of 0.2T1 to 1.5T1 period by using the data base from PEER-NGA West 2. Story displacement, IDR, story shear and overturning moment gave the maximum values in both X and Y direction while assigning the scale factor limit (10-15) range for LTHA which is described as Case 2 in this paper. All of the ground motions selected are needed to scale upward to match with the target response spectrum and the bias in lateral displacement demands occurred while using the large-scale factor. The results of the study showed the bias is significant and also can be seen the seismic demands increase as the period of vibration of the structure decrease. To conclude, the lateral displacement demands are increasingly overestimated with an increasing scale factor which is not needed. Therefore, following the TBI (2010) and ASCE-7 codes guideline for limiting the scale factor range (1-4) is safer and can prevent the bias in analysis.

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