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Evaluation of Different Lateral Load Patterns in Estimating Seismic Demands of 3D Mass Eccentric Mid-rise Building

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Abstract— **Nowadays, architects tend to create more complex structures than before. So engineers should become compatible with these ideas especially when they would be located on hazarded areas. For gaining this, two different kinds of 10-story structures for considering Different degrees of coupling between translational and torsional modes, have created from a symmetric structure, considering effects of Soil-Structure Interaction (SSI). Then a series of Nonlinear Response History Analysis (NLRHA) under bidirectional ground motions, are performed to calculating seismic demands of them. Finally, modal pushover analysis (MPA), modified consecutive modal pushover procedure (MCMP) and some lateral load pattern that recommended in FEMA-356 are performed to estimate seismic demands of them. Comparing results of NLRHA and other methods indicate that MCMP procedure is able to catch a good estimation of seismic demands of one way asymmetric plan building.**

Keywords— Consecutive Modal Pushover Procedure (MCMP), Nonlinear Response History Analysis (NLRHA), Pushover, Soil-Structure Interaction

I. Introduction

In recent days, engineer attentions to nonlinear static procedure for estimating seismic demands of buildings are increased. Although, some attempts have been made, most of them are restricted to fundamental mode response and planar frames. To overcome these restrictions, some researches like: modal pushover analysis (MPA) [1], modified modal pushover analysis (MMPA) [2], and a consecutive modal pushover (CMP) procedure [3], have been proposed.

Above mentioned procedures are developed and proposed to estimate seismic demands of asymmetric plan buildings: modal pushover analysis (MPA) [4] and consecutive modal pushover (CMP) procedure [5]. Recently the CMP procedure is modified (MCMP) for estimating seismic demands of one way asymmetric plan tall building with dual systems [6] and with moment resistance frame considering SSI under bidirectional ground motions [7].

The main objective of this paper is to evaluate the MCMP procedure for mid-rise building with moment resistance frame considering SSI under bidirectional ground motions. The outline of this paper could be as follow. First, the definition of structural models and SSI model are given. In continue different types of analyses for specifying and estimating Engineering Demand Parameters (EDPs) such as NLRHA, MCMP procedure, MPA and load patterns recommended in FEMA 356 [8] are mentioned. Finally, some discussion and conclusion over results are done.

II. Definition of models

A. *Structural models*

In this study, a 10-story symmetric plan building with typical 3.5m story height is considered. As shown in Fig. 1, it is a 20m in 20m plan with four bays in each direction that each length of bays is 5m. Rigid diaphragms are assumed in each floor level. The lateral load resistance system is Special steel Moment Resistance Frame (SMRF) in both directions. Beam and column sections are made from ASTM A992 steel. For considering material nonlinearity, Hinges are defined at the ends of the frame members according to the ASCE/SEI 41-06 [9].

The building is located on stiff soil in San Diego, California. The structure is loaded and designed, based on Load and Resistance Factor Design (LRFD) method, using ASCE/SEI 7-10 [10] and AISC 360-10 [11] respectively. The intensity of dead and live load for typical floors are 5.4 and $1.92KN/m^2$ respectively. For roof, the intensity of dead load is $4.91KN/m^2$ and live load is $0.97KN/m^2$. The intensity weight of premier walls is 3.68KN/m. Seismic effects are determined using Response Spectrum Analysis (RSA).

In order to create asymmetric plan, symmetric plan have modified. While the stiffness properties were preserved, the center of mass (C.M.) was defined eccentric relative to the center of stiffness (C.S.) along the y-axis, equal to 20% of the plan dimension, Fig. 2. FEMA P695 [12] recommends to calculate seismic mass using combination of dead (D) and live (L) load: 1.05D+0.25L. Considering this load combination, total translational mass in typical floors and roof are 282078Kg and 219891Kg respectively. Two different types of structure are created from symmetric plan using different polar mass moment of inertia for floors [13]. For creating TS system, the polar mass moments of inertia of floors, in symmetric condition, are multiplied by factor 0.5 to distinguish the translational and torsional modes perfectly. This factor for creating TF system is 3. Applying those factors to create TF and TS system, total polar mass moments of inertia for typical floors of TF system is 69373608Kg.m^2, for roof of TF system is 49475406Kg.m^2, for typical floors of TS system is 11562268Kg.m^2 and for roof of TS system is 8245901Kg.m^2.

B. *Soil-Structure Interaction Model*

Cone model is used for modeling the soil-structure interaction with adequate accuracy in engineering problems [14]. This model assumes that foundation acts as a rigid and soil is a homogeneous half-space. In this study, the mass density of soil and Poisson coefficient are assumed 1800kg/m^3 and 0.3 respectively. The shear wave velocity of the soil is taken 300m/s based on the location of the structure, on soil type D for stiff soil according to ASCE/SEI 7-10 [10]. The structure is erected on 22m in 22m matt foundation with thickness of 1.1m.

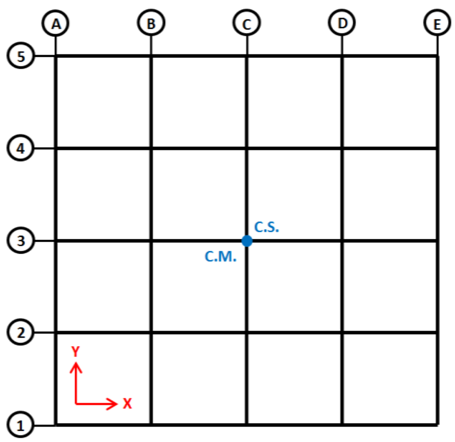

Figure 1. The original symmetric plan

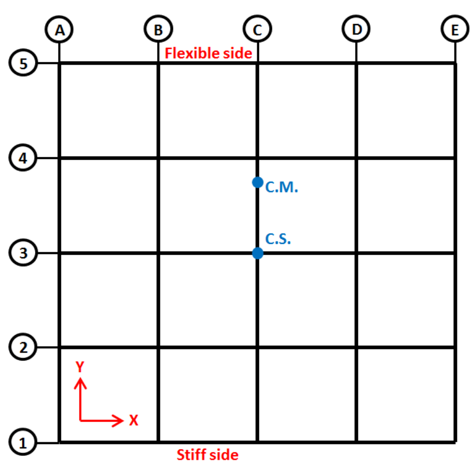

Figure 2. The asymmetric plan

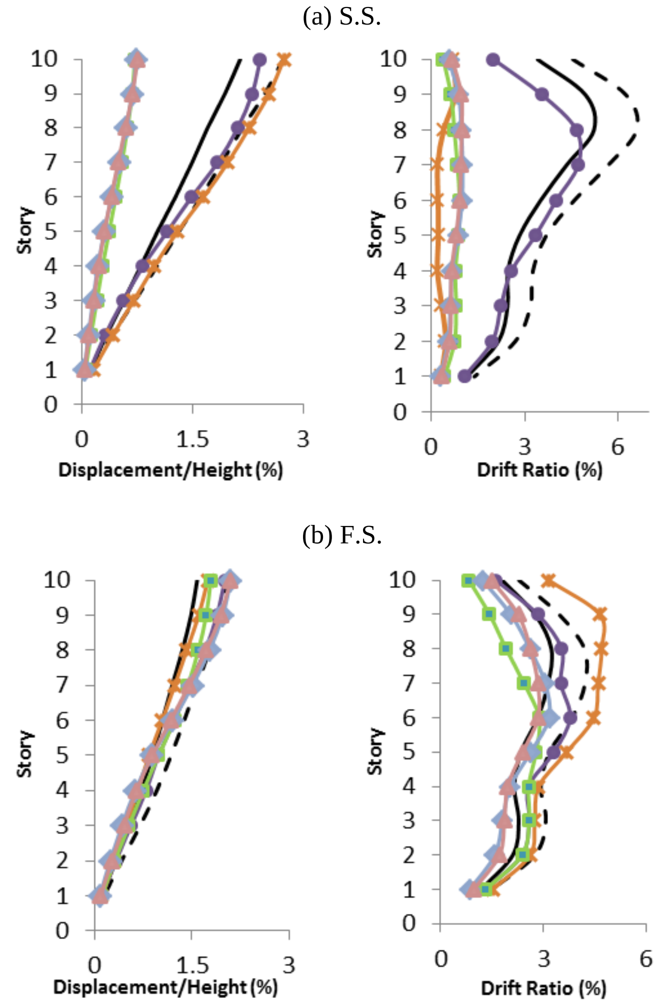

Figure 3. Height-wise displacement and story drift of TF in (a) S.S. and (b) F.S.

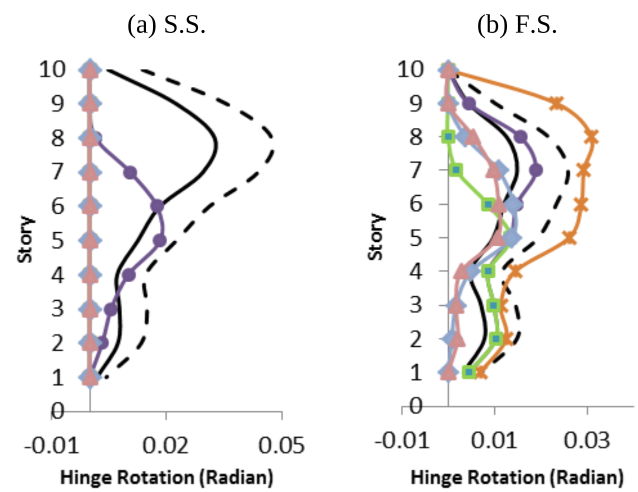

Figure 4. Height-wise hinge plastic rotations of TF in (a) S.S. and (b) F.S.

III. Ground Motions

The Far-Field record set recommended in FEMA P695 [12], includes twenty-two records (44 individual components) selected from the PEER NGA database. As described in FEMA P695 [12], for each record, Table I summarizes the year, name of the event and the name of the station. The twenty-two records are taken from 14 events that occurred between 1971 and 1999. Event magnitudes range from M6.5 to M7.6 with an average magnitude of M7.0 for the Far-Field record set. The minimum site-source distance is 11.1km, the maximum distance is 26.4km and the average distance is 16.4km for the Far-Field record set. More information, have stated in FEMA P695 [12].

TABLE I. LIST OF USED GROUND MOTIONS

Earthquake Name	Station	Com x	Com y	PGA x(g)	PGA y(g)	Year
Northridge	Beverly Hills - Mulhol	279	009	0.516	0.416	1994
Northridge	Canyon Country-WLC	270	000	0.482	0.410	1994
Duzce, Turkey	Bolu	090	000	0.822	0.728	1999
Hector Mine	Hector	090	000	0.337	0.266	1999
Imperial Valley	Delta	352	262	0.351	0.238	1979
Imperial Valley	El Centro Array #11	230	140	0.380	0.364	1979
Kobe, Japan	Nishi-Akashi	000	090	0.509	0.503	1995
Kobe, Japan	Shin-Osaka	000	090	0.243	0.212	1995
Kocaeli, Turkey	Duzce	270	180	0.358	0.312	1999
Kocaeli, Turkey	Arcelik	000	090	0.216	0.150	1999
Landers	Yermo Fire Station	270	360	0.245	0.152	1992
Landers	Coolwater	TR	LN	0.417	0.283	1992
Loma Prieta	Capitola	000	090	0.529	0.443	1989
Loma Prieta	Gilroy Array #3	000	090	0.537	0.367	1989
Manjil, Iran	Abhar	L	T	0.515	0.496	1990
Superstition Hills	El Centro Imp. Co.	000	090	0.358	0.258	1987
Superstition Hills	Poe Road (temp)	270	360	0.446	0.300	1987
Cape Mendocino	Rio Dell Overpass	360	270	0.549	0.385	1992
Chi-Chi, Taiwan	CHY101	N	E	0.440	0.353	1999
Chi-Chi, Taiwan	TCU045	N	E	0.512	0.474	1999
San Fernando	LA - Hollywood Stor	090	180	0.210	0.174	1971
Friuli, Italy	Tolmezzo	000	270	0.351	0.315	1976

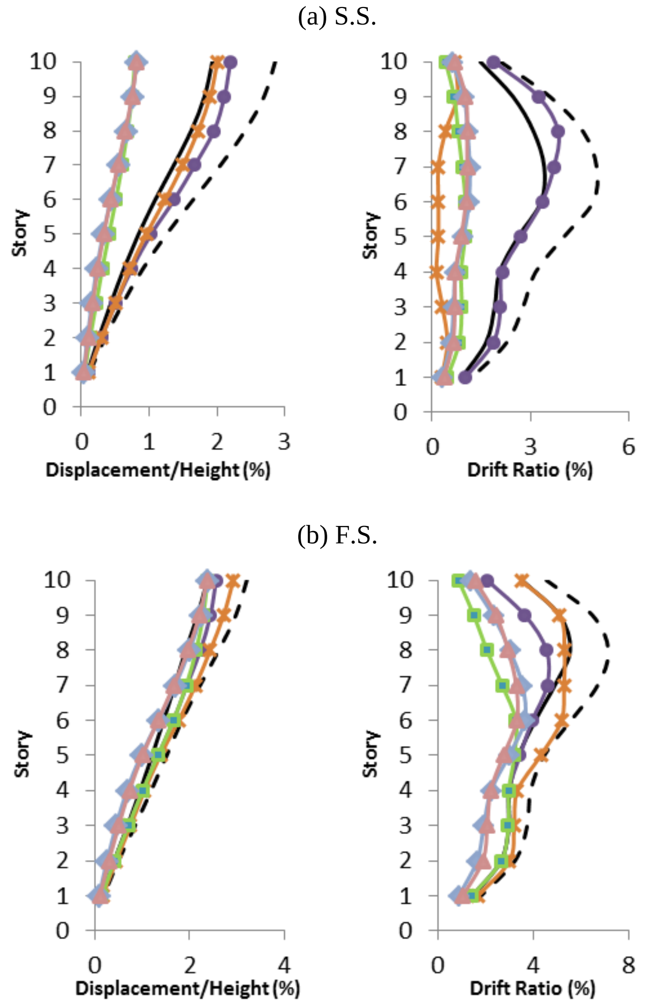

Figure 5. Height-wise displacement and story drift of TS in (a) S.S. and (b) F.S.

IV. Description of Analyses and Results

First for evaluating different pushover procedures and load patterns, especially MCMP procedure [7], a series of NLRHAs under bidirectional above mentioned ground motions are performed and the median maximum of responses are defined as Engineering Demands Parameters (EDPs). The NLRHAs are performed using Wilson Θ direct integration method. Each record is scaled as described in ASCE/SEI 41-06 [9] using maximum considered earthquake spectrum function (one and a half times design spectrum). Then using obtained Target Displacement (TD) from NLRHAs, FEMA 356 [8] recommended load patterns and MCMP procedure, have performed. Here TD from NLRHAs is used in order to normalize various procedures from TD, and only assess these load patterns. Finally for comparing the results of MCMP procedure, MPA [4] and some lateral load patterns mentioned in FEMA 356 [8], containing Uniform, ELF and SRSS load patterns, are applied. SAP2000 is used to perform nonlinear static and dynamic analyses.

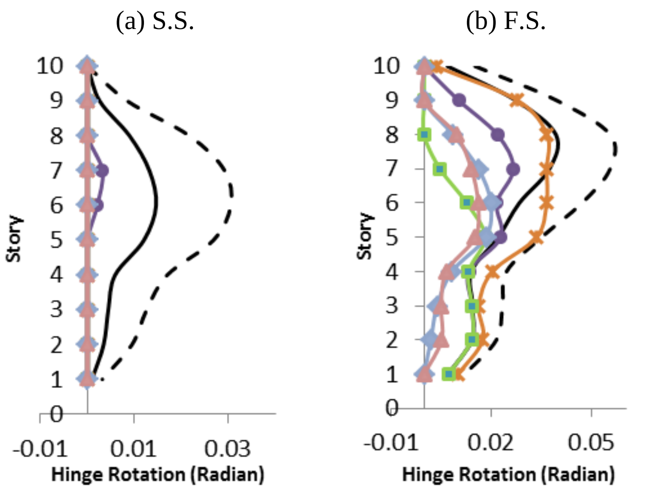

Figure 6. Height-wise hinge plastic rotations of TS in (a) S.S. and (b) F.S.

Responses of structures such as displacements, story drift ratios and hinge plastic rotations due to above mentioned analyses are presented here. The mean values of maximum responses due to NLRHAs and NLRHA plus standard deviation (σ) are presented in this section in comparison with the results of FEMA 356 load patterns [8], MPA and MCMP procedure. Displacements over structural height for Stiff Side (S.S.) and Flexible Side (F.S.) are shown in Fig. 2 and Fig. 4 for TF and TS systems respectively. Comparing the displacements in different points of plan, it can be observed that the displacements of S.S. and F.S. are greater than C.M. in both TF and TS systems. The results of center of mass are not shown here due to the briefness. In TF system the displacements of S.S. are greater than F.S. and in TS system is vice versa; the displacements of S.S. are smaller than F.S.; TD in MPA is calculated during the process. Estimated TDs in MPA are greater than obtained TD from NLRHAs. MPA by using dynamic modal properties of the structure and MCMP by using modification factor to responses can estimate the displacements of C.M., S.S. and F.S. accurately, but FEMA 356 recommended load patterns could not estimate displacements of S.S. due to neglecting the torsional component in load patterns.

Fig. 2 and Fig. 4 also illustrate drift ratios (difference of top and bottom of story over story height) in S.S. and F.S. of TF and TS systems respectively. Uniform load pattern have good estimation of drift ratios at F.S. in lower stories, but it have significant errors at mid and higher stories. SRSS and ELF load patterns can estimate the middle story drift ratios at F.S. reasonably however, their errors are bigger in lower and higher stories. Uniform, ELF and SRSS are not able to predict the drift ratios of S.S. due to lack of torsional component in their load patterns. MPA procedure has over estimation and lower estimation of story drift ratios at F.S. and S.S. respectively due to lack of torsional component in imposed displacements. Using single stages and multi stage pushover analyses and applied modification factor to responses; MCMP procedure can estimate the story drift ratios in all points of structure accounting for S.S. and F.S. perfectly.

Hinge plastic rotations in S.S. and F.S. are shown in Fig. 3 and Fig. 5. FEMA 356 [8] load patterns and MPA procedure are not able to push the frame located at S.S. to inelastic range in both TF and TS systems causes 100% errors. MCMP procedure is also not able to estimate hinge plastic rotations of S.S. in TS systems but it can estimate hinge plastic rotations of S.S. in lower floors of TF systems reasonably. Trend of estimating hinge plastic rotations of F.S. are like to story drift ratios. Uniform is suitable for F.S. in lower stories and ELF and SRSS are good for middle stories of F.S. in both TF and TS systems. Estimation of hinge plastic rotations of F.S. in MPA procedure is usually over estimated for TF system and is reasonable for TS systems. MCMP procedure can estimate the hinge plastic rotations of F.S. for both TF and TS systems well.

V. Conclusion

This study assesses the different lateral load patterns and procedures especially MCMP procedure for estimating seismic demands of mid-rise building that effects of torsion and higher modes are not negligible. In this regards two 10 story mass eccentric buildings are created from a symmetric building with two different level of coupling between lateral and torsional modes: TF and TS systems. Then a series of NLRHAs are performed to catch the EDPs and MCMP procedure is applied after. Additionally, FEMA 356 load patterns [8] and MPA procedure are implemented too in manner of comparison. Some important conclusions are:

The displacement of S.S. and F.S. are greater than C.M. in one way asymmetric plan with both TS and TF systems under bidirectional ground motions whereas in TF system under one component of ground motion the displacement of S.S. is bigger than C.M. and C.M. is bigger than F.S. and in TS system under one component of ground motion the displacement of F.S. is bigger than C.M. and C.M. is bigger than S.S. [5].

TD estimated by MPA procedure is usually greater than the median maximum of responses of NLRHAs.

FEMA 356 load patterns [8] have lack of ability to obtain displacement and story drift ratios of S.S. due to lack of torsional component in load patterns. Altogether FEMA 356 load patterns [8] have lots of errors in estimation of story drift ratios and hinge plastic rotations.

Using modal properties of structure and response modification factor in MPA and MCMP procedures respectively; they can be used to estimate displacements of every point of plan with adequate accuracy.

Story drift ratios obtained by MPA procedure can be used for C.M. and for F.S. with a little over estimation, but it should not be used for S.S. of plan. MCMP procedure can estimate the story drift ratios of every point reasonably.

MCMP procedure is able to estimate hinge plastic rotations of F.S. in both TF and TS systems and in lower stories of S.S. in TF system. MPA procedure can just estimate hinge plastic rotations of F.S. in both TF and TS systems.

References

[1] A. K. Chopra, and R. K. Goel, "A Modal Pushover Analysis Procedure for Estimating Seismic Demands for Buildings," Earthquake Engineering and Structural Dynamic, vol. 31, pp. 561–582, 2002.

[2] A. K. Chopra, R. K. Goel, and C. Chintanapakdee, "Evaluation of a Modified MPA Procedure Assuming Higher Modes as Elastic to Estimate Seismic Demands," Earthquake Spectra, vol. 20(3), pp. 757–778, 2004.

[3] M. Poursha, F. Khoshnoudian, and A. S. Moghadam, "A Consecutive Modal Pushover Procedure for Estimating the Seismic Demands of Tall Buildings," Engineering Structures, vol. 31, pp. 591–599, 2009.

[4] J. C. Reyes, and A. K. Chopra, "Three-dimensional modal pushover analysis of buildings subjected to two components of ground motion, including its evaluation for tall buildings," Earthquake Engineering and Structural Dynamic, vol. 40, pp. 789–806, 2011.

[5] M. Poursha, F. Khoshnoudian, and A. S. Moghadam, "A consecutive modal pushover procedure for nonlinear static analysis of one-way unsymmetric-plan tall building structures," Engineering Structures, vol. 33, pp. 2417–2434, 2011.

[6] F. Khoshnoudian, and M. Kiani, "Modified consecutive modal pushover procedure for seismic investigation of one-way asymmetric-plan tall buildings," Earthquake Engineering and Engineering Vibration, vol. 11, pp. 221–232, 2012.

[7] M. Hadikhan Tehrani, "Assessment of Nonlinear Static Analysis Procedures for Asymmetric Plan Tall Buildings Considering Soil-Structure Interaction," M.Sc. Thesis, Department of Civil and Environmental Engineering, Tehran, Iran, 2013.

[8] American Society of Civil Engineers, "Prestandard and Commentary for the Seismic Rehabilitation of Buildings," FEMA 356, Federal Emergency Management Agency, Washington, D.C., USA, 2000.

[9] American Society of Civil Engineers, "Seismic Rehabilitation of Existing Buildings," ASCE/SEI 41-06, Reston, Virginia, USA, 2006.

[10] American Society of Civil Engineers, "Minimum Design Loads for Buildings and Other Structures," ASCE/SEI 7-10, Reston, Virginia, USA, 2010.

[11] American Institute of Steel Construction, "Specification for Structural Steel Buildings," ANSI/AISC 360-10, Illinois, USA, 2010.

[12] American Society of Civil Engineers, "Quantification of Building Seismic Performance Factors," FEMA P695, Federal Emergency Management Agency, Washington, D.C., USA, 2009.

[13] A. K. Chopra, and R. K. Goel, "A modal pushover analysis procedure to estimate seismic demands for unsymmetric-plan buildings," Earthquake Engineering and Structural Dynamic, vol. 33, pp. 903–927, 2004.

[14] J. P. Wolf, and A. J. Deeks, "Foundation Vibration Analysis: A Strength-of-Materials Approach," Elsevier, 2004.