

Research Note**Investigation of the Effects of Recorded and Simulated Earthquakes on Buildings with Different Heights Using the ASCE 7-22****Pouya Hassani^{1*}, Sallar Rasti² and Saeed Tariverdilo³**

1. Ph.D. Student, Department of Civil Engineering, Urmia University, Urmia, Iran,
*Corresponding Author; email: p.hassani@urmia.ac.ir

2. Ph.D. Student, Department of Civil Engineering, Urmia University, Urmia, Iran

3. Professor, Department of Civil Engineering, Urmia University, Urmia, Iran

Received: 04/06/2024**Revised:** Not Required**Accepted:** 02/07/2024**ABSTRACT****Keywords:**

Seismic safety; Scale factor; Spectrally matched; Amplitude scaling, Performance-based design

This paper considering two buildings different in height as a case study to inquiries into the effect of recorded and spectrally matched ground motions (simulated ground motion). Model of structures are developed using design procedure of Chapter 12 of ASCE 7-22 and linear analysis is adopted using requirements of Chapter 16 of ASCE 7-22. In this study, the effects of recorded and simulated ground motions on drift distribution and also floor acceleration are investigated. It could be seen that all of the structures, when subjected to simulated ground motions, give acceptable performance, even though this is not the case with amplitude-scaled ground motions.

1. Introduction

The incidence of new earthquakes in nations internationally raises the want for a fundamental exchange in the present seismic design process (Ghobarah, 2001). Present seismic design codes are force-based totally, that is, forces and displacements inside elastic limits are calculated, and their combination is used to design the structural and nonstructural elements. Serviceability checks are applied using displacement limits and ductile detailing. Inelastic responses are calculated by way of making use of the response discount factor, which pertains to force or displacement amplification; but, such an oblique method reasons misjudgment in the real building response (Liu et al., 2004). According to the philosophy of designing, structures are designed to resistance from forces that much less than the seismic ones. Hence when a structure is against a severe seismic force, an

earthquake, it may exceed the elastic deformations and undergoes that inelastic. Even though the structure may not collapse, but too much economic loss (Chaudhari & Dhoot, 2016). In PBS, performance stages are defined in terms of displacements and drifts. A structures' damage state may be related to overall performance levels. This concept has given a brand new design approach based totally on displacement, known as displacement-based seismic design (DBSD) of structures (Priestley et al., 2007; Moehle, 1992).

PBSD is an iterative method, which begins with the choice of overall performance objectives (that are defined with the aid of the proprietors, designers, and constructing officers), accompanied via the development of a preliminary layout, an assessment of whether the design meets the

overall performance goals, and finally remodel and reassessment, if required, till the favored performance stage is executed (ATC, 2003). The literature showed a wide range of research in performance-based seismic design (PBSD). Considering seismic safety and restrengthening, concrete buildings are seismically evaluated and retrofitted (Chaudhari & Dhoot, 2016). The advantages of PBSD are as follows (FEMA, 2006):

1. Designing individual structures with a better stage of confidence and being able to meet the stated set of performance objectives with lower building costs.
2. Designing individual structures to achieve higher overall performance than supposed the use of present seismic codes.
3. Assessing the capacity seismic overall performance of present systems, and estimating the capability losses inside the event of seismic risk.

In compliance with most international building codes, the philosophy of PBSD is to maintain the safety and health of building inhabitants, in other words, that is governed by Life-Safety (LS) criteria (Pampanin, 2012; Bianchi et al., 2021).

Since the damage to non-structural components is not as important as structural elements, this group of components is more vulnerable and despite their inherently high cost neglected. Recent promotions in PBSD tend to seismic design of non-structural elements somehow damages observed in non-structural elements significantly affect the performance and economic losses in typical buildings (Miranda et al., 2012; Perrone et al., 2018; Dhakal, 2010; O'Reilly et al., 2018; Sousa & Monterio, 2018; Merino et al., 2019). Non-structural elements are commonly divided into two groups: sensitive to displacement and sensitive to acceleration (ASCE/SEI, 2016; CEN, 2004). In recent years, significant efforts have concentrated on the assessment of the floor acceleration demand on non-structural elements (Merino, et al., 2019). Lin and Mahin (1984) and Sewell et al. (1988) carried out studies on the evaluation of floor acceleration in yielding structures.

In keeping with the importance of nonlinear modeling of structures and studying effects of

higher modes, nonlinear dynamic analysis is a proper approach to this aim. Hence, using this method needs appropriate ground motion records. To achieve this, there are two types of ground motions: existing ground motion records and simulated ground motions (spectrally matched). In the case of using recorded GMs, they should be scaled (Rezaei et al., 2020).

In this study performance of designed models subjected to recorded and simulated GMs are evaluated and fragility functions are obtained by using incremental dynamic analyses (IDA).

2. Nonlinear Response History and Ground Motions used in the Analyses

ASCE 7 nominates a comprehensive framework for assessing the seismic safety of structures using performance-based methods. Zimmerman et al. (2017), Jarrett et al. (2017), and Haselton et al. (2017) widely studied the developments leading to ASCE requirements (ASCE/SEI, 2017).

In accordance with ASCE 7-22 far-field GMs suggested by FEMA P695 (FEMA, 2009) are considered in this study as listed in Table (1) and Table (2) shows a group of recorded and correspondingly a group of simulated GMs, where each group includes 11 GMs.

Obtaining recorded GMs is based on soil type, magnitude of GMs, and fault mechanisms, which have their own difficulties. There are two common ways to modify GMs: scaling and spectral matching (simulated). Simulated GMs are generated by SeismoMatch software (RSPMatch, 2018).

For nonlinear response analyses, ASCE 7-22 provisions suggested 2.5% viscous damping at fundamental structures' period, whereas the target spectrum is based on 5% damping so this issue could introduce significant dispersion in the first and higher mode responses (Anjafi & Medina, 2019).

Figure (1) shows response spectrum for recorded and simulated GMs. Also target and mean spectrum of three different groups of unscaled ground motions are illustrated in Figure (2). As could be seen, the mean spectrum of unscaled GMs has the same intensity and vary in the same range, approximately. The period range for the amplitude scaling method is the range between $0.2T_1$ and

Table 1. Far-Field recorded ground motions - FEMA P695.

ID No.	M	Year	Name	Recording Station	Lowest Frequency (Hz)	PGA _{max} (g)	PGV _{max} (cm/s)
1	6.7	1994	Northridge	Beverly Hills - Mulhol	0.25	0.52	63
2	6.7	1994	Northridge	Canyon Country-WLC	0.13	0.48	45
3	7.1	1999	Duzce	Bolu	0.06	0.82	62
4	7.1	1999	Hector Mine	Hector	0.04	0.34	42
5	6.5	1979	Imperial Valley	Delta	0.06	0.35	33
6	6.5	1979	Imperial Valley	El Centro Array #11	0.25	0.38	42
7	6.9	1995	Kobe	Nishi-Akashi	0.13	0.51	37
8	6.9	1995	Kobe	Shin-Osaka	0.13	0.24	38
9	7.5	1999	Kocaeli	Duzce	0.24	0.36	59
10	7.5	1999	Kocaeli	Arcelik	0.09	0.22	40
11	7.3	1992	Landers	Yermo Fire Station	0.07	0.24	52
12	7.3	1992	Landers	Coolwater	0.13	0.42	42
13	6.9	1989	Loma Prieta	Capitola	0.13	0.53	35
14	6.9	1989	Loma Prieta	Gilroy Array #3	0.13	0.56	45
15	7.4	1990	Manjil	Abbar	0.13	0.51	54
16	6.5	1987	Superstition Hills	El Centro Imp. Co.	0.13	0.36	46
17	6.5	1987	Superstition Hills	Poe Road	0.25	0.45	36
18	7.6	1999	Chi-Chi	CIHY 101	0.05	0.44	115
19	7.6	1999	Chi-Chi	TCU 045	0.05	0.51	39
20	6.6	1971	San Fernando	I.A-Hollywood	0.25	0.21	19
21	6.5	1976	Friuli	Tolmezo	0.13	0.35	31

Table 2. Selected group of recorded GMs for NRHA*.

ID No.	Name	Recording Station	PGA _{max} (g)	Scale Factor			
				5 St	15 St	25 St	35 St
1	Northridge	Beverly Hills - Mulhol	0.52	1.8089	1.5926	2.9368	3.3999
2	Northridge	Canyon Country-WLC	0.48	1.2865	3.0996	4.3913	5.0762
5	Imperial Valley	Delta	0.35	2.3578	2.4602	2.8603	2.8409
6	Imperial Valley	El Centro Array #11	0.38	3.1779	5.3265	5.1872	5.0752
8	Kobe	Shin-Osaka	0.24	2.2799	3.9589	5.3401	8.8592
9	Kocaeli	Duzce	0.36	2.3922	1.7365	1.7366	2.5396
12	Landers	Coolwater	0.42	1.3207	3.1963	5.4287	6.8374
14	Loma Prieta	Gilroy Array #3	0.56	3.1521	5.4723	8.5220	9.2354
15	Manjil	Abbar	0.51	2.0336	5.0392	3.7854	2.7887
17	Superstition Hills	Poe Road	0.45	3.7106	4.7574	3.6848	3.4920
21	Friuli	Tolmezo	0.35	4.3583	7.0831	9.6662	12.2617

*Nonlinear Response History Analysis

2T1 whereas T1 is the fundamental period of the structure. Also, the scale factors for the selected group of GMs are calculated that given in Table (1).

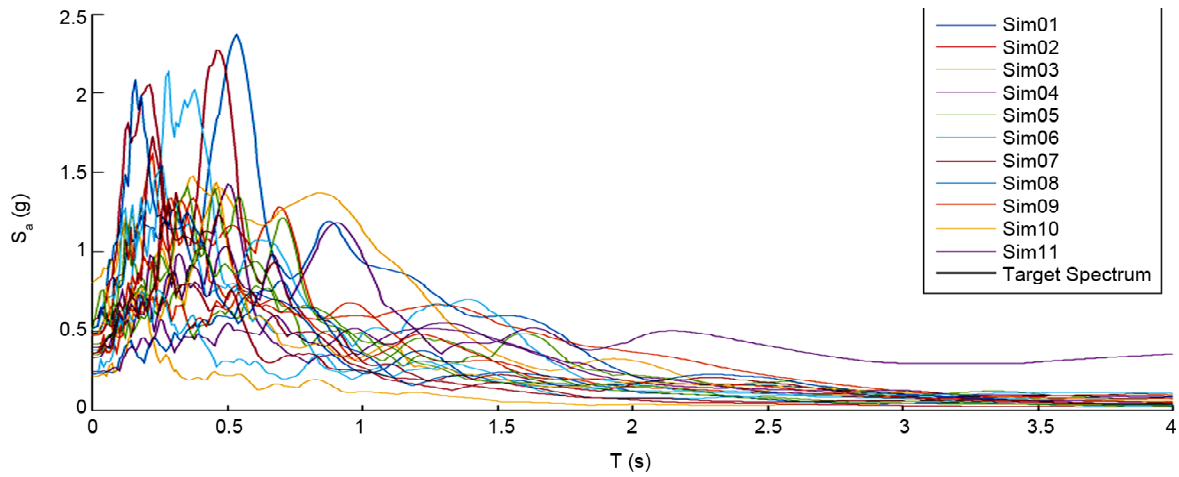
3. Case-Study Buildings

A performance-based investigation is carried out for 2 multistory reinforced concrete buildings with the same plan of 15×15 m, the same inter-story height of 3.2 m, and a different number of stories 5 and 15 respectively. The building use is residential,

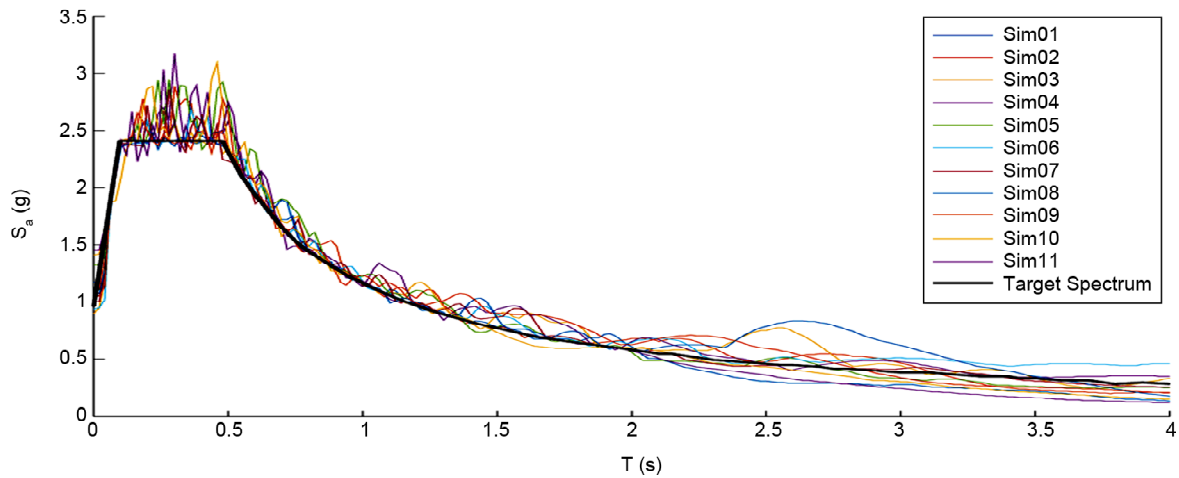
with the moment-frame lateral resisting system. Models are designed in accordance with ACI 318-19 requirements (ACI, 2019; Hassani et al., 2024). Some of the design parameters are shown in Table (3).

Table 3. Material Properties..

	Material		
	Concrete		Steel
f'_c (MPa)	30	Grade	A615Gr60
f_{ce}	$1.5f'_c$	f_y (MPa)	414
E_c (MPa)	$4700\sqrt{f'_c}$	f_{ye}	$1.25f_y$



(a) Recorded GMs



(b) Simulated GMs

Figure 1. Spectrum Response.

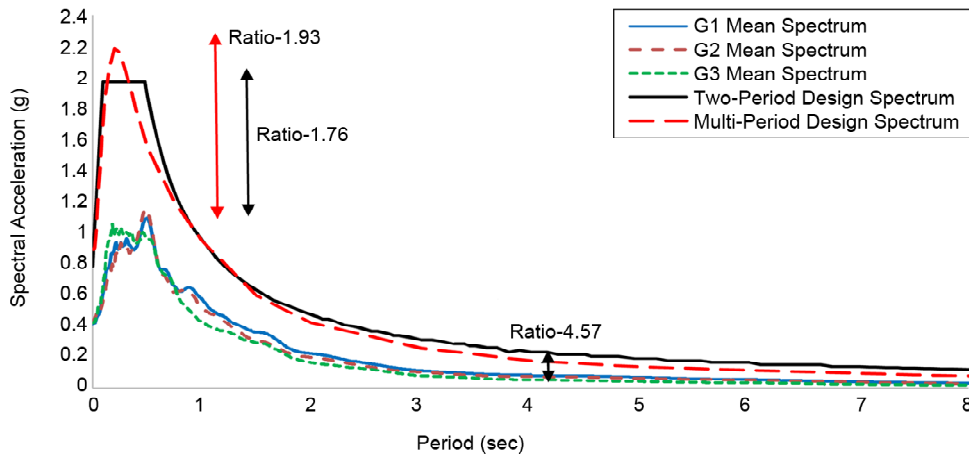


Figure 2. Compared mean spectrum of different group of unscaled GMs with target spectrum of ACSE 7-22.

4. Numerical Modeling

Models for linear analyses are developed by SAP2000 (CSI, 2021) and for nonlinear analyses are prepared by OpenSees-Python (OpenSees-Py) (OpenSees-Py, n.d.) where OpenSees-Py models are in 2D (Liu et al., 2004).

5. Results

Figure (3) shows story drift distribution for all models subjected to recorded ground motions in comparison with the same ones due to simulated ground motions.

It could be understood that maximum responses

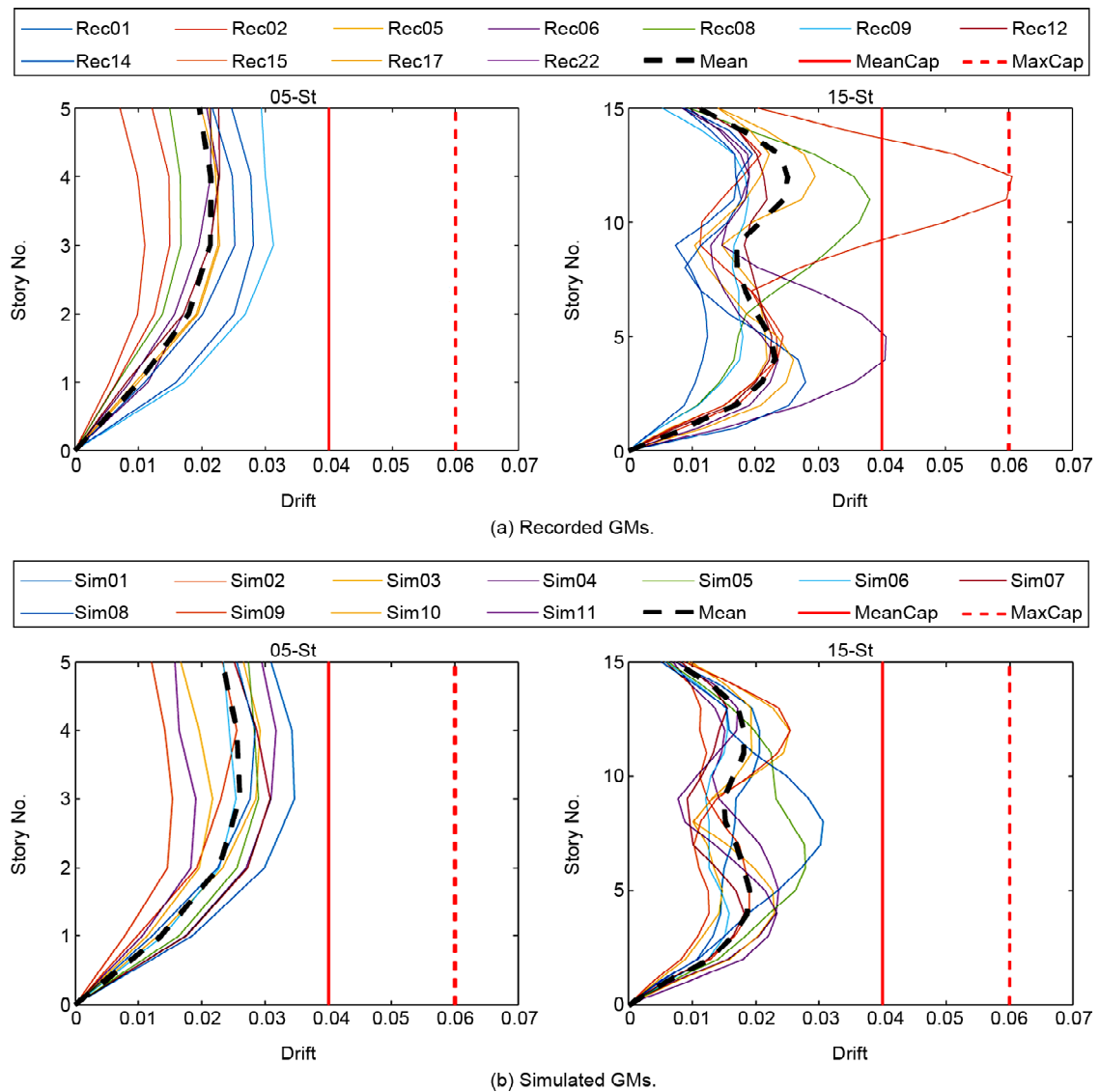


Figure 3. Drift distribution under (a) Recorded GMs. & (b) Simulated GMs.

are focused on middle stories because of the significant contribution of higher modes in the behavior of structures. For recorded ground motions, the variation is much larger than the simulated ones. As could be seen, for all models with recorded GMs the design requirements are not satisfied, but the simulated ones are in contrast with that and the design requirements are satisfied.

Figure (4) shows the mean values for drift distribution along the height of the structure. As it is evident, the same pattern in mean values for all models is inferred.

The seismic safety of nonstructural components mainly depends on the assessment of floor acceleration. The mean values of floor acceleration for both recorded GMs and simulated GMs are plotted in Figure (5) and Appendix A contains all

floor acceleration distributions for all models obtained from recorded and simulated GMs. As illustrated, lower levels experience much larger amount of floor acceleration compared with higher stories. As shown, it is clear that the variation of recorded GMs is significantly larger than the simulated GMs as well. Model with 5 stories despite different values in distribution of acceleration, the mean value for both recorded and simulated GMs perfectly matched.

To evaluate the fragility behavior of structures, the incremental dynamic analysis (IDA) has been conducted. IDA curves and its 84%, 50%, and 16% percentiles are shown as well in Figure (6), and its relative fragility function for both Life Safety (L.S.) and Collapse Prevention (C.P.), performance levels, are assessed and illustrated in Figure (7).

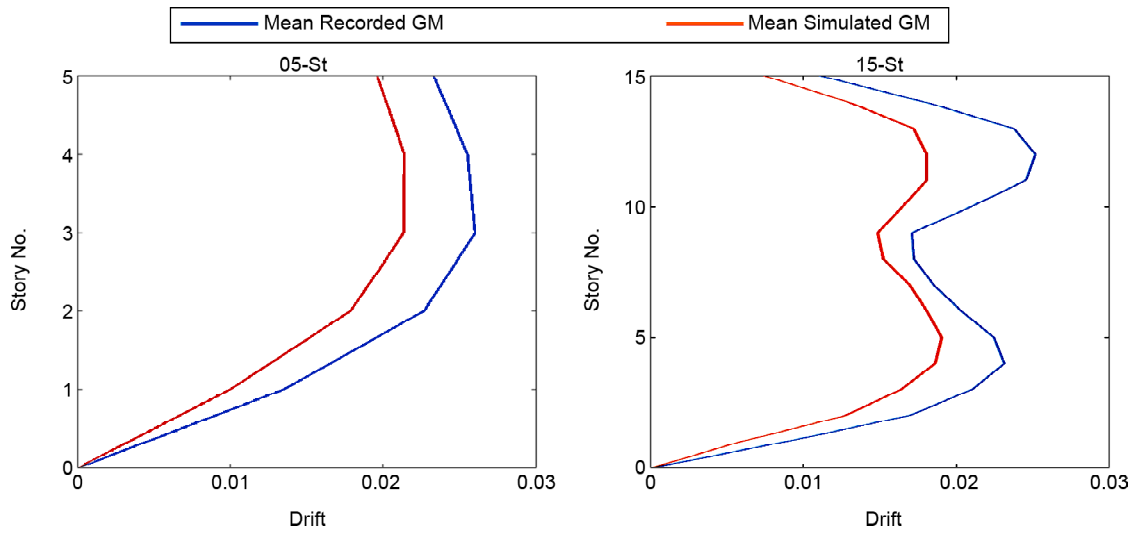


Figure 4. Mean values for drift distribution along the height for recorded and simulated GMs.

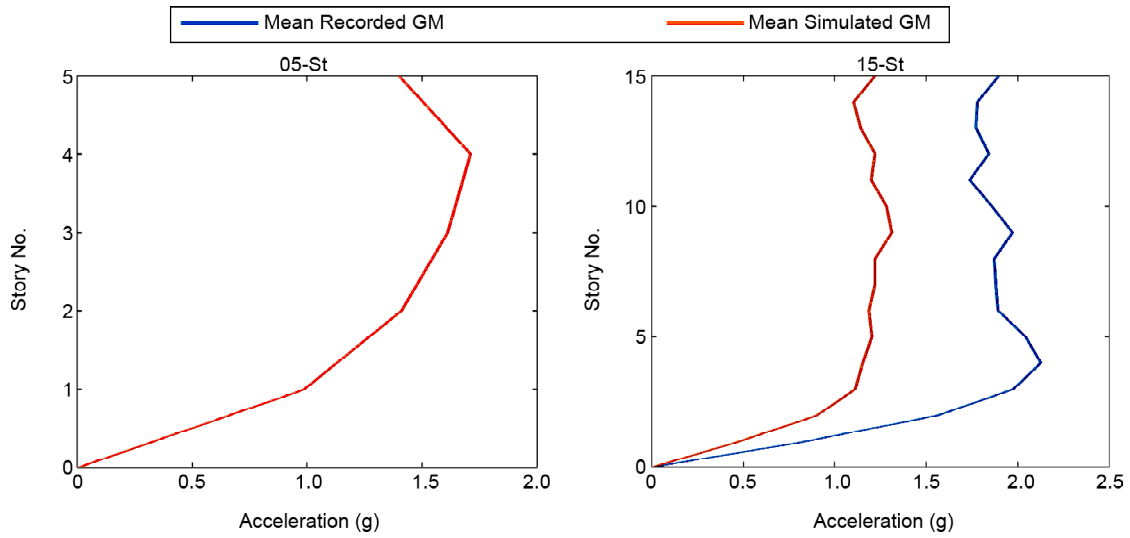


Figure 5. Mean values of acceleration distribution for recorded and simulated GMs in comparison.

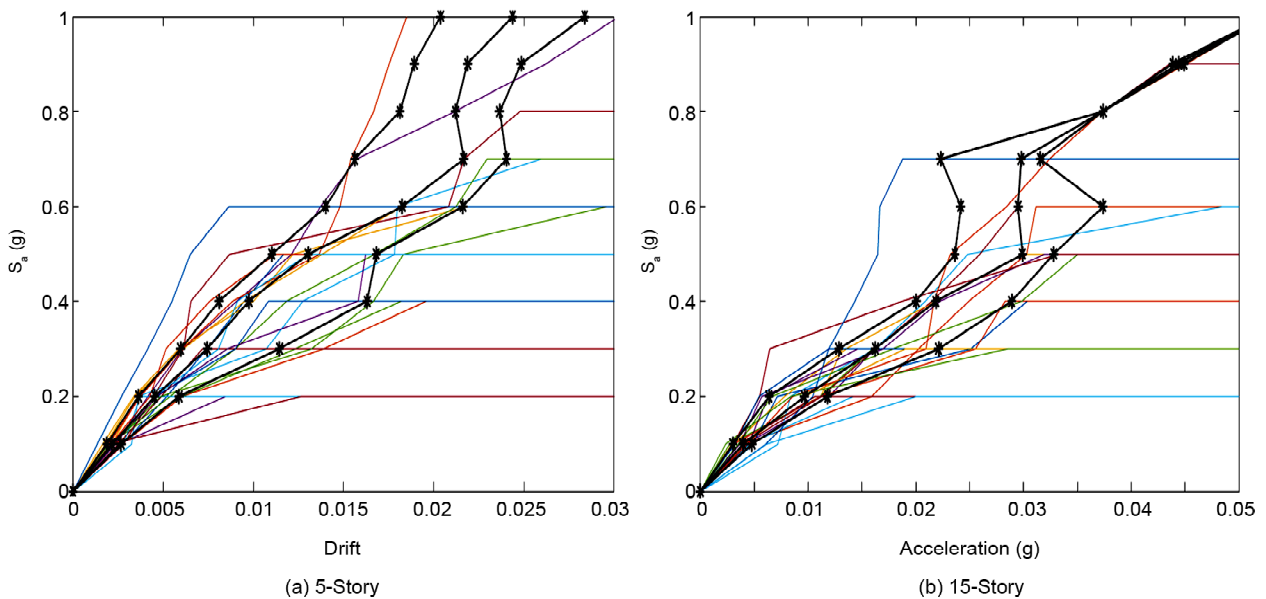


Figure 6. IDA curves for models.

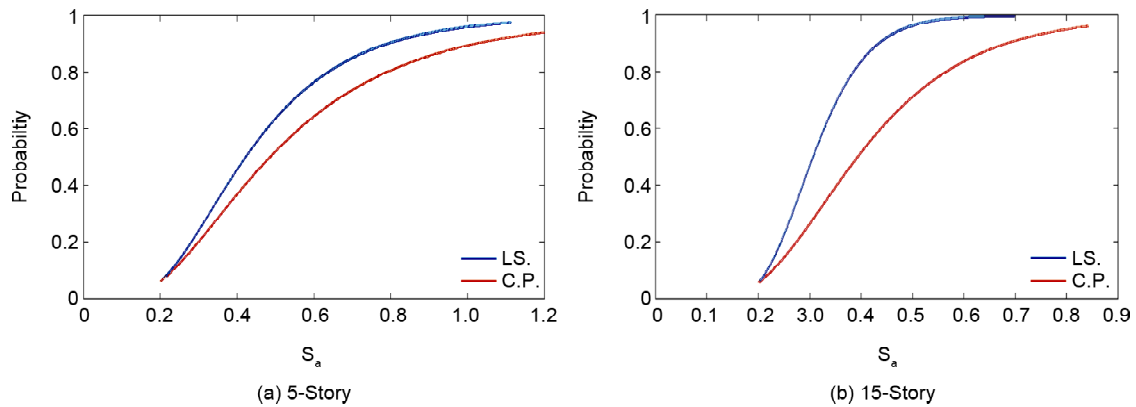


Figure 7. Fragility curves obtained from fragility function for both Life Safety & Collapse Prevention for models.

References

- ACI. (2019). *Building Code Requirement, ACI 318*.
- Anjafi, H., & Medina, R.A. (2019). *Earthquake Spectra*.
- ASCE/SEI. (2016). *Minimum Design Loads for Buildings and Other Structures, ASCE/SEI Standard 7-16*. Reston: American Society of Civil Engineers.
- ASCE/SEI. (2017). *ASCE/SEI Standard 41-17, Seismic Rehabilitation of Existing Buildings*. American Society of Civil Engineers and Structural Engineering Institute.
- ASCE/SEI (2005). *ASCE/SEI Standard 43-05, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities*. American Society of Civil Engineers and Structural Engineering Institute.
- ATC (2003). *Preliminary Evaluation of Methods for Defining Performance, ATC 58-2*. Redwood City, (CA): Applied Technical Council.
- Bianchi, S., Ciurlanti, J., & Pampanin, S. (2021). Comparison of traditional vs low-damage structural and non-structural building systems through a cost/performance-based evaluation. *Earthquake Spectra*, 366-385. doi:https://doi.org/10.1177/8755293020952445.
- CEN (2004). *Eurocode 8, Design Provisions for Earthquake Resistant Structures, EN-1998-1*. Brussels, Belgium: Comite Europeen de Normalization.
- Chaudhari, D., & Dhoot, G. (2016). Performance Based Seismic Design of. *Open Journal of Civil Engineering*, 188-194. doi:http://dx.doi.org/10.4236/ojce.2016.62017.
- Chaudhari, D., & Dhoot, G. (2016). Performance based seismic design of reinforced concrete building. *Open Journal of Civil Engineering*, 188-194.
- CSI. (2021). *SAP2000, Integrated Building Design Software*. Berkeley CA.
- Dhakal, R. (2010). Damage to non-structural components and contents in 2010 Darfield earthquake. *Bulletin New Zealand Society Earthquake Engineering*, 404-411.
- FEMA. (2006). *FEMA-445, Next-Generation Performance-Based Seismic Design Guidelines Program Plan for New and Existing Buildings*. Washington (DC): Federal Emergency Management Agency.
- FEMA. (2009). *Quantification of Building Seismic Performance Factors, FEMA P695*.
- Ghobarah, A. (2001). Performance-based design in earthquake engineering: state of development. *Eng. Struct.*, 878-84. doi:http://dx.doi.org/10.1016/S0141-0296(01)00036-0.
- Haselton, C.B., Fry, A., Hamburger, R.O., Baker, J. W., Zimmerman, R.B., Luco, N., . . . Whittaker, A. S. (2017). *Earthquake Spectra*.
- Hassani, P., Rasti, S., & Tariverdilo, S. (2024). Application of ASCE 7-22 performance-based design procedures for different building types in height using recorded and simulated ground

- motions. *SEE9 Conference*. Tehran, Iran.
- Jarrett, J.A., Zimmerman, R.B., Charney, F.A., & Jalalian, A. (2017). *Earthquake Spectra*.
- Lin, J., & Mahin, S.A. (1984). Seismic response of light subsystems on inelastic structures. *Journal of Structural Engineering*, 400-417. doi:[https://doi.org/10.1061/\(ASCE\)0733-9445\(1985\)111:2\(400\)](https://doi.org/10.1061/(ASCE)0733-9445(1985)111:2(400)).
- Liu, B.-q., Liu, M., & Li, Y.-b. (2004). Research and development of performance-based seismic design theory. *The 13th World Conference on Earthquake Engineering*, Vancouver (B.C.), Canada Paper No. 2457. Retrieved from www.iitk.ac.in/nicee/wcee/article/13_2457.pdf.
- Merino, R.J., Perrone, D., & Filiatrault, A. (2019). Consistent floor response spectra for performance-based seismic design of nonstructural elements. *Earthquake Engineering Structural Dynamics*, 1-24. doi:<https://doi.org/10.1002/eqe.3236>.
- Miranda, E., Mosqueda, G., Retamales, R., & Pekcan, G. (2012). Performance of nonstructural components during the 27 February 2010 Chile Earthquake. *Earthquake Spectra*, 453-471.
- Moehle, J. (1992). Displacement-based design of RC structures. *Earthquake engineering, 10th World Conference*, Balkema, Rotterdam, 403-427. Retrieved from Moehle JP. Displacement-based design of RC structures. *Earthquake engineering, 10th world conference*, Balkema, Rotterdam; 1992. 4299-302.
- OpenSees-Py. (n.d.). *The Open System for Earthquake Engineering Simulation Software*.
- O'Reilly, G., Perrone, D., Fox, M., Monteiro, R., & Filiatrault, A. (2018). Seismic assessment and loss estimation of existing school buildings in Italy. *Engineering Structures*, 142-162. doi:<https://doi.org/10.1016/j.engstruct.2018.04.056>.
- Pampanin, S. (2012). Reality-check and renewed challenges in earthquake engineering: Implementing low-damage structural systems-From theory to practice. *Bulletin of the New Zealand Society for Earthquake*, 45(4), 137-160. doi:10.5459/bnzsee.45.4.137-160.
- Perrone, D., Calvi, P., Nascimbene, R., Fischer, E., & Magliulo, G. (2018). Seismic performance and damage observation of non-structural elements during the 2016 Central Italy Earthquake. *Bull Earthquake Engineering*, 5655-5677. doi:<https://doi.org/10.1007/s10518-018-0361-5>.
- Priestley, M., Calvi, G., & Kowalsky, M. (2007). Direct Displacement-Based Seismic Design of Structures. Pavia, Italy: IUSS Press, 2-23. Retrieved from Priestley, M.J.N., Calvi, G.M., Kowalsky, M.J. Displacement-Based Seismic Design of Structures. Pavia, Italy: IUSS Press; 2007.
- Rezaei, R., Tariverdilo, S., Sheidaii, M.R., & Khodabandehlou, A. (2020). Application of codes performance-based design procedures for a tall building using recorded and spectrally modified ground motions. *The Structural Design of Tall and Special Buildings*, 1-18. doi:<https://doi.org/10.1002/tal.1783>.
- RSPMatch. (2018). Retrieved from <http://www.seissoft.com/en/seismomatch.aspx>.
- Sewell, R., Cornell, C., Toro, G., McGuire, R., Kassawara, R., & Sing, A. (1988). *Factors Influencing Floor Response Spectra in Nonlinear Multi-Degree-of-Freedom Structures*. Stanford University.
- Sousa, L., & Monterio, R. (2018). Seismic retrofit options for non-structural building partition walls: Impact on loss estimation and cost-benefit analysis. *Engineering Structures*, 8-27. doi:<https://doi.org/10.1016/j.engstruct.2018.01.028>.
- Zimmerman, R. B., Baker, J. W., Hooper, J. D., Bono, S., Haselton, C. B., Engel, A., . . . Jalalian, A. (2017). *Earthquake Spectra*.

Appendix A.

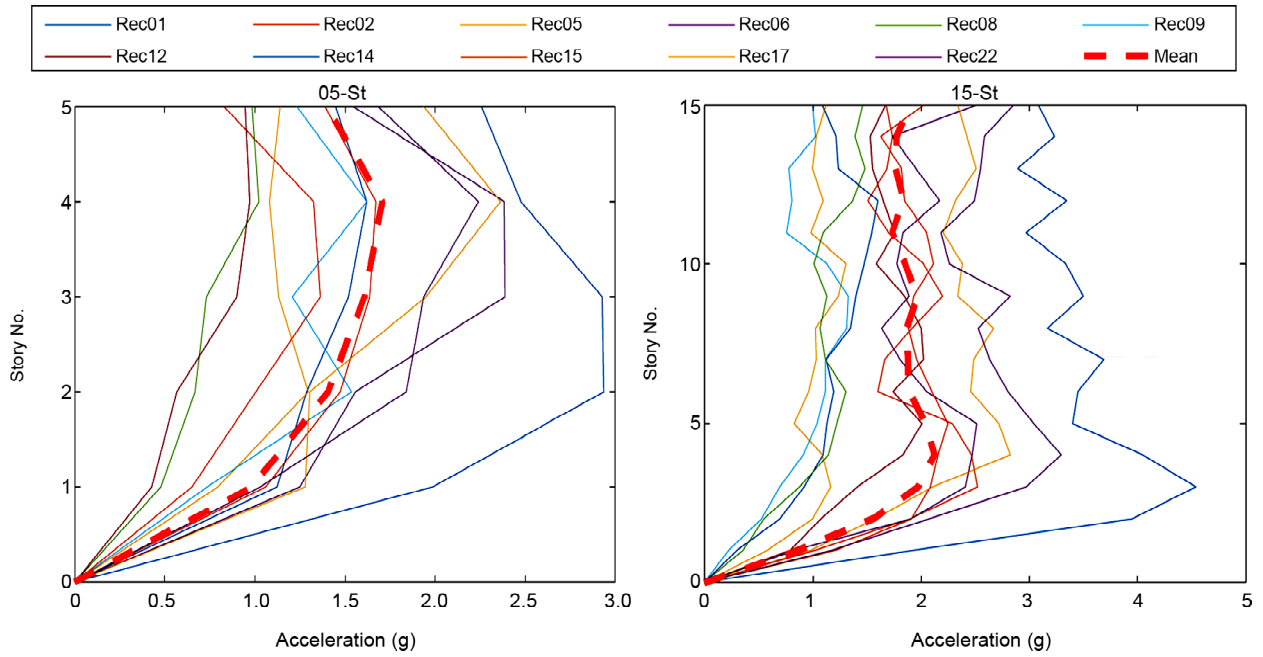


Figure A-1. Distribution of Floor Acceleration for Recorded GMs.

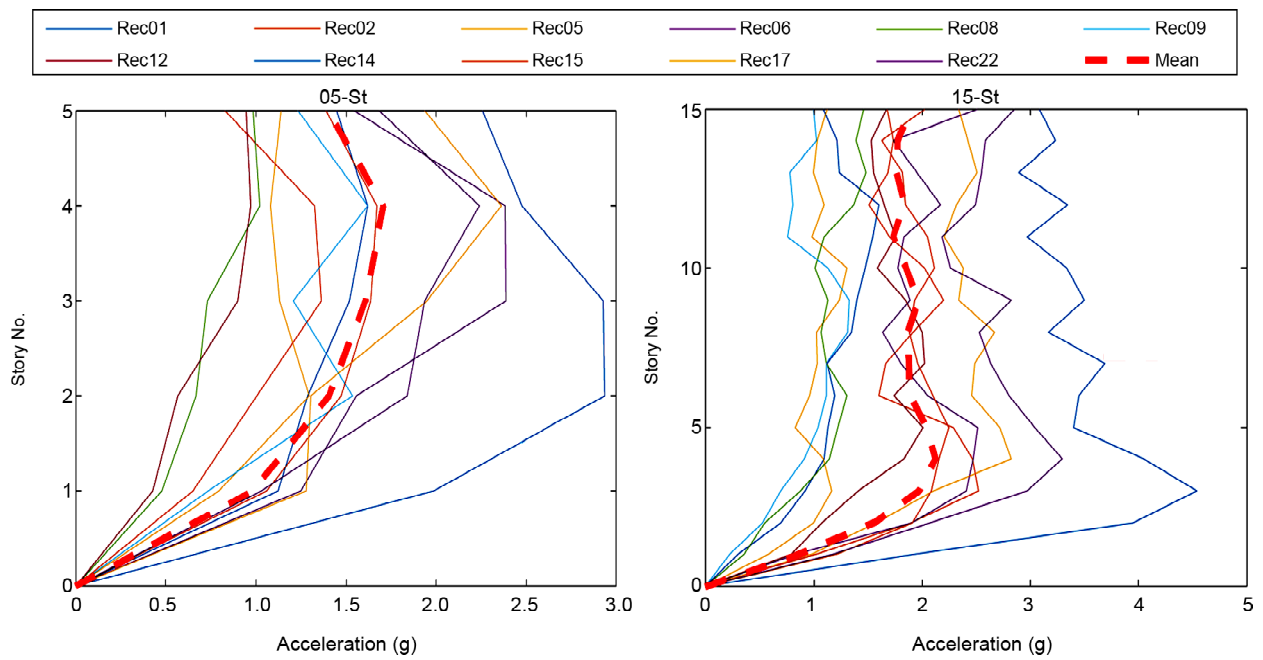


Figure A-2. Distribution of Floor Acceleration for Simulated GMs.