IOP Conf. Series: Materials Science and Engineering **920** (2020) 012012 doi:10.1088/1757-899X/920/1/012012

Assessment of Seismic Scenario- Structure Based Limit State Criteria for a Reinforced Concrete High-Rise Building

Puteri Nihal Che Kamaludin[1], Moustafa Moufid Kassem[1], Ehsan Noroozinejad Farsangi[2], Chee Ghuan Tan[3], and Fadzli Mohamed Nazri[1*],

[1]School of Civil Engineering, Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Penang, Malaysia.

[2]Faculty of Civil and Surveying Engineering, Graduate University of Advanced Technology, Kerman, Iran.

[3]Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

*Email: cefmn7@gmail.com/cefmn@usm.my

Abstract. Issues regarding reinforced concrete (RC) high-rise buildings involve different seismic scenarios, such as near- and far-field earthquakes, which can result in different levels and complex seismic scenario structures related to global damage. This study aims to evaluate the seismic scenario structures of a 23-storey RC high-rise building based on different damage measures and to develop a fragility curve with different limit state criteria. Six ground motions are selected to represent two seismic scenarios. Seismic scenario-based global response of the building at increasing earthquake intensity measures is adopted using incremental dynamic analysis (IDA). IDA curves and interstorey drift are used in the parametric study. The structural performance and damage measure of RC high-rise buildings are evaluated with performance-based seismic design limit state. The four performance levels proposed by ATC-43 are operational performance, immediate occupancy, life safety and collapse prevention. The IDA curves showed that near-field effect has a high frequency that gives impact at early intensity measures on building collapse compared with far-field effect. Meanwhile, interstorey drift result indicates that the near-field effect has a larger effect on building damages compared with the far-field effect. Based on the fragility curves, near-field earthquakes have a larger effect towards structural damages than far-field earthquakes.

1. Introduction

At present, the number of high-rise buildings has expanded rapidly because of the changing socioeconomic conditions, rapid population growth and urbanisation. The expansion of high-rise buildings has spread to cities that are subjected to multiple-scenario earthquake-prone regions. The development of commercial high-strength concrete and new advances in construction technologies has influenced the developments of RC high-rise buildings. This development increases exposure to seismic risks that need to be accurately quantified, and thus, the hazard and vulnerability of RC high-rise buildings should be appropriately mitigated [1-4]. Issues regarding RC high-rise buildings involve different seismic scenarios, such as near- and far-field earthquakes, and can result in different levels and complex seismic scenario structures related to global damage. Engineering demand parameters (EDPs) for buildings include interstorey drift ratios and inelastic component structure deformations, such as plastic hinge rotations and floor accelerations, which can be defined from inelastic time history. The structural element performance results from analyses have been used to link EDP to damage measure (DM). DMs describe the physical condition of a structure, including effective descriptions of damage to characterise the performance limit state criteria as reported [5-8]. Noting that, the observation is given to the maximum interstorey drift ratio as a structural damage measure, to evaluate the seismic performance of buildings. Instead of directly considering the distributions of maximum interstorey drift ratio, fragility curves are developed for three different limit states, namely, immediate occupancy (IO), life safety (LS) and collapse prevention (CP). These states will provide a framework to examine the sensitivity of seismic structural responses to ground motion duration on a wide variety of earthquake intensity levels.

Therefore, the behaviour of the structure of RC high-rise buildings must be studied where suitable DMs need to be considered. Two of the major objectives of this research are to evaluate the seismic scenario structure for a 23-storey RC high-rise building based on different damage measures and to develop a fragility curve for the building with different limit state criteria.

2. Methodology
Figure 1 shows the flowchart of the research methodology.

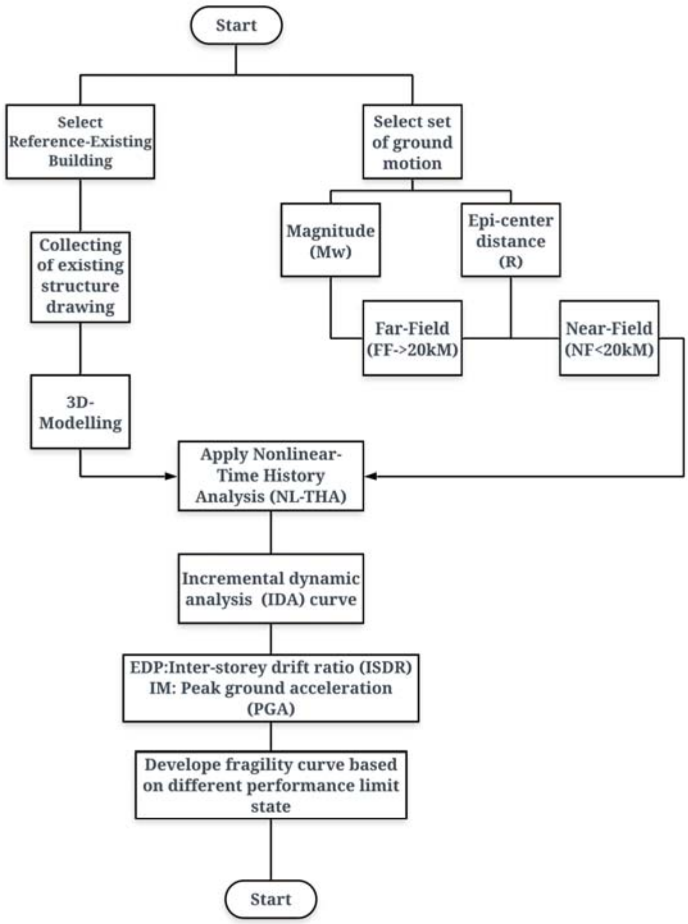

Figure 1. Flowchart of the research methodology

This study focuses on the reinforced concrete of an RC high-rise building. A 23-storey, 83.95 m in height, RC structure is selected as a representative sample building to evaluate seismic scenario structures. The building consists of a basement, 3 storeys for car parking, 16 typical storeys for apartments, a storey for roof floor and 2 storeys for motorised lift. The site class of the building is assumed as site class A (hard rock). Table 1 shows the material properties used to model the building. Table 2 shows the size of slabs, shear walls, columns and beams used to model the building. Table 3 shows the design loads used to define the loads in SAP2000 software. A brief summary of the structure details are presented as follows:

Table 1. Material properties

Material Name	Strength (MPa)
Concrete Compressive Strength, f'c	40
Yielding Tensile Steel Strength fy	420

Table 2. Section properties

No.	Section	Size (mm)
1	Slab	250 mm
2	Shear Wall	200 mm
3	Column	400 x 400 mm
4	Beam	400 x 200 mm

Table 3. Design loads

No.	Design Load	kN/m²
1	Dead Load	2
2	Live Load	4

Earthquake scenarios are a major source of determining seismic demand. According to Oyguc et al. [9], the distances from the considered stations to the epicentre, soil properties and peak ground acceleration (PGA) values are the key parameters for selecting the records. In addition, liquefaction effects are neglected. In this study, seismic scenarios, which are near- and far-field ground motions, are recorded. Three sets of near- and far-field records with magnitudes ranging from 5 to 7 are selected for conducting IDA. The records are downloaded from the Pacific Earthquake Engineering Research Centre website. Selection of the ground motion records is conducted based on the method of Vahdani et al. [10]. Table 4 shows the list of far-field ground motion records selected for this study. Table 5 shows the list of near-field ground motion records selected for this study. Each of the ground motion records is applied to the building by using SAP2000 under time history analysis until the building collapses or reaches the drift limits of 2.5%.

Table 4. Far-field ground motion records (FF record set)

No	Earthquake	Magnitude (M)
1	Imperial Valley-01, 6th of June 1938	5.00
2	Northridge-01, 1st of July 1997	6.69
3	Northern Calif-06, 18th of December 1967	5.20

Table 5. Near-field ground motion records (NF record set)

No	Earthquake	Magnitude (M)
1	Northwest China-03, 11th of April 1997	6.10
2	Parkfield-01 CA, 28th of September 2004	6.00
3	Taiwan SMART1 (40), 20th of May 1986	6.32

A 3D analytical tool is utilised to create a nonlinear model of the sample building as shown in Figure 2. IDAs are performed using six records of earthquake ground motion records. To construct IDA curves that can represent the variable state of the response of the structure related to different earthquake records with increasing intensities, a suitable ground motion intensity measure needs to be defined. Peak ground acceleration (PGA) have been used to be the most accepted intensity measure[11, 12]. A nonlinear time history analysis (NL-THA) is adopted. Ground motion intensity will increase until the building collapses or reaches the drift limit of 2.5%. Based on the analysis, the displacement for each of the storey can be obtained. This finding will help plot the IDA curves, interstorey drifts and fragility curves.

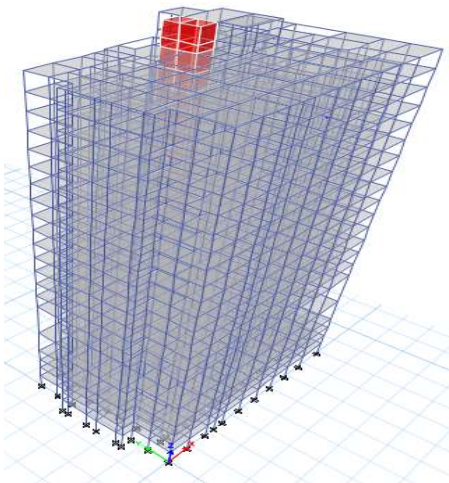

Figure 2. 3D- model of 23-storey RC high-rise building

3. Results and Discussion

The analysis of a 23-storey RC high-rise building is performed based on incremental dynamic analysis (IDA), and the development of the fragility curves for different performance levels OP, IO, LS and CP.

3.1. Incremental dynamic analysis (IDA) curves

As shown in Figure 3, the building experienced operational performance (OP) limit state (drift=0.5%) according to Imperial Valley, Northern California and Northridge ground motions when the PGA reached 0.387g, 0.099g, and 0.055g, respectively. In addition, the building experienced IO limit state (drift=1%) when the PGA reached 0.773g, 0.198g, and 0.111g, respectively. Nevertheless, the building experienced LS limit state (drift=1.5%) when the PGA reached 1.159g, 0.297g, and 0.166g, respectively. Lastly, the building experienced CP limit state (drift=2.5%) when the PGA reached 1.932g, 0.495g, and 0.277g, respectively.

As shown in Figure 4, the building experienced OP limit state (drift=0.5%) according to Northwest, Taiwan and Parkfield seismic records when the PGA reached 0.129g, 0.156g, and 0.066g, respectively. Moreover, the building experienced IO limit state (drift=1%) when the PGA reached 0.257g, 0.310g, and 0.131g, respectively. As well, the building experienced LS limit state (drift=1.5%) when the PGA reached 0.386g, 0.464g, and 0.197g, respectively. Lastly, the building experienced CP limit state (drift=2.5%) when the PGA reached 0.643g, 0.772g, and 0.328g, respectively.

On the basis of the results of the seismic scenarios, by comparing far- and near-field ground motions, the near-field effect experiences of the CP limit states are faster compared with the far-field effect. According to the result, the highest PGAs from the three records of ground motion under far- and near-field cases are 1.932 and 0.772 g, respectively. This finding indicates that the near-field effect affects the ground motion at the site through path attenuation and induced high-frequency filtration. Moreover, the value depends on the characteristics of the site soil strata, where the seismic wave is either amplified or dissipated while moving from the bedrock to the ground level. The modification in the seismic wave impacts the dynamic behaviour of high-rise buildings [2].

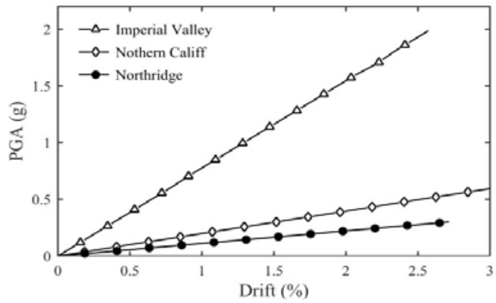

Figure 3. IDA curve for far-field effect

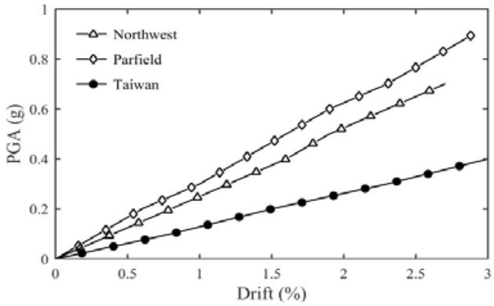

Figure 4. IDA curves for near-field effect

3.2. Fragility Curves

Based on the fragility curve in Figure 5, under far-field effect, the OP limit state achieved 100% of damage when PGA is equal to 0.2g. The IO limit state achieved 100% of damage when PGA is equal to 0.4g. The LS limit state achieved 100% of damage when PGA is equal to 0.55g. Lastly, the CP limit state achieved 100% damage when PGA is equal to 0.95g.

Based on the fragility curve in Figure 6, under near-field effect, the OP limit state achieved 100% of damage when the PGA is equal to 0.25g. The IO limit state achieved 100% of damage when the PGA is equal to 0.5g. The LS limit state achieved 99% of damage when PGA is equal to 1.0 g. Lastly, the CP limit state achieved 81% damage when the PGA is equal to 1.0g.

The far-field effect has a larger effect on the structural damage compared with the near field effect. However, this conclusion is only valid for the present case study. This argument may not be true for all case studies because each has different ground motion that depends on frequency, soil strata and seismic waves.

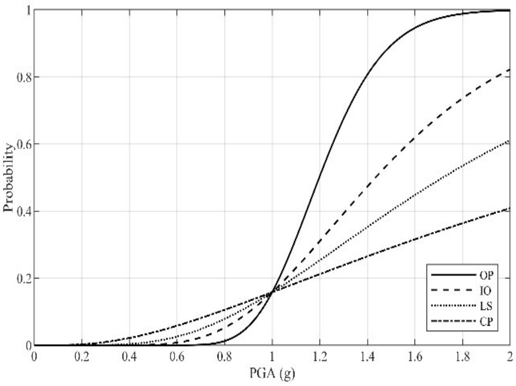

Figure 5. Fragility curve for far-field effect

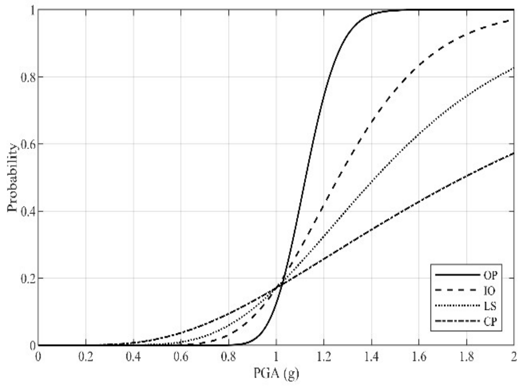

Figure 6. Fragility curve for near-field effect

4. Conclusion

This study evaluates a 23-storey RC high-rise building under different seismic scenarios. Damage measures of the 23-storey RC high-rise building were evaluated with different seismic scenarios, and the fragility curves were developed with different limit criteria. From the numerical comparisons, the following findings can be concluded:

1) In IDA curves, near-field effect produces high frequency that gives impact at early intensity measures on building collapse compared with the far-field effect. Meanwhile, in interstorey drifts, the near-field effect has large effects towards the building damage compared with the far-field effect. This finding indicates that the near-field effect affects the ground motion at the site through path attenuation and induced high-frequency filtration. The effect also depends on the characteristics of the site soil strata. The seismic wave is either amplified or dissipated while moving from the bedrock to the ground level. The modification in the seismic wave impacts the dynamic behaviour of wide-frequency sensitive high-rise buildings.

2) Regarding fragility curves, near-field effect has a larger effect towards the structural damage compared with the far-field effect. However, this conclusion is only valid for the present case study. This argument may not be true for all case studies because each has different ground motion that depends on frequency, soil strata and seismic waves.

Acknowledgement
This research was funded under the Research University Individual (RUI) Grant Scheme (8014080) by the Universiti Sains Malaysia.

References

[1] Alwaeli W, Mwafy A, Pilakoutas K, Guadagnini M 2014. Framework for developing fragility relations of high-rise RC wall buildings based on verified modelling approach. *The Proceedings of the Second European Conference on Earthquake Engineering and Seismology*;.
[2] Alwaeli W, Mwafy A, Pilakoutas K, Guadagnini M 2017. A methodology for defining seismic scenario-structure-based limit state criteria for rc high-rise wall buildings using net drift. *Earthquake Engineering & Structural Dynamics*.;**46**(8):1325-44.
[3] Alwaeli W, Mwafy A, Pilakoutas K, Guadagnini M 2017. Multi-level nonlinear modeling verification scheme of RC high-rise wall buildings. *Bulletin of Earthquake Engineering*;**15**(5):2035-53.
[4] Ji J, Elnashai AS, Kuchma DA 2009. Seismic fragility relationships of reinforced concrete high-rise buildings. *The Structural Design of Tall and Special Buildings*;**18**(3):259-77.
[5] Cornell C 2004. Hazard, ground motions and probabilistic assessment for PBSD. Performance based seismic design concepts and implementation PEER report. **5**:39-52.
[6] Dantanarayan H, MacRae G, Dhakal R, Yeow T, Uma S 2012. Quantifying building engineering demand parameters in seismic events.
[7] Kiani J, Camp C, Pezeshk S 2018. Role of conditioning intensity measure in the influence of ground motion duration on the structural response. *Soil Dynamics and Earthquake Engineering*;104:408-17.
[8] Kassem MM, Nazri FM, Wei LJ, Tan CG, Shahidan S, Zuki SSM 2019. Seismic fragility assessment for moment-resisting concrete frame with setback under repeated earthquakes. *Asian Journal of Civil Engineering*;**20**(3):465-77.
[9] Oyguc R, Toros C, Abdelnaby AE 2018. Seismic behavior of irregular reinforced-concrete structures under multiple earthquake excitations. *Soil Dynamics and Earthquake Engineering* ;**104**:15-32.
[10] Vahdani R, Gerami M, Razi M 2017. Seismic vulnerability assessment of steel moment-resisting frames based on local damage. Journal of Earthquake and Tsunami;11(05):1750016.

[11] Vamvatsikos D, Cornell CA 2002. Incremental dynamic analysis. Earthquake *Engineering & Structural Dynamics*;**31**(3):491-514.
[12] Whittaker A, Deierlein G, Hooper J, Merovich A, Rojahn C, Hamburger RO, et al. *ATC-58 Project Task Report*.