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Case study

Seismic risk analysis of multistory reinforced concrete structures in Saudi Arabia

Yasser E. Ibrahim[1]

Engineering Management Department, Prince Sultan University, Riyadh, 11866, Saudi Arabia

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ABSTRACT

In this research, analytical fragility curves for typical mid-rise plane reinforced concrete moment-resisting frames in Kingdom of Saudi Arabia, KSA, which is considered low-seismicity area, are presented. The fragility curves are developed for 12-story reinforced concrete structure designed according to Saudi Building Code under dead, live and seismic loads. Three cities with different seismic intensities; Abha, Jazan and Al-Sharaf were selected to cover various values of mapped spectral accelerations in KSA. The 0.2-second spectral accelerations range from 0.21 g to 0.66 g while the 1.0-second spectral accelerations range from 0.061 g to 0.23 g. Incremental Dynamic Analysis, IDA, was performed under twelve ground motions using SeismoStruct. Five performance levels; Operational, Immediate Occupancy, Damage Control, Life Safety and Collapse Prevention, which define different possible damage states of a building after an earthquake, were considered and monitored in the analysis. Based on the results of the IDA and statistical analysis, the probability of reaching or exceeding a specific damage state was calculated for each structural model in the three cities. The results were fitted and the fragility curves were developed and presented.

1. Introduction

Performance-based design concept is applied or under considerations in many building codes all over the world in order to provide a comprehensible and quantitative definition for expected structural damage from probable earthquakes. Performance-based earthquake engineering aims to satisfy both the owners and users of structures by considering their design, assessment and construction. The structural engineer and the owner of a structure can select different desired structural performance levels when subjected to potential earthquakes with different seismic intensities. Performanc-based design leads to the ability of the well-prediction of these performance levels with sufficient confidence. The selection of these performance levels depend on many parameters such as the use and importance of the structure and its life-sycle. The performance level can be defined by the maximum desired extent of damage to a structure under specific earthquake design level [1,2,30,3].

Performance levels can be classified as structural and nonstructural levels. These levels are categorized according to [4,2] as following:

- ***Operational (OP):*** The building is immediately suitable for normal use with minimal or no damage to the structural and nonstructural components.

[1] On leave from Structural Engineering Department, Zagazig University, Egypt.

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- ***Immediate Occupancy (IC):*** The building experiences minimal or no damage to the structural elements and only minor damage to the nonstructural components. Immediate occupancy may be possible. However, some clean-up, repair, and restoration of service utilities may be necessary before the building can function as before earthquake.
- ***Life Safety (LS):*** The structural and nonstructural components are subjected to extensive damage and are in need of repairs before re-occupancy. Repair is possible but may be economically impractical.
- ***Collapse Prevention (CP):*** The structural collapse is prevented with no consideration of nonstructural vulnerabilities. The building may create a significant hazard to life safety and be considered as a complete economic loss.

In order to estimate expected structural response and damage during an earthquake, Incremental Dynamic Analysis (IDA) method was introduced through performance-based earthquake engineering. IDA provides quantification of a structural response of a structure, whether it is a building, bridge or others, under ground motions with a wide range of intensities. IDA curves depict the relationship between the maximum interstory drift ratio and the seismic intensity, which can be represented by different ground motion parameters such as spectral acceleration, spectral displacement or peak ground acceleration [3]. IDA curves were developed by many researchers for different types of structures [5–9]. The quantification of structural and nonstructural damage obtained through IDA can be used to estimate the expected life and financial losses, which are important for the designers and owner of the structure.

Although there is no agreement about their exact relationship, the desired performance levels are commonly specified in terms of interstory drift ratios. Typical values of interstory drift ratios for the corresponding performance levels were provided by FEMA 356 for different structural systems. Considering reinforced concrete frames, IO, LS and CP performance levels are achieved at corresponding interstory drift ratios of 1%, 2% and 4%, respectively.

For different structural systems rather than that with masonry shear walls, Xue et al. [10] suggested values of maximum interstory drift ratio for each performance level as tabulated in Table 1. Compared to FEMA 356 values, interstory drift ratios are the same for IO and LS levels. Considering CP level, FEMA 356 estimated the corresponding interstory drift value is 4% while Xue et al. were conservative and recommended using 2.5%. The Damage Control (DC) level is an intermediate level between IO and LS that lies in the Damage Control Range specified by FEMA 356. Accordingly the maximum interstory drift ratio of 1.5% was suggested by Xue et al. for this performance level.

IDA can be used in developing analytical fragility curves, which are useful tools in estimating the extent of probable damage. These curves provide the probability of attaining or exceeding specific damage state considering different intensities of earthquakes. Fragility curves are used in estimating the losses in lives and economic losses under a ground motion with certain seismic intensity. Also, they can be used in retrofitting decisions and disaster response planning. Many researchers have developed fragility curves for different types of structures such as multistory reinforced concrete buildings [7,11,12], steel frames [6], bridges [13–15] and facades [16].

Besides being used in the assessment of structural response under earthquakes, fragility curves were used in the assessment of the effectiveness of different retrofitting techniques of multistory structures [17,18]. Williams et al. [19] used fragility curves for the decision-making process for two-story RC buildings in Memphis, Tennessee and San Francisco, California considering IO, LS, and CP performance levels.

In this research, analytical fragility curves are developed for 12-story moment-resisting reinforced concrete frames, designed according to Saudi Building Code in different seismic regions in KSA. With the aid of previously developed fragility curves for typical 4-story and 8-story moment-resisting reinforced concrete frames for residential buildings in KSA [7], the fragility curves are extended to cover a range from 4-story to 12-story structures considering two performance levels; OP and CP in Abha, Jazan and Al-Sharaf. Considering KSA, the seismic risk is not high compared to other high seismicity areas. No specific values of interstory drift ratios were suggested by the Saudi Building Code for desired performance levels. Researchers used similar values of interstory drift ratios suggested by Xue et al. to define performance levels of structures designed according to Saudi Building Code [7] because the definition of performance level, which depends on the desired damage status of a building after a specific earthquake, is not affected by the seismic risk of the location. Accordingly, the values suggested by Xue et al. are used in this research.

2. Structural model

Most of structures located in KSA are low to medium rise buildings due to the vast area of the kingdom. Reinforced concrete structures are the most common structures in the kingdom. The structures considered in this research are 12-story moment-resisting reinforced concrete frames. The structures are designed according to the Saudi Building Code considering

Table 1
Maximum interstory drift ratios for different performance levels [10].

Performance Level	OP	IO	DC	LS	CP
Maximum interstory drift ratio	0.005	0.01	0.015	0.02	0.025