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Assessment of seismic risks in code conforming reinforced concrete frames

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ABSTRACT

The main objective of this study is to employ performance-based earthquake engineering procedure to evaluate earthquake-induced risks in modern code-conforming reinforced (RC) concrete moment frames in terms of collapse risk and possible human and financial losses. A set of 30 archetype RC moment frames, designed based on the ASCE 7-05 and ACI 318-05 requirements, is selected for the evaluation purpose. The buildings are classified into 4-, 8- and 12-story and are designed with different levels of structural system ductility. The archetypes are assumed to be located in three zones with low, moderate and high levels of seismic hazard. The findings of the collapse assessment procedure indicate that the seismicity of the location significantly affects the collapse performance and the ductility, as long as the structure conforms to the requirements of modern design codes, has the least influence on the collapse risk. Also, it has been found that the expected annual repair costs lie in an interval with the minimum and maximum of 0.02% and 1.5% of the replacement cost and expected annual number of deaths ranges from $2 \times 10^{-4}\%$ to $29 \times 10^{-3}\%$ of the total occupants with the buildings located in the low seismicity zone having the minimum amounts of losses. Sensitivity analysis is employed to study the variations of earthquake consequences due to the variations in the design decisions.

1. Introduction

In recent years, the emerging performance-based earthquake engineering (PBEE) proposed by the Pacific Earthquake Engineering Research Center (PEER), has provided engineers with a robust approach to evaluate the seismic risks in buildings [1,2]. The probabilistic nature of PBEE allows engineers to incorporate different sources of uncertainty in the performance assessment procedure and, instead of an absolute outcome, provide a probabilistic distribution of every response parameter of interest. The outcomes of the PBEE methodology are usually reflected in collapse risk and human and monetary consequences of earthquake. These metrics have widely been employed by researchers in a comparative assessment to investigate how successful the modern seismic provisions are in providing approximately uniform safety against collapse and saving human lives during strong motions [3–7]. Past studies conducted on the seismic performance of modern reinforced concrete (RC) frames have shown that, despite the approximately acceptable collapse performance of these structures, variations in design parameters in RC frames results in significant discrepancies in the seismic performance [7–9].

This study applies the PBEE methodology through the nonlinear dynamic time history analysis to assess the seismic performance of a set of 30 RC moment frame archetypes, which are designed to be in accordance with the requirements of ASCE 7-05 [10] and ACI 318-05 [11]. Past studies conducted by Haselton [4], Liel [6] and Zareian [12] have indicated that variations in the design parameters such as height and space and perimeter frame could have a significant impact on the seismic performance. These studies have focused on special and non-ductile (1967-era) RC moment frames and RC shear walls buildings; all located in regions with high seismic hazard. This paper, taking advantage of the collapse assessment methodology proposed by Haselton [4] and Liel [6] and the FEMA P-58 [13] recommended loss evaluation process, focuses on expanding the previous findings to buildings located in different seismic zones and have distinct levels of structural ductility to

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examine to which extent the modern loading and design provisions are successful in achieving the uniform risk among conforming buildings. Moreover, this paper not only expands the previous studies conducted on collapse assessment of the RC structures, but also it goes further and presents a comprehensive evaluation of the seismic risk of modern RC buildings by estimating seismic loss using most advanced guideline.

2. Archetypes design and specifications

In order to clarify how the variations in height, ductility, seismicity and redundancy would affect the seismic risk in modern code-conforming RC moment frames, the set of representative archetypes is selected to include 4-, 8- and 12-story buildings. The lateral-force resisting structural system consists of two orthogonal, two-bay and three-bay frames with the bay span of 6-m width and plan dimensions of 18 by 24 m. Story heights are 4 m in the first story and 3.3 m in the all other above stories. Fig. 1 shows the plan and elevation of the 4-story archetypes and details of the columns and beams.

According to the Table 11.6-2 of ASCE 7-05, seismic design category of the archetypes is A for Austin and D for Las Vegas and Los Angeles. The main purpose of the ASCE's seismic design category classification is to provide enough ductility for the structures according to the seismicity of the location. Based on this classification, all three special, intermediate and ordinary RC frames are permitted in Austin and only special RC frames are permitted in Las Vegas and Los Angeles. Ordinary RC moment frames are not required to meet any special seismic requirements. However, the special and intermediate archetypes must conform to the additional seismic requirements of Chapter 21 of ACI 318-05 including strong column-weak beam (SCWB) ratio and joint shear panel provisions for special frames, special transverse reinforcements at probable hinging areas and minimum continuous flexural bars throughout beams. Past studies on the behavior of structures during earthquake occurrence have shown that RC moment frames, based on the stringency of seismic detailing in structural elements and their ductility, can be designed for reduced seismic forces and yet, due to the period elongation, inherent overstrength and hysteretic damping, be expected to response acceptably during actual seismic events. Based on the degree of expected inelastic response for each type of RC frames, ASCE 7-05 uses response modification factors (R) of 8, 5 and 3 for special, intermediate and ordinary frames to reduce the design seismic lateral forces.

The differences in the response modification and deflection amplification factors proposed by ASCE 7-05 and the seismic design requirements and detailing established by ACI 318-05 for ordinary, intermediate and special frames, have a drastic influence on the design outcomes. Table 1 reports the results of the design for the beams and columns of the first story of the seismic-force resisting system.

3. Site selection and seismic hazard

The selected archetypes are located in Los Angeles, Las Vegas and Austin at which the NEHRP-recommended maximum considered earthquake (MCE) level 1-s spectral accelerations correspond to the values of 0.912 g, 0.363 g and 0.078 g. These values are modified for the soil site class D. Site-specific seismic hazard parameters are extracted from the USGS hazard maps [14] and the corresponding application tool for ASCE 7-05. Fig. 2a compares the uniform hazard MCE spectra of ASCE 7-05 for the selected sites. Fig. 2b compares the 1-s-period-spectral-acceleration USGS hazard curves of the selected sites.

Three different approaches are employed by NEHRP to develop seismic design maps and lateral loading requirements for these three zones with three distinct levels of seismicity. These three major approaches include a combined probabilistic–deterministic method based on characteristic earthquakes for regions near known active faults such as high seismic hazard zones in coastal California (Los Angeles), a probabilistic method with design ground motions on the order of 2/3 of ground motion with 2% probability of exceedance in 50 years for regions with moderate hazard (Las Vegas) and finally a minimum set of requirements for regions with very low seismic hazard (Austin) [15].

4. Structural nonlinear modeling and analysis procedure

4.1. Modeling and analysis

The purpose of performing IDA analysis in this study is to determine the collapse point for each of the archetypes and also to find the response of the structures at several levels of intensity, from the lowest levels to the collapse point, in the forms of drift ratio

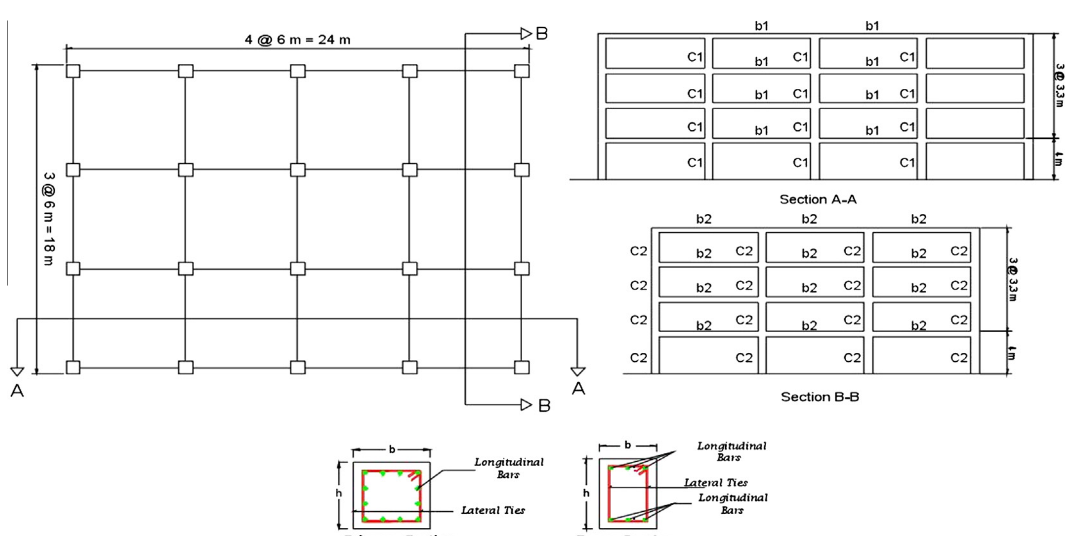

Fig. 1. Plan, elevation and details of the columns and beams of the 4-story archetypes.