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Seismic Design Evaluation of Reinforced Concrete Buildings for Near-Source Earthquakes by Using Nonlinear Time History Analyses

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Abstract

Seismic design codes mostly claim that their requirements lead to Life Safety (LS) Performance Level (PL) for buildings. This is while many buildings, designed based on the current codes have shown unacceptable performance, and even have collapsed in some recent earthquakes, particularly near-source events. On this basis, it seems that the code provisions still need further improvement to create sufficient confidence in the engineering community. This study has been conducted to find out how IBC 2009 And ACI 318-2014 codes are effective in providing the LS PL in reinforced concrete multi-story regular buildings with special moment frame lateral load bearing system. For this purpose, a set of multi-story buildings up to 16 stories were considered in the highest seismic hazard zone of Tehran, and were designed based on the codes. Then, a set of near-source three-component accelerograms were employed and scaled according to the code, and a series of nonlinear time history analyses were conducted for all buildings. Roof displacement and acceleration, and base shear forces were calculated, and also the formation trend of plastic hinges and their distribution in the structures were investigated for evaluating the seismic performances. Results show that for some earthquakes the buildings performance exceed LS PL, and even in some cases they reach collapse level.

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Keywords: Multi-story buildings with special moment frames, three-component accelerograms, roof displacement and acceleration, base shear, inter-story drift, plastic hinges, life safety performance level.

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1. Introduction

Most of the current seismic design codes for building systems claim, either explicitly or implicitly, that design of buildings' structures based on their requirements leads to Life Safety (LS) as their minimum Performance Level (PL). This is while some buildings, designed based on the current codes' provisions, and constructed based on high standards, under good supervision, have shown unacceptable PLs, even collapse in some recent earthquakes, particularly near-source events. Also in many cases the extent of damage in the earthquake stricken buildings has been so high, that the demolishing and reconstruction of the building have become inevitable. On this basis, it seems that the code provisions still need improvement to create sufficient confidence in the engineering community.

So far, several studies have been conducted on the adequacy evaluation of seismic design codes' provisions and requirements. Hosseini and Yaghoobi Vayeghan (2000) worked on design verification of an existing 8-story irregular steel building by both push-over and three-dimensional dynamic analyses [1]. With regard to concrete buildings Memari and colleagues (2000) conducted a seismic assessment of an existing 32-story reinforced concrete framed tube building using inelastic dynamic time-history analysis to obtain force and deformation response of the structure subjected to three ground motion records [2]. Fajfar (2000) presented a relatively simple nonlinear method for the seismic analysis of structures (the N2 method) [3]. It combines the pushover analysis of a multi-degree-of-freedom model with the response spectrum analysis of an equivalent single-degree-of-freedom system. Alchalabi (2000) described the application of the Japanese standard method of seismic capacity evaluation of existing reinforced concrete buildings to a hypothetical simple Syrian building, and three level evaluations were made to estimate the building's seismic capacity [4]. Goulet and colleagues (2007) illustrated a state-of-the-art seismic performance assessment through application to a reinforced-concrete moment-frame building designed per 2003 building code provisions [5]. Virote (2008) evaluated the seismic performances of reinforced-concrete buildings by nonlinear static analysis (pushover analysis and modal pushover analysis) and nonlinear time history analysis [6]. Epackachi (2012) studied the linear and nonlinear behavior of one of the tallest RC buildings, a 56-storey structure, located in a high seismic zone in Iran [7]. Masi (2012) evaluated the seismic capacity of some structural models which represent real RC existing buildings designed to gravity loads only, through non-linear dynamic simulations [8]. Thwin (2014) carried out computer aided analysis of twelve storied reinforced-concrete rectangular shape residential building for static and dynamic approach by using ETABS software [9]. Moniri (2014) investigated the results of illustrious characteristics of near-fault ground motions on the seismic response of three reinforced concrete structures (6-Story, 10-Story and 15-Story) [10]. Finally, Yoo (2016) carried out nonlinear dynamic analysis using the PERFORM-3D for small-size pilloti-type RC buildings and assessed their seismic performance [11].

The present study has been conducted to find out how some common seismic design codes are capable in providing LS PL in reinforced concrete multi-story regular buildings with special moment frame lateral load bearing system. For this purpose, a set of multi-story reinforced concrete buildings were considered in the highest seismic hazard zone of Tehran, the capital of Iran, assuming site soil classification of Sc according to IBC-2009. First, the considered buildings were designed based on the regulations of IBC-2009 and ACI 318-2014 code, and it was tried to keep the over-strength as low as possible. In the next step, a set of three-component accelerograms of selected near-source selected earthquakes were employed and scaled according to the code, and a series of nonlinear time history analyses were conducted for all buildings. The response values which were used for evaluating the buildings' seismic performance included roof displacement and acceleration, and base shear forces, all in both main directions. Also, the formation trend of plastic hinges, their corresponding PL as well as their distribution in the buildings' structures were investigated for evaluating the achieved seismic performance.

2. The Considered Buildings

Five 4-, 7-, 10-, 13- and 16-story concrete moment resisting frame buildings with composite floors, were considered, all with the same rectangular plan of 3 by 5 bays, spanning 4.0 to 4.6 meters, and located in the highest seismic hazard zone of Tehran, the capital of Iran, assuming site soil classification of Sc according to IBC-2009. All the considered buildings were designed according to ACI 318-14 and IBC 2009, and it was tried to keep the over-strength as low as possible. Table 1 gives the natural periods of the first three modes of the designed buildings, Figure 1 shows the 3D views of the considered buildings, and Tables 1 to 3 present their specifications.