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Necessity of Applying Seismic Sequence in Building Regulations

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Abstract

Sequential earthquakes have severe destruction on structures, including the accumulative structural and nonstructural damage, compared to single earthquakes and due to the lack of sufficient opportunity to repair of the structure, the possibility of structural damage increases. In this research, the effect of seismic sequence on the relatively new system of reinforced concrete frames equipped with steel plate shear walls has been investigated. Based on this, four system of 4, 8, 12 and 24 stories, which represent low-, mid-, and high-rise structures, are modeled in finite element software and subject to four sets of single and sequential earthquake and with a variety of application methods. Sequential earthquakes, including real, repetitive and randomized methods, are subjected to nonlinear dynamic analysis under four sets of single and sequential acceleration. The seismic scenarios used include sequential recorded critical earthquakes. The analysis showed that the predominant period of the aftershock significantly influences the post main shock response. Real seismic sequence increases the ratio of peak inter story drift by an average of 2 times the similar demand in a single earthquake and increases the ratio of maximum ductility demand by 1.52 times in the structure. In artificial sequence, the ratio of peak maximum inter story drift demand increase is in 100%, 150% and 200% aftershocks, In the iteration method, it is equal to 1.2, 2.0 and 2.6 times the single earthquake. Aftershocks may change the direction and magnitude of residual displacement in real and artificial seismic sequences. The effect of seismic sequence should be considered in building regulations. Continuation of the equation to calculate the demand for seismic sequence ductility was extracted.

Keywords: Reinforced Concrete Frame; Steel Plate Shear; Seismic Sequence; Drift; Residual; Nonlinear Dynamics

Introduction

Because aftershocks usually occur shortly after the main earthquake, and some of these aftershocks cause damage to the structure with a destructive force equal to that of the main earthquake, strengthening the damaged structure of the main earthquake in this short time interval is not possible and in order to reduce the level of hazards, it is necessary to evaluate the performance of the damaged structure in general under the main earthquake and aftershocks [1]. It is necessary to study the performance of structures during an earthquake and determine the capacity required to resisting possible aftershocks in response to the structure and the possibility of collapse of the building. Research in recent years has shown that the occurrence of aftershocks can significantly increase the demand for ductility of structures and lead to an increase in earthquake risk [2]. Recently, the reinforced concrete frame equipped with steel plate shear wall has been proposed as a new system against lateral loads [3]. The effect of sequence earthquakes (near and far field) on this system has not been studied. In this research the effects of aftershocks on the response of the reinforced concrete frame equipped with steel plate shear wall and residual displacement is studied. For this purpose, a number of sequence real and artificial records of far and near field, including the main earthquake and aftershock records have been used. Effect of main shocks and aftershocks of real and artificial earthquakes in different scenarios including main earthquakes in near and far field and different aftershocks were scaled to a peak grand acceleration of 0.15g, 0.3g, 0.45g, 0.6g by back to back and randomized methods in ratio of peak maximum inter story and residual drift and critical scenario is determined.

Numerical Modeling Validation

In this research, in order to validate the model, the laboratory study of Choi and Park in 2011 [4] according to Figure 2a has been used. He conducted a laboratory study to investigate the cyclic behavior of walls consisting of boundary elements of reinforced concrete frames and thin steel plates. In order to ensure the accuracy of the modeling, the numerical model of the laboratory sample was modeled and analyzed in OpenSees finite element software [5].

Methodology

Four models of 4, 8, 12 and 24 story with height to the smallest dimension ratios of 0.54, 1.09, 1.63 and 3.26 in the classification of low, low, mid and high structures with a rectangular plan according to Figure.1, is selected with a reinforced concrete frame equipped with steel plate shear wall and high ductility. In the analysis and design of the studied structures, the sixth [6] and ninth [7] national building regulations and the Iranian 2800 earthquake standard, fourth edition [8] have been used, according to sixth of the National Building Regulations and the criteria set by the American loading code ASCE07-2010 [9] for steel plate shear wall.

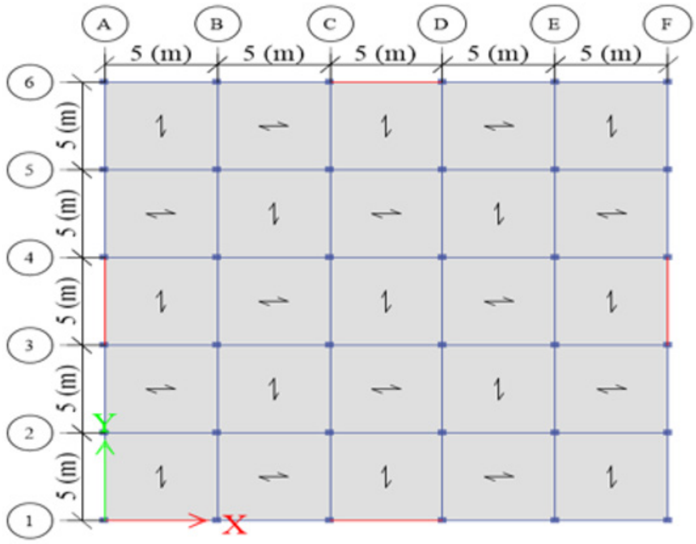

Figure 1: Plan of structural models.

In the OpenSees software, after defining the geometry of the model, the gravitational analyzes are gravitationally analyzed (non-linear static) and by setting the time in the amplitude of the problem to zero before performing the nonlinear dynamic analysis, the gravitational load values remain constant in subsequent dynamic analyzes. The effect of P-Delta is considered in the analyses. In the nonlinear dynamic analysis, the selection of a time interval of 30 seconds between the main earthquakes and aftershocks with zero acceleration amplitude is considered in order to stabilize the frame under the effect of the main earthquake excitation. 5% damping was applied for all models. In order to evaluate the seismic demands of reinforced concrete frames equipped with steel plate shear walls, the parameters of peak maximum of drift demands and peak maximum displacement of stories and the maximum ductility and residual drift of stories have been selected to assess the seismic demand of models.

Seismic Scenarios

Sequence seismic records have been applied to the models in two ways, including real seismic records and artificial seismic records. In the real seismic records method, using the sequence seismic records recorded in the recorded stations in three groups of include group I with effective peak acceleration, group II nearly maximum effective peak acceleration and group III with acceleration used by researcher, in the artificial method group IV with main important earthquake records due to the unavailability or insufficient number of sequence real seismic records an artificial aftershock have been applied to the models. In the artificial method different scenarios of S1, S2, S3 and S4 of sequence earthquakes (combination of main earthquake + aftershock) have been used.

Results and Discussion

Estimation of Ductility Demands of Models Under Seismic Sequence

The peak story displacement parameter is used to calculate the total ductility coefficient μ, as equation 1.

$$\mu = \frac{u_{max}}{u_y} \qquad (1)$$

To estimate of the cumulative ductility of the seismic sequence, equation 2 is presented.

$$\mu_{seq} = 1 + \left[\sum_{i=1}^{n} \langle \mu_i - 1 \rangle^{p}\right]^{\frac{1}{p}} \qquad (2)$$

Figure 2 Comparison of cumulative ductility demand results of different models for combining Group I and II earthquakes. The value of R^2, which shows the correlation of ductility of equation 2 with the ductility obtained from the analyzes, is considered appropriate because it is close to 1 [Figure 2].

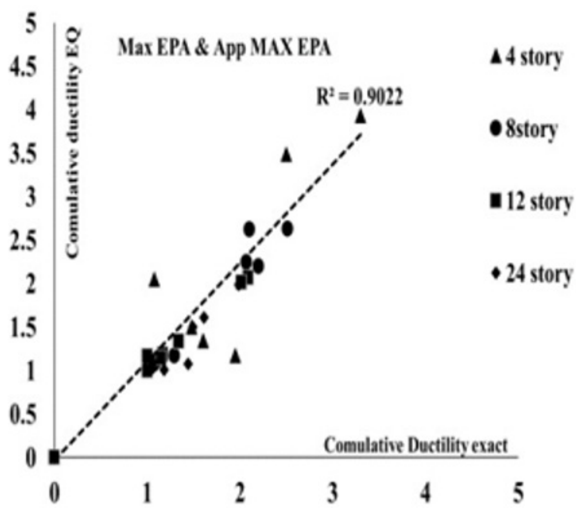

Figure 2: Comparison of cumulative ductility demand of models for real earthquake sequences groups I and II.

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Effect of Seismic Sequence on Peak Ductility Demand

In the nonlinear dynamic analysis, for each of the real seismic scenarios, the peak ductility demand and the ratio of this parameter for the sequence to the main seismic are calculated. The ductility demand of the short model for the PGA ratio are 0.28, the intermediate model for the PGA ratio of 0.74 and the tall model for the PGA ratio of 0.97 are equal to 1.66, 1.54 and 1.34, respectively. Larger ratios than 1 mean that structural systems require more ductility against sequence earthquakes. In this study, in the most critical, the peak ductility demand for due to seismic sequence has increased by 79% compared to the single main seismic. Based on the expected use and performance, the structures have ductility criteria corresponding to the main earthquake. Thus, there is a need to review the ductility criteria of structures.

Effect of Seismic Sequence on Peak Maximum Inter Story Drift

According to this study, the real seismic sequence has increased the peak maximum inter story drift of the stories of reinforced concrete frame equipped with steel plate shear wall is an average 2 and the maximum is 2.31 times to single main earthquake for PGA aftershock ratio 1.89. However, in the artificial seismic sequence, this demand has increased up to a maximum of 3 times to single main earthquake for PGA aftershock ratio of 2 times the compared to a single main earthquake. Also, according to the results of the analysis, aftershocks may change the direction and magnitude of residual displacement in real and artificial seismic sequences.

Conclusions

From this study the following conclusions are drawn:

A. Real seismic sequence increases the ratio of peak maximum inter story drift demand of reinforced concrete frame equipped with steel plate shear wall by an average of 2 times the similar demand in a single earthquake and in the artificial seismic sequence in PGA aftershock to main shock of 2 equal 3 times the similar demand in the main earthquake.

B. In real seismic sequence the ratio of critical PGA aftershock to the main earthquake related to the peak maximum ductility demand in the reinforced concrete frames equipped with steel plate shear wall is not constant and this ratio approximately 0.25 for short, 2 for intermediate and 0.5 for tall models.

C. Aftershocks may change the direction and magnitude of residual displacement in real and artificial seismic sequences. Also, in estimating the residual drift of the models, the randomized method of artificial sequence is more critical than the back to back method.

D. According to this research, in determining the peak maximum inter story drift demand and the peak maximum ductility demand of reinforced concrete frame equipped with steel plate shear wall, the back-to-back method in artificial sequence is more critical than the randomized method. However, in the artificial sequence randomized method, near field aftershocks caused more damage to reinforced concrete frame equipped with steel plate shear wall than far field aftershocks.

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