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Effects of Seismic Sequence on Increased Response of Concrete Moment Frames with and without Shear Wall

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ABSTRACT: This study investigates the effect of seismic sequence on the behavior and increased response of concrete moment frames with/without shear walls. At first, three moment resisting concrete frames with 4, 7 and 10 stories are designed and analyzed under critical single and consecutive records. In order to investigate the effect of seismic sequence phenomena, frames were subjected to nonlinear time history analysis and some parameters such as, maximum ductility demand, inter-story drift and shear deformation of shear walls are calculated. It was seen that records with peak ground acceleration (PGA) ratio of consecutive records to single's less than 0.46 do not have any significant effect on the response of frames. As PGA ratio increased, the effect of seismic sequence on the frames is more considerable. Results show that seismic sequence phenomena has more effective on the moment frames with shear walls compared to moment frames. Moreover, for both structural systems, its effectiveness decreased as the number of stories increased.

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1- Introduction

Most of current seismic risk assessment tools consider risk due to a main-shock event only. However, it is common to observe many aftershocks following the main-shock event, some of which could be strong enough to cause further damage to the building and even loss of human life [1]. Usually, these aftershocks occur close in time to the main-shock. Therefore, repair or retrofit activities are often not possible to be applied within this time interval; this, in turn, may increase the risk associated with already damaged structures. Consequently, it is necessary to evaluate structural performance after a main-shock and during aftershocks in order to aid emergency management procedures and repair/retrofit decision processes [2]. It has been shown that current standards used as the starting point of the seismic design of new structures, as well as of the seismic assessment of existing ones, can be significantly improved through an explicit account of ductility demands [3]. According to above mentioned reasons, the importance of considering seismic sequence phenomena can be seen. Thus, this paper aims to investigate the effect of seismic sequence on reinforced concrete frames with/without shear wall.

2- Methodology

OpenSees software is used to simulate and analyze the models in this paper. Developed models categorized into two groups of reinforced concrete frames with shear wall and reinforced concrete frames without shear wall. Each group contains 4, 7 and 10 story frames which, have been designed according to standard No. 2800, seismic resistant design of buildings, 4th version and verified with experimental result of structures under consecutive scenarios [4]. A schematic view, 3 story frame is shown in Figure 1.

3- Seismic scenarios

Since, artificial seismic records have insufficient accuracy in simulating real subsequences of seismic sequence, 11 sets of real seismic sequences records is selected from PEER database in this study. All seismic sequence records were recorded in the same station and similar direction with maximum time interval of 10 minutes together. Records have been selected based on Effective Peak Acceleration (EPA) parameter [5]. Due to similar design procedure, and regarding to standard No.2008, records were scaled to have PGA of 0.4g.

4- Results

All frames with and without shear wall were subjected to single and consecutive records. The time-history responses of these frames are evaluated by means of nonlinear dynamic analysis. It was seen that records with PGA ratio of consecutive records to single's less than 0.46 do not have any significant effect on the response of frames. Therefore results

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of 3 sets of seismic records analysis with PGA ratios equal to 0.74, 0.97 and 1.23 are reported in this section.

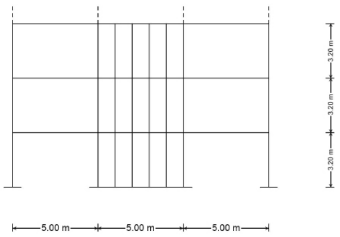

Figure 1. Schematic view of 3 story frame

4- 1- Effect of seismic sequence on inter story drift

Figure 2 illustrates the effect of seismic sequence on inter-story drift. Results indicate that seismic sequence can significantly affect inter-story drift of frames, as it can be seen, this phenomena can increase inter story drift up to 80 percent. Expectedly as PGA ratio of seismic sequence record to first record (PGA_{seq}/PGA_{f}) increases, effect of seismic sequence becomes more noticeable.

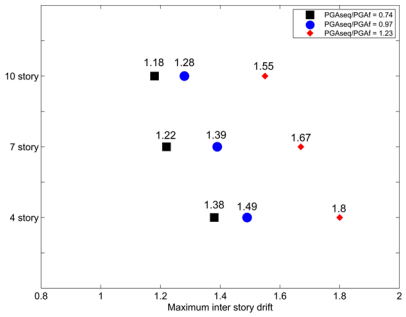

Figure 2. Ratio of peak inter story drift in moment frames with shear wall results for Chi Chi 1, Irpina 2 and Hollister main shock and aftershock records

4- 2- Effect of seismic sequence on peak ductility demand

The global displacement ductility factor, μ, can be defined according to Equation 1, in terms of the maximum displacement u_{max} at the top level of the examined buildings and the corresponding yield displacement u_y.

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

Fig. 4 presents the result of peak ductility demand parameter under single and sequence events. It is clear that the seismic sequences phenomena leads to different response in comparison with the corresponding single seismic events. Successive ground motions with major intensity require more ductility demands.

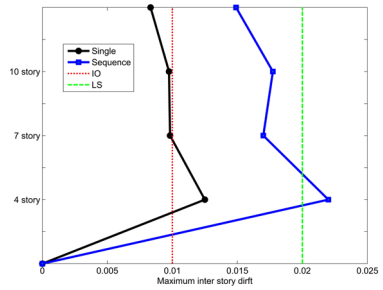

Figure. 3. Effect of seismic sequence on limit sate of 4 story moment frame under consecutive record of Chi Chi 2 (1999)

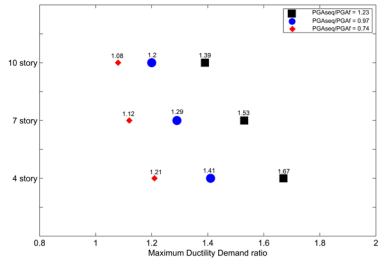

Figure. 4. Ratio of peak ductility demand in moment frames with shear wall results for Chi Chi 1, Irpina 2 and Hollister main shock and aftershock records

4- 3- Effect of story height on the response of frames under seismic sequence

Analytical results of the frames with 4, 7 and 10 stories, representing low rise, medium rise and high rise frames is reported in this section. In order to evaluate the effect of story height, average values of frame responses under 3 single and consecutive events are presented in Fig. 5.

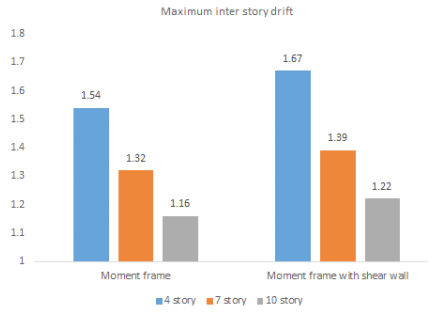

Figure. 5. The average values of inter story drift (average results from Chi Chi 1, Irpina 2 and Hollister records)

According to Figure 5, it can be seen that for both structural systems, effect of seismic sequence decreases as the frame height increases. It might be explained by over strength caused by typing and also due to increase of frame height, vibration period lengthens and applied earthquake force to the frame decreases.

4- 4- Effect of structural system type on the response of frames under consecutive earthquakes

In order to compare the effect of seismic sequence phenomena on moment frames with/without shear wall, average results of

inter-story drift and peak ductility demand, under three single and consecutive events have been examined for these two structural systems In Figure 6.

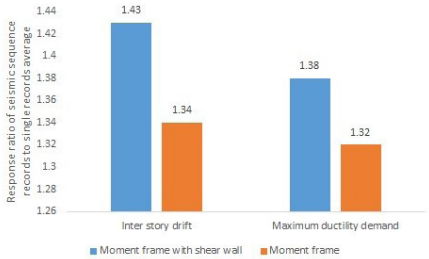

Figure .6. Comparison between structural systems (average results from Chi Chi 1, Irpina 2 and Hollister records)

Figure 6 indicates that moment frames with shear wall experience more increased responses due to seismic sequence phenomena. The difference can be justified by lower period time of frames with shear wall and consequently stronger earthquake force applied to these frames. It is implied that different structural systems require different approaches regarding seismic sequence phenomena.

5- Conclusions

From this study the following conclusions are drawn:

1. Successive earthquakes with PGA_{seq}/PGA_{f} up to 0.46 do not have any significant effect on the response of frames.
2. Seismic sequence phenomena can considerably affect inter story drift and peak ductility demand of both structural systems and also shear deformation of shear walls.
3. As PGAseq/PGAf grows the effect of seismic sequence becomes more evident.
4. Neglecting seismic sequence phenomena can lead to underestimate design of structures, due to change of expected performance caused by seismic sequence phenomena.
5. The effect of seismic phenomena sequence on structural responses decreases as frame height increases.
6. Reinforced concrete moment frames with shear walls experience severe effects of seismic sequence, compared to reinforced concrete frames.

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