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The effect of near-fault earthquake on seismic behavior of concrete buildings

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Abstract

Due to losses and damages incurred by earthquake in seismic countries, necessity of design of earthquake- resistant structures seems inevitable. For design of a building to resist against earthquake, it is necessary to have comprehensive information about the behavior of building against forces resulted from earthquake. It must be noted that following terms and conditions of seismic design regulations do not ensure the resistance of buildings against seismic forces. For this reason, behavior of structures must be taken into account generally and accurately. In this study, effect of near-fault earthquakes on plasticity of the concrete buildings will be studied in accordance with regulation 2800. For this end, three near-fault earthquakes were selected and matched with Seismo Signal software according to regulations and then, the effect of these earthquakes on three 5, 10 and 15-storey concrete buildings is analyzed.

Keywords: Seismic behavior, earthquake, concrete buildings

Introduction

Movements recorded near active faults differ from that of regions away from fault owing to the effects of progressive directivity and permanent displacements. Among the most important characteristics of these arrangements, presence of long-period pulses in acceleration, velocity and displacement history, high ratio of maximum velocity to maximum acceleration in history, high frequency content of mapping and short-term duration of the normal component of the fault map are notable. Each of these characteristics has its specific effects on various structures. Moreover, in such type of earthquakes, accumulation of energy in a short time and in a pulse can lead to an impulsive movement.

In the past years, due to limited number of seismographic networks all around the world, it was not easy to record the near-field earthquakes. By the advance of these networks and improvement of seismographic machines, today we have numerous maps of the earthquakes in different points. Penzien (2000) attributes the reasons of technical advances in structure and earthquake engineering to advances in computers, development of methods of nonlinear analysis of structures, understanding and utilization of allowable plastic deformation of structures, changes in details of plasticity, resistance and so on. According to recent advances, researchers observed different between the effects of near-fault earthquakes and that of far from fault ones. After 1966 earthquake of Park Field, California and 1971 of Pacoima, San Fernando, the term “near-fault” was introduced by Bullet (1975) (Bruce, 2004). Although near-fault effects were known previously, the importance of this issue was not fully understood until devastating earthquakes such 1992 of Landers, 1994 of Northridge, 1995 of Kobe and 1999 of Chichi (Choi et al, 2005; Galal & Ghobarah, 2006). Such earthquakes which occur near faults, have pulse mappings with long pulse period and one or more peak of velocity. This pulse is produced by the sliding of fault and results in sudden exertion of a main part of the seismic energy in one or two pulses to the structure. In near-fault field, horizontal component normal to the fault has the greatest effect on the response of

structures and its effect dominated the horizontal component parallel to the fault and the component normal to the earth surface. However, if necessary for performance of the structure, in this case, component normal to the earth surface must be estimated (i.e. for design of the deck of bridges) (John, 1997). Since some of the Iranian cities including Tehran are located near fault, exploring the effect of near-fault field is inevitable. Therefore, in this paper, behavior of structures in near-fault earthquakes is analyzed.

In past years, behavior of structures in near-fault fields is studied so that each of works investigated this issue from one point of view and explored the near field effects. In this section, a review of the results of literature is presented and then, a 7-storey structure is analyzed under 10 near-fault and 10 away from fault mappings.

In 2010, Liu et.al investigated the characteristics of nonlinear response of concrete frames and designed two 5 and 12-storey moment frame ac using two near-fault earthquakes according to building regulations of Taiwan and analyzed them under four near-fault mapping of Chichi earthquake and many other mappings from the rest of the world. Mappings were matched to the 3m/s2 peak acceleration. It was found out that relative displacement in both structures was larger under near-fault earthquakes compared to away from the fault ones (Galal & Ghobarah, 2006). Al-Sheikh et.al studied the effect of near-fault earthquakes in 3, 6, 12 and 20-storey moment frames. Results of the increasing static loading analysis and dynamic analysis showed that for a fixed base shear, displacement obtained by the increasing loading analysis is more conservative compared to dynamic analysis and it was revealed that the increasing static loading is more appropriate for design based on displacement for structures under near-fault earthquakes (Galal & Ghobarah, 2006).

Saeidi and Summerwill (2005) explored the effect of near-fault earthquake on columns designed in accordance with Caltrans v.1.3 regulations. Two concrete column samples with main periods; TMN=0.66s and TETN=1.5s with the same materials were tested under mapping of near-fault earthquakes. Results suggested that under mappings containing directivity effects, permanent deformations will remain in both columns (Saiidi & Somerville, 2005).

In 1987, Anderson and Bertro investigated the behavior of structures using impulsive movements of the earth. For this purpose, they studied a 10-storey and 3 and 4-bay steel structure under Imperial Valley earthquake (1997) and showed that increase in the ratio of the period of impulsive movement of the earth to the natural period of the structure and the ground acceleration to yield strength of the structure leads to increase in nonlinear response and damages of the structure. According to their results, concentration of deformations in lower parts of the building whose columns support significant axial loading leads to the P-Δ effect in lower floors. Consequently, damages resulted from impulsive movements of the earth concentrates in lower floors of the building. Moreover, near-fault earthquakes lead to improvement of the ductility of the rigid structures. Hall (1995) designed structures according to available regulations and investigated their behavior under near-fault earthquakes and observed that ductility imposed to the structures having long periods and flexible and isolated structures exceeds their capacity considerably (Tehrani Zadeh & Labbaf Zadeh, 2005).

Geometric properties of the buildings

In this study, three 5, 10 and 15-storey buildings are analyzed. Bottom cross section of each building is 18×18m and the height of each floor is 3m. Fig. 1 represents the model of 5-storey building.

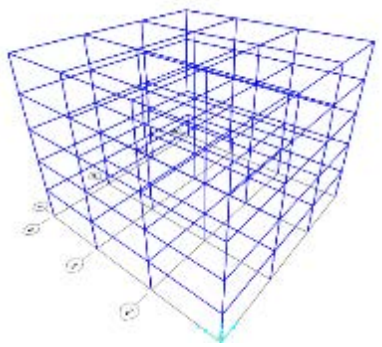

Figure 1: Model of 5-storey building

Characteristics of case study earthquakes

Table 1 summarizes the characteristics of near field and far field earthquakes. According to various regulations, earthquakes with distance less than 20km from the site are considered near-field and directivity of all six earthquakes is progressive. Maximum acceleration of Imperial Valley occurs in 1.2s as much as 0.148g. Moreover, effective duration of it is 14.9s. Maximum acceleration of Kobe occurs in 7.27s as much as 0.567g and its effective duration is 11.5s. Maximum acceleration of Coyote occurs in 2.26s as much as 16.82g.

Table 1: The characteristics of near field and far field earthquakes

	Case	Magnitude	Station	R (km)	D5-95	Mechanism	Vs(m/s)
Near-field	1979 Coyote Lake	5.6	Gilory Array 6	1.2	6	Strike-Slip	251
	Imperial Valley-06	6.53	Brawley Airport	8.54	14.9	Strike-Slip	208
	1995 Kobe, Japan	6.9	Port Island (0 m)	3.31	11.5	Strike-Slip	199

Spectrum of selected accelerograms

In two diagrams shown below, accelerograms extracted from earthquakes using seismosignal software are illustrated. It must be noted that all earthquakes are scaled to accerlation of gravity and compared to 1.4 times of the standard spectrum in accordance with regulations 2800. In addition, according to regulations, 5% attenuation coefficient is considered.

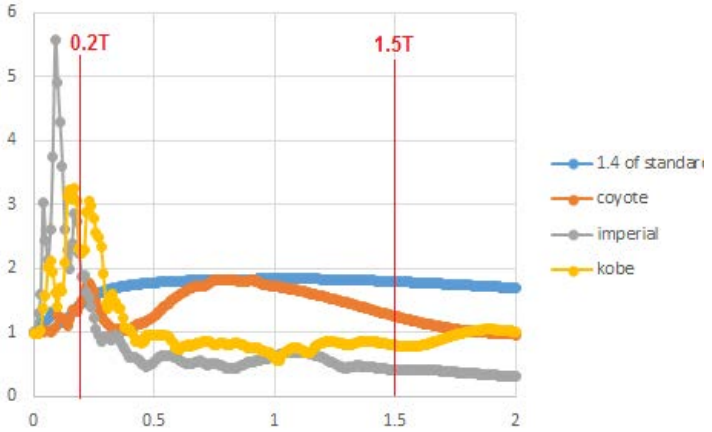

Figure 2: Comparison of the spectrum of near-field accelerograms

In above diagrams, earthquakes of Kobe and imperial Valley have three peaks and that of Coyote has two peaks. However, it must be noted that Kobe earthquake is attenuated faster than two other earthquakes and Coyote has the lowest attenuation coefficient. Area under the diagram of the

spectrum represents the effectiveness of the earthquake. Therefore, Coyote earthquake has the greatest effect on the seismic response of the building.

Results

In below figures, effect of above earthquakes on the displacement and velocity behavior of the building are shown.

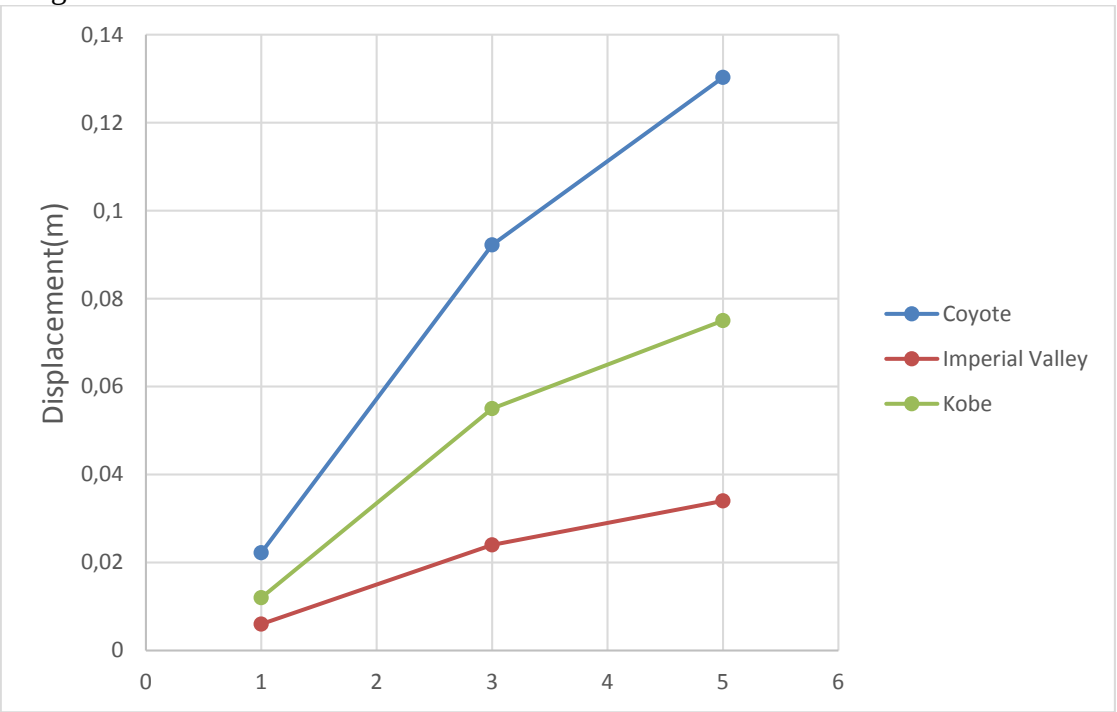

Figure 3: Comparison of displacement in three earthquakes for 5-storey building

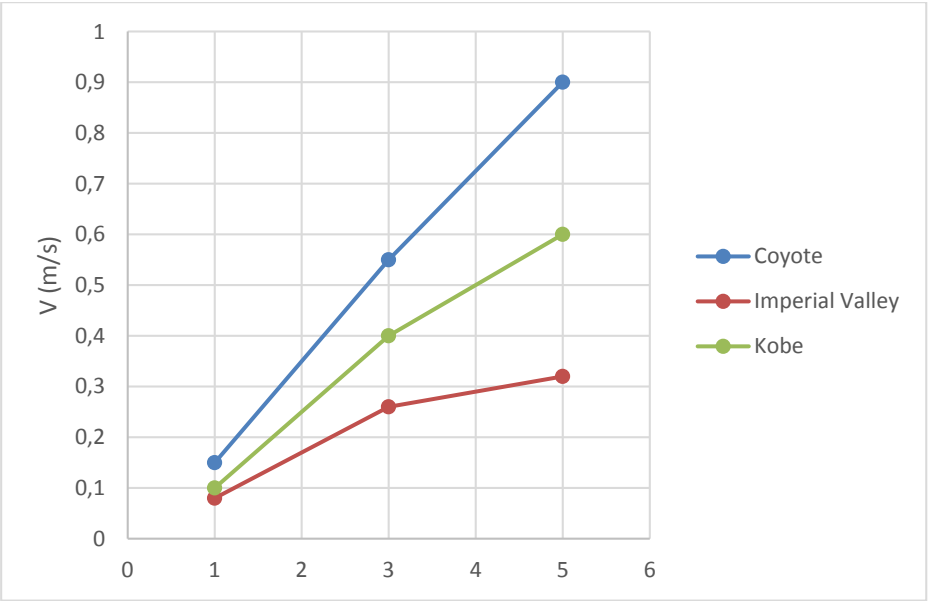

Figure 4: Comparison of velocity in three earthquakes for 5-storey building

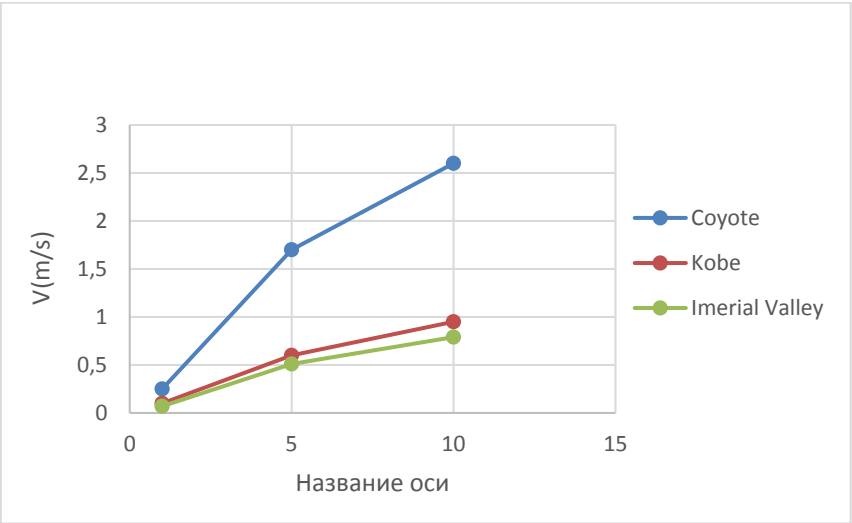

Figure 5: Comparison of velocity in three earthquakes for 10-storey building

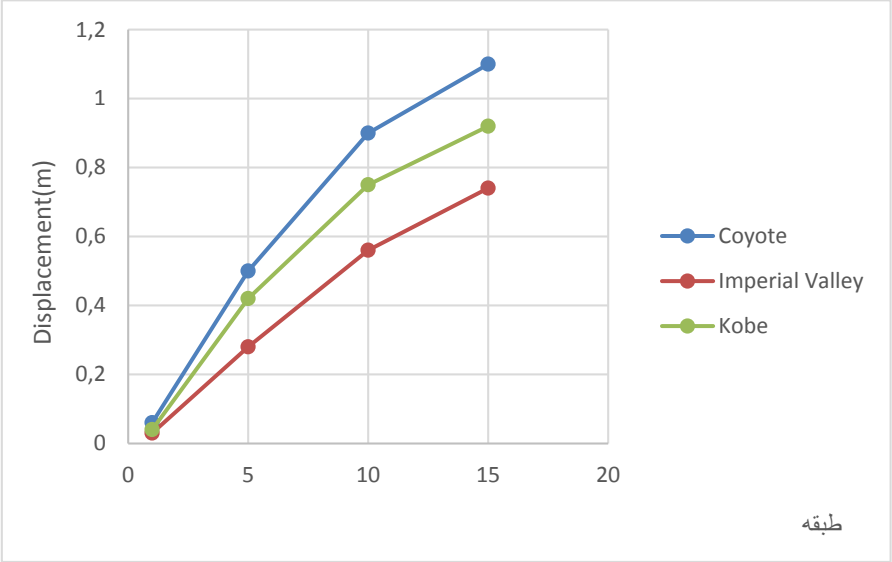

Figure 6: Comparison of displacement in three earthquakes for 15-storey building

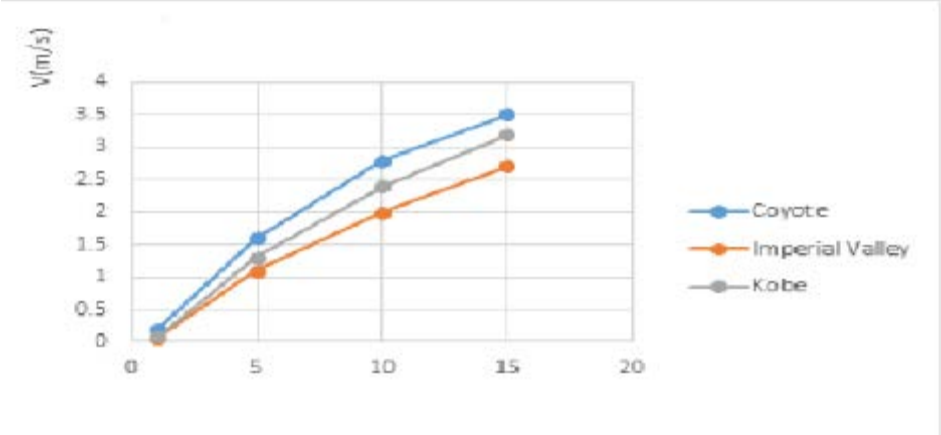

Figure 7: Comparison of velocity in three earthquakes for 15-storey building

According to above diagrams, in all three buildings, effect of Coyote earthquake is more serious than two other earthquakes with respect to displacement and velocity and Kobe are Imperial Valley earthquakes rank after that. This is in agreement with the area under the diagram of the spectrum of earthquakes. As can be seen in above figures, values corresponding to Coyote diagram are significantly different from two other earthquakes the reason of which is that the maximum accerlation of this earthquake is 16 times of accerlation of gravity and is regarded as one of the biggest earthquakes while two other earthquakes have peak accelerations as much as 0.6 and 0.15 of the accerlation of gravity. Furthermore, the distance of Coyote earthquake from the station is about 0.5km which is considerably less than two other earthquakes. Therefore, as the distance of fault from the site decreases, values of displacement and velocity increase and earthquake will be more devastating.

Conclusion

In this paper, the effect of near-fault earthquakes on the ductility of concrete buildings was studied in accordance with regulations 2800. According to results:

• In the analysis of history, maximum displacement increases by height. For example, in Coyote earthquake, displacement of the last floor of three buildings is 5.8, 10.4 and 19.7 times of that of first floor, respectively.

• Maximum velocity increases by height. For instance, in Coyote earthquake, displacement of the last floor of three buildings is 6.2, 10.5 and 21.8 times of that of first floor, respectively.

• In study of all three structures under target displacement, all hinges are below the level of safety and meet the acceptance criteria.

• As shown by results, in far from fault earthquakes, more distance of fault from the site leads to lower values of displacement and velocity of floors. For example, in 15-storey building under the earthquake of central California, by moving the fault away from the site, value of displacement and velocity of the last floor decreases by 49 and 76%, respectively.

• Results of the plastic and fiber elements suggests that results obtained from fiber elements are more conservative than that of plastic hinges and it is better to use these results in seismic design of buildings.

• Effect of the earthquake on the behavior of structure depends upon the area under the spectrum diagram.

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