Damage assessment of RC buildings subjected to the different strong motion duration

Alireza Mortezaei¹, Mohsen Mohajer Tabrizi²

¹ Assistant Professor, Civil Engineering Dep., Engineering Faculty, Semnan Branch, Islamic Azad University, Semnan, Iran
² M.Sc. Student, Civil Engineering Dep., Engineering Faculty, Semnan Branch, Islamic Azad University, Semnan, Iran

a.mortezaei@semnaniau.ac.ir

Abstract. An earthquake has three important characteristics; namely, amplitude, frequency content and duration. Amplitude and frequency content have a direct impact but not necessarily the sole cause of structural damage. Regarding the duration, some researchers show a high correlation between strong motion duration and structural damage whereas some others find no relation. This paper focuses on the ground motion durations characterized by Arias Intensity (AI). High duration may increase the damage state of structure for the damage accumulation. This paper investigates the response time histories (acceleration, velocity and displacement) of RC buildings under the different strong motion durations. Generally, eight earthquake records were selected from different soil type, and these records were grouped according to their PGA and frequency ranges. Maximum plastic rotation and drift response was chosen as damage indicator. In general, there was a positive correlation between strong motion duration and damage; however, in some PGA and frequency ranges input motions with shorter durations might cause more damage than the input motions with longer durations. In soft soils, input motions with longer durations caused more damage than the input motions with shorter durations.

1. Introduction

One of the most seismically active regions, that have 5–6% of earthquakes and 17% of the world's largest earthquakes, is the Alpide belt. Iran is one of the most seismically active countries in this belt, being crossed by several major fault lines that cover at least 90% of the country [1]. Accordingly, earthquakes in Iran are inevitable [2]. In order to accurately describe any earthquake, one must be able to describe the three major characteristics of the motion: a) amplitude, b) frequency content and c) duration. These parameters describe characteristics of the recorded ground motion time history, which fully describes the ground motion at a particular site.

The duration of strong ground motion is an important characteristic affecting the response of the structures. It is widely recognized that strong motion duration is one of the challenging characteristics of ground motion, which affects the damage level of structures.

The duration of strong ground motion, rather than the duration of the entire time history, is the main interest of engineers. It is important to recognize the strongest part of an accelerogram and its characteristics, by identifying which part of the ground motion have most of energy and therefore the highest damage potential. For example, as it has been known, for equal accelerations greater duration is generally more damaging and for equal energy shorter duration presents a greater damage.
There are more than 30 different definitions of strong motion duration [3]. While there is no common view regarding which of the definitions of strong motion duration is to be chosen. Although a large number of definitions of strong motion duration have been presented in the literature, the available definitions can be grouped into four different categories: (a) bracketed duration [4, 5]; (b) uniform duration [6]; (c) effective duration [3], and; (d) significant duration [7]. In recent years, Montejo and Kowalsky [8] proposed a procedure for estimation of frequency dependent strong motion duration based on the continuous wavelet transform and the decomposition of the earthquake record. Yaghmaei-Sabegh et al. [9] presented a simple and effective empirical model for predicting the significant duration of ground motions based on recorded earthquake events in Iran.

Bracketed duration is defined as the interval between the first and last acceleration excursions greater than certain absolute amplitude of an accelerogram (Figure 1).

Uniform duration is the total sum of time intervals, during which a particular level of acceleration is exceeded.

Trifunac and Brady [7] defined the duration of the strong motion as the time interval in which a significant contribution to the integral of the square of the acceleration, referred to as the accelerogram intensity, takes place. They selected the time interval between the 5% and the 95% contributions as the duration of strong motion. Hence, significant duration is based on the accumulation of energy in the accelerogram represented by the integral of the square of the ground acceleration, velocity or displacement (Figure 2).

Response based duration is related to the energy input in structures as well as structural frequency and damping. Since there is no standard definition of strong-motion duration, the selection of a procedure for computing it for a study depends on the purpose of the study.

2. Characteristics of selected records
Ground motions often lead to stiffness and strength weakening of structures. For two earthquake ground motions with similar amplitude but of different duration, the motion of longer duration would be anticipated to be more damaging. Hence, the duration of earthquake ground motion should be considered an important parameter in addition to the maximum amplitude and frequency content for adequately characterizing the effect of earthquake ground motion on seismic damage of structures.

In this paper, a total of 8 records were selected to cover a range of frequency content, duration and amplitude. These records come from earthquakes having a magnitude (Mw) range of 6.2 to 7.3, and were recorded at closest fault distance of 0.0 to 7 km. Information pertinent to the ground motion data sets, including station, components of earthquake and peak ground acceleration (PGA) of vertical and
horizontal components are presented in Table 1. The comparison of response spectrum of selected records has been shown in Figure 3.

Utilized in this study is a data processing technique proposed by Iwan et al. [10] and refined by Iwan and Chen [11].

### Table 1. Near-fault ground motion database

| Earthquake            | Year | Station         | Distance (km) | Mw  | Component | PGA (g) |
|-----------------------|------|-----------------|---------------|-----|-----------|---------|
| Tabas                 | 1978 | 9101 Tabas      | 10            | 7.4 | TAB-TR    | 0.85    |
| Imperial Valley       | 1979 | Bonds Corner    | 2.68          | 6.4 | 0         | 0.588   |
| Morgan Hill           | 1984 | Coyote Lake Dam | 0.30          | 6.2 | 90        | 0.711   |
| Erzican (Turkey)      | 1992 | Erzincan        | 4.38          | 6.8 | 111       | 0.496   |
| Landers               | 1992 | Lucerne         | 2.19          | 7.3 | 90        | 0.721   |
| Northridge            | 1994 | Rinaldi Rec Stn | 6.50          | 6.7 | 180       | 0.472   |
| Kobe (Japan)          | 1995 | KJMA            | 0.96          | 6.9 | 360       | 0.599   |
| Chi-Chi               | 1999 | TCU072          | 7.9           | 7.6 | 360       | 0.37    |

**Figure 3.** Comparison of response spectrum of selected records

### 3. Description of Buildings used for Evaluation

Six existing reinforced concrete special moment-resisting frame buildings of 3, 6, 10, 14, 16 and 19 stories were selected as representative case studies to evaluate their seismic demands when subjected to the different ground motions. These buildings were designed in compliance to the Iranian Code of Practice for Seismic Resistant Design of Buildings [12]. The rectangular plan of all buildings measures
30 m × 25 m. The floor plans view of the buildings is shown in Figure 4. The buildings are assumed to be fixed at the base with a damping ratio of 5% in all modes, and the floors as rigid diaphragms with infinite in-plane stiffness.

The modulus of elasticity (Young’s modulus) $E = 30 \text{kN/mm}^2$, Poisson’s ratio $\nu = 0.20$ and the mass density $\rho = 24 \text{kN/m}^3$ are assumed in all models. The uniaxial strength for nonlinear modeling of the concrete is considered to be 35 MPa. The rebar is modeled as steel with yield strength of 400 MPa and an ultimate strength of 600 MPa.

4. Analytical results

All buildings were analysed under the selected ground motions. The shear strength of a column tended to degrade faster than its flexural strength with cycling of the lateral load. For beam members, flexural cracks were observed. In some cases, flexural cracks occurred on the bottom face of the beams. Shear cracking was observed in the columns and beam-column joints during the earthquakes.

For the sake of clarity, results of the demands on the interior frame of the 10-story building experiencing the largest demand among each ground motion category are presented. For the 10-story building, plastic hinges occurred at the upper and lower levels of the building (Fig. 5). The results show that the failure mechanism is formed of two main damage zones, one at the base and one in the top part of the structures. In almost all the analyses, the cracking is always initiated at the second story which may be due to stress concentration.
For the seismic motions associated with a short duration, the actual response of the low-rise buildings will exhibit some tensile cracking, and some small damage is identified. But it will not severely influence the analytical results of the building. The buildings subjected to the moderate duration, some moderate damage is found. However, the results corresponding to the input motions with a long duration show major strength degradation in the buildings, with a cracking pattern that extends across the upper level.

Figure 6 is the surface plot for Displacement-Duration-PGA. Based on this figure, there is a relative relation between maximum nonlinear displacement (damage) and duration due to large nonlinear displacements for different duration motions. For example, larger nonlinear displacements occur at short durations and low frequencies and larger nonlinear displacements are at short duration and moderate PGA levels. Based on this figure, it can be concluded that maximum nonlinear displacement has a positive relation with strong motion duration.

![Figure 6. Displacement-Duration-PGA relationship](image)

After the nonlinear dynamic analyses of the building structures for all the selected records, the peak displacement and damage energy dissipation are found, and the local and global damage indices are computed for each seismic excitation. The damage index values for each used record are presented in Table 2. To analyze the effects of strong motion duration on the damage of building structures, damage of the buildings subjected to the 8 records for a given level of intensity in terms of local and global damage indices are determined. Trend lines for each level of intensity are determined with the aim of identifying a general tendency. The results show that S-form trend lines are fitted to the plots to show the general trends for the relationship between strong motion duration and local damage index. The trend lines show that, as would be expected, the local and global damage indices of the building structures during the records with longer duration are generally greater than those under shorter events for the same level of spectral acceleration.
Table 2. Damage index values for each used record

| Earthquake     | Local damage index | Global damage index |
|----------------|--------------------|---------------------|
|                | PGA=0.2g           | PGA=0.25g           | PGA=0.3g | PGA=0.35g | PGA=0.2g | PGA=0.25g | PGA=0.3g | PGA=0.35g |
| 1 Tabas        | 0.20               | 0.23               | 0.27     | 0.30     | 0.18     | 0.22     | 0.24     | 0.27     |
| 2 Imperial Valley | 0.17            | 0.18               | 0.21     | 0.24     | 0.20     | 0.23     | 0.27     | 0.30     |
| 3 Morgan Hill  | 0.15               | 0.19               | 0.21     | 0.25     | 0.17     | 0.19     | 0.21     | 0.24     |
| 4 Erzican (Turkey) | 0.17            | 0.19               | 0.21     | 0.24     | 0.18     | 0.21     | 0.24     | 0.28     |
| 5 Landers      | 0.10               | 0.14               | 0.16     | 0.20     | 0.13     | 0.15     | 0.18     | 0.22     |
| 6 Northridge   | 0.13               | 0.15               | 0.18     | 0.22     | 0.17     | 0.19     | 0.21     | 0.24     |
| 7 Kobe (Japan) | 0.15               | 0.18               | 0.21     | 0.25     | 0.20     | 0.23     | 0.27     | 0.30     |
| 8 Chi-Chi      | 0.18               | 0.22               | 0.24     | 0.27     | 0.22     | 0.26     | 0.31     | 0.34     |

5. Conclusion

Different definitions of strong-motion duration are considered in the study including uniform duration, bracketed duration, significant duration, and effective duration. The structural damage is represented by interstorey drift, column ductility, beam ductility, and base shear. Based on the results from the study, it was found that for building structures, the effect of strong motion duration, which measured by different definitions, depends on both the peak ground acceleration and the using damage indices. Although measure using peak response is mostly used in design and evaluation purposes because of simplicity, the damage measure based on the peak displacement response has a poor relationship with the duration of the ground motion. Strong motion duration has been found to be important to the damage of the building structures. Damage measures such as local damage index, global damage index and damage energy dissipation are consistently greater for ground motions with longer duration. Among the examined definitions of strong motion duration, the significant duration has the better relationship with the damage. The influence of duration depends on a number of different factors including the definition of strong motion duration, the damage measure, the strong motion record and the structural model. These results are the starting point for further exploration, of more seismic records and of other types of building structures including regular or irregular.

6. References

[1] Probabilistic seismic hazard analysis, phase 1: greater Tehran regions. Final report. Vice-presidency for Strategic Planning and Supervision, 2005.
[2] Tavakoli, B., and Ghafory-Ashtiany, M. 1999. Seismic hazard assessment of Iran. Annali Di Geofisica 42, The Global Seismic Hazard Assessment Program (GSHAP) 1992-1999, 1013-1021.
[3] Bommer JJ, Martínez-Pereira A. 1999. The effective duration of earthquake strong motion. J Earthq Eng, 3(2):127–72.
[4] Ambraseys NN, 1967. Sarma SK. The response of earth dams to strong earthquakes. Geotechnique, 17(3):181–213.
[5] Bolt BA. 1973. Duration of strong ground motion. In: Proceedings 5th World conference on earthquake engineering. Rome, p. 1304–13.
[6] Bommer JJ, Stafford PJ, Alarcon JE. 2009. Empirical equations for the prediction of the significant, bracketed, and uniform duration of earthquake ground motion. Bull Seismol Soc Am, 99(6):3217.

[7] Trifunac MD, Brady AG. 1975. A study on the duration of strong earthquake ground motion. Bull Seismol Soc Am, 65(3):581–626.

[8] Montejo LA, Kowalsky MJ. 2008. Estimation of frequency-dependent strong motion duration via wavelets and its influence on nonlinear seismic response. Comput Aided Civil Infrastruct Eng, 23(4):253–64.

[9] Yaghmaei-Sabegh S, Shoghian Z, Neaz Sheikh M. 2014. A new model for the prediction of earthquake ground-motion duration in Iran. Nat Hazards, 70(1):69–92.

[10] Iwan, W. D., Moser, M. A. & Peng, C. Y. 1985. Some observations on strong-motion earthquake measurements using a digital accelerograph. Bulletin of the Seismological Society of America, Vol. 75, pp. 1225–1246.

[11] Iwan, W. D. & Chen, X. D. 1994. Important near-field ground motion data from the Landers earthquake. Proceedings of the 10th European Conference on Earthquake Engineering, Vienna, Austria.

[12] Iranian Code of Practice for Seismic Resistant Design of Buildings. 2005. Standard NO. 2800-05, Building and Housing Research Center.