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Correlation between strong motion durations and damage measures of concrete gravity dams

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ABSTRACT

Strong motion duration affects the cumulative damage of structures significantly. There are more than 30 different definitions of strong motion duration. This study describes numerically, the interdependency between several different definitions of strong motion duration and structural accumulated damage indices, and the aim is to determine the definitions of strong motion duration that exhibit the strongest influence on structural damages. For this purpose, 20 as-recorded accelerograms with a wide range of durations, which are modified to match a 5% damped target spectrum, are considered in this study, and several different definitions of strong motion duration, such as significant duration, bracketed duration and uniform duration are proposed for measuring these durations. On the other hand, nonlinear seismic analyses of concrete gravity dams subjected to earthquake motions with different strong motion durations are conducted according to the Concrete Damaged Plasticity (CDP) model including the strain hardening or softening behavior. Peak displacement, local damage index, global damage index and damage energy dissipation are established for characterizing the influence of strong motion duration on the dynamic response of concrete gravity dams. The degree of the interrelationship between strong motion durations and damage measures is provided by correlation coefficients. Comparison of the correlation between the different durations of the ground motion and different damage measures reveals that strong motion durations calculated from different definitions have no significant influence on damage measure based on the peak displacement response of the dam, but are positively correlated to the accumulated damage measures such as the local damage index, global damage index and damage energy dissipation for events with similar response spectrum.

1. Introduction

As is well known, earthquake ground motion can be characterized by amplitude, frequency content and strong motion duration [1], each of which reflects some particular feature of the shaking. Amplitude is generally characterized by the peak ground acceleration (PGA), the peak ground velocity (PGV) and the peak ground displacement (PGD). The frequency content is generally described by the Fourier spectrum of the ground motion. Nonetheless, both amplitude and frequency distribution can be described by the widely accepted response spectrum (in terms of acceleration, velocity, or displacement). The importance of the amplitude and frequency content has been universally recognized. However, the conclusions with regard to the relevance of strong motion duration to structural response differ widely, ranging from null to significant, which remains a topic of considerable debate. This is mainly because the influence of strong motion duration on structural response and damage depends on many factors including the type of structure examined, the construction model, the other parameters used to characterize the ground motion, the measure of structural damage employed, and the large number of widely differing duration definitions that have been proposed [2–4].

There are more than 30 different definitions of strong motion duration [5]. While there is no unanimous view regarding which of the definitions of strong motion duration is to be preferred, which probably reflects the fact that different definitions may be more or less suitable for different applications. Although a large number of definitions of strong motion duration have been

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presented in the literature, the available definitions can be grouped into four different categories: (a) bracketed duration [6,7]; (b) uniform duration [8]; (c) effective duration [5], and; (d) significant duration [9], and then classified by whether the amplitude or energy thresholds used for their measurement are absolute or relative to the peak value in the recording. Subsequently, several new definitions and prediction models of strong motion duration have been put forward. For example, Taflampas et al. [10] proposed a new definition of strong motion duration combining the alternative bracketed and significant duration definitions based on the time integral of the absolute ground velocity, and their presented bracketed-significant duration was found to be well correlated with the strong motion part of the records. Montejo and Kowalsky [11] proposed a procedure for estimation of frequency dependent strong motion duration based on the continuous wavelet transform and the decomposition of the earthquake record. Arjun and Kumar [12] developed a neural network approach for estimation of strong motion duration based on earthquake records and site characteristics. Yaghmaei-Sabegh et al. [13] presented a simple and effective empirical model for predicting the significant duration of ground motions based on recorded earthquake events in Iran.

Experiences from a number of earthquakes show that a ground motion with moderate peak ground acceleration and a long duration may cause greater strength and stiffness degradation than a ground motion with a large acceleration and a small duration [5]. The duration of strong motion may significantly affect the damage of structures and plays an important role in assessing the damage potential of earthquake ground motions. However, current approaches for the earthquake-resistant design and structural analysis based on the response spectrum have not yet considered the influence of the ground motion duration. There are many studies reporting that link structural damage to parameters related either directly or indirectly to strong motion duration. However, the relevance of strong motion duration to structural response remains an open question, with some research indicating no effect [14,15] and other research indicating a possible correlation [16,17]. At least part of the reason that researches have differing conclusions on the importance of strong motion duration is the use of different duration definitions, structural models and damage metrics. For example, Hancock and Bommer [2] presented a summary and critical review of the literature with regard to the influence of strong motion duration on structural demand, and concluded that those studies employing damage measures related to cumulative energy usually found a positive correlation between strong motion duration and structural damage, while those using damage measures, such as maximum response parameters, generally found little or no correlations between duration and damage.

In order to investigate the influence of the strong motion duration on structural response and damage, a substantial amount of research has been carried out over the past decades. Youd et al. [18] clearly recognized that the strong motion duration has profound effects on the behavior of saturated soils. Mahin [19] found that strong motion duration might play an important role in the inelastic deformation and energy dissipation demands of short period structures. Bommer et al. [4] showed that the duration of strong motion can make a significant influence on the strength degradation of masonry structures. Chai and his co-workers [20,21] found that long duration will increase inelastic design base shear. Iervolino et al. [22] addressed the question of which nonlinear demand measures are sensitive to ground motion duration by statistical analyses of several case studies. The results led to the conclusion that duration of ground motion does not have a significant influence on displacement ductility and cyclic ductility demand. Hancock and Bommer [23] revealed that duration of strong motion has no influence on damage measures employing the peak response such as inter-storey drift, but if cumulative parameters are used to measure the damage, the duration of strong motion is found to have a significant influence on the inelastic structural response. It should be noted that few studies have focused their attention on the nonlinear dynamic response and seismic damage of concrete gravity dams subjected to earthquake motions with different strong motion durations. For example, Zhang et al. [24] investigated the effects of strong motion duration on the dynamic response and accumulated damage of concrete gravity dams based on the definition of significant duration. Their result showed that strong motion duration is insignificant to peak displacement response assessment. While studies employing damage measures using local and global damage indices showed that strong motion duration is positively correlated to the accumulated damage for events with similar response spectrum. Léger and Leclerc [25] suggested that short duration analytic records should not be used as a substitute for other types of more appropriate records in the earthquake safety evaluation of concrete dams.

The objective of this paper is to provide a method for quantifying the interrelationship between strong motion durations and damage measures of concrete gravity dams. 20 as-recorded accelerograms with a wide range of durations, which are scaled and matched to match a 5% damped target spectrum, are selected in this study. Three different definitions of significant duration, bracketed duration and uniform duration are presented for measuring strong motion durations. Local damage index, global damage index, peak displacement, and damage energy dissipation are employed as the measures of structural damage. A Concrete Damaged Plasticity (CDP) model including the strain hardening or softening behavior is selected for the concrete material. Nonlinear dynamic response and seismic damage analyses of Koyna gravity dam under different strong motion durations are conducted to furnish the structural damage status. The interrelationships between the different strong motion durations and the damage measures are given.

2. Strong motion duration-related measure used in this study

2.1. Definitions of strong motion duration

Any attempt to study on the correlation between strong motion durations and structural damage levels immediately faces the problem that there is currently no universally accepted definition of strong motion duration. Several researches in the past have been conducted for the quantification of strong motion duration [8,10,12,26], and there are more than 30 different definitions of strong motion duration [5]. There is no clear consensus as to which of the multiple definitions of duration is to be preferred, which probably reflects the fact that different definitions may be more or less suitable for different applications. In the past, a number of researchers have proposed procedures to compute strong motion duration of an earthquake record. In general, the available definitions can be classified in four different groups: (a) bracketed duration (T_B) [6,7] in which the duration is defined as the time interval between the first and the last exceedances of a particular threshold of acceleration (usually 0.05g); (b) uniform duration (T_U) [8], which rather than a continuous time window are defined as the sum of time intervals during which the record exceeds a particular acceleration threshold; (c) effective duration (T_E) [5] that defines the duration of strong motion as the time interval between two particular thresholds of the Arias intensity, and; (d) significant duration (T_S) [9], it is defined to be the interval between the times at which a given percentage of Arias intensity of the record is reached. Most of the proposed definitions are