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Response of nonlinear single-degree-of-freedom structures to random acceleration sequences

Abbas Moustafa [a,*], Izuru Takewaki [b]

[a] Department of Civil Engineering, Minia University, Minia 61111, Egypt

[b] Department of Urban & Environmental Engineering, Kyoto University, Kyotodaigaku-katsura, Kyoto 615-8540, Japan

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ABSTRACT

Current seismic codes specify design earthquake loads as single events. The structure, however, may experience multiple ground accelerations in a short period of time. The evidence from recent earthquakes confirms this scenario. For instance, the 2004 Niigata earthquake consisted of two acceleration sequences. An earthquake of repeated sequences can cause more damage to the structure than a single ordinary event, due to the accumulation of inelastic deformations. However, information on repeated acceleration sequences is currently limited. This paper proposes a simple stochastic model for representing repeated acceleration sequences. Subsequently, the model is used in investigating the response of nonlinear single-degree-of-freedom (SDOF) structures to random earthquakes of repeated sequences. The ground acceleration is represented as a stationary Gaussian random process modulated by an envelope function of repeated character. The structural response is quantified in terms of the input and hysteretic energies, ductility demand, damage indices and failure probability. Numerical demonstrations of the response of nonlinear SDOF systems to acceleration sequences are provided.

1. Introduction

In performance-based design, the structure is designed to behave linear elastically without damage under a moderate frequent earthquake and to undergo repairable damage under a rare strong earthquake [1,2]. Design earthquakes are specified in current seismic codes as single events [3–5]. However, the structure may experience repeated accelerations in a short period of time. Ground accelerations of multiple sequences could result in more damage to the structure than a single ordinary event. This is because the structure gets damaged in the first sequence, and additional damage accumulates from secondary sequences before any repair is possible. The evidence from recent earthquakes confirms this scenario. For example, the 2004 Niigata earthquake recorded at Nagaoka-shisho (NIG028) consisted of two acceleration sequences (see Fig. 1). Multiple acceleration sequences result from mainshock–aftershock earthquakes. For instance, the 2010 Haiti earthquake had a mainshock of 7.0 M_w, followed by about 14 aftershocks of 5.0–6.1 magnitude [6]. Repeated acceleration sequences separated by short time intervals have also been observed at other regions of the world, as shown in Table 1 [7,8]. Thus, ground accelerations of repeated sequences represent a real situation that requires special treatment in seismic design.

Ref. [9] reported the first evidence of repeated acceleration sequences in the 1997 Umbria–Marche Italy earthquake. The response of inelastic steel structures to simulated acceleration sequences was studied in [10,11]. In [12], the spectrum of the force ratio was used in designing single-degree-of-freedom (SDOF) structures to survive all possible earthquakes during their service life without undergoing repairs. Recently, recorded accelerograms were used to investigate the implication of repeated acceleration sequences on the inelastic displacement ratio and the ductility demand of SDOF and multi-degree-of-freedom (MDOF) structures [13–17]. Extensive parametric studies were conducted in these studies to derive expressions for the inelastic displacement ratio and the ductility demand in terms of the period of vibration, the viscous damping ratio, the strain-hardening ratio, the force reduction factor and the soil class. More recently, the characteristics of strong ground motion of multiple sequences have been studied [18]. The definitions of the effective number of sequences and the effective strong duration have also been introduced.

Dunbar and Charlwood [19] reported the significant difference in the frequency content for the M6.2 earthquake and the M4.9 aftershock recorded at the C-00 of the SMART array in Taiwan. The statistical properties of aftershock sequences were studied in [20]. The study showed that aftershocks are associated with

* Corresponding author.
E-mail addresses: abbas.moustafa@eng.miniauniv.edu.eg, abbas.moustafa@yahoo.com (A. Moustafa), takewaki@archi.kyoto-u.ac.jp (I. Takewaki).

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