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Influences of the duration and frequency content of ground motions on the seismic performance of high-rise intake towers

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ABSTRACT

The main purpose of this study is to investigate the influences of the duration and frequency content of ground motions on the seismic performance of high-rise intake tower considering structures-reservoir-foundation interactions. Thirty earthquake records matched with the standard design response spectrum according to Chinses code for seismic design of hydraulic structures of hydropower project were selected as ground motion input. The nonlinear seismic responses were classified according to the duration to investigate the effects of ground motion duration; while the nonlinear dynamic response under other fourteen earthquake records matched with previous standard design response spectrum with different response spectrum curves and characteristic periods were compared to study the effects of frequency content. The results show that the duration and frequency content in the seismic input can have significant effects on the seismic performance of high-rise intake towers.

1. Introduction

The seismic safety and proper functioning of high-rise intake towers in an earthquake are important to the seismic performance of the whole hydropower project. Incremental dynamic analysis (IDA) is a performance-based method to assess the seismic limit state and performance of intake towers based on non-linear dynamic analysis. However, various uncertainties need to be taken into account in nonlinear dynamic time history analysis, among which the input of earthquakes can have a very significant effect. Ground motion can be characterized by three parameters, including amplitude, frequency content and duration [1]. The ground motions records are usually selected based on spectral matching, and the seismic-resistant design and damage measure of IDA are typically based on peak parameters of ground motion, such as peak ground acceleration (PGA), peak ground velocity and peak ground displacement. The importance of ground motion amplitudes in determining the damage potential of seismic ground motion has been well addressed, while the influences of strong-motion duration and frequency content have been overlooked in current IDA and seismic performance assessment.

The seismic acceleration generally consists of rising, strong motion and decaying phase. A ground motion with a moderated peak and a long duration of strong motion is likely to cause more severe damage than that with a large peak but a short duration of strong motion. There is increasing evidence that the strong motion duration of a seismic excitation can significantly affect the seismic performance of a structure [2,3]. Ou et al. investigated the seismic responses of flexural-dominated reinforced concrete bridge columns under long-duration ground motion, and the results showed that the column subjected to long-duration loading had a similar peak strength but a lower ductility capacity compared with that subjected to a baseline loading [4]. Song et al. investigated the

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influences of earthquake duration (5–95% significant duration D_s) and frequency content (mean period T_m) on the collapse risk of post-mainshock building, and the results showed that both D_s and T_m played a critical role in collapse capacity of the structure [5]. van de Lindt and Goh proposed the term duration effect factor (DEF_β) to compare earthquake duration studies [6]. Zhang et al. investigated the effects of strong motion duration on the accumulated damage of concrete gravity dams [7]. Wand et al. investigated the relationship between three types of strong motion duration (significant, bracketed and uniform durations) and the damage of concrete gravity dams [8]. Wang et al. proposed an integrated definition of strong-motion duration for multi-component seismic excitations, which was found to have a strong effect on the cumulative over-stress duration, the accumulative damage and the residual plastic deformation [9,10]. Barbosa et al. conducted an analytical study evaluating the influence of ground motion duration on structural damage of steel moment resisting frame building, and the results showed that ground motion duration could affect the combined damage measure, although some effect on the drift-based response measures was also observed for large levels of drift. It has also been suggested that both performance-and code-based assessment methodologies should be revised to consider damage measure that are sensitive to duration [11]. Cakir investigated effects of earthquake frequency content on dynamic behavior of cantilever retaining wall subjected to different ground motions, and they found that the dynamic response of the cantilever wall was highly sensitive to the frequency of earthquake record [12]. Li et al. found that the time-varying frequency content in the seismic input significantly affected stochastic properties of linear elastic system responses [13]. Khoshnoudian et al. investigated the effects of various frequency-content components of near-fault ground motions on the seismic responses of nonlinear multi-story structures considering soil-structure interaction, and the results showed that soil-structure interaction had increasing and mitigating effects on structural response to the pulse-type and high-frequency components, respectively [14].

In this study, the influences of the duration and frequency content of ground motion on the seismic performance of high-rise intake tower were investigated. Thirty earthquake records in Pacific Earthquake Engineering Research Center-Next Generation Attenuation (PEER-NGA) [15] were classified according to the duration and then input as seismic loading in IDA. The effects of ground motion duration on seismic responses, IDA results and seismic potential failure modes were compared. The influences of frequency content of ground motion were also investigated by nonlinear dynamic analysis under earthquakes matched with different design response spectra (DRS).

2. IDA method

2.1. Description of the numerical model

In order to identify the effects of duration and frequency content of ground motion on the structure response, a high-rise intake tower of a hydropower station was selected as the representative numerical example. The seismic design intensity is VII, and the horizontal peak ground acceleration (PGA) of the maximum design earthquake (MDE) and the maximum credible earthquake (MCE) is 0.1*g* and 0.25*g*, respectively. The geometry and finite element discretization of structure-reservoir-foundation system were illustrated in Figs. 1 and 2.The main structure was discretized into 3D solid elements; the hoist room was discretized into 3D-solid and truss elements based on separated reinforced concreted element [16]; and the equipment was considered as added masses. The

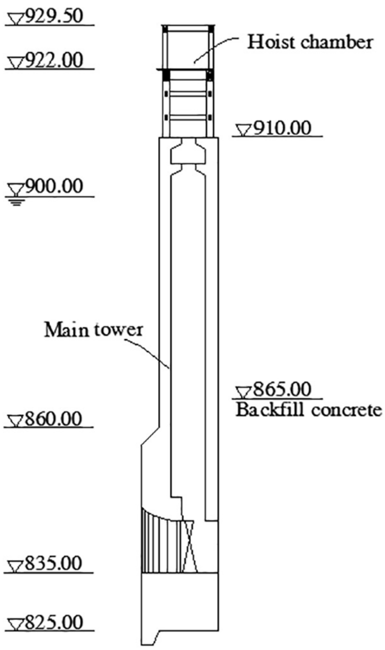

Fig. 1. A typical section of the intake tower (elevations in m above sea level).