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Seismic failure modeling of concrete dams considering heterogeneity of concrete

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ABSTRACT

Study on the failure process of high concrete dams subjected to strong earthquakes is crucial to reasonable evaluation of their seismic safety. Numerical simulation in this aspect involves dynamic failure analysis of big bulk concrete dam subjected to cyclic loading. The Rock Failure Process Analysis (RFPA) proposed by C.A. Tang, with successful applications to failure modeling of rock and concrete specimens mainly subjected to static loading, is extended for this purpose. For using the proposed model, no knowledge on the cracking route needs to be known beforehand, and no remeshing is required. Simulation of the whole process of elastic deformation, initiation and propagation of microcracks, severe damage and ultimate failure of concrete dams in earthquakes with a unified model is enabled. The model is verified through a shaking table test of an arch dam. Finally a practical gravity dam is employed as a numerical example. Considering the uncertainty in ground motion input and concrete material, typical failure process and failure modes of gravity dam are presented. Several small cracks may occur due to tension particularly at dam neck, dam faces and dam heel, and a few of them evolve into dominant ones. Relatively smaller earthquake may cause damage to the dam neck while a bigger one may bring on cracks at lower parts of the dams. Cracking at the dam bottom may incline to a direction almost perpendicular to the downstream face after propagating horizontally for a certain distance when the shaking is strong enough.

1. Introduction

With the outburst of strong earthquakes in China, Haiti and Chile during the last two years, it seems that the earth has come into an era with more and stronger earthquakes. The majority of high dams are being built or to be built in countries with active seismic activities such as China, Turkey, etc. Considering the possible disastrous results brought about by dam failures, seismic safety of high dams remains a crucial problem to be solved in dam construction. In the seismic design guidelines in China [1], two levels of earthquakes are adopted. The design of earthquake is assumed with non-exceeding probability of 98% in one hundred years, and 99% of non-exceeding probability is assumed for the checking of earthquake. However, Shapai Arch Dam, with a design PGA of 0.10 g, has undergone earthquake shocks with an intensity higher than IX in the Wenchuan Earthquake in 2008 [2], which poses the problem that dams might be subjected to earthquake shocks much stronger than the design value owing to the complexity and randomness of seismic activities. Seismic analysis of concrete dams considering its failure process and failure modes, leading to more realistic and comprehensive insights into the seismic response of dams, has become one important frontier in dam analysis.

Seismic hazard documents and shaking table tests are our main sources of understanding the seismic failure of high concrete dams. However, there are only few examples of high concrete dams subjected to strong earthquakes shocks, and cases of severe damage are even rare. The Xinfengjiang Dam, Sefid Rud Dam and Koyna Dam are the ones that have suffered damage in earthquakes. The shaking table test can reproduce the seismic response of any dams to dynamic loading, and models of many important dams have been shaken on the table to comprehensively investigate their seismic capacity [3,4]. For model tests, many issues need to be clarified. Among them, similarity relation is the most difficult particularly for a nonlinear response of the dam.

Numerical analysis is a promising alternative owing to the ability to take many factors into consideration and perform analysis of different cases with low costs. Many numerical models have been developed for the seismic nonlinear analysis of concrete dams. Among them, models in the context of Finite Element Method have gained the most popularity owing to the convenience in dealing with nonlinearity of concrete and complex geometry of structures. The discrete Crack Model (DCM) [5] and the Smeared Crack Model (SCM) [6] in the framework of Fracture Mechanics as well as

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