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A hybrid distinct element–boundary element approach for seismic analysis of cracked concrete gravity dam–reservoir systems

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ABSTRACT

This paper proposes a new algorithm for modeling the nonlinear seismic behavior of fractured concrete gravity dams considering dam–reservoir interaction effects. In this algorithm, the cracked concrete gravity dam is modeled by distinct element (DE) method, which has been widely used for the analysis of blocky media. Dynamic response of the reservoir is obtained using boundary element (BE) method. Formulation and various computational aspects of the proposed staggered hybrid approach are thoroughly discussed. To the authors' knowledge, this is the first study of a hybrid DE–BE approach for seismic analysis of cracked gravity dam–reservoir systems. The validity of the algorithm is discussed by developing a two-dimensional computer code and comparing results obtained from the proposed hybrid DE–BE approach with those reported in the literature. For this purpose, a few problems of seismic excitations in frequency- and time-domains, are presented using the proposed approach. Present results agree well with the results from other numerical methods. Furthermore, the cracked Koyna Dam is analyzed, including dam–reservoir interaction effects with focus on the nonlinear behavior due to its top profile crack. Results of the present study are compared to available results in the literature in which the dam–reservoir interaction were simplified by added masses. It is shown that the nonlinear analysis that includes dam–reservoir interaction gives downstream sliding and rocking response patterns that are somehow different from that of the case when the dam–reservoir interaction is approximated employing added masses.

1. Introduction

Concrete gravity dams are distinguished from other structures because of their size and their interactions with the reservoir and foundation. In practice, concrete gravity dams might have well cracked at their base or at a specific height caused by seasonal temperature variations, shrinkage of concrete or previous earthquakes. These cracks may propagate in the dam body or, through monoliths. As a result, these existing cracks weaken the stability of concrete gravity dams mainly due to the nonlinear behavior of sliding and overturning, during strong ground motions. Therefore, nonlinear seismic analysis of a cracked concrete gravity dam has been investigated by different approaches to study the propagation of cracks in this kind of dams. The discrete crack approach, models the crack by separating the nodes of crack surfaces [1–7], while the smeared crack approach, tries to represent the physical discontinuity introduced in a system of cracks by modification of material properties in the zone of cracking [8–16].

Many researches have been conducted, including shake table experiments [17–19]. They focused mainly on the process of crack initiation and propagation. On the other hand, little efforts has been done for the case in which cracks are expected to penetrate from upstream to downstream in non-overflow monoliths of the dam.

In comparison with numerous works concerning crack occurrence and propagation in concrete gravity dams, there are limited researches on the seismic response of concrete gravity dams with penetrated cracks. Assuming no sliding of the top block and adopting a horizontally penetrated crack, the overturning analysis of a concrete gravity dam was first studied by Saini and Krishna [20], in which the top block of the monolith above the crack was modeled as a rigid block. Léger and Katsouli [21] used contact elements located at the dam–foundation interface in order to determine the seismic sliding and uplifting response of concrete gravity dam monoliths. Chopra and Zhang [22] investigated the frictional base sliding of concrete gravity dams subject to seismic loading, in which the whole dam was modeled as an one-degree-of-freedom system. This study indicated that the flexibility of the dam affects considerably the downstream residual sliding. Based on a sliding rigid block concept and the equivalent single-degree-of-freedom system criteria, Danay and Adeghe [23] suggested an

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