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Effects of material properties and boundary conditions of discontinuous foundation on the seismic performance of arch dams

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Abstract

This paper details the influence of material properties change of discontinuous rock foundation on the seismic behavior of arch dams. In this regard, proper modeling of far boundary conditions at far-end of rock foundation and reservoir fluid domain is important. Nonlinear seismic response of dam - reservoir - foundation system includes dam-canyon interaction, dam body contraction joint opening, discontinuities (sliding planes) of foundation rock and failure of the jointed rock and concrete materials. Therefore, a finite element program for nonlinear dynamic analysis of 3D dam - reservoir - foundation system was developed. Karun 4 Dam as a case study was analyzed the results revealed the essential role of modeling discontinuities and boundary conditions of rock foundation under seismic excitation.

Keywords: Concrete arch dam, Non-homogeneous and discontinuous rock foundation, Nonlinear dynamic analysis, Boundary conditions.

1. INTRODUCTION

Structural strength of an arch dam under ground motion is dependent on the stability and strength of its abutments. Actually, even high safety margins for unexpected ground motions do not guarantee the stability of dam if it is established on uncertain foundation. In a addition, due to the complex nature of rock foundation including non-homogeneous materials, existing of joints sets and faults and propagation of seismic waves from far or near field, as well as errors due to the simplified analytical simulation, final judgment about the performance of dam will be difficult. Collapse of Malpasset Dam in France which failed in 1959 is an obvious example of lack of foundation strength.

During the past years, extensive research in various fields related to the analysis and design of concrete dams has been done, but the need for more accurate modeling of abutments in a coupling system with considering the mass, flexibility and non-homogeneity of discontinuous rock foundation is still be felt. In the present study, a numerical program for nonlinear dynamic analysis of concrete arch dams is developed in FORTRAN. For this purpose, Karun 4 Dam is considered as a case study. The main features of this study are considering the correct in-situ stress for bed rock and choosing a proper boundary condition for far-end which has a direct effect on the accuracy and precision of analytical results.

2. A REVIEW OF RESEARCH AREAS AND SOLVING METHODS

In the analysis and design process of an arch dam, it is necessary to model the following features: [1)] Dam - reservoir interaction and distribution of hydrodynamic pressure, [2)] Reservoir - foundation interaction and effects of reservoir bottom sediments, [3)] Dam - foundation interaction and role of non-homogeneous and discontinuities in bed rock, [4)] Non-uniform input of the free-field motions, and [5)] Nonlinear behavior of quasi-brittle material of concrete and jointed rock and contact in contraction and peripheral joints of dam body.

Fundamentals and analytical methods of all above mentioned is outside the scope of this article and just a brief review of the main issues related to research are presented here.

Simple and primary models in earthquake analysis of dams are the added mass approach of Westergaard for fluid-structure interaction. Westergaard's analytical solution neglected dam flexibility and water compressibility, so several researchers developed advanced numerical methods based on the finite elements, boundary elements or both of them to model dynamic dam–reservoir interactions. Two common finite element approaches in fluid domain are Eulerian- and Lagrangian-based formulations [1]. The former