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Comparison of stochastic and deterministic dynamic responses of gravity dam–reservoir systems using fluid finite elements

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Abstract

In this paper, stochastic and deterministic dynamic responses of gravity dam–reservoir systems are compared using the displacement fluid finite elements. For stochastic dynamic analysis of gravity dam–reservoir systems, variable-number-nodes two-dimensional fluid finite elements based on the Lagrangian approach is programmed in FORTRAN language and incorporated into a general-purpose computer program, which is used for stochastic dynamic analysis of solid systems, STOCAL. The Sarıyar concrete gravity dam, constructed in Turkey is selected for numerical example. The S16E component recorded at Pacoima dam during the San Fernando Earthquake in 1971 is used as a ground motion. Displacements and hydrodynamic pressures occurring on the upstream face of the dam and stresses occurring on the dam section are calculated by using stochastic and deterministic methods and compared with each other.

Keywords: Stochastic analysis; Random excitation; Lagrangian approach; Dam–reservoir interaction; Fluid finite element

1. Introduction

Dam–reservoir systems are fluid–structure interaction problems. Most fluid–structure interaction analyses are based on simplifying assumptions (e.g. inviscid flow) which allow one of two approaches [1]:

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(1) displacements are the variables in the solid, pressures (or velocity potentials) are the variables in fluid (Eulerian approach); (2) displacements are the variables in both the fluid and solid (Lagrangian approach).

Dynamic responses of dam–reservoir systems have been investigated using the Eulerian and Lagrangian approaches by many researches [2–11]. In these studies, loads due to earthquake forces, which are one of the most important actions in the design of dams are considered as deterministic. Since seismic waves are initiated by irregular slippage along faults followed by numerous random reflections, refractions, and attenuations within the complex ground formations through which they pass, seismic actions have essentially stochastic characteristics and they should be considered as random loads [12]. Dynamic analysis of dam–reservoir systems subjected to random loads has been performed in Ref. [13]. In this paper, dam–reservoir interaction system is analysed using the Eulerian approach. Since the variables in fluid and solid are different in the Eulerian approach, a special-purpose computer program is required for the solution of the coupled systems, because existing formulations generally involve asymmetric matrices that render them difficult to incorporate in general finite element analysis programs [7].

In the Lagrangian approach, the behaviour of the fluid and structure is expressed in terms of displacements. For that reason, compatibility and equilibrium are automatically satisfied at the nodes along the interfaces between the fluid and structure. This makes a Lagrangian displacement-based fluid finite element very desirable, which can be readily incorporated into a general-purpose computer program for structural analysis, because special interface equations are not required.

The focus of the present paper is to perform the stochastic dynamic analysis of gravity dam–reservoir systems by using the Lagrangian (displacement-based) fluid finite elements. For that reason, variable-number-nodes two-dimensional fluid finite elements proposed by Wilson and Khalvati [14] were programmed in FORTRAN language by the authors and incorporated into a general-purpose computer program for stochastic dynamic analysis of structure systems, STOCAL [15]. The program STOCAL [15] is modified for the stochastic dynamic analysis of fluid–structure systems based on the Lagrangian approach and named as STOCALF. The program STOCALF is used in the stochastic dynamic analysis of the coupled system. The program MULSAPF [16] developed for asynchronous dynamic analysis of fluid–structure systems based on Lagrangian approach is used in the deterministic dynamic analysis of gravity dam–reservoir interaction system.

2. Formulation

In this section, formulation of fluid systems based on the Lagrangian approach is obtained by using the finite element method and stochastic dynamic analysis formulation of fluid–structure interaction systems is given.

2.1. Finite element formulation of fluid systems

The formulation of the fluid system based on Lagrangian approach is given according to Refs. [14,17]. Fluid is assumed to be linear-elastic, inviscid and irrational. For this fluid, the relation between pressure and volumetric strain is given by

$$P = \beta \varepsilon_{\mathrm{v}}, \tag{1}$$