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An exact truncation boundary condition for incompressible–unbounded infinite fluid domains

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Abstract

In this paper, dam–reservoir interaction for a vibrating structure in an unbounded and incompressible and inviscid fluid is analyzed by using finite element approach. An exact boundary condition is developed for truncating surface of unbounded fluid domain. In the derivation of boundary condition, it is assumed that vibration of dam is in the normal direction of dam–reservoir interface and this interface is vertical. Moreover, bottom of fluid is rigid and horizontal. The derived boundary condition is implemented in the finite element code and results are compared with by using Sommerfeld's and Sharan's boundary conditions. It is seen that the proposed boundary condition is efficient and gives better results than the previous published results.

Keywords: Dam–reservoir interaction; Finite element method; Truncating boundary; Hydrodynamic pressure

1. Introduction

An important factor in the design of dams in seismic regions is the effect of hydrodynamic pressure exerted on the face of the dam as a result of earthquake ground motions. For an accurate analysis of hydrodynamic pressure on the dam having irregular geometries, the reservoir is generally treated as an assemblage of finite elements.

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Zienkiewicz et al. [1] presented the finite element formulation for analyzing the coupled response of submerged structures assuming water to be incompressible. Nath [2] analyzed the problem using the method of finite differences but neglecting radiation damping. Chakrabarti and Chopra [3] have formulated the reservoir as a continuum of infinite length. Two-dimensional problem of the added-mass effect of horizontal acceleration of a rigid dam with an inclined upstream face of constant slope was solved analytically by Chwang and Housner [4] using a momentum balance approach.

In the finite element formulation, unbounded domain of reservoir arise a problem in modeling. To achieve this difficulty, the unbounded domain should be truncated at a certain distance away from the structure. The most commonly used boundary condition along the truncation surface is the Sommerfeld radiation condition [5]. Since this boundary condition takes the form of that for a rigid stationary boundary, the behavior of the reservoir domain is not truly represented. An another boundary condition along the truncating surface for an unbounded and incompressible fluid domain is developed by Sharan [6]. Although this boundary condition is better than the Sommerfeld radiation condition, it does not represent the behavior well when truncation surface is very near to dam surface.

An exact boundary condition along the truncating surface of an unbounded reservoir domain is developed by approximating the analytical solution of the hydrodynamic pressure. A numerical study is done to compare the results of Sommerfeld's and Sharan's boundary conditions.

2. Formulation of unbounded reservoir domain

2.1. Analytical formulation of the hydrodynamic pressure

For incompressible and inviscid fluid, the hydrodynamic pressure p resulting from the ground motion of a rigid dam (Fig. 1) satisfies the *Laplace* equation in the following form

$$\nabla^2 p = 0. \tag{1}$$

Following boundary conditions are defined by assuming effects of surface waves and viscosity of the fluid are neglected:

At fluid–solid interface (S1),

$$\frac{\partial p}{\partial n} = -\rho a_n, \tag{2}$$

where a_n is the ground acceleration subjected on dam face.

At bottom of fluid domain, if bottom is rigid (S2), one can write the following