Acoustic Fluid-Structure Interaction Modeling of Gravity Dams in the Frequency Domain

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Abstract

The dynamic interaction between a fluid and a structure is a significant concern in the field of safety evaluation of concrete dams. Studies of hydrodynamic pressure acting on dam bodies during earthquakes date back to the '50s. In this context, the acoustic model for the water made possible to obtain a closed-form solution for the pressure acting on a moving rigid barrier, which gave rise to the well-known Westergaard added mass model [1].
Starting from these studies, this work aims to provide physical significance to a simple fluid-structure interaction model simulating the dam and the infinite length reservoir.

Since the fluid is thought inviscid, irrotational and is supposed to undergo small displacements, the classic wave equation of D'Alembert implemented in the Acoustic Module [3] of COMSOL Multiphysics® software is applied to the fluid domain with the standard "Water" material provided by the built-in material library.
Initially, the 2D model simulates a basin of 150 m x 50 m and the dam as a rigid body (Figure 1), with the following boundary conditions:
• Rigid boundary at the bottom surface.
• Zero pressure at the free upper surface.
• Prescribed normal accelerations at the dam surface.
In order to reproduce the condition of semi-infinite reservoir, the fourth side is modeled by using two different methods, Plane Wave Radiation (PWR) and Perfectly Matched Layer (PML). Dynamic properties are investigated via both, modal and frequency response analyses, by using the Pressure Acoustics, Frequency Domain interface in the latter case.
In the second stage, the hypothesis of rigid dam has been removed and the Solid Mechanics interface [4] has been applied on the model [5].

The main issue of this work is the strong influence on the analysis results of the unavoidable truncation of the domain in the modal analysis of the basin only. In fact, two categories of mode shapes are captured (Figure 2): the principal modes, with an almost constant pressure distribution along the reservoir bottom, and the secondary modes, which exhibit pressure variations along this profile (Figure 3).
In order to clarify this matter, the differences between the two options PWR and PML are investigated. As for the modal analysis, the PWR provides certain regularity in the secondary modes, whereas in the frequency response analysis PML suffers much less than PWR from basin truncation and produces results that almost perfectly fit the theoretical

solution provided by Chopra [2].
In the second stage of this work the frequency response analysis of the complete basin-dam system is performed and, starting from the knowledge of the modal frequencies of the basin only, the meaning of the peaks of the response curve is provided (Figure 4).

COMSOL has proved to be a suitable software to perform frequency response analyses of basin-dam interaction. The recognition of the peaks in the frequency response curve of the complete basin-dam model provides a deep knowledge of the dynamic behavior of the interactive system in sight of the seismic safety assessment of gravity dams.

Reference

[1] H. M. Westergaard, Water Pressures on Dams during Earthquakes, Trans. ASCE, Vol. 98, p. 418-433 (1933)
[2] A. K. Chopra, Hydrodynamic Pressures on Dams during Earthquakes, J. Eng. Mech. Div., Vol. 93(EM6), p. 205-223 (1967)
[3] COMSOL Multiphysics, Acoustic Module – User's Guide (2015)
[4] COMSOL Multiphysics, Structural Mechanics Module – User's Guide (2015)
[5] A. Frigerio, G. Mazzà, A Concrete Arch Dam under Seismic Loading Conditions, European COMSOL Conference 23-25 (2013)

Figures used in the abstract

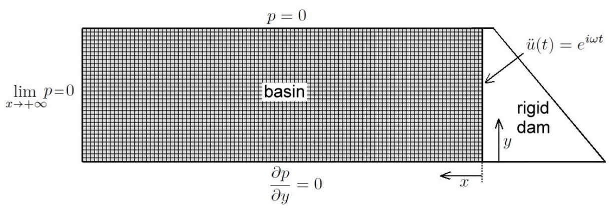

Figure 1: The 2D model.

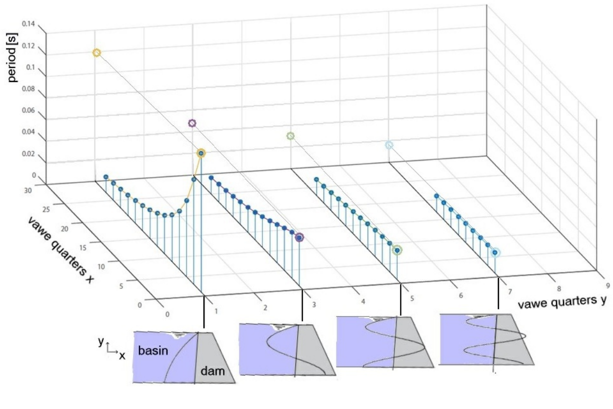

Figure 2: Principal and secondary modes.

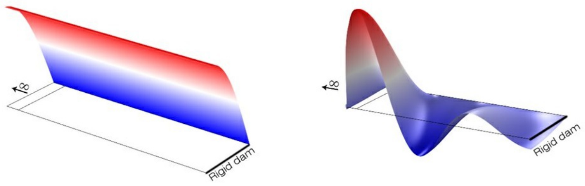

Figure 3: The first of the primary eigenmodes and one of the secondary eigenmodes.

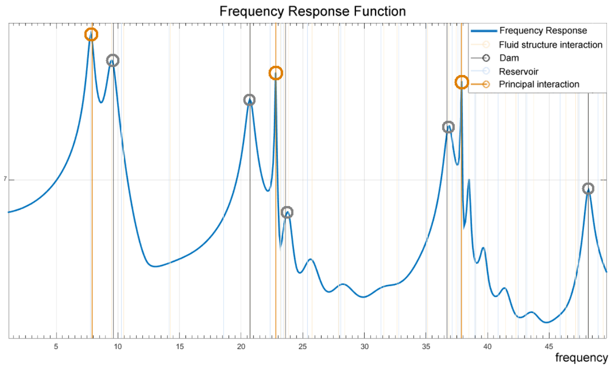

Figure 4: Localization of the modal frequencies in the response curve.