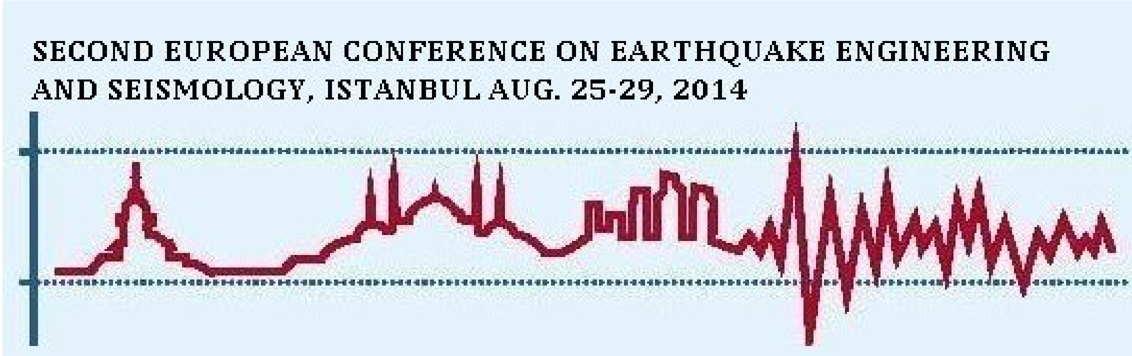

BEM-FEM DYNAMIC ANALYSES OF ARCH DAM-FLUID SYSTEM

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ABSTRACT

The dam-fluid interaction is significantly affected by the irregularity of the terrain in the vicinity of the dam-fluid interface. The joint vibration of the dam and canyon walls generates pressure and dilatational waves as functions of several variables. Besides the geometry and mechanical properties of the dam-reservoir system, the distance to the non-reflecting truncation boundary is important parameter to be considered in the computation of the hydrodynamic forces. The direction of the seismic excitation should also be taken into account. Different modelling scenarios of arch dam-fluid-reservoir systems were conducted and compared via a time dependent indicator referred to as 'cumulative hydrodynamic energy'. The comparison indicates that, depending on the direction of excitation, the combined vibration of the dam and reservoir with complex topography could generate between 10% and 100% higher hydrodynamic energy at the dam-fluid interface than that generated by a dam-regular reservoir system. The highest cumulative hydrodynamic energy was obtained for cross-stream excitation.

INTRODUCTION

The dynamic response of a dam-fluid-reservoir system subjected to seismic excitation is a complex problem and a major safety concern in seismic active areas. To ensure adequate design, the magnitude and distribution of the hydrodynamic pressure along the dam-fluid interface must be accurately determined. The intensity of the hydrodynamic pressure (HDP) is a function of the amount of energy transmitted to the fluid by the vibration of the dam itself and the surrounding terrain. This energy is manifested by the generation of compressive and dilatational waves which in turn dynamically interact with the dam and the reservoir. It depends on multiple parameters including: intensity and direction of the seismic excitation; dam geometry and reservoir configuration; dam deformability; water level, compressibility and viscosity; energy absorption by bottom deposits; and radiational damping. Among these parameters, the geometry of reservoir walls and bottom seems to be of critical significance.

Numerous studies have treated dam-fluid-reservoir dynamic interactions, however, with a reservoir of regular or simplified irregular geometry and uniform cross section, e.g., Liu's (1986), Akköse et al. (2008), Bouaanani and Lu (2009) using the ADINA software (2006), Bayraktar et al. (2011) using the ANSYS software (2008), etc. Obviously, there is a lack of fully 3D analyses of the dam-fluid reservoir systems with the consideration of the influence of the irregular canyon shape. The present work contributes to the quantification of the impact of the reservoir topography on the intensity of the generated HDP. To get an insight into the hydrodynamic energy exerted at the entire dam-fluid interface, the hydrodynamic energy is calculated and compared for reservoirs with regular

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and complex geometry, and for seismic excitations applied to the dam-reservoir system in the stream-wise, cross-stream, and vertical directions.

The coupled dam-fluid-reservoir system was simulated with the boundary element method (BEM). The developed algorithm for modelling the 3D fluid boundaries according to the topographic geodetic survey data was embedded within the ADAD–IZIIS software (Mircevska and Bickovski, 2008).

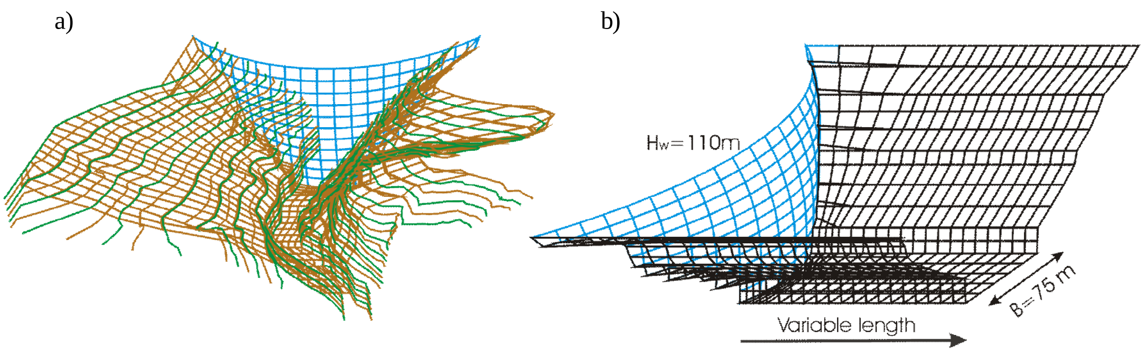

Figure 1. Boundary element discretization of the arch-dam for a) complex reservoir, and b) regular reservoir

TERRAIN IRREGULARITIES

Dam-fluid interaction is strongly affected by the irregularity of the terrain in the vicinity of the dam-fluid interface. The terrain topography also dictates the 'most adequate' location of the simulated truncation surface where non-reflecting truncation boundary conditions should be imposed. The reservoir contribution to the generation of a wave-field of compressive and dilatational waves beyond this boundary is neglected. The principle used for the determination of the 'most adequate' location of this boundary condition is based on the conventional BEM (Mircevska et al., 2013). An arch-dam with a typical reservoir of complex geometry was considered to illustrate the approach (Figure 1). The Laplace differential equation governing the motion of incompressible and inviscid fluid was applied over the rigid dam-reservoir system.

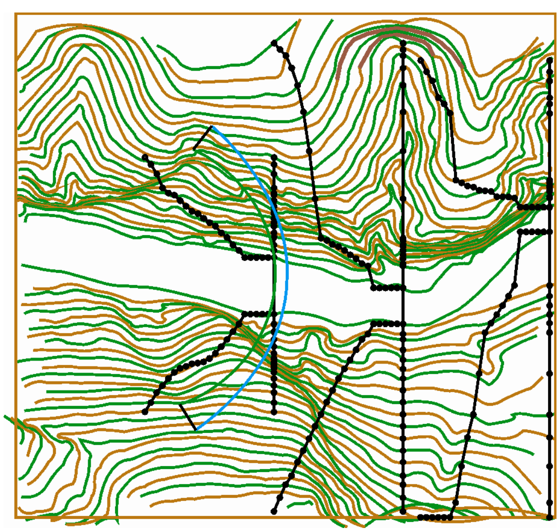

Figure 2. Complex terrain configuration of the considered canyon with the location of the arch-dam

Three different types of truncation boundary conditions (TBC) were considered: a) stationary type, where perpendicular acceleration at all nodes on the truncation surface is set to zero; b) HDP at all nodes on the truncation surface set to zero; and c) non-reflecting boundary condition is set to all nodes of the truncation surface. In total, sixteen different distances from the dam to the location of the truncation surface ranging from 50 m to 210 m were considered and analyzed. Each of these is characterized with different portion of the considered complex canyon and a different wave-field length (Figures 1 and 2). First, the horizontal acceleration of 1g was applied in the stream-wise direction and then under 45 degrees with respect to stream-wise direction. The acoustic elastic ‘p’ waves were then generated as a result of the vibration of the upstream dam face and the rigid canyon walls. The type of the generated waves and the direction of their propagation as compressive or dilatation waves with respect to the dam face depend on the direction of the seismic excitation, the specified boundary conditions and, what is equally important, on the reservoir geometry.

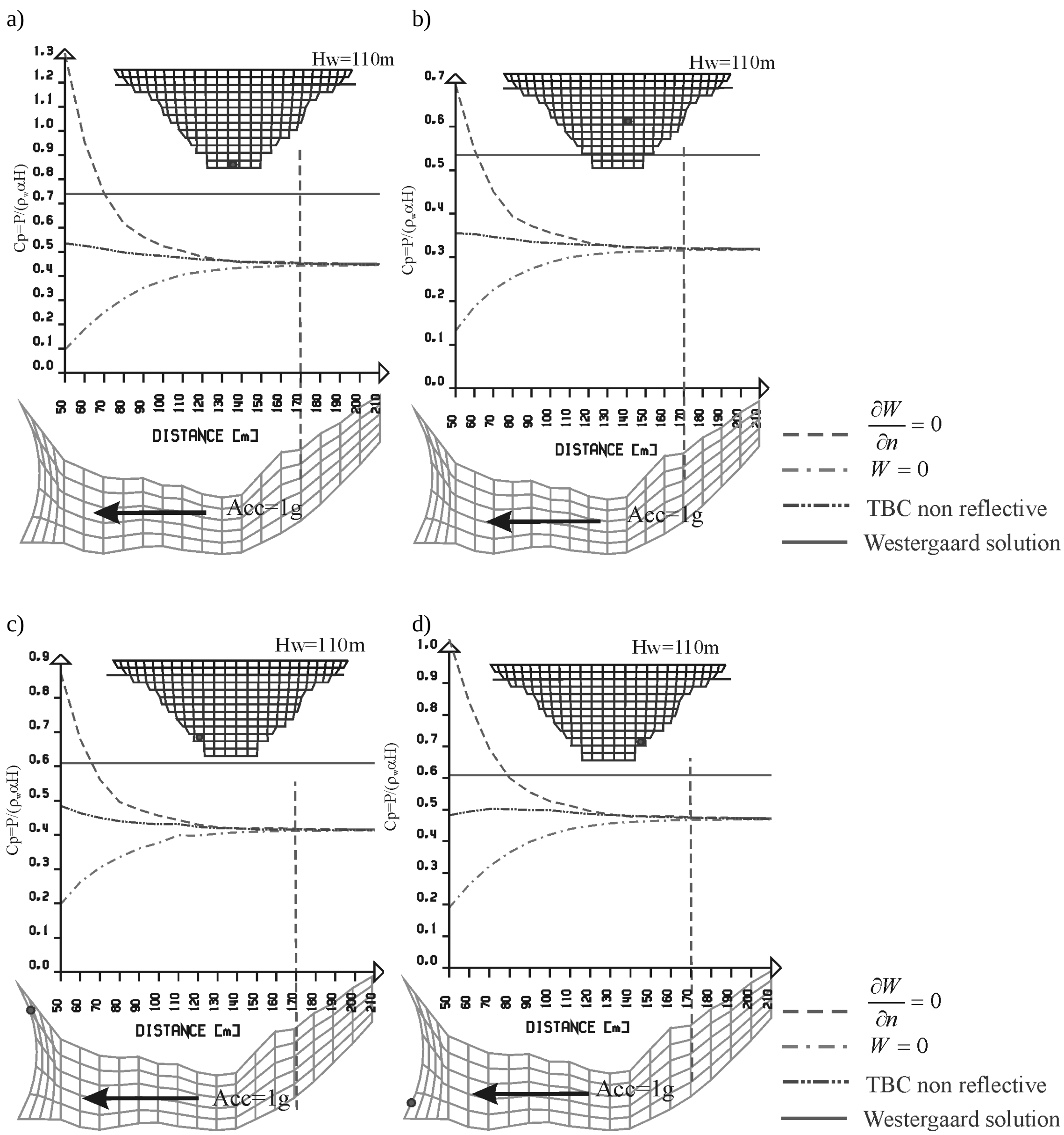

Figure 3. Variation of the normalized hydrodynamic pressure magnitudes as a function of the considered 16 locations of the truncated surface for selected nodes a) at the bottom of the crown cantilever, b) at the middle of the crown cantilever, c) at the bottom of the dam close to the left bank side, and d) at the bottom of the dam close to the right bank side. Truncation boundary conditions are of type-a (accelerations at all points on the truncation surface are set to zero), type-b (hydrodynamic pressure at all points on the truncation surface are set to zero), and type-c (non-reflective boundary condition)

Figures 3 show functions representing the normalized magnitudes of the hydrodynamic pressure associated with the TBC which allow dissipation of the outgoing waves. These functions have mostly asymptotically decreasing tendency until reaching the intersection point between TBC type (a) and TBC type (b), indicated the with vertical dashed line. Beyond this distance, both curves remain almost horizontal indicating almost constant value of the generated HDP at the dam-fluid interface, i.e., almost equal generated compressive and dilatational wave-fields.

For the considered configuration of the dam-reservoir system, the intersections occurs at distance of L=180 m away from the dam, or approximately L=1.7Hw, where Hw is the depth of impounded water. This signifies that it is irrelevant whether the TS is positioned at a distance greater than L=180m since, beyond this distance, the effect of the model length on the intensity and type of the generated waves is negligible. It can be observed in Figures 3, however, that for distances L<180m the hydrodynamic pressure varies significantly. The detected position of TS at L=180m is the "most adequate" location of the truncation surface for the considered terrain configuration. Therefore, placing the truncation surface closer to the dam will necessarily lead to an under-estimation of the HDP.

HYDRODYNAMIC ENERGY

It is important to have a consistent quantitative measure of the intensity of the hydrodynamic energy exerted at the dam-fluid interface as it can obtain important proportions. To this end, a time dependent indicator referred to as 'cumulative hydrodynamic energy', E_C, was developed, (Mircevska et al., 2014).

In this case, both reservoir configurations with regular and complex terrain geometry were considered (Figure 1). The number of nodes was NP=385 and the maximal time was set to 7 sec, which corresponds to 700 time increments with dt=0.01sec. For the stream-wise direction of the seismic excitation, the ratio of the cumulative hydrodynamic energies observed at 7 seconds is $E_{C\text{-}regular}/E_{C\text{-}complex}$=0.65, which signifies that the cumulative hydrodynamic energy generated by the complex reservoir topology is approximately 53% higher of that generated by the regular terrain. The respective ratio in the case of cross-stream seismic excitation is $E_{C\text{-}regular}/E_{C\text{-}complex}$=0.5, implying almost doubling of the exerted hydrodynamic energy. Finally, in the case of vertical seismic excitation and under the assumption of reflective boundary conditions at the reservoir bottom, the respective ratio is $E_{C\text{-}regular}/E_{C\text{-}complex}$=0.90, implying that the cumulative hydrodynamic energy generated by the complex reservoir topology is approximately 11% higher of that generated by the regular terrain.

Table 1. Cumulative hydrodynamic energy exerted at the dam-fluid interface at time=7 sec

Direction / Terrain	Cumulative hydrodynamic energy E_C (kNs)			
Direction of the seismic excitation	Stream-wise	Cross-stream	Vertical (Bottom reflection)	Vertical (Bottom absorption)
Regular terrain	9.50×10^7	2.27×10^7	8.8×10^7	3.45×10^7
Complex terrain	1.45×10^8	4.5×10^7	9.71×10^7	3.98×10^7
$E_{C\text{-}regular}/E_{C\text{-}complex}$	0.65	0.50	0.90	0.90

CONCLUSIONS

Dam-fluid interaction is affected by the irregularity of the terrain in the near surrounding of the dam-fluid interface. The topology of the terrain determines the 'most adequate' location of the truncation surface where non-reflecting truncation boundary conditions should be imposed. This surface defines the required completeness of the wave-field bordered by the dam and the complex shape of the canyon walls. The vibration of the dam and canyon walls generates pressure and dilatational waves in accordance with the topographical conditions. The generated energy in the fluid can be under or overestimated in the computations if the truncation boundary conditions are not defined at or beyond the “most adequate” location. This inevitably leads to impingement of the calculation accuracy. The comparison of the cumulative hydrodynamic energies indicates that, depending on the direction of excitation, the combined vibration of the dam and irregular terrain with complex topography could generate between 10% and 100% higher hydrodynamic effects at the dam-fluid interface than when a dam-regular reservoir system is assumed. The highest impact of the terrain irregularities on the cumulative hydrodynamic energy was obtained for cross-stream excitation, whereas the cumulative hydrodynamic energy was least sensitive in the case of vertical excitation.

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