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Wave Propagation

Chair : M. N. Guddati, North Carolina State University
Co-Chair : E. Siebrits, Schlumberger
Room : 3.110
Date and Time : Monday, 22 May, 3:00-5:00

Sponsored by Dynamics Committee
Organized by M. N. Guddati

1. Spectral Analysis of Wave Propagation in Linear Elastic and Viscoelastic Multi-Layer Systems
   R. Al-Khoury, A. Scarpas and J. Blaauwendraad, Delft University of Technology, The Netherlands
2. Numerical Stability Properties of Elastodynamic Direct Boundary Element Methods
   B. Birgisson[⋆], *E. Siebrits*[†] *and A. P. Peirce*[‡], [⋆]University of Florida, [†]Schlumberger, [‡] University of British Columbia, Canada
3. Dynamic Response of a Padded Annular Footing on a Uniform Elastic Half-Space
   B. B. Guzina and S. F. Nintcheu, University of Minnesota
4. Reduced-Dispersion Finite Elements for Time Harmonic Wave Propagation Problems
   M. N. Guddati, North Carolina State University
5. Traveling Wave Effects on the Seismic Response of Arch Dams
   O. Maeso[⋆], *J. J. Aznárez*[⋆] *and J. Domínguez*[†], [⋆]Universidad de Las Palmas de Gran Canaria, Spain, [†]Universidad de Sevilla, Spain
6. Finite Element Method for Full-Wave Analysis of Waveguides at Very Low Numerical Frequencies , *L. Vardapetyan and L. Demkowicz*, The University of Texas at Austin

Travelling Wave Effects on the Seismic Response of Arch Dams

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1. Introduction

In many cases the size of a dam may be close to the length of the seismic waves that would arrive to the dam site in the event of an earthquake. As a consequence, when seismic waves impinge on a large dam, the excitation of the dam-foundation rock interface is not uniform. Different points along the interface are under the effects of different foundation acceleration values at the same time. In other words, the seismic waves travel along the dam-foundation rock interface. The importance of this effect depends on the dam size, the length of the seismic waves and its direction of propagation but it seems clear that assuming a uniform excitation along the dam-foundation rock interface may lead to erroneous consequences.

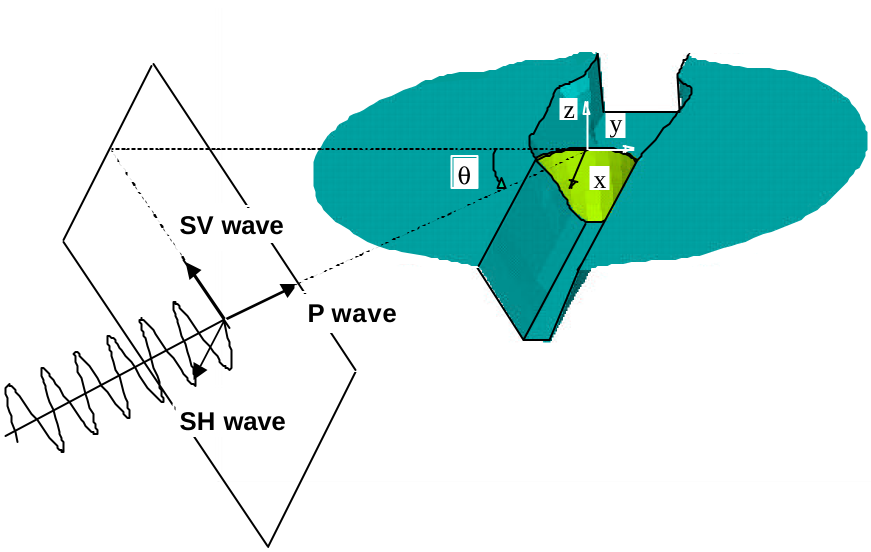

Figure 1: Description of the problem.

Figure 1 shows the kind of problem that is studied in the present paper to show the importance of the travelling wave effect. The figure shows an arch dam closing a cannon with a geometry which is arbitrary in a large region close to the dam. The reservoir may be filled to any given level. The excitation is a harmonic wave (SH, SV, P, Rayleigh) which impinges on the dam site from any direction. Dam, water and foundation rock are coupled in a three dimensional boundary element model which takes rigorously into account these three media.

The present study is based on the three-dimensional boundary element model presented by Maeso and Dominguez (1993), and Dominguez and Maeso (1993) which allows for the analysis of the coupled system dam-foundation rock-reservoir taking into account the interaction effects and the unbounded nature of the foundation. The model was recently improved by Maeso et al. (1999) to include the effects of bottom sediments on the absorption of the hydrodynamic waves by adding a saturated poroelastic region to the boundary element model. Since the foundation is represented as a fully three-dimensional domain the actual cannon geometry can be considered and the excitation can be any prescribed wave front coming from a distant source. The seismic response of arch dams has been studied in the last fifteen years by Chopra and his coworkers (Fok and Chopra 1986,1987) using a finite element model. More recently Tan and Chopra (1995) have incorporated to the F.E. model a boundary element representation of the foundation. This model of the foundation is not fully three-dimensional and uses a two dimensional B.E. model together with a Fourier expansion to represent a uniform cannon geometry.

2. Boundary Element Model

The Morrow Point dam has been chosen for this study. Data about the geometry and properties of the dam and the cannon are taken from Hall and Chopra (1983). The boundary element discretization is shown in Figure 2. The elements are nine node quadrilaterals and six node triangles with a cubic representation of the geometry and the boundary variables. The properties of the different regions are the same as given by Hall and Chopra (1983) and Maeso and Dominguez (1993). The dam is modeled as a viscoelastic medium with the discretization of the soil free surface extending up to a distance to the dam equal to 2.5 times the dam height. The impounded water is considered as a compressible inviscid fluid. Its boundary element representation is done using the same elements as for the cannon upstream of the dam. The geometry of the reservoir is assumed to vary smoothly within the model and to be uniform from the limits of the discretized zone to infinity. This boundless reservoir geometry is used to be consistent with the previous FE and BE studies. Reservoirs which are not very long in the direction perpendicular to the dam, may be represented using a realistic geometry fully modelled by boundary elements.

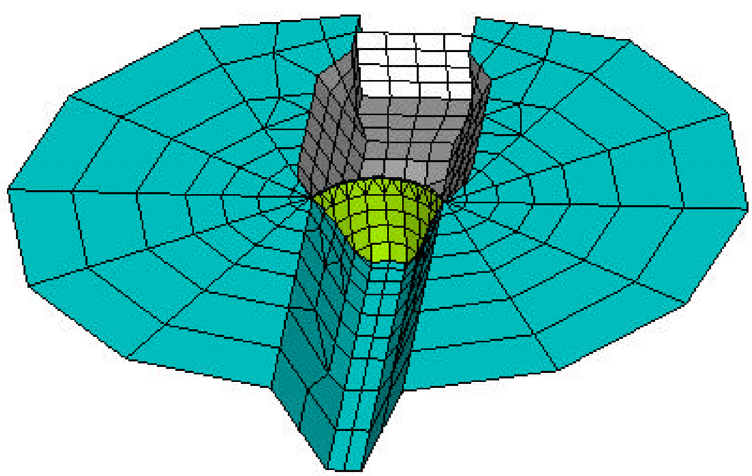

Figure 2: Boundary Element discretization of Morrow Point dam on compliant foundation rock.

The interaction effects are taken into account by introducing equilibrium and compatibility conditions over the boundary elements which belong to two different regions.
The seismic excitation has been assumed to be a time harmonic plane wave coming from infinity. To satisfy the radiation conditions, the problem has been solved in terms of scattered wave fields. The total displacements and stresses are the superposition of the incident field corresponding to a uniform half-space and the field scattered by the dam-reservoir-cannon system. The incident field, which analytic solution is known, becomes part of right hand side vector in the system of equations (Dominguez and Abascal, 1989).

3. Results

Several numerical examples have been studied to show the influence of the angle of incidence of the waves on the seismic response of the dam. SH, P and SV waves propagating in the plane y-z perpendicular to the cannon axis of symmetry x have been considered (Figure 1).

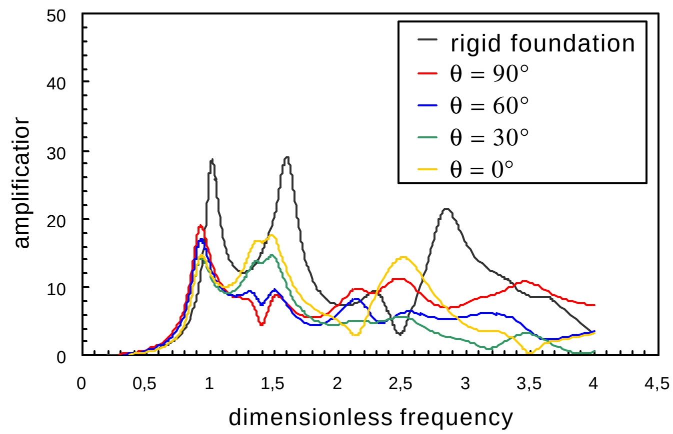

Figure 3: Response at dam crest to SH wave excitation. Empty reservoir.

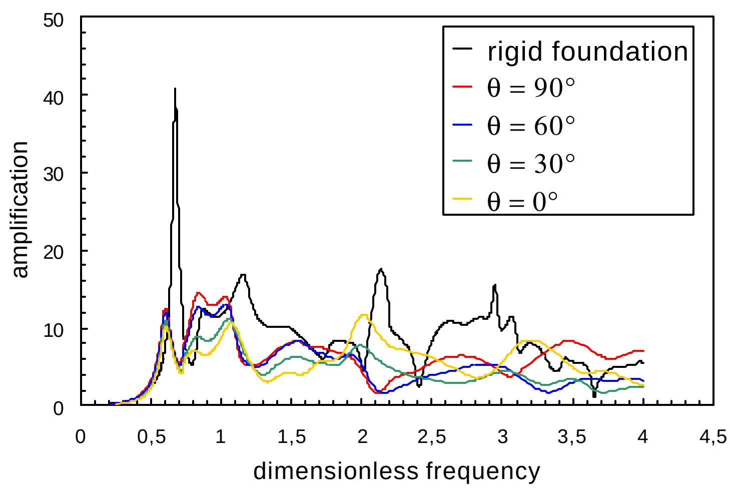

Figure 4: Response at dam crest to SH wave excitation. Full reservoir.

The first case analyzed corresponds to the reservoir empty of water and SH waves arriving to the dam site with several different angles θ. Figure 3 shows the amplitude of the displacement at the dam crest mid-point normalized by the amplitude of the motion at the same point in the case of a uniform half-space (i.e., without cannon, dam or reservoir). The response is represented versus frequency for four different angles of incidence. The response for rigid foundation conditions is also included in the figure. Frequencies are normalized by the first natural frequency of the dam on rigid foundation. It is clear from Figure 3 that foundation rock flexibility reduce the amplitude of the resonance peaks and the first natural frequency. In addition to that the travelling wave effect and the angle of incidence of the wave modify the response in particular for dimensionless frequencies higher than one. Similar conclusions can be drawn from the response in the case of reservoir full of water (Figure 4).
Figure 5 and 6 show the dam crest response when P waves with different angles impinge on the dam. The effect of the angle of incidence is important in particular for values of $\theta \leq 30º$.

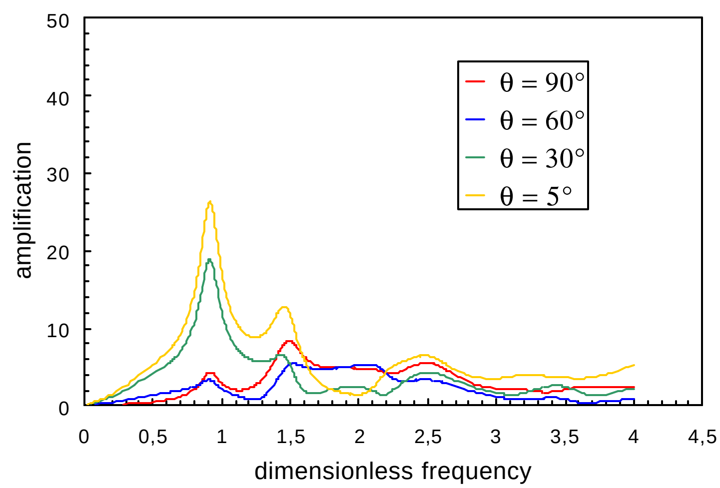

Figure 5: Response at dam crest to P wave excitation. Empty reservoir.

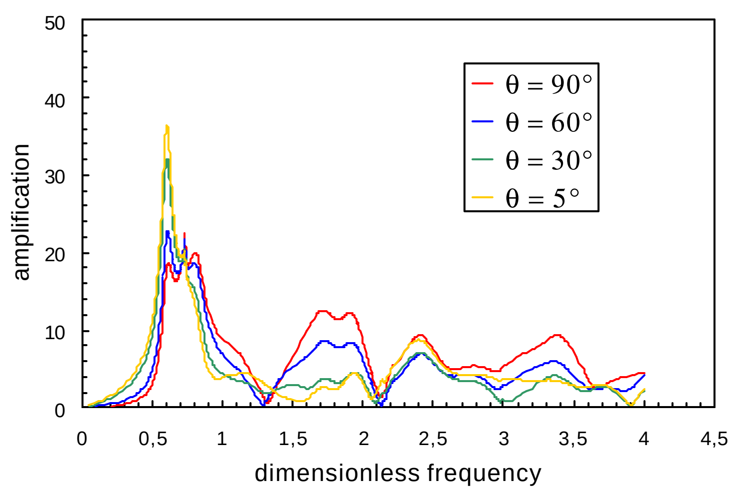

Figure 6: Response at dam crest to P wave excitation. Full reservoir.

Results for incident SV waves are shown in Figure 7 for empty reservoir and Figure 8 for full reservoir. In this case the displacements shown correspond to a point of the dam crest located at one quarter of its length and the frequency is normalized with respect to the first antisymmetric natural frequency.

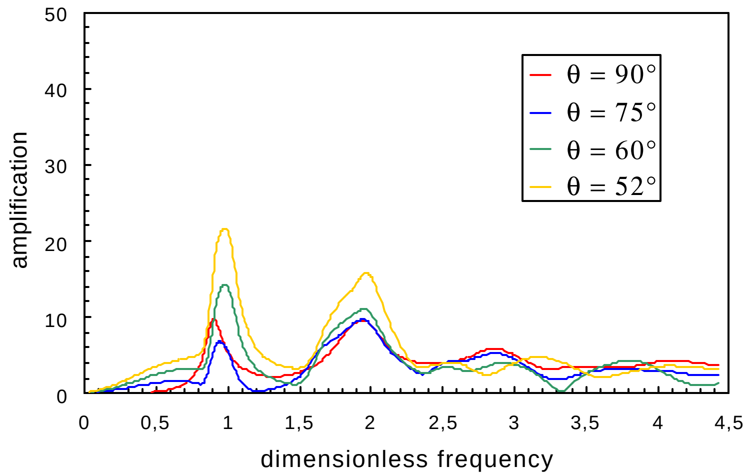

Figure 7: Response at dam crest to SV wave excitation. Empty reservoir.

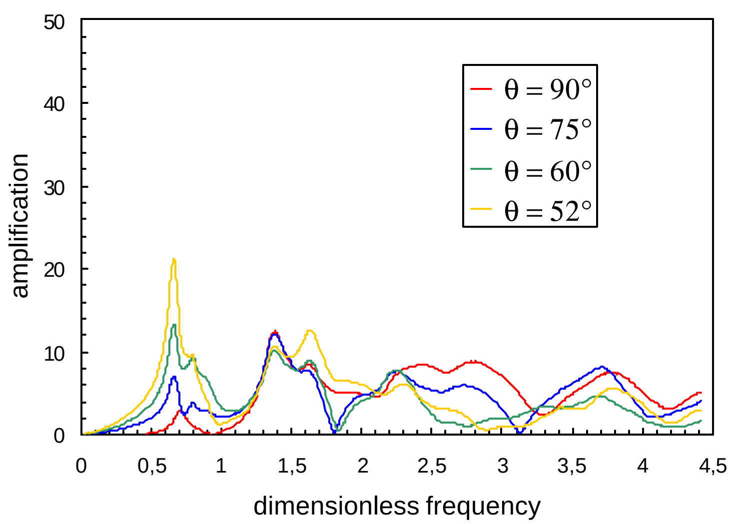

Figure 8: Response at dam crest to SV wave excitation. Full reservoir.

The values of θ considered are all above the critical angle for which surface waves would appear under free-field conditions. Figures 7 and 8 show once again the important effect of the angle of incidence.

4. Conclusions

The above results have shown the important effects that the foundation rock flexibility and the space distribution of the excitation have on the seismic response of arch dams. These effects have been shown to be relevant in the case of full reservoir and also when the reservoir is empty. The influence of the angle of incidence of the waves is important for all the different kinds of waves considered.

5 Acknowledgments

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6 References

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