Boundary Element Model for the Seismic Analysis of Arch Dams

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Summary

A three-dimensional boundary element model for the seismic analysis of arch dams is presented. The soil and the dam are assume to be viscoelastic domains the former being boundless. The water is assume to be compressible subject to small amplitude motions. The soil-water, soil-dam and water-dam dynamic interactions are taken into account rigurously. The analysis is done in the frequency domain and factors such as an infinite soil, the effect of the local topography, the actual non-uniform geometry of the reservoir and the spacial distribution of the ground motion about the canyon walls are taken into account in a direct way as apposite to the existing FEM models which are not able to consider those factors.

Introduction

The analysis of the seismic response of dam-reservoir systems is an important problem within the field of earthquake engineering. The seismic response can not be studied considering the structure as an isolated body under the influence of the base motion. There are important effects due to dam-water, dam-foundation and water-foundation interaction that make necessary the use of models including the three media and the interaction between them. Among the factors affecting the response one can mention the soil characteristics at the site (topography, mechanical properties, layering), the water compressibility and the geometry of the botton. A great effort has been dedicated to this subject in the last two decades. The studies of Chopra and his co-workers [1,2] who analysed the significance of a number of factors contributing to the response shold be metioned. Those studies have been done using the Finite Element Method. However, due to the great complexity of the

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problem the models include important simplifications. A promising alternative to the FEM is the Boundary Element Method (BEM). Medina et al.[3,4] showed that the BEM, due to its particular characteristics, is very well suited for this kind of problems and allows to overcome some of the most important shortcomings of the FE models. The abovementioned B.E. studies refer to gravety dams which can be represented by two-dimensional models.

The analysis of arch dams requires of a three-dimensional model and is in this context where the shortcomings of existing F.E. models become more obvious. These models represent the soil as a massless elastic finite domain; the reservoir, as a small irregular region connected to an infinite channel with uniform cross section and the water-soil interaction by means of an absortion coefficient which takes into account in a simplified manner the transmition of waves from the water to the soil. Because of these simplifications the F.E. models are unable to represent the propagation of the waves in the soil and consequently the different values of the excitation at different points of the dam foundation and the diffracted waves going into the soil. This effect is particularly important when the wavelength of the incident field is similar to the dimensions of the dam. The F.E. model is also unable to represent properly, the soil topography, large irregular geometries of the reservoir, the water-soil interaction and the combine water-soil-structure interaction. On the contrary, the B.E. model presented in this paper is able to represent in an easy and direct form the abovementioned factors which have important effects on the seismic-response of arch dams[5].

Model for the solid domains. Dam-soil interaction.

The system to be analysed, shown in Figure 1, consists of two solid regions (the soil and the dam) and a fluid region (the water). A dynamic interaction exist among the three regions and the analysis of the response of the dam to incident seismic waves requires of the study of the whole dam-soil-water system.

Time harmonic waves propagating vertically from the soil which produce a unit free field vertical or horizontal motion either along the transversal or the upstream direction are assumed.

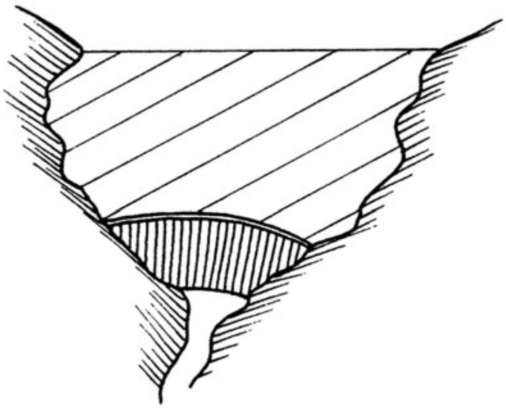

Fig.1. Arch dam-water-foundation system.

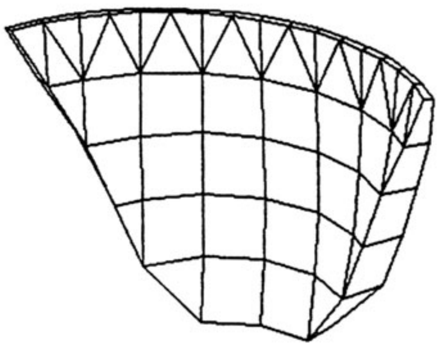

Fig.2. Boundary elements model of the arch dam substructure.

In the present paper the Morrow-Point dam-soil-reservoir system previously studied using F.E. by Fok and Chopra [2] is considered. The dam is modeled as a viscoelastic domain using nine node quadrilateral and six node triangular elements with quadratic shape functions in two directions both for the field variables and the geometry. Figure 2 shows the B.E. model for the dam. The properties of the concrete are: density = 2481.55 Kg/m^3; Poisson's ratio = 0.2; shear modulus = 11500 MPa and damping ratio = 0.05 . Because of the available space only the response of the dam to a horizontal upstream excitation is shown in this paper. Figure 3 shows the amplification of the upstream motion at the dam crest versus frequency when the soil is assumed to be rigid and the reservoir empty. The results show a very good agreement with the F.E. ones obtained using shell elements [2]. The frequency is normalyzed by the first natural frequency of the dam. The dam crest displacement is normalyzed by the horizontal motion produced by the incident waves at the soil free surface far from the dam.

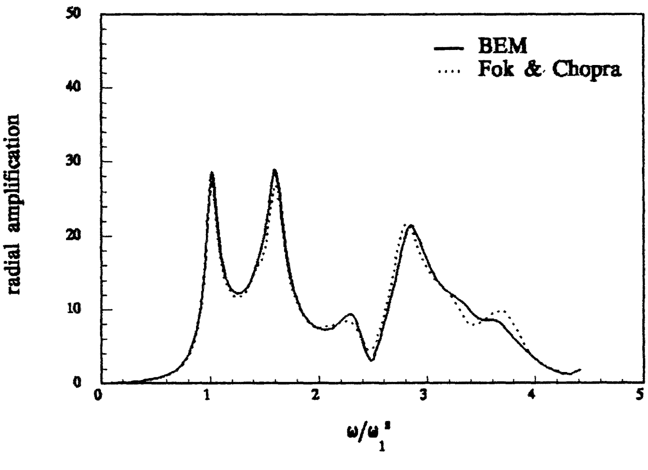

Fig.3. Radial amplification. Rigid foundation, empty reservoir.

The effect of the soil-dam interaction is analysed by doing coupled models including the dam and the soil. The soil is modeled as a linear viscoelastic solid with the following properties: density = 2641.65 Kg/m^3; Poisson's ratio = 0.2; shear modulus = 11500 MPa and damping ratio = 0.05. The soil is discretized using the same kind of elements as for the dam. The discretization is left open at a certain distance from the dam. Figure 4.a shows the dam-soil model for the Morrow-Point reservoir in which the water basin is consider to extend uniformly to infinity for the sake of comparison with the F.E. model. In Figure 4.b the model for the more realistic case of a finite reservoir is shown. The Figure shows one half of the symmetric models. The analysis of the dam response for both geometries when the reservoir is empty produces almost identical results. This shows that the soil topography far from the dam does not have influence on the dam response for empty reservoir conditions.

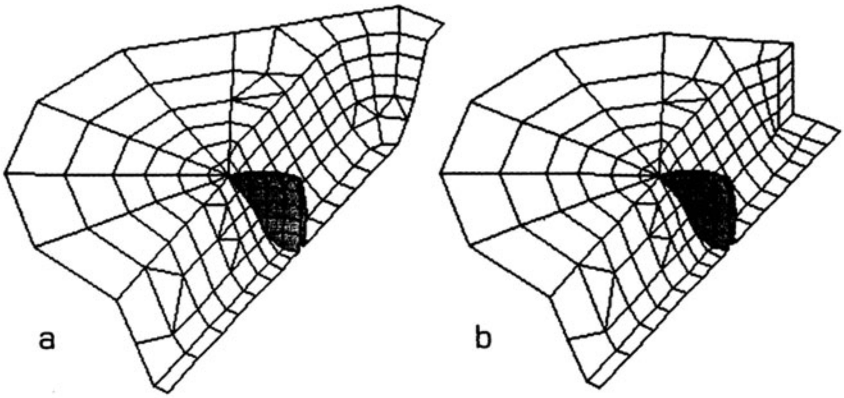

Fig.4. Geometry and boundary elements discretization of the coupled system. (a) finite reservoir; (b) infinite reservoir.

Figure 5 shows the upstream amplification at the dam crest for the dam-soil system. The results obtained show important differences with those obtained by Fok and Chopra [2] using finite elements. It can be easily shown that the differences are due to the fact that the F.E. model, which includes a massless soil assumption, can not take into account the spatial distribution of the excitation. If the B.E. code is run assuming density $= 0$, the obtained results are very close to the F.E. results as shown in Figure 5.

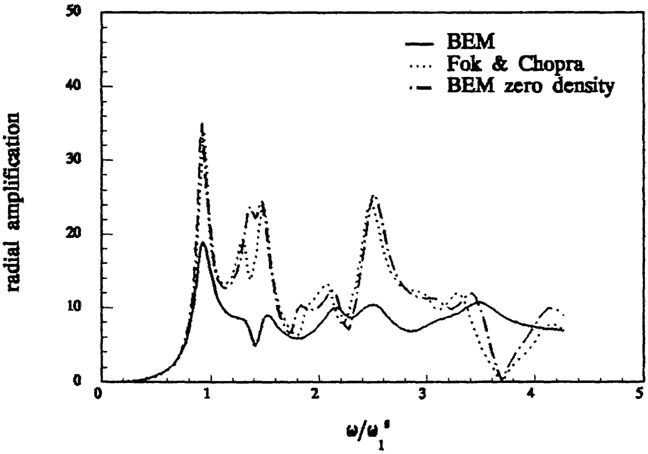

Fig.5. Radial amplification. Compliant foundation, empty reservoir.

Model for the fluid domain. Dam-soil-water interaction.

The water is modeled as an inviscid compressible fluid under small amplitude harmonic motion. It's behaviour is governed by the Helmholz aquation. The B.E. for the fluid are quadratic nine or six node elements as in the solid case. The interaction conditions between the water and the solid regions (dam and soil) are: equal normal pressure and displacement on the solid and fluid boundaries in contact, and zero shear traction on the solid elements of the contact surfaces. Two geometries for the reservoir are considered as shown in Figure 4. One includes an infinite uniform rectangular cross section channel to represent the reservoir extending towards a very long distance; the other is finite consisting of an uniform region closed by a spherical surface. For simplicity, the geometry of the reservoir has been consider to be uniform; nevertheless, non uniform geometries of the reservoir can be easily modeled with the quadratic isoparametric elements used. The infinite channel in one of the geometries allows for the propagation of standing waves which send energy out of the system. The boundary conditions for this infinite channel can be easily established as a relation between water pressure and it's normal derivative at the cross section [6].

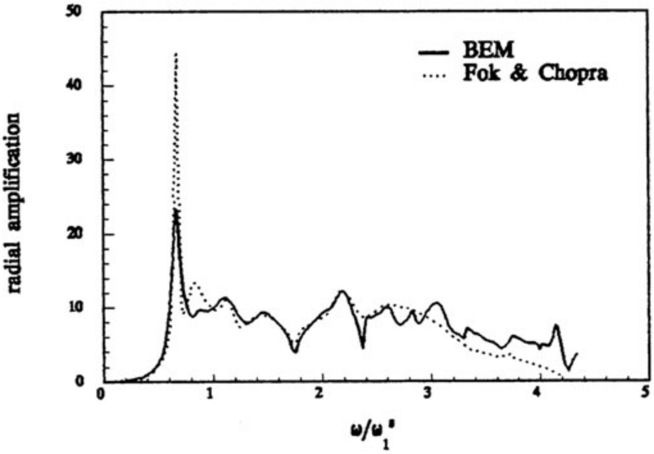

Fig.6. Radial amplification. Rigid foundation, infinite reservoir full of water.

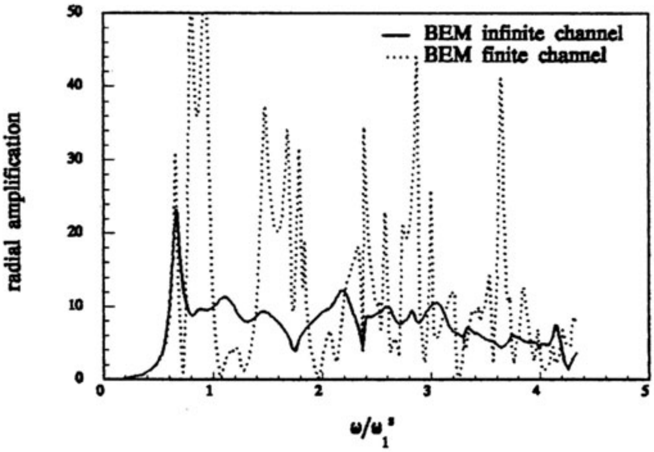

Fig.7. Radial amplification. Rigid foundation, finite and infinite reservoir full of water.

Figure 6 shows the radial amplification at the dam crest for full reservoir, rigid foundation and infinite reservoir geometry. The results show a good agreement with the F.E. ones [2]. The important effect of the reservoir geometry for rigid foundation can be seen in Figure 7 where the difference between the dam response for the infinite and the finite reservoir cases is shown. The importance of a good representation of the reservoir geometry, provided easily by the B.E. models as opposite to F.E., is obvious.

The full interaction problem including the dam, the compliant foundation and the water is analysed next. Figure 8 shows the radial amplification at the dam crest for the model including the infinite channel. The results are compared with those obtained with the existing F.E. model [2]. Substantial differences between the B.E. and the F.E. results exist. This differences are due to the simplifications of the F.E. model as can be shown by running the B.E. code with zero density for the soil and an absorption coefficient for the water-soil interaction as the F.E. model does. In such a case, results very similar to those corresponding to F.E. are obtained as shown in Figure 8. A comparison between the dam crest radial amplification for the infinite and the finite reservoir models is shown in Figure 9. The important effect of the reservoir geometry on the seismic response of the dam is clearly shown. Again, the importance of a good representation of the reservoir geometry, as the B.E. can easily accomplish, becomes clear.

Conclusions

A three-dimensional boundary element model for the seismic analysis of dam-soil-reservoir systems has been presented. The model takes into account rigurously the spatial distribution of the excitation, the wave propagation in a viscoelastic boundless soil, the soil-water interaction and the actual reservoir geometry. All this factors have an important effect on the seismic response of arch dams ad can not be taken into account in a proper way by the existing F.E. models. Previous B.E.

models took only into account some of the interaction effects and include important simplifications.

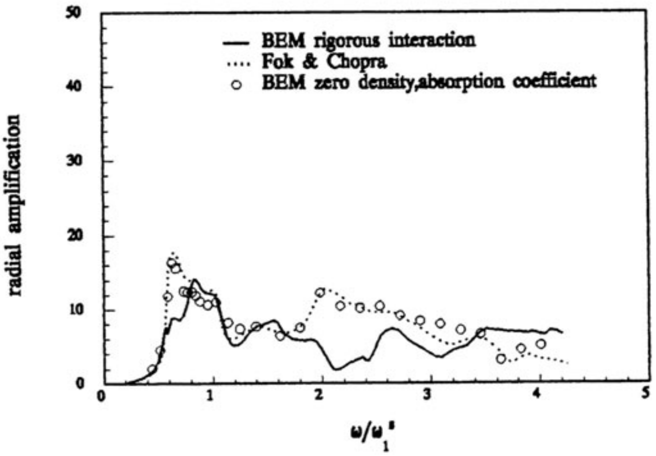

Fig.8. Radial amplification. Compliant foundation, infinite reservoir full of water.

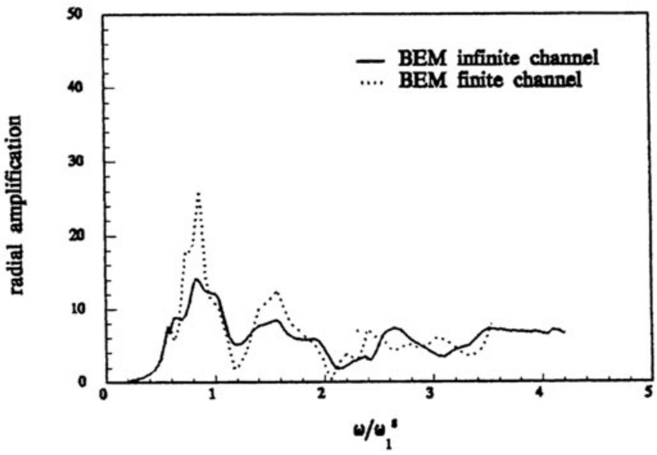

Fig.9. Radial amplification.Compliant foundation, finite and infinite reservoir full of water.

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