ARCH DAM-RESERVOIR INTERACTION DURING EARTHQUAKES

by

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SYNOPSIS

The paper presents an analysis of the arch dam-reservoir system subjected to the seismic motion. The theoretical aspects of the interaction problem between the structure and the fluid mass, during earthquakes, on an adequate mathematical model are included. The reservoir-dam system is considered to have a linear elastic behaviour. The problem is solved starting from the assumption that the arch dam is a flexibile structure, the foundations and the abutments are rigid, and the water in the reservoir is compressible. The small displacements hypothesis is considered to be valid. A combined finite element-finite difference method is used in the analysis, being taken into account only the horizontal seismic motion along the valley. Finally, numerical results and conclusions are given.

GLOSSARY OF TERMS

$[A]$	influence coefficients matrix.
$\{a_g\}$	ground acceleration vector.
a_n	projection of the ground acceleration on the normal to the interface.
$[C]$	viscous damping matrix.
$\{D\}$	nodal displacement vector (relative to the foundation).
$\{D_a\}$	absolute nodal displacement vector.
$\ddot{D}$	relative acceleration of a nodal point from the dam-reservoir interface, on the normal to the interface.
$\ddot{D}_n$	absolute acceleration of a nodal point from the dam-reservoir interface, on the normal to the interface.
$\{H(t)\}$	the vector of the hydrodynamic forces in the nodal points of the dam-reservoir interface.

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$[K]$	stiffness matrix.
$[M]$	mass matrix.
$p(x,y,z,t)$	hydrodynamic pressure.
v_s	velocity of sound in water.
∇^2	Laplace's operator.

INTRODUCTION

In the latest years, many studies have treated the dam-reservoir interaction problem during earthquakes. Obviously, the calculation of hydrodynamic pressure with Westergaard's method do not fully satisfy all the actual design requirements. The investments and the degree of safety imposed by the construction of a dam are very high. It must be done a good estimation of the safety coefficient for dams by taking into account all the causes which determine their behaviour in time - the earthquakes being one of the most important of them /1/.

The rigorous analysis of the arch dam-reservoir system is an extremely complex problem, due to the complicated shape of the dam as well as of the reservoir. Solutions are available only under severe restrictions. Thus, Zienkiewicz and Nath /2/ have computed the hydrodynamic pressure during earthquakes considering the water incompressible and the dam rigid; Perumalswami and Kar /3/ have solved the problem including in the analysis the compressibility of water, but the dam was rigid and had a simplified shape; Moroianu and Mihalcea /4/ have assumed the dam to be flexible but the water to be incompressible. More recent studies /5,6/ have taken into account the flexible arch dam-compressible reservoir interaction pressures developed during earthquakes but only for cylidrical dams. These papers have demonstrated that by omitting the compressibility of water or the flexibility of the dam, significant errors are generated.

The present paper is concerned with the analysis of the seismic interaction arch dam-reservoir. The problem is assumed to be spatial, the dam - flexible, consisting of a linear-elastic material and the water - compressible. The equations of motion are solved by a combined finite element-finite difference method.

THE MOTION EQUATIONS

The dynamic equations of the arch dam discretized in finite elements, considering the dam-reservoir interaction forces, may be written in matrix form as follows:

$$[M]\{\ddot{D}_a\} + [C]\{\dot{D}\} + [K]\{D\} = \{H(t)\} \qquad (1)$$

where:

$$\{\ddot{D}_a\} = \{\ddot{D}\} + [A]\{a_g\} \tag{2}$$

If the vector $\{H(t)\}$ was known, equations (1) could be solved by the usual methods of dynamic analysis.

Supposing that the viscousity and turbulence of water are neglected, that the liquid motion is of small amplitudes, the hydrodynamic pressures are determined by solving the wave equation:

$$\nabla^2 p(x,y,z,t) = \frac{1}{v_s^2}\,\ddot{p}(x,y,z,t) \tag{3}$$

for the appropiate boundary conditions. The orthogonal coordinates system is presented in Fig.1. In solving Eq.(3) the dam is considered flexible, double-curved, situated in an arbitrary shaped valley with rigid sides and the reservoir is of a finite length L. Only the ground acceleration component along the valley is taken into account. Thus the boundary conditions for which Eq.(3) is solved, are:

1. The surface waves in the reservoir are neglected, therefore, the dynamic pressures vanish at the free surface:

$$p(x,y,z,t) = 0 \tag{4}$$

2. On the bottom and on the sides of the reservoir:

$$\frac{\partial p(x,y,z,t)}{\partial n} = 0 \tag{5}$$

where n is the outward normal at these interfaces.

3. At the end of the reservoir opposite to the dam:

$$p(x,y,z,t) = 0 \tag{6}$$

The distance L is so long that the hydrodynamic pressure may be neglected /2,7/.

4. On the arch dam-reservoir interface, considering the flexibility of the dam:

$$\frac{\partial p(x,y,z,t)}{\partial n} = -\rho\ddot{D}_n \tag{7}$$

where:

$$\ddot{D}_n = \ddot{D} + a_n \tag{8}$$

THE SOLVING METHOD AND NUMERICAL RESULTS

The equation (3) whose boundary conditions are given by Eqs.(4),(5),(6) and (7) is solved by the finite difference technique, discretizing the reservoir by a spatial orthogonal mesh (Fig.1). The dam is discretized in thick shell finite elements /8/.

The seismic response of the arch dam in interaction with the reservoir is obtained in the following three steps:

1. The seismic response of the dam without reservoir is computed by solving Eq.(1) for $\{H(t)\} = \{0\}$.

2. Once the absolute acceleration response of the dam is obtained, the absolute acceleration vector for the nodal points on the dam-reservoir interface is established. Then Eq.(3) is solved for the boundary conditions (4), (5), (6) şi (7) step by step using the finite difference method. Thus, the time history of the hydrodynamic pressures occuring in the reservoir's nodal points is computed.

3. Starting from the pressures in the nodal points on the dam-reservoir interface, the vector of the hydrodynamic forces $\{H(t)\}$ is established; the seismic response of the dam is recalculated for the values of the previously computed vector $\{H(t)\}$ by using Eq.(1).

Following this method of analysis,it was computed a double curved arch dam - 100 m high, having 6.0 m at the crest and 15.0 m at the base in the crown section. The length of the reservoir was 400 m. The seismic response of the dam was obtained for the N-W component of the Taft earthquake, 1952. Results for the hydrodynamic forces are presented in the Fig.2.

CONCLUSIONS

This paper has presented a numerical technique for the analysis of the complex arch dam-reservoir interaction problem. It has been used a combined finite element-finite difference technique which made possible the evaluation of the seismic response for double-curved dams, having in view compressibility of water. The numerical results emphasize the great influence on the response of the interaction phenomenon and of the compressibility of water which cannot be neglected in the case of the arch dam-reservoir seismic interaction.

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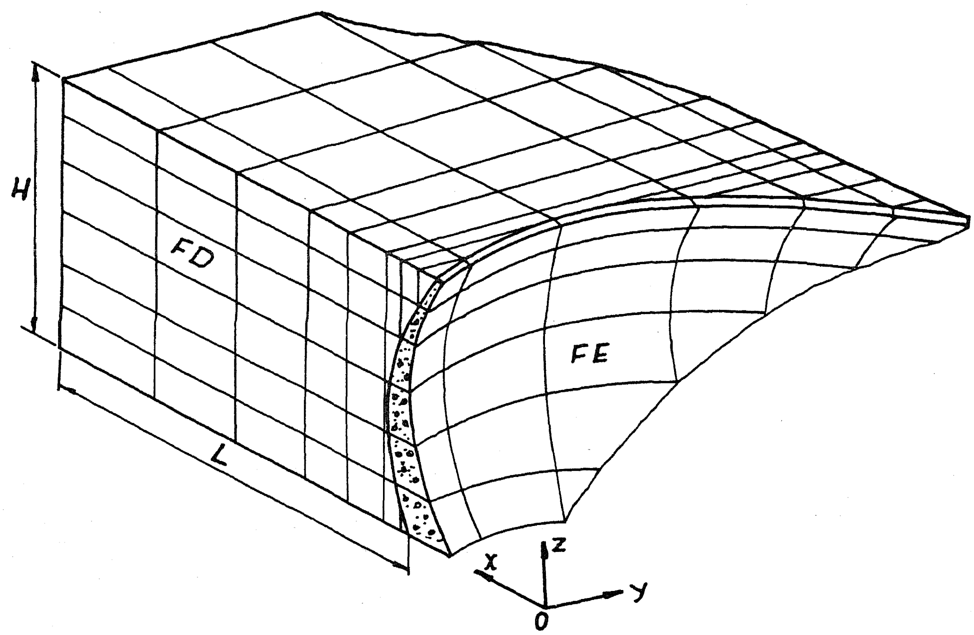

FD - Finite Difference Mesh;   FE - Finite Element Mesh
Fig.1 Arch Dam-Reservoir System

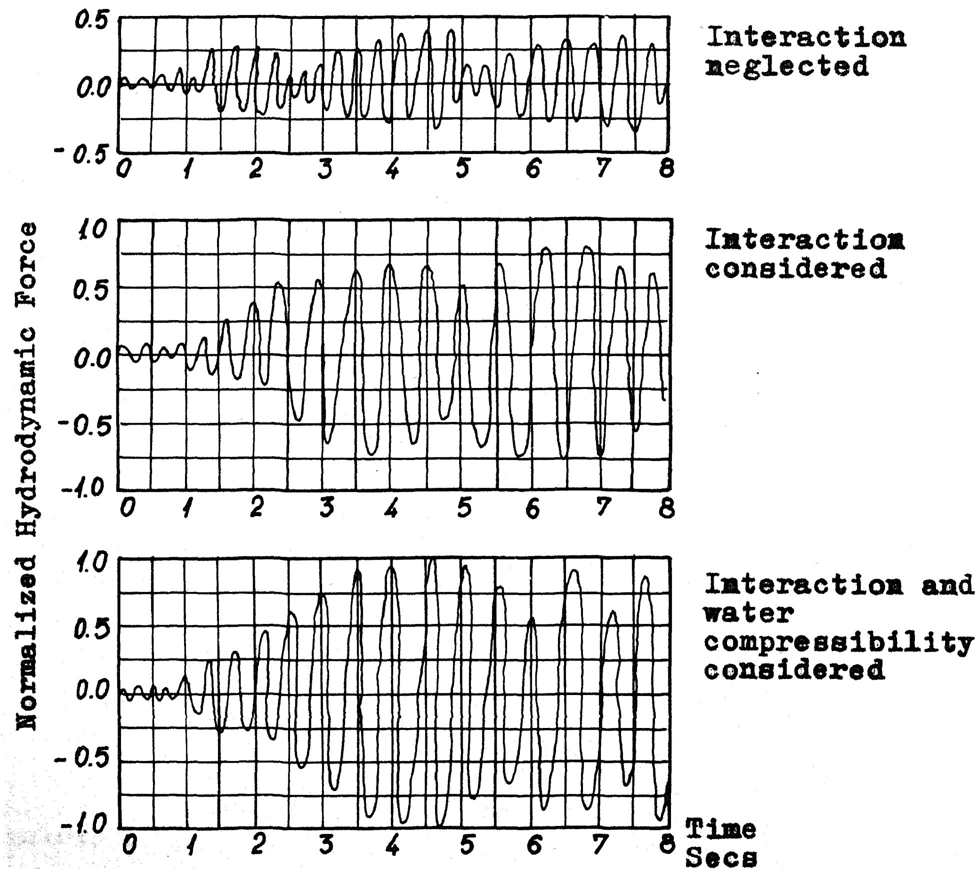

Fig.2 Hydrodynamic Force Response