I-298 A Study of The Dynamic Behaviour of Arch Dam

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1. Introduction :

The dynamic pressure of reservoir water on arch dam during earthquakes has been approximated by an extension of Westergaard's "Added Mass" approach. The outcome of such proposed added mass have shown reasonable reduction in the characteristic frequencies , and a rise in the dynamic response or stresses at the presence of water.

Furthermore the interaction equation for the dam-foundation system is used and resulted in a response far different from that of a usual earthquake analysis in which all degrees of freedom(DOFs) of the system are excited regardless of the direction of the free field earhquakes.

2. Method of Analysis:

One layer of 20-noded hexahedral parabolic isoparametric three dimensional curved finite elements are used for the dam, together with the similar but linear ones for the foundation.

3. Hydrodynamic Effect:

The width of the added mass distributed over a flat infinitely continuous vertical dam could be readily expressed as ;

$$b=0.368h\left(h/y\,(2-h/y)+\sqrt{h/y\,(2-h/y)}\right)$$

h is reservoir depth
y is the depth at which the point is located

Noting that for an arch dam only the radial component of the inertia force of water is effective, for each nodal point a 3 3 submaterice is constructed which embraces all of the added mass components corresponding to any direction of earthquakes.

$$M_w^i=mbA^i\begin{bmatrix} l_x^i l_x^i & l_x^i l_y^i & l_x^i l_z^i \\ & l_y^i l_y^i & l_y^i l_z^i \\ \text{Sym.} & & l_z^i l_z^i \end{bmatrix}$$

A^i is the tributary area integrated for node i
m is the mass density of water
M_w^i is the added mass submatrice lumped at node i
l_x^i , l_y^i , l_z^i are direction cosines of surface normal(radial) vector at node i

The overall added mass matrix is composed of these submatrices and finally the mass matrice of the solid domain , i.e; dam+foundation is added to it for the dynamic analysis at the presence of water.

Results: The frequencies as shown in Fig.1 decrease about 30% at the presence of water which is well acceptable for the first two modes of arch dams. The response has asignificantly increased for both the longitudinal and transverse earthquakes as shown in Fig.2

4. Foundation interaction :

The dam foundation system if subjected to an assumed free-field eathquake, would suffer an earthquake load equal to

$$-(MK^{-1}K_g-M_g)\,I\,\ddot{v}_g$$

rather than the usually assumed load , $-Mr\ddot{v}_g$, where ;

M is the total mass matrice
K is the total stiffness matrice
K_g and M_g are the rectangular matrices composed of columns concerning the dam-foundation interface DOFs in the dam stiffnes

and mass matrices respectively

I is a vector of "1"s with a dimension equal to the number of DOFs of the interface

$\ddot{v}_g$ is the free-field earthquake acceleration

Results : Fig. 3 shows that the symmetricity is lost if such eartyhquake load is applied. Also great changes both in the amplitude and the pattern of the response under the transverse earthquake is observed.

5. Conclusions :

An acceptable method of inclusion of the hydrodynamic effect of reservoir in the dynamic analysis of arch dam is proposed. Also the consistent earthquake load, having taken the dam-foundation interaction into the account , is shown to give a response greatly different from that of the regular analysis.

6. References :

1. Bulletin No. 30 ICOLD , 1977
2. Clough R. W. and Penzien , Dynamics of Strutures , 1975
3. Ahmadi M. T. , M. S. thesis , Tohoku Univ. Feb. 1985

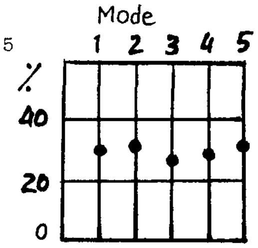

Fig.1

Arch dam frequency reduction (Reservoir full)

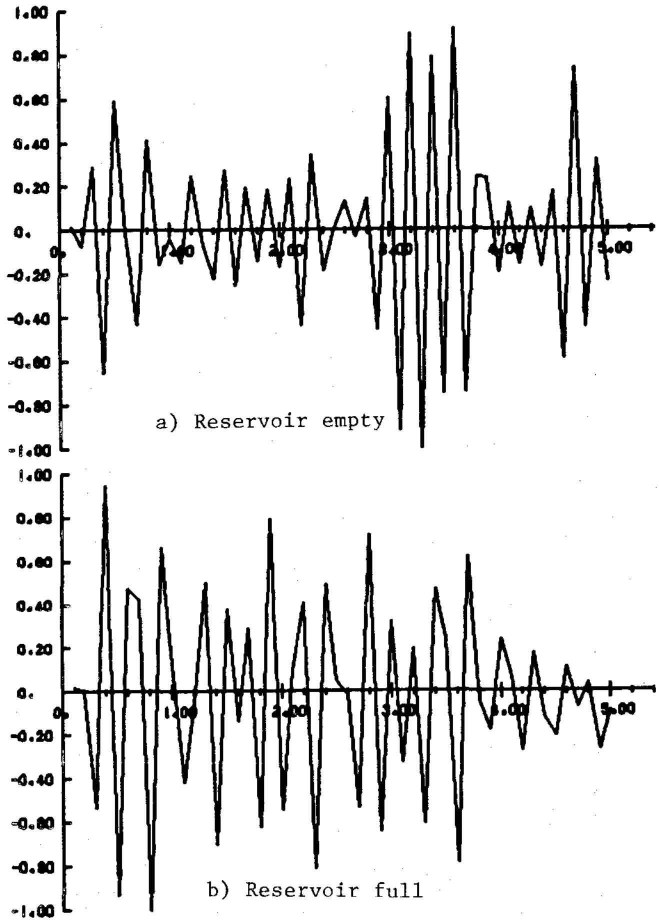

Fig.2 Normalized longitudinal displacements of crest crown

longitudinal earthq.

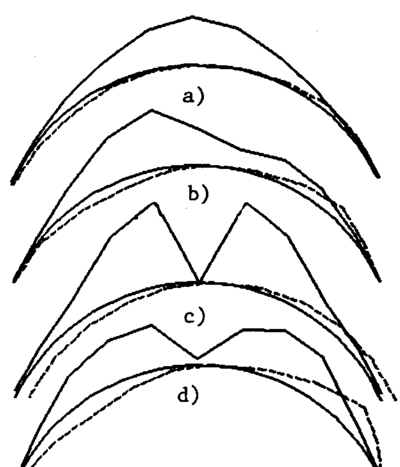

Fig.3

Maximum absolute value of crest displacement (Reservoir empty)

a) Usual long. earthq.
b) Consistent long. earthq.
c) Usual transvers. earthq.
d) Consistent transvers. earthq.

——— Longtudinal displ.
------ Transverse displ.