# NEW METHOD OF ANALYSIS FOR DYNAMIC INTERACTION OF ARCH DAM

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OBJECT To derive a consistent as well as practical methodology for dynamic analysis of arch dam due to hydrodynamic and foundation interactions is very interesting and desirable. While the Euler-Lagrangian method for such a fluid-structure problem is too complicated; demanding the coupling of pressure and displacement fields, the full Lagrangian method in which the hydrodynamic interaction is quite naturally accounted for is promising.

THEORY The model of arch dam as a shell structure is appropriately available in displacement-based finite element formulation.[4] Furthermore the Lagrangian formulation of the fluid domain is described elsewhere.[1,2] The significant problem remained here is how to couple these two domains at their interface. In the Eulerian method the interface condition is

$$\frac{\partial P}{\partial n} = -\rho\, n^T \ddot{u}_s$$

in which P and $\rho$ are the fluid pressure and mass density, n is suaface normal vector and $u_s$ is the structural dispalacement. But if the fluid is modelled by displacement formulation, three independent conditions should be satisfied, i.e.,

i ) Identity of normal displacements of fluid and of structure.
ii ) Zero tangential force at the interface.
iii ) Identity of normal forces at the interface.

These define the " slip " condition of fluid-structure interface. To satisfy the slip conditions (at least partially), there are methods such as employing very thin fluid elements adjacent to the dam and gradually increasing such thickness toward upstream. This not only is expensive due to the large number of element layers needed, but also is inaccurate. Other techniques like the coordinate transformation at each sample point on the interface is not appropriate for curved structures.

To solve this problem here we employ a zero thickness interface element originally developed for solid contact problems[3]. The constitution of the interface element is expressed in relative displacements in curvilinear coordinates as

$$\begin{Bmatrix}\tau_1\\ \tau_2\\ \sigma_n\end{Bmatrix}=\begin{bmatrix}C_{s1} & 0 & 0\\ 0 & C_{s2} & 0\\ 0 & 0 & C_n\end{bmatrix}\begin{Bmatrix}\delta_1\\ \delta_2\\ \delta_n\end{Bmatrix} \quad \text{or,} \quad f_I=D\Delta$$

in which $\tau_i$, $C_{si}$, and $\delta_i$ are a relative tangential force component, its corresponding elastic coefficient and its relative displacement component respectively. $\sigma_n$, $C_n$, and $\delta_n$ are the same quantities but for the normal direction.

To meet the requirments of the slip interface we choose $C_n=\infty$ which makes $\delta_n=0$ i.e., the first condition. Also by allowing $C_{s1}=C_{s2}=0$ we get $\tau_1=\tau_2=0$ i.e., the second condition. However the third condition is not satisfied as

$$\sigma_n=C_n\delta_n\neq 0$$

but its error is apparently very insignificant as shown in examples. Such fluid-solid models could be employed for the dynamic analysis of a dam-reservoir system only when the appropriate radiation conditions for the reservoir upstream end, and for the foundation boundaries are implied. Furthermore the wave refraction on the reservoir walls and bottom are essential for such an analysis.[2,4]

NUMERICAL RESULTS A thin flat concrete dam, 60.m high and 3.m thick, is standing against a rectangular reservoir. The natural modes of this system are shown in Fig.2. Case 3 has the consistent model presented here. As shown in Case 2 the error involving the " locked " interface is about 20%. The added mass solution is relatively reasonable but only for the lowest modes.

The 3-D models of Naruko arch dam and its reservoir are modelled by only 4 solid 22-node, 4 interface 9-node, and 8 fluid 27-node elements. Fig.1 demonstrates that when the gravity load is applied as a body force, the displacements coincide with the exact (based on the hydrostatic traction) solution. Finally application of the full methodology including the above, to Yuda arch dam seismic response analysis proves excellent when compared with the measured respnse as shown in Fig.3.

CONCLUSIONS A full Lagrangian method is developed for the dynamic analysis of arbitrary fluid-structure linear systems sush as in the case of arch dam. The new algorithm employs a unique interface model which helps high accuracy and economy of the solution. It is compatible with standard codes and is easy to use.


REFERENCES 1) WILSON E.L., KHALVATI MEHDI, "Finite Elements for Dynamic Analysis of Fluid-Solid Systems," Int., J. Num. Meth. Eng., Vol.19, 1983.

2) AHMADI M.T., "Displacement-Based Finite Elements for the Dam-Reservoir System," JSCE 41st annual meeting, Fukuoka, Japan, 1986.

3) BEER G. "An Isoparametric Joint/Interface Element for Finite Element Analysis," Int. J. Num. Meth. Eng., Vol.21, 1985.

4) AHMADI M.T., "New Method of Analysis for Arch Dam: Reservoir and Foundation Dynamic Interactions, and Static Joint Opening," Ph.D. Thesis, Grad. School of Engineering, Tohoku University, Japan, 1988.

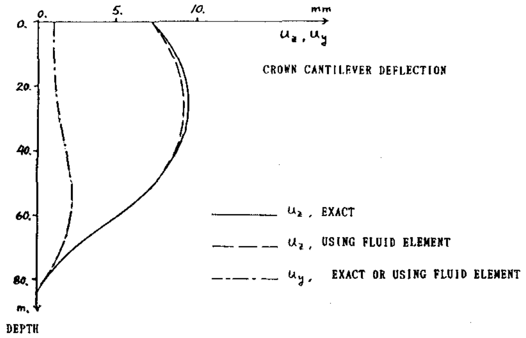




FIG. 1 —HYDROSTATIC LOADING OF NARUKO ARCH DAM.

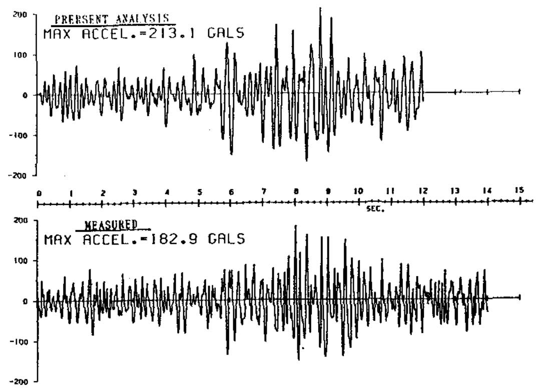
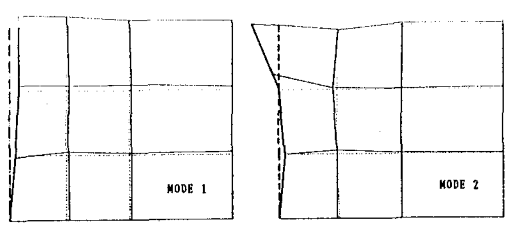



FIG. 3 —COMPARISON OF STREAM COMPONENT ACCELERATIONS OF MEASURED AND CALCULATED RESPONSES OF YUDA ARCH DAM (AT THE CREST CENTER) DUE TO SIMULTANEOUS VETRICAL AND STREAM COMPONENTS OF 1978 EARTHQUAKE.

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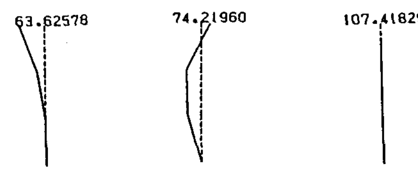


FIG. 2. a —MODE SHAPES AND CIRCULAR FREQUENCIES OF A FLEXIBLE FLAT DAM.
CASE 1, DAM ALONE

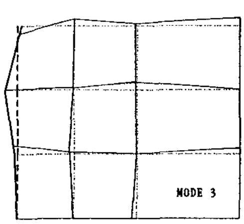


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FIG. 2. C
MODE SHAPES AND CIRCULAR FREQUENCIES OF A FLEXIBLE FLAT DAM-RESERVOIR SYSTEM.
CASE 3, BY USING FLUID ELEMENTS AND SLIP INTERFACE.

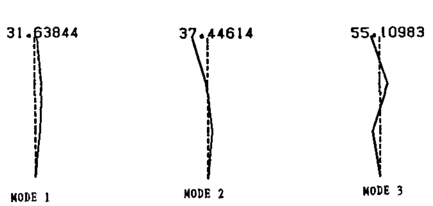


FIG. 2. d —MODE SHAPES AND CIRCULAR FREQUENCIES OF A FLEXIBLE FLAT DAM-RESERVOIR SYSTEM.
CASE 4, BY ADDED MASS METHOD

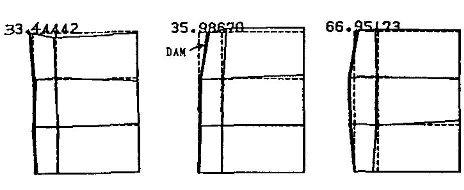


FIG. 2. b —MODE SHAPES AND CIRCULAR FREQUENCIES OF A FLEXIBLE FLAT DAM-RESERVOIR SYSTEM.
CASE 2, BY USING FLUID ELEMENTS WITH LOCKED INTERFACE.