Water Waves and Deformable Bodies

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There has been a growing demand or need to develop a rapidly and reusable floating breakwater. One possible concept would be a fluid-filled membrane suspended in the fluid domain, but how would such a concept perform. To address the effectiveness of the concept a numerical model of fluid/structure interaction was developed and large scale model studies were conducted.

A three-dimensional fluid-filled membrane is placed in a fluid domain. The fluid domain is then subject to long crested finite amplitude waves, a two-dimensional sea state. The waves will cause motion in the body; large rigid body motions and large deformations. The presence of the body and the motions of the body will alter the local wave field producing scattered and radiated waves. Then these changes in the local wave field will cause additional motions in the body and the cycle of wave structure interaction continues.

The numerical model involves the iterative coupling of a boundary element model of the fluid domain and a finite element model of the membrane. An iterative coupling procedure was selected because both the boundary element model and the finite element model are nonlinear. In this procedure each model are solved for at each time step and compatibility on the interface is insured in an iterative process. The position of the boundary is assumed in the boundary element model and the hydrodynamic loadings are computed. The hydrodynamic loads are used as input into the finite element model and the position of the boundary is computed. The computed and assumed conditions are compared, an iterative procedure follows until the desired accuracy is achieved.

The finite element model was developed (Lo, 1982) for tension structures, cables and membranes. Cables are assumed to be in a state of uniaxial stress, while the membranes are assumed to be in a state of plane stress in local surface coordinates. This implies that the normal component of stress is negligible. The thickness of the membrane is assumed small such that: lines normal to the undeformed midsurface and the motion of the membrane is characterized by the motion of the midsurface. Membrane stress is assumed constant throughout the thickness which implies that the flexural rigidity is negligible. No assumptions are made on the magnitudes of the displacements and strains.

The boundary element model was developed using Volterra's method, which produces an implicit time domain model. The boundary element integral is derived in the same manner as the typical boundary element model but in Volterra's method the starting point is the time derivative of the governing field equation (Laplace).

$$\frac{\partial}{\partial \tau} \nabla^2 \phi = \nabla^2 \phi_\tau = 0 \quad and \quad \nabla^2 G = 0$$

$$where \quad G = \frac{1}{4} \pi r$$

Integrate over the domain and use Green's Second Identity and the resulting boundary element integral is:

$$C(\xi,t)\phi(\xi,t) - C(\xi,0)\phi(\xi,0) =$$

$$\int_S \left(\phi(x,0)\frac{\partial}{\partial n} - \frac{\partial}{\partial n}\phi(x,0)\right)G(\xi,x,t)dS$$

$$- \int_S \left(\phi(x,t)\frac{\partial}{\partial n} - \frac{\partial}{\partial n}\phi(x,t)\right)G(\xi,x,0)dS$$

$$+ \int_0^t \int_S \left(\phi(x,\tau)\frac{\partial}{\partial n} - \frac{\partial}{\partial n}\phi(x,\tau)\right)G_\tau(\xi,x,t-\tau)dSd\tau$$

In the boundary element integral the full nonlinear kinematic and dynamic boundary conditions are used.

To verify the numerical model large scale model test were conducted in the large 2-dimensional wave tank at Oregon State University. A fluid-filled membrane in the form of a circular cylinder was placed horizontally across the wave tank, Figure 1. Two water depths were tested, D = 10.5' and D = 9.0'. The reflection coefficients for the test are shown on Figure 2. Figure 3 shows the measured and predicted displacements of a quarter point of the membrane.

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REFERENCE

A. Lo, Nonlinear Dynamic Analysis of Cable and Membrane Structures, PhD Dissertation, Oregon State University, Corvallis, Oregon, 1982.

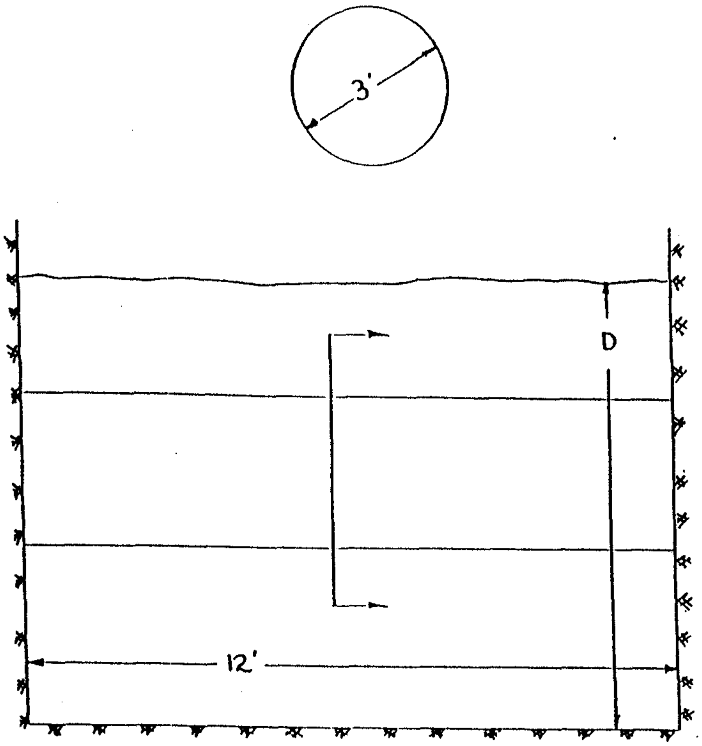

Figure 1 Schematic of the Physical Model Test

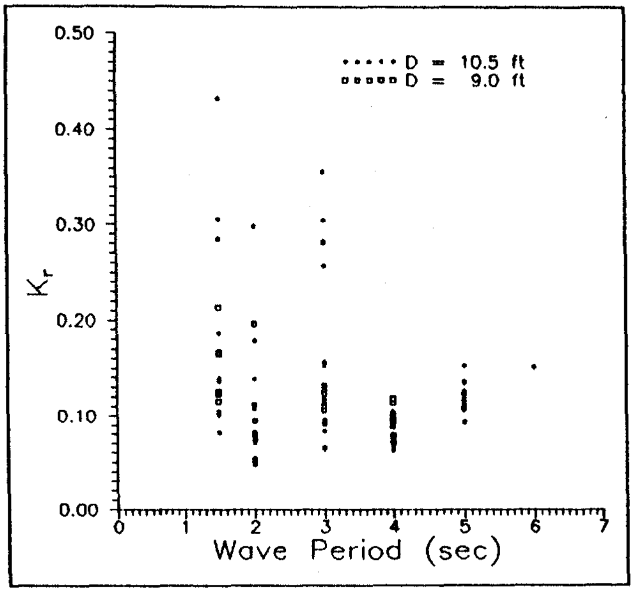

Figure 2 Reflection Coefficient

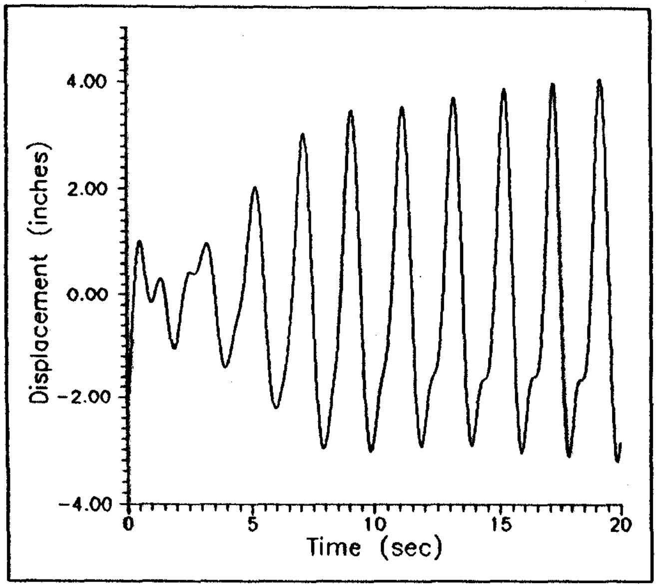

Figure 3a Measured Displacement

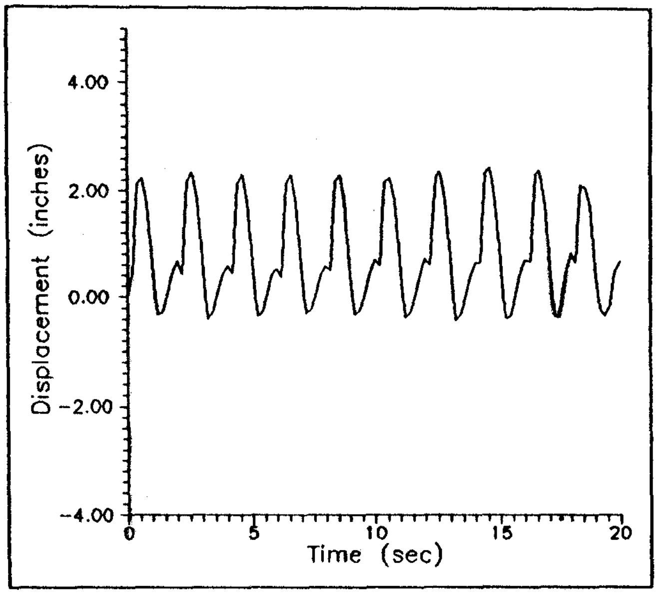

Figure 3b Predicted Displacement

Wehausen: Do reflection and transmission coefficients have much significance when the motion is no longer two-dimensional?

Broderick: Yes and no, it is important to determine if there is less energy on the lee side of the structure. A better measure would be to compare the energy in a transverse cut several body diameters in front and several diameters behind the body.

Beck: How did you measure the transmission and reflection coefficient?

Broderick: In the physical model test the water surface profile was measured using several sonic profilers at various locations along the center line of the tank. Two different procedures were used to measure the coefficients: Goda's method for stationary profiles, and the wave envelope method for moving profiles.(???)

Tulin: I am under the impression that a rigid circular cylinder under the free surface, when radiated by planar waves, does not reflect? Why then would you want to use this body as a breakwater?

Broderick: True, a submerged rigid right circular cylinder has a theoretical (and physically verified) zero reflection coefficient. Thus it is not an ideal shape – but in reality a membrane bladder is most likely to be elliptical in shape. The circular cylinder has been modeled here because of our ability to conduct the physical model test on it.

Tuck: I do not understand why the fact that the membrane is simulated only coarsely should cause the theory to underestimate the experimentally observed response. It would seem equally likely that it should overestimate it.

Broderick: In the results presented, the membrane was modeled using 12 eight-node quadrilateral elements, six around and two longitudinally. The model is stiff resulting in smaller displacements. The stiffness of the model can be seen by the lack of degrees of freedom in the model versus a continuous system.