A parametrized design space for pneumatic flood barriers

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Abstract

Pneumatic membrane structures have found numerous architectural and structural engineering applications. Inflatable flood and storm-surge barriers based on existing pneumatic dam technology promise several economic and environmental advantages over traditional structures such as sea walls. The numerical modeling of such structures, which is the subject of past [1] and ongoing work, must consider the complex hydrodynamic loads, the flexibility of the structure, and the ensuing fluid-structure interaction. The pneumatic membrane barrier itself is analyzed using a total Lagrangian formulation based on an isoparametric reference configuration, similar to [2]. The fluid flow is modeled via the two-phase incompressible Navier-Stokes equations using an arbitrary Lagrangian-Eulerian (ALE) formulation. The numerical method of choice is the finite element method.

Once a system can be modeled, it can be optimized; it is hypothesized that the barrier's resistance to hydrodynamic loads can be optimized by improving upon the typical cylindrical design of inflatable dams, for example, by introducing double curvature (corrugations). To this end, this paper explores a simple, yet powerful parametrization of the design space for this type of pneumatic structure, based on the analytical solution of the volume maximization problem for cylindrical pneumatic membranes [3]. The design space becomes a set of admissible mappings from the isoparametric domain to the initial configuration. Any ensuing shape optimization problem can be then posed as an optimization of the coefficients of these mappings, with state variables in the governing PDEs. To demonstrate the parametrization approach, the effects of design parameters (such as transverse support width, cross-sectional length, the frequency and amplitude of crown and base corrugations in the longitudinal direction) on the stress distribution and the deflection resulting from a hydrostatic load are investigated. This paper is a necessary stepping stone to more rigorous shape optimization studies of pneumatic barriers subjected to hydrodynamic loads and is of relevance to the practitioner and researcher interested in the design of non-traditional pneumatic structures.

References

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