Kinetic umbrellas for coastal defense applications

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Abstract

This research introduces an innovative structural system in the form of deployable four-sided hyperbolic paraboloidal (hypar) shells as hard countermeasures against nearshore hazards. Inspired by the works of Spanish-Mexican architect-engineer Félix Candela [1], the proposal seeks to formalize the amalgamation between structural art and coastal engineering. In this study, a symmetrical four-sided hypar roof structure (Figure 1a) is modified to incorporate a hinge at the vertex, allowing the umbrella to tilt from its initial upright position (Figure 1b). When simultaneously deployed in a row, the panels effectively form a physical barrier against coastal inundation during surge or extreme tidal events (Figure 1c). The umbrellas are to remain in their upright position during normal operation, providing shade and shelter along the waterfront while not limiting visibility and access to the shore. The deployment of this defense system during imminent hazard scenarios therefore introduces the concept of flexibility and reversibility into coastal hazard adaptation strategies not demonstrated by classical shoreline armoring initiatives.

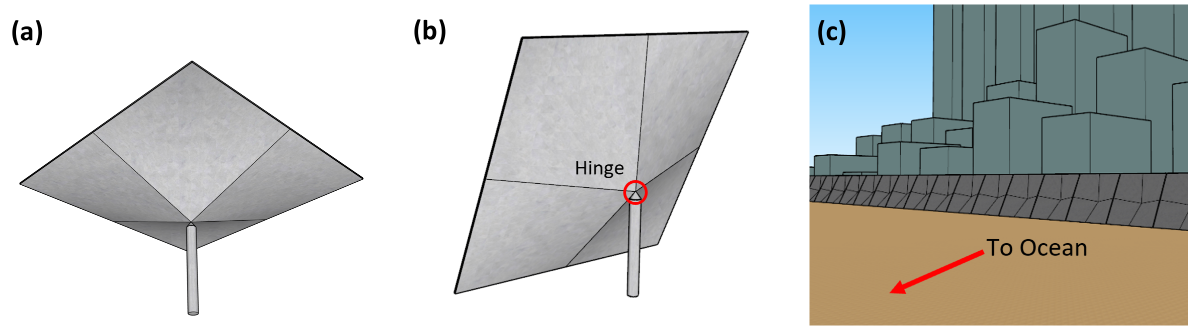

Figure 1: Four-sided hypar umbrella in upright (a) and deployed configuration with location of hinge indicated (b). Concept of deployed panel system in an urban waterfront setting also illustrated (c)

The structural feasibility of such a system was validated via the consideration of fluid-structure interaction (FSI) in the hydrostatic regime. A decoupled numerical scheme constituting smoothed particle hydrodynamics (SPH) and the finite element method (FEM) was introduced to simulate fluid inundation on the concave surface of a deployed umbrella, enabling the determination of shell bending moments and forces in the supporting column. A proof-of-concept study was considered for a squarely projected hypar with sides 8 m, vertex rise 1.92 m, and thickness 105 mm positioned atop a 500 mm square column 3 m tall. Fluid forces associated with 5.6 m of hydrostatic inundation were computed via the open source CUDA-enabled SPH solver DualSPHysics and applied to a 3D finite element model constructed using OpenSees. Critical bending moments of the shell and supporting column (accounting for axial-shear interaction) were extracted and compared against their reinforced concrete sectional capacities determined within Response-2000. It was identified that the structural capacity exceeded the hydrostatic demand, hence successfully validating the proposal. Through this work, we have effectively established a theoretical foundation for the analysis and design of dynamic hypar shells for coastal defense applications.

References

[1] M. E. M. Garlock and D. P. Billington, *Felix Candela: Engineer, Builder, Structural Artist*. Princeton, NJ 08544: Princeton University Art Museum, 2008.