

Calculations of Nonlinear Free Surface Flows Around Submerged and Floating Sea Caches

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INTRODUCTION

The present study addresses some of the hydrodynamic issues relevant to the operation of a modular, submersible pontoon system (sea cache) in littoral water. Knowledge is limited about environmental loads as well as sea-keeping characteristics of pontoon-based submersible structures in littoral water. The primary objective of the present study is to develop a numerical method in support of the design efforts providing pontoon structures with the integrity, stability and maneuverability required to operate in littoral environments. The sea caches may be moored on the surface as platforms for access by helicopters, anchored on the ocean floor for covert activity from below, or tethered for operation at any intermediate depth. Pertinent issues needing to be addressed include: (1) hull shape optimization in terms of maximizing payload, stability and strength, and minimizing drags; (2) dynamic response of a floating or tethered sea cache subjected to the combined action of waves and currents; (3) automated ballasting and de-ballasting systems that are remotely activated and self-stabilizing within a variable range of cargo load-out density options; and (4) an automated anchor and mooring system that will enable a sea cache to remain grounded, or tethered beneath or on the free surface.

RESULTS AND DISCUSSION

In order to accurately predict the hydrodynamic forces on large pontoon structures while afloat or fully submerged, the chimera Reynolds-Averaged Navier-Stokes (RANS) method of Chen and Liu (1999) and Chen et al. (2000) was extended for time-domain simulation of various sea caches in littoral environments. For completeness, the chimera potential-flow method of Chen and Lin (2000) was also used to estimate the wave drag and quantify the viscous effects. Calculations were performed for 3 candidate sea-cache configurations (Fig. 1). The length, width and height ($L \times W \times H$) for all sea caches are 18.29 m \times 9.14 m \times 4.11 m (60 ft \times 30 ft \times 13.5 ft). A constant water depth of 12.19 m (40 ft) is used in all of the simulations. The first sea cache is a simple rectangular container. The second configuration is a more streamlined, sharp-edged sea cache consisting of 26 flat surfaces. The third round-edged sea-cache configuration eliminated the sharp edges and corners with circular and spherical sections. All calculations

were performed at a current speed of 6 knots (3.08 m/s), which corresponds to a Reynolds number of 5×10^7 and a Froude number of 0.23 based on the body length.

Viscous flow simulations were performed for each sea-cache configuration at 3 different positions: (a) anchored on the seafloor; (b) tethered at mid-height; and (c) floating on the surface. For each sea-cache position, it is further assumed that the current may approach the structure either from the broad side ($\alpha = 0^\circ$) or the narrow side ($\alpha = 90^\circ$). This gives a total of 18 turbulent flow simulations for the 3 sea-cache configurations considered. In addition, 6 potential-flow simulations were also performed for the round-edged sea-cache configuration to examine the effects of viscosity on the predicted drag forces and free-surface wave fields. Fig. 2 shows selected simulation results for sea caches at either the bottom or middle positions. When the sea cache is anchored on the seafloor with a 0.3048-m (1-ft) clearance, the free-surface wave is significantly smaller than those generated by the sea caches tethered at mid-height. It is clearly seen that the fluid viscosity has caused massive 3-dimensional flow separations that were completely absent in the potential flow solutions (not shown). Further, the sizes and locations of the shedding vortices exhibit significant oscillations with a nearly periodic shedding pattern.

For the rectangular sea cache, the flow separates at the sharp corners of the leading edge with large regions of flow recirculation extending across the entire length of the sea cache. This results in a much wider wake and produces a form drag significantly higher than those observed for the sharp-edged and round-edged configurations. It is worthwhile noting that the sharp-edged sea cache gives very low drag coefficients when the flow approaches from the narrow side (i.e., $\alpha = 90^\circ$). In this orientation, the boundary layer remains attached all the way to the tail end of the sea cache. The recirculating zone is confined to a small region in the near wake, and the pressure recovers almost completely. The free-surface wave elevation produced by the sharp-edged sea cache at $\alpha = 90^\circ$ is also found to be considerably smaller than the other 2 configurations. However, the sharp-edged sea cache is still not as effective as the round-edged configuration in terms of the drag reduction when the flow approaches from the broad side with $\alpha = 0^\circ$.

Table 1 shows the predicted drag coefficients ($C_D = D_f / LH$) for all 24 cases considered, where D_f is the drag force, L the body length, and H the height of the sea caches. In the potential-flow solutions, the friction drag is exactly zero and the wave drag can be computed by a direct integration of pressure distribution on the body surface. At the bottom position, the free-surface wave is very weak and the potential-flow drag coefficients very small. When the sea cache is tethered at mid-height or floating on the

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