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Chimera RANS Simulation of Ship and Fender Coupling for Berthing Operations

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ABSTRACT

A Reynolds-Averaged Navier-Stokes (RANS) numerical method has been coupled with a six-degree-of-freedom motion program for time-domain simulation of ship and fender coupling during berthing operations. The method solves the mean flow and turbulence quantities on embedded, overlapped, or matched multiblock grids. The unsteady RANS equations were formulated in an earth-fixed reference frame and transformed into general curvilinear, moving coordinate systems. A chimera domain decomposition technique was employed to accommodate the relative motions between different computational blocks. Calculations were performed first for a full-scale motor vessel in berthing operations. Comparisons have been made between the computations and measurements to demonstrate the feasibility of the chimera RANS approach for time-domain simulation of the hydrodynamic coupling between the ship and berthing structures. The method was then employed for a parametric study of full-scale berthing ships under different approach speeds, waterdepth-to-draft ratios, quay-wall clearance distances, and fender stiffnesses.

INTRODUCTION

Damage due to berthing operations can result in substantial financial and operational penalties to ships and wharves. Even in a well-executed berthing, a large ship possesses enormous kinetic energy that could seriously damage the berthing structure as well as the ship itself. Fender systems are provided at a berth to absorb and dissipate the kinetic energy of the berthing ship and to mitigate impact forces. The amount of energy absorbed and the maximum impact force imparted are the primary criteria applied in accepted fender design practices. However, because berthing is a highly complex process that involves structural and fluid coupling between a vessel, a fender system and the surrounding water, a reliable and accredited assessment tool for computing berthing energy has not been developed to date. Currently, most accepted fender design methods account for the influence of the ambient water by using a simple constant coefficient. Fenders designed this way tend to be either underdesigned, resulting in a high rate of failure, or overdesigned, producing a costlier product.

In order to improve the design of berthing facilities, it is desirable to develop a reliable hydrodynamic assessment system for accurate time-domain simulation of the berthing processes, which involve complex interactions among the ship, the fender system and arbitrary harbor floor bathymetry. Recently, Chen, Chen and Davis (1997), Chen and Chen (1998), and Chen and Huang (1998) developed a chimera RANS method for the simulation of transient flows induced by berthing operations of practical ships in fully sheltered harbors. The method solves the mean flow and turbulence quantities on embedded or overlapped grids using a domain decomposition approach. Calculations have been performed by Chen and Chen (1998) for a DDG-51 ship in combined translational and rotational motions to demonstrate the capability of the chimera RANS method for time-domain simulation of berthing ships.

In order to assess the general performance of the chimera RANS method for practical berthing operations, a series of full-scale experiments was conducted by Huang, Davis and Hatch (1998) at a small harbor in Port Hueneme, California using a 57.30-m-long (188 ft) motor vessel. Current meters were placed at 10 selected locations along the path of the berthing ship to measure the longitudinal, transverse and vertical components of the fluid velocities. In addition, 8 load cells were used to measure the impact forces on the fender system. In the present study, time-domain simulations were performed for the berthing ship to identify the important parameters and flow features associated with berthing operations. Comparisons were made between the calculated and measured time histories of velocities and fender forces to illustrate the general capability of the present method. The method was then employed for a parametric study of 2 other full-scale ships to establish a comprehensive database for fender design and analysis.

NUMERICAL METHOD

In the present study, the chimera RANS method of Chen, Chen and Davis (1997) and Chen and Chen (1998) was employed for time-domain simulation of transient flow induced by a berthing ship. In this approach, the transport equations for both momentum and turbulence quantities are solved using the finite-analytic method of Chen, Patel and Ju (1990). To solve for the pressure, the SIMPLER/PISO pressure-velocity coupling technique of Chen and Patel (1989) and Chen and Korpus (1993) is used. A brief summary of the governing equations and solution procedures is provided below.

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KEY WORDS: Chimera domain decomposition, berthing ships, fender forces, fender deflection, fender stiffness, waterdepth-to-draft ratio, underkeel clearance, quay-wall clearance.