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CFD Simulation of Bow and Stern Slamming on a Container Ship in Random Waves

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Slamming is a common phenomenon as a ship navigates in rough seas, and it can cause severe structural damage to the hull structure. Full-domain computational fluid dynamics (CFD) simulation of random wave and structure interaction is considered impractical by many researchers. Simplified approaches are usually adopted to alleviate expensive CFD random wave simulation. In this paper, we present a rigorous methodology that solves the Navier–Stokes equations entirely without any need for matching. In our simulation scenario, a container ship cruising at a constant speed is allowed to heave and pitch in random waves. Both head-sea bow slamming at a speed of 6 knots and following-sea stern slamming at 0 and 5 knots are studied. Irregular waves are used to simulate a realistic seaway environment. A very effective procedure is developed to capture the desired waves at a specific part of the sailing vessel. A level-set function is employed to capture the violent free surface and to simulate the interaction of the random wave and the ship. This rigorous Navier–Stokes numerical approach is able to capture complex mechanisms and show results that are possible only with CFD simulations, thus providing useful information for ship designs.

INTRODUCTION

Research on ship maneuvering and sea-keeping is conventionally done with potential flow codes. Though the practice enjoys quick results and low computational costs, it is incapable of treating some critical events like green water, breaking waves, and extreme slamming. For these relatively short-term extreme scenarios, it is logical to perform computational fluid dynamics (CFD) simulation based on more realistic physics, although it becomes substantially more expensive in the complex setup preparation and longer computational time.

Green water and slamming on ships and offshore structures have long been problems causing great concern and generating many studies. In rough seas, a vessel's bow and stern may occasionally emerge from seawater and reenter it with a heavy impact. The vessel experiences high-pressure impact loads between the vessel's hull and water surface. These impact loads are of a transient nature and can cause serious structural damage. Severe green water may also affect the stability of the ship and cause considerable structural damage. It is thus important to estimate the magnitude of the impact loads and the peak pressure for structural design purposes.

CFD simulation of slamming phenomena is challenging. Due to the transient nature of slamming, a simulation in the time domain requires a time increment sufficiently small to capture the peak impact pressure. This makes the computation very time consuming. Both the large motion of the vessel and the violent free surface must be solved accurately for a realistic wave–structure interaction. Simulating and capturing the desired irregular wave for a cruising ship add another level of difficulty. Full-domain CFD simulation of random wave and structure interaction has been deemed impractical by many researchers. Regular waves are commonly substituted in the case of a ship with forward speed. When random waves are employed, a simplified approach is usually adopted to circumvent the expensive CFD simulation. The essence of the approach is (i) using potential theory to calculate the far wave field and the ship motion, (ii) selecting the time window of random waves for simulation, and (iii) CFD computation of wave–ship interaction in the near field with solutions from step (i) as boundary conditions (for example, see Kleefsman et al., 2005). More recently, Oberhagemann and el Moctar (2011) and Oberhagemann et al. (2012) employed a coupled CFD and computational structural dynamics (CSD) approach to calculate the response of a flexible ship in regular and irregular waves. The long-term extremes of ship responses and wave-induced loads can be determined efficiently using the conditioned random response waves (CRRW) and the most likely response waves (MLRW) sequences, as shown in Oberhagemann et al. (2012) and Ley et al. (2013).

In this paper we present a rigorous methodology that solves Navier–Stokes equations directly in conjunction with a six degree-of-freedom motion program for the study of bow and stern slamming of a rigid ship in random waves. In our simulation scenario, a container ship sailing at a constant speed is free to heave and pitch. Long crested random waves are generated as incident waves to simulate a realistic seaway operation environment. Speeds of 6 knots in head-sea conditions and 0 and 5 knots in a following-sea scenario are investigated. A validation study of the ship motions in regular waves is also made to compare with the experimental results. Our CFD solver is based on the finite analytic Navier–Stokes (FANS) numerical method of Chen and Yu (2006, 2009). The interface-capturing level-set method is used to provide an accurate simulation of the violent free surface and green water loads. Our multiblock overset grid code is fully parallelized and greatly reduces the computation time to make the simulation practical.

NUMERICAL METHOD

Ship Model

To demonstrate our numerical approaches, the KCS container ship that is available for public access (www.simman2008.dk) is selected. The full-scale ship exists only in design, and various databases are not all consistent on its freeboard. To attain maximum

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KEY WORDS: CFD, random waves, head sea, following sea, bow slamming, stern slamming, green water.