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Editorial

Ship Motions and Wave Loads

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1. Introduction

Seagoing ships operate in ocean waves for the majority of their service lives. The waves can induce not only six degree-of-freedom (DOF) motions, but also loads acting on the ship's hull structure. The prediction of ship motions and loads induced by waves is a central problem of hydrodynamics and is fundamental for structural design, and has been highlighted in almost all the previous sessions of the International Towing Tank Conference (ITTC) Seakeeping committee and the International Ship Structure Congress (ISSC) loads committee.

Up to now, a wide variety of potential flow theories have been developed to estimate motions, wave loads, and the hydroelasticity of ships in waves. Recently, the computational fluid dynamics (CFD) technique has also been rapidly developed as a novel tool to address these problems. Tank model tests and sea trials have also been conducted to experimentally investigate the seakeeping and wave loads of ships. However, due to the complexity of interactions between water waves and the arbitrary shapes of moving bodies in the presence of a free surface and forward speed, the problems of wave-induced ship motions and loads are still far from being satisfactorily addressed, especially for problems involving a high forward speed, harsh weather, an instantaneous wetted surface, irregular sea waves, and strong nonlinear slamming loads.

This Special Issue aims to gather the latest developments in the prediction of ship seakeeping and wave loads using theoretical, numerical, and experimental methods. The topics discussed mainly include:

- Ships hydrodynamics;
- Water waves and floating bodies;
- Ship seakeeping;
- Wave loads;
- Environmental loads;
- Hydroelasticity;
- Slamming and whipping;
- Springing;
- Fluid–structure interaction;
- Shallow water hydrodynamics;
- Marine computational fluid dynamics.

To instigate renewed interest in the well-rehearsed subject of ship motions and wave loads, this Special Issue presents a collection of 11 high-quality research contributions with a focus on the prediction and analysis of the motions and loads of ships or floating structures in calm water or wind wave environment. These papers are co-authored by leading academics and practitioners worldwide. The use of novel numerical and experimental tools including potential flow theory, CFD tools, and model measurements in addressing the relevant problems is included in the papers published in this Special Issue.

2. Summary of the Special Issue Papers

2.1. Ship Hydrodynamic Behavior in Calm Water

The prediction of ship hydrodynamic behavior in calm water is fundamental for motion and load responses in waves. Two papers regarding ship hydrodynamic behavior in calm water are also included. The potential flow theory constitutes an invaluable and efficient tool to naval architects. Green function and Rankine source methods are commonly used to solve flow problems in ship and marine engineering. Wu and Fang [1] present a frequency-domain Rankine source method based on a biquadratic B-spline scheme with an improved radiation mechanism. This method can be used to solve unsteady flow problems regardless of the τ condition (making this method practical for use). This method contrasts with the unsteady Rankine source approaches in the literature that are applicable only to the overcritical condition. Specifically, the present study constructs the resultant boundary integral equation by employing simplified Seto explicit conditions and Rayleigh artificial damping to accommodate wave radiation.

Ship navigational resistance in calm water or even restricted water areas is the most classical problem in both academic research and industrial applications. A ship's hull surface condition is crucial to its hydrodynamic performance, which can affect fuel consumption and emission reduction. The consequences of poor hull surface conditions on fuel consumption and emissions are well-known. However, their rationales are yet to be thoroughly understood. As potential flow theory ignores the fluid viscosity, it is necessary to use viscous flow theory for the estimation of ship resistance. Ravenna et al. [2] studied the effect of hull roughness on ship resistance using a fully turbulent flow channel. The present study investigates the hydrodynamics of fouling control coatings and mimicked biofouling. Novel experimental roughness function data were obtained from the "new" fully turbulent flow channel facility of the University of Strathclyde in Glasgow. Different surfaces, including a novel hard foul-release coating, were tested. Finally, the performance of a benchmark full-scale containership was predicted using Granville's similarity law scaling calculations.

2.2. Wave-Induced Motions and Loads of High-Performance Ships

Compared with traditional monohulls, the hydrodynamic behavior of high-performance ships is more complex mainly due to their high advancing speed. This Special Issue published two papers on the seakeeping problem for high-performance ships (tunneled planing hull and trimaran) using a CFD tool.

Tunneled planing hulls are marine vehicles that use aerodynamic pressure to reduce the drag-over-lift ratio of the lifting surface by trapping the airflow in tunnels. The dynamic motions of tunneled planing hulls operating in head sea conditions are numerically replicated by employing state-of-the-art CFD simulations in Roshan et al. [3]. In this paper, two different tunneled planing hulls with two DOF in heave and pitch motions are studied in regular waves by using the CFD method based on the Unsteady Reynolds Averaged Navier–Stokes Equations (URANSE). The results demonstrate that tunneled planing hull motions in waves are nonlinear.

Compared with the head wave condition, the prediction of seakeeping and slamming behaviour of trimarans in oblique waves is more challenging and has more value for practical applications. The interference between the main hull and side hulls of trimaran makes the problem more difficult. The CFD prediction of ship seakeeping and slamming behaviors of a trimaran in oblique regular waves is conducted using a CFD-based STAR-CCM+ software package in Liao et al. [4]. The main novelty of this study is the determination of the motion characteristics leading to trimaran slamming as well as the relationship between slamming position and slamming time in oblique regular waves. The conclusion drawn in this study would help ensure the safety of ships navigating in waves.

2.3. Ship Hydroelasticity

With the development of ships towards having large dimensions, high speeds, and light weights, the natural frequency of hull girder falls within the vicinity of the harmonics of encountered wave frequencies. Unlike the rigid hull concept, the structural deformation and hydrodynamic response of large flexible ships are fully coupled and the hydroelastic effects should be considered. The hydroelasticity is an issue of the fluid–flexible structure interaction (FFSI) problem and involves the mutual interactions among inertial, hydrodynamic and elastic forces. Chen et al. [5] present a three-dimensional nonlinear hydroelasticity theory, in which the nonlinear hydrostatic restoring force caused by an instantaneous wetted surface as well as slamming force are taken into consideration, and the bending moments with/without slamming effects are calculated. The method is based on potential flow theory in combination with a modal superposition method. The wave loads and hydroelasticity responses of a bulk carrier in different conditions are investigated. High-frequency whipping responses are well-simulated and analyzed.

Even though ship hydroelasticity has becoming a great concern in the scientific community of naval architecture and ocean engineering since the 1970s, it is still a hot research topic now. The traditional hydroelasticity theories (e.g., in Chen et al. [5]) are mainly developed in the framework of potential flow theory. Recently, with the development of computer science and computational technology, different CFD methods have been used to solve the hydroelasticity issue. Wei et al. [6] present a fully coupled CFD and discrete module beam (DMB) method for the numerical prediction of nonlinear hydroelastic responses of a ship advancing in regular and focused wave conditions. A two-way data communication scheme is applied between two solvers, whereby the external fluid pressure exported from the CFD simulation is used to derive the structural responses in the DMB solver, and the structural deformations are fed back into the CFD solver to deform the mesh.

2.4. Slamming Loads

The slamming phenomenon is one of the most concerning issues in the field of naval architecture and ocean engineering. Slamming events occur when a structure is impacted with water at a relatively high speed, which is a strongly nonlinear problem involving fluid–structure interaction (FSI) issues. When a ship sails in rough seas, the tremendous slamming loads caused by the ship's structure interacting with waves may result in local or global damage to the ship structure. Chen et al. [7] coupled CFD and the Finite Element Method (FEM) to study the FSI problem of a wedge structure with stiffeners, which is simplified from a part of the ship's structure, impacted with water during the free-falling water entry process. In the numerical model, a partitioned two-way coupling of CFD and FEM solvers is applied to deal with the FSI problem, where the external fluid pressure exported from the CFD simulation is used to derive the structural responses in the FEM solver, and the structural deformations are fed back into the CFD solver to deform the mesh. Almost all the physical characteristics of interest within the scope of water impact and structural response can be satisfactorily reproduced by the presented CFD-FEM co-simulation approach, which include displacement, velocity, acceleration, slamming pressure, deformation, structural stresses and total forces on the wedge accounting for hydroelasticity effects, as well as graphical visualizations. The presented method has wide application values in slamming simulation, and it is a more powerful tool compared with analytical methods, potential flow theory or traditional CFD methods.

In addition to ship slamming, the slamming load on floating structures is also a reason of concern. Even though they have no forward speed, the harsh waves can pose a threat to the global or local strength of floating structures. Huo et al. [8] investigated the slamming loads on semisubmersible platforms under different operating conditions using CFD and tank model experiment. During the towing of semisubmersible platforms, waves impact and superpose in front of the platform to form a "water ridge", which protrudes near the platform and produces a large slamming pressure. The water ridges occur frequently in the towing conditions of semisubmersible platforms. The wave slamming on the braces and columns of platform is aggravated due to the water ridges, particularly in rough sea conditions.

The slamming loads on ships and floating bodies in regular waves have been widely studied. However, freak waves have great peak energy, a short duration, great contingency and strong nonlinear characteristics, which can cause severe damage to ships and marine structures. Therefore, the slamming pressure characteristics of the platform under freak waves are investigated in Huo et al. [9]. In this study, numerical simulations in conjunction with experimental tests are conducted to study air gap response and wave slamming loads of a semisubmersible offshore platform under a freak wave.

2.5. Sloshing Loads

Tank sloshing is widely involved in many engineering fields, especially in marine fields, such as research on liquefied natural gas (LNG) carriers. Extreme ship motions encountered during rough sea conditions while transporting liquid cargo within partially filled tanks may induce substantial dynamic loads, which may be detrimental to vessel seakeeping and maneuverability. Significant sloshing dynamics within LNG cargo tanks may result in breaking waves that potentially bring about structural damage and stability loss due to high-impact slamming. Borg et al. [10] put forward a CFD sloshing analysis of partially filled chamfered rectangular tanks undergoing sinusoidal oscillatory kinetics with the use of the explicit volume-of-fluid and noniterative time-advancement schemes. This study formed part of the 'DeSloSH' research project, which developed an experimentation and numerical framework for the suppression of sloshing within naval tankers by means of perforated-partitioned containment units when succumbing to oscillatory motion.

Although the tank sloshing problem has been widely studied using different methods, the coupled effect of ship seakeeping and tank sloshing is complex and less studied. Due to the trend of large-scale liquid cargo ships, it is of great significance to study the coupled motion response of ships with tanks in beam waves. He et al. [11] used the CFD method and experiments to study the response of a ship with/without a tank in beam waves. In their paper, several different working conditions are set up, and the effects of the liquid height in the tank, the size of the tank and the wavelength ratio of the incident wave on the ship's motion are studied.

3. Concluding Remarks

This Special Issue of *Journal of Marine Science and Engineering* provides a snapshot of the current state of research in the broad field of ship motions and wave loads. The 11 collected papers, even though the quantity is limited, comprehensively cover almost all the topical areas listed in the introduction and show the state of the art in this field. Nine out of the 11 papers use the CFD method, while only two papers use traditional potential flow theory. Therefore, there is a trend of using CFD solvers for the flow computation in ship hydrodynamics and wave loads, especially in high sea states or at high forward speed. Hot topics such as hydroelasticity, slamming and whipping, sloshing problems, severe sea state and their uncertainties are also widely covered in these papers. All 11 papers mainly focus on numerical methods and calculation. Although in some papers experiments are conducted to validate or compare with numerical data, specialized experimental techniques or measurement methods for ship motions and wave loads are not included. It is hoped that this Special Issue will stimulate some interest in ship hydrodynamics and wave loads and contribute to our understanding on the subject and its strategic scope in the prediction of ships motions and wave loads.

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