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An Experimental Investigation on the Dynamic Response of a Damaged Ship with a realistic arrangement of the flooded compartment

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ABSTRACT

The dynamics of a damaged ship in waves is a complex phenomenon regarding fluid and structure interactions. Flooded water motions in the damaged compartment could be influenced by decks, obstructions and obstacles in the compartment. This becomes particularly relevant in case of flooding in the engine room that is usually characterized by the presence of large objects such as engines and machineries. In such cases the possibility to better understand the behavior of a damaged ship, influenced by the fluid and structure interactions, could provide novel outcomes and thus enhance the damaged ship safety.

In this paper an experimental campaign is conducted on a passenger ferry hull. The effects of obstacles in the engine room compartment, such as decks and engines, on ship roll responses, are studied. Roll decay in still water and steady roll responses in beam regular waves at zero speed are measured for the empty compartment and for the compartment with obstructions, as defined above.

The main outcomes from the conducted experiments disclose a mitigation of the resonant behavior of the coupled system, ship with damaged compartment, by having engine shapes occupying the flooded engine room. Moreover it is possible to observe how the resonant frequency of the ship modifies having a more realistic arrangement of damaged compartment and how motion RAOs and roll decay characteristics modify accordingly.

1. Introduction

One of the main issue with ship safety remains the stability of a damaged ship. When a ship is damaged, for example due to a collision or grounding, water starts to flood in. In case of tanker, the carried fluids could also leak in the sea [1]. Apart from the need for research on operational improvements, for preventing accidents, and on ship design, to ensure ship floatation and stability after damage, it is important to be aware of ship behavior for an efficient response to maritime incidents and accidents.

The current trend for enhancing the safety of a flooded ship after damage involves the possibility to communicate the safety status of a vessel and provide support accordingly [2]. This approach requires a deeper knowledge of the behavior of a damaged ship in order to allow simulation based guidelines in critical scenarios [3,4]. Thus, the possibility to better understand and predict the dynamic behavior of a damaged vessel, accounting for more realistic scenarios, becomes of particular relevance and interest. In this context, experimental campaigns can be useful to observe specific phenomena and provide novel outcomes to enhance the safety of a damaged ship.

The flooding process is generally divided into three main phases [5,6]: transient flooding, progressive flooding, and final equilibrium after damage. Several experimental researches deal with transient flooding condition such as [7–9]. In these researches, the damaged compartments are modeled as empty spaces, eventually connected to adjacent compartments, allowing for cross flooding. The experimental results supported the development on numerical simulation tools, that disclose the importance of a proper numerical modeling of the water inflow [10,11]. The water inflow during transient flooding is influenced by obstacles, as pointed out in [12]. In particular, in this reference work, numerical simulations of transient flooding are conducted, assuming different breaches and different opening widths in the damaged compartment.

Progressive flooding happens during intermediate stages and consists in the leaking of the water in undamaged compartments usually through trunks, pipes and staircases. Experimental works regarding progressive flooding are conducted on ship model char-

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acterized by leaking through adjacent undamaged compartment such as [13,14]. In [15] experimental measurements are carried out in full scale on a decommissioned fast vessel. The main outcomes of progressive flooding researches point out the importance of the air compression effects on the water flow rate across the compartments [16–18].

In [19] experimental tests are conducted to study the effects of several engine room layouts on a flooded engine room compartment. The experiments focus on transient and progressive flooding of a ship section, represented by a rectangular compartment. Forced oscillation tests are also conducted.

The majority of the experimental transient and progressive flooding tests are conducted in still water. Actually, for a damaged ship in waves the main focus is on the flooded vessel dynamics at the steady equilibrium after damage [20–25]. This is extremely important in order to achieve knowledge and experience in the behavior of the damaged ship in waves coupled with sloshing effects [26].

Different numerical methods were developed dealing with ship damage stability in waves. The CFD approach is used intensively for studying sloshing phenomena [27–29] and the dynamics of a damaged ship in waves [30–32]. Also the mesh-less technique named SPH-Smoothed-Particle Hydrodynamic is applied to simulate ship flooding problems [33,34]. In [35] a 6-DOF ship motions simulation code is coupled with a SPH solver addressing the behavior of the fluid in the tank. The dynamics of a damaged ship in waves can be also investigated by means of the so-called fast methods such as [36–39]. In all the simulated cases of these reference works, differently from transient and progressive flooding tests, the flooded water is freely moving in a single compartment. In other words, no obstruction in the compartment is modeled.

Experimental campaigns on anti-roll tanks are conducted to observe the roll behavior by modifying the tank internal damping [40–42]. Several baffles characterized by different openings are tested.

Recently permeability effects on the motions of a damaged ship in waves are studied in [43] by means of experimental tests. This research is carried out in head waves at zero speed, focusing on heave and pitch responses. Permeability variation is achieved by different numbers of cans being placed to represent machinery, furniture and other obstructions within the compartments.

It can be observed that in the current state of the art, the experimental data for a flooded ship in beam waves account mainly for sloshing in empty compartments or bi-dimensional obstructions. Thus, the effects of a more realistic arrangement in the damaged compartments are only sparsely studied, mainly referring to transient and progressive flooding stages. Moreover, the lack of experimental data, precludes the development of numerical tools accounting for shaped obstructions in the damaged compartment.

In this paper we focus on the dynamics of a damaged ship in waves, with flooded water in the engine room compartment. This represents a complex phenomenon regarding fluid and structure interactions, accounting for the presence of deck and obstructions in the compartment such as engines and machineries.

The novelty of the current paper is to observe and disclose novel outcomes concerning a more realistic arrangement in a flooded engine room compartment. Comparative analysis are conducted for a damaged ship in waves. Obstructions in the engine room compartment are modeled by horizontal decks and wooden shapes of the engine machineries. The experimental campaign is conducted on a passenger ferry. This hull has been already introduced in a previous experimental research to study the effects on ship motions, of the water dynamics, across damage openings [22].

Roll decay in still water and steady roll responses in beam regular waves at zero speed are measured and compared for the empty and not-empty compartment configurations. The tests are repeated by assuming a flooded compartment with no openings and a side damage opening as defined in [22]. In this research, bottom damage is disregarded in order to guarantee a steady connection of the machinery components with the bottom of the model.

The experimental set of data here presented, are intended as test cases for verifications and development of numerical modeling tools, accounting for more realistic compartment arrangement. With this aim, the tests are performed on a hull geometry open to general use. Only one initial equilibrium condition is simulated during the tests. The whole data set provided in this paper strictly refers to the case in object.

2. Experimental setup

2.1. Description of the towing tank

The tests are conducted in the towing tank of the Industrial Engineering Department of "Universitá degli Studi di Napoli, Federico II". The towing tank is 136 m long, 9 m wide and 4.5 m deep, and it is equipped with an Edinburgh design wave generator. QUALISYS motion capture system is used to measure the motions of the ship model in waves. The six-degree-of-freedom model motions are measured and outputted in real time by gauging the coordinates of infra-red reflective markers, read by suited cameras. Five infra-red reflectors are rigidly placed on the deck of the hull model and the cameras are positioned on the towing carriage near the vessel.

Fig. 1. Model arrangement during the test in beam waves.