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An experimental investigation into the influence of the damage openings on ship response

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ABSTRACT

Ship motions after damage are difficult to evaluate since they are affected by complex phenomena regarding fluid and structures interactions. The possibility to better understand how ship behavior in damage is influenced by these phenomena is important for improving ship safety, especially for passenger vessel.

In this paper an experimental campaign is carried out on a passenger ferry hull, to show the effects of the water dynamics across damage openings on ship motions. Novel aspects of this research include the study of the effects of the damage position on the ship roll response. The study is carried out for still water and for beam regular waves at zero speed.

Results from the experiments carried out underline that the roll behavior of a damaged ship is affected by the position of damage opening and not only by its size. Assuming the same final equilibrium conditions after flooding but characterized by different damage openings it is possible to observe how motions RAOs and roll decay characteristics modify according to the opening locations.

1. Introduction

Despite the many efforts done in the recent years, in order to avoid ship from sinking after damage, accidents still keep happening. Nowadays the improvement in the safety of a damaged ship is more oriented on simulation based guidelines in critical scenarios rather than keeping improving ship subdivision [1,2]. In this context, the possibility to better predict the dynamic behavior of a damaged ship represents a challenge with the aim to improve the safety of the vessel and of the human life at sea.

Ship motions after damage are difficult to evaluate since they are affected by complex phenomena regarding fluid and structures interactions. 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 [3].

The flooding process can be mainly divided into three main phases [4,5]: transient flooding, progressive flooding, and final equilibrium after damage. In all these phases the size and the location of the damage opening could affect the ship response.

It was shown by experiments on a model of a large passenger ship in calm water [6] that large and slow roll motions can appear in the intermediate stages of flooding. The effects of different parameters during the flooding process were analyzed [7] such as air compression and cross flooding scenarios [4,8]. Recently permeability effects on the motions of a damaged ship were studied by means of experimental tests [9]. In [10] an extensive study on the experimental prediction of the motions of a frigate hull in damage condition is presented. The damage was assumed to be on the ship side. Free roll motion and roll motion in waves of a tanker model, coded as TNK, in three partially flooded conditions, were investigated in [11]. This model belongs to the 24th ITTC International Benchmark Study [12]. An experimental set of data regarding the damaged ship motions in waves was provided by [13]; also in this case side damage was assumed. In [30] the effects of different flooded water amounts on the roll damping were investigated for a barge model in still water: the compartment, for the purpose of these experiments, presents no opening. In [14] the roll decay coefficients were obtained and compared for the intact and damaged ship assuming a side damage.

Several research works developed numerical code in time domain, to estimate ship behavior in damage scenarios [12]. In [15,16] attention is given to the effects of the sudden water ingress on the behavior of a damaged ro-ro pax ship, during intermediate stage of flooding; the study was conducted in still water.

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Different methods were developed dealing with ship damage stability in time domain, like the particle methods [17,18] and CFD methods [19,20]. The CFD approach has been intensively used for studying sloshing phenomena [21–23]. Recently many efforts have been done dealing with the problem of ship damage in wave by means of numerical and experimental research works [10,24,31,32]. It is well known that when a ship is damaged in waves, its behavior is not only influenced by the excitation of sea waves but also by the internal liquid loads due to water flooding and sloshing.

It can be observed that the whole damage ship research focused mainly on one position of the opening at the time or they deal with a flooded compartment with no opening at all. Moreover there are still few data available for experiments on ship bottom damage. Numerical and experimental studies of water dynamics from an opening at the bottom have been carried out for ship with moon-pools [25,26].

The novelty of this research work is represented by the study of the effects of the damage position on the ship roll response. In this way it is possible to observe and analyze how a bottom damage differs from a side damage of the same size in terms of roll responses in still water and in regular beam waves. A flooded scenario with no opening was also investigated and compared to the other damaged cases. All these conditions were characterized by the same initial stability and by the same amount of flooded water at the final stage after damage. During the roll decay tests for the intact conditions, the waves radiated by the ship model were measured as well.

Only one initial equilibrium condition was simulated during the tests, thus only one filling ratio of the compartment resulted after the damage. The whole data set provided in this paper strictly refers to the case in object. The experimental set of data here presented, are intended as test cases for verifications and development of numerical modeling tools, according to the different damage scenarios. With this aim the tests are performed on a hull geometry open to general use.

2. Experimental setup

2.1. Description of the facility and equipment

The tests were conducted at the “Universitá degli Studi di Napoli, Federico II” in the Laboratory of the Industrial Engineering Department. The towing tank of the Department is 136 m long, 9 m wide and 4.5 m depth, with a maximum carriage speed of 8 m/s. It is equipped with an Edinburgh design wave generator.

The roll response of the ship model was investigated in intact and damage conditions in still water and regular beam waves. During the tests the motion responses of the model were measured by using QUALISYS motion capture system. This system is capable to gauge the coordinates of infra-red reflective markers by means of three suitable cameras. Four infra-red reflectors were rigidly placed on the deck of the hull model while the cameras were positioned on the towing carriage near the vessel. The six-degree-of-freedom model motions were calculated and output in real time. In carrying out the tests, the towing carriage was moved almost at 2/3 of the towing tank length and the model was placed transversely beneath it (see Fig. 1). This was done in order to avoid wave reflection problems.

The wave elevation was measured by using two ultrasonic probes (previously compared with capacitive probes). The first one was located at 2.3 m from the model side (in the y-direction), the other one at 2.5 m from the ship bow (in the x-direction). The first probe was used to monitor and record the free-surface elevation caused by the waves radiated by the model in the y-directions (roll decay test); the other probe, instead, monitored and recorded the waves generated by the wave maker with no vessel perturbation (roll in wave tests) (see Fig. 2). QUALISYS sampling frequency was set to 72 Hz; wave elevation, measured by the probes, was obtained with a sampling frequency of 500 Hz.

Fig. 1. Towing tank and ship model during the test.

Fig. 2. Model arrangement during the test in beam waves.

2.2. Description of the model

The model used for the tests represents a generic passenger ferry operating in the Mediterranean Sea. The construction lines of the 1/22 model scale hull are showed in Fig. 3. In Table 1, the principal particulars of the passenger ferry at full and model scale are given. The model is constructed in fiberglass and it has been fitted with four watertight bulkheads, located as shown in Fig. 4; the given dimensions are relative to the model scale. The ship model is open at the top with no main deck: this assures no air compression during the test. For a more realistic simulation of the phenomenon, air compression should be taken into account. However air effects are not suited to be scaled by applying the Froude law and depend on inside arrangement (piping and openings) [4].

The flooded compartment is assumed to be empty, while in the real case compartments can be full of equipments that modify the flow of the water. The model was tested without helms and appendage.

The model was loaded with fixed weights in order to achieve the desired displacement and the vertical center of gravity. The longitudinal weight distributions assured an even-keel position of the model.

A preliminary analysis was carried out by means of a fine CAD model of the ship plus the distributed weights. The proper densities were associated to each item in the CAD environment: from this, it was possible to estimate the total weight of the model, its center of gravity and its moments of inertia.

An inclining test was carried out on the free floating model in the towing tank and the vertical center of gravity was evaluated; the measured value (see Table 2) differs from the estimated one of less than 0.02%. The metacentric height (GM) of the model is 0.246 m.