Numerical Simulation of Intact and Damaged Ship Motions in Head Waves

Jing Li  Yafeng Huang  Kai Dong  Xianzhou Wang*
School of Naval Architecture and Ocean Engineering, Huazhong University of Science and Technology,
Key Laboratory of ship and ocean hydrodynamics of Hubei Province,
Wuhan, Hubei, P. R. of China

ABSTRACT

In order to investigate the seakeeping performance of naval ships, this study presents numerical simulations on the prediction of motions for the DTMB 5415 model at zero speed in intact and damaged conditions under head waves. Wave heights of simulations have been verified and validated. The harmonic response amplitude operators (RAOs) of heave and pitch responses for intact and damaged ships are acquired and compared with the experimental results. The comparisons of the intact and damaged ship motions under different wave circular periods are analyzed.

KEY WORDS: Head wave; Damaged ship; Motion responses; Pitch; Heave

INTRODUCTION

Ship stability refers to the ability that a ship rotates transversely by an external force and can return to the original equilibrium condition when the external force disappears. The intact stability is the ship stability when the ship hull is intact without damage. The International Maritime Organization had developed the Second Generation Intact Stability Criteria (IMO MSC.1/Circ.1627, 2020). The damaged stability refers to the residual stability of the ship after the ship hull damages and water inflows. It means that the ship can still maintain buoyancy and stability after one or more adjacent compartments are damaged and flooding. Therefore, the ship will not sink or delay sinkage and ensure the safety of personnel and property. After a ship gets damaged at sea in waves, its motion is affected adversely due to transient flooding and continuous ingress and egress of floodwater and may capsize eventually. Therefore, it is important to study the motion responses of damaged ship in waves to predict the adaptability and survivability of damaged ships under different wave conditions.

The motion prediction of damaged ship in waves involves the coupling of waves, hull motion and ingress and egress of water. These interactions cause the nonlinear wave force and moment, right moment and roll damping of the ship, which leads to a complex problem. Many previous studies have investigated the motion of damaged ship in waves.

The motion of a damaged ship in waves was investigated through strip theory in the early period (Turan and Vassalos, 1994; Lee et al., 2007). The roll behavior of a Ro-Ro vessel in intermediate stages of flooding was investigated by numerical simulation (Spanos and Papanikolaou, 2001). The response of the damaged ship during transient flooding was found to be quite nonlinear and sensitive to the damage opening. The experimental results of drift force and drift motion for a damaged Russian tanker in waves were described (Hoshino et al., 2002). A damaged frigate was tested in calm water and waves at different heights and periods, and the simulations of selected waves was also carried out (Palazzi and de Kat, 2004). This simulation results highlighted the effect of air flow on the motion of the damaged frigate. A Ro-Ro model was tested in different wave heights and frequencies experimentally for the head, beam and stern quartering seas in order to explore the effect of different damage locations and wave heights on the global loads acting on the model (Korkut et al., 2005). The experimental study of DTMB-5415 model in intact and damaged conditions at zero speed in different seas were performed (Begovic et al., 2013, 2017). A segmented ship model in a towing tank were experimented to study the permeability of the damaged ship (Domotianos et al., 2015). The results showed that permeability have a large effect on the pitch and heave motion responses when the ship travelled forward, while have a neglect effect on the stationary ship. A new compartment model that could adjust the inner pressure automatically in simulation of flooding was proposed (Lee, 2015). In that study, the flooding for different openings of compartment was simulated considering the effect of air flow. The model simulation had been verified and the results indicated that the point opening was not adopted for the cases of compartment with only one opening and dynamic orifice equation has its ability to resolve the numerical instability especially for small pressure difference.

This study investigates the motion response characteristics of a DTMB-5415 model in intact and damaged conditions under head waves. Firstly, the verification and validation of the wave height is conducted. Secondly, the simulation results of three-degrees-of freedom (3-DOF) motion response (roll, heave and pitch motions) are presented. The heave and pitch RAOs under different wave frequencies are examined in accordance with the results of experiment (Begovic et al., 2013, 2017). Lastly, the ship motion responses in both of intact and damaged