Collision and Grounding of Ships and Offshore Structures – Amdahl, Ehlers & Leira (Eds)

Grounding resistance capacity of a bulk carrier considering damage confined to the bow

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ABSTRACT: This study deals with the ship soft grounding mechanics applied to a Capsize bulk carrier. In this scenario, the ship runs aground by the bow on a smooth seabed. The grounding resistance capacity can be evaluated considering bow damage confined ahead of the collision bulkhead. The grounding capacity is characterized by the critical initial forward speed; if this speed is exceeded, the damage may propagate beyond the collision bulkhead when the ship comes to rest. This study proposes a mathematical model to analyze ship grounding and then validates the mathematical model predictions using a few ship grounding dynamic Finite Element Analyses (FEA). Results show that the predicted critical initial speed is significantly lower than the ship service speed. This study also presents a simplified formulation from the mathematical model to assess the critical initial speed. This formulation was used to evaluate the bow structural strengthening required to increase the ship grounding resistance capacity.

1 INTRODUCTION

An accidental grounding is a statistically non-negligible risk in ship operation. This problem is of great concern because of the catastrophic consequences that may occur. In the past, regulations have been adopted to mitigate those consequences in such a manner that they would have no immediate effect on the safety of the ship.

The SOLAS convention (IMO 2009) provides a double bottom arrangement for ship bottom tearing and crushing, so that a hull split only affects the double bottom water ballast tank. In a similar manner, for soft grounding by the bow (see Fig. 1), the collision bulkhead limits the water ingress to the fore peak tank and, potentially, to the adjacent double-bottom water ballast tank.

The ship considered in this study is a Capsize bulk carrier. This study presents an assessment of the ship grounding resistance capacity as a function of the collision bulkhead location. The grounding resistance capacity is characterized by the ship's critical initial forward speed. If this speed is exceeded, the collision bulkhead in way of the inner bottom may be damaged causing water ingress in the No.1 cargo hold when the ship rests. This consequence may directly endanger the safety of the ship because it is more difficult to refloat rapidly. Due to waves and receding tide actions, the sectional forces in the grounded ship may then rise significantly, leading to failures in the hull girder.

Pedersen (1994) proposed a mathematical model to analyze ship grounding. This model allows for the assessment of the bow final lifted distance. The purpose was to evaluate the sectional forces in the grounded ship's hull girder and thus to investigate its ultimate strength. Based on the Pedersen formulation, the authors (Quéméner et al. 2012) have recently presented a mathematical grounding model (MGM) that allows for the assessment of the bow final crushing. The purpose of this approach is to analytically evaluate the grounding resistance capacity of the ship as it relates to the bow crushing distance. A comparison

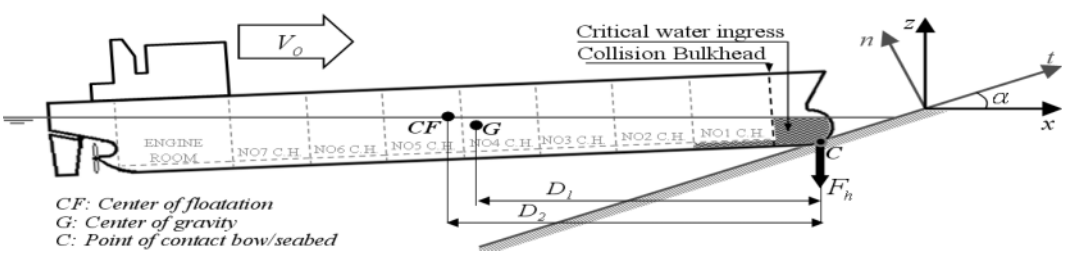

Figure 1. Ship soft grounding by the bow.

with ship grounding dynamic FEAs shows that these mathematical model predictions are optimistic. An examination of the FEA results reveals several modifications of the mathematical model formulation, as implemented in this study.

This study consists of four sections. The first section presents the MGM formulation. The second section presents a discussion of the ship grounding FEA modeling assumptions. The third section presents mathematical model predictions validated by comparison with FEAs. Finally, the fourth section provides a simplified formulation of the grounding resistance capacity. This formulation is used to evaluate the bow structural strengthening required to increase the ship grounding resistance capacity.

2 MATHEMATICAL GROUNDING MODEL

In (Quéméner et al. 2012), a comparison of the Mathematical Grounding Model (MGM) predictions with ship grounding FEAs shows that grounding mechanics should be divided into three phases. During these three phases, the kinetic energy of the ship is dissipated by friction with the seabed, bow structure plastic crushing, and trim increase. This study assumes that the seabed is rigid so that no energy is dissipated by seabed deformation.

2.1 *Model implementation*

The entire grounding event is driven by a small and constant increase in the ship's horizontal motion dU_x. Each step i includes an evaluation forces and motions at the bow. Thus, Equation 1 provides the total dissipated energy (E_d):

$$E_d = \int F_c dU_n + \int F_h dU_z + \int F_f dU_t \quad (1)$$

The bow response to crushing (F_c) is extracted from the nonlinear crushing FEAs presented by Quéméner et al. (2012). For these FEAs, the bow FE model quasistatically translates perpendicularly to the inclined seabed considered rigid. Equation 2 can also compute the bow crushing distance (U_n).

$$U_n(i) = U_n(i-1) + dU_x \sin\alpha \quad (2)$$

Pedersen (1994) proposed a linear relationship linking the ship hydrostatic response (F_h) in C to the bow lifted distance U_z (see Eq. 3).

$$F_h = K_h \cdot U_z \quad (3)$$

where K_h = hydrostatic stiffness to the vertical displacement of the center of floatation induced by a trim increase. Equation 4 provides the K_h formula.

$$K_h = \frac{\rho \cdot g \cdot A_z}{1 + (D_2/R)^2} \quad (4)$$

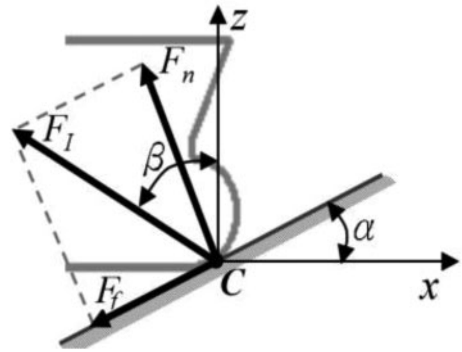

Figure 2. Impulse force direction.

where ρ = seawater density; A_z = the waterplane area; D_2 = horizontal distance (see Figure 1); and R = the equivalent radius of inertia expressed in Equation 5 as a function of ship mass (M) and the longitudinal metacentric height (GM_L).

$$R = \sqrt{\frac{M \cdot GM_L}{\rho \cdot A_z}} \quad (5)$$

Equation 6 can also compute the bow lifted distance (U_z).

$$U_z(i) = U_z(i-1) + dU_x \tan\alpha \quad (6)$$

Finally, Equation 7 produces the friction force (F_f) between the bow and the seabed using the Coulomb friction law.

$$F_f = \mu \cdot F_n \quad (7)$$

where μ is constant and the nature of the reaction force normal to the ground (F_n) depends on the grounding phase (see Sections 2.2 and 2.3). Equation 8 computes the sliding motion of the bow over the seabed (U_t).

$$U_t(i) = U_t(i-1) + dU_x \cos\alpha \quad (8)$$

2.2 *Phases 1 and 3: Bow crushing*

During these two phases, bow crushing and friction with the seabed dissipate kinetic energy. The friction force can be computed by Equation 7 with F_n corresponding to the bow crushing response F_c.

During Phase 1, the horizontal motion of the ship at the contact between the ship and the seabed must then change to be compatible with the new kinematic restrictions. This is the change in momentum. The ship change of motion is driven by impulse force F_I, as shown in Figure 2. The impulse direction (β) is determined from the Coulomb friction law (see Eq. 7).

The change in momentum ends when the ship starts sliding over the ground. The amount of energy dissipated during the change in momentum is termed