International Journal of Offshore and Polar Engineering
Vol. 11, No. 2, June 2001 (ISSN 1053-5381)

An Analysis of the Motions of Grounded Ships

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ABSTRACT

Ship groundings are a frequent occurrence, often with severe environmental and financial consequences. Although the grounding event has been studied extensively, primarily in the prediction of the loading, structural response and failure due to the partial embedment of the hull in the bed, little work has been published on the motion prediction of a grounded ship. In this paper, the 2-dimensional linearized equations of motions of a sectional element of a grounded ship in beam seas are derived. The hydrodynamic reactions on the hull are analyzed using wave-maker theory, and expressions are developed for the coefficients of added-mass, added-mass moment of inertia and radiation damping. The wave-ship-soil interaction is treated using a quasi-elastic model for the soil responses to the sway and roll of the ship.

INTRODUCTION

The grounding of a ship in the coastal zone is usually the result of a power loss. Assuming that this is the case, there are 3 phases of a ship grounding in near-shore waters, as sketched in Fig. 1. The first phase is the grounding event itself. That is when the ship's bow comes in contact with the seabed, and the ship may experience structural damage. See, for example, Kitamura et al. (1988) and Wierzbicki, Peer and Rady (1993). The second phase is the orientation phase, where the ship's position is altered by wave action. The last phase, assuming that the bed is of straight and parallel contours, is that when the ship's centerplane is parallel to the shoreline. During the third phase, the ship will have 2 dominant degrees of freedom. Those are the coupled sway and roll. The heaving motions are negligible as the hull is continually embedded. The analysis of these coupled motions is complicated by both the elastic and frictional properties of the soil in which the ship is embedded. References on the motions of grounded ships in the second and third phase are practically nonexistent. For this reason, it is assumed that little or no work has been done on this problem.

The seabed can be composed of one of several types of soils. The most general classifications are sands (which are cohesionless) and clays (which are cohesive). In addition, the soils can be treated as elastic, viscoelastic, elastoplastic and poroelastic, depending on the soil and the extent and frequency of the motions. Moran, Syvertsen and Haver (1977) give an extensive analysis of the motions of a gravity platform in a linear, isotropic elastic half-space. Those investigators assume that the motions of the platform are of a rocking nature. Wang and Rajapakse (1991) analyze the motions of a rigid strip foundation embedded in an orthotropic elastic soil. Mita et al. (1989) study the motions of a square foundation embedded in an elastic half-space, while Fotopoulou et al. (1989) focus on the damping of rocking motions of an arbitrary shaped foundation. Motions in viscoelastic soils are discussed by Wu (1976) and Ishihara (1996). Wave-soil interactions, where the seabed is poroelastic, are studied by Jeng, Lee and Tsai (2000). The friction effects in the soil-structure interaction of the ship and the bed are transient, as discussed by Abascal (1995), which further complicates the analysis.

In this paper, the equations of motion of the midship section of a long ship (in the third phase of the grounding) are derived. The ship is assumed to be always embedded in the seafloor. If the equations were solved in their nonlinear forms, the ship would be found to migrate (drift) toward the shoreline. This is not the case here. Only the linearized equations of motion are solved, and the resulting ship motions are coupled swaying and rolling. The soil reactions to the ship motions are analytically represented by the discrete soil dynamics models developed by Wolf (1988).

SHIP MOTIONS

For a freely floating, rigid ship, there are 6 degrees of freedom: surge, sway, heave, roll, pitch and yaw. In the most general case of a grounded ship, all of these motions will be experienced, as described by Bhattacharyya (1977). In the present study, we concentrate on the planar motions of sway and roll, assuming that the section under investigation is that of a very long ship whose centerplane parallels both the wave front and the shoreline.

Referring to the sketch of the section of the grounded ship in Fig. 2, the analysis begins by simply deriving the expressions for the position vectors, velocities and accelerations of points on the bottom, the leeward (shore) side and the weather (incident wave) side of the ship. These respective points are *D, E* and *F* in Fig. 2. The center of gravity of the resting ship section (at time $t = 0$) is point G_0. At any time $t > 0$, the center of gravity of the ship section is point *G*.

There are 2 coordinate systems: The origin (*o*) of the first system (y, z) is at a point on the calm-water level above the initial

Received March 11, 2000; revised manuscript received by the editors March 5, 2001. The original version was submitted directly to the Journal.
KEY WORDS: Ship grounding, ship dynamics, wave-soil-structure interaction.