Proceedings of the Eighteenth (2008) International Offshore and Polar Engineering Conference
Vancouver, BC, Canada, July 6-11, 2008

ISBN 978-1-880653-70-8 (Set); ISBN 1-880653-68-0 (Set)

Submarine Moving Close to the Ice-Surface Conditions

Victor M. Kozin, Alexandra V. Pogorelova
Institute of Machining and Metallurgy, Far Eastern Branch of the Russian Academy of Sciences
Komsomol'sk-on-Amur, Russia

ABSTRACT

This paper deals with the submarine in ice conditions. Ice cover is modeled by a floating elastic plate. The hydrodynamic problem of the submarine motion is modeled by a point source which steady uniformly moves in water under floating ice plate. The analysis is carried out by using analytical methods theory of function of complex variables and integral transformations. Then the integral for ice deflection is evaluated numerically. The given solution is analyzed depending on a velocity of submarine, ice thickness, and submergence depth.

KEY WORDS: Submerged point source; flexible plate; vertical deflection; flexural-gravity wave.

INTRODUCTION

Waves are known to appear on the surface of the water in case a solid body is moving in the water, the waves moving in the direction of the body motion. The floating ice cover causes changes in the water surface boundary conditions. The velocity field in the water caused by the moving body also changes compared to the free-surface water case. Thus, corresponding changes can be expected in the characteristics of the wave formation.

The investigations by Kheisin (1967) should be mentioned among the theoretical works dedicated to the problem. Kheisin's paper (1967) considered the two dimensional problem of the motion of a point vortex under a layer of broken ice. There it was found that the broken ice produced only minor changes to the gravitational waves caused by the motion of the submerged body. The article by Kozin, Onishchuk (1994) is devoted to model experiments proving the possibility of the ice plate destruction by the moving submarine.

The aim of this paper is to study the form of flexural waves caused by the uniform motion of a point source submerged beneath a uniform layer of ice.

MATHEMATICAL STATEMENT

To solve the problem of solid body motion under the surface of water covered by floating ice we are using the procedure of solving analogous problem without ice conditions (Sretensky, 1977).

Stationary straight motion of the point source Q (strength q) with velocity V under surface of infinitely deep water of density ρ_2 is considered. An elastic plate of density ρ_1 and thickness h is floating on the surface of the water. The Cartesian coordinate system $Oxyz$ connected with source Q is arranged as follows: the Oxy plane coincides with the unperturbed ice-water interface, the x direction coincides with the direction of the source motion, and the Oz axis is directed vertically upwards. The liquid motion is assumed to be irrotational.

In the moving coordinate system the velocity potential function $\Phi(x, y, z)$ is assumed independent of time. It represents the sum of: velocity potential of the unperturbed water flow possessing velocity $-V$, velocity potentials of the source $Q(0,0,-H)$ and sink $Q'(0,0,H)$ (here H is submergence depth), and the velocity potential of the wave motion. The velocity potential $\Phi(x, y, z)$ is given in the form:

$$\Phi(x,y,z) = -Vx - \frac{q}{4\pi\sqrt{x^2+y^2+(z+H)^2}} + \frac{q}{4\pi\sqrt{x^2+y^2+(z-H)^2}} + \varphi(x,y,z), \tag{1}$$

where the function $\varphi(x, y, z)$ describes the velocities of the wave motions. To define this function we consider the boundary condition on the water surface (Kheisin, 1967; Squire *et al*, 1995):

$$\frac{D}{\rho_2 V^2}\nabla^4\zeta + \frac{\rho_1 h}{\rho_2}\frac{\partial^2\zeta}{\partial x^2} + \frac{g}{V^2}\zeta - \frac{1}{V}\frac{\partial\Phi}{\partial x} = 0 \qquad (z=0) \tag{2}$$

and the kinematic condition on the ice-water interface

$$\left.\frac{\partial\Phi}{\partial z}\right|_{z=0} = -V\frac{\partial\zeta}{\partial x}. \tag{3}$$

Here ζ is the vertical deflection of the ice plate; $D = Eh^3/12(1-\nu^2)$ is the flexural rigidity of the plate; E is the Young's modulus; ν is the Poisson's ratio.