Unsteady Motion of Submarine under an Ice Sheet

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ABSTRACT

The paper deals with the theoretical investigation of the straight unsteady motion of a slender axisymmetric body submerged into the liquid below the Euler-Bernoulli plate floating on the liquid surface. The formulae describing the plate deflection and obtained with the help of integral and asymptotic methods are numerically analyzed with respect to velocity, acceleration, submergence depth and linear dimensions of the moving body and the plate thickness. The experimental model tests on a submarine (scale of 1:500) moving under a polymeric plate 0.001m thickness in the test basin measuring \( L \times B \times H = 2.15 \times 1.2 \times 1.5 \) m are carried out. Good agreement between theoretical and experimental results regarding the values of the plate maximum deflections for various submergence depths and velocities of the moving body is obtained.

KEY WORDS: Submerged body; Euler-Bernoulli plate; vertical deflection; flexural-gravity wave.

INTRODUCTION

The problem of a solid body moving in the liquid under a floating ice sheet is interesting from both theoretical and practical points of views. The use of submarines in ice conditions may entail the necessity of their surfacing from under the solid ice. For a vessel to have a safe surfacing, the ice sheet may be first broken or weakened by cracks by way of exciting flexural-gravity waves generated by a submarine moving near the ice-water interface.

The problem of wave motion caused by a body moving near the water surface covered by a floating ice cover was first dealt with in the work by Kheisin (1967). There the two-dimensional problem of vortex motion under a layer of broken ice was solved. Steady motion of a point source in non-homogeneous liquid of finite depth with an elastic plate floating on the surface was considered in the paper by Bukatov and Zharkov (1995). There the effect of the source submergence depth on the plate deflection was analyzed for the point source moving with low velocities. Making use of model experiments, Kozin and Onishchuk proved in their works (1994, 2005) the possibility of breaking ice sheets by exciting flexural-gravity waves generated by a submarine moving near the ice-water interface. In the article by Kozin and Pogorelova (2008) on the assumption of the ice cover inertia forces being negligible in comparison with its elastic forces, the amplitudes of the ice cover deflections during steady motion of a submerged source under an elastic plate were obtained. The work by Pogorelova (2010) is devoted to unsteady motion of a point source immersed into the liquid below the floating Euler-Bernoulli plate.

The aim of this article is to conduct a theoretical and experimental study of flexural-gravity waves generated in the “water - ice cover” system during unsteady motion of a submarine in the liquid under an indestructible ice sheet. For that purpose within the scope of the linear wave theory, the interaction between the submergence depth, velocity and acceleration of a slender solid axisymmetric blunt-ended body advancing in the liquid and the deflection amplitude of an elastic plate is analyzed. In the study it is assumed that in the low-speed and/or deep submergence regime a body submerged below a free surface can be approximately represented in terms of the source-sink pair.

The experimental part of the work deals with the model experiments on the submarine motion below an indestructible ice sheet.

In the conclusions, the theoretical and experimental results are compared. To evaluate the theory, both the known and newly-obtained experimental data is used.

MATHEMATICAL STATEMENT

An infinite elastic plate \( (h \) being its thickness and \( \rho \) being its density) floating on the surface of infinitely deep liquid is considered. A slender solid axisymmetric body advances along the plate at the depth of \( d \) with the velocity of \( u(t) \). The \( Oxyz \) coordinate system connected with the body is arranged as follows: the \( xOy \) plane coincides with the unperturbed plane of the plate-water interface; the \( x \) axis is directed along the source motion and the \( y \) axis is directed vertically upwards. The water is assumed to be ideal incompressible liquid of the \( \rho \) density and the liquid motion is potential.

Let us assume that on condition of \( F_d = u / \sqrt{gd} < 1 \) (low-speed and/or deep submergence regime) the problem of free-surface liquid flowing around an axisymmetric body may be solved by replacing this body...