Effect of Water Depth on Ice Plate Deflections for Moving Submarine

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ABSTRACT

The paper deals with the theoretical and experimental investigation of the straight unsteady motion of a slender solid body submerged into the liquid of finite depth below the floating ice plate. The formulae describing the plate deflection with the help of integral and asymptotic methods are numerically analyzed with respect to velocity and submergence depth of the body, and basin depth. The experimental model tests on a submarine (scale of 1:500) moving under a polymeric plate 0.002m thickness in the test basin measuring L×B×H=2.15×1.2×1.5m are carried out. Good agreement between theoretical and experimental results regarding the values of the plate maximum deflections for various submergence depths, water depth and velocities of the moving body is obtained.

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

INTRODUCTION

The use of submarines in ice conditions may entail the necessity of their surfacing from under the solid ice. At present the technique of surfing consists in static loading of the ice cover from below due to creation of positive flotage (buoyancy force) by water extraction from the ballasting tanks. The experience of surfacing mentioned above leads to inevitable damages of the cabin, building of upper desk, stern rudders, and the external can. Besides, to break down the ice cover by static loading could result in losing stability, i.e. in overturning of the submarine. The possibility of breaking ice sheets by exciting flexural-gravity waves generated by a submarine moving near the ice-water interface was considered in the paper by Pogorelova and Kozin (2010b) for infinitely deep water.

The work by Pogorelova and Kozin (2010a) is devoted to unsteady motion of a point source immersed into the liquid of finite depth below the floating Euler-Bernoulli plate. The aim of this paper is to analyze an influence of water depth on possibility of ice cover destruction by means of moving submarine.

MATHEMATICAL MODEL

An infinite elastic plate (h being its thickness and ρi being its density) floating on the surface of water with basin depth H is considered. A slender solid body advances along the plate at the depth of d with the velocity of u(t). The Oxzy coordinate system connected with the body is arranged as follows: the xOy plane coincides with the unperturbed plate-water interface; the x axis is directed along the source motion and the z axis is directed vertically upwards. The water is assumed to be ideal incompressible liquid of the ρ2 density and the liquid motion is potential. Let us assume that the problem of free-surface liquid with finite depth flowing around an axisymmetric body may be solved by replacing this body with the source-sink pair. According to Pogorelova and Kozin (2010a, 2010b) for the range of -H<z<0 bounded by a free surface z=0 and solid bottom z=-H, we consider the flow due to point source of strength q>0 at (L_w, 0, -d), point sink of strength -q<0 at (-L_w, 0, -d), three imaginable point sources of strength q>0 at (L_w, 0, -2H+d), (-L_w, 0, -d), and (-L_w, 0, -2H-d) and three imaginable point sinks of strength -q<0 at (-L_w, 0, -2H+d), (L_w, 0, d), and (L_w, 0, -2H-d) (see Fig. 1). Here 2R being approximately diameter of solid body and 2L being its length. We note, that R is an effective body radius defined as \( R_\text{eff} = \sqrt{\Omega} \) where \( \Omega \) stands for the cross-sectional area at midbody.

Define the nondimensional variables \( \delta, r, \chi, \gamma \) as

\[
\delta = \frac{\Delta}{L}, \quad r = \frac{R}{L}, \quad \chi = \frac{d}{L}, \quad \gamma = \frac{H}{L}
\]  

(1)

By analogy with Pogorelova and Kozin (2010b) for small \( r \to 0 \) we can receive next asymptotic expansions for \( q \) and \( \delta \):

\[
q \approx \frac{1}{2\pi R^2} \left( 1 + \frac{r^2}{2} (1 + C) + \ldots \right); \quad \delta \approx \frac{L}{2} \left( 1 + \frac{r^2}{4} \left( \frac{7}{8} + C + \frac{1}{8} B \right) + \ldots \right)
\]

(2)

\[
C = \frac{1}{\left( 4\chi^2 + 1 \right)^{3/2}} - \frac{1}{\left( 4\chi^2 + 1 \right)^{3/2}} \left( \frac{4\gamma^2 + 1}{\left( 4\gamma^2 + 1 \right)^{3/2}} \right)^2
\]

\[
B = \frac{1}{\left( 4\gamma^2 + 1 \right)^{3/2}} + \frac{1}{\left( 4\chi^2 + 1 \right)^{3/2}} - \frac{1}{\left( \left( 4\gamma^2 + 1 \right)^{3/2} \right)^2}
\]

These relations agree with Pogorelova and Kozin (2010b) in the deep-