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Effects of Cross-Sectional Shape on Vertical Ice Load Acting on Pile Structure

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ABSTRACT

In cold regions, vertical ice loads act on pile structures with ice sheet adfrozen to them, as the water level changes due to tides. Therefore, vertical ice loads must be considered fully in the design of offshore structures. In addition to developing theoretical equations to calculate ice load, their verification based on a limited number of full-scale experiment was made in this research. In the experiment, we compared ice loads acting on piles with three different cross-sectional shapes (circular, elliptical and square) and found a circular cross-section to be the most effective, i.e., to receive the lowest ice load.

Keywords: vertical ice load, piles with circular, elliptical and square cross-sections, radial cracking, adfreeze bond failure.

INTRODUCTION

In January 1997, we conducted a full-scale field experiment at Lake Abashiri, northern Japan. In this experiment, hollow steel piles were prepared as model pile structures. The cross-sectional shapes used for the model pile were circular, elliptical and square. Furthermore, we performed theoretical analyses of the vertical ice loads acting on the piles of circular, elliptical and square cross-section.

1. THEORETICAL ANALYSIS OF VERTICAL ICE FORCES

1.1 Circular Cross-Section

In general, a pile with a circular cross-section is used for pile structures built on coasts and lakes, including marine structures. Vertical ice loads acting on a structure with a circular cross-section are divided into the following categories (Terashima, et al., 1997):

a) ice load until radial cracking (P_l)
b) ice load at radial cracking (P_{maxl})
c) ice load until circumferential cracking (P_2)
d) ice load at circumferential cracking (P_{max2})
e) ice load at adfreeze bond failure (P_B).

1.2 Elliptical Cross-Section

The ice load acting on a structure with an elliptical cross-section until radial cracking (P_l) is analyzed using the elliptical cylindrical coordinates (Kioka, et al., 1996) and can be expressed by Equation 1-1.

$$P_1 = 2\pi N D \lambda^3 \Delta \frac{\left[kei'(\lambda N)\right]^2 + \left[ker'(\lambda N)\right]^2}{kei(\lambda N)ker'(\lambda N) - kei'(\lambda N)ker(\lambda N)} \qquad \text{(Eq. 1-1)}$$

Where D is the flexural rigidity of an ice sheet, Δ is the change in the water level, and $\lambda = (k_w/D)^{1/4}$, where k_w is the unit weight of water. A and B are minor and major axes of the cross-section, respectively, and $N\,(=(A+B)/2)$ is the average length of the minor and major axes. The ice load at radial cracking (P_{maxl}) can be expressed by Equation 1-2.

$$P_{\max 1} = \frac{4\pi\lambda N K^2 \sigma_f h^2}{3(K+1)} \frac{\left[kei'(\lambda N)\right]^2 + \left[ker'(\lambda N)\right]^2}{ker(\lambda N)ker'(\lambda N) + kei(\lambda N)kei'(\lambda N)} \qquad \text{(Eq. 1-2)}$$

Where K ($=A/B$) is the oblateness of the elliptical cross-section, σ_f is the bending strength of an ice sheet, h is ice thickness. The ice load at adfreeze bond failure until radial cracking (P_{Bl}) can be expressed by Equation 1-3.

$$P_{B1} = \frac{4\pi N K \tau_B h}{K+1} \qquad \text{(Eq. 1-3)}$$