Mechanical Properties Between Ice and Various Materials Used in Hydraulic Structures: The Jin S. Chung Award Lecture, 2010

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Ice has been a serious obstacle and problem for the construction of hydraulic and marine structures, lighthouses, and the like in cold regions. For these structures, ice forces are the major design criteria. Because the ice loads caused by sea ice on offshore structures have been fully reviewed a few times, they are purposely set aside in this paper. Instead, two major problems are discussed here in some detail: the adfreeze bond strength of sea ice and the abrasion by ice on hydraulic and marine structures. These discussions are mainly based on the results of the studies carried out by the author and various combinations of colleagues, postgraduate and graduate students under his Chairmanship for over 20 years; these groups are hereafter referred to as the SCS.

INTRODUCTION

Cold regions, for engineering purposes, have generally been defined by the 0°C isotherm for the average temperature of the coldest month. In Japan, Hokkaido and the northern portions of Honshu Island are classified as a cold region, where engineering problems associated with freezing temperatures, ice, snow and frost heave occur.

In regard to hydraulic and marine structures in cold regions, one of the most important forces in their design is the force applied to them by a solid ice sheet or large ice block, even in the regions where ice-free conditions are dominant through the year and fluid-dynamic forces, such as waves and wind forces, have to be taken into account. There are essentially 4 modes of ice action against these structures:

• static force from expanding or contracting ice sheets;
• dynamic force of moving ice sheets, etc.;
• pressure of unconsolidated ice accumulations; and
• vertical force exerted by ice.

Hokkaido University has long investigated every mode of ice action and developed preventive measures against damage caused by ice forces as well as the means to reduce the risk of damage.

In order to respond to growing world energy demand by exploiting and transporting energy resources deposited in the Arctic Ocean, ice engineers have had to face the problems of dynamic ice loads on offshore rigs and vessels. The focus has been on global and local ice loads on structures, because in design practice, vertical forces on a hydraulic structure have often been neglected. The adhesive strength of ice on various construction materials is high. With a rise in water level, piers, piles, caissons and wharf sheeting may be partly lifted off their foundations and damaged. The risk of damage depends on the following: adfreeze bond strength to the surface of materials; the adfrozen area on the surface of materials; temperature and temperature gradient between ice and the surface of materials; ice properties with and without solid particles; velocity and amplitude of water level fluctuations.

Abrasion of the surface of materials has often caused serious damage to hydraulic and marine structures, and it has a complex feature: The abrasion rate depends on temperature, contact pressure (vertical stress), relative velocity, total sliding distance of the ice sheet onto the surface of structures, physical properties and roughness of material surfaces.

In this paper, the discussion on the adfreeze bond strength and abrasion of materials by ice is mainly based on the results of studies carried out by the author and various combinations of colleagues, postgraduate and graduate students under his Chairmanship; these groups are hereafter referred to as the SCS.

This paper summarizes the theoretical and experimental results on adfreeze and abrasion problems of ice carried out by the SCS. Because the SCS has extensively studied ice loads on structures for over 20 years and these subjects have already been fully reviewed a few times, these matters could be set aside.

ADFREEZE BOND STRENGTH

Adfreeze to Structures

Changes in water level produce vertical forces on hydraulic and marine structures—such as offshore structures, wharves, bridge piers, intake towers in rivers, lakes and seas—when ice sheet-to-structure adfreeze bonding is present, as shown in Fig. 1.

The ice load required to cause the adfreeze bond to fail essentially depends on the shear strength of the adfrozen ice and cone angle of the structure. However, even when the ice sheet does not adfreeze to an inclined structure, the fluctuation of the water level may exert ice forces on the structure. A major feature of an inclined structure is that it provides the possibilities for the ice to ride up on the structure and fail to bend.

Some reports have described failures of structures due to the vertical ice force, such as pullouts of piles of pier structures and collapses of intake towers.

Fig. 2 shows the SCS calculation scheme with which to estimate a vertical ice force due to changes in water level, based on the theoretical approaches proposed by the SCS (Saeki et al., 1983; Nakazawa et al., 1988; Terashima et al., 2006).