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# Ice Loads on Conical Piers — A Finite Element Investigation

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## ABSTRACT

**A finite element program is used to compute ice loads on a rigid conical pier. A numerical parametric study is performed to investigate the effect of ice-floe size, ice thickness, and ice strength on the magnitude of ice loads. The finite element results are used to develop a simple equation for quick estimations of ice loads on conical piers. The ability of the equation to predict ice loads on actual piers is evaluated with respect to some field measurements.**

## INTRODUCTION

Bridge and light piers constructed in ice-infested environments are designed to withstand the forces generated by ice. Conical-shaped piers are preferred over the vertical ones because of the belief that ice loads are lower. Over the years, Canadian design codes recommended various design equations for the calculation of ice loads on bridge and light piers. However, it is believed that application of the design equations results in very conservative ice-load estimations, and consequently there is room for less severe design regulations.

Prior to 1974, the Canadian Standards Association "Standards for Design of Highway Bridges" recommended an effective ice-pressure value of 2.8 MPa. Ice loads were, then, calculated by multiplying 2.8 MPa by the thickness of ice and the width of the pier. This recommendation was applied to all piers regardless of either pier shape or ice conditions. The result was very conservative ice-load estimations. Bridge piers in the USSR and Northern Europe were designed for effective ice pressures much lower than 2.8 MPa and survived for a long time (Roads and Transportation Association of Canada, RTAC, 1981).

The Alberta Research Council (1980) conducted field research projects to investigate whether or not the recommended effective ice-pressure value of 2.8 MPa is too conservative, or even appropriate for bridge piers design. Bridge piers at two locations in North-Central Alberta (the Hondo bridge over the Athabasca River, and the Pembridge bridge over the Pembina River) were instrumented and data were collected during 1973-1979. The data consisted of measurements of ice forces on the piers, ice thickness, ice velocity, and observations of the failure modes of ice during its interactions with the piers. The measured ice loads were much smaller than those calculated following the design recommendation.

Frederking et al. (1992) presented measurements of ice forces on navigation light piers in the St. Lawrence Seaway. Five conical-shaped piers, from the St. Clair River to Lac St. Pierre, were instrumented and data were collected during 1983-1991. Frederking et al. (1992) used the most recent design equation to predict ice loads on the Yamachiche light pier in Lac St. Pierre, and they showed that the measured ice forces were substantially below those predicted by the recommended design equation.

The improvements in the Canadian design code, over the years, were accompanied by tremendous advancements in ice engineering. The last two to three decades have seen a considerable amount of ice-related research work. Results of physical model tests, field measurements of ice forces, and development of various empirical and analytical models have been reported. Although most of the reported research work was directed towards understanding the interaction processes of ice with structures, there is an uncertainty of understanding the mechanisms by which ice loads are developed, and how the variability of the natural conditions affects the intensity of ice loads.

In ice engineering, when computing ice loads on conical structures, the general approach is to consider a cantilever beam (uniform or wedge shape) or a plate on an elastic foundation. The beam (or plate) is loaded at the front end by a vertical force, and often the axial forces are ignored. The load corresponding to the bending failure of the beam is taken as the maximum vertical ice load. The maximum horizontal ice load is calculated from the vertical ice-load component, forces induced by the ride up-ice, and frictional forces.

Also, model indentation test results are used to derive empirical and semi-empirical equations for the calculation of ice loads on conical structures. Ice loads on actual structures are estimated from those measured in the laboratory using scale factors. Literature reviews of most existing analytical and empirical methods are given by Marcellus et al. (1987), Cammaert and Muggeridge (1988), and Sanderson (1988). Evaluations of the performance of several methods are given by Croasdale (1980), Timco (1984), Marcellus et al. (1987), and Chao (1992).

Application of analytical and empirical methods to compute ice loads on actual offshore structures requires considerable engineering judgements. First, empirical methods are valid only for the conditions and the geometries of the experiments. Extrapolation of empirical equations to compute ice loads on actual structures is underlined by a number of uncertainties. Second, most analytical methods are formulated as a function of the uniaxial strength of ice. Field observations of ice-structure interactions (Sodhi and Cox, 1987) indicate that ice fails in a complex state of stress and the use of uniaxial strength of ice could result in unrealistic ice-load estimations.

In this study, it is recognized that the complexities of ice-structure interaction problems dictate that the method of calculating ice loads on offshore structures should be numerical (finite element, discrete element, etc.). The universality of these methods allows for comprehensive analyses of ice-structure interaction problems

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KEY WORDS: Ice loads, mechanical behaviour, failure criterion, bending, buckling, design equation.