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Global Design Ice Loads' Dependence of Failure Mode

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ABSTRACT

This paper addresses the prediction of global design ice loads on offshore structures related to the structural width. Fourteen events from full-scale measurements on the Norströmsgrund lighthouse are analysed to find out how the effective width should be taken into account for estimating ice forces. Simultaneous failure is found during ductile crushing, initial hit and static loading with a drift speed/ice thickness (v/h) ratio from 0 to 0.05 l/s. Brittle crushing of level ice is found in events with v/h in the range of 0.2 to 0.4 l/s. During brittle crushing of level ice, both nonsimultaneous and a quasi-simultaneous failure modes occur. This work indicates that care should be taken in reducing the effective width when calculating global design ice loads.

INTRODUCTION

There is a recurrence of interest in building activities in Arctic and sub-Arctic areas. Oil and gas fields in areas with first-year sea ice such as the Caspian Sea, Pechora Sea and offshore Sakhalin Island are explored and/or under development. As a further example, Germany is planning significant offshore windmill plants in potential ice-covered waters (SKY 2000).

Loads from floating ice sheets induce one of the most significant horizontal loads on offshore structures in areas where only first-year ice features are present. The effective or nominal pressure p is defined as the measured ice load divided by the ice thickness (h) times a structural width (D) as $p = F/Dh$. Already in 1888, Runeberg stated that the pressure from an ice floe on a structure could not exceed the ice strength. Sanderson (1988) collected the available data from ice load measurements and showed how the effective pressure decreases with the nominal contact area. Later, Masterson and Frederking (1993) found the same trend as Sanderson and presented a design curve where the effective pressure scales with the contact area to the power of -0.5 for areas between 0.2 and 20 m^2. For contact areas greater than 20 m^2, the design pressure is recommended to be constant at 1.5 MPa.

This paper addresses how the effective structural width used in ice load prediction is affected by changes in the failure mode of the ice sheet to a vertical structure. Special consideration is paid to the alternation between simultaneous and nonsimultaneous failure dependent on a ratio between drift speed and ice thickness. Further, a link is drawn between simultaneous/nonsimultaneous failure and the effective structural width in predicting design ice loads. The work is based on observations and analysis of full-scale data from the Norströmsgrund lighthouse in the Gulf of Bothnia, Sweden.

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KEY WORDS: Ice load, zonal failure, structural width, simultaneous, quasi-simultaneous, nonsimultaneous.

BACKGROUND

Blanchet and DeFranco (1996) summarised field data obtained from 1966 to 1988 from several full-scale measurements. Their results indicate that the ice force per unit width decreases with the width and depends only slightly on the ice thickness. Løset et al. (1999a and b, 2003) undertook further review studies on the effective pressure p. They proposed that it is convenient to look for a global load F and p in the dimensional form:

$$F = p \cdot D \cdot h \quad \text{where} \quad p = A_k D^m h^n \tag{1}$$

where m and n are factors and A_k is an experimental parameter that depends on further relevant parameters—ice quality, strength or fracture toughness, temperature, drift speed, etc. (Kärnä and Qu, 2003).

The factor m addresses the uneven contact along the structural width and scale effects in ice crushing. The perimeter effective width used later reads $D_{\text{eff}} = D^m$. The factor n addresses the uneven distribution of pressure through the entire ice thickness.

Fig. 1 shows an arbitrary rigid body with vertical sides. Fig. 1a illustrates how the pressure p is unevenly distributed around the perimeter of the structural width D. Fig. 1b highlights how the

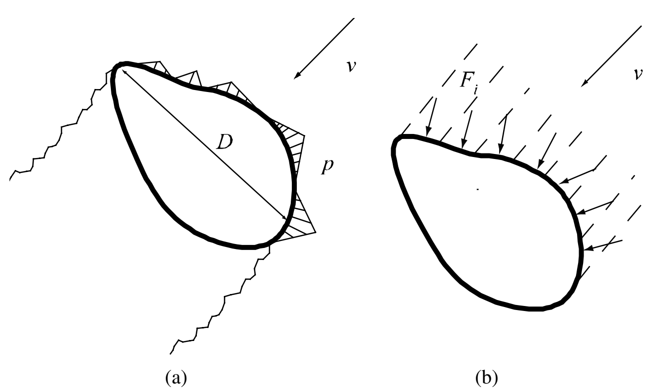

Fig. 1 Arbitrary rigid body (top view) affected by ice forces: (a) unevenly distributed pressure p, (b) structural width D divided in zones ($D/h \gg 1$) (after Eranti, 1993)