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The action of short multi-year ridges on upward sloping conical structures

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ABSTRACT

Multi-year (MY) ridges often control the design ice loads on Arctic structures. Ice loads due to MY ridges on sloping structures vary with whether the ridge is long or short. This paper addresses short ridges. A parallel paper addresses long ridges. For short ridges, critical lengths for loads are usually when they are shorter than their characteristic length; in particular, when no hinge cracks occur. In this situation, loads in prior methods were dominated by ride up forces. New methods have been developed which include two load relieving mechanisms. These are 1) failure across the ridge width as it rides-up and 2) a limit to ride-up based on downward failure of the pushing ice sheet. These limit mechanisms can lead to lower loads than in prior methods and usually result in loads from short ridges being lower than for long ridges of the same cross section and strength. Nevertheless, in any comprehensive load approach the engineer may wish to check loads from both long and short ridges. In fact this is necessary in probabilistic methods into which these new algorithms have been incorporated.

The new methods for short ridges result in a relatively simple set of equations and these are provided in the paper. The equations have been incorporated into spreadsheets and example inputs and outputs are given.

1. Introduction

1.1. Past work

The first recorded work on developing methods for multi-year (MY) ridge loads on sloping structures commenced in about 1972 in Canada. In addition to model testing, (e.g. Lewis and Croasdale, 1978), equations for ridge failure loads based on beams on elastic foundations were developed (as described by Croasdale (1975, 1980)). Ralston (1977) showed that theoretically, short ridges when treated as beams on elastic foundations with free ends could require greater loads to fail them in bending than long ridges. The issue of short ridges was addressed specifically by Winkler and Nordgren (1986), Nordgren and Winkler (1989). Their work indicated that loads from short ridges would be most critical when the ridges were sufficiently short that a centre crack could not form and that forces were solely due to ride up-and rotation of the "longest short ridge" that would not form a centre crack.

1.2. Current practise

In ISO 19906 (2010), there are no specific algorithms provided for multi-year ridges (long or short), however references are provided for a range of methods; to quote:

> "Multi-year ridge actions against conical structures can be estimated using a variety of methods (Croasdale, 1980, Nordgren and Winkler, 1989, Wang, 1984)."

1.3. Scope of work

The aim of this work was to fill the gap in ISO 19906 and develop a methodology with algorithms for ice loads due to MY ridges on upward sloping structures. The emphasis was to be on closed-form algorithms (and/or iterative methods) that could be used by engineers (especially within a probabilistic framework).

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The study was conducted over a period of about 2 years by a team composed of Ken Croasdale (Consultant), Tom Brown (University of Calgary) and George Li and Walt Spring (of Shell Development). In the final stages of the study the algorithms and logic were entered into a probabilistic model by C-CORE. During this process, Mark Fuglem and Jan Thijssen helped with valuable refinements. The project reports to Shell are KRCA, 2014a, 2014b.

In conducting the work, it was again found appropriate to consider very short ridges as a special case (as Nordgen and Winkler had in the past). Long ridges were those long enough that after a centre crack, the two side pieces would form a series of hinge cracks prior to final clearing by rotation. Short ridges never form hinge cracks and may not form a centre crack either.

The work on long ridges during this study has resulted on improved methods, and these are reported in (Croasdale et al., 2016a) and in a parallel Journal Article to this one (Croasdale et al., 2018). Some results from that work are used later in this paper to compare loads for short and long ridges. The users of the new methods developed in this paper for short ridges should also use the new methods developed for long ridges.

2. Short ridges

2.1. Definition

As discussed in Croasdale et al. (2016a), Croasdale et al., 2018) and prior work, a long ridge is idealized as a long floating beam which is pushed broadside on to the structure. As it is rides up the slope of the structure it fails in bending. The first failure is a centre crack which creates two side beams, and the second failures are hinge cracks in the two side beams as each end is further lifted. By definition, short ridges are those that are so short, and end conditions are such, that hinge cracks do not form. Furthermore, the analysis recognizes that if such a ridge is pushed up a slope, a centre crack as depicted in Fig. 1 may or not form depending on length and other ridge parameters. As suggested conceptually in Fig. 2 if the centre crack forms, the pieces are more likely to rotate around the cone rather than riding up. If the ridge is too short for a centre crack to form, the forces will be due to ride-up. However as depicted in Fig. 3, other processes may also limit the loads.

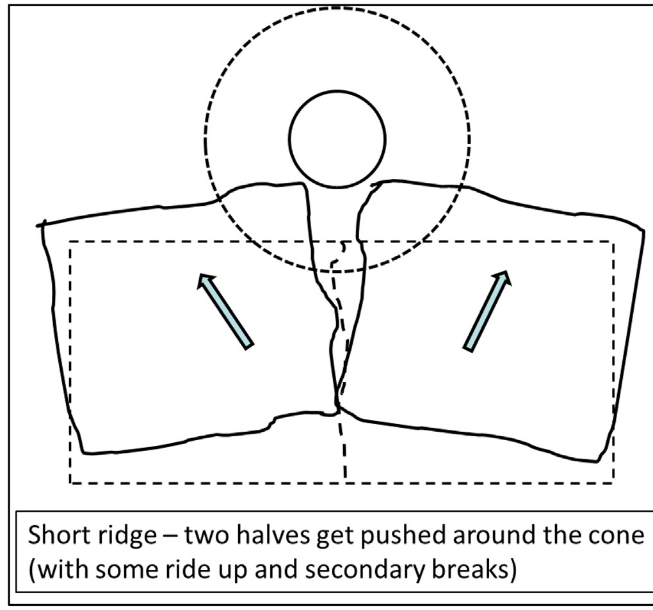

Fig. 2. Clearing of short ridge fragments after a centre crack occurs.

In this work (as in prior work) the equations are developed for the condition after a thick ridge has broken out from the thinner surrounding ice sheet. Typical forces for this process have been calculated for long ridges in Croasdale et al. (2018) where it shown that the later ridge breaking forces always govern. A similar conclusion was reached by Winkler and Nordgren (1986), who also addressed this issue relating to short MY ridges.

The first step in the assessment of how to treat a "short ridge" is to estimate the limiting length when the centre crack will no longer form.

2.2. Work by Winkler and Nordgren

Winkler and Nordgren (1986) (W&N) addressed the short ridge issue in detail. It is appropriate to follow their logic, but at the same

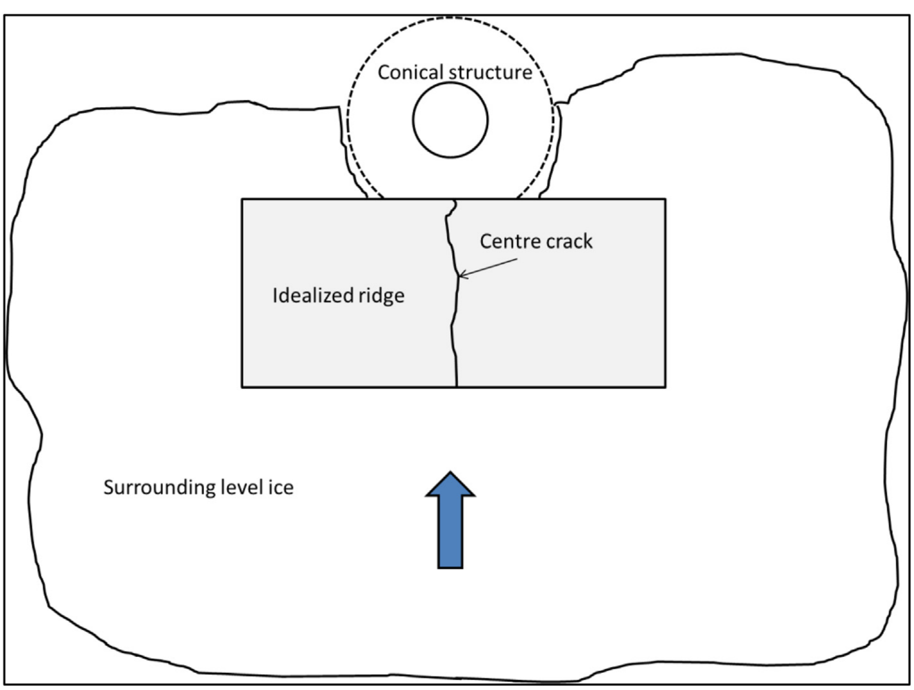

Fig. 1. Short ridge but long enough to form a centre crack.