8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

Computation of Ice Loads on Structures in the Arctic

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Key Words: *Arctic, Ice Mechanics, Ice Loads, Applications, Computing Methods.*

ABSTRACT

During recent years major discoveries of oil and gas reserves have been made in offshore areas of the far North. The oil and gas industry is faced with major challenges in developing and exploiting these resources because of the extreme weather and environmental conditions experienced in these waters. In particular, production platforms may be exposed to severe loading from ice sheets, ice ridges and even icebergs. Being able to estimate global forces and local pressures from ice loads is a prerequisite for developing designs that will safely survive these conditions.

The paper gives a brief reference to some of the most important hydrocarbon discoveries and potential fields for future development in the arctic. Characteristics of the ice conditions in some of these areas are outlined. Furthermore, examples of structures that have been built and proposed are described. The most important aspects of estimating the ice loads in structural design are emphasized.

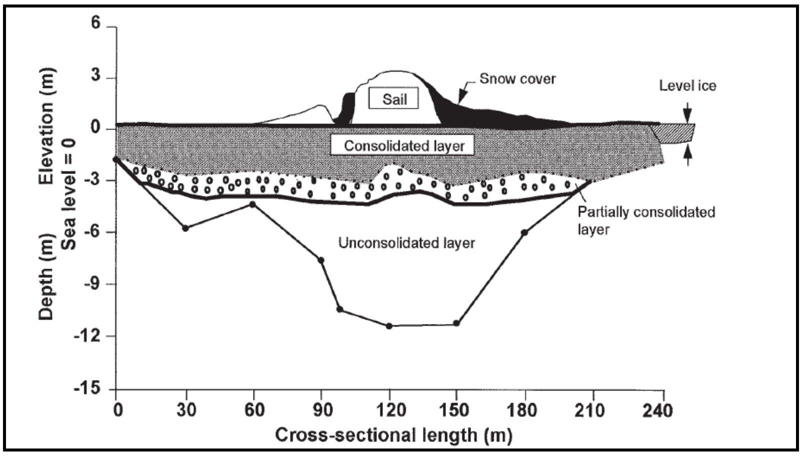
The finite element method and related numerical computational techniques have over the years been developed and greatly refined; such methods are currently being applied in almost every aspect of scientific and engineering analysis. Numerical simulation techniques are also gradually being developed and implemented for computation of ice forces on structures, see e.g. [1], [2]. It seems clear, however, that there are many difficulties with including the majority of complex mechanisms that govern the failure of uniform ice sheets and accumulation of ice blocks in ice ridges. Hence, the current state-of-the-art primarily deals with simplified, two-dimensional models when simulating ice behaviour and computing ice forces.

Ice ridges are the most critical design ice feature in such areas as the Barents Sea, but at the same time they are the most complex and difficult ice form to model. As seen in the figure, a typical ridge is a linearly-extended pile of broken ice blocks with a sail and a keel extending above and below the waterline with a triangular-shaped cross section. The layer below the waterline is made up of randomly-oriented ice blocks; the voids are filled with crushed ice, slush, and water. With time, the voids freeze very quickly towards the bottom, and the ice blocks in that layer become bonded. This results in a solid ice sheet and forms the so-called consolidated layer.

Existing force models are primarily empirical formulations; the consolidated layer is assumed to fail in compression or bending, while the keel is assumed to behave like a granular material. Typical calculations assume that the total ridge failure load is simply the sum of the individual failure loads for each layer, while recent field observations have shown that each ridge layer fails non-simultaneously across the height and width of the structure, resulting in a much lower global load.

The authors point to the development of more powerful techniques for two- and three-dimensional simulation of ice behaviour and ice forces. There are many challenges to be considered in this connection such as nonlinear material behaviour, cracking and crushing of solid ice, cohesion and friction between ice blocks, contact and pile-up of pieces of ice, large displacements, interaction between ice and water and ice and structure, etc. As it is neither realistic nor feasible to include all of these effects in the model it is necessary to focus on the primary and most important ones.

The paper discusses some alternative formulations for nonlinear, numerical simulation of ice loads on structures. In particular it is directed to so-called particle finite element formulations which can be used for modelling of the structural boundary, the water and the behaviour of and interaction between ice blocks. Initial numerical studies are reported. The paper presents conclusions regarding current capabilities in ice mechanics simulations and points to research themes to be explored in the future.



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