

Analysis and modelling of ice ridge consolidation

First Year Ice ridge loads are often the design loads for offshore structures in Arctic regions. Based on the field observation data for Confederation bridge, the calculated upper limit for the ice ridge loads according to ISO 19906 Standard were quite high when compared to the measured loads. There is a need to obtain an improved description of the internal structure of the ice ridge to understand its mechanical behavior. Finite Element (FE) thermodynamic analysis on a large ridge in 3 dimensions is computationally expensive due to the large number of elements required to accurately capture the phase change process occurring in the pores. Thus, the aim of this thesis is to analyze the thermodynamic consolidation process on an ice ridge composed of 2-dimensional ice bodies, construct the analytical function to predict increase in boundaries of the ice bodies and then finally obtain a consolidated ice ridge geometry.

Firstly, a ridge formation model was created to obtain the arrangement of the ice bodies within the ridge internal structure. The bodies were allowed to interact with each other under the influence of buoyancy and gravity and the contacts between the loose ice bodies were resolved using impulses calculated using Non-smooth discrete element method (NDEM). Finite Element (FE) thermodynamic analysis was carried out on the ice body arrangement based on constant temperature boundary conditions to model the consolidation process and obtain the temperature distribution within the ridge. The proposed consolidation model was validated by comparing with results from Stefan's Law predictions for growth in level ice thickness.

Analytical functions to predict the increase in dimension of the ice bodies were based on simplified heat transfer processes within the ridge. One dimensional heat conduction was used to model the influence of the initial temperature of the ice body at each corner point. The influence of the cold ambient air was modelled using Stefan's Law expression. In this case, average thermal conductivity of the area directly above the ice body was used to model the heat flux. Non-linear regression analysis was then performed using the results from the FE analysis to fit the function to the dataset. The functions were then used to predict the expansion of the ice bodies after a given time duration and the boundaries were merged to give the final ridge geometry.

Finally, a comparison was made with the FE results. It was concluded that the major increase at the top of the ridge is caused by the contribution from 'ambient temperature' and the depth of the ice body below the waterline was the major variable for this case. The major variable for the ice bodies in the lower part of the keel, was the corner point temperature. Some deviations from the FE model results were observed due to the fact that deterioration of ridge keel due to surrounding water is not included in the regression model and thus the blocks near the bottom of the ridge keel do not show the expected decrease in boundaries. Overall, the modelling work presented in this thesis provides a good framework to approximate the FE consolidation results and the analytical functions can be improved to include more variables that are involved in consolidation process.

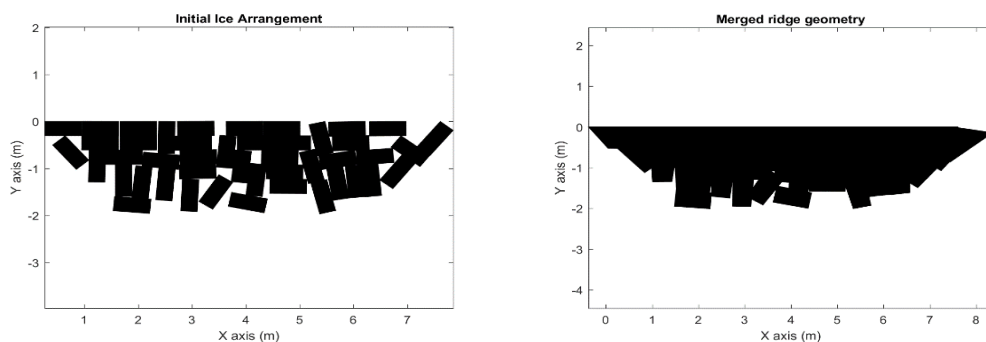


Figure 1 Initial Ice arrangement of blocks and final merged ice ridge geometry after 15 days of consolidation