

## Physical Testing and Finite Element Analysis of Icebreaking Ship Structures in the Post-Yield Region

James Bond<sup>†</sup>  
American Bureau of Shipping, Houston, Texas, USA

Stephen Kennedy  
Carleton University, Ottawa, Ontario, Canada

### ABSTRACT

The Canadian Equivalent Standards for the Construction of Arctic Class Ships provide a methodology to determine design loads and scantlings for the hull plating and framing members of icebreakers and cargo ships operating in Arctic waters. The design equations explicitly recognize the post-yield capacity of the hull structure (plastification of framing and membrane behavior of the plating) under extreme load conditions. This paper summarizes the analytical and experimental work conducted to assess the post-yield stability behaviour of typical icebreaker hull panels, particularly in regard to the behaviour of the main frames. Tested were two large-scale panels, measuring 5000 mm by 2600 mm in plan, representative of a section of the midbody hull structure along the icebelt that extends between the main deck and the bottom structure and between transverse bulkheads of a Canadian Arctic Class 3 (CAC3) vessel. Described are the behaviour, load deformation characteristics and progression of failure from plastic hinge formation to plastification and tripping of the framing system, to rupture of the plating. A comparison has been made between the behaviour of the panels as predicted by a nonlinear finite element analysis and the physical test results to determine the effectiveness of the finite element method in modelling post-yield behaviour.

### INTRODUCTION

The Canadian Equivalent Standards for the Construction of Arctic Class Ships (Transport Canada, 1995), the background of which is presented in the Proposals for the Revision of the Arctic Shipping Pollution Prevention Regulations (Transport Canada TP9981, 1989), generally call for thinner shell plating and higher-strength framing than the 1972 Arctic Shipping Pollution Prevention Regulations. In the Equivalent Standards, for the shell, the elasto-plastic behaviour of the required ductile steel is recognized. For the framing the shear strength and bending strength, as well as tripping and buckling stability, are explicitly considered. The background report makes the observation that framing stability appears to be not fully understood. In response to this and recognizing the advances in analysis software and computing capabilities, work has been performed to investigate the post-yield and post-buckling strength of a typical icebreaking ship midbody side shell structure, with particular focus on the stability of the main frames. This paper describes the project tasks and results for the completion of Phase 2 of the work. Phase 1 (Martec Ltd, 1994) work was conducted to establish the boundaries and scope of Phase 2. The primary objective of the Phase 2 work was to demonstrate that the finite element method (FEM), as an analysis tool, is capable of predicting the post-yield behaviour of icebreaking ship structure. The secondary objective of the work was to provide further insight into post-yield structural instability under

lateral loads. These objectives were accomplished by designing 2 icebreaker midbody panels in compliance with the Equivalent Standards, analyzing them using the FEM, physically testing the panels, comparing the FE and test results and drawing conclusions.

- The project team responsibilities were as follows:
- MIL Systems - Project Management, Panel Design, Finite Element Analysis, Results Reduction and Reporting
  - Carleton University - Physical Testing and Results Reduction
  - Transport Canada (Transportation Development Centre) - Project Sponsorship under the direction of Mr. Ian Bayly.

### EXPERIMENTAL FACILITIES

One of the project aims was to physically test on a large scale. The achievable scale is a function of the capacity of the test facility. The Carleton University Structures Laboratory has the following characteristics:

- Test area of dimensions 11 m × 33 m with a clear height of 11m
- 1-m-thick reinforced concrete strong floor with tie downs through the floor 600 mm on centre in both directions
- 2 10-ton-capacity overhead cranes
- Double-acting load actuators; three 500-ton-capacity and two 200-ton-capacity (total capacity = 16900 kN).

### PANEL DESIGN PROCESS

The panels were designed to the Equivalent Standards through an iterative process.

- Constraints on the design outcome included:
- testable to failure (material rupture) at the experimental facilities
  - modellable using the FEM
  - fabricated from a readily available steel grade (representative of ship steels) in readily available plate thicknesses.

<sup>†</sup>Formerly with MIL Systems, Ottawa, Ontario, Canada.

Received March 16, 1998; revised manuscript received by the editors August 23, 1999. The original version (prior to the final revised manuscript) was presented at the Eighth International Offshore and Polar Engineering Conference (ISOPE-98), Montréal, Canada, May 24-29, 1998.

KEY WORDS: Icebreaker structure, post-yield stability, large-scale experiment, nonlinear finite element.