Ultimate Strength of Ice Class Ship Structures in Intact and Damaged Conditions

1.0 OBJECTIVE.

1.1 The objective of the present research project is to improve the ability to estimate the residual strength of ship structures operating in low temperatures and in ice-covered waters that have sustained damage. Damage sustained by ships in these conditions will necessarily impair to some degree the ultimate strength of the ship structure. The purpose of this study is to quantify, to the degree possible, the loss of strength of the structures as a result of in-service damages (e.g., local denting) and accidental damages (e.g., resulting from collision or grounding), taking into account the effect of low temperatures.

2.0 BACKGROUND.

2.1 There is increasing interest in extracting resources from Arctic and other low-temperature regions. A further impetus derives from climatic changes which have resulted in less ice in the Arctic a consequence of which is serious consideration of trans-Arctic commercial voyages. In many cases ships larger than have typically operated in these regions in the past are now being built for service in ice-covered waters. Given the many technical issues relevant to Arctic operation, it is timely to seek a framework of robust design and safety assessment for ice-strengthened hull structures of ice class ships. The technical issues related to shipping in ice-covered waters include the effect of low temperatures on the ultimate strength of hull structures in the intact and damaged conditions.

2.2 While in service, hull structures of ice class ships may suffer local denting due to contact with ice floes and/or even accidental damages resulting from collision with icebergs or ships, or from grounding on rocks. The studies related to the effects of structural damages on the ultimate (residual) strength of ship structures in cold temperature conditions are very lacking.

2.3 The overall failure of ship structures is mainly governed by the failure of the stiffened panels in the deck, bottom, and sometimes in the side shell. Therefore, the accurate and efficient calculation of the ultimate strength of stiffened panels is an important task in the design and safety assessment of ship structures. For the stiffened panels of conventional ship structures, predominantly axial compressive loads are a primary load component in terms of the panel failure associated with buckling and plastic collapse, while axial tensile loads do not cause any technical issues until the ultimate strength associated with gross yielding is reached. For the stiffened panels of ice class ship structures, however, the effect of low
temperatures must be taken into account on the panel ultimate strength subject to transverse ice loads and under axial tensile or compressive loads, especially when structural damages exist.

2.4 More refined nonlinear finite element (FE) method computations and experimental validations are required to identify accurately the failure mechanisms of the hull structures with the cold temperature effect taken into account. Ultimate strength design formulations are required for structural design and safety assessment of ships.

3.0 REQUIREMENTS.

3.1 Scope.

3.1.1 Computing the ultimate limit states of ships operating in ice-covered waters requires the material and strength modeling of the hull structures, with the effect of cold temperatures representative of the Arctic Ocean environment taken into account. Such modeling will be based on the substantial test database of ice class steel materials available from the existing literature. Where the available data are insufficient, new tests will be performed to compile a new test database.

3.1.2 While in service, ice class ships suffer in-service damages and/or even accidental damages. The effects of structural damages on the ultimate strength of hull structures in cold temperature conditions will be identified. A comparison of the ultimate strength will be made between intact and damaged conditions. The focus will be at the level of plates and stiffened panels.

3.1.3 Nonlinear FE method modeling techniques for ultimate strength analysis involving buckling, yielding, and brittle/ductile fracture will be established in association with the ultimate limit states taking into account the effects of cold temperatures. The resulting techniques and applied computations will be verified through structural model tests.

3.1.4 The Contractor will prepare a detailed report of all work undertaken.

3.2 Tasks.

3.2.1 Task 1 – Literature review. A review of the literature on (a) statistics on the structural failures for ships operating in the Arctic Ocean, and (b) the effect of cold temperatures on material mechanical properties and structural elements will be carried out.

3.2.2 Task 2 – Target ship selection. A hypothetical ice class tanker will be selected.
3.2.3 Task 3 – Ice class hull structural material modeling. A series of tests on ice class hull structural materials will be undertaken in cold temperature conditions to obtain a test database of mechanical properties and fracture toughness. Statistical analysis of the resulting test database will be performed to formulate an ice class hull structural material model that explains the stress-strain relationship.

3.2.4 Task 4 – Ultimate panel strength analysis. Elastic-plastic large deformation analysis of stiffened panels without or with hypothetical damages, subject to either axial compressive loads or axial tensile loads will be performed by nonlinear FE method, taking into account the effects of cold temperatures. A closed-form formulation of ultimate panel strength will be derived. Experimental validations will be performed in association with Task 6.

3.2.5 Task 5 – Ultimate strength panel model tests. A series of ultimate strength tests on stiffened panel models in intact and damaged conditions will be undertaken in room and cold temperature conditions. Hypothetical in-service or accidental damages will be considered in terms of shape and size.

3.2.6 Task 6 – Reporting: Biannually and final reports are prepared.

3.3 Project Timeline.

| Task | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|
| 1    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |
| 2    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |
| 3    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |
| 4    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |
| 5    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |
| 6    |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |

4.0 GOVERNMENT FURNISHED INFORMATION.

4.1 Standards for the Preparation and Publication of SSC Technical Reports.

5.0 DELIVERY REQUIREMENTS. (Identify the deliverables of the project).

5.1 The Contractor shall provide quarterly progress reports to the PTC, the Ship Structure Committee Executive Director, and the Contract Specialist.

5.2 The Contractor shall provide a print ready master final report and an electronic copy, including the above deliverables, formatted as per the SSC Report Style Manual.
6.0 **PERIOD OF PERFORMANCE.**

6.1 Project Initiation Date: date of award.

6.2 Project Completion Date: 18 months from the date of award.

7.0 **GOVERNMENT ESTIMATE.** These contractor direct costs are based on previous project participation expenses.

7.1 Project Duration: 18 months.

7.2 Total Estimate: $150,000.

7.3 The Independent Government Cost Estimate is attached as enclosure (x).

8.0 **REFERENCES.**

NOTE:

- Please do not submit any proprietary information in this outline. This will be posted on the SSC Website regardless if the project is selected to be funded.
- All projects will be competed via Government Services Administration (GSA) or Commerce Business Daily (announced)