SSC Project Recommendation for FY 2018

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

1.0 OBJECTIVE.

1.1 The objective of this research project is to improve the ability to estimate the residual strength of ship structures operating at cold 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 ship structures. The purpose of this study is to quantify, to the degree possible, the loss of strength of ship structures as a result of in-service damage (e.g. local denting) and accidental damage (e.g. resulting from collision or grounding), taking into account the effect of cold temperatures.

2.0 BACKGROUND.

2.1 The Arctic is rapidly transforming into a navigable ocean due to the effects of global warming reducing the extent of the sea ice. Substantial savings in voyage times and fuel consumption can be made using Arctic routes: 22 days from China to Europe, compared to 35 days via Singapore and the Suez Canal. There is also increasing interest in extracting resources from the Arctic and other cold-temperature regions, with the Arctic estimated to contain (according to the U.S. Geological Survey) 13% of the world's undiscovered oil and 30% of its undiscovered gas and abundant deposits of valuable minerals.

2.2 Ships larger than having 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 in association with damage tolerance and survivability. The technical issues related to shipping in ice-covered waters include the effect of cold temperatures on the ultimate strength of hull structures in the intact and damaged conditions.

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

2.4 Overall collapse of a ship's hull followed by sinking still rarely takes place. 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 and eventually the ultimate strength of ship hull girder structures 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. However, for the stiffened panels of ice class ship structures the effect of cold 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 damage exists. For hull girder structures, vertical bending moment is a primary load component on ships. For the collapse strength of ice class ship hull structures under vertical bending moment, the effects of cold temperatures as well as structural damage should be taken into consideration.

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

2.6 The effects of extreme and accidental actions are highly nonlinear by nature, associated with geometric and material nonlinearities together with non-Gaussian aspects, multi-physics, multi-scale and multi-criteria. It is obvious that integrated and multi-disciplinary approaches should be applied, because computation itself is insufficient to solve such highly nonlinear problems. Testing using large-scale models is therefore essential; small-scale model tests are inadequate since scaling laws are not always adequate to convert the small-scale test results to the real full-scale structures.

3.0 REQUIREMENTS.

3.1 Scope.

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.
2. While in service, ice class ships suffer in-service damages and/or accidental damage. The effects of structural damage 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. 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.
4. Perform large scale structural model tests to obtain validation data for the modeling techniques.
5. The Contractor will prepare a detailed report of all work undertaken.
6. The Contractor is required to bring at least the same amount of the matched fund as the SSC funding in association with the maximization of the expected benefits in experimental investigations.

3.2 Tasks.

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's mechanical properties and structural elements will be carried out.
2. Task 2 – Target ship selection. A hypothetical ice class ship will be selected.
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 engineering (or true) stress-engineering (or true) strain relationship.
4. Task 4 – Ultimate panel strength analysis. Elastic-plastic large deformation analysis of stiffened panels without or with hypothetical damage, 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 5.
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 at room and cold

temperature conditions. Hypothetical in-service or accidental damage will be considered in terms of damage shape and size.

6. Task 6 – Ultimate hull girder strength analysis. Progressive collapse analysis of hull girder structures with or without hypothetical damages, subjected to vertical bending moments will be performed by nonlinear FE method, taking into account the effects of cold temperatures. A closed-form formulation of ultimate hull girder strength will be derived. Experimental validations will be performed in association with Task 7.
7. Task 7 – Ultimate strength hull girder model tests. A series of ultimate strength tests on hull girder models in intact and damaged conditions will be undertaken at room and cold temperature conditions. Hypothetical in-service or accidental damages will be considered in terms of damage location (bottom or side) and size.
8. Task 8 – Reporting: Biannually and final reports are prepared.
9. Phase 1 covers Tasks 1 – 5 and Phase 2 covers Tasks 6 and 7.

3.3 **Project Timeline.**

	Phase 1 (Year 1)												**Phase 2 (Year 2)**											
Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	■	■																						
2	■	■	■																					
3	■	■	■																					
4				■	■	■	■	■	■	■	■													
5				■	■	■	■	■	■	■	■													
6													■	■	■	■	■	■	■	■	■	■	■	
7													■	■	■	■	■	■	■	■	■	■	■	
8						■						■						■						■

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: 12 months for Phase 1 and 12 months for Phase 2 from the date of award.

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

7.1 Project Duration: 12 months for Phase 1 and 12 months for Phase 2.

7.2 Total Estimate: $150,000 for Phase 1 (with a matched funding of $150,000) and $150,000 for Phase 2 (with a matched funding of $150,000).

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

8.0 <u>REFERENCES</u>.

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)