SSC Project Recommendation for FY 2022

Failure Characteristics of Ship Structural Steels and Members at Cold Temperatures and Cryogenic Condition with High Strain Rates

1.0 OBJECTIVE.

1.1 A collation of full- or large-scale physical model test database available in the literature shall be undertaken to identify the failure characteristics of ship structural steels and members under tensile and compressive loads at cold temperatures and cryogenic condition with high strain rates. New test databases of material properties shall be generated to make full a room where relevant databases are unavailable or lacking in the literature.

1.2 Effects of not only cold temperatures associated with Arctic environments but also cryogenic condition due to unwanted release of liquefied natural or hydrogen gases shall be investigated on the failure characteristics at the levels of both materials and structural members under quasi-static or impact tensile or compressive loads. Brittle or ductile fracture, among other failure modes, is emphasized.

1.3 Based on the collated test database, a computer software shall be coded to generate the engineering stress-engineering strain relationships of ship structural steels including elastic modulus, yield strength, ultimate tensile strength and failure strain at different temperatures and strain rates.

1.4 Advanced computational models useful for the ship structural crashworthiness analysis at cold temperatures and cryogenic condition under quasi-static or impact loading are proposed in association with extreme conditions and accidents.

2.0 BACKGROUND.

2.1 Modern ship structural steels have high quality in fracture toughness, among other aspects of properties. In general, however, carbon steels tend to become brittle at cold temperatures / cryogenic condition and/or high strain rates. Despite an excellent quality of fracture toughness at the material level, it is reportedly recognized that ship hull structures exposed to cold temperatures or cryogenic condition under impact loading can reach the ultimate limit states triggered by brittle or ductile fracture. The Arctic routes are increasingly used for shipping, where the average temperature in winter is -40 deg. C and the lowest temperature is recorded as -68 deg. C. Natural and hydrogen gases are increasingly used as energy source, and they are liquefied at cryogenic condition to efficiently transport or manage. Also, they are increasingly used as an alternative of fuels for ship propulsion. There are always hazards that unwanted release of liquefied natural or hydrogen gases happens, leading to cryogenic condition in ship hull structures.

2.2 In Arctic operation, ship hull structures are exposed to cold temperatures. There are always hazards that ship hull structures are exposed to cryogenic condition due to unwanted release of liquefied natural or hydrogen gases. Ship hull structures are likely subjected to impact loading with high strain rates arising from extreme conditions and accidents. Crashworthiness behavior involving not only buckling and plastic collapse but also brittle or ductile fracture is exhibited until and after ship hull structures reach the ultimate limit states.

2.3 Numerical algorithms or small-scale physical model testing may not capture real phenomena or even twist the reality of structural crashworthiness in extreme and accidental conditions which involve multiple physics, multiple scales and multiple criteria until and after the limit states are reached. Full-scale or at least large-scale physical model testing can help resolve the issues, and ultimately manage the challenges effectively.

2.4 This project is of paramount importance to clarify and model such failure characteristics at both ship structural material and member levels which should be considered for limit states based safer ship structural design. No SSC reports are available in the proposed subject.

3.0 REQUIREMENTS.

3.1 Scope. (Identify the phases of the project).

3.1.1 The Contractor shall conduct the collation of full- and large-scale physical model test databases on the failure characteristics of ship structural steels and members under quasi-static or impact tensile or compressive loads at cold temperatures or cryogenic condition. The grades of ship structural mild and high tensile steels shall include Grades A, D and E. The range of the temperature under consideration shall be -300 deg. C to 20 deg. C. It is realized from a pre-review of the literature that the test databases for ship structural steels at the temperatures lower than -200 deg. C equivalent to cryogenic condition of liquefied hydrogen gases are lacking and thus new test databases shall be generated in the present project. The range of high strain rates shall cover up to at least 100/s which may be likely to happen in ship hull structures under extreme conditions and accidents. Database obtained from full- or large-scale physical model testing on plates or stiffened plate structures under compressive loading at cold temperatures or cryogenic conditions shall be collated.

3.1.2 The Contractor shall identify the mechanical properties and their constitutive equations at the material level in association with the literature review and new test database mentioned in 3.1.1. Failure characteristics at the structural member level (e.g., plates, stiffened panels) under compressive loading shall also be identified until and after ultimate strength is reached. Brittle or ductile fracture, among other types of failure modes, shall be emphasized.

3.1.3 The Contractor shall develop a test data based computer software to predict the engineering stress-engineering strain relationships of ship structural steels including elastic modulus, yield strength, ultimate tensile strength and failure strain at different cold temperatures and strain rates.

3.1.4 The Contactor shall propose advanced computational models useful for the ship structural crashworthiness analysis in extreme conditions and accidents.

3.2 Tasks. (Identify the tasks to carry out the scope of the project).

3.2.1 The Contractor shall collate the full- and large-scale physical model test databases which have been obtained in the literature to identify the failure characteristics of ship structural steels (e.g., mild and high tensile steels with different grades) and structural members (e.g., plates and stiffened panels) at cold temperatures and cryogenic condition under quasi-static and impact tensile and compressive loading.

3.2.2 The Contractor shall perform the material testing of ship structural steels at the temperatures lower than -200 deg. C and high strain rates under tensile or compressive loading.

3.2.3 The Contractor shall code a computer program based on the collated test database to predict the engineering strain-engineering strain relationships of ship structural steels at cold temperatures / cryogenic condition and impact loading with high strain rates. The graphical user interface (GUI) system shall be employed to make the software user-friendly.

3.2.4 The Contactor shall propose advanced computational models for the ship structural crashworthiness analysis at cold temperatures / cryogenic condition and quasi-static or impact tensile or compressive loading, where brittle or ductile fracture is a triggering factor affecting the ultimate limit states. Nonlinear finite element method modeling techniques associated with multiple criteria, multiple physics and multiple scales shall be described in detail together with applied examples verified by comparison with full- or large scale physical model test data.

3.3 Project Timeline. See Enclosure (A1).

4.0 <u>GOVERNMENT FURNISHED INFORMATION</u>.

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

5.0 <u>DELIVERY REQUIREMENTS</u>. (Identify the deliverables of the project).

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

5.2 The Contractor shall provide the executable of the test data based computer software together with the user's manual.

5.3 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 <u>PERIOD OF PERFORMANCE</u>.

6.1 Project Initiation Date: date of award.

6.2 Project Completion Date: 12 months from the date of award.

7.0 <u>GOVERNMENT ESTIMATE</u>. These contractor direct costs are based on previous project participation expenses.

7.1 Project Duration: 12 months.

7.2 Total Estimate: $ 100,000

7.3 The Independent Government Cost Estimate is attached as enclosure (A2).

8.0 <u>REFERENCES</u>.

8.1 O.F. Hughes and J.K. Paik, Ship structural analysis and design, The Society of Naval Architects and Marine Engineers, Alexandria, VA, USA, 2013.

8.2 J.K. Paik, Ultimate limit state analysis and design of plated structures, 2nd Edition, John Wiley & Sons, Chichester, UK, 2018.

8.3 J.K. Paik, Advanced structural safety studies with extreme conditions and accidents, Springer, Singapore, 2019.

8.4 J.K. Paik and A.K. Thayamballi, Ship-shaped offshore installations: design, building, and operation, Cambridge University Press, New York, NY, USA, 2007.

9.0 <u>SUGGESTED CONTRACTING STRATEGY</u>.

9.1 Contracting strategy. The proposal shall describe the details of test facilities that will be employed for the material testing of ship structural steels at cold temperatures / cryogenic condition with strain rates.

10.0 PROJECT TIMELINE (A1).

Month	01	02	03	04	05	06	07	08	09	10	11	12
Literature review												
Material testing												
Computer software												
Advanced computational models												
Reporting												

11.0 COST ESTIMATE (A2).

Item	Description	Sub-total
Labor	• 1 PhD student. $3,000/m × 12 months = $ 36,000 • 1 technician. $3,000/m × 3 months = $ 9,000	$ 45,000
Procurement for material testing at cryogenic condition	• Mild and high tensile steels, Grades A, D, and E • Liquefied gases • Test set-up	$ 20,000
Technical meetings, travels, etc.	• 6 technical meetings • 1 travel • Miscellaneous	$ 10,000
Overhead	25% of total	$ 25,000
Total		$ 100,000