1.0 **OBJECTIVE.**

1.1 The objective of this project is to systematically study the effect of various types of structural damage on the hull girder ultimate strength using state of the art nonlinear finite element analysis techniques as well as to identify the most suitable modeling techniques. The results of this study could aid in rapid hull girder residual strength evaluations following an accident, and for improving the criteria for ship residual strength requirements.

2.0 **BACKGROUND.**

2.1 The hull girder failure is considered to be one of the most critical failure modes for many ship types. It usually occurs suddenly with severe consequences such as loss of life, environmental pollution, and significant financial losses. Catastrophic hull girder failures can happen due to:

- Severe environmental loads such as waves in extreme storm conditions;
- Human error such as overloading of the ship structure;
- Poor maintenance and occurrence of excessive corrosion and cracks on critical parts in the ship structure;
- Collision or grounding damage after which the hull girder ultimate capacity can be severely diminished;
- Any combination of the aforementioned causes.

Currently available methods for intact ultimate strength calculations can be categorized, in the increasing order of accuracy and complexity, as follows:

- Simple Beam Theory;
- Presumed Stress Distribution Methods (Caldwell 1965, Paik and Mansour 1995);
- Smith’s Idealized Structural Unit Method (Smith 1977);
- Intelligent Supersize Finite Element Method (Paik 2006);
- Nonlinear Finite Element Method (NLFEM).

This project focuses on estimating the hull girder vertical bending moment ultimate capacity in a damaged condition using the most advanced method – NLFEM. Accurate calculation of the residual strength is very important for a number of reasons including:

- Calibration of requirements governing the residual strength requirements of ship hulls;
- Establishing a matrix of residual strength values for most commonly experienced damage types and extents, which can be used in emergency situations for rapid residual strength estimates of severely damaged ship hulls;
- Evaluating ship residual strength by modeling the actual damage as a part of rapid response actions in emergency situations.

2.2 Calculations of the hull girder residual strength presents more challenges than the ultimate strength calculations in the intact condition. For the purposes of establishment of damage case scenarios, a statistical analysis of recorded severe ship hull damages is required. Hydrostatic and stability analysis of the damaged vessel is also needed in order to calculate the additional hull girder loads due to flooding and resulting trim / list. The neutral plane of the damaged cross section rotates due to asymmetry of structure and loading. This has to be taken into account by the analysis method. Finally, the method for residual strength calculation must facilitate proper modeling of the damage to the transverse structure which provides support for the longitudinal structural members.
2.3 The most advanced analysis technique for residual strength calculations that is available today is the NLFEM. It satisfies the requirements of the previous section, it gives a refined computation of the progressive collapse behavior, it accounts for the interaction between the local and global failure modes, and it accounts for geometric, as well as material nonlinearities. When using the NLFEM, it is very important to assess the adequacy of the modeling techniques applied since the results that the method produces can be completely wrong if inadequate models are used to represent the damage.

2.4 Although the hull girder ultimate strength in the intact condition has been extensively studied, the residual strength calculations using the most advanced analysis techniques are still scarce. This is in part related to complexities and time requirements associated with the nonlinear finite element modeling and analysis. Aspects of the NLFE residual strength analysis that have to be specially considered are: fine mesh modeling of the hull flanges, modeling of the structural damage, applied loads in addition to the vertical bending moment, boundary conditions, longitudinal extent of the model, geometric imperfections applied, and the numerical algorithm and stabilization techniques used. The uncertainties related to the damage type, location, and extent also contribute to the complexity of residual strength calculations. The proposed project will address these issues identifying the most suitable approaches and perform a number of residual strength case studies on different ships for different damages. Results of this project could provide a basis for verification of published requirements, e.g., ABS July1995, ABS November 1995, IACS CSR 2012.

3.0 REQUIREMENTS.

3.1 Scope.

3.1.1 The Contractor will conduct an assessment of the state of the art in hull girder residual strength calculations, as well as review the existing databases on hull girder damages due to accidents (collisions and groundings). These damages will be categorized according to their type, size, location, frequency, and consequence. A damage risk matrix will be calculated to facilitate the selection of damage cases and ship types associated with those damages.

3.1.2 The Contractor will identify the current practices for nonlinear finite element modeling and analysis. These will later be applied and tested. The ones that offer the best tradeoff between efficiency and accuracy will be identified for future use.

3.1.3 The Contractor will conduct the residual strength evaluation for selected:

- ship types;
- ship sizes;
- damage type;
- damage location and extent;
- finite element model parameters (length, mesh size, boundary conditions, initial geometric imperfections, numerical algorithm, and stabilization techniques);

3.1.4 The Contractor will assess the sensitivity of hull girder residual strength to selected parameters mentioned in Section 3.1.3.

3.1.5 The Contractor will present all the results in the form of a report and submit it to the Ship Structures Committee.

3.2 Tasks.
3.2.1 Literature survey on nonlinear finite element analysis with applications to hull girder residual strength (2 weeks).

3.2.2 Literature survey on databases of ship accidental damages. These databases provide valuable historic data on accidental damage type (grounding, collision), damage extent, and location (2 weeks).

3.2.3 Categorize accidental damages according to their size, location, frequency, and consequence and establish the risk matrix which will serve as criteria for damage parameter selection (2 weeks).

3.2.4 Select the ships associated with identified critical damage cases (2 weeks).

3.2.5 Build a series of generic finite element models of selected ships. Different approaches to FE modeling will be tested such as model extent, mesh size, boundary conditions, and initial geometric imperfection models (4 months).

3.2.6 Perform nonlinear finite element analysis of hull girder residual strength for selected combinations of ship type, ship size, damage parameters, and model parameters. Special attention will be given to modeling of the ship load combinations in the damaged condition (2 months).

3.2.7 Identify the relationship between model parameters and the efficiency and accuracy of the final solution. Propose best practices for future analyses (1 month).

3.2.8 Assess sensitivity of the hull girder residual strength to values of the selected parameters from Section 3.1.3 (2 months).

3.2.9 Compile all the results and findings in a report and submit it to the Ship Structures Committee (1 month).

3.3 Project Timeline.
The project will be completed in one calendar year from the date of contract award. Project timeline is indicated in brackets in Section 3.2.

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 Project Technical Committee, 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 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.

7.2 Total Estimate: $50,000

8.0 **REFERENCES.**


8.4 IACS (2012), CSR Double Hull Oil Tanker;


9.0 **SUGGESTED CONTRACTING STRATEGY.**

9.1 Proposed work will be performed by American Bureau of Shipping (ABS), Houston, TX. ABS has personnel with experience in nonlinear finite element modeling and analysis, as well as in the ultimate strength calculations.