

Reliability-Based Performance Assessment of Damaged Ships

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1.0 OBJECTIVE.

1.1 The objective of the proposed research is to develop a reliability-based analysis procedure for determining survivability, recoverability and operability of damaged ships, adopting a systematic approach. The wave excitation loads will be predicted by a non-linear method. The experimental study will compare the results obtained from the prediction with those obtained from measurements. The ultimate hull girder strength of damaged ships will then be evaluated considering effects of horizontal bending moment and shear. The reliability of damaged ships will be estimated, and a reliability-based decision format will be developed for damaged ships.

2.0 BACKGROUND.

2.1 A large number of ship accidents continue to occur despite the advances in navigation systems. So it is very important to ensure an acceptable safety level for damaged ships. In 1995-2000, 1336 ships were lost, with 6.6 million gross tonnage cargo loss and 2727 people reported killed or missing (Lloyd's Register, 2000).

Conventional design, assessing an adequate structural strength in intact condition, does not necessarily guarantee an acceptable safety margin in damaged conditions. However, when a ship is damaged the operators need to decide the immediate repair actions by evaluating the effects of the damage on the safety of the ship using residual strength assessment procedure. International Maritime Organization (IMO) has therefore proposed an amendment, which states: 'All oil tankers of 5000 tonnes deadweight or more shall have prompt access to computerized, shore-based damage stability and residual structural strength calculation programs.' Pioneer research work in this area has assessed: residual strength of damaged ships and offshore structures (Smith and Dow, 1981); simplified method for assessing residual strength of hull girders of damaged ships (Qi, et al 1999); use of the section modulus to indicate the residual strength of damaged ships (Wang, et al 2002). Other papers also discuss residual strength of damaged ships, but all these studied the ultimate vertical bending moment capacity without considering the effect of horizontal bending moment, and the torsion and critical load case were not evaluated. Hence, the assumption was that the worst load case was vertical bending moment, and that horizontal bending moment and torsion are negligible, which may only be valid for intact ships. The floating condition of a damaged ship is normally quite different from its intact condition, and the worst load case could be quite different from its

intact condition, e.g. the most critical condition of a damaged Ro-Ro ship is in quartering seas (Chan, et al, 2001).

This project will provide ship owners and operators with needed tools and processes for improved decision-making in the operation of conventional existing ships as well as lightweight, high-performance, littoral combat craft given degradation or damage to the ship structure. Damage mechanisms include collision, corrosion, fatigue cracking, and combat.

Recognizing the urgent need of this research, Office of Naval Research (ONR) has decided to partially sponsor the project since July 2004 for two years. The present project proposal is to apply for SSC sponsorship to complement ONR funding.

2.0 REQUIREMENTS.

2.1 Scope.

3.1.1 The Contractor shall conduct experimental investigation of wave-induced hydrodynamic loading on a damaged ship so that these results could be used to validate the theoretical model and to provide model uncertainties for reliability analysis.

3.1.2 The Contractor shall carry out reliability analysis of a damaged ship so this will form the basis for developing reliability-based decision-making procedure.

3.2 Tasks.

The major tasks proposed in this project are as follows:

3.2.1 Task 1: Experimental Investigation of wave-induced hydrodynamic loading on a damaged ship. Participants: UNew and NSWCCD; Time: 20 months

A segmented model of ships will be constructed. The model, which will have a damaged compartment, will be equipped with load and pressure gauges to measure global vertical and horizontal bending moment, shear forces and torsion at two stations, and local pressures inside the damaged compartment. The motion responses will be measured in six degrees of freedom with a Sellspot system. The model will be tested in a number of regular waves and irregular sea states.

Tools for predicting the hull girder loading of a damaged ship under asymmetric loading has been developed at University of Newcastle, but requires validation through measurements and improvement/enhancement. The experimental results will be correlated with those of theoretical models, which are developed in the project sponsored by ONR. In addition the model uncertainty, which is defined as the ratio of experimental results to predicted results, of the numerical method will be calculated.

As pointed out in the previous sections, the worst load case of a damaged ship could be quite different from its intact condition. The most critical load case will be determined through proper strength assessment, which is one of the main tasks in Task 2. The results of the model uncertainty and the different load scenarios will be passed on to the University of Glasgow & Strathclyde team for strength assessment and reliability calculation.

3.2.2 Task 2: Reliability analysis of damaged ships Participants: UG&S and NSWCCD; Time: 20 months

Prediction of ultimate strength of damaged ships will be assessed by using a two-dimensional method (Smith and Dow, 1981), which provides reasonably accurate results and is suitable for being integrated in reliability analysis (ISSC,1997). As pointed out in the previous section, the existing studies neglect the effects of horizontal bending moment and torsion on the ultimate vertical bending capacity. In the proposed work, the effects of horizontal bending moment, shear forces, torsion and lateral load on vertical bending moment will be assessed. The cross-section of a ship will be divided into many elements, such as stiffened panels, unstiffened panels. The progressive loss of stiffness caused by buckling and post-buckling load-reduction in elements can be considered. The curvature of the hull girder is applied incrementally. For each increment, the corresponding strains in all the elements are calculated under the assumption that the cross-section plane will remain plane. The stress in each element will then be calculated from the stress-strain relation, which is predicted in advance by a non-linear analysis (Dow, 1980). The increment of bending moment of the cross-section can be obtained by integrating the stresses of all elements. In this way, the bending moment-curvature relationship of the cross-section is established. So the ultimate strength (maximum bending moment) of the cross-section is obtained.

When Smith's method is applied to damaged ships, the damaged part of the ship is normally assumed being fully cut off. This simplified way to consider the effects of damage is quite conservative. To investigate the accuracy of Smith's method in this case, a full non-linear explicit finite element code, ANSYS LS-DYNA, will be used to predict the extent of damage in a collision. The effects of assumed failure strain, friction coefficient, loading condition and the forward speed of the striking speed on the collision damage will be investigated. On the top of this analysis, another non-linear finite element analysis will be applied to predict the ultimate strength of the hull girder with the extent of damage determined in the above non-linear collision analysis. The results will be compared with Smith's method.

The ultimate strength of hull girder will be compared with the extreme hull girder loads, which are predicted in Task 1, so that the safety margin for each load conditions can be evaluated, and the most critical load case can be determined.

A simulation-based reliability method and Smith's method for predicting ultimate strength of hull girder will be integrated. Reliability of a damaged ship will be predicted.

3.2.3 *Task 3: Write final report* Participants: UNew, UG&S and NSWCCD;
Time: 4 months

4.0 GOVERNMENT FURNISHED INFORMATION.

4.1 *Final Report Style Manual. See Enclosure (2).*

5.0 DELIVERY REQUIREMENTS.

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, formatted as per the SSC Report Style Manual. In the report, the details of experimental results and their correlation with theoretical results shall be included. In addition the reliability of the damaged ship shall be reported.

6.0 PERIOD OF PERFORMANCE.

0.1 Project Initiation Date: date of award.

0.2 Project Completion Date: 24 months from the date of award.

1.0 GOVERNMENT ESTIMATE.

1.1 Project Duration: 24 months.

1.2 Total Estimate: \$US 100,000.

2.0 REFERENCES.

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3.0 SUGGESTED CONTRACTING STRATEGY.

9.1 The project is preferred to be contracted directly with individual members of the consortium separately.