Mean Stress Assessment in Fatigue Analysis and Design

Submitted by:
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1.0 OBJECTIVE

1.1 The mean stress is an important component of loading history and fatigue of ship hull structural details. When tensile, it increases maximum stress in the load cycle and reduces fatigue life of structural components. The lack of commonality between different approaches makes it necessary to validate the models, and to harmonize the codes.

1.2 However, in case of combination of random and constant loading components the appropriate methodology of assessing effects of mean stress is lacking.

1.3 The objective of the project is to review the available data on the subject, to plan and carry out experiments on a structural steel, to analyze the results and to develop methodology of assessment of the mean stress effects in fatigue analyses for marine applications.

2.0 BACKGROUND

2.1 The design codes of hull and marine welded structures recently mostly neglected influence of mean stress on fatigue performance of critical details. A survey carried out in 2003 by ISSC reported that 6 out of 8 major classification societies used a mean stress correction factor. In the recently adopted Common Structural Rules for Tankers and Bulk Carriers (IACS, 2005) mean stress corrections are implemented, albeit in a very different form for tankers and bulk carriers respectively. Procedure of considering it suggested recently in IACS documents in the form of introducing an equivalent stress, which allows to take into account residual welding stress and mean stress due SW loading condition.

2.2 However, application of corrections and of equivalent stress may be regarded only as an approximation since it is based on implied assumption of combined cyclic stress with constant amplitude and mean stress.

2.3 Specific property of load sequences in marine applications is the combination of a narrow-banded random wave loading and of slowly varying (or constant) loading regarded the source of mean stress. This means that the implied experimental procedure and respective modeling of fatigue behavior of material should consider the effects of mean stress in conjunction with realistic variable amplitude loading. This would reveal specific properties of cyclic strain hardening or softening of
particular material and the nature of the damage. Such approach to fatigue analysis of materials and structures would allow to physically and quantitatively more precisely assess fatigue properties of hull structural components.

2.4 An important component of stress field in a ship structure is residual welding stress. Typically, areas of residual stress are superimposed with the stress concentration due to geometry of structural details. Occasional relatively high wave loads may cause part relief (shakedown) of residual stress in stress concentrations with resulting effect on the local load ratio and on fatigue resistance. These effects should be assessed based on the present knowledge and experimental program, feasible within the frames of the time and cost of the project. Respective recommendations should be developed.

2.5 These are the reasons for development of a procedure of fatigue analysis and design of structural components considering effects of mean stress.

3.0 REQUIREMENTS (Performing the following tasks)

3.1 Task 1: Literature survey

(1) Literature review of relevant available experimental data on the mean stress and residual stress effects related to the crack initiation phase of fatigue of structural steels and structural details.

3.2 Task 2: Construction of Test Equipment and Manufacturing of Specimens

(1) Construction and manufacturing of test equipment (grips providing precise axial loading, transducers for strain measurements and records)

(2) Manufacturing of steel specimens (a low carbon mild structural steel is assumed appropriate material)

(3) Development of software for test sequences aimed at providing parametric tests at variable standard deviation of the oscillating load component and mean load (a Gaussian correlated process with Raleigh load range distribution should be modeled)

3.3 Task 3: Experimental Procedure

(1) Tensile testing of selected material to characterize mechanical properties.

(2) Cyclic testing of hourglass specimens under strain-control conditions aimed at evaluation of the material fatigue failure criterion

(3) Cyclic testing of specimens at block-program loading sequences comprising constant-load component with varied parameters under strain-control conditions

(4) Cyclic testing of plate specimens with a stress concentration at block-program loading sequences comprising constant-load component with varied parameters
(5) Combined random-load plus constant load testing with varied parameters of specimens under strain-control conditions

(6) Fatigue testing of specimens at combined random-load plus constant load sequences in the range of fatigue lives where intelligible inelastic strain might be recorded and analyzed. The tests will be aimed at evaluation of appropriate criterion for material failure.

(7) Fatigue testing of welded specimens that contain large welding residual stresses, for investigation of:
Shake-down of residual stresses due to load cycles simulating extreme load cases for a hull structure
Fatigue strength (SN curve) for welded joints that have been subjected to shake-down, and for load histories with tensile, zero and compressive mean stress.

3.4 Task 4: Analysis of test results and development of appropriate fatigue model

(1) Analysis of constant strain-range and block-program loading tests results should be performed aimed at evaluation of similitude of inelastic material response. A preliminary fatigue model of material should be developed.

(2) Analysis of combined random-load plus constant load tests results aimed at validation check of the preliminary material model efficiency. Adjustment of the preliminary material model.

(3) Analysis of block-program loading tests results of specimens with stress concentration aimed at evaluation of similitude of inelastic material response in stress concentration. FE re-analysis of tests results. Validation of the material model.

(4) Analysis of welded test models that have been subjected to residual stress shake-down with respect to remaining residual stress, and fatigue strength for load histories with zero and compressive mean stress.

(5) Composing the progress reports, draft the final report, and presenting the final report to the Project Technical Committee (PTC).

3.5 Project Timeline. See Enclosure (1).

4.0 GOVERNMENT FURNISHED INFORMATION


5.0 DELIVERY REQUIREMENTS

5.1 Quarterly progress reports to the Project Technical Committee, the Ship Structure Committee Executive Director, and the Contract Specialist.

5.2 Final report presenting suggested material model and methodology of fatigue analysis considering effects of mean stress at the completion of the project (paper copy
and on 3.5” diskette in MS Word format) including the above deliverables formatted as per the Final Report Style Manual.

6.0 PERIOD OF PERFORMANCE

6.1 Project Initiation Date: Date of Award.

6.2 Project Completion Date: 15 months from the Date of Award

7.0 COST ESTIMATE.

7.1 Project Duration: 18 months.

7.2 Total Estimate: $74,136.

7.3 The details of cost estimate are attached as enclosure (3).

REFERENCES


Enclosure (b)

Project cost estimate

1. Direct labor cost (2 Project advisers, 1 fatigue analyst, 2 FE analysts, 2 technicians and 3 senior students, both, in Norway and Russia) ($23,20, Norwegian team, $23,80, - Russian team),

   total                                                                                             - $47,000

2. Fringe (Government established labor tax, in Russia) – 26.2% of the direct labor cost,

   $6,236

3. Other direct costs (Travel, expendables)

   - $17,000

   Subtotal:                                                                                               $70,236

4. Overhead (University established): 0.1 of the total project cost (Russian share - $40,936)

   - $3,900

Totalcost:                                                                                                     $74,136

Note: The detailed description in the form advised by SSC to be submitted if the project would be accepted
### Project Timeline

(Approximate; to be refined if accepted)

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