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An Overview of Fatigue Assessment and Control in Naval Welded Details

by

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ABSTRACT

QETE surveyed the current literature on fatigue design procedures, analytical methods and fatigue control in welded structural details in surface ships. The survey addressed the issues of material selection, geometry of fabricated detail, post fabrication processes and availability of fatigue design data for specific steels on the CPF. Most of the reported Canadian tests had been conducted on thick steel plates for offshore structural platforms to improve weld profiles and corrosion protection. QETE found that the US Coast Guard had published an extensive materials data Handbook which contained data from thousands of tests on eleven structural steels commonly applied in surface ship construction. The databases include tensile strength and Charpy impact values, DT energies, NDTT and J_{Ic} values for a limited number of critical design details. The US Handbook contains fatigue design data for two steels which match the composition and constituents of two Canadian steels. It was concluded that there is a need to generate fatigue design and durability data for susceptible structural details manufactured from ASTM A715, ASTM A570 and CSA CAN3-350WT steels.

QETE Tasking on Fatigue of Welded Ship Details

- Determine the feasibility of generating material database for CPF steels.
- Review fatigue control approaches and life assessment of weldments.
- Review the current developments on application of Marine Structural Integrity Program (MSIP).

Considerations

- The majority of accidents are unrelated to the ship structures.
- Corrosion and fatigue cracking are responsible for structural failure,
- Fatigue cracking is generally associated with welds and stress concentrations in the critical joints.

Points to Remember

- Management of corrosion and fatigue are of paramount importance.
- Economic pressures have forced reductions in the time allocated for design, inspection, QA and maintenance.
- Most of ship structural problems are associated with durability design considerations and/or maintenance procedures.

Steels In The CPF

- HIGH STRENGTH STEEL for ballistic protection: ASTM 715 gr. 70.
- HIGH STRENGTH STEEL for No. 1 plating & flight decks: ASTM 517* gr F
- MEDIUM STRENGTH STEEL for primary and superstructures: CSA CAN 3- G40.21-350 WT*
- (ASTM A 570 gr 50) & ASTM 572* gr.50
- REGULAR STRENGTH STEEL: for other applications.

CPF Material Systems of Interest

- CSA CAN 3- G40.21-350 WT
- ASTM A517 Grade F
- 350 WT/E7018/350 WT (Weldment)
- A517 / E11018M /A517 (Weldment)
- 350WT / E7018M /A517 (Weldment)
- 350 WT / E11018M / A517 (Weldment)

Available Fatigue Data in the Marine Structural Hdbk

- Data were generated from 10000 tests of 11 steels including : ABS EH-32, ABS-36, A36, A572, A588, A710/ A710A, HY 80, HY100 and BS 4360. The following properties are listed:
- Fracture toughness (J1c).
- Tensile strength (UTS & yield).
- Charpy impact values.
- Dynamic Tear DT energy and NDTT.

Classification of Marine Steels

- HSLA Steels containing Ni, Cr, Mn & Mo: (A 514, HY 80 & HY100)
- HSLA Steels containing Cu, Ni, Cr & Mo: (A710 & HSLA 80).
- Medium/high strength Steels containing Mn: (A537, A656, A737 & ABS-EH36)
- Medium/low strengthSteels containing Mn: A36, A572, A588, A633 & BS4360.

Steels for Marine Applications

- The specifications and properties of marine steels overlap;
- Steels of close composition may not be completely equivalent for the same application due to heat treatment and/or fabrication practices; and
- A great amount of information is required for building useable material engineering database for design.

Priority & Equivalent Marine Steels

Priority steels	Equivalent steels
HY 80	A543
A710 gr. A	A736
ABS EH36	A737 gr. B
A514E	A517 E
HY100	A543 gr. C

Fatigue Data Needed for CPF Steels

- There is a need to generate fatigue data for critical design details manufactured from ASTM 715 gr.70, ASTM A570 and special alloy steels which are unique to CPF.
- Critical weldments has to identified for planning future maintenance.

Further Research on Ship Structural Details

- Develop a database of mechanical properties and characterize crack growth, propagation and arrest in critical details of the CPF.
- Conduct engineering analysis to determine stress levels acting on critical welded details using adequate modeling techniques.

Classes of Ship Details

- Type 1, non weldable details;
- Type 2, welded details on surface; and
- Type 3, welded details at end connections of joints.

Classification of Structural Details

- Details are classified in terms of the following variables:
  - Direction of applied stress relative to the structural detail;
  - Location (s) of possible crack initiation;
  - Geometrical configuration of the detail; and
  - Method of manufacture and inspection.

Cracked Fatigue Details and Availability of Data

- See Table 5.1 pg 39 in SSC 318, Fatigue Characterization of fabricated ship details
- Include structural details in fig. B.1 page 131-133.

Fatigue Cracking & Durability Design

- Fatigue Cracks occur at:
  - bracketed end connections of supporting structural details;
  - openings & cut-outs in primary structures;
  - intersection of welded detail with bulkheads;
  - discontinuities in highly stressed details, and
  - bad weld profiles .

Causes of Fatigue Failure of Welded Ship Details

- Low quality construction, poor welding, assembly & maintenance practices;
- Weld failure, incomplete fusion, undercut;
- Inappropriate design or poor materials;
- Inadequate NDT inspection; and
- Frequency and amplitude of random loading at low temperature.

Common Problems in Fatigue Design of Ship Details

- Service loads differ greatly from loads that are used in laboratory simulation.
- Fatigue design criteria are based on constant amplitude/Cycle fatigue data from smooth specimens in the laboratory.
- Fatigue resistance information is not available for all the structural details currently found in ship construction.

Issues That Impede Reliable Design

- There is a lot of variety of welded joints;
- Weldments of the same joint type are not usually alike;
- The behavior of simple weldments can be very complex; and
- Stresses in a weldment are not precisely known.

Factors Affecting Fatigue Behavior of Welded Details

- **Geometry and Configuration of the detail;**
- **Stresses and Loading conditions including: amplitude, frequency, directionality of random loads and residual stresses;**
- **Steels from which the structure is fabricated (yield strength ranges from 30 to 100 ksi)**
- **Quality and integrity of the Weld .**

Fatigue Design Process

- **SSC 318- FATIGUE CHARACTERIZATION OF FABRICATED SHIP DETAILS FOR DESIGN (PHASE 1), 1983**
- **SSC 346- FATIGUE CHARACTERTIZATION OF FABRICATED SHIP DETAILS FOR DESIGN (PHASE 2), 1990**
- **D-03-002-008/SG-001- DESIGN PROCDURES FOR CF SURFACE SHIP STRUCTURES 1993/94**
- **D-03-002-008/SG-002- STRUCTURAL DESIGN OF CF SURFACE SHIPS. 1993/94**

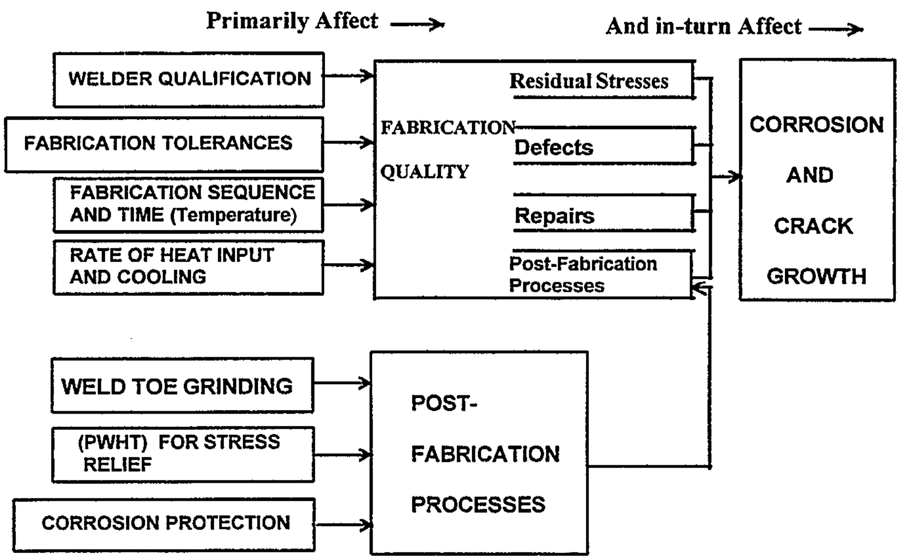
Design Parameters for Ship Structures

- Component Characteristics and Structural Details.
- Global Configuration
- Material Selection.
- Fabrication procedures and Specifications.

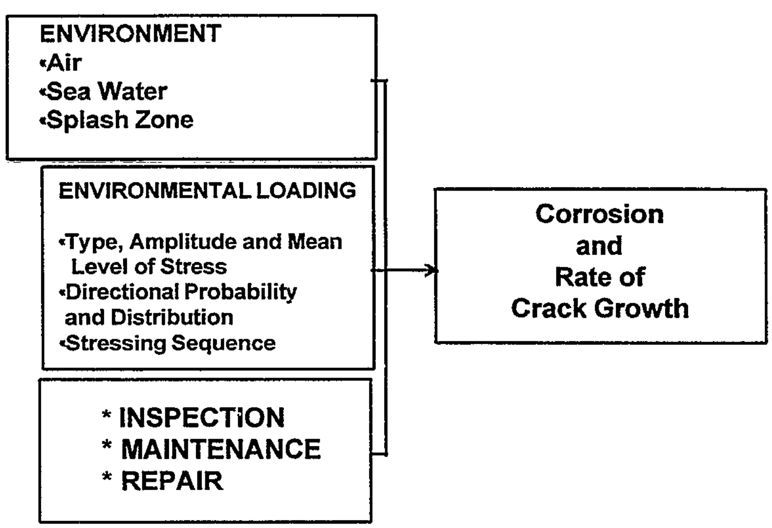
Design Parameters

	Primarily Affect →
GLOBAL CONFIGURATION	Applied Forces Structure Response Structure Redundancy
COMPONENT CHARACTERISTIC AND STRUCTURAL DETAILS	Stress Levels Stress Concentration Access, Workmanship and Details
MATERIAL SELECTION	Chemical Composition and Weldability Mechanical Properties and HAZ Corrosion Fatigue Behavior
FABRICATION PROCEDURE AND SPECIFICATIONS	Local Deformations and Residual Stress Pattern Defect Distribution and Initial Rate of Growth

Fabrication and Post-Fabrication Parameters



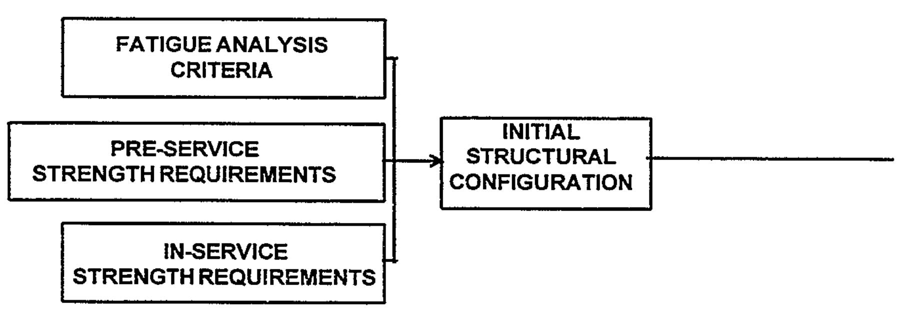
In-Service Parameters



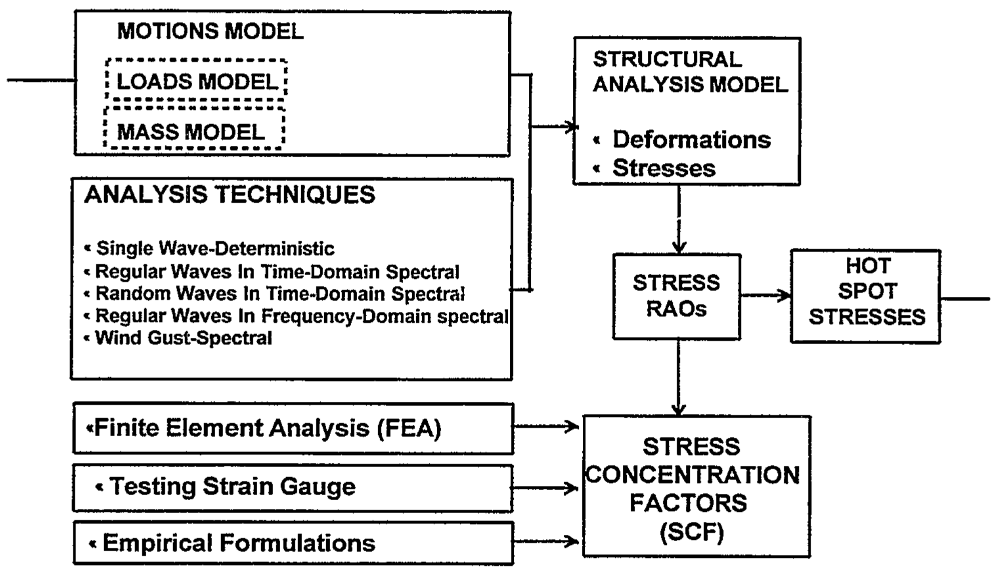
Fatigue Anlaysis Models & Parameters

- **SSC 346 1990**
- **SSC-367 May 93**
- **Naval Platform Fatigue Considerations by J.F. Porter, DREA, Halifax, December 1993**
- **Residual Strain Effects on Fatigue Crack Initiation and Growth in Marine Structures- Literature Review by L.Malik, Fleet Technology Inc., Ottawa 1993**

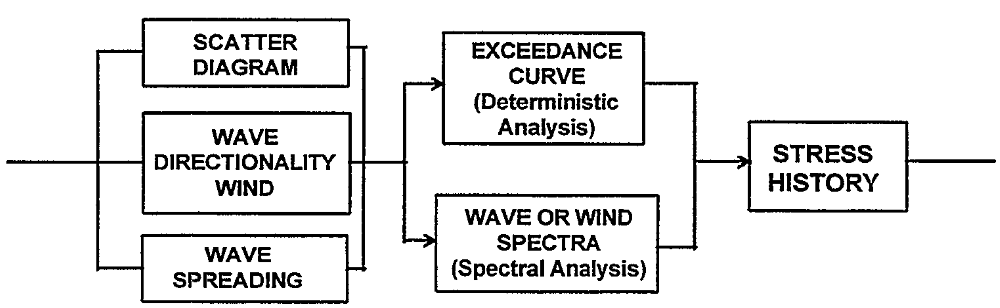
Global Parameters



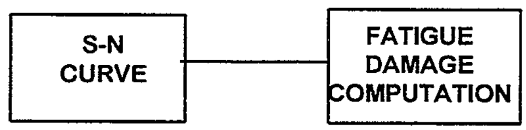
Stress Model Parameters



Stress History Model Parameters



Fatigue Damage Computation Parameters



TYPICALLY UNACCOUNTED PARAMETERS

- Stress Sequence
- Maintenance/ Repairs
- Lapses in Corrosion Protection

Effect of Materials on the Integrity of Welded Details

- Ship steels exhibit adequate damage/ flaw tolerance under service conditions IF the structural details and welds are designed and fabricated properly.
- Fatigue crack initiation and propagation lives are insensitive to material properties of welded structural details.
- The quality and integrity of the welds are the main controlling factors.

Effect of Weld Profile and Attachment Thickness

- Improved weld profiles delay crack initiation and increase propagation lives.
- Concave weld profiles reduce stress concentrations at the toes, which in turn, extend fatigue life of the structure.
- Fatigue strength is reduced when the section thickness of the detail is increased.

Effect of Stress Cycles on Fatigue of Weldments

- (S-N) Fatigue data are generated under constant amplitude cyclic conditions;
- Fatigue resistance is a function of the alternating stress range and mean stress;
- The Stress range is the most important factor controlling the fatigue life of welded ship details.

Effect of Stress on Fatigue Behavior of Details

- Residual stresses caused by welding and/or assembly may significantly affect fatigue life of cetrtain types of structural details.
- Variable alternating random loads may degrade fatigue life.
- Repeated loadings and stress concentration factors tend to equalize the fatigue resistance of the structural detail regardless of the type of steel used.

Conclusions

- Fatigue strength of steel weldment does not increase in proportion to the increase in yield or ultimate strength. Increased strength is beneficial only in the <u>initiation phase in smooth specimens.</u>
- Fatigue life of weldments is dominated by <u>crack propagation phase.</u>
- The use of high strength steels in fabricated ship details facilitates fatigue cracking .

Fatigue Behavior of Welded Details

- <u>Effects of Residual Stresses</u>: may be negligible.
- <u>Effect Of Material:</u> may be negligible since fatigue life of the weldment is spent in propagating welding flaws and/or internal defects.

Ways to Control Fatigue and Fracture

- **Minimize weld defects during fabrication;**
- **Minimize Stress Concentrations and misalignments in structural weldments;**
- **Avoid welded joint eccentricity;**
- **Design the details for NDT inspection;**
- **Enforce adequate QA/QC procedures; and**
- **Minimize degradation of the assembled details.**

Improvement of Fatigue Behavior of Welded Details

- Reduction in stress concentrations by modifying the weld profile;
- Removal of Weld toe defects;
- Improvement of welding practices and control;
- Introduction of Local Compressive stresses by shot-peening of the weld;

MARINE STRUCTURAL Integrity PROGRAM (MSIP)

SSC-365/1991

Summary

Marine Structural Integrity Program (Msip)

- The objective is to develop procedures for the definition of advanced marine structural integrity program that would ensure more effective inspection, proper maintenance, and economical operation of naval vessels.

Msip- Design Objectives

- Create an efficient and durable Ship structural details which are devoid of unanticipated costly maintenance requirements.
- Ensure that the structure is able to withstand the expected maximum lifetime loading without significant deformation.

Components of MSIP

- Identification of critical components and potential failure modes
- Material selection
- Durability and damage tolerance analysis.
- Inspection strategy
- Tracking of individual structures.
- Full scale testing of critical structures.
- Management of aging structures
- Record keeping of structural maintenance.

Durability & Design Considerations

- Materials
- Connections, welding and fasteners systems;
- Structural configuration,
- Design stress levels,
- Manufacturing Processes & controls,
- Inspection level and quality,
- Interacting variables during design and fabrication.

Fatigue Analysis Tasks

- Characterization of short and long term cyclic loading conditions.
- Determination of the cyclic forces and strains in the critical details and components.
- Determination of potential degradation in strength and corrosion resistance of weldments.

MSIP- Fatigue Fracture Control Approaches

- Design and Fabrication of the Detail IAW to Specific Codes;
- Structural design based on redundancy and multiple load paths;
- Fail-safe design by including crack arrest provisions, such as using damage tolerant steels and geometric interruptions.