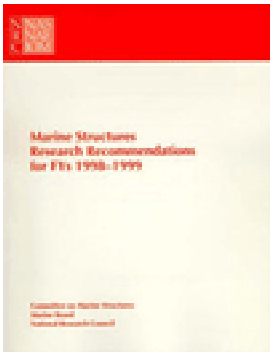

Marine Structures Research Recommendations

Recommendations for the Interagency Ship Structure Committee's FYs 1998–1999 Research Program

Committee on Marine Structures
Marine Board
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C.1994

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the panel responsible for the report were chosen for their special competencies and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This report represents work supported under provisions of Contract DTCG23-93-C-EO1037 between the National Academy of Sciences and the U.S. Coast Guard, acting for the Ship Structure Committee. This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States government and the Ship Structure Committee assume no liability for the contents or use thereof.

Limited copies are available from
Marine Board
Commission on Engineering and Technical Systems
National Research Council
2101 Constitution Avenue
Washington, DC 20418

Additional copies are for sale from either National Academy Press Box 285 2101 Constitution Avenue Washington, DC 20055 800-624-6242 202-334-3313 (in the Washington, D.C. Area) http://www.nap.edu
International Standard Book Number 0-309-05786-8

Additional Copies are for sale from
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

Printed in the United States of America

COMMITTEE ON MARINE STRUCTURES

The Committee on Marine Structures (CMS) provides technical projections, reviews, and advice to the interagency Ship Structure Committee (SSC) on a research program that addresses materials, design, fabrication, and inspection related to marine structures. The appendices address the relationship of the CMS, the SSC, the Ship Structure Subcommittee (SSSC), and liaison members.

JOHN LANDES (chair), University of Tennessee, Knoxville
HOWARD M. BUNCH, Office of Naval Research—Europe, London, England
DALE G. KARR, University of Michigan, Ann Arbor
ANDREW KENDRICK, Fleet Technology Ltd., Montreal, Quebec, Canada
JOHN NIEDZWECKI, Texas A&M University, College Station
ALAN W. PENSE, **NAE**, Lehigh University, Bethlehem, Pennsylvania
BARBARA A. SHAW, Pennsylvania State University, University Park

The CMS selects individuals with additional technical expertise to develop (for the CMS' consideration) research agendas in their individual areas of expertise. These individuals (comprising the work groups noted below) are not appointed by the National Research Council.

DESIGN WORK GROUP

JOHN M. NIEDZWECKI (chair), Texas A&M University, College Station
BILAL AYYUB, University of Maryland, College Park
ANDY DAVIDSON, National Steel and Shipbuilding Company, San Diego, California
OVIDE J. DAVIS, Pascagoula, Mississippi
JEFFREY GEIGER, Bath Iron Works, Bath, Maine
HUGH S. RYNN, Sea-Land Service, Inc., Elizabeth, New Jersey

MATERIALS WORK GROUP

BARBARA A. SHAW (chair), Pennsylvania State University, University Park
DAVID P. EDMONDS, Edison Welding Institute, Columbus, Ohio
HAROLD S. REEMSNYDER, Bethlehem Steel Corporation, Bethlehem, Pennsylvania

STAFF

ROBERT A. SIELSKI, Senior Staff Officer
DELPHINE D. GLAZE, Administrative Assistant
THERESA M. FISHER, Administrative Assistant

MARINE BOARD

JAMES M. COLEMAN (chair), **NAE**, Louisiana State University, Baton Rouge
JERRY A. ASPLAND (vice chair), California Maritime Academy, Vallejo
BERNHARD J. ABRAHAMSSON, University of Wisconsin, Superior
BROCK B. BERNSTEIN, EcoAnalysis, Ojai, California
LILLIAN C. BORRONE, **NAE**, Port Authority of New York and New Jersey, New York
SARAH CHASIS, Natural Resources Defense Council, Inc., New York, New York
CHRYSSOSTOMOS CHRYSSOSTOMIDIS, Massachusetts Institute of Technology, Cambridge
BILIANA CICIN-SAIN, University of Delaware, Newark
BILLY L. EDGE, Texas A&M University, College Station
JOHN W. FARRINGTON, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts
MARTHA GRABOWSKI, LeMoyne College and Rensselaer Polytechnic Institute, Cazenovia, New York
JAMES D. MURFF, Exxon Production Research Co., Houston, Texas
M. ELISABETH PATÉ-CORNELL, **NAE**, Stanford University, Stanford, California
DONALD W. PRITCHARD, **NAE**, State University of New York at Stony Brook
STEVEN T. SCALZO, Foss Maritime Company, Seattle, Washington
MALCOLM L. SPAULDING, University of Rhode Island, Narragansett
ROD VULOVIC, Sea-Land Service, Inc., Charlotte, North Carolina
E.G. "SKIP" WARD, Shell Offshore, Inc., Houston, Texas

STAFF

CHARLES A. BOOKMAN, Director
DORIS C. HOLMES, Staff Associate

Abstract

This biennial report of the Marine Board's Committee on Marine Structures proposes updates to the multiyear research program of the Ship Structure Committee (SSC). The SSC is an interagency body through which the U.S. Coast Guard, Naval Sea Systems Command, Maritime Administration, Military Sealift Command, American Bureau of Shipping, Transport Canada, and Defence Research Establishment Atlantic coordinate their research on structural integrity of marine structures. The SSC's research program is intended to accommodate advanced concepts and long-range planning. It supports research in the focus areas of materials; loading and response; design methods; productivity and producibility; and inspection, maintenance, and repair.

The updated research program covers the fiscal years (FYs) 1997–1999. The report includes (1) a comprehensive review of the entire research program, including work performed in FY 1996, work planned for FY 1997, and the rationale for new projects proposed for FY 1998–1999; (2) detailed project descriptions for the 16 projects proposed for FY 1998 and FY 1999; and (3) brief summaries of recently completed projects and all active or pending projects in the program. Two appendices provide background on the SSC, the Committee on Marine Structures, and the approved SSC Strategic Plan.

Foreword

The purpose of the Ship Structure Committee (SSC) is to promote safety, economy, education, and marine environmental protection in the U.S. and Canadian maritime industry through the advancement of marine structures technology. The role of the Committee on Marine Structures (CMS) is to advise the SSC on its research program. To accomplish this task, the CMS has developed five specific focus areas: materials; loading and response; design methods; productivity and producibility; and inspection, maintenance, and repair of marine structures.

On June 5, 1992, the SSC unanimously endorsed the SSC Strategic Plan, addressing national goals and SSC strategies in support of those goals. The plan provided the focus for the research projects and programs addressed herein. On May 10, 1994, the plan was slightly modified to reflect the inclusion of two Canadian organizations as members of the SSC: Defence Research Establishment Atlantic (DREA) and Transport Canada. Each of the projects supports at least one of the SSC national goals as well as at least one of the strategies of the plan. The above-mentioned five focus areas were developed to support these goals and associated strategies by helping the SSC enhance the design of ships and shipbuilding capability in North America, the inspectability and maintenance of aging ships, and the safety of ships at sea.

A large number of SSC projects are related to reliability of marine structures. The failures of bulk carriers and weld cracking of structural members of Trans-Alaska Pipeline Service trade tankers are cause for concern. The CMS held a short, hands-on workshop on March 30–31, 1995, that addressed fracture assessments and the application of reliability methods to real design problems. Challenges abound in this area, and the CMS addressed them in its letter report for FY 1997 and in this report.

Recognizing the strong interrelationship between materials and design, the two working groups of the CMS, the Design Working Group and the Materials Working Group, met concurrently in August 1996. This scheduling fostered enhanced communications between the two groups, which is reflected in the proposed projects for FY 1998 and FY 1999. In addition, the committee is implementing a more systematic, documented review of finished projects. This will ensure that any necessary technology extensions are adequately identified and fully considered when future fiscal year recommendations are submitted.

Four members of the CMS completed their terms of service since the last biennial report: Subrata K. Chakrabarti, Bruce G. Collipp, Roger G. Kline, and Robert G. Loewy. Five new members have been appointed to the CMS: Howard M. Bunch from the Office of Naval Research-Europe, Andrew Kendrick from Fleet Technology; John M. Niedzwecki from Texas A&M University; Alan W. Pense from Lehigh University; and Barbara A. Shaw from Pennsylvania State University.

JOHN D. LANDES, CHAIR

COMMITTEE ON MARINE STRUCTURES

Contents

List of Tables and Figures

1

Introduction

The Committee on Marine Structures (CMS) biennial report outlines a coordinated research plan for the interagency Ship Structure Committee (SSC). The SSC is an interagency body through which the U.S. Coast Guard, Naval Sea Systems Command, Maritime Administration, Military Sealift Command, American Bureau of Shipping, Transport Canada, and Defence Research Establishment Atlantic coordinate their research on the structural integrity of marine structures. Technical input to the SSC is provided by the Ship Structure Subcommittee (SSSC), which is composed of four members from each SSC member agency. The responsibilities of the CMS and its relationship to the SSC are summarized later in this chapter. They are described fully in Appendix A.

The SSC research program is intended to accommodate advanced concepts and long-range planning in support of goals set forth in its Strategic Plan. The SSC unanimously endorsed a strategic plan on June 5, 1992. This approved plan, as amended in May 1994, is reproduced in its entirety in Appendix B. Periodic review and revision by the SSC will keep the plan current with changing circumstances.

The SSC celebrated its fiftieth anniversary in 1996 and has maintained a strong research program in ship structures throughout its history. The length of the committee's involvement provides evidence of the commitment of the member agencies to continuing research into ship structures.

REPORT ORGANIZATION

This report encompasses a multiyear research planning program to develop recommendations for specific SSC research projects for fiscal years (FYs) 1998 and 1999. Research activities from FY 1997 and earlier years are also reviewed. The report contains four color-coded sections comprising the following:

1. introduction, focus areas, recommendations for the research program, and Appendices A and B—white
2. FYs 1998–1999 project recommendations—green
3. active and pending projects—yellow
4. recently completed projects—blue

In the following chapters, projects designated with an "SSC" prefix are published SSC reports; those designated with an "SR" prefix are currently being funded or are recently completed but not yet published; and those with a "98" prefix are recommended for initiation in FYs 1998–1999. A number of the projects proposed for FYs 1998–1999 are recommendations from the CMS report for FYs 1996 and 1997. These projects were reviewed by the CMS and were found relevant as written or were revised to reflect changes in technology or industry requirements. These continued projects have their previous number appended to their titles.

PROGRAM AND PROJECT DEVELOPMENT

The CMS recognizes that research in ship structures is being sponsored independently by agencies that have different overall objectives compared with those of the SSC. Therefore, the challenge to the CMS becomes one of developing research agendas and recommending meaningful and timely research programs that are complementary to the major agency-funded programs, will fill in gaps, and will provide initial guidance for, or otherwise enhance, sponsoring agency efforts. The CMS recognizes that its recommendations may become the basis for establishing agency research programs. For example, the U.S. Navy's program in reliability-based structural design stems from, and is supported by, CMS work in this area. In addition, the SSC itself is interested in leveraging its limited funds through joint industry projects and independent support.

Industries, agencies, and research committees should contact the executive director of the SSC if they are interested in projects listed in this report or in related initiatives, if they are willing to sponsor and fund a project, or if they are willing to cosponsor a project and share costs.

The CMS provides advice that is independent and objective in accordance with the National Research Council process. The CMS keeps abreast of major technical issues of interest to federal agencies and national programs in which marine structures research can have significant positive impacts. The CMS also meets regularly with the SSC and the SSSC to ensure that the research the SSC considers most important is taken into account in the deliberations of the CMS.

The CMS develops its research agendas and recommendations for programs and projects by drawing on a wide range of expertise. Its two work groups include representatives from all relevant technical disciplines, academia, the research community, and the marine industry. These groups use their own knowledge, experience, and contacts to prepare project outlines, which are submitted to the CMS for consideration and further development.

RECOMMENDATIONS FOR IMPLEMENTING THE STRATEGIC PLAN

In September 1996, the CMS held its annual joint meeting with the SSSC. In this and other 1996 meetings, the committee discussed the agency research and development programs presented at the SSSC's spring 1996 meeting; the areas of national interest that might be affected by CMS research recommendations; the availability of financial resources; and the special technical topics concerning the SSC national goals listed below:

Goal 1. Improve the safety and integrity of marine structures.

Goal 2. Reduce marine environmental risks.

Goal 3. Support the U.S. and Canadian maritime industry in shipbuilding, maintenance, and repair.

As a result of these discussions and deliberations, 16 projects—some entirely new, some continued from the 1996–1997 recommendations—were selected for inclusion in this report. Although each of the recommended projects is capable of standing alone, to provide a proper context the projects are presented as parts of total-program focus areas that support SSC strategic goals. Each project description also identifies one or more goals to which the project is particularly relevant. Finally, the projects have been prioritized on the basis of the evaluations of the work groups and other inputs to the CMS, including feedback from its meetings with the SSC and SSSC. The project numbering (98-1 to 98-16) reflects the rankings assigned. Additional criteria the CMS used in making its judgments are set forth in Chapter 4, where the project descriptions are to be found.

2

Focus Areas

The SSC serves as a coordinating body for marine structures technology. This leadership includes sponsorship, management, and coordination of research as well as information collection and dissemination. In recognition of global-scale pressures in the maritime industry, the implementation of the SSC's Strategic Plan emphasizes design tools and information systems development that encompass a broad customer base, including designers, owner/operators, educators, manufacturers, regulators, and insurers. Consequently, planned activities span the entire life cycle of ships—from identification of initial requirements through design, construction, and operation.

The past several issues of *Marine Structure Research Recommendations* grouped the proposed research projects into four thrust areas. The first area, producibility/competitiveness, sought to improve industry performance in ship design and construction. The second area, reliability, reflected a long-range program to develop a probability-based design approach for ship structures. The third area, inspection/maintenance, identified the increasing need for dealing effectively with the anticipated problems associated with an aging fleet. The fourth area, composites, identified the need for taking advantage of opportunities for utilizing advancements in new materials.

In addition to these thrust areas, the CMS linked research program development to the five technology areas of materials criteria, loading and response, design methods, fabrication and maintenance techniques, and reliability. As projects in each of these areas advanced, issues regarding the interrelationship of the CMS thrust and technology areas arose repeatedly. In the reliability studies, for example, the design life expectancy of a vessel cannot be established without considering load conditions, operational routes, material properties, and stress analyses. Composite materials cannot be used effectively without considering safety issues such as fire and toxicity, cost assessment, load-bearing capacity, and durability. Producibility/competitiveness cannot be judged solely on initial costs and requires direct linkage with design improvement, repair, inspection and maintenance cost considerations, and global market demands.

The committee reviewed its earlier organizational strategy and reached the consensus that the earlier strategy did not adequately reflect the synergism between the research projects. In light of this finding—and considering the five technology areas and the four thrust areas discussed above—the CMS established five new focus areas:

- materials
- loading and response
- design methods
- productivity and producibility
- inspection, maintenance, and repair

Each of the recommended research projects contributes to the advancement of at least one of the focus areas. Advances in each of these areas are considered to be important in achieving the strategic goals of the SSC.

Rapid changes in technology worldwide, throughout the general industrial spectrum, have enabled increasing integration of what were at one time somewhat disparate disciplines. Examples from the marine industry include structural design, ship production, fleet operations, and vessel inspection. Computer technology has provided advancements in structural analysis, computer-aided design, and data management systems. Integration of these technologies is now advancing, in particular with regard to data exchange standards. These advancements provide a basis for increased systematic linkage of life cycle component analyses that can support marine structures technology. The advancements should be considered as a common thread running through all focus areas.

Another common thread is the impact of human and organizational elements on the life cycle costs and performance of marine structures. These factors are the primary causes of unexpected failures in many industries; therefore, the possible impact of the human element needs to be considered when undertaking any research effort. An example related to ship structures is human variabilities when performing tasks such as hull fabrication or life cycle inspections. Advanced tools, such as hull monitoring systems or finite element methods programs, offer great support for the operator or engineer; however, they must recognize the human interface. Human factors were the focus of the eighth triennial symposium on marine structures, "Human and Organizational Error in Marine Structures," held by the SSC and the Society of Naval Architects and Marine Engineers November 18–20, 1996, in Arlington, Virginia. The CMS will use recommendations from that meeting as a basis for developing future project proposals.

The focus areas of design methods; productivity and producibility; and inspection, maintenance, and repair reflect three phases of ship life cycles. All these phases require a description of materials properties as well as loading and response effects. Therefore, the five focus areas are strongly interlinked as shown in Figure 2-1. However, the CMS established a primary focus for each project based on the intent of the project. There is, of course, not always a clear distinction as to the proper category to which a particular project should be assigned. In the following chapter, the projects are discussed in relation to the five focus areas. Where appropriate, commonality and important linkages with other projects are also described. The following sections briefly describe each of the focus areas.

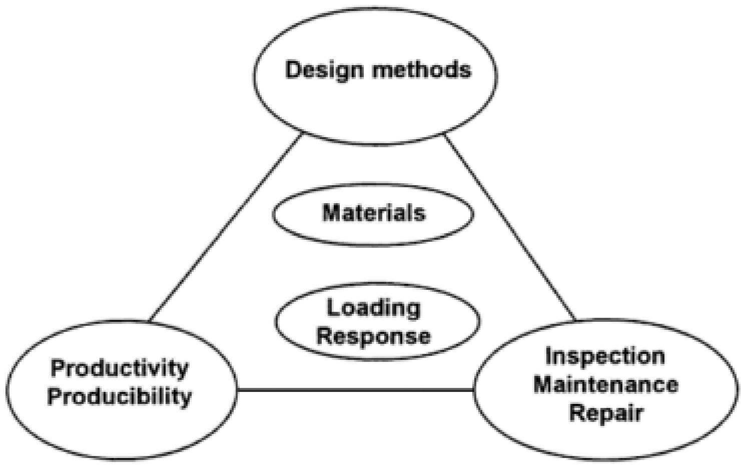

Figure 2-1 Relationships among the five focus areas.

MATERIALS

The proper characterization of materials properties is fundamental to sound ship structure design, fabrication, and maintenance. Traditional working stress design approaches establish estimates of loading and the resulting stress states. These in turn are compared to stress allowables for yield strength, ultimate strength, and fatigue life. Yield criteria, plastic flow models, fracture toughness, and S-N curves apply to both ship structural design and assessment of existing vessels.

New data are required in several important areas for the development of reliability-based design methods. Many relevant material properties for steels have been established over the years because structural steels are the primary materials used for the structure of larger ships. The need to advance our knowledge in many areas, including polymer-based composite materials; corrosion, elastic-plastic fracture, and crack arrest; fatigue properties of aluminum; and effects of weld heat-affected zones has been identified. Only with knowledge of relevant material properties can progress be made.

The materials focus area is strongly linked to other focus areas. Material properties data are needed for reliability and life expectancy assessment in design methodology projects. In productivity and producibility projects, materials criteria are essential to assess joining techniques. Finally, corrosion characteristics of materials form a major component of the inspection, maintenance, and repair focus area.

LOADING AND RESPONSE

Two principal areas of concern for rigorous ship structure design are extreme forces on the hull and repeated, lower-level cyclical loading caused by operations at sea. Extreme loading conditions often influence the development of structural arrangements as well as the vessel scantlings, and the resulting designs highly influence weight and construction costs for stiffened hull configurations. Cyclical forces and stresses from wave loading contribute directly to fatigue of structural components, particularly in areas of high stress concentration at connections and structural discontinuities. Accurate dynamic loading assessment techniques are needed for slamming and frontal impact, and structural integrity analyses of damaged vessels and fatigue-damaged components are needed to improve the process and establish inspection, maintenance, and repair methodology.

Standard methods that treat wave-bending loading as quasi-static processes are of very limited value when estimating hydrodynamic impact. Complicated fluid-structural interaction theories are evolving; however, these theories must be established and confirmed for use in a design environment. As is the case in the materials area, expanding the knowledge base involves new challenges. Existing procedures, developed over many years, need to give way to more rigorous analysis capabilities for predicting and understanding dynamic loading and response. Computational methods for simulating these areas are rapidly expanding, and the need to verify analysis methods and improve assessments of structural response to extreme loading states has been identified.

The loading and response area is linked to the other four focus areas, but the strongest immediate link is to the design methods area. The ability to predict expected loading scenarios is fundamental to the structural design process. Improvements in vessel performance, the use of new materials, and the design of novel hull forms require an increased level of sophistication to establish appropriate loading and vehicle response. Rationally selecting materials from an expanding list of options is possible only if materials criteria can be matched with expected performance demands. These issues, in turn, affect the processes used to produce and operate vessels in the marine environment.

DESIGN METHODS

Like the other focus areas, design methods face a rapidly changing environment. Current trends in design require concurrent engineering methods and the need to consider manufacturing and cost constraints in the early stages of design. Developing advanced information systems and enhancing computational power are key components of the industry response needed to provide advanced life cycle support. These systems have considerably improved the availability of technical information for integrated product and process design.

Design is integral to all of the other focus areas, and integrating it creates a considerable demand for data exchange. Accessible, flexible database systems are currently receiving considerable attention because they are needed to provide frameworks for common purpose application of computer-aided design, manufacturing, and engineering analysis tools. Application protocols for ship product models that encompass both design and manufacturing are now being developed. These modeling and data exchange efforts are essential in the development of design environments capable of optimizing the total life cycle costs of ships, including their fabrication, operation, and maintenance.

Linkage of the design methods area with the other areas is also quite striking when the influence of reliability-based ship design is considered. The demand for data to support reliability analyses is extremely high compared to that required for deterministic, working stress approaches. Materials data require not only stiffness and strength parameters but also statistical variations of these parameters. Failure modes and limit states must be clearly defined and properly anticipated for novel and unique structures. Hence, accurate simulation capability is essential for loading and response prediction and variability. In a concurrent engineering design environment these issues must be addressed rapidly in parallel with producibility and life expectancy considerations.

PRODUCTIVITY AND PRODUCIBILITY

Improving productivity and quality has long been recognized as a key factor in reducing costs and meeting market needs. Among the challenges are to use advanced systems and procedures for information handling. This will lead to enhanced marketing decisions, construction methods, purchasing, and material supply. Information databases hold the key for providing technical and administrative information about a product for production support. Advances in computer-integrated manufacturing allow for developing build strategies in parallel with early design activities. Designs can now be assessed for suitability and better tailored to production facilities.

A common product model should have consistent data for design, production, and operational support. Linkage of design and production helps ensure that the design can be produced efficiently. Early in the design process, the product should be considered as a set of assemblies and assembly sequences. The assembly information is established so that it contains relevant information for each stage in the process. Major construction units and assembly processes can be developed to meet the build program. Both an overall build strategy and production information specifically created for each stage of manufacture are essential in developing an integrated engineering environment. To bring such an environment to fruition, several major structural issues must be addressed. Consistent information along with proper accuracy control ensures that when manufacturing items are joined at later stages in the shipbuilding process they will fit together correctly. Standardization of parts and assemblies should be advanced for more general production automation and design efficiency. The shipbuilding process itself also has direct consequences related to residual stresses and to distortion of the components. These consequences influence the downstream processes and the life cycle performance of the operating vessel. Production automation, selection of materials, and fastening processes are examples of areas demanding attention and likely to be of major concern in the near future.

INSPECTION, MAINTENANCE, AND REPAIR

Degradation of ship structures will progress at varying rates depending on numerous design, construction, and operational factors. Corrosion of marine structures incurs considerable costs for preventive measures as well as for repair. Time-variable stresses from winds, waves, and service loading lead to damage accumulation and fatigue crack growth. Over the past several years, the CMS has recommended several research programs supporting inspection and repair strategy.

There are always economic considerations encouraging the extension of the service life of vessels. There are also demands for safety and reduced environmental risk. These considerations and demands call for a proper service life program for vessel inspection and new approaches for maintaining the structural integrity of ships and their structural components.

New methods of collecting inspection data are needed, and new ideas for integrating these data concurrently in the engineering environment should be explored. With new maintenance systems being developed, more uniform methodologies for damage assessment and repair documentation are needed both for ship structural components and for coatings.

The operational performance of marine structures manifests the integration of materials, loading and response, design methods, and production of marine structures. The linkage of these focus areas will be incomplete if attention is not directed to the ability of the operational systems to perform their tasks. Superior inspection, maintenance, and repair methodology are essential for safe operation; they should also serve as a verification or check on the evolving state-of-the-art of design and also the life cycle support environment.

3

Research Program Development

The proposed research projects are listed in Table 3-1 by CMS focus area. The numbering system shows the relative priorities CMS assigned to the projects. These priorities are based on factors discussed in Chapter 4, where full descriptions of each project are also provided. The material following Table 3-1 provides an initial rationale for the proposed projects in each of the focus areas and describes their relationships to ongoing and recently completed SSC projects.

TABLE 3-1 Recommended Projects in Support of Focus Areas for Fiscal Years 1998–1999

Number	Project Title
Materials Projects	
98-2	Fatigue of Aluminum Structural Weldments
98-8	Fracture Toughness of Marine Structural Steels
98-9	Fatigue Strength and Adequacy of Weld Repairs
Loading and Response Projects	
98-4	Full-Scale Verification of Bow Hydrodynamic Loading and Structural Response
98-11	Fillet Welding of Bottom Structure to Resist Rupture in Impact Loading (97-8 Revised)
98-15	Effects of Residual Stress and Distortion on Thin Panel Performance
Design Methods Projects	
98-1	Multimedia and Web Site: Case Studies of Ship Structures
98-6	Workshop: Reliability Analysis of Ship Structures
98-16	Life Expectancy Assessment of Ship Structures

Number	Project Title
Productivity/Producibility Projects	
98-5	Use of Adhesives for Structural Bonding of Marine Structures (97-7)
98-7	Workshop on Accuracy Control for Ship Construction
98-13	Implementation Plan for Use of Polymer-Based Composites in Ship Structures (96M-K)
Inspection/Maintenance/Repair Projects	
98-3	Software for the Rapid Assessment of the Structural Integrity of Damaged Ship Structures
98-10	Methodology for Systematic Collection of Corrosion Data Using Ultrasonic Thickness Measurements of Ship Structures (97-10)
98-12	CD-ROM Course on Shipboard Corrosion and Corrosion Control
98-14	Condition Assessment and Optimal Maintenance of Existing Surface Coating Systems for Tankers (96-18)

MATERIALS

Understanding the properties of materials used in ship construction is fundamental to developing structures that have the necessary strength and reliability for acceptable through-life performance. Widespread cracking and corrosion of various types of ship structural members indicate the areas in which knowledge of materials properties, or application of that knowledge, is deficient. Materials-related projects recommended in this report address traditional and new shipbuilding steels, aluminum, and polymer-based composites.

Recent developments in the commercial fast-craft marketplace have increased the use of aluminum in shipbuilding. The fast-craft market is expanding rapidly in both Canada and the United States; however, there is still relatively limited understanding of some specific potential problems associated with the use of aluminum alloys in demanding environments. Design, construction, and inspection approaches, for example, should be based on a better appreciation of the fatigue behavior of aluminum weldments than is currently available. Project 98-2, "Fatigue of Aluminum Structural Weldments," is a two-phase project. The first phase will include (1) gathering available data, (2) organizing those data in a form suitable for input to damage tolerance analysis, (3) determining deficiencies in the databases, and (4) designing programs to procure the data through testing. A program to develop fatigue design criteria for marine aluminum weldments will also be designed in Phase I of the project. The CMS will review the results of the first phase and develop project recommendations to conduct the programs designed in Phase I.

"A Guide to Damage Tolerance Analysis of Marine Structures," currently under development in project SR-1374, requires input on fatigue and fracture toughness characteristics of ship steels as well as fatigue and fracture design criteria. Project 98-8, "Fracture Toughness of Marine Structural Steels," is a complementary two-phased project. It will provide the necessary fracture toughness data and will supplement existing information through new test programs.

The CMS is also proposing a continuation of the current project SR-1376, "Methodology to Establish the Adequacy of Weld Repair," as project 98-9, "Fatigue Strength and Adequacy of Weld Repairs." In the current project (scheduled for completion in early 1997) the fatigue properties of simplified repair methods on welded beam specimens were evaluated. Findings indicated that repair welds (gouged out and repair welded) have properties comparable to those of the original welds. CMS believes that this work needs to be extended to fatigue testing of realistic, repair-welded ship structural details matched against comparative tests on alternate repair schemes, such as hole drilling and bolting. This will allow industry to make appropriate, safe, and cost-effective selections of fatigue damage limitation techniques.

LOADING AND RESPONSE

As understanding of both loads and the structural response to them has grown, load predictions have been extended from quasi-static idealizations to realistic predictions that cover dynamic, cyclic, and probabilistic design cases. An area of continuing uncertainty in the definition of hydrodynamic loads relates to bow loads under wave impact and slamming. Hydrodynamic loads were a major factor in the ferry *Estonia* disaster and are under investigation by the roll-on/roll-off ferry community, the International Maritime Organization, and the International Association of Classification Societies. As an example, the International Maritime Organization recently enacted new safety measures for roll-on/roll-off ferries that included the strengthening of bow doors.[1] Hydrodynamic loads are also an important issue for many other ship types that have bluff and fine bows. Local strength and overall hull girder response are areas of concern. Local strength concerns may lead to structural arrangements that are complex and costly to fabricate; hull girder response concerns are fatigue related.

Project 98-4, "Full-Scale Verification of Bow Hydrodynamic Loading and Structural Response," is intended to combine measured data with theoretical methodologies to provide guidance of practical use to designers, shipbuilders, and operators of all vessel types.

Recently, there has been increased attention on quantifying accident and overload conditions and on designing structures that will degrade relatively gracefully

[1] Agreement reached on ro-ro ferry safety measures. IMO News. London, U.K. International Maritime Organization. 4/1995 and 1/1996:3–6.

in such scenarios rather than suffering rapid or immediate catastrophic collapse. Project 98-11, "Fillet Welding of Bottom Structure to Resist Impact Loading" (97-8 Revised), grew out of recent research on double-hull construction; however, it is relevant to a wide range of collision and grounding scenarios. Premature weld failure in these circumstances can significantly reduce the rate of energy absorption. This in turn will increase the extent of hull rupture, the consequent flooding or loss of cargo, and the risks to the safety of life and the environment. The project aims to develop design and fabrication criteria that will result in adequate weld strength to provide full tearing and penetration resistance. The results will also be fed back into damage prediction methods now available or under development to improve their accuracy and widen their applicability.

Some of the loadings and stresses that a structure must withstand are built in during its fabrication. If the levels of distortion and residual stresses present in thin-shell stiffened panels can be predicted or measured, these factors can be incorporated into predictions of the performance of the structure using new analytical methods. Project 98-15, "Effects of Residual Stress and Distortion on Thin Panel Performance," will develop a methodology to analytically predict the performance of stiffened panels by incorporating the residual stress and distortions introduced during the fabrication process. This will be of value both in assessing the need for expensive corrective procedures and for identifying potential problem areas as a focus for through-life inspection efforts.

DESIGN METHODS

In the last 20 years the complexity of "standard" design approaches in the marine industry, including those used in developing structural arrangements, has increased significantly. There is now an increased emphasis on direct design methods to develop the basic strengthening levels as well as a need to consider a wider array of complementary requirements such as producibility, through-life performance (including inspection, maintenance, and repair), and damage tolerance. Information technology and the increasing availability of computerized tools for analysis and design can help marine structural engineers develop high-quality designs that will adequately address these needs. However, there is a growing need to ensure that (1) a new generation of designers fully understands the challenges that must be faced and (2) the design community as a whole is provided with usable tools that allow them to exploit the available state-of-the-art effectively. To address these issues the CMS recommends three projects in the area of design methods.

Project 98-1, "Multimedia and Web Site: Case Studies of Ship Structures," will produce a series of professional quality multimedia presentations to be used at universities, research institutes, and other appropriate organizations. They will serve principally as a study model for use in instruction and secondarily as a standardized basis for research investigations. The presentations will be in electronic format and will include design details of ships and other marine structures together with explanations of the design processes used in their development. The instructor, or analyst, will be able to use the electronic-formatted information to build instructional presentations or to perform sensitivity studies or other relevant studies. Students will be able to use the design information to develop an understanding of design requirements and methodologies. They will also learn how electronic data are used in ship design in the manufacturing processes. The project results will be of benefit to all marine structural designers, but they are expected to be of particular benefit to designers who enter the marine industry with a background in other structural engineering disciplines.

The SSC is completing a four-phase effort to develop a reliability-based structural design methodology. The final phase, project SR-1362, "Probability-Based Design (Phase 4), Synthesis of the Reliability Thrust Area," is reviewing completed SSC projects in the structural reliability area and will recommend future developments. Project 98-6, "Workshop: Reliability Analysis of Ship Structures," will provide a mechanism for the exchange of information between developers of reliability-based design procedures and actual and potential users of these procedures. This will help identify the approach that should be taken for the widespread introduction of reliability-based design procedures for ship structural design. The viewpoint of a larger audience will greatly enhance this area in ship structures because it will identify technical problem areas and procedural barriers that a range of organizations have experienced when developing structural designs and applying reliability methods to them. The proceedings report of the workshop will focus on a clear presentation of the key issues and provide recommendations for addressing them.

One consideration that has not been extensively dealt with in any of the SSC's reliability-and probability-based design projects is life expectancy assessment. This is becoming a more important consideration both for new designs and for existing vessels. A number of owners, particularly the U.S. Navy and other navies, are explicitly requiring relatively long hull lives of 30 years or more for new classes. At the other end of the spectrum, some commercial owners—with the concurrence of their classification societies—are aiming to acquire ships intended to last for little more than the expected life of a relatively short contract or service requirement. There is not much useful guidance available to the designer (or client) about how different aspects of the structure should be tailored to these specific requirements. Project 98-16, "Life Expectancy Assessment of Ship Structures," will begin the process of closing the gap in this regard by assessing life expectancy from the perspective of various failure modes for ship structures. There will be a literature review, followed by analysis of the acquired information. The investigators will then develop life expectancy assessment models for various failure modes of ship structures and validate these models with appropriate examples. Recommendations for further improvements of the models will be presented.

PRODUCTIVITY AND PRODUCIBILITY

The SSC Strategic Plan identified a decline in the competitiveness of the North American merchant marine industry and developed the goal of supporting the U.S. and Canadian maritime industry capabilities in shipbuilding, maintenance, and repair. In support of this critical objective, the CMS recommended in its earlier reports a number of research projects that targeted the producibility of structures and improvements in the design and assembly productivity. Three new projects in this area are additionally recommended.

Project 98-5, "Use of Adhesives for Structural Bonding of Marine Structures" (97-7), will investigate the potential use of adhesives for structural bonding in marine structural applications, particularly for lightweight structures and members or subassemblies that carry limited direct load. A manual will also be prepared for designers and engineers. The manual will contain information on application procedures and performance characteristics of those adhesives found to be especially appropriate for primary or secondary structural bonding. Chemical adhesives are finding increasing application in the bonding of manufactured assemblies in general and have possible benefits if appropriately used in marine structures. Research in Europe has confirmed that chemical adhesives are feasible as primary fastening systems; however, there are uncertainties as to their long-term viability. There are indications that the potential of chemical adhesives is increased if they are used as a secondary fastening system but there is uncertainty about the most appropriate configurations. These questions will be addressed in this project.

Concepts of advanced modular construction are being increasingly applied in ship production. Benefits of modular construction include an increase in the proportion of work performed in shipbuilding shops, where both quality and productivity are higher than on the traditional building berth. Modular construction requires improved dimensional control of production assemblies because significant rework to allow fit-up is unacceptable. Project 98-7, "Workshop on Accuracy Control for Ship Construction," will provide a forum for shipbuilders and others to discuss accuracy control needs for the shipbuilding process and the technology and procedural methods by which they can be met. The workshop report will propose methods to alleviate problems and prioritize issues. A position paper or roadmap for future development initiatives will also be developed.

Composite materials can be tailored to meet a range of structural needs. There are many more potential marine applications for composites than those already in use. Projects SR-1367, "Design Guide for Marine Applications of Composites," and SR-1389, "Risk Assessment of the Use of Polymer Matrix Composites in Marine

Environments," will be complemented by the proposed Project 98-13, "Implementation Plan for Use of Polymer-Based Composites in Ship Structures" (96M-K). The plan developed in this project will identify ship structural components where composites can most effectively replace conventional materials. Project 98-13 will include performing risk assessments, identifying challenges in fabrication and joining, and developing a comprehensive implementation plan for replacing conventional materials with composites in identified areas.

INSPECTION, MAINTENANCE, AND REPAIR

Structural behavior during and after accidents and overloads is receiving increasing attention because structural failures are frequently associated with the highest risks to safety of life and the environment. Project 98-3, "Software for the Rapid Assessment of the Structural Integrity of Damaged Ship Structures," aims to respond to the needs of operators, inspectors, and others who may be called on to make decisions on the continued fitness-for-service of ships after damage occurs or is discovered. Whether or not immediate repair or diversion of the ship is needed can have major cost and schedule implications that need to be balanced against accurate risk assessments. A suitable software package will provide rapid support for decision making in urgent and stressful situations.

Catastrophic failures of marine structures—when not associated with accident conditions—are more often caused by in-service degradation of an initially adequate structure than by deficiencies in the original design. The efforts required to maintain the structure in its intended condition can be expensive directly, as well as indirectly, if steelwork replacement or preservation causes frequent downtime for the vessel. The CMS believes that the safe operation of ships, improved structural inspection, and reduced maintenance costs would result from a better understanding of corrosion and corrosion control methods; therefore, three projects are proposed for this area.

Project 98-10, "Methodology for Systematic Collection of Corrosion Data Using Ultrasonic Thickness Measurements of Ship Structures" (97-10), will develop a standardized methodology for the collection and analysis of thickness measurements on ship structures. Steel condition at the time of inspection and the corrosion rate between successive inspections will also be determined. This will involve designing a standard format for gathering, storing, and presenting data and analyses. The scope of the project will also include using available data to develop an initial probabilistic model for predicting corrosion rate and recommending a methodology for updating this model as further standard data become available.

Project 98-12, "CD-ROM Course on Shipboard Corrosion and Corrosion Control," will increase the level of understanding of this underappreciated field in the marine industry at large. This proposed course for ship designers, constructors, inspectors, and operators would include sections covering fundamentals of corrosion, forms of shipboard corrosion, and corrosion control. The course could be used as an initial training course, a refresher, or a reference for use in the field.

The cost of applying and maintaining modern coating systems is high, and factors such as workplace safety and residue disposal are increasing both the cost and complexity of the work. Therefore, it is increasingly important that initial coating systems and the approaches applied to their maintenance are appropriately selected. Project 98-14, "Condition Assessment and Optimal Maintenance of Existing Surface Coating Systems for Tankers" (96-18), aims to develop the guidelines that will allow owners and designers to provide the necessary through-life performance in an economical and reliable manner. This proposed project will include a review of the current techniques, criteria, and guidelines for evaluating coating performance. A methodology for determining optimum coating maintenance and repair strategies will also be developed. The proposed project is complementary to recently completed projects SR-1377, "Commercial Ship Design and Fabrication for Corrosion Control," and SR-1366, "Corrosion Control of Inter-hull Spaces" (SSC-390).

4

Project Recommendations for Fiscal Years 1998–1999

Table 4-1 lists the projects proposed for the 1998–1999 program in priority order, based on the composite judgment of the CMS members. Detailed descriptions of each project follow below. Every project recommended by the CMS is considered to be of significant potential value to the marine industry. However, important factors taken into account in setting individual rankings have included:

1. new and continuing needs of the marine industry as a whole
2. current needs of the sponsor agencies, with particular emphasis on interagency relevancy
3. continuing or completing work under multiphase SSC programs
4. benefits of specific project recommendations to the overall goals of the SSC
5. necessity of maintaining a balanced research program that gives adequate attention to each focus area.

Several of these points, in particular item 3, should be recognized when selecting the final 1998 and 1999 programs. The priority for a number of projects will increase when current work is completed, as discussed in Chapter 3. Other projects may need to be revisited for content or priority on the basis of new circumstances. This will be discussed future CMS reports.

TABLE 4-1 Project Recommendations for Fiscal Years 1998-1999 in Priority Order

Number	Project Title	Page
98-1	Multimedia and Web Site: Case Studies of Ship Structures	23
98-2	Fatigue of Aluminum Structural Weldments	26
98-3	Software for the Rapid Assessment of the Structural Integrity of Damaged Ship Structures	28
98-4	Full-Scale Verification of Bow Hydrodynamic Loading and Structural Response	30
98-5	Use of Adhesives for Structural Bonding of Marine Structures (97-7)	32
98-6	Workshop: Reliability Analysis of Ship Structures	34
98-7	Workshop on Accuracy Control for Ship Construction	36
98-8	Fracture Toughness of Marine Structural Steels	38
98-9	Fatigue Strength and Adequacy of Weld Repairs	40
98-10	Methodology for Systematic Collection of Corrosion Data Using Ultrasonic Thickness Measurements of Ship Structures (97-10)	42
98-11	Fillet Welding of Bottom Structure to Resist Rupture in Impact Loading (97-8 Revised)	44
98-12	CD-ROM Course on Shipboard Corrosion and Corrosion Control	46
98-13	Implementation Plan for Use of Polymer-Based Composites in Ship Structures (96M-K)	48
98-14	Condition Assessment and Optimal Maintenance of Existing Surface Coating Systems for Tankers (96-18)	50
98-15	Effects of Residual Stress and Distortion on Thin Panel Performance	52
98-16	Life Expectancy Assessment of Ship Structures	54

98-1 Multimedia and Web Site: Case Studies of Ship Structures

Objective Produce a series of professional multimedia presentations to enhance understanding of issues and provide a forum for the dissemination of information to universities and practicing naval architects.

Benefit The multimedia presentations (e.g., CD-ROMs) would provide case studies of structural failures and learning tools for improved teaching of ship structure design. A web site would provide a forum for the presentation of critical ship structure design issues for use by students and professionals worldwide. This will help create a better appreciation by engineering students, faculty, and practitioners in the field of naval architecture and the unique problems encountered in the marine environment.

SSC National Goals

- Support the U.S. and Canadian maritime industry in shipbuilding, maintenance, and repair.
- Improve the safety and integrity of marine structures.

SSC Strategies

- Improved engineering analysis and evaluation
- Development of better design tools and information systems, such as computer-aided design systems, design information systems, and artificial intelligence
- Development of principles of design for production
- Prevention research including damage-tolerant structures, structural monitoring, and human factors
- Structural reliability engineering
- Sponsoring university research in areas such as design tools development, producibility, production processes, reliability design, and damage-tolerant structures

Background The recent report SSC-391, "Evaluation of Marine Structures Education in North America," identified several needs to support the marine industry. The number of universities and institutions producing naval architects is declining. Many engineers working in the field of naval architecture are trained as civil or mechanical engineers. This, to a large extent, reflects the state of the industry in North America and student perceptions about the limited university and career opportunities. There is a need for increased appreciation of the problems which to a large extent are unique or at least important to the shipbuilding industry. Thus, it is important to make information readily available that will demonstrate the challenges of this field of study. It may also assist in the reintroduction of appropriate course material in university and continuing education courses.

It is proposed that a team of practitioners, faculty at key institutions, and representatives of technical societies such as the Society of Naval Architects and Marine Engineers, American Society of Naval Engineers, and the American Society of Civil Engineers be charged with defining the topical content to be used as either supplements to existing courses or self-contained 45–50 minute seminars. The topics should span the range of the SSC goals and strategies. By a review of such publications as reports of the National Transportation Safety Board and the U.S. Navy and U.S. Coast Guard boards of investigation, *Marine Technology,* and *Proceedings of the Marine Safety Council,* examples of a wide variety of structural failures may be gathered. These case studies can vividly illustrate the need to focus on different aspects of design, maintenance, and repair that may not otherwise be appreciated. A series of fully developed designs for ships' hulls in computer-aided design (CAD) format would provide realistic tools with which students could perform structural analyses, optimization studies, production planning, or parametric modifications. The team should also provide a compendium of suggested materials and course outlines and a contact list to support the expected student and faculty interest in pursuing the subject matter. These would also be made available on a web site which would then serve as the point of contact. The location of the web site would have to be determined. The project would facilitate the transfer of technology by direct dissemination of information relating to marine structure technology of critical importance.

Recommendations Perform the following tasks:

- Assemble a team of practicing naval architects reflecting the range of civilian and military endeavors and a representative group of faculty from universities and institutions reflecting the source of the work force.
- Review the previously mentioned literature and any other appropriate sources for illustrative case studies to demonstrate a wide variety of failures. Document accidents, structural failures, and solutions to important structural design problems. Summarize each event in a one-or two-page case study to use as a lead into a workshop.
- Plan and organize a two-day workshop, inviting a balanced list of international experts of practitioners and researchers to give presentations and participate in the panel presentations and open discussion, with the objective of finalizing plans to be reflected in the white paper (see next task).
- Prepare a white paper on the proposed plan of action and time line, to be reviewed by the Committee on Marine Structures, the Ship Structure Committee, and perhaps the Hull Structures Committee and

the Education Committee of the Society of Naval Architects and Marine Engineers prior to implementation.

- Work with a professional multimedia group to produce the presentations using the most appropriate media.
- Develop the web site material and establish a public web site at a facility supporting the North American Maritime Community Plan and implement hotlinks to the site from other well-known maritime sites.
- Assist in the dissemination of the materials at several fora, including company and campus sites in the United States and Canada.
- Prepare a final report.

Duration 2,000 labor hours over one year

98-2 FATIGUE OF ALUMINUM STRUCTURAL WELDMENTS

Objective Assist the designers and fabricators of high-speed vessels by providing information on the fatigue of commercial aluminum structural details. Develop data-based fatigue-design criteria for both the design and damage tolerance analysis of welded aluminum ship structures.

Benefit Enhance the durability, reliability, efficiency, and safety of aluminum structures. Assist in the growth of the high-speed ship industry in North America, helping to produce ships that will be structurally reliable but have low hull weight.

SSC National Goals

- Improve the safety and integrity of marine structures.
- Reduce marine environmental risks.
- Support the U.S. and Canadian maritime industry in shipbuilding, maintenance, and repair.

SSC Strategies

- Improved engineering analysis and evaluation
- Development of better design tools and information systems
- Prevention research including damage-tolerant structure

Background Criteria for fatigue-resistant design, fatigue-damage repair, and life extension are based on laboratory-generated fatigue data. The fatigue database for structural steel weldments is mature, extensive, and the subject of many SSC research, syntheses, and analyses projects. However, the picture is not as complete for fatigue of welded aluminum. Fatigue data for aluminum weldments are scattered among various agencies including the Association of American Railroads (AAR), the Aluminum Association, military laboratories, university studies, and liquefied petroleum gas (LPG) and liquefied natural gas (LNG) transport vehicles. The AAR railway freight car fatigue design criteria address both welded steel and aluminum. The fatigue of structural details for navy ships has been investigated, but little work has been done for those details used in commercial vessels. Data-based fatigue-design criteria for aluminum weldments in marine structures will serve as input to both initial design and structural maintenance, such as that developed in the project SR-1374, "A Guide to Damage Tolerance Analysis of Marine Structures."

The loading of high performance vessels is significantly different from that of the displacement surface ships for which current fatigue design criteria have been developed. Hydrodynamic loading of displacement ships was surveyed in the report "Hydrodynamic Impact on Displacement Ship Hulls" (SSC-385) which included information applicable to high performance vessels. However, that report did not address fatigue spectra for these impact loadings, a necessary part of the development of fatigue design criteria.

Project 98-2 is conceived as a two-phase project. The first phase will be a literature survey and development plan. The second phase would consist of execution of the tasks resulting from the developed plan. This phase would require experimental and analytical work to fill in critical gaps in the data and develop the fatigue-design criteria and application methodologies. It is anticipated that the Phase II project, to be carried out subsequently, would take two years and require 2,500 labor hours.

Recommendations Perform the following Phase I tasks:

- Gather the available data on fatigue of welded aluminum and prepare a single database of those data in a format suitable for input to damage tolerance analyses.
- Determine whether that database is adequate for the development of fatigue design criteria applicable to marine structures. Review loading information available for high performance vessels and determine if sufficient information exists to develop fatigue loading spectra.
- Design a program to develop fatigue-design criteria for aluminum weldments suitable for both initial design and as input to the "Guide to Damage Tolerance Analysis of Marine Structures" developed in SSC project SR-1374.
- Identify data gaps to be filled, e.g., aluminum grades, structural details, and loading environments.
- Design a program to gather the necessary data.

Duration 1,000 labor hours over one year

98-3 SOFTWARE FOR THE RAPID ASSESSMENT OF THE STRUCTURAL INTEGRITY OF DAMAGED SHIP STRUCTURES OF DAMAGED SHIP STRUCTURES

Objective Develop laptop personal computer software to support the need to make timely, on-site decisions about the fitness for service of a ship having damage to secondary structural components.

Benefit Software for the rapid assessment of damage will enhance the ability of ship surveyors, inspectors, and ship's officers to make structural integrity assessments of damaged marine structures immediately when the damage occurs or is discovered.

SSC National Goals

- Improve the safety and integrity of marine structures.
- Reduce marine environmental risks.
- Support the U.S. and Canadian maritime industry in shipbuilding, maintenance, and repair.

SSC Strategies

- Improved engineering analysis and evaluation
- Development of better design tools and information systems
- Improved structural inspection techniques
- Prevention research including damage-tolerant structure
- Improved efficiency for repair technology

Background Formal damage tolerance and structural integrity analyses of damaged ship structures require sophisticated personnel, ample computer facilities, and sufficient time for performance. Indeed, one purpose of the SSC project SR-1374, "A Guide to Damage Tolerance Analysis of Marine Structures," is to assist in the performance of fitness-for-purpose assessments.

Today, many ships have computer systems but these systems and their operators (the ship's officers) do not have the capability to perform the complex analyses to assess consequences of damage. Also, surveyors from classification societies and U.S. Coast Guard inspectors may need to make timely, on-site decisions about continued operation of a fatigue-, corrosion-, collision-, or accident-damaged ship but lack the computer power and, perhaps, the background, available in their home offices.

Galaxy Scientific, Northrop-Grumman, and McDonnell Douglas have developed for the Federal Aviation Administration a Windows-based computer program RAPID (Repair Assessment Procedure and Integrated Design) to address similar needs in the aviation industry. RAPID is a tool for the analysis and design of damage-tolerant airframe (at present, fuselage skin) repairs that targets small operators and maintenance and repair facilities that do not have the capabilities for, or the familiarity with, formal damage tolerance analyses and philosophies. RAPID includes the input of administrative details for the final report, both text and graphical design of the repair, static strength analysis of the repair, damage tolerance analysis of the repair, determination of inspection intervals for the repair, and output of a final report summarizing the repair and analyses.

A concept similar to RAPID would be useful for ship structural components. Damage to secondary structural components such as stiffeners, frames, and brackets is an all too common occurrence. Operators and inspectors make on-the-spot decisions as to the severity and consequences of accidents. Structural rules-of-thumb are often used to make such damage assessments, to establish fitness, and to develop repair requirements. The availability of a rapid assessment software for the structural integrity of ship structures would assure that these on-the-spot decisions are made using the appropriate knowledge and technology.

Recommendations Perform the following tasks:

- Develop algorithms to address the need to make timely, on-site decisions about the continued operation of a damaged ship. Draw upon the results of previous SSC projects to establish for damage tolerance analysis (1) the ship details most likely to be damaged, (2) simplified load spectra, and (3) simplified analysis techniques.
- Develop laptop personal computer software to implement these algorithms in the performance of both static strength and damage tolerance analyses for two cases: (1) the damaged detail without repair, and (2) the repaired detail. Ensure that the algorithms are compatible with the approach of "A Guide to Damage Tolerance Analysis of Marine Structures" developed in SSC project SR-1374.
- Develop a library of load spectra for the software.
- Develop a materials database for the software.
- Develop a library of appropriate ship details and repair techniques for the software.
- Include, in the software, the capability to output a report describing the damage, repairs if required, and the results of the static strength and damage tolerance analyses.
- Develop recommendations for the appropriate training needed to use the tools developed.

Duration 4,000 labor hours over two years

98-4 FULL-SCALE VERIFICATION OF BOW HYDRODYNAMIC LOADING AND STRUCTURAL RESPONSE

Objective Provide new knowledge of actual, real-time loading and response of ship's bows from a well-designed field test program coupled with analytical and numerical simulations using modern analysis techniques. Provide guidance to ship structural designers regarding bow design to improve performance and producibility.

Benefit Rational approaches to the design of ship bows will improve structural reliability and safety, reduce production costs, and provide industry designers and operators with the appropriate analytical methods required for determining hydrodynamic design loading and structural response

SSC National Goals

- Improve the safety and integrity of marine structures.
- Support the U.S. and Canadian maritime industry in shipbuilding, maintenance, and repair.

SSC Strategies

- Development of better design tools
- Improved engineering analysis and evaluation

Background The structural design of a ship's bow is a complex matter. In this context, the term "ship's bow" refers to the forward 10 to 15 percent of the ship's length. Bow design balances needs for hydrodynamic performance against ship design requirements such as internal volume, anchor handling, and cargo loading.

The bow structure represents a significant portion of the hull structure weight, cost, and fabrication time. Contributing factors include the additional strengthening required to resist slamming loads. Sufficient access for inspection and maintenance is also a problem on hulls with fine bows.

Development of the structural configuration of a ship's bow is currently very much an art owing to the complexity of the imposed requirements, many of which do not lend themselves to simple analysis. Bow structure design is more directly linked with hydrodynamic loads than is any other aspect of ship structural design. The SSC project "Hydrodynamic Impact on Displacement Ship Hulls" (SSC-385) reviewed the state of the art in predicting hydrodynamic impact forces. The report identifies and evaluates numerous theories that have been developed over the years and recommends research programs for further development of the technology of predicting loads. Development of numerical techniques for the prediction of hydrodynamic loads, including bow impact forces, is currently being done under an extensive U.S. Navy research program that includes some full-scale testing. Nevertheless, a critical lack of full-scale, real-time data for establishment of appropriate methodology currently exists. As the analytical capabilities for assessing wave-induced loads, slamming, and frontal impacts continues to develop, there is an ever increasing need for verification of these advancing theories.

Recommendations

Phase I

- Review available analysis techniques to establish validation requirements for a variety of vessel classes.
- Review available information on recent and ongoing field test programs, including those of the U.S. Navy, identifying issues that need to be addressed, including vessel rigidity, low versus high frequency response behavior, and instrumentation requirements.
- Define concise achievable objectives for this field test program.
- Develop a strategy to promote the sponsorship of the test program by industry and additional sponsoring agencies.
- Plan and convene a meeting of ship owners, ship operators, and related agencies to present the test plan and objectives, with the intent to develop commitments for in-kind and cash contributions to the project.

Phase II

- Form an industry advisory panel for the project.
- Develop a plan of action in conjunction with the industry advisory panel, defining the instrumentation package and procedures for recording and reporting the field data.
- Establish transit scenarios for appropriate vessels.
- Perform the field tests and collect the data, performing checks on the quality of the measured data during collection process.

Phase III

- Analyze the field data and compare the results with selected analytical and numerical predictive models.
- Prepare a final report and provide the data on an acceptable CD-ROM format for distribution.

Duration

Phase I: 2,000 labor hours over one year
Phase II: 2,000 labor hours over one year
Phase III: 2,000 labor hours over one year

98-5 USE OF ADHESIVES FOR STRUCTURAL BONDING OF MARINE STRUCTURES (97-7)

Objective Identify and investigate the potential for use of adhesives as the primary and/or secondary structural bonding agents in marine structures applications. Prepare a manual for use by designers and engineers that contains information and guidance on application procedures and performance characteristics of appropriate chemical adhesives.

Benefit The proposed manual will provide the designer with information on the use of those adhesives found potentially useful as fastening mechanisms for marine structures. Increased use of adhesives could simplify construction procedures and reduce costs.

SSC National Goal

- Support the U.S. and Canadian maritime industry in shipbuilding, maintenance, and repair.

SSC Strategies

- Development of structures-related producibility technology
- Development of principles of design for production
- Improved efficiency for repair technology

Background Chemical adhesives are finding increasing application in both the primary and secondary bonding of manufactured assemblies. The use of adhesives would be extremely valuable in the area of hull outfitting items when used in conjunction with composite materials such as joiner bulkheads. In steel fabrication, the use of adhesives has the benefit of being less disruptive than welding in completed spaces or in areas where hot work is restricted. It has been found that adhesive bonding can add structural integrity to a mechanically fastened assembly. Adhesives are being used as the primary fastening systems in places where welding is difficult to accomplish, and they are also being used to augment traditional fastening methods to provide additional strength. A recent paper[1] described research confirming that adhesives are feasible as the primary fastening mechanisms for ship structure.

There is also the potential for using adhesives as a secondary bonding agent to provide additional support to other fastening systems. The use of adhesives in a secondary role provides additional options to the designer and manufacturer and further enhances producibility and productivity.

[1] I.E. Winkle, M.J. Cowling, S.A. Hashi, and F.M. Smith. 1991. What can adhesives offer to shipbuilding? Journal of Ship Production 7(3).

Recommendations Perform the following tasks:

- Identify and investigate the potential use of adhesives as a fastening mechanism in marine structures, considering the current usage in other industries, including the aerospace industry.
- Identify and evaluate the questions surrounding adhesive strength/retention as a function of time and life cycle.
- Determine the potential advantages and disadvantages of this fastening method for possible use in the assembly of marine structures.
- Prepare a manual describing the technology and its potential application in marine structures. The report would also include: (1) formulation description, (2) mechanical and environmental stress performance, (3) application procedures, (4) storage and handling requirements, (5) nondestructive testing and inspection, and (6) other information deemed appropriate for a structural designer and manufacturing engineer.
- Develop recommendations for follow-on work, including testing for fatigue strength, environmental and temperature degradation, and performance in fires.

Duration 1,500 labor hours over one year

98-6 WORKSHOP: RELIABILITY ANALYSIS OF SHIP STRUCTURES

Objective Conduct a workshop involving practitioners experienced in using reliability methods for marine and other structures. Exchange information between developers of reliability-based design procedures and users of these procedures to identify the approach for development and implementation of reliability-based design procedures for ship structures.

Benefit This project will provide a forum for open discussion of developments in reliability-based structural design and a review of efforts to adapt these methods for ship structures. Other issues covered will include difficulties in the use of reliability methods and in their application to ship structures.

SSC National Goals

- Improve the safety and integrity of marine structures.
- Reduce marine environmental risks.

SSC Strategies

- Development of better design tools and information systems, such as computer-aided design systems, design information systems, and artificial intelligence
- Development of reliability design techniques to optimize material use
- Development of principles of design for production
- Structural reliability engineering
- Improved engineering analysis and evaluation

Background The CMS has recommended research projects in the reliability thrust area for several years, and the SSC has funded a four-phase effort for the development of reliability-based structural design. As part of Project SR-1310, "Application of Reliability Methods to Analysis and Design of Marine Structures," a one-week tutorial and workshop on structural reliability was held on October 22–26, 1990, in Arlington, Virginia. A one-week course and workshop was also held in Annapolis, Maryland, on May 20–24, 1996, as part of Project SR-1344, "Assessment of Reliability of Existing Ship Structures." Project SR-1362, "Probability-Based Design (Phase 4), Synthesis of the Reliability Thrust Area," is reviewing the completed projects of the SSC and will make recommendations for further development of the methodology. The viewpoint of a broader audience will greatly benefit this effort in ship structures by identifying key issues for the development and application of reliability methods for structural design in other fields. Examples include the Load and Resistance Factor Design codes of the American Petroleum Institute and the American Institute for Steel Construction. Also, the Carderock Division of the Naval Surface Warfare Center is developing a reliability-based structural design procedure for naval ships, and the approaches taken in this work and those of the other studies should be compared with the efforts of the SSC.

Recommendations Perform the following tasks:

- Form a planning group to organize, conduct, and report on the workshop. This group should include developers of reliability-based design codes, designers of ship structures, and experts in reliability methods for ship structures.
- Conduct a two-day, no-fee workshop. During the first day and one-half, a series of invited presentations should be made by the developers and users of structural design procedures for ship, offshore, and civil engineering structures. Special emphasis should given to practical and theoretical problems to be faced in applying these methodologies and to techniques for overcoming these problems.
- Document the results of the workshop, including recommendations for additional research and development, the preparation of educational materials, and the modification of regulatory and control procedures. Include a long-term plan for development of an industry-driven reliability-based design code.

Duration 1,000 labor hours over one year

98-7 WORKSHOP ON ACCURACY CONTROL FOR SHIP CONSTRUCTION

Objective Provide a forum for shipbuilders, materials suppliers, equipment manufacturers, software developers, and other technology organizations to discuss accuracy control needs for shipbuilding, propose methods to alleviate problems, rank/prioritize issues, and develop a position paper or roadmap for future development and implementation initiatives.

Benefit Better control of accuracy in manufacture of panels and subassemblies for shipbuilding will significantly reduce scheduling impacts of fit-up and rework, facilitate the use of modular construction, improve the quality of the final product, and as a result reduce processing costs. This workshop will provide the basis for and direction of future development and implementation activities to address critical issues in controlling accuracy.

SSC National Goals

- Improve the safety and integrity of marine structures.
- Support the U.S. and Canadian maritime industry in shipbuilding, maintenance, and repair.

SSC Strategies

- Development of better design tools and information systems, such as computer-aided design systems, design information systems, and artificial intelligence
- Development of structures-related producibility technology, such as faster welding techniques, robotics, laser alignment, and automated material storage and handling equipment
- Development of principles of design for production
- Improved engineering analysis and evaluation

Background The level of application of accuracy control in U.S. and Canadian shipyards is generally lower than in many European countries, in Japan, and in other countries. Some of the techniques that have been successfully employed in many foreign and some domestic yards include:

1. Purchasing plates and stiffeners with greater fairness, sometimes using fabricated stiffeners.
2. Using more accurate processes for cutting plates and stiffeners, such as lasers or plasma arc.
3. Using automated or robotic processes for cutting and welding.
4. Using block or unit manufacturing, with neat-cut techniques.

Effectively implementing these techniques has significantly enhanced the ability of shipyards to compete in the global marketplace. In order for U.S. and

Canadian shipyards to match productivity levels elsewhere, these and other issues need to be addressed.

Recommendations Perform the following tasks:

- Form a planning group to organize, conduct, and report on the workshop. This group should include representation from the Ship Production Committee of the Society of Naval Architects and Marine Engineers and the National Shipbuilding Research Program.
- Conduct the workshop, involving North American and overseas shipbuilders, materials and equipment suppliers, and other relevant technology organizations.
- Compare North American shipyards to overseas shipyards to get a perspective of where North America stands globally.
- Identify and prioritize needs and solutions to revitalize North American shipyards based on comparison during the workshop.
- Identify and prioritize needs and solutions during the workshop.
- Develop and publish a roadmap, for greater implementation of accuracy control and to provide direction to future development activities. This document should address both the technological and the organizational efforts required to achieve world-class results.

Duration 1,000 labor hours over one year

98-8 FRACTURE TOUGHNESS OF MARINE STRUCTURAL STEELS

Objective Develop a database for the fracture toughness of base-metal, weld-metal, and heat-affected zones of marine structural steels to be used in the damage tolerance analysis of marine structures.

Benefit The assessment of structural reliability will be enhanced through the use of fracture-mechanics-based analysis that recognizes the reserves of elastic-plastic fracture toughness that exist in materials after crack initiation. Conservatism in design and material selection can be reduced through better knowledge of material properties.

SSC National Goals

- Improve the safety and integrity of marine structures.
- Reduce marine environmental risks.

SSC Strategies

- Improved engineering analysis and evaluation
- Development of better design tools and information systems
- Prevention research including damage-tolerant structures

Background Criteria for fracture-resistant design, fatigue-damage repair, and damage tolerance and structural integrity analyses require laboratory-generated elastic-plastic fracture-toughness data from fracture-mechanics-based tests, e.g., J-integral or crack-tip opening displacement (CTOD). Such data, gathered over a range of temperatures, thicknesses, chemistries, thermo-mechanical processing, and welding parameters for marine steels, will serve as input to the "Guide to Damage Tolerance Analysis of Marine Structures" developed in SSC project SR-1374. A previous project, "Marine Structural Steel Toughness Data Bank," SSC-352, focused on the development of a data bank that included the then available (1990) values of Charpy V-notch impact energy, critical initiation J-integral (J_{IC}), nil-ductility transition temperature (NDTT), and dynamic tear (DT) energies for 12 structural steels. However, these data may be of limited value for damage tolerance and structural integrity analyses. Such analyses require more general elastic-plastic fracture-toughness data, such as the J-integral (not limited to planestrain fracture toughness) or CTOD.

To achieve the full intent of the project, it will be necessary to define the available data and the extent of the additional work required before any testing should be undertaken. This will require a Phase I program to gather the existing data and identify gaps, followed by a Phase II program of data generation if needed. Owing to the nature of testing required to obtain elastic-plastic toughness data, any Phase II program will be a focused effort aimed at the most critical data gaps, rather than an attempt to cover the missing toughness properties of all or many materials. This work should also aim to complement but not duplicate other parallel programs. The Phase II program is expected to take two or three years and may require 3,000 labor hours.

Recommendations Perform the following Phase I tasks:

- Investigate the data available in the "Marine Structural Steel Toughness Data Bank," SSC-352, and determine the applicability of those data to fracture-mechanics-based damage tolerance analysis.
- Gather available fracture-toughness data for base-metal, weld-metal, and heat-affected zones of marine and similar steels that are not included in SSC-352. The first priority is applicable base plate and whole weldment data.
- Organize the available fracture-toughness data for base-metal, weld-metal, and heat-affected zones of marine steels as input to the "Guide to Damage Tolerance Analysis of Marine Structures" developed in SSC project SR-1374.
- Identify the data needed to fill in gaps, e.g., grades, thicknesses, welding processes, and parameters.
- If needed, design a program to obtain such data over a two-year period.

Duration 1,000 labor hours over one year

98-9 FATIGUE STRENGTH AND ADEQUACY OF WELD REPAIRS

Objective Experimentally evaluate the fatigue strength and fitness-for-purpose of weld repairs to provide a technical basis for decisions regarding the necessity of weld repairs for certain types of damage and the type and extent of the weld repairs that are required to qualify as a permanent repair. This is an extension of work under way on project SR-1376, "Methodology to Establish the Adequacy of Weld Repairs."

Benefits Many types of repairs which seem adequate as permanent repairs are currently approved only as temporary repairs. Specific, simple guidelines for design of fatigue-resistant ship repair-weld details and a methodology for performing calculations of the remaining fatigue life after repair will enable more confident scheduling of inspection and repair and may, in some cases, eliminate the need for additional repair.

SSC National Goals

- Improve the safety and integrity of marine structures.
- Support the U.S. and Canadian maritime industry in shipbuilding, maintenance, and repair.

SSC Strategies

- Development of better design tools
- Prevention research including damage-tolerant structures, structural monitoring, and human factors
- Structural reliability engineering
- Improved engineering analysis and evaluation

Background During service, commercial ships develop large numbers of fatigue cracks which are repaired by veeing out the crack and rewelding. The adequacy of these repairs for continued application is determined primarily by the remaining fatigue life. Initial research to address this issue is being performed at Lehigh University and Edison Welding Institute, as well as in SSC project SSC-1376, "Methodology to Establish the Adequacy of Weld Repairs." A worldwide survey of government agencies, classification societies, researchers, shipbuilders, and owners conducted during the SSC project established the following important fatigue-testing activities: (1) details that are most frequently in need of repair; (2) repairs that have significant uncertainty in their fatigue strength; and (3) evaluation of a simplified repair method that could be shown to have adequate fatigue strength and provide economic benefit. Fatigue tests on full-scale beams with a variety of butt welds in the flanges were conducted to compare the fatigue strength of "new" welds with that of cracked welds that were gouged out and rewelded multiple times after cracking. The tests have shown that the repair welds had fatigue resistance as good as the original welds. Data were also acquired on weld access holes and repair welds for cracks at weld access holes.

Further data are required to broaden the scope of this research and to permit determination of more effective and economic methods to arrest fatigue cracks. For example, it is known that hole drilling, both with and without bolting the hole, may be an effective way to arrest fatigue cracks and is considered in some structures to be a superior alternative to weld repairing of cracks. However, currently there are limited experimental data for this approach for full-scale ship structural details. In addition, the current work is restricted to idealized geometries. To enable industry acceptance, full-scale testing of realistic ship structural details is essential.

Recommendations Perform the following tasks:

- Determine the original fatigue strength of model detail as well as the remaining fatigue strength after (1) only drilling a stop hole and hole drilling/bolting for temporary repair; (2) typical weld repairs; and (3) modifying the detail by welding or other processes to upgrade the fatigue strength.
- After determining the optimum procedure, verify this with full-scale fatigue tests on large models of ship structural details, including (1) longitudinal-to-transverse web-frame connection, and (2) bracket-to-girder connection.
- Prepare guidelines and examples for design of fatigue-resistant ship repairs and a method for calculating the remaining fatigue life after repair. Differentiate, as appropriate, between repairs to ordinary-strength and high-strength steel structure.

Duration 3,000 labor hours over two years

98-10 METHODOLOGY FOR SYSTEMATIC COLLECTION OF CORROSION DATA USING ULTRASONIC THICKNESS MEASUREMENTS OF SHIP STRUCTURES (97-10)

Objective Develop a standardized methodology for the collection and analysis of ultrasonic thickness measurements on ship structures in order to determine conditions at the time of measurement, to accurately determine corrosion rate, and to help develop an optimum structure maintenance program.

Benefit A standard methodology for ultrasonic thickness measurements will allow regulatory agencies and ship owners to determine corrosion rates and trends which can be used to develop long-term inspection and maintenance plans.

SSC National Goals

- Improve the safety and integrity of marine structures.
- Reduce marine environmental risks.

SSC Strategies

- Improved structural inspection techniques
- Improved engineering analysis and evaluation

Background Currently, ultrasonic inspections are performed periodically on ship structures, and extensive thickness measurement data are collected. These data are used to determine the steel condition at the time of the inspection and to develop repair plans based on certain methods for minimum plate thickness or smeared thickness techniques as described in "Strength Assessment of Pitted Plate Panels," (SSC-394). Since ultrasonic thickness measurements are not usually taken at the same location during inspections and there is no systematic approach for the data collection (including the number of points and distribution of points per location), accurate determination of the corrosion rate is not possible. As a result, the data have limited application and are not suitable for predicting steel condition and developing long-term maintenance plans that would minimize costs and failure risks.

With the increased surface area of ballast spaces in double-hull tankers and the potential for large maintenance costs associated with steel and coating repair, it has become very important to determine corrosion trends in order to optimize maintenance plans as well as determine the current condition. Sources of randomness in corrosion include type and usage of tank, location within the tank, existing corrosion control systems, and temperature. A probabilistic model for corrosion should be developed that includes all these factors. Based on this model, a systematic approach for ultrasonic thickness measurements should be proposed. The inspection results would then be used to update the probabilistic model. This probabilistic model should be appropriate for use in probability based structural design such as that developed in the SSC project "Probability Based Ship Design: Implementation of Design Guidelines" (SSC-392).

Recommendations Perform the following tasks:

- Carry out a literature survey on corrosion of tankers in order to determine parameters that influence corrosion rate. Confer with regulatory agencies, classification societies, and ship operators regarding information currently recorded and perceived needs.
- Develop a probabilistic model for corrosion rate that depends on parameters selected in the first task.
- Based on this model, develop a standard approach for collecting and recording ultrasonic thickness measurement data. This approach should identify grid patterns and locations of readings for each structural member.
- Develop a methodology for updating the probabilistic model based on inspection data.
- Recommend a format for storing and presenting the data (graphical, pictorial, database) and related results such as corrosion rate, alarm and action limits, and the anticipated time to reach the limits.

Duration 1,500 labor hours over 18 months

98-11 FILLET WELDING OF BOTTOM STRUCTURE TO RESIST RUPTURE IN IMPACT LOADING (97-8 REVISED)

Objective Evaluate the effect of weld design on structural rupture resistance. This study will establish criteria for fillet weld selection, evaluate the risks resulting from premature weld failure, and provide appropriate guidelines to designers and builders.

Benefit This project will enhance safe operation of vessels with respect to pollution prevention and structural integrity under accident conditions. More effective and efficient welding would improve structural reliability and integrity under accident conditions.

SSC National Goals

- Improve the safety and integrity of marine structures.
- Reduce marine environmental risks.
- Support the U.S. and Canadian maritime industry in shipbuilding, maintenance, and repair.

SSC Strategies

- Prevention research including damage-tolerant structures
- Improved engineering analysis and evaluation
- Structural reliability engineering
- Research of double-hull vessel technology

Background Premature weld failure may severely limit the energy absorption of ship structures during large deformation resulting from collision, grounding, and explosion. This is particularly true for the case of large deformations perpendicular to the direction of the weld for stiffening members. A review of a number of tanker casualties has shown that the strength of welds can have a major impact on the amount of energy absorbed. In some instances the fillet welds have held; in others, they have not. This project will analyze varying impact scenarios and propose a rational approach to improve weld-strength effectiveness. A recent three-year Massachusetts Institute of Technology (MIT) joint industry project (JIP) on tanker safety covered the development of a computational model of the process of steady tearing of hull plating. However, the computer code DAMAGE from MIT's JIP does not explicitly consider weld performance. A basic understanding of weld performance during grounding needs to be developed to complement other work in this area.

Recommendations Perform the following tasks:

- Evaluate the strength of differing-strength fillet welds under various grounding/stranding scenarios. Validate the findings.
- Establish weld-strength criteria and design methods for achieving given strength levels.
- Provide weld-strength characteristics that can be incorporated into the DAMAGE computer model.
- Prepare guidelines for designers and builders.

Duration 2,000 labor hours over 18 months

98-12 CD-ROM COURSE ON SHIPBOARD CORROSION AND CORROSION CONTROL

Objective Develop instructional materials for designers, construction and maintenance personnel, naval architects, and others interested in corrosion and corrosion control on ships.

Benefit The results of the program are expected to enhance safe operation of ships, improve structural inspection, and reduce life cycle costs.

SSC National Goals

- Improve the safety and integrity of marine structures.
- Reduce marine environmental risks.
- Support the U.S. and Canadian maritime industry in shipbuilding, maintenance, and repair.

SSC Strategies

- Structural reliability engineering
- Improved structural inspection techniques
- Improved efficiency for repair technology
- Improved engineering analysis and evaluation

Background A number of corrosion-related problems on board ships could be prevented through better understanding of the causes of corrosion and effective corrosion control methods. Corrosion is a topic that often receives inadequate emphasis in undergraduate engineering courses and, as a result, those involved in the design, construction, and maintenance of ships may have only a cursory knowledge of the subject. An intensive CD-ROM lecture series on topics ranging from the fundamentals of corrosion to specific problems associated with corrosion control systems would be a cost-effective means of training personnel who need an understanding of corrosion and corrosion control applied to shipboard structures. Information from SSC project SR-1377, "Commercial Ship Design and Fabrication for Corrosion Control" (which identifies corrosion control methodologies that should be used to improve life-cycle maintenance costs), should be incorporated into the course content.

Recommendations Perform the following tasks:

- Develop a course using a CD-ROM format, containing the following elements: (a) fundamentals of corrosion, (b) forms of shipboard corrosion, (c) common shipboard corrosion problems, (d) shipboard corrosion control measures, and (e) designing for corrosion control.
- Work with a professional multimedia group to produce the presentations using the CD-ROM format.

- Assist in the dissemination of the CD-ROM at several fora, including company and campus sites in the United States and Canada.
- Prepare a final report.

Duration 1,000 labor hours over one year

98-13 IMPLEMENTATION PLAN FOR USE OF POLYMER-BASED COMPOSITES IN SHIP STRUCTURES (96M-K)

Objective Identify applications for polymer-based composite materials in commercial ship structures. These applications should have the potential to reduce weight, provide better damage tolerance, and optimize material use. Draft a plan to incorporate these materials into new and existing ship structures.

Benefit The results of this project will be of great benefit in efforts to replace conventional materials with composites for the purpose of enhancing performance, producibility, reliability, maintainability, and safety.

SSC National Goals

- Support the U.S. and Canadian maritime industry in shipbuilding, maintenance, and repair.
- Improve the safety and integrity of marine structures.

SSC Strategy

- Development of structures-related producibility technology

Background Polymer-based composites are an attractive class of materials for marine applications. The properties of composites can be tailored to meet specific engineering needs; they offer high specific strength and stiffness. Composites have the potential to reduce weight and corrosion, provide better damage tolerance, and optimize material use. In order to fully realize the benefits of composites as applied to commercial ship structural applications, it is necessary to identify those applications that have a high probability for incorporation into ship structure based on currently available and rapidly evolving technology. Therefore, a comprehensive study must be directed toward identifying those structures or components of commercial ships that are the most appropriate candidates for composite usage. To accomplish this, risk assessments should be conducted in the areas of environmental compatibility, toxicity, and fire resistance. Manufacturing and joining problem areas must be identified. The project should develop a comprehensive plan to phase in the use of composites that will meet SSC goals and strategies. Related studies have been undertaken by the Great Lakes Composites Consortium[1] and the National Research Council.[2] There are two major MARITECH projects that are presently addressing application of polymer composites to ship structures, one at the University of California at San Diego, the other at Structural Composites Inc., West Melbourne Florida. Structural Composites Inc. has performed considerable research on fire performance of polymer composites for the U.S. Navy, coordinates fire aspects of all the Navy Center of Excellence for Composite Manufacturing Technology (CECMT) projects, and is responsible for fire performance testing for the two MARITECH composite projects. In addition, structural design methodologies for implementation are contained in the ongoing SSC project SR-1367, "Design Guide for Marine Applications of Composites." This information should be used in the development of an implementation plan for the use of composites in ship structures.

Recommendations Perform the following tasks:

- Conduct a survey on the use of composites in marine applications.
- Identify those structures and components made of conventional materials in commercial ships that could be designed and fabricated from composite materials.
- Establish the benefits of replacing conventional material in commercial ships with composites and compare the benefits of using each of the materials.
- Perform risk assessments in terms of environmental concerns.
- Identify challenges to manufacturing, fabrication, and joining.
- Develop a comprehensive plan to phase in the use of composites in those areas previously identified.
- Develop the scope of follow-on research needed to facilitate incorporation of composites into ship structures.

Duration 1,500 hours over one year

[1] Roadmap for Use of Composites in Shipbuilding. GLCC Inc., Trade Zone Drive, Suite 26C, West Columbia, SC 29170.

[2] NRC (National Research Council). 1991. Use of Composite Materials in Load-Bearing Marine Structures. Marine Board, NRC. Washington, D.C.: National Academy Press.

98-14 CONDITION ASSESSMENT AND OPTIMAL MAINTENANCE OF EXISTING SURFACE COATING SYSTEMS FOR TANKERS (96-18)

Objective Develop guidelines for determining when cargo tanks should be coated, for assessing the condition of the existing coating systems, and for determining an optimal coating maintenance program.

Benefit Results of this project would reduce maintenance costs, enhance safe operation of tankers with respect to structural integrity and pollution prevention, and improve the consistency of coating evaluation and maintenance planning.

SSC National Goals

- Improve the safety and integrity of marine structures.
- Support the U.S. and Canadian maritime industry in shipbuilding, maintenance, and repair.

SSC Strategy

- Improved structural inspection techniques

Background As a result of the double-hull design requirements, there is a separation between the liquid cargo and the ballast in new double-hull oil tankers. This means that future tankers will have corrosion-exposure profiles significantly different from those of tankers of the past. The affected areas will be more difficult to evaluate because of problems associated with visual access. Anticipating these difficulties, more stringent survey and maintenance requirements have been imposed by the classification societies and by the International Maritime Organization. There is a critical need to more accurately assess a coating's condition during inspection and to determine an accurate coating condition and effective replacement program.

Several institutions have defined rating systems for coating effectiveness and recommended coating maintenance and replacement strategies based on these ratings. For instance, the American Bureau of Shipping (ABS) and the Tanker Structure Cooperative Forum "Condition Evaluation and Maintenance of Tanker Structures" classify coating conditions as "good," "fair," and "poor" based on percentage and location of coating breakdown and hard scale. Det Norske Veritas has published "Guidelines for Corrosion Protection of Ships," in which coating maintenance requirements and coating useful life are defined based on percentage of surface area with breakthrough rust. Owing to difficulties in quantifying the degree of coating failure by visual inspection, an optimum decision for repairing or replacing the coating is not always made. The assessment of coating failure will, in many cases, depend on the inspector's experience.

In order to accurately evaluate coating effectiveness and improve coating maintenance, it is necessary that clearer and more specific guidelines be developed for coating evaluation. In addition, strategies for coating maintenance should be developed.

This project is complementary to the recently completed SSC projects in the area of corrosion control, SR-1377, "Commercial Ship Design and Fabrication for Corrosion Control," and SR-1366, "Corrosion Control of Interhull Spaces" (SSC-390). These two projects address the selection, as opposed to the maintenance, of effective methods of corrosion control.

Recommendations Perform the following tasks:

- Carry out a literature survey on evaluation of coating performance and criteria for repair.
- Review current guidelines, including the ABS publication "A Guidance Manual for Field Surveyors, 1995," for condition assessment and maintenance of coating, including information generated by painting manufacturers, classification societies, ship owners, and shipyards.
- Develop a methodology for determining optimum maintenance strategies for coatings that would result in minimum life cycle costs. This methodology should take into account various parameters affecting the problem, such as the remaining life of the vessel, frequency of repairs, another corrosion protection system (e.g., cathodic protection), and heating condition. Alternatives for surface preparation (e.g., hydroblasting or grit blasting) and their associated costs should be taken into account.
- Develop and propose a system for more specifically quantifying the degree of coating failure.

Duration 2,000 labor hours over one year

98-15 EFFECTS OF RESIDUAL STRESS AND DISTORTION ON THIN PANEL PERFORMANCE

Objective Develop a methodology to analytically predict the performance of stiffened panels incorporating the residual stress and distortions introduced during the fabrication process.

Benefit This study will assist designers in incorporating manufacturing effects in structural performance analyses and in linking designers to production techniques. This will promote efficiency in manufacture by ensuring that fabrication standards are no more stringent than necessary to provide the required structural performance.

SSC National Goals

- Improve the safety and integrity of marine structures.
- Support the U.S. and Canadian maritime industry in shipbuilding, maintenance, and repair.

SSC Strategy

- Improved engineering analysis and evaluation

Background Recently, advances have been made in predicting the levels of distortion and residual stresses present in thin-shell stiffened panels used in the shipbuilding industry. Most of this work has been performed in a distortion control project funded by the Navy Joining Center (NJC).[1] The results of this project have led to methodologies that can be useful in reducing the amount of weld-induced distortion and thus minimize the amount of flame straightening needed.

Even when the distortion can be reduced to achieve the required fairness, some level of distortion and residual stress is still present in the panel. This can have a direct impact on the fatigue life, buckling strength, fracture toughness, and other performance criteria of the panel. Typically, to account for the presence of distortion and residual stress, safety factors are introduced into the design. However, now that distortion and residual stress levels can be predicted and directly incorporated into structural analyses of the panels, a more realistic determination of their effects and appropriate design modifications can be determined.

[1] C.A. Conrardy, A. DeBiccari, R. Dull, M. Kirk, and P. Michaleris. 1995. Control of Residual Stresses and Distortion in Thin Section Panel Fabrication. Project No. J8662. Columbus, Ohio: Edison Welding Institute.

Recommendations Perform the following tasks:

- Extend NJC work to cover additional panel geometries typical in ship construction.
- Experimentally validate residual stress and distortion predictions.
- Develop methodologies to incorporate the predicted residual stresses and distortions into panel structural analyses.
- Develop guidelines for design modifications and appropriate safety factors based on panel geometry and welding conditions.

Duration 3,000 labor hours over two years

98-16 LIFE EXPECTANCY ASSESSMENT OF SHIP STRUCTURES

Objective Develop a method for assessing the life expectancy of ships based on reliability methods for ship structures.

Benefit The ability to evaluate true life expectancy and to match this to life cycle costs will allow improved acquisition decisions by ship owners and operators.

SSC National Goals

- Improve the safety and integrity of marine structures.
- Reduce marine environmental risks.
- Support the U.S. and Canadian maritime industry in shipbuilding, maintenance, and repair.

SSC Strategies

- Development of better design tools and information systems, such as computer-aided design systems, design information systems, and artificial intelligence
- Improved engineering analysis and design

Background The life expectancy of a ship depends on several key issues. These issues include the quality of the ship's initial design and construction; the service in which it operates; the owner's maintenance and repair strategies; the rate of change of technology during its service; and the prevailing economic circumstances affecting operations, upkeep, scrapping, and new construction. An owner's investment decisions will, ideally, be able to balance initial cost, maintenance costs, and probable residual value at the end of a forecast period in selecting a required life expectancy for a new (or used) ship. But, few of the tools needed to do this are currently available.

There is a general sense among shipbuilders and naval architects that the life expectancy of newer ships has decreased from levels achieved by much earlier designs. However, this is difficult to quantify. Questions regarding issues differentiating between ship designs adequate for 20- and 40-year life cycles are somewhat esoteric and point to the need to develop a general framework.

Over the last decade, the SSC has sponsored several projects that have dealt with reliability analysis and probability-based design of ship structures. These projects focused on the design of new structures. For existing, as well as new, structures there is a need to assess life expectancy for the purpose of capital-expenditure planning, comparative evaluation of alternate designs, and inspection and maintenance scheduling. Life expectancy assessment can be expressed only in probabilistic terms, thereby requiring the use of probability and reliability theories. The results of such assessment can be of use to practicing engineers, economists, and decision makers.

Recommendations Perform the following tasks:

- Conduct literature review on time-dependent reliability and life expectancy assessment for various failure modes of ship structures.
- Develop methods for life expectancy assessment for various failure modes of ship structures.
- Demonstrate the developed methods using examples.
- Discuss the limitations of these methods.
- Provide recommendations for future work.

Duration 2,500 labor hours over 18 months

5

Active and Pending Projects

This section covers current projects funded with FY 1995 (or earlier) funds, those continued with FY 1996 funds, and those that will be supported with FY 1997 funds. They constitute the current program. Table 5-1 lists projects under way; Table 5-2 lists projects scheduled to start during 1997. The majority of projects are for one year; multiyear projects are funded incrementally on an annual basis.

Project descriptions following Tables 5-1 and 5-2 include the project number and title, the name of the principal investigator and organization (when determined), a brief statement of the project's objective, and the names of project chairs and technical advisers (when assigned).

ACTIVE PROJECTS

TABLE 5-1 Active Projects

SSC Number	CMS Number[a]	Project Title	Projected Completion Date	Page
SR-1335	89-3	Interactive Nature of Cathodic Polarization and Fatigue	Feb 97	58
SR-1354		Grounding Protection of Tankers	Dec 95	59
SR-1357	93-2/4	Retention of Weld Metal Properties and Prediction of Hydrogen Cracking	Feb 97	59
SR-1359		U.S.-Russian Cooperative Research Effort	Sep 95	59
SR-1360		Structural Maintenance Project		60
SR-1362	94-2	Probability-Based Design (Phase 4), Synthesis of the Reliability Thrust Area	May 97	60
SR-1365	94-6	Optimal Strategies for Inspection of Ships for Fatigue and/or Corrosion Damage	Dec 96	61

SSC Number	CMS Number[a]	Project Title	Projected Completion Date	Page
SR-1367	94-5	Design Guide for Marine Applications of Composites	Mar 97	61
SR-1368	94-16	Compensation for Openings in Structural Members	Apr 97	62
SR-1369		Fleet of the Future Publication Review	Mar 97	62
SR-1374	95-10	A Guide to Damage Tolerance Analysis of Marine Structures	Dec 96	62
SR-1375	95-4	Detection Probability Assessment of Visual Inspection of Ships	Dec 96	63
SR-1376	95-2	Methodology to Establish the Adequacy of Weld Repairs	Mar 97	63
SR-1378		Strength and Stability Testing of Stiffened Plate Components	Oct 96	64
SR-1381		Development of CD-ROM Library of SSC Reports	Feb 97	64
SR-1382	96-1	Evaluation of Effect of Construction Tolerances on Vessel Strength	Mar 97	64
SR-1383	96-3	Failure Definition for Structural Reliability Assessment	Dec 97	65
SR-1384	96-14	Crack-Arrest Toughness of Steel Weldments	Mar 97	65

[a] Where CMS numbers do not appear, the project is either a joint industry project (not a result of a CMS proposal) or an agency proposal.

SR-1335 Interactive Nature of Cathodic Polarization and Fatigue

Investigator Carl E. Jaske

Contractor Cortest Columbus Technologies Inc., Columbus, Ohio

Objective Investigate the effects of cathodic polarization on fatigue of steel in sea water and how cathodic polarization is influenced by notch severity, crack size, and material composition and microstructure (steel strength).

Project Chair William Hanzalek, American Bureau of Shipping, Houston, Texas

Technical Adviser William H. Hartt, Florida Atlantic University, Boca Raton

SR-1354 Grounding Protection for Tankers

Investigator Thomas Wierzbicki

Contractor Massachusetts Institute of Technology, Cambridge

Objective Evaluate analytical methods to calculate the energy-absorption capability of double-hull tanker structures during grounding.

Project Chair H. Paul Cojeen, U.S. Coast Guard, Washington, D.C.

Technical Adviser none assigned

SR-1357 Retention of Weld Metal Properties and Prediction of Hydrogen Cracking

Investigator Richard J. Wong, Gene Franke

Contractor Carderock Division, Naval Surface Weapons Center, Carderock, Maryland

Objective Develop a method for ensuring that required weld metal properties are produced over the complete range of welding conditions, processes, and consumables used during new construction and repair. Also, develop a reliable test for predictions of weld metal cracking to allow establishment of safe conditions to facilitate introduction of higher-strength and more productive steels.

Project Chair J. Allen Manuel, Naval Sea Systems Command, Arlington, Virginia

Technical Adviser Santiago Ibarra, Amoco Corp., Naperville, Illinois

SR-1359 U.S.—Russian Cooperative Research Effort

Investigator Vladimir Ankudinov

Contractor Designers and Planners, Inc., Arlington, Virginia

Objective Contract to assess the depth of Russian technology in the area of ship structures by conducting a research effort parallel to selected existing or recent SSC projects. The primary project selected was Project SR-1352, "Extreme Waves and Wave Impact Forces."

Project Chair Alexander Malakhoff, Arlington, Virginia

Technical Adviser none assigned

SR-1360 Structural Maintenance Project

Investigator Robert Bea

Contractor University of California, Berkeley

Objective Continue research on structural maintenance programs, specifically: "A Repair Management System," "Fatigue Classification of Critical Structural Details," and "A Fatigue Study of Proposed Critical Structural Details in Double-Hull Tankers."

Project Chair H. Paul Cojeen, U.S. Coast Guard, Washington, D.C.

Technical Adviser none assigned

SR-1362 Probability-Based Design (Phase 4), Synthesis of the Reliability Thrust Area

Investigator Paul A. Frieze, Twickenham, United Kingdom

Contractor Paul A. Frieze Associates

Objective Provide a coherent synthesis of the projects in the reliability thrust area and related SSC projects, as well as the most recent developments that are likely to impact marine structural-reliability analysis and design. Provide a document that summarizes the state of the art in marine structural reliability. This document would be the fundamental reference for (1) development of a probability-based ship-structure design code, (2) definition of procedures for performing failure analysis, and (3) reliability analysis for existing ships.

Project Chair H. Paul Cojeen, U.S. Coast Guard, Washington, D.C.
Technical Adviser none assigned

SR-1365 Optimal Strategies for Inspection of Ships for Fatigue and/or Corrosion Damage

Investigator I.R. Orisamolu
Contractor Martec Ltd., Ottawa, Ontario, Canada
Objective Develop an optimal strategy for inspection of ships in service. The focus will be on tankers. Reduce maintenance costs for ships, while maintaining or improving safety and reliability.
Project Chair Philip G. Rynn, American Bureau of Shipping, Houston, Texas
Technical Adviser Rong T. Huang, Chevron Shipping Company, San Francisco, California

SR-1367 Design Guide for Marine Applications of Composites

Investigator Eric Greene
Contractor Eric Greene Associates, Annapolis, Maryland
Objective Develop a guide for the safe and cost-effective design of composite components for ships and offshore structures. A design guide for the application of composites to marine structures would provide a valuable resource to ship and offshore platform designers and fabricators.
Project Chair Edward E. Kadala, Naval Sea Systems Command, Arlington, Virginia
Technical Adviser none assigned

SR-1368 Compensation for Openings in Structural Members

Investigator John Hopkinson

Contractor Vibtech, Inc., North Kingstown, Rhode Island

Objective Establish rational methodologies and guidelines for the determination of appropriate compensation for small and large openings in primary structural members of ships. Two sets of guidelines are required, one suitable for preliminary and contract design and another for detailed design. The efficiency and reliability of structural reinforcements around openings in primary structures should be improved and their design and construction should be made less costly.

Project Chair Stephen G. Arntson, Arlington, Virginia

Technical Adviser none assigned

SR-1369 Fleet of the Future Publication Review

Investigator JohN W. Fisher

Contractor Lehigh University, Bethlehem, Pennsylvania

Objective Review the work published by the Center for Advanced Technology for Large Structural Systems of Lehigh University under the U.S. Navy-sponsored "Fleet-of-the-Future" program. Summarize the material in a single volume and publish it as an SSC report.

Project Chair William J. Siekierka, Naval Sea Systems Command, Arlington, Virginia

Technical Adviser none assigned

SR-1374 A Guide to Damage Tolerance Analysis of Marine Structures

Investigator Lalit Malik

Contractor Fleet Technology Inc., Kanata, Ontario, Canada

Objective Develop an engineering guide for the analysis of the damage tolerance of marine structures that is suitable for (1) initial design, (2) fitness-for-purpose analysis during in-service inspection, and (3) life-extension analysis.

Project Chair Peter Noble, American Bureau of Shipping, Houston, Texas

Technical Adviser Harold Reemsnyder, Bethlehem Steel, Bethlehem, Pennsylvania

SR-1375 Detection Probability Assessment of Visual Inspection of Ships

Investigator Laura A. Demsetz

Contractor University of California at Berkeley

Objective Develop a probabilistic model, based on inspection data, that will help eliminate uncertainties associated with the use of visual methods for the detection of fatigue cracks.

Project Chair Linwood Pendexter, American Bureau of Shipping, Houston, Texas

Technical Advisers Bilal Ayyub, University of Maryland, College Park; Rong T. Huang, Chevron Shipping Company, San Francisco, California; David J. Witmer, BP Oil Company, Cleveland, Ohio

SR-1376 Methodology to Establish the Adequacy of Weld Repairs

Investigator Jeffrey Crompton

Contractor Edison Welding Institute, Columbus, Ohio

Objective Experimentally evaluate the adequacy of weld repairs, so that a decision regarding whether to repair at all, to repair further, or to operate without such repairs can be made on a technical basis. This will both improve safety and reduce the costs of maintenance procedures.

Project Chair John Dorn, Naval Sea Systems Command, Arlington, Virginia

Technical Adviser Hugh S. Rynn, Sea-Land Service, Elizabeth, New Jersey

SR-1378Strength and Stability Testing of Stiffened Plate Components

Investigator Thomas J.E. Zimmerman

Contractor Centre for Engineering Research, Inc., Edmonton, Alberta, Canada

Objective Develop and use a general purpose experimental test frame to complement and verify several past and current SSC projects as well as Defence Research Establishment Atlantic and Transport Canada research work. The tests are to measure the strength and stability of single stiffened-plate components with doubly symmetric boundary conditions to represent the behavior of a stiffened grillage structure under any combination of in-place or lateral loads.

Project Chair Neil Pegg, Defence Research Establishment Atlantic, Halifax, Nova Scotia, Canada

Technical Adviser Owen Hughes, Virginia Polytechnic and State University, Blacksburg

SR-1381 Development of CD-ROM Library of SSC Reports

Contractor Dynamic Resources, Inc., Arlington, Virginia

Objective Develop a library of all past reports of the SSC on a compact-disk read-only-memory (CD-ROM) file.

Project Chair Robert E. VanJones, Military Sealift Command, Washington, D.C.

Technical Adviser none assigned

SR-1382 Evaluation of Effect of Construction Tolerances on Vessel Strength

Investigator Daniel Bruckman

Contractor Carderock Division, Naval Surface Warfare Center, Carderock, Maryland

Objective Evaluate the suitability of typical shipyard fabrication standards for ship structure constructed of mild steel and high-tensile steels. The evaluation of these standards should be based on an analysis of the structural imperfections that are introduced during ship construction on the structural behavior of the ship. Evaluate the need for revising these standards.

Project Chair Philip G. Rynn, American Bureau of Shipping, Houston, Texas

Technical Advisers Rong T. Huang, Chevron Shipping Company, San Francisco, California; Bruce K. Jackson, Bath Iron Works, Bath, Maine

SR-1383 Failure Definition for Structural Reliability Assessment

Investigator Paul E. Hess

Contractor Carderock Division, Naval Surface Warfare Center, Carderock, Maryland

Objective Develop a method for defining failure, which is needed for structural reliability assessment of marine structures and suitable for structural reliability assessment. Establish definitions of failures for surface ship structures at several levels that include fatigue of details, fracture, and collapse of stiffened and unstiffened panels, grillages, and hull girders. The analytical criteria (or failure definitions) will be compared with data developed from actual practice.

Project Chair George J. Snyder, Naval Sea Systems Command, Arlington, Virginia

Technical Adviser Andrew Kendrick, Fleet Technology, Montreal, Quebec, Canada

SR-1384 Crack-Arrest Toughness of Steel Weldments

Investigator Lalit Malik

Contractor Fleet Technology Inc., Kanata, Ontario, Canada

Objective Develop fracture mechanics test methods and analytical models for the crack-arrest assessment of marine weldments. Develop small-scale fracture-mechanics test methods to estimate the crack-arrest toughness of steel weldments. Develop a fracture-mechanics model for the assessment of crack arrest in marine structures.

Project Chair Ernest Czyryca, Carderock Division, Naval Surface Warfare Center, Carderock, Maryland
Technical Adviser Harold S. Reemsnyder, Bethlehem Steel Corporation, Bethlehem, Pennsylvania

PENDING PROJECTS

TABLE 5-2 Pending Projects

SSC Number	CMS Number	Project Title	Start Date	Completion Date	Page
1385	96-5	In-Service Nondestructive Evaluation of Fatigue and Fracture Properties of Ship Structures			66
1386	97-5/6	Fatigue-Resistant Detail Design Guide and Short Course on Fatigue and Fracture Analysis of Ship Structure	Jun 97	Dec 98	67
1387	97-2	A Predictive Methodology for the Evaluation of Residual Stress and Distortion in Ship Structures	Jun 97	Jun 99	67
1388	97-9	Sea-Operational Profile for Structural Realiability Assessments	Jun 97	Jun 98	68
1389	97-4	Risk Assessment of the Use of Polymer Matrix Composites in Marine Environments	Jun 97	Dec 98	68

SR-1385 In-Service Nondestructive Evaluation of Fatigue and Fracture Properties of Ship Structures

Investigator not yet determined
Contractor not yet determined

Objectives Develop an innovative method to nondestructively evaluate the fatigue and fracture properties of in-service ship structures so that a remaining life evaluation can be performed. Review the literature to identify possible methods for nondestructive evaluation of fatigue and fracture properties. Develop or adapt a nondestructive method to evaluate the fatigue and fracture properties of ship steels that have had extensive service exposure. Show how these properties can be used to evaluate the remaining life of ship structural components.

Project Chair Michael J. Touma, Military Sealift Command, Washington, D.C.
Technical Adviser John D. Landes, University of Tennessee, Knoxville

SR-1386 Fatigue-Resistant Detail Design Guide and Short Course on Fatigue and Fracture Analysis of Ship Structure

Investigator not yet determined
Contractor not yet determined
Objective Develop a guide for the design of fatigue-resistant structural details by practicing engineers. The guide should include a standardized fatigue design approach and a fatigue-life prediction method for the details. Design, organize, and conduct a continuing education course on the performance of ship structural integrity analyses by ship designers.
Project Chair Nash Gifford, Carderock Division, Naval Surface Warfare Center, Carderock, Maryland
Technical Adviser Harold S. Reemsnyder, Bethlehem Steel Corporation, Bethlehem, Pennsylvania

SR-1387 A Predictive Methodology for the Evaluation of Residual Stress and Distortion in Ship Structures

Investigator not yet determined
Contractor not yet determined
Objective Develop a predictive methodology, including the effect of the use of block welding, for evaluating residual stress and distortion in ship structures. This methodology will be used to mitigate residual stress and distortion problems due to welding fabrication. Assess the suitability and applicability of ongoing work in the determination of residual stress and distortion, including ongoing work at the Navy Joining Center. Identify potential applications of residual stress and distortion predictive capabilities on double-hull ship construction and perform an economic assessment of their impact. Develop a predictive model that incorporates global structural interactions into the evaluation of residual stress and distortion produced by welding. Validate the model with experimental

measurements. Develop guidelines for residual stress and distortion modeling in ship structure that account for joint configuration and the welding processes employed.

Project Chair not yet determined

Technical Adviser Paul Blomquist, Pennsylvania State University, State College

SR-1388 Sea-Operational Profile for Structural Reliability Assessments

Investigator not yet determined

Contractor not yet determined

Objective Assess the effects of the variability in the sea-operational profiles of surface ships on the evaluation of their structural reliability. Develop a method for determining operational profiles of ships and assess a typical profile with the associated uncertainties. The typical profile can be developed using either analytical techniques or field surveys, or both.

Project Chair Layton Gilroy, Defence Research Establishment Atlantic, Halifax, Nova Scotia, Canada

Technical Adviser Bilal M. Ayyub, University of Maryland, College Park

SR-1389 Risk Assessment of the Use of Polymer Matrix Composites in Marine Environments

Investigator not yet determined

Contractor not yet determined

Objective Determine the flammability, smoke, and toxicity properties of composite materials and identify promising candidate material systems for ship and offshore platform structures designed to meet international standards for firesafety and environmental protection. From a human-factors viewpoint and considering fire and smoke standards, recommend changes to existing regulations and standards for maximum acceptable smoke and toxicity threshold levels.

Project Chair not yet determined

Technical Adviser not yet determined

6

Summary of Completed Projects

Projects completed since the 1996–1997 biennial report was published are listed in Table 6-1. Each of the project descriptions that follow Table 6-1 includes a brief summary of that project's final report. These summaries represent the CMS's understanding of the results as reported by the authors of the reports.

Project reports have been published, are in publication, or will be available from the National Technical Information Service (NTIS), 5285 Port Royal Rd., Springfield, VA 22161. Where they exist, NTIS numbers are given with each project description, along with the SSC report number (unless that number has not yet been assigned). NTIS numbers also appear in Table 6-2 at the end of the chapter.

Many recent reports may be available from the executive director of the SSC. Requests may be mailed to Lt. Thomas Miller (G-MMS/SSC), 2100 Second St., S.W., Washington, DC 20593-0001.

TABLE 6-1 Completed Projects

SSC Project Number	SSC Report Number[a]	CMS Number[b]	Project Title	Completion Date	Page
SR-1343	383	91-2	OptimumWeld Metal Strength for High-Strength Ship Structures	Dec 95	71
SR-1344		91-11	Assessment of Reliability of Existing Ship Structures (Phase 2)	Nov 96	71
SR-1345	392	92-1	Probability-Based Ship Design: Implementation of Design Guidelines	Sept 96	72

SSC Project Number	SSC Report Number[a]	CMS Number[b]	Project Title	Completion Date	Page
SR-1349	393	93-9	Evaluation of Ductile Fracture Models for the Prediction of Fracture Behavior of Ship Structure Details	Jun 96	73
SR-1355	389	93-5	Inspection of Marine Structures	Jun 96	73
SR-1356	394		Strength Assessment of Pitted Plate Panels	Sept 96	74
SR-1358		93-6	Optimized Design Parameters for Welded TMCP Steels	Jan 97	75
SR-1363		94-1	Symposium and Workshop on the Prevention of Fracture on Ship Structures	Dec 96	75
SR-1364	387	94-7	Guideline for Evaluation of Finite Elements and Results	Feb 96	76
SR-1366	390	94-3	Corrosion Control of Inter-hull Spaces	Jun 96	77
SR-1370	380		Ship Structural Integrity Information System	Mar 95	78
SR-1370	388		Ship Structural Integrity Information Systems (Phase II)	Mar 96	78
SR-1371	395		Ships Maintenance Project (phase III)	May 96	78
SR-1372	391	95-16	Evaluation of Marine Structures Education in North America	Jun 96	79
SR-1373		95-9	Hull Response Monitoring Systems	Nov 96	80
SR-1377		95-3	Commercial Ship Design and Fabrication for Corrosion Control	Dec 96	80
SR-1379		95-6	Weld Detail Fatigue-Life Improvement Techniques	Mar 97	81
SR-1380	384	95TC	Post-Yield Strength of Icebreaking Ship Structural Members	Aug 95	82

[a] Where report numbers do not appear, they have not yet been assigned.

[b] Where CMS numbers do not appear, the project is either a joint industry project (not a result of a CMS proposal) or an agency proposal.

SR-1343 OPTIMUM WELD METAL STRENGTH FOR HIGH-STRENGTH SHIP STRUCTURES (SSC-383) (NTIS PB96-129036)

Investigator Robert J. Dexter

Contractor Lehigh University, Bethlehem, Pennsylvania

Objective Develop guidelines to improve productivity by optimizing weld metal properties for use with high-strength steels.

Summary This report provides data and analysis to support the acceptance of undermatched welds in high-strength steel in shipbuilding. Wide-plate tensile tests made from HSLA-100 steel plate (690 MPa minimum yield strength) with transverse groove welds demonstrated that moderately undermatched joints (actual weld yield strength up to 12 percent less than actual base-plate yield strength) can achieve strength and ductility as high as overmatched welds. Welds undermatched between 18 percent and 28 percent exhibited full strength but minimal ductility. Relatively coarse-mesh elastoplastic finite-element analysis adequately reproduced the behavior observed in the experiments. Wide-plate specimens were prepared with various controlled intentional defects in both moderately undermatched and overmatched welds. These defect specimens exhibited remarkable performance and there was no consistent difference between the results of the moderately undermatched welds and the overmatched welds. When loaded in shear, groove welds undermatched up to 28 percent developed the required minimum shear strength of the HSLA-100 plate and had excellent ductility. Guidelines and commentary for design, finite-element analysis, selection of weld filler metal, and welding procedure for various types of joints are given to facilitate the use of high-strength steel with optimum weld metal properties.

Project Chair J. Allen Manuel, Naval Sea Systems Command, Arlington, Virginia

Technical Adviser James M. Sawhill, Jr., Newport News Shipbuilding, Newport News, Virginia

SR-1344 ASSESSMENT OF RELIABILITY OF EXISTING SHIP STRUCTURES (PHASE 2)

Investigator Alaa Mansour

Contractor Mansour Engineering, Inc., Berkeley, California

Objective Estimate reliability levels associated with important failure modes of existing ship structures.

Summary The report presents a detailed approach for assessing structural safety and reliability of ships, providing a means for determining reliability levels associated with modes of failure of the hull girder, stiffened panels, and unstiffened plates. The methodology is demonstrated on four ships: two cruisers, a double-hull tanker, and a containership, providing reliability levels associated with each mode of failure. Recommendations are made of target reliability levels, identifying the design variables that have the highest impact on reliability. Guidelines are provided for making improvements to existing structural design criteria.

Project Chair William M. Richardson, Carderock Division, Naval Surface Warfare Center, Carderock, Maryland

Technical Advisers Keith Hjelmstad, University of Illinois, Urbana; Solomon C.S. Yim, Oregon State University, Corvallis

SR-1345 PROBABILITY-BASED SHIP DESIGN: IMPLEMENTATION OF DESIGN GUIDELINES (SSC-392)

Investigator Alaa Mansour

Contractor Mansour Engineering, Inc., Berkeley, California

Objective Develop a prototype probability-based design or safety-checking criteria for ships.

Summary A reliability-based structural design code for ships was developed and demonstrated for two ship types, cruiser and tanker. The prototype codes cover serviceability and ultimate limit states for four failure modes: hull girder buckling, unstiffened plate yielding and buckling, stiffened plate buckling, and fatigue cracking of critical details. The report provides a roadmap for a multiyear effort to develop a complete ship structural design code.

Project Chair William M. Richardson, Carderock Division, Naval Surface Warfare Center, Carderock, Maryland

Technical Adviser Achintya Haldar, University of Arizona, Tucson

SR-1349 EVALUATION OF DUCTILE FRACTURE MODELS FOR THE PREDICTION OF FRACTURE BEHAVIOR OF SHIP STRUCTURE DETAILS (SSC-393)

Investigator Robert J. Dexter

Contractor Lehigh University, Bethlehem, Pennsylvania

Objective Establish the effectiveness of ductile fracture-mechanics models for predicting the fracture behavior of component ship-structure details.

Summary The report provides guidelines for calculating the load-displacement curves for ductile fracture of cracked ship structural members as a means for determining the maximum crack size that can be tolerated in a typical ship structure without significant loss of load capacity or ductility. This guidance is based upon the analysis of experiments conducted on 30 large-scale welded structural members that contained fatigue cracks and were tested beyond the net-section collapse load to deformations several times the yield-point displacement.

Project Chair Walter G. Reuter, Idaho National Engineering Laboratory, Idaho Falls, Idaho

Technical Adviser John Landes, University of Tennessee, Knoxville

SR-1355 INSPECTION OF MARINE STRUCTURES (SSC-389) (NTIS PB96-167572)

Investigator Laura Demsetz

Contractor University of California, Berkeley

Objective Survey current practices for inspection of marine structures to estimate costs associated with various inspection methods and to quantify, for various methods and types of structures, the sensitivity of inspection methods and accuracy of measured levels of corrosion and fatigue damage.

Summary This report presents a review of the factors affecting the likelihood that a person checking the structure of a ship for failures will find the existing failures. This study was necessitated by several factors: even a small hull failure on a tanker can create a significant oil spill, with damages costing millions of dollars; the cost of lay days for inspections narrows profit margins for the shipping industry; conducting a full inspection of a large ship's structure is a time-consuming process; and there is continued emphasis on reducing the size of all government work forces. Each of these factors requires better understanding of the human factors in the hull inspection process. Through this improved understanding inspections can be better focused to receive the greatest return on the effort invested. A follow-on project is aimed at analyzing the results of actual inspections to quantify the impact of each of the factors identified in this project.

Project Chair Linwood Pendexter, American Bureau of Shipping, Houston, Texas

Technical Adviser Rong T. Huang, Chevron Shipping Company, San Francisco, California

SR-1356 STRENGTH ASSESSMENT OF PITTED PLATE PANELS (SSC-394) (NTIS PB97-131353)

Investigator John C. Daidola

Contractor M. Rosenblatt and Son, Inc., New York, New York

Objective Develop a simple procedure to assess the strength and integrity of pitted and grooved shell plate and other structural components of vessels in service. The procedure will evaluate corrosion damage by determining an effective thickness of pitted plate.

Summary The report presents graphs and a computer program to evaluate residual thickness and strength of a pitted plate and to help make a quantitative judgment in the field whether to repair or to replace the plate. The residual thicknesses of pitted plates computed using these tools can be used to plan ship inspections and make economic decisions. Further research is needed to define the difference between pitted plates and corroded plates under structural loading, to evaluate the accuracy of effective thickness models, and to obtain information on the probabilistic characteristics of the pitting that occurs in service.

Project Chair Stephen E. Sharpe, U.S. Coast Guard, Washington, D.C.

Technical Adviser Maria Celia C. Ximenes, Chevron Shipping Company, San Francisco, California

SR-1358 OPTIMIZED DESIGN PARAMETERS FOR WELDED TMCP STEELS

Investigator Lalit Malik

Contractor Fleet Technology Inc., Kanata, Ontario, Canada

Objective Develop static, fatigue, and fracture strength requirements for high-strength thermo-mechanical control processed (TMCP) steels and weldments.

Summary TMCP steels have been used increasingly in the fabrication of offshore structures because these steels have higher yield strengths and excellent weldability and toughness. These steels have a higher ratio of yield strength to tensile strength than other steels, but this should not adversely affect structural reliability, although the recommended factors for ship design should be used. Because the relationship between the Charpy V-notch transition temperature and the drop weight, nil-ductility transition temperature is different from that of conventional steels, the latter should be specified for the grades of TMCP steel where high toughness is required. These steels behave the same as conventional steels under fatigue loading, for both crack initiation and crack growth, but additional data are needed on the effectiveness of weld fatigue improvement techniques.

Project Chair William Hanzalek, American Bureau of Shipping, Houston, Texas

Technical Adviser Harold S. Reemsnyder, Bethlehem Steel Corporation, Bethlehem, Pennsylvania

SR-1363 SYMPOSIUM AND WORKSHOP ON THE PREVENTION OF FRACTURE IN SHIP STRUCTURES

Investigator John Landes, University of Tennessee, Knoxville

Contractor Committee on Marine Structures

Objective For the purpose of rationally addressing causes and remedies for the rash of structural failures occurring in ships, provide the means for bringing together experts in the fields of fatigue, fracture, and reliability of marine structures and the researchers, designers, fabricators, and operators of these marine structures.

Summary Action is required by regulators, designers, fabricators, maintainers, owners, and operators of ships to reduce the fracture-related failures in ships. The CMS recommends that specific action be taken in the areas of design, loads, inspection and repair, and communications. For design, develop a ship-detail guidebook/standard; expand simplified fatigue analysis methods; gather additional data on the fatigue strength of various large-scale ship details; and design ship structure to include access for service inspections. For loads, develop a rigorous approach for combining high-and low-frequency response; compute loads using mechanics-and geometry-based simulations; develop a relatively inexpensive, easily operated hull-stress monitoring system that provides real-time feedback to the operators; and quantify the degree of uncertainty in load predictions. For inspection, develop guidelines for fitness-for-purpose assessments; develop new inspection tools and improve existing tools; and quantify the fatigue life of temporary repairs. For communications, develop a cradle-to-grave ship structural integrity database system that includes hull-stress monitoring, inspection, and repair data; develop and promulgate a manual or library, sorted by levels of fatigue strength of predictable standard details for fatigue resistance; educate and train future structural designers at the undergraduate level in fatigue and fracture design methods; and use concurrent engineering in ship design to include designers, owners, operators, fabricators, and surveyors/inspectors in the process.

Project Chair Steve Allen, U.S. Coast Guard Research and Development Center, Groton, Connecticut

Technical Adviser Committee on Marine Structures

SR-1364 GUIDELINE FOR EVALUATION OF FINITE ELEMENTS AND RESULTS (SSC-387) (NTIS PB96-153077)

Investigator Roger Basu

Contractor Mil Systems Engineering, Ottawa, Ontario, Canada

Objective Develop a methodology for efficiently qualifying finite element method codes and models for engineering analysis of ship structures. Provide guidelines for modeling in typical marine applications and for rapid assessment of validity of results. Increase the usefulness and confidence level of finite element analyses in the design and evaluation of ship structures. Establish the feasibility of developing specific guidelines for the development and validity assessment of finite element method models and results.

Summary In response to the difficulty faced by those who evaluate finite element analyses (FEA), a systematic and practical methodology has been developed to assess the validity of FEA results based on the choice of analysis procedure, type of elements, model size, boundary conditions, load application, etc. In support of this methodology, a selection of finite element models that illustrate variations in FEA modeling practices are also presented. Benchmark tests have also been developed which can be used to evaluate the capabilities of FEA software packages to analyze several typical ship structure problems.

Project Chair Stephen Gibson, National Defence Headquarters, Ottawa, Ontario, Canada

Technical Adviser none assigned

SR-1366 CORROSION CONTROL OF INTER-HULL SPACES (SSC-390) (NTIS PB96-167580)

Investigator Miles Kikuta

Contractor M. Rosenblatt and Son, Inc., New York, New York

Objective Investigate methods for controlling corrosion in the region between the inner and outer hulls in new double-hulled designs. These methods will help ensure the safety and integrity of the vessels and mitigate corrosion in the inter-hull area of double-hulled vessels. Feasible methods will be ranked according to potential cost-effectiveness.

Summary The advent of double-hull vessels provides a new era of spill resistant tankers. However, with this new increased protection comes the problem of maintaining the closed-in double bottom space. This study, focused primarily on merchant vessels, follows a worldwide survey of commercial shippers and shipyards for the U.S. Navy. The results conclude that the use of readily available coating systems, but with increased emphasis on quality of surface preparation and personnel training, will yield impressive results. If these practices are put in place the North American shipping companies can achieve dramatic savings in recoating of tanks, structural repairs, and the requisite repair lay days.

Project Chair Richard Anderson, Military Sealift Command, Washington, D.C.

Technical Adviser John F. McIntyre, ManGil, Inc., Cleveland, Ohio

SR-1370 SHIP STRUCTURAL INTEGRITY INFORMATION SYSTEMS (PHASE I) (SSC-380) (NTIS PB95-178588)

SR-1370 SHIP STRUCTURAL INTEGRITY INFORMATION SYSTEMS (PHASE II) (SSC-388) (NTIS PB96-167564)

Investigator Robert Bea

Contractor University of California, Berkeley

Objective Develop a plan for an industry-wide database system intended to connect owners, operators, designers, shipbuilders, regulatory bodies, and classification societies with vessel design particulars, failure records, and repair information in order to better prevent future failures.

Summary In 1992 the SSC published a report by Robert Bea of the University of California, Berkeley, that introduced the need to tie together all of the failure information on the U.S. maritime fleet. A program was proposed to mirror that which is currently used in the airline and other industries. The system could be used to identify developing problems earlier and address them before they manifest themselves as a severe catastrophe. Phase I of the project, published as SSC-380, evaluated databases currently in use by ship operators to monitor their vessels and proposed a system to address the data capture needs for design, construction, inspection, maintenance, and operations. Phase II goes further into the topic by examining the reengineering of the structural inspection, maintenance and repair process to improve the integrity and quality of operating ships' structural systems. A prototype of the system, in Microsoft Access format, will be included in the electronic version of the report, which will be issued on a CD-ROM. This program was conducted to provide a tool to assist the industry in management of their fleets, which would result in safer shipping and cleaner waterways. It is hoped that, used in conjunction with other joint initiatives, it will develop into a universal industry-driven Ships Maintenance System.

Project Chair Robert Holzman, U.S. Coast Guard, New Orleans, Louisiana

Technical Adviser Rong T. Huang, Chevron Shipping Company, San Francisco, California

SR-1371 SHIPS MAINTENANCE PROJECT (PHASE III) (SSC-395)

Investigator Robert Bea

Contractor University of California, Berkeley

Objective Develop an analytical approach to estimate the remaining fatigue life of a repair to a cracked ship structural detail. The estimate will be made using stress reduction factors for typical repair cases that have been calibrated by the use of historical ship-inspection data.

Summary The Ships Maintenance Project was a joint industry project in which the SSC participated. The results of Phase II were reported as report SSC-386. This report identifies a series of critical structural details of tanker structure and provides stress reduction factors for various repair alternatives based on finite element analyses. Typical structural survey data that were used for calibration include 358 cracks of one type that were repaired by veeing out and welding, of which four had recracked within three years.

Project Chair H. Paul Cojeen, U.S. Coast Guard, Washington, D.C.

Technical Adviser Rong T. Huang, Chevron Shipping Company, San Francisco, California

SR-1372 EVALUATION OF MARINE STRUCTURES EDUCATION IN NORTH AMERICA (SSC-391) (NTIS PB96-167598)

Investigator Raymond A. Yagle

Contractor The University of Michigan, Ann Arbor

Objective Provide the knowledge needed for the SSC to wisely and effectively take steps to improve the structural engineering departments in North American colleges and universities in support of ship structural design.

Summary The report reviews the structural engineering curriculum contained in the undergraduate and graduate programs in the ocean engineering and naval architectural departments of North American universities. There has been a trend toward increasing emphasis on ship production and fabrication practices in these curricula, but more emphasis is needed on teaching the principles of material behavior, including fatigue and fracture. A survey of industry made by the contractor indicates a feeling that a sufficient number of annual graduates of these schools are currently available, but this may represent an opinion of those inside the marine industry that there is no need for advances in structural technology. The report states that the Ship Structure Committee needs to obtain increased funding and direct more research towards the schools, ensuring that students as well as faculty participate in the research projects.

Project Chair Robert Holzman, U.S. Coast Guard, New Orleans, Louisiana

Technical Adviser none assigned

SR-1373 HULL-RESPONSE MONITORING SYSTEMS

Investigator Maxwell C. Cheung

Contractor MCI Engineering, Costa Mesa, California

Objective Define a hull-response monitoring system capable of measuring, recording, and storing hull-girder stresses and their associated external loadings and of providing real-time information to the operators as critical stress values are approached or exceeded.

Summary The report describes the state-of-the-art in commercial hull-response monitoring systems for wave and ice loading. Information about real-time motions and stresses of the hull, especially when augmented by other navigational and performance data, assists mariners in making tactical ship-handling decisions to mitigate current dangers and can assist in making fatigue assessments and in quantifying design constraints for future ships. Clear presentation of a limited data set in a reliable manner is important for effective shipboard use of these systems. Over 200 systems have been installed on ships worldwide by 11 different manufacturers. Efforts are under way by classification societies, government regulators, and the International Maritime Organization to regulate the installation of these systems.

Project Chair Peter Timonin, Transport Canada, Ottawa, Ontario, Canada

Technical Adviser none assigned

SR-1377 COMMERCIAL SHIP DESIGN AND FABRICATION FOR CORROSION CONTROL

Investigator John C. Daidola

Contractor M. Rosenblatt and Son, Inc., New York, New York

Objective Identify corrosion control methodologies that, when incorporated into ship design and fabrication, can improve life cycle maintenance costs and enhance the safety and integrity of marine structures.

Summary Methods and procedures to accomplish control of corrosion during the design, construction, and in-service phases of a ship's life are investigated. The corrosion control practices currently being used by shipyards, shipowners, ship operators, regulatory agencies, and ship designers are reviewed. The report provides detailed design recommendations for corrosion prevention to reduce life cycle costs. These recommendations are evaluated for their practicality and applicability, and they reflect a survey of industry.

Project Chair Richard A. Anderson, Military Sealift Command, Washington, D.C.

Technical Adviser John F. McIntyre, ManGil, Inc., Cleveland, Ohio

SR-1379 WELD DETAIL FATIGUE-LIFE IMPROVEMENT TECHNIQUES

Investigator Roger I. Basu

Contractor Mil Systems Engineering, Ottawa, Ontario, Canada

Objective Review fatigue-life improvement techniques and procedures to provide design guidance relating to these techniques, including the feasibility of techniques and procedures.

Summary Fatigue cracks usually occur at welded structural details where stress concentrations are high and the fatigue strength of welds is low. When design constraints prevent the use of details that offer improved fatigue performance, or where modifications to the structure of existing ships with fatigue-prone details are not practicable, procedures can be used to improve the fatigue strength of the welds at these details. Methods for improving weld fatigue life include grinding, weld toe remelting, special welding techniques, peening, stress relief, and overloading. The report evaluates these methods, compares their effectiveness, and, based on tests performed in a shipyard, evaluates the relative cost-effectiveness of the techniques.

Project Chair W. Thomas Packard, Naval Sea Systems Command, Arlington, Virginia

Technical Advisers Gerald Cobb, Newport News Shipbuilding, Newport News, Virginia; Peter Lacey, SeaRiver Maritime, Inc., Houston, Texas

SR-1380 POST-YIELD STRENGTH OF ICEBREAKING SHIP STRUCTURAL MEMBERS (SSC-384) (NTIS PB96-109129)

Investigator C. G. DesRochers

Contractor Martec Ltd., Ottawa, Ontario, Canada

Objective Conduct an exploratory investigation into the post-yield behavior of icebreaking vessels. The underlying objective is to determine whether or not the new Canadian Arctic Ship Pollution Prevention Regulations are adequate in regard to buckling prevention.

Summary In this project an icebreaker hull, as modified to meet the requirements of the proposed Canadian Arctic Ship Pollution Prevention Regulations (ASPPR), was modeled. The model was then given a load that was extreme enough to cause some minor plastic deformations of the degree that would be allowed under ASPPR. Through analysis it was determined that the load at which main frame buckling would occur was less than that which had been anticipated. This was interpreted to be due to the progressive yielding of the surrounding structure. Through this and other work the ASPPR will be reviewed for adequacy. This study will also be used to determine how global effects can be applied to local area models of ship structures to avoid the need to model the entire vessel structure.

Project Chair Ian Bayly, Transport Canada, Ottawa, Ontario, Canada

Technical Adviser none assigned

TABLE 6-2 Cross-Reference of Ship Structure Committee Project Numbers and Report Numbers

BY SSC REPORT NUMBER				BY SSC PROJECT NUMBER		
SSC Report Number	SSC Project Number	CMS Number[a]	NTIS Accession Number[b]	SSC Project Number	CMS Number[a]	SSC Report Number[c]
369	1336	89-10	PB94-121928	1339	90-5	374
370	1333	89-11	PB94-121936	1340		386
371	1334	89-6	PB94-121944	1341	91-4	381
372	1347	92-7	PB94-121951	1342	91-10	385
373	1337	90-1	PB94-188208	1343	91-2	383
374	1339	90-5	PB95-100376	1344	91-11	
375	1338	90-3	PB95-126819	1345	92-1	392
376	1348	92-17	PB95-250593	1346	92-5	379
377	1351	92-11	PB95-144366	1347	92-7	372
378	1353	92-8	PB95-126827	1348	92-17	376
379	1346	92-5	PB95-144382	1349	92-2	393
380	1370		PB95-178588	1350	92-16	382
381	1341	91-4	PB95-185419	1351	92-11	377
382	1350	92-16	PB95-188181	1352	92-3	Project canceled
383	1343	91-2	PB96-129036			
384	1380	95TC	PB96-109129	1353	92-8	378
385	1342	91-10	PB96-129101	1355	93-5	389
385A	1342	91-10	PB96-129119	1356		394
386	1340 Vol. 1		PB96-113683	1358	93-6	
386	1340 Vol. 2		PB96-113691	1363	94-1	
386	1340 Vol. 3		PB96-113709	1364	94-7	387
386	1340 Vol. 4		PB96-113717	1366	94-3	390
387	1364	94-7	PB96-153077	1370		380
388	1370 (Phase II)		PB96-167564	1370 (Phase II)		388
389	1355	93-5	PB96-167572	1371		395
390	1366	94-3	PB96-167580	1372	95-16	391
391	1372	95-16		1373	95-9	
392	1345	92-1		1377	95-3	
393	1349	92-2		1379	95-6	
394	1356			1380	95TC	384
395	1371			1381[d]		

[a] Where CMS numbers do not appear, the project is either a joint industry project (not a result of a CMS proposal) or an agency proposal.
[b] Not available for all reports at this time.
[c] Where no number appears, the report number has not yet been assigned. Report numbers are assigned when reports are published.
[d] Compact-disk read-only-memory (CD-ROM) with all completed SSC reports will be available from the executive director of the SSC.

Appendix A

Organization and Administration of Committee on Marine Structures and Ship Structure Committee

ESTABLISHMENT OF COMMITTEES

The Ship Structure Committee (SSC) was established in 1946 on the recommendation of a board of investigation convened by the Secretary of the Navy to inquire into the design and methods of construction of welded-steel merchant vessels. As that investigation concluded, several unfinished studies and items worthy of investigation remained. The board of investigation recommended that a continuing organization be established to formulate and coordinate research on matters pertaining to ship structures.

The purpose of the SSC is to promote safety, economy, marine environmental protection, and education in the U.S. and Canadian maritime industry through the advancement of marine-structures technology.

Since 1946, the National Research Council has rendered technical services to the SSC by developing a continuing research program through the Committee on Marine Structures (CMS) and its predecessors. Sponsored by the SSC and funded collectively by its member agencies, this research program determines how marine structures can be safer and perform better without adverse economic effects.

Figure A-1 shows the relationships of the organizations involved in SSC work.

MEMBERSHIP

The SSC is composed of one senior official from each of the U.S. Coast Guard, the Naval Sea Systems Command, the Maritime Administration, the Military Sealift Command, the American Bureau of Shipping, Transport Canada, and Defence Research Establishment Atlantic. The SSC formulates policy, approves program plans, and provides financial support for the research program through its member agencies.

The Ship Structure Subcommittee, with four representatives from each agency, meets periodically to ensure achievement of program goals and to evaluate research results in terms of structural design, inspection, construction, and operation. Current membership of the SSC and the subcommittee, and the liaisons to them, are listed following Figure A-1.

The CMS and its two work groups, the Materials Work Group and the Design Work Group, are composed of members with academic, governmental, and industrial experience, who were selected for their competence and experience in relevant areas. They serve as individuals contributing personal knowledge and judgment, not as representatives of organizations with which they are employed or associated. Current membership of the CMS and its work groups is listed at the front of this report.

RESPONSIBILITIES

The CMS provides technical projections, reviews, and advice to the SSC on a research program that addresses materials, design, fabrication, and inspection related to marine structures. Specific activities include:

- technical review and analysis of the active and projected SSC research program to improve marine structures in the areas of materials, fabrication methods, and analysis and design
- preparation of a biennial report, which conveys the committee's long-range philosophy, technical review, and analysis and recommends a research agenda for the SSC
- Preparation of a letter report during the years between the biennial reports containing recommendations for additional research based on emerging needs, and a review of previous research recommendations
- technical symposia to assess essential technologies

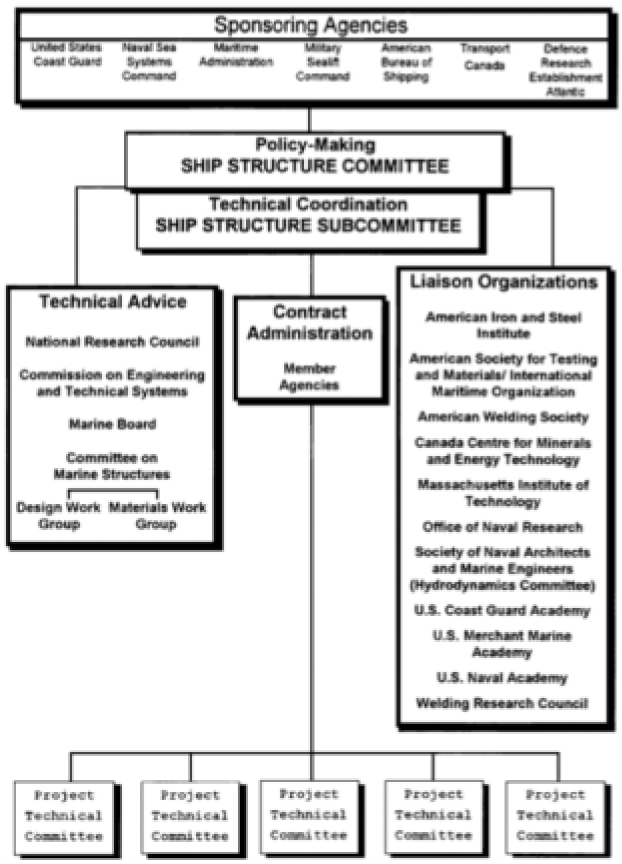

Figure A-1 Ship Structure Committee organization chart

SHIP STRUCTURE COMMITTEE

RADM James C. Card, USCG (Chairman)
Marine Safety and Environmental Protection
U.S. Coast Guard
Mr. Robert McCarthy
Director, Survivability and Structural Integrity Group
Naval Sea Systems Command
Mr. Edwin B. Schimler
Associate Administrator for Shipbuilding and Technology Development
Maritime Administration
Mr. Thomas Conners
Director of Engineering
Military Sealift Command
Dr. Donald Liu
Senior Vice President American Bureau of Shipping
Mr. John Grinstead
Director, Policy and Legislation
Transport Canada
Dr. Ross Graham
Head, Hydronautics Section
Defence Research Establishment
Atlantic

CONTRACTING OFFICER TECHNICAL REPRESENTATIVE

Mr. William J. Siekierka
Naval Sea Systems Command

EXECUTIVE DIRECTOR

CDR Stephen E. Sharpe (Until April, 1997
LT Thomas C. Miller (From April, 1997)
Ship Structure Committee
U.S. Coast Guard

SHIP STRUCTURE SUBCOMMITTEE

U.S. COAST GUARD
CAPT George Wright
Mr. Walter B. Lincoln
Mr. Rubin Sheinberg
NAVAL SEA SYSTEMS COMMAND
Mr. W. Thomas Packard
Mr. Allen H. Engle
Mr. Edward E. Kadala
Mr. Charles L. Null
MARITIME ADMINISTRATION
Mr. Chao H. Lin
Dr. Walter M. Maclean
Mr.Richard P. Voelker
MILITARY SEALIFT COMMAND
Mr. Robert E. VanJones (Chairman)
Mr. Richard A. Anderson
Mr. Jeffrey E. Beach
Mr. Michael W. Touma
AMERICAN BUREAU OF SHIPPING
Mr. Glenn Ashe
Mr. John F. Conlon
Mr. William Hanzalek
Mr. Philip G. Rynn
TRANSPORT CANADA
Mr. Peter Timonin
Mr. Feliz Connolly
Mr. Francois Lamanque
DEFENCE RESEARCH ESTABLISHMENT ATLANTIC
Dr. Neil Pegg
LCDR Steve Gibson
Dr. Roger Hollingshead
Mr. John Porter
SSC STUDENT MEMBER
Mr. Jason Miller
Massachusetts Institute of Technology

SHIP STRUCTURE COMMITTEE LIAISON MEMBERS

AMERICAN IRON AND STEEL INSTITUTE
Mr. Alexander D. Wilson
AMERICAN SOCIETY FOR TESTING AND MATERIALS/INTERNATIONAL MARITIME ORGANIZATION
CAPT Charles H. Piersall (Ret.)
AMERICAN WELDING SOCIETY
Mr. Richard Frank
CANADA CENTRE FOR MINERALS AND ENERGY TECHNOLOGY
Dr. William R. Tyson
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAPT Alan Brown
OFFICE OF NAVAL RESEARCH
Dr. Yapa Rajapaksie
SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS-HYDRODYNAMICS COMMITTEE
Dr. William Sandberg
U.S. COAST GUARD ACADEMY
LCDR Bruce Mustain
U.S. MERCHANT MARINE ACADEMY
Dr. C. B. Kim
U.S. NAVAL ACADEMY
Dr. Ramswar Bhattacharyya
WELDING RESEARCH COUNCIL
Dr. Martin Prager
NATIONAL RESEARCH COUNCIL COMMITTEE ON MARINE STRUCTURES
Dr. John D. Landes
Dr. Robert A. Sielski

RESEARCH PROGRAM DEVELOPMENT

Each organization represented on the SSC annually presents its perceived needs for near-term and long-range research efforts. An annual joint meeting of the CMS and the Ship Structure Subcommittee is held to review these suggestions.

At a subsequent meeting, the CMS carefully considers these suggestions, those generated within the CMS and its advisory groups, those not funded from the previous year, and those obtained from other sources. At the fall meeting of the SSC, the CMS presents its considerations and those of member agencies.

PROJECT DEVELOPMENT

CMS work groups convene to review in detail the status of ongoing projects, suggested new work, and the overall research program plan. Then the groups (individually or in small task forces) prepare the descriptions of recommended projects. The groups then develop recommendations for the establishment of priorities of the recommended projects and develop the multiyear research program in their respective area of competence. Each group also prepares a draft of the status reports on active, pending, and completed projects.

The CMS receives these documents and ranks projects for the biennial *Marine Structures Recommendations* report. Ranking is based on the composite judgment of CMS members, who consider the recommendations of the work group; applicability of the projects to the SSC research program in terms of needs, immediacy, program continuity, and likelihood of success; importance of the project to marine structures; potential of the projects for significant results; and whether the work is being done elsewhere.

PROJECT INITIATION AND REVIEW

The SSC determines which projects to support. Requests for proposals are prepared and issued through the cooperative efforts of the Naval Sea Systems Command, which provides technical contract administrative support services (including the function of Contract Officer's Technical Representative), and the U.S. Coast Guard, which handles the actual contracting. The requests for proposals are sent to research laboratories, universities, shipyards, and other organizations and are advertised in the *Commerce Business Daily*. Interested organizations submit proposals and cost estimates to the U.S. Coast Guard contracting office. In some instances, alternative means of contracting for projects are used.

The Ship Structure Subcommittee appoints project technical committees to evaluate proposals and monitor projects. The membership of these committees generally consists of individuals from the subcommittee, its liaisons, or other agency personnel. In addition, the CMS chairman engages one or two members from the cognizant work group, the CMS, or other experts in the field as technical advisers to clarify technical issues and to provide information about ongoing projects to the CMS.

The subcommittee sends its proposal evaluations to the U.S. Coast Guard contracting officer who, following routine procurement practices, then awards a contract. After a contract has been awarded, the project technical committee for that project meets periodically with the contractor (investigator) to review project status.

DISSEMINATION OF SSC RESEARCH INFORMATION

Contractors prepare reports on completed tests or units of work, on major changes in a project, on significant discoveries, and on conclusions and recommendations. The Project Technical Committee reviews all such reports.

Normally, the SSC disseminates the research results through publication. In addition, the SSC encourages investigators to prepare papers for professional society meetings and technical journals.

To foster the use of the published information, the SSC distributes the reports to individuals and agencies associated with, and interested in, its work. These reports are available through the National Technical Information Service and are reviewed in various marine and naval architecture journals.

Appendix B

Ship Structure Committee Strategic Plan

On June 5, 1992, the SSC unanimously endorsed the SSC Strategic Plan. On May 10, 1994, the Executive Committee of the SSSC reviewed the Strategic Plan to determine the need for updating it. The Purpose and Scope statements were revised, as were the plans for implementation contained in "taking action now." At its annual meeting on June 13, 1994, the SSC approved these changes. The revised plan is reproduced in its entirety below.

BACKGROUND

The annual fall meeting of the Ship Structure Committee (SSC) was held on 16 October 1991. During the meeting, the results from the Subcommittee Strategy Meeting held in July 1991 were presented to the SSC. The Strategy Meeting was convened to review the SSC Charter and redefine the SSC's purpose and scope. The committee has approved the revised Purpose and Scope Statements and concurred with the subcommittee's plans for implementation contained in "Taking Action Now." This plan outlines how best to meet these newly approved statements.

PURPOSE

The purpose of the Ship Structure Committee is to promote safety, economy, marine environmental protection, and education in the North American maritime industry through the advancement of marine structures technology.

SCOPE

The Ship Structure Committee shall carry out the following activities:

1. Sponsor, manage, and coordinate research that will, in the light of changing technology in marine transportation, improve the design, material, construction, inspection, and maintenance and repair of the hull structure of ships, boats, and other marine structures by an extension of knowledge in these fields.
2. Sponsor, manage, and coordinate the collection and dissemination of information on or related to marine structures technology to government and industry and facilitate the transfer of technology.
3. Serve as a coordinating body for ship structures technology, providing leadership to U.S. and Canadian industries to foster their development.
4. Serve as a coordinating body for international ship structures issues, promoting Canadian and U.S. industries and communications with the global maritime industry.
5. Cooperate with other committees and societies for any purpose for which the Ship Structure Committee is responsible and become a member of such organizations.

GOALS FOR THE 1990S

Critical Trends and Factors

The following trends and factors define the present reality and future expectations of the U.S. and Canadian maritime industry. The SSC must be cognizant of these when formulating its policies:

1. The North American merchant marine industry has been contracting for some time and will not be restored without a significant national commitment. Some shipyards are closed or idle, and others have reduced workloads. Major merchant ship construction is at an all-time low. It can be expected that professional education in naval architecture will decline as a result of the downturn in the North American shipbuilding industry. The decline in our shipbuilding can be traced to long delivery times, high engineering and materials costs, and inefficient use of labor in the global shipbuilding market.
2. There could be a continued reduction in the number of our flag vessels in foreign trade. The U.S. government may need to assist in the acquisition of

additional sealift vessels to augment a declining operational fleet. In addition, the changes in world politics are leading to a reduction in overall naval forces.

3. On the global scale, more emphasis will be placed on life extensions for existing ships than on construction of new ships. There will be a large market for repair work.
4. Maritime industry liability for environmental pollution, and government laws and regulations, are causing marine environmental protection to become a key consideration in the design and maintenance of structures.

National Goals

The Ship Structure Committee recognizes the following national goals relating to the maritime industry. It will support research and development that focuses on these goals:

1. improve the safety and integrity of marine structures,
2. reduce marine environmental risks, and
3. support the U.S. and Canadian maritime industry in shipbuilding, maintenance, and repair.

Assumptions

1. The safety and integrity of marine structures, which are the SSC's historical priorities, are not the only pressing needs of the Canadian and U.S. maritime industry at present. However, the SSC will focus on structural issues.
2. Marine environmental protection is one of the highest national priorities of the Canadian and U.S. government and peoples. It must receive high priority from the SSC.
3. The Ship Structure Committee alone cannot restore the North American maritime industry. However, the SSC can and must work to this end. The ship design and construction sector of the industry is the primary vehicle for implementing new and advanced structures technology. Without this sector, the committee cannot be as effective in developing or transferring new technology.

IMPLEMENTATION OF THE SSC GOALS: STRATEGIES FOR THE 1990S

In light of the critical factors and trends, national goals, and the assumptions noted above, the Ship Structure Committee will, through sponsorship of research projects, address the following topics:

1. development of better design tools and information systems, such as computer-aided design systems, design information systems, and artificial intelligence
2. metrification for commonality with world maritime industry
3. development of structures-related producibility technology, such as faster welding techniques, robotics, laser alignment, and automated material storage and handling equipment
4. development of reliability design techniques to optimize material use
5. development of principles of design for production
6. research of double-hull vessel technology
7. prevention research including damage-tolerant structures, structural monitoring, and human factors
8. structural reliability engineering
9. improved structural inspection techniques
10. structural monitoring of vessels in service.
11. improved efficiency for repair technology
12. improved engineering analysis and evaluation
13. sponsoring university research in areas such as design tools development, producibility, production processes, reliability design, and damage-tolerant structures

TAKING ACTION NOW: IMPLEMENTATION BY THE SSC

What actions should the SSC take to implement the new Strategic Plan? Each of these actions needs further definition and planning prior to implementation, but each will serve to make better use of resources through more innovative processes.

The following should be accomplished within the next three years:

1. Revise SSC procedures for more timely and efficient—in terms of labor and cost—accomplishment of committee work.

2. Work with CMS to ensure that the composition of the working groups reflects the needs of the SSC member agencies by including, for example, representatives from design agents, schools of naval architecture, and ship operators.
3. Improve the SSC's customer orientation. Customers are the end users of structures technology and include students, designers, insurers, owners, operators, regulators and class societies, and shipbuilding and repair yards.
4. Provide more information about the SSC activities and SSC reports to more end users. Develop an extensive mailing list for announcements, brochures, and biographies.
5. Increase the number of joint industry projects to better leverage SSC funds and to develop a closer working relationship with the maritime industry.
6. Study and define the SSC's relationship with the OPA-90 Interagency Oil Pollution Research Committee.
7. Investigate and expand SSC involvement in the international standards development arena.
8. Develop a process for selecting among contracting alternatives.
9. Study, define, and implement methods to improve the structural engineering departments in schools of naval architecture.
10. Investigate the practicality of holding symposiums more often than every three years and consider inviting other organizations to assist as cosponsors. Investigate whether the SSC could participate in other organizations' symposiums as a cosponsor.
11. Authorize the SSC Executive Director to become a member of F25.04, Ship Structural Standards Committee, of the American Society for Testing and Materials.
12. Invite the Ship Production Committee and National Shipbuilding Research Program to send liaisons to the SSC.
13. Reemphasize the key roles that the SSC should play in the marine industry.

The SSSC chairman will appoint subcommittee members to husband the implementation of the items listed above. The SSSC chairman will report the subcommittee's progress to the SSC at the biannual SSC meetings.

Technical Report Documentation Page

1. Report No. DTCG23-93-C-EO1037	2. Government Accession No. PB97-147995	3. Recipient's Catalog No.
4. Title and Subtitle Marine Structures Research Recommendations for FY 1998–1999		5. Report Date April 1997
		6. Performing Organization Code
7. Author(s) Committee on Marine Structures		8. Performing Organization Report No.
9. Performing Agency Name and Address National Research Council Marine Board 2100 Constitution Avenue, N.W. Washington, DC 20418		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTCG23-93-C-EO1037
12. Sponsoring Agency Name and Address Commandant (G-MMS/SSC) U.S. Coast Guard Headquarters 2100 Second Street, N.W. Washington, DC 20593-0001		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code G-M
15. Supplementary Notes The USCG acts as the contracting office for the Ship Structure Committee		

16. Abstract

This biennial report of the Marine Board's Committee on Marine Structures proposes updates to the multiyear research program of the Ship Structure Committee (SSC). The SSC is an interagency body through which the U.S. Coast Guard, Naval Sea Systems Command, Maritime Administration, Military Sealift Command, American Bureau of Shipping, Transport Canada, and Defence Research Establishment Atlantic coordinate their research on structural integrity of marine structures. The SSC's research program is intended to accommodate advanced concepts and long-range planning. It supports research in the focus areas of materials; loading and response; design methods; productivity and producibility; and inspection, maintenance, and repair.

The updated research program covers the fiscal years (FYs) 1997–1999. The report includes (1) a comprehensive review of the entire research program, including work performed in FY 1996, work planned for FY 1997, and the rationale for new projects proposed for FY 1998–1999; (2) detailed project descriptions for the 16 projects proposed for FY 1998 and FY 1999; and (3) brief summaries of recently completed projects and all active or pending projects in the program. Two appendices provide background on the SSC, the Committee on Marine Structures, and the approved SSC Strategic Plan.

17. Key Words Ship Structures	18. Distribution Statement This Document is available to the public through National Technical Information Service Springfield, Virginia 22161		
19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 108	22. Price