AD-A148 212 TOWARD AN INTEGRATED DESIGN INSPECTION AND REDUNDANCY RESEARCH PROGRAM(U) NATIONAL RESEARCH COUNCIL WASHINGTON DC MARINE BOARD 1984 1/1

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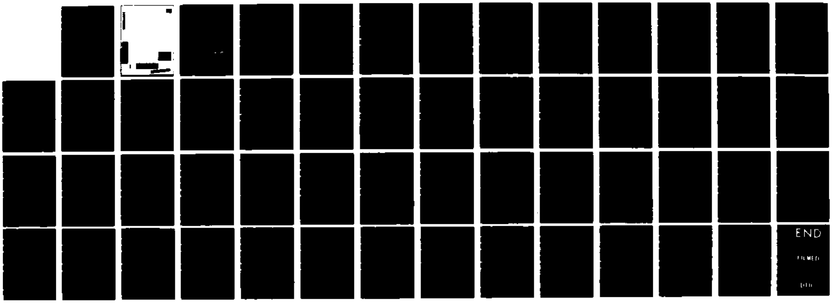

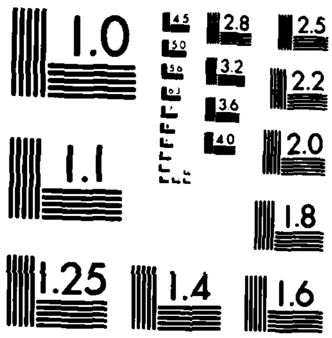

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TOWARD AN INTEGRATED DESIGN, INSPECTION, AND REDUNDANCY RESEARCH PROGRAM

Design-Inspection-Redundancy Symposium Steering Committee
of the
Committee on Marine Structures
Marine Board
National Research Council

National Academy Press
Washington, D.C.
1984

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ABSTRACT

This report contains the elements toward integrated design, inspection, and redundancy marine structure research programs where the descriptions are only in sufficient detail to serve as a guide for further development by the established mechanisms of the interagency Ship Structure Committee. The studies outlined are of long-term development and synthesis of existing information as well as deterministic/probabilistic information yet to be acquired. They are based on the results of a three-day symposium program and a two-day workshop organized and held to examine the emerging technologies of ultimate strength and failure mode analysis. While relatively reasonable computations of structural systems in the elastic range, and approximate estimates of some modes of maximum, ultimate strength can be made, the ability to detect degrees of damage and to assess the margin of strengths is limited at best. A great deal of deterministic (experimental and analytical) work is yet to be done to arrive at a satisfactory predictive position of practical usefulness.

COMMITTEE ON MARINE STRUCTURES

of the

Marine Board
Commission on Engineering and Technical Systems
National Research Council

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CONTENTS

PREFACE

The Loads Advisory Group of the Committee on Marine Structures recognized in October 1981 that the emerging technologies of ultimate strength and failure mode analysis have indicated a relationship among design-inspection-redundancy practices not heretofore fully appreciated. To examine these relationships properly in more detail, and in terms of their implications on structural reliability, the Loads Advisory Group recommended that a symposium/workshop be held. At the request of the interagency Ship Structure Committee, the National Research Council, through its Commission on Engineering and Technical Systems' Marine Board, established a steering committee in 1982 to identify and define the most pressing problems. The committee organized a program consisting of a coordinated series of invited papers addressing the role of design, inspection, and redundancy in marine structures and a workshop to analyze the material and its implications and to recommend a program of research and development.

A three-day international symposium on the role of design, inspection, and redundancy in marine structural reliability was held on 14-16 November 1983 at the Magruder Inn and Convention Center in Williamsburg, Virginia. The symposium was open to interested scientists and engineers and was attended by approximately 120 registrants. The technical program consisted of 23 formal papers organized in five sessions that reviewed existing information and methods of practice in several diverse fields of marine structures (single hull ships, fixed offshore structures, and floating offshore structures) and examined the current practices in nonmarine structures. The symposium also provided the opportunity to identify common problems and delineate differences in the required solutions and to identify needed research and development in the marine structures field. The proceedings of the symposium, <u>The Role of Design, Inspection, and Redundancy in Marine Structural Reliability</u>, is available from the National Academy Press.

A two-day research workshop immediately followed the symposium. The workshop was organized to delineate problem areas and identify areas in which information or further development is needed. The purpose of the workshop was to examine, in an integrated way, the problems of design, inspection, and redundancy relative to marine structural reliability. The 45 workshop participants were members of the steering committee, authors of the papers, and selected personnel from member agencies of the Ship Structure Committee.

The workshop consisted of independent meetings of small groups conducted in two stages. In the first stage, the participants were divided into five groups in accordance with the technical sessions of the symposium; namely, single hull ships, fixed offshore structures, floating offshore structures, other structures, and design and construction strategies. Members of each group were composed of corresponding session chairman, authors of the papers, and others with particular interest in the subject of the group. In the second stage, the participants were divided into three separate disciplinary groups, each of which was chaired by a member of the steering committee. In this case, the participants were divided into groups for synthesis and design, inspection and repair, and applied generic tools.

Finally, the steering committee met in executive session immediately after the conclusion of the workshop session to formulate its final report and provide a basis for the orderly development of a research program for guidance.

A. H-S. Ang
Chairman
Steering Committee

INTRODUCTION

Marine structural reliability requires the integration of strategies for design, inspection, and redundancy. The degree of fail-safe redundancy (defined in terms of multiple load paths) and element ductility (defined as the load-carrying capacity of structural components) that have been generally incorporated into the design of a structure have important implications in terms of its tolerance for flaws and/or overloads and influence and limit the strategies and techniques that may be adopted for inspection and repair throughout the life of the structure. Each of the three types of marine structures considered in this report (conventional ship hulls, fixed offshore platforms, and floating offshore platforms) is subject to unexpected or premature failure by buckling, fatigue, or fracture. While many of their problems are similar, there are significant differences that must be accommodated in the optimal strategies for design, inspection, and redundancy that may be adopted.

Buckling failures of elements are influenced by the imperfections that are present, both those which are permitted by rules, codes, and standards during construction and those introduced in installation or in service due to slamming, minor collisions, etc. For tubular bracing elements and for shell and stiffener elements, the peak capacity is maintained for only a limited range of ductility, beyond which the element degrades and unloads. The overall strength and ductility of the entire structure depends not only on these same characteristics of the elements, but also on the ability of the system to accommodate the unloading of the individual elements as they fail. This ability depends on the configuration of the system, which includes the degree of redundancy (multiple load paths) as well as the degree of complexity.

Fatigue failure is also progressive, in terms of both crack growth in an individual element and load shedding from the failed elements to intact elements in the system. Total fatigue life depends also on the initial flaws permitted during construction. At some later stage in the life of a structure, the remaining life can be related to the current state of fatigue damage. Again the damage tolerance of the system and the ability to detect damage depend on the configuration of the system.

Fracture control involves not only the selection of notch-tough materials, but also the interrelated strategies for design, welding, inspection, and maintenance appropriate to the service conditions and consequences of failure. Damage due to fatigue and repeated local buckling can lead to terminal failure by fracture. As with the other failure modes, the tolerance of a structure for flaws and isolated fractures is highly dependent on its degree of redundancy.

In the interest of achieving a degree of synthesis which not only combines design, inspection, and redundancy into an integrated strategy for each of the three types of marine structures, but also seeking areas of commonality among the various types, a symposium was organized and held to examine the emerging technologies of ultimate strength and failure mode analysis. The symposium program and abstracts of the invited papers are provided in Appendix A. The symposium was immediately followed by a two-day workshop where the participants, listed in Appendix B, delineated the most pressing problems. This was accomplished by small working groups examining the problems presented and discussed during each symposium session, and by another grouping of the participants according to disciplines. The results of the session working groups are summarized in Appendix C, and those of the discipline working groups are summarized in Appendix D. The steering committee then met in executive session to develop the bases for a program for research and development to improve marine structural reliability that is described in this report.

BASIS AND EMPHASIS

The committee relied heavily on the discussions offered by the symposium participants, and the suggestions developed by the workshop groups as summarized in Appendixes C and D. In determining priorities and developing its final recommendations, they also took into consideration the following:

(1) Importance to marine structures.
(2) Application of existing knowledge (including technology transfer) rather than developing new information.
(3) Relevance to design, inspection, and redundancy.
(4) Promise of significant results.
(5) The research is not being done elsewhere.

On the basis of these guidelines, the committee identified a number of programs and project areas they consider worthy of priority support. A number of other topics, even though important, were assigned lower priorities. Table 1 provides an outline of the committee's recommended research and development programs to improve marine structural reliability based on their analysis of the results of the symposium/workshop. The programs are described only in sufficient detail to serve as a guide for further development by the established mechanisms of the interagency Ship Structure Committee.

PRIORITY PROJECTS

Three broad program areas (each with multiple projects) and several single projects receiving a high-priority recommendation are described below with specific statements for (a) objectives and scope, (b) necessary tasks, and (c) expected input of results.

PROGRAM ON RELIABILITY OF STRUCTURAL SYSTEMS

This program would encompass several projects dealing with methods for determining and unifying reliability of marine structural systems. It is generally recognized that structural safety and reliability is a function of design and degree of redundancy, in addition to quality of construction and fabrication, and degree of

TABLE 1 OUTLINE OF RECOMMENDED RESEARCH AND DEVELOPMENT PROGRAMS TO IMPROVE MARINE STRUCTURAL RELIABILITY

PROGRAM ON RELIABILITY OF STRUCTURAL SYSTEMS	PROGRAM ON METHODOLOGY FOR EXAMINING REDUNDANCY, RESERVE STRENGTH, AND RESIDUAL STRENGTH	PROGRAM ON INSPECTION AND MAINTENANCE
Practical Methods for Assessing System Reliability	Test Programs for Discrete and Continuous Systems	Strategies for Inspection and Repair
Reliability Methods for Continuous Structures	Nonlinear Finite-Element Analyses	Cost-Effective and Reliable Methods of Inspection
Assessment and Updating Uncertainties	Generic Network and Energy-Release Analyses	Response to Detected Flaws
Cost-Effectiveness of the Factors Which Affect Reliability	Fracture Mechanics for Multiple Load Paths and High-Stress Gradients	Cost-Effective and Reliable Methods of Repair
		Development of Inspection Guides

PILOT STUDIES

Better Definition of Structural Redundancy for Continuous Structures

Lifetime Structural Integrity Management for Mobile Marine Structures

FEASIBILITY STUDIES

Gross Errors Coping Determination

Data Bank for Design Variables

Expert Knowledge System

Remaining Structural Life Considerations inspection. In order to tie these components together, methods for system reliability analysis are required. These methods should include the capability to evaluate the reliability of damaged systems, the significance and correlation of multiple failure modes, and alternative load paths (i.e., redundancy). On the basis of such developments, the significance of residual system strength may be delineated relative to the safety of a structural system. Finally, the importance of increasing structural reliability should be established as the effectiveness of some of the available methods relative to cost is not obvious.

(a) Objectives and Scope. The ultimate objectives of this program are to improve the mathematical modeling and analytical techniques of system reliability; to obtain meaningful and consistent definitions of redundancy; and to study redundancy in terms of systems reliability. The emphasis should include the application of systems reliability analysis to safety assessments of marine structures.

The systems reliability analysis should include the effects of stress concentrations, misalignment, corrosion, fatigue (e.g., of components in stiffened plate and shell structures) in the definition of failure modes or limit states. Various definitions of redundancy should be examined, and one or more definitions may be selected for use in the investigation.

(b) Necessary Tasks. Several tasks would be necessary under this program, each of which could be a separate project. Among these are the following:

(1) Practical Methods for Assessing System Reliability. This would involve the development of practical methods for calculating the reliability of realistic structural systems, taking into account the multiplicity and correlation between failure modes of a system. Because the environmental loadings and types of structures in the marine area are unique, the methods should be oriented specifically to marine structural systems. Problems peculiar to welded marine structures, including combined loading, complex geometry, and stress concentration factors that are functions of relative member forces should be considered.

(2) Reliability Methods for Continuous Structures. Available reliability methods should be extended and/or modified for continuous structures, particularly for orthogonally stiffened cylinders (as might be found in column stabilized vessels) and longitudinally stiffened plates used in ship hulls. Consideration of potential failure modes and their interactions may lead to more efficient structures in terms of residual strength.

(3) Assessment and Updating of Uncertainties. This project should establish the essential information necessary for implementing any reliability method. The uncertainties in the design parameters such as load, strength, and fatigue life, as well as imperfections of calculational methods and design

assumptions, must continually be carefully examined and assessed for specific types of marine structures. Where experimental or field data are available, the appropriate uncertainty measures should be evaluated on the basis of these data. However, where data are lacking or insufficient, the necessary uncertainty should be assessed with the experienced judgment of those expert in particular types of structures. The basis of such judgments, however, should be carefully documented.

(4) Cost-Effectiveness of the Factors Affecting Reliability. The factors affecting structural reliability often involve significant cost; thus, concepts and methods for evaluating the cost-effectiveness of these factors need to be examined and developed. Then the relative cost-effectiveness should be identified. Besides redundancy, the factors would include the level of safety margins, the stringency of quality control of fabrication and construction, the material specifications, the design criteria, the frequency and thoroughness of inspection, and the sophistication of repair procedures.

(c) Expected Impact of Results. The research projects recommended above should lead to improvement in system reliability and safety assessment methods. Moreover, the results of this research should lead to better definition of redundancy and quantitative methods for evaluating the significance of redundancy on the overall structural safety.

PROGRAM ON METHODOLOGY FOR EXAMINING REDUNDANCY, RESERVE STRENGTH, AND RESIDUAL STRENGTH

(a) Objective and Scope. This program will develop physical models and generic tools for analyzing the effects of redundancy, reserve strength, and residual strength on the system behavior of marine structures. The study should give due consideration to the type of marine structure, the type of structural components, varying degrees of element ductility, various scenarios for damage and accidental loading, the interrelationship of inspection and monitoring at various levels of redundancy and reserve strength, and the effects of fatigue on residual strength.

(b) Necessary Tasks. For each project within the broad program area, necessary tasks may be defined in terms of the configuration or type of structures, e.g., for discrete systems such as space-frame structures, and continuous systems such as stiffened plates and stiffened shells, each with various degrees of complexity and redundancy. Also, the determination of reserve strength and/or residual strength should be defined in terms of different limit states, such as ultimate strength which may deteriorate or degrade with time as a function of fatigue and corrosion. The methodologies that may be applicable for this study would include test programs or the application of nonlinear finite-element analysis, generic network and energy-release analyses, and fracture mechanics, which accounts for multiple load paths and high-stress gradients. Additional work is needed to determine the scope of specific projects.

(c) Expected Impact. In order for the probabilistic analyses to be applicable to real-world problems, this program needs to provide the deterministic physical models and generic tools upon which the proceeding program on reliability would be built.

PROGRAM ON INSPECTION AND MAINTENANCE

(a) Objective and Scope. This program consists of five separate projects, starting with the development of a research guide to identify the necessary tasks and proceeding to the development of an inspection guide for the three major types of marine structures. This program is based on the recommendations of the disciplinary group on Inspection and Maintenance (described in Appendix D).

(b) Necessary Tasks. The specific projects may be summarized as follows:

(1) Strategies for Inspection and Repair, A Research Guide. This project will analyze the existing inspection and repair techniques in terms of its effectiveness and to determine the adequacy of the present strategies for inspection and repair, to suggest the development of alternative inspection strategies for the three types of marine structures, and to identify deficiencies where additional research is needed, taking into consideration the results of past SSC research projects and other related research.

(2) Cost-Effective and Reliable Methods of Inspection. This project will look at the various methods of inspection for detecting cracks, corrosion, and other types of significant structural damage, and to develop methods that appear promising. The project should develop methods that can be applied consistently throughout the marine industry.

The specific task in this project must rely heavily on the results of the overview developed in the first project described above, i.e., what should we be looking for? The project should stress inspection methods that will reveal the type of defects most critical.

(3) Response to Detected Flaws. This project should develop and suggest effective ways to deal with specific types of defects, such as cracks, corrosion or general wastage, pitting corrosion, buckles, dents, and bent members. The appropriate response should be considered in terms of the consequences of potential failure associated with a given defect.

The project may contain a group of subprojects, as it will involve elements of the following types of technology: fitness for purpose, practical fracture mechanics, damage tolerance studies, and repair strategies. These are all needed to determine how to deal with the different types of defects.

(4) Cost-Effective and Reliable Methods of Repair. This project should review and evaluate available procedures for repair in terms of their effectiveness for improving structural reliability and performance, present guidelines for their use, and recommend areas where new procedures should be developed. Existing repair procedures are usually very expensive and may not consistently contribute to the improvement of a structure, and in fact may even contribute to further structural deterioration.

The project would essentially review and evaluate available procedures in terms of their present applicability and whether or not they actually improve a structure and, if necessary, recommend areas where new procedures should be developed.

(5) Development of Inspection Guides. This project would develop a set of three separate guides to be used in the development of inspection programs for both construction, start-up or shakedown phase, operational phases, and the later phases of the three types of marine structures; namely, ships, fixed offshore platforms, and floating offshore platforms. The objectives of these guides are to improve the structural safety and operating efficiencies of each of these three classes of structures.

This project should develop a set of workable guidelines and implement the results of the other four projects.

(c) Expected Results. The results of this program would be to supplement existing guides for use by industry, to improve the quality of construction of the three types of structures, and finally to enhance the operational life and safety of marine structures.

PILOT STUDIES

Besides the priority projects recommended above, two small studies are recommended for pilot studies as follows:

(1) Definition of Structural Redundancy. This is a pilot project aimed at developing better definition and methods for quantifying redundancy, especially for continuous structures. Redundancy is currently quantified and defined in terms of the residual strength capacity following some specified damage of given elements. In the case of continuous structures, such as stiffened and unstiffened plates and shells, the current definition becomes vague and difficult to quantify. The proposed pilot study, therefore, should suggest alternative methods for defining redundancy, taking into account alternative load paths following structural damage and/or deterioration. This is crucial to relevant physical models on which a structural system reliability method would be based.

(2) Lifetime Structural Integrity Management for Mobile Marine Structures. At present, many mobile marine structures are designed by one firm, built by another, owned by a third, and operated by a fourth. Over the lifetime of a structure there may be many owners, operators, and yards involved in conversions

and/or repair work. Furthermore, these structures are operated on different service routes (or geographic areas), carrying various load distributions under different environmental loading conditions. A system for managing a structure over its life is needed.

The initial approach would be to convene a task group to review and examine practices in the aerospace, pressure vessel, nuclear systems, bridges, and other disciplines for technology transfer of lifetime structural integrity management. The study should include economic factors and provide an example of how the "cradle-to-grave" system can be used in the marine industry.

OTHER IMPORTANT TOPICS FOR FEASIBILITY STUDIES

A number of other topics were examined and discussed by the committee. These were all considered to be important; however, they were all assigned to a lower priority as a group in light of the criteria indicated earlier. These topics would include the following:

(1) Gross Errors Coping Determination. Gross errors in engineering design are very important. The study would be concerned with determining ways for coping with gross errors. This might be defined as any decision, however trivial it might appear on the surface, that can lead to actual or potential disaster. Gross errors may be imbedded in design codes, or may occur in analysis and design including interpretation of codes, fabrication, inspection, or operation.

The study might include a survey of recorded disasters in the marine, civil engineering, and aerospace fields to identify and classify the underlying errors. Many past disasters are extensively documented. One possible strategy for avoidance of gross errors might be to establish, for a major project, a small group of able and knowledgeable individuals to oversee the safety of the project throughout its design, fabrication, and operation phases.

An initial feasibility study might include a conference or workshop on gross errors that could help to identify the types of skills and attributes required in such a team, and the procedures to be employed.

(2) Data Bank for Design Variables. Reliability analysis provides a methodology for incorporating all important factors, and their respective uncertainties that influence the safety of an engineering structure. To implement reliability methods successfully in practical engineering, information on the design variables are obviously needed. The objective in this project is to identify and, where possible, to estimate the importance of these variables, especially those that cannot now be quantified deterministically or statistically.

Although the information that can be compiled would be important to design, the necessary efforts would be extensive, and it is not clear that the most relevant data would be forthcoming. Thus, a feasibility study should precede the main project.

(3) Expert Knowledge System. A great amount of knowledge may be available in the diverse disciplines that are concerned with marine structures. The traditional way of disseminating knowledge to designers is through formal education, technical journals, symposia, etc. Knowledge is transferred to field personnel (fabricators, inspectors, etc.) by short-term training and written guides or manuals. These traditional methods may not be effective in disseminating the wealth of knowledge that is available. Moreover, young or inexperienced engineers may overlook important aspects of a given design. The problem is most acute in the field, where mistakes are made, even though the knowledge to avoid such mistakes is available in the expert community.

The technology and experience currently exists for the development of computer-based expert knowledge systems that bring together the knowledge from diverse fields having relevance to a particular subject. Using this technology to transfer knowledge from research and experts to practicing engineers would greatly enhance the availability of expert knowledge in the marine structural field.

The initial task would be to develop a prototype computer-based expert knowledge system for a particular subject on marine structures. The system would serve as a demonstration model for future expert systems as well as provide users with needed information on a particular subject.

(4) Remaining Structural Life Considerations. It is not clear how one determines the necessary actions as structure approaches the end of its design service life. The current approach is to increase in-service inspection, proof testing, replacement of parts before failure, repair whenever damage is noted, implementation of damage control procedures, derating, and demanning. There is a need to reduce operating and repair costs, as well as to minimize unexpected major structural failures, and to reduce unnecessary or misdirected requirements for inspection and repair. Thus, there is a need to identify the degree of structural degradation that justifies repair, as well as determine the appropriate degree of repair. Also, there is a similar need for determining when to derate or remove structures from service.

The necessary tasks would include the following:

(1) Evaluate inspection techniques (including nondestructive evaluations) for determining current structural conditions and assessing deterioration to date.

(2) Evaluate the effects of various degrees of corrosion.

(3) Evaluate the effects of various sizes of out-of-roundness, dents, cracks, etc.

(4) Evaluate the effect of various repair procedures on the load carrying capacity and flexibility for various materials and structural shapes.

(5) Evaluate the current structural analysis techniques and identify their limitations.

(6) Develop new in-service evaluation techniques that are based on the above tasks.

(7) Test and evaluate these new techniques.

SUMMARY

In its analysis, the committee found no deficiencies in the existing technologies that would point to adverse conditions or glaring inadequacies but did recognize where improvements needed to be done to increase the effectiveness and efficiencies in our current practice.

The recommended research and development programs to improve marine structural reliability as outlined in Table 1, although responsive to the workshop deliberations, are comprehensive and complex in nature. The steering committee did not have time nor was it intended to provide a more definitive discussion or development of the processes and/or steps that should be taken to develop a step-wise program, with options, which will permit an orderly and cost-effective effort. Further, all three of the key program elements are interactive and it was not deemed realistic to attempt to undertake all of these activities simultaneously. The coordination role will be critical to its success. Therefore, a definitive (do-able) program plan will have to be developed by a competent group prior to execution.

The study outlined is one of long-term development and synthesis of existing information as well as deterministic/probabilistic information yet to be acquired. Although relatively reasonable computations of structural systems in the sensibly elastic range, and approximate estimates of some modes of maximum/ultimate strength can be made, the ability to detect degrees of damage and to assess the margin of safety is limited at best. A great deal of deterministic (experimental and analytical) work is required to provide a satisfactory predictive position of practical usefulness. Further, in the area of inspection, it appears that it should be possible in the near future to provide more useful in-service instrumentation.

APPENDIX A:

SYMPOSIUM PROGRAM WITH ABSTRACTS

Opening Session
Presiding: A. H-S. Ang, University of Illinois

THE DESIGN-INSPECTION-REDUNDANCY TRIANGLE

Peter W. Marshall, Shell Oil Company

This paper introduces the Design-Inspection-Redundancy Triangle (D.I.R.T.) as a unifying concept for the issues involved in structural integrity. The objectives of a Committee on Marine Structures Symposium/Workshop on the subject are outlined. Applications to ships, floating offshore platforms, and fixed structures are considered. Finally, some examples are presented, illustrating generic similarities in the role of redundancy in such progressive failure modes as buckling and fatigue.

INTERRELATION BETWEEN DESIGN, INSPECTION, AND REDUNDANCY IN MARINE STRUCTURES

Stanley G. Stiansen, American Bureau of Shipping

Current practices in the design and inspection of marine structures are outlined, with a view to illustrating their interrelated roles in achieving a safe and reliable structure. The significance of redundancy in design considerations is discussed along with its influence on inspection aspects. A short review of recent developments and trends is given. General comments and recommendations with respect to future research and improvement are also offered.

Session on Single Hull Ships
Presiding: D. Faulkner, The University of Glasgow

STRUCTURAL DESIGN OF MONO HULL SHIPS

J. C. Chapman Chapman & Dowling
R. Adams, British Shipbuilders

The paper attempts to present a broad but not comprehensive perspective of ship structural design. A possible design code format is outlined which it is suggested would simplify international harmonization. The need for analytical research and computation to be deployed for the development of design formulae is emphasised. Performance in service is discussed and it is suggested that on-board stress indicators should be routinely installed as an operational aid and to accumulate loading data.

APPLICATION OF SUBJECTIVE RELIABILITY ANALYSIS TO THE EVALUATION OF INSPECTION PROCEDURES ON SHIP STRUCTURES

H. Itagaki, Yokohama National University
Y. Akita, Nippon Kaiji Kyokai
A. Nitta, Nippon Kaiji Kyokai

In this paper, discussion is made on a general aspect of the application of the Bayesian reliability analysis method to the evaluation of the results of periodical inspections of hull members to be incorporated with improvement of the reliability of ship structures.

The analysis takes into consideration the effect of the uncertainties involved in (1) the statistical distribution functions of fatigue life for these members, (2) the probabilistic characteristics of crack growth, and (3) the detectability of the cracks.

Numerical calculations are carried out for the simple, hypothetical results of inspection of member failures in order to describe the essential procedures of the method developed in this paper.

STRUCTURAL REDUNDANCY AND DAMAGE TOLERANCE IN RELATION TO ULTIMATE SHIP-HULL STRENGTH

C. S. Smith, AMTE, Dunfermline, United Kingdom

Factors influencing the ultimate strength of a ship's hull under combined loads are examined. Reference is made to the results of recent research on behavior of plate elements and stiffened panels

under combinations of in-plane tensile and compressive load, shear, and lateral pressure. Consideration is given to the influence of imperfections resulting from fabrication processes, together with the consequences of damage as may be caused by collisions, grounding, hydrodynamic overload or weapon effects. The relationship between structural redundancy and hull strength is discussed and illustrated with reference to some typical ship designs.

STRATEGIES FOR ASSESSING DESIGN AND INSPECTION REQUIREMENTS FOR REDUNDANT STRUCTURES

J. E. M. Jubb, Consultant

The current balance of resources in design is too much mental effort on analysis and too little attention given to the realities of inspection and fabrication.

Simple examples are given to underline the importance of basic truths in inspection and fabrication; these illustrate the need for the design concept being turned into a workable solution.

The range of current design skills are criticized.

A point is made that the current massive effort in the field of crack analysis in fracture mechanics should be matched or resources switched to crack detection and crack growth monitoring. The former is little use without the latter.

<u>Session on Fixed Offshore Platforms</u>

Presiding: A. L. Guy, Exxon Company

FIXED OFFSHORE PLATFORMS DESIGN CONSIDERATIONS

F. J. Domingues, McDermott Incorporated

Acknowledging the importance of functional considerations and stress analysis calculations in establishing sbructural reliabiliby for fixed offshore platforms, this paper focuses on the more subjective and practical aspects, which are not as well documented, but which can be even more influential in the final reliability of a structure. Design considerations such as material selection, structural configuration (load path, redundancy, stiffness), constructability (fabrication access, welding procedures, design details), and erectability (loadout, transportation, and installation) are discussed in the context of structural reliabiliby. The design process relative to these considerations is illustrated with specific experiences based on our work worldwide, including deep-water platforms in both Gulf of Mexico and North Sea environments. From these examples, the paper draws some conclusions relative to a systematic approach to reliable, cost-effective design.

RESERVE AND RESIDUAL STRENGTH OF PILE FOUNDED, OFFSHORE PLATFORMS

J. R. Lloyd and W. C. Clawson
Exxon Production Research Company

The safety of pile-founded offshore platforms is assured by both explicit and implicit conservatisms in design practice. These conservatisms lead to substantial platform reserve strength and residual strength. Reserve strength is measured by the ratio of the ultimate or collapse strength to the strength necessary to resist design loads. The design loads are chosen to be caused by rare environmental events, usually with a return period of 100 years. The residual strength, on the other hand, is measured by the level of load the system can resist relative to the ultimate strength while in a damaged condition. Both forms of strength are needed to achieve safe and reliable platforms.

OFFSHORE PLATFORM INSPECTION

F. P. Dunn, Shell Oil Company

This paper deals with in-place inspection, which is conducted to identify structural damage or degradation that may require remedial measures to ensure safety, prevent pollution, and protect a substantial investment. It discusses the author's experience with platform inspections over the past 20 years, the tools now being used, being developed, and being written about.

DESIGN INSPECTION AND REDUNDANCY INVESTMENT VS. RISK FOR PILE-FOUNDED OFFSHORE STRUCTURES

J. B. Weidler, Jr. and D. I. Karsan
Brown & Root, Inc.

In this study, an attempt is made to define the effects of overall design safety, redundancy, and inspection requirements on the initial cost, investment at risk, and total expected cost of investment for a typical pile-founded, jacket type, steel offshore platform. Basic relations between the risk and cost variables are formulated and demonstrated using a typical Gulf of Mexico jacket-type platform. The effect of inspection and verification activities in the design fabrication and installation, operation, and demobilization phases of an offshore platform life on the cost and risk of failure are also investigated. Three levels of inspection for three phases of the platform life, (1) design, (2) fabrication, and installation, and (3) operation and demobilization, are defined and associated costs and influences on the failure risk are studied. Costs, inspection levels, and risk factors are then used to study the inspected platform costs versus the risk of failure. Formulations provided in this study represent the authors' conception of the design-inspection activities and related costs and would require further investigation and data gathering before more elaborate formulations and conclusions are made.

Session on Floating Offshore Platforms

Presiding: W. M. Martinovich, Earl and Wright

DESIGN OF FLOATING OFFSHORE PLATFORMS

Cuneyt C. Capanoglu
Earl and Wright Consulting Engineers

This paper discusses the development of a design strategy for floating offshore platforms and identifies the research areas which offer most benefits to the design, fabrication, installation, and the lifetime maintenance of these structures. The paper first briefly covers critical variables that control the determination of structure type and general configuration. Next, it discusses in detail specific design areas, evaluating critical parameters, their interaction, and their relative uncertainties within the context of overall structural integrity/redundancy, project schedule, and capital and operational cost-effectiveness. Finally, areas requiring further research are identified to allow development of cost-effective and realistic research programs.

INSPECTION OF FLOATING OFFSHORE PLATFORMS

Felix Dyhrkopp, U.S. Minerals Management Service

This paper discusses the need for structural inspection of offshore floating platforms, the development of an inspection program, and the various inspection techniques employed. Both construction and operation (in-service) phase inspection highlights are discussed with an attempt being made to identify the main players and point out their respective contributions to the total inspection effort. Finally, with a view towards reducing inspection-related construction costs, recommendations are made for inspection-related research to be carried out.

REDUNDANCY CONSIDERATION IN THE STRUCTURAL DESIGN OF FLOATING OFFSHORE PLATFORMS

J. G. de Oliveira and R. A. Zimmer
Conoco, Inc., Houston, Texas

Structural redundancy and its impact on the design process are discussed, with particular emphasis on floating offshore platforms. Different aspects of structural redundancy are reviewed and related to common structural components. Some fundamentals of structural reliability theory and how they can be related to redundancy are presented. A methodology for considering redundancy in the design process is described. Recommendations concerning the structural design of floating offshore platforms and suggestions for future research are included.

SYNTHESIS: FLOATING OFFSHORE PLATFORMS -- PROBLEMS AND PRESCRIPTIONS, FROM DESIGN TO INSPECTION

Walter H. Michel, Friede & Goldman, Ltd.

Discourse is directed toward problem areas that exist in the various activities involved in the creation of a floating offshore platform. Some inadequacies, vagaries, and contradictions in the various rules and regulations that influence design are pointed out, as are some standard practices in construction and inspection that are unacceptable. Areas in which further research is considered necessary, along with more in-depth analyses and appraisals of procedures, are pointed out.

Session on Other Structures
Presiding: A. B. Stavovy, David W. Taylor Naval Ship R&D Center

SAFETY EVALUATION OF BUILDINGS AND BRIDGES

Fred Moses, Case Western Reserve University
James T. P. Yao, Purdue University

Problems of safety may even be more acute in buildings and bridges than for marine structures. Public exposure, liability actions, and historical expectations ensure that structural failure rates must be extremely low. In this paper, the general practices of structural engineers in the design, inspection, and redundancy implementation of buildings and bridges are reviewed and summarized. Such practices are then critically reviewed.

Some examples include recent failures in steel bridges which have led to code restrictions on nonredundant configurations including

severe safety factor penalties expecially for fatigue loading. In building design, the trend is towards failure scenarios and progressive damage evaluations. However, the required controls are not often clear to designers and further research on system performance and risks are needed. This results because fail-safe reliability depends on both structure configuration and loading.

Various tools and their applications including failure analysis, risk analysis, and evaluation and decision analysis are discussed. Moreover, the expert system approach and its application to damage assessment are described along with other possible methodologies.

DESIGN, INSPECTION, AND REDUNDANCY OF PRESSURE VESSELS

W. R. Mikesell, C. J. Pieper, and R. A. Whipple
CBI Industries, Inc.

The early 1900's were plagued by a series of catastrophic boiler explosions. In response to this and to the fact that a myriad of regulations were being set up by the various states, the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers was written. Over the yeers, the scope of this code has been revised and expanded to encompass changes in both the state of the art and the specific needs of the industry.

This paper focuses on the requirements contained in the unfired pressure vessel and nuclear codes. In addition, the rules developed for in-service inspection of nuclear vessels will be discussed since in-service inspection of marine structures is an important subject.

INTEGRATION OF DESIGN, FABRICATION, AND INSPECTION PROCEDURES FOR ATTAINING AND MAINTAINING SAFE SUBMERSIBLE PRESSURE HULL STRUCTURE

Robert H. McCarthy, Jr., Naval Sea Systems Command

The design of a submersible pressure hull structure is accomplished by optimizing scantlings for minimum weight in accordance with established design procedures. Design procedures are verified by full-scale and model tests of the full range of submersible geometry. Assurance that fabrication methods produce satisfactory structure with respect to the parameters assumed in design and fabrication is accomplished by thorough quality-assurance procedures. Life-cycle structural integrity is maintained by periodic inspections to monitor hull condition, performance of welds, and critical structural configurations. Evaluations of results of inspections are used to determine repairs, modify design criteria, improve fabrication procedures, improve structural configuration, and improve preservation techniques.

DESIGN AND INSPECTION INTERRELATION FOR COMMERCIAL JET TRANSPORT STRUCTURE

Dale S. Warren, McDonnell Douglas Corporation

An overview is given of design criteria and practices to achieve long-term reliability of commercial jet transport structure through inspection. Subjects discussed are structural design concepts and philosophy; principal design and inspection methods and procedures; the requirements for development testing; the roles of manufacturer, certification agency, and aircraft operator in inspection programs; and extended service life programs. Specifics and trends are considered, and emphasis is given to the significance of redundancy or damage tolerance.

AIR CUSHION LANDING CRAFT--STRUCTURAL DESIGN APPROACH

Wilfred H. Dukes, Bell Aerospace Textron

The LCAC is a high-performance Navy craft that is unique in two respects: It is the Navy's first air cushion marine craft, and it is designed for large-scale production at a high production rate. The structure is a deliberate compromise between low weight, essential to a high-performance airborne craft, low-recurring fabrication cost, and high reliability and easy maintenance for low life-cycle cost.

This paper describes how the compromise has been achieved in terms of structural design criteria and the basis for these criteria; the type of construction and its effect on fabrication costs; the extensive optimization studies conducted to minimize weight within fabrication cost constraints; the emphasis on corrosion resistance in the design to minimize maintenance; the consideration given to quality requirements to avoid unnecessary and costly quality levels; and the significance of an extended prototype craft program in achieving high reliability in the structure.

Redundancy is inherent in the LCAC structure by virtue of its basic geometry, in combination with stiffened shell construction. To minimize weight, this redundancy has been exploited with extensive finite element analyses to make use of all available load paths. Redundancy, in combination with fracture analyses and a tough structural material, has been used to establish structural inspections and corrective maintenance actions, again with emphasis on minimum life-cycle costs. Studies of residual strength in the presence of failures or damage and studies of failure progression have not been a requirement of the LCAC program.

This paper concludes with recommendations for development work; but, in the nature of the LCAC program, future development requirements are primarily in proof of concept by operational use in the Fleet, and the study of structural areas where the potential for further weight and cost reductions have become apparent following initial completion of the design.

Session on Design and Construction Strategies
Presiding: R. Plunkett, University of Minnesota

RESEARCH NEEDS FOR MARINE STRUCTURES

O. Furnes, Det norske Veritas, Norway

The paper will focus on (a) required development to meet demands from deeper waters and more hostile environment and (b) scope of research and development to provide systematic feedback and safety criteria in the design-inspection-redundancy context. Reliability engineering and methods for analyses of reliability of structural systems in ocean environment will be emphasized. Integrated structural analysis systems, including fluid-structure and soil-structure interaction and reanalysis aspects, will be addressed. Inspection and aspects of maintenance and repair techniques will be assessed in the same context.

A GOVERNMENT PERSPECTIVE ON THE SAFETY OF MARINE STRUCTURES

A. E. Henn and J. S. Spencer, U.S. Coast Guard Headquarters

Public safety is a matter over which the government has traditionally assumed domain. Safety of people, protection of property, and more recently, protection of the environment are social concerns which extend beyond the basic profit-oriented objectives of a commercial venture. In the area of marine structures, the Coast Guard enforces the safety laws of the United States. Recent advances in the technology of structural design and analysis and new applications for marine structures have required the Coast Guard to modify its approach to regulatory approval. Traditional factors of safety and deterministic structural standards are being supplanted by probabilistic approaches where basic design assumptions must receive the closest scrutiny.

THE USAF APPROACH TO STRUCTURAL LIFE MANAGEMENT

Howard A. Wood, Wright-Patterson Air Force Base, Ohio

This paper highlights the Air Force Structural Integrity Program, its development, overall strategies, and key experiences. Discussions emphasize the interrelationship of performance requirements, design and development, manufacturing and quality, in-service surveillance, and inspection and maintenance. A comparison with civil aircraft practice will be made. Increased emphasis on damage tolerance and durability aspects has given prominence to "Fracture Control" or identification of critical structural elements and control of critical material and quality parameters throughout production. Discussion will include the USAF strategy for maintaining older, in-service airframes. Force inspection philosophy and structural limit criteria are described. The requirement to "protect redundancy" in multiple load path structure is examined.

CIVIL ENGINEERING APPLICATIONS OF THE THEORY OF STRUCTURAL RELIABILITY

James T. P. Yao, Purdue University
Colin B. Brown, The University of Washington

Current research activities on first passage probability calculations, random vibration, fatigue and fracture reliability, design and operation, and structural control are summarized and reviewed. In addition, research needs as envisioned by authors are outlined and discussed in some detail.

Closing Session--Research Issues Wish Listing
Presiding: A. H-S. Ang, University of Illinois

APPENDIX B:

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APPENDIX C:

TECHNICAL GROUPS' SUMMARIES

A two-day research workshop consisting of two stages of independent meetings of small groups immediately followed the symposium. In the first stage, the participants were divided into five groups in accordance with the technical sessions of the symposium, namely, single hull ships, fixed offshore structures, floating offshore structures, other structures, and design and construction strategies. The members of each group were composed of the corresponding session chairman, authors of the papers, and others with particular interest in the subject of the group. Each group considered recommendations presented in the related papers of the symposium, relevant SSC reports, and suggestions noted by the participants at the closing session of the symposium.

Membership of each group in the first stage was as follows:

Single Hull Ships

D. Faulkner, Chairman
S. G. Arntson
J. C. Chapman
T. P. Gallagher
J. G. Gross
H. Itagaki
J. E. Jubb
W. J. Siekierka

Fixed Offshore Platforms

A. L. Guy, Chairman
R. J. Giangierelli
G. C. Lee
J. R. Lloyd
P. W. Marshall
S. G. Stiansen
J. B. Weidler

Floating Offshore Platforms

W. M. Martinovich, Chairman
A. H-S. Ang
C. C. Capanoglou
F. Dyrhkopp
D. Liu
W. H. Michel
J. S. Spencer
R. A. Zimmer

Other Structures

A. B. Stavovy, Chairman
W. H. Dukes
D. S. Warren
F. Moses
C. J. Pieper
M. Shinozuka
D. B. Anderson
G. D. Woods
R. H. McCarthy

Design and Construction Strategies

R. Plunkett, Chairman
S. Valsgard
H. A. Wood
J. T. P. Yao
A. E. Henn
E. Runnerstrom
J. B. O'Brien
W. M. Lundy

WORKING GROUP ON SINGLE HULL SHIPS

Recommendations of this group are listed below:

Topics

1. Crack propagation in redundant stiffened Plating
2. Extreme waves and "freak" conditions
3. Slam-induced whipping analysis
4. Subjective uncertainties study
5. Nonlinear behavior of complex structures
6. Reliability-based inspection strategy
7. Welding imperfections and repair
8. Corrosion related to reliability
9. Data base of damage and losses
10. Overall reliability procedures
11. Expert knowledge system

Overall, the working group stressed the importance of inspection for priority treatment in the DIR context. This was considered to be the weak link in the triangle. However, the group was concerned that any research and development should support a strategy for construction and in-service crack inspection, and acceptance-repair decisions that are firmly based on design and redundancy considerations, preferably developed in the context of a reliability framework. These considerations should include such factors as the importance of the structural component, relevant stress levels and material properties, quality of detail design and welding, the nature and magnitude of redundancy and behavioral ductility (fail-safe and damage-tolerance concepts), as well as operational and other requirements. For in-service crack inspection, effective in-service monitoring of crack growth should also be vital part of such a strategy.

To have such an inspection-repair strategy succeed, effective specification and control of materials and fabrication techniques must be developed for the marine structures community, together with a much closer and more effective link than usually exists between those who design, construct, and inspect. This would assist designers, who may have insufficient practical experience, and inspectors, who have difficulty understanding the design importance of the defects they examine. The group, therefore, feels that these educational and communication problems might best be served initially by seminars with invited keynote speakers to encourage understanding and discussion.

There is a strong feeling by the working group that an orientation away from research towards "applications" was desirable to ensure that present knowledge is more effectively used. This is in itself a respectable activity, and one which the Japanese apparently spend much worthwhile effort on.

The group endorses "demonstration projects," e.g., the application and use of system reliability could be illustrated with a structural example in which a number of system approaches could be tested and conclusions compared. The group also endorses educational and training seminars, workshops, and short courses (and the sponsorship of key academics for training in industry to take on responsibility for the development of workshop materials), as well as the production of handbooks, etc. For example, welding imperfections and repair would be suitable topics for such treatment. Finally, with regard to technology transfer, the ship group suggests that programs at NASA and the aircraft industry, which make effective use of fracture mechanics to establish inspection periods and to aid crack acceptance-repair decisions, be studied by the marine structure community.

WORKING GROUP ON FIXED OFFSHORE PLATFORMS

This group emphasized applications-oriented type research for the following five areas:

1. Develop improved structural reliability models capable of calibrating to and extrapolating from field experience.
2. Assess the effect of analysis techniques on calculated reliability levels.
3. Develop accurate stress intensity factor solutions for relevant stress fields and geometries of concern (welded tubular connections) and make available as a handbook or software library. Include evaluation of displacement control exhibited by most tubular joint crack geometries.

4. Develop methodology to quantify and guidelines to determine generic studies on redundancy, optimal levels of redundancy, reserve strength, and residual strength.
5. Develop cost-effective and reliable methods for in-service inspection and repair.

WORKING GROUP ON FLOATING OFFSHORE PLATFORMS

Nine structural research proposals were selected for priority consideration as follows:

1. Inspection strategy.
2. Reliability, redundancy, reserve strength, and residual strength.
3. Data bank of random variables for design.
4. In-service monitoring systems.
5. Integrated design considering lifetime structural integrity.
6. Crack growth and fabrication factors.
7. Fitness for purpose-defect assessment.
8. Fatigue in imperfect redundant joints.
9. Capsize stability and wind/wave actions on deck structure.

The broad subject of inspection was of great concern to the participants and symposium attendees and requires formal attention. The group recommends that research should lead to guidelines for determining: (a) minimum visual and nondestructive evaluation (NDE) inspection levels required during construction and in-service; (b) operational inspection intervals; and (c) fitness-for-purpose welding criteria for acceptance or rejection, and repair decisions. Such guidelines should recognize and account for differences in primary and secondary structural components and should be tied into the design requirements through a reliability based overall strategy.

The second broad subject area that requires emphasis may be called the four R's (reliability, redundancy, reserved strength, and residual strength). In order to tie the four R's together, further development is required in system reliability analysis. This should include the capability to evaluate the reliability of damaged systems, the significance and correlation of multiple failure modes, and alternative load paths. Residual system strength may then be delineated relative to system safety. Specific topics for R&D would be:

(a) Develop methods for calculating reliability of realistic structural systems taking into account the multiplicity of potential failure modes and correlations between them. In view of the unique environmental forces, reliability analysis should be oriented specifically for marine structures.

(b) Extend reliability methods to continuous marine structures. This would include, in particular, stiffened shell structures such as orthogonally stiffened cylinders, as might be found in column-stabilized vessels. Careful consideration of possible failure modes and their interactions can lead to more efficient structures. Questions of the effectiveness of redundancy may be better clarified on the basis of reliability of a damaged system, so that trade-off between high capacity-lower redundancy systems and low capacity-higher redundancy systems can be studied more effectively.

(c) Integrate the above two studies into a reliability-based design approach. Strategies for design should be developed which explicitly include the effective redundancy of a system and can lead to a practical design procedure.

(d) Develop a reliability-based inspection strategy based on existing inspection technology. These developments should be linked closely with research on inspection strategies and in-service monitoring systems. It would be important to calibrate any proposed procedure with those found in current practice.

(e) Continuously assess and update design uncertainties. This would include variabilities of loads, strength, fatigue life, as well as imperfections in the calculational methods and design assumptions, or those underlying the design codes. The uncertainties for specific types of marine structures should be systematically assessed and quantified, using experimental or field data where available. Where data are lacking or insufficient, well documented expert judgments should supplement the more objective data.

(f) Include performance versus cost (including fabrication and inspection) and other trade-offs to achieve optimal design in an integrated design approach. There is already much progress in many design and fabrication organizations that exploit computer-based technology. Such projects should be examined in more detail to establish a general framework for design, and to bring forth a compilation of methods, procedures, programs, empirical rules, etc.

WORKING GROUP ON OTHER STRUCTURES

This group agreed to recommended ways in which technology from other areas of structures could be transferred to the marine group.

1. The first and strongest recommendation is that a task force be commissioned to make a feasibility study of hull lifetime structural integrity management. The task force should consider how military and civilian aerospace industries, the nuclear power industry, the civil engineering community, and similar fields conduct such lifetime management with due regard to economic factors. Examples should be developed to show how the "cradle-to-grave" philosophy may be used in the marine industry.

2. Establish a data base for failure incidents. The project should review the experience in other industries that have established such data bases.

3. Study the effect of repairs on the fatigue life of a structure. Full-scale repairs should be made under field conditions. Elements should be tested to determine, quantitatively, how the remaining fatigue life is affected by the repairs.

4. Conduct experiments on models to determine the relationship between redundancy and residual strength.

5. Appoint a task force or convene a workshop to develop detailed recommendations for evaluating the effect of structural analysis, redundancy, nondestructive evaluation, inspection intervals, and economics for obtaining damage-tolerant acceptance criteria appropriate to the marine industry.

6. Evaluate analysis techniques now being used in other industries for their possible applicability in the marine industry.

7. Determine which projects of the Welding Research Council-Pressure Vessel Research Committee (WRC-PVRC) are of most significance. This might include a worldwide program to determine the reliability of ultrasonic and radiographic examination; a project to develop a basis for defining conditions that require post-weld stress relief heat treatment; or a project to determine the significance of weld discontinuities in the performance of weldments.

8. Determine the state of the art in other countries with respect to design, inspection, and redundancy. In this regard, the resources of organizations such as the International Ship Structures Congress (ISSC) and International Maritime Organization (IMO) should be used.

9. Set up an educational program on the philosophy and techniques of inspection for the marine industry.

10. Study aerospace and other advanced craft industries to determine commonalities and differences in terminology in order to facilitate communication across industry lines.

WORKING GROUP ON DESIGN AND CONSTRUCTION STRATEGIES

Five research projects were developed by this group as follows:

1. Study of the Effects of Wastage. Degradation of structures due to wastage (e.g., corrosion) is both a technical and an economic problem. Local and global criteria for replacement needs to be established, but the cost of making the necessary measurement might preclude utilizing any global scheme tied to overall wastage. Concepts might be developed with a graduated wastage allowance based on local and general strength requirements that would maintain strength by local replacement. This might be compared to the value of increasing the allowance in construction thus permitting a longer time before replacement. Another question is the strength of corroded structures. Estimates of strength in the corroded state require that we understand how structures perform under load. At present, estimates are based on the presumption that the plate is thinner. These would suggest both economic studies involving design, inspection and maintenance, and a test program to compare corroded structures to the virgin one.

2. Study of Structural Redundancy. The objective here is on how to quantify redundancy for discrete and continuous structures. Generally, in design and construction strategy, redundancy has a bearing on how comprehensive inspection and maintenance should be and on the choice of the initial design. This relates sensitivity of the overall structural strength and failure to defects in various components. To quantify some of these aspects, a means is necessary to quantify the significance of alternative load paths in structures following damage and/or deterioration. In this context, it is necessary to have the best possible knowledge of the various components, including the effect on strength of general corrosion, wastage, crack detection and growth, strength of damaged components, etc.

Redundancy may be quantified by the residual strength capacity following damage. The approach is to put together all available information and the performance of those structural details which are typical components in marine structures, such as beam columns, stiffened plates and shells, and their respective influence on the main structure. This information may be used in a linear or nonlinear computer program to determine the residual strength as compared to the original reserve strength capacity.

3. Develop a Procedure for Reaction to Detected Cracks. Currently, any crack detected in a ship hull or supporting structure of a ship or floating unit subject to administration requirements (for example the Coast Guard) or classification society rules is required to be repaired immediately; cracks in the parent metal and in weld locations must meet the same standards. The emphasis on immediate repair causes costly interruption in service. The concern here is that not all detected cracks are necessarily potentially catastrophic to the structure of a ship or floating unit, and the repair of the crack, as brought out in the symposium discussions, may sometimes be more damaging to the structure than the crack itself. Also, no differentiation in requirements for repair of cracks is made as to location, e.g., whether it is in the primary or secondary structure; whether it is in high- or low-strength steels; whether it is in the parent metal or welds; or as to the size of the crack, or the orientation of the crack with regard to the local stress field.

The objective is to establish some qualitative criteria to discriminate characterization of a crack. The benefits could be substantial cost savings to the industry, and the structural integrity of a ship or floating unit could be enhanced by eliminating unnecessary and potentially damaging repairs.

4. Feasibility of Establishing a Clearing House for Failure Data. There is a need in research, education, and design and analysis for data on structural failures. Such data are generally not available due to proprietary concerns on liability and the lack of an established system to collect, organize, and distribute such data.

The objective would be to determine the feasibility of establishing a clearinghouse for failure data related to marine structures. The data should be current, complete, accurate, easy to retrieve, and accessible to the industry. The study should produce and recommend a budget, amount and sources of funds, who should perform the function, the structure of and the feasibility of agreements needed between all the parties involved, the technical requirements for the data base, and the scope of the data base. Methods for resolving the concerns of owners, insurance companies, classification societies, regulatory agencies, and others must be identified and determined.

5. Inspection Techniques. The group considers current inspection techniques to be adequate. However, they are not necessarily being employed with maximal effectiveness. To do so, the inspection methods should be improved with current knowledge to meet current needs in the construction and maintenance of marine structures. Rather than new research, a critical need is the development of an inspection guide that would include items such as available inspection methods; inspection techniques; determination of type and level of inspection to maintain a desired level of reliability taking into account detectability, inspection, and quality of repair; inspection strategies for fatigue-life control; member importance; and the characterization of defects during in-service inspection to assess remaining life.

Nevertheless, some research may still be necessary, such as the determination of proper inspection intervals and possibly for different marine structures. Inspection intervals should take into consideration the criticality of the structural element, such as a beam or tubular joint. Some areas may be more crucial and need shorter intervals. Further, the usefulness and significance of fracture-mechanics principles in establishing inspection intervals ought to be examined.

The short-range goal of this project would be to collect and disseminate information including that available in other areas of engineering practice, whereas the long-range goal would be to develop a set of guidelines for decision making by the inspector based on quantitative results from specific inspection procedures for particular types of structural applications.

APPENDIX D:

DISCIPLINARY GROUPS' SUMMARIES

During the second stage of the workshop sessions, the workshop participants were reassigned into the following three disciplinary groups, each chaired by a member of the steering committee:

Synthesis and Design Group:

A. H-S. Ang, Chairman	E. Runnerstrom
J. C. Chapman	S. G. Arntson
C. C. Capanoglu	C. J. Pieper
J. E. Jubb	J. T. P. Yao
H. Y. Jan	A. B. Stavovy
G. R. Marine	J. S. Spencer
W. H. Michel	J. G. Gross
W. J. Siekierka	D. Liu

Inspection and Maintenance Group:

P. W. Marshall, Chairman	H. Itagaki
G. C. Lee	F. Dyrhkopp
S. Valsgard	A. E. Henn
G. D. Woods	W. M. Lundy
A. L. Guy	J. W. Boller

Applied Generic Tools Group:

R. Plunkett, Chairman	F. Moses
W. M. Martinovich	H. A. Wood
R. H. McCarthy	R. J. Giangerelli
C. S. Smith	J. B. O'Brien
J. R. Lloyd	D. B. Anderson
R. A. Zimmer	R. G. Eastin

Each disciplinary group reviewed and discussed reports of all five working groups developed from the earlier working sessions. In some cases, additional new topics that emerged during the disciplinary group discussions were also examined. At this stage, all the topics were classified into program areas whenever appropriate, and specific statements were developed for each research topic or program in terms of problem definition, objectives and scope, necessary tasks, and expected impact of results. The reports of the three disciplinary groups are summarized as follows.

DISCIPLINARY GROUP ON SYNTHESIS AND DESIGN

Recommendations of this group consisted of five topics for research and one suggestion for educational workshops, seminars and/or short courses.

RELIABILITY OF STRUCTURAL SYSTEMS

(a) Problem Definition. Problems of redundancy and design require information on system reliability. In order to tie these together, methods for system reliability analysis must be developed. These should include the capability to evaluate the reliability of damaged systems, the significance and correlation of multiple potential failure modes, alternative load paths, and redundancy of discrete and continuous structures. On the basis of such methods, the significance of residual system strength may be delineated relative to the system safety.

(b) Objectives and Scope. The objectives of this research project are to improve mathematical modeling and analytical techniques of system reliability, obtain a meaningful and consistent definition of redundancy, and study redundancy in terms of system reliability. The emphasis should include the application of system reliability analysis to stiffened plates in ship structures. The system reliability analysis will include the effects of stress concentrations, misalignment, corrosion, fatigue, local tripping of components of stiffened plate structures, such as shell plating, transversely stiffened frames, and longitudinal girders in ship structures. Various definitions of redundancy should be examined and one or more definitions will be selected for usè in the investigation. The reliability of this type of structural system will be evaluated and related to redundancy and other safety measures.

(c) Necessary Tasks. Review of various definitions of redundancy and available techniques for system reliability analysis (including safety against collapse); identification of significant failure modes and definition of appropriate limit states; development of practical methods for calculating reliability of stiffened plates for ship structures; correlation of system reliability results for this type of structures with other safety measures (e.g., conventional safety factors).

(d) Expected Impact of Results. In addition to the expected improvement in system reliability calculations, the results of this research should lead to better definition of redundancy and quantitative methods for evaluating the significance of redundancy on the overall structural safety of ships.

FATIGUE AND FRACTURE RESEARCH

(a) Problem Definition. Even though few catastrophic failures of ship structure or offshore platforms have occurred worldwide, a substantial number of fatigue and brittle fracture failures of platform components have been observed during inspections or reported by operating personnel. These failures range from joint failures of tubular intersection to hull plate intersections with transverse-stiffening systems. Current ship disaster rules, government regulations, and the state of the art do not account for all the variables influencing this phenomena, plus substantial differences of opinion exist between the technical bodies in the United States and other countries. Some of these concerns include fatigue design based on an S-N curve approach developed from constant-amplitude laboratory tests of few geometries and limited plate thicknesses; failure of laboratory testing to incorporate real-life fabricated structures, thus such results are not directly applicable to offshore structures functioning in the ocean environment; and results of post-fabrication processes applied to joints such as corrosion protection, weld toe grinding, and post-weld heat-treatment that show substantial scatter of data and differences of opinion.

(b) Objective and Scope. Because of the critical importance of both brittle fracture and fatigue failure mechanisms on all types of marine structures, it is recommended that studies be undertaken leading to a better understanding of the interacting parameters in these fields.

(c) Typical Task Scope. The existing rules and regulations pertaining to brittle fracture and fatigue, as well as previous research efforts, should be carefully reviewed to establish the ground work for scrutinizing on-going research. A set of guides should be established to provide a better understanding of the interacting parameters. The effort should be followed by identifying and developing research areas that would benefit the marine industries. The project scope should include a literature search, a definition of terms and loading conditions as well as geometries of the structural details, the conduction of limited analysis, and estimation of criticality of the various factors on brittle fracture and fatigue, as well as the establishment of the needs and priorities and recommendations for follow-on work.

(d) Impact of Results. The results should lead to better criteria for determining inspection requirements and acceptability limits and an improved approach to designing for a specified life.

APPLICATION OF EXPERT KNOWLEDGE SYSTEM TO MARINE STRUCTURES

(a) Problem Definition. A tremendous amount of knowledge may be available in the diverse disciplines that are concerned with marine structures. The traditional way of disseminating knowledge to designers is through formal education, technical journals, symposia, books, codes and regulations, etc. Knowledge is transferred to field personnel (fabricators, inspectors, etc.) by short-term training and written guides or manuals. These traditional methods may not be effective in disseminating the knowledge that is available. Moreover, young or inexperienced engineers may overlook important aspects of a given design. The problem is most acute in the field where experienced supervisory people are not always available.

The technology exists for the development of computer-based expert knowledge systems that bring together knowledge from diverse fields that may have relevance to a particular subject, such as has been used in the medical field for diagnostic aids. State-of-the-art computer technology can make this knowledge easily accessible to the user. Through an interactive questioning-answering process, the system guides the user to necessary information in an effective and efficient manner. Using this technology to transfer knowledge from research and experts to practicing engineers would greatly enhance the availability of expert knowledge in the marine structural field.

(b) Objective and Scope. To develop a prototype computer-based expert knowledge system for a particular subject on marine structures. The system would serve as a demonstration model for future expert systems as well as provide users with needed information on a particular subject. Although the expert knowledge system can provide some training, its primary function would be used as a day-to-day source of expertise for the design engineer or decision maker. The system could range in sophistication from just providing text to providing video as well. The sophistication of the system must be balanced with the cost and reliability of the system.

(c) Needed Tasks. The necessary tasks would include selection of a subject for the expert knowledge system, e.g., inspection of structures, repairing structures, corrosion, etc.; determination of the requirements for the system (updating and maintaining the system must be considered); development of the system; providing the system to users; monitoring each performance; obtaining feedback from each user; and development of requirements for future expert knowledge systems.

(d) Impact of Results. The availability of such an expert system should improve future designs and reduce potential mistakes in the field.

SLAM-INDUCED WHIPPING ANALYSIS

(a) Problem Definition. Current methods of sizing primary ship hull structure for longitudinal strength purposes do not adequately address the dynamic loadings associated with slam-induced whipping for lack of data.

(b) Objective. The study should identify wave-induced and whipping response components of hull girder loadings from existing computer simulations and develop sufficient data to verify this program.

(c) Necessary Tasks. Identify computer simulations that are capable of calculating hull girder response to wave and whipping-induced loads; select the best available computer programs for comparison with existing model and full-scale data; identify applicable data sources that will provide full-scale and model test information; perform computer programs/data comparison for verification of analysis method; and recommend additional data collection (full and model scale) to achieve validation of computer programs.

(d) Expected Impact of Results. The study should lead to an improved capability for hull girder analysis method to address the effects of hull flexibility.

DATA BANK FOR DESIGN VARIABLES

(a) Problem Definition and Objectives. Reliability analysis provides a methodology for incorporating into design all known factors and their associated uncertainties that influence the successful realization of a project. The objective is to identify and, where possible, to estimate the importance of these factors, especially those that cannot be quantified deterministically or statistically at present.

(b) Necessary Tasks. Prepare a summary to gather information on factors and their uncertainties that may effect design; analyze survey results and identify the factors and their uncertainties; estimate their importance to design; and translate the results into the form or context of relevant existing activities.

Most of the factors to be considered in this project include design for operation and for construction; material properties and uncertainties; design for maintenance; structural detailings; welding defects as related to working conditions; tolerances including fairness, alignment, fit; influences of heat-treatment procedures; pitfalls in welding; quality assurance/quality control (QA/QC) system; inspection and monitoring practices; predicted and actual life of structures; method of repair, durability of repair; data on partial and complete failures.

(c) Impact of Results. The results should lead to a better design process. Reliability analysts would be better informed of the totality of factors affecting the outcome of a project. It should also provide the designer with a better appreciation of the factors to be considered in design, construction, operation, maintenance, monitoring and repair. The material may then be used for better education of designers, fabricators, and operators.

OTHER SUGGESTIONS

The group also feels that there are a number of topics that are important to the marine industry, but may not be suitable as research projects. The technology and/or information already exists; however, the available technology is not widely or generally known, or its wider application needs to be encouraged. For these topics, the group recommends that educational or tutorial workshops, seminars, or short courses conducted. The topics that are particularly important include the following:

(a) Nonlinear analysis for marine structures.

(b) Welding technology and design.

(c) Inspection and maintenance.

DISCIPLINARY GROUP ON INSPECTION AND MAINTENANCE

This group developed a broad program on inspection and repair with five specific recommended projects, collectively aimed at answering three questions: "What are we looking for; how do we look; and what do we do when we find something wrong?"

Among the five recommended projects, the first one is a research guide that will essentially provide an advance basis for the remaining four projects, identify gaps, and outline the necessary research to follow. The fifth and last project is to develop and write an inspection guide; separate guides will be developed for the three types of structures, and each guide will consider both the inspection during construction and in-service, and would consider not only how to inspect but also how to respond, and how to make repairs. The five recommended projects can be described as follows:

STRATEGY FOR INSPECTION AND REPAIR

(a) Problem Definition. Currently, the unavailability of effective inspection and repair guidelines often results in undetected defects and potential failures in structures, or in unnecessary inspection and repair. There is no comprehensive inspection and repair strategy at present that would permit evaluation of current methods, and few analysis techniques to determine their effectiveness.

(b) Objectives and Necessary Tasks. The tasks would be to establish and define the terms of reference, to survey and summarize cost-effective analysis techniques, to develop alternate inspection strategies for the three types of marine structures, to evaluate these strategies with regard to their adequacy relative to the needs for marine structure reliability, and to identify deficiencies on which research would be necessary.

(c) Impact of Results. The impact of this research would be to determine how to improve the inspection practices that now exist. Furthermore, by looking at the needs first, the potential for misdirected research can be greatly avoided.

COST-EFFECTIVE AND RELIABLE METHODS OF INSPECTION

Objectives and Necessary Tasks. This project will develop methods that can be applied consistently throughout the marine industry; to look at the various methods of inspection for detecting cracks, corrosion, and other types of structural damage; and to further develop some of the methods that appear promising. The specific tasks for this project must rely heavily on the results of the overview developed in the first project described above, i.e., what is it that we should be looking for. The project should stress inspection methods that are geared to the kind of defects needed to be found, and not available inspection programs that various proprietary interests are promoting.

RESPONSE TO DETECTED FLAWS

Objectives and Scope. This project may contain a group of subprojects, as it will involve elements of the following types of technology: fitness for purpose, practical fracture mechanics, damage tolerance studies, and repair strategies. These are all needed to determine how to deal with the different types of defects, such as cracks, corrosion or general wastage, pitting corrosion, buckles, dents, and bent members. Each of these should be considered in terms of the potential consequences of the failure that might follow.

COST-EFFECTIVE AND RELIABLE METHODS OF REPAIR

(a) Problem Definition. Existing repair procedures are usually very expensive. Also, they may not consistently contribute to the improvement of the structure and, in fact, may even contribute to further structural deterioration. An example is the heat-affected zone from wet underwater welding in which a cosmetic repair might set up an initiation site for a more catastrophic fracture.

(b) Scope and Necessary Tasks. The project would essentially review and evaluate available procedures and technology in terms of their present applicability, whether or not the existing procedures actually improve the structure, and if necessary recommend areas where new procedures could be developed.

DEVELOPMENT OF INSPECTION GUIDES

(a) Objectives and Scope. To develop a set of three separate guidelines to be used in the development of inspection programs for both construction and operational phases of the three types of marine structures, namely, ships, fixed offshore platforms, and floating offshore platforms. The objectives of such a guide are to improve the structural safety and operating efficiencies of each of these three classes of structures.

(b) Necessary Task. The task under this research would be to evaluate all pertinent existing guidelines, develop a set of directions aimed at correcting any deficiencies that might be present in the existing guidelines, and to implement the results of the other four projects of this program.

(c) Impact of Results. The results of this project would be to supplement existing guidelines for use by industry, to improve the quality of construction of the three types of structures, and finally to enhance the operational life and safety of these structures.

DISCIPLINARY GROUP ON GENERIC TOOLS

This group formulated five topics for research and one general suggestion.

METHODOLOGY FOR REDUNDANCY, RESERVE STRENGTH, AND RESIDUAL STRENGTH

(a) Objective and Scope. The study will be to develop methodology and guidelines for determining the proper level of redundancy, reserve strength, and residual strength that should be recommended for marine structures. The study should give due consideration to the type of marine structure, the type of structural components, existing requirements for damage and accidental loading, the interrelationship of inspection and monitoring at recommended levels of redundancy, reserve strength, and the effects of fatigue life on recommended levels of residual strength.

(b) Necessary Tasks. The necessary tasks may be defined in terms of the configuration or type of structures, e.g., for space-frame structures, stiffened plates, stiffened shells. Also, the determination of reserve strength and/or residual strength should be defined in terms of different limit states, such as ultimate strength which may degrade with time due to fatigue damage and corrosion.

The generic tools that may be applicable for this study would include test programs or the application of finite-element analysis, system reliability analysis, and fracture mechanics which must be improved to the point of accounting for multiple load paths and high stress gradients.

SYSTEM RELIABILITY METHODS

(a) Problem Definition. System reliability depends on many factors, including type of structure, redundancy, chance of exposure to extreme environment, amount of quality control, degree of inspection and maintenance, extent of analysis and verification of original design, and availability of performance data of similar structures. Current means for determining reliability include failure mode analysis, instrumentation, and model tests. Beside redundancy, various other ways exist to increase reliability, including use of higher safety factors, more stringent control on fabrication, specification of tough materials in design, and development and implementation of improved inspection and maintenance procedures.

(b) Objective. The objective here is to identify and disseminate methods of determining and increasing system reliability of marine structures.

(c) Task Definition. The project should conduct a feasibility study to identify ways for determining and increasing reliability and associated costs. An adjunct to this work would be a workshop or symposium to educate the marine industry in methods to determine and increase system reliability.

DETERMINATION OF REMAINING STRUCTURAL LIFE

(a) Problem Definition. It is not clear how one determines the necessary action when a structure approaches the end of its designed service life. Often, the action may be based on reducing exposure to adverse publicity, or legal liabilities, rather than on engineering evaluations. The current approach is to increase in-service inspection, proof testing, replacement of parts before failure based on statistical failure rates, repair whenever any damage or wastage is noted, implementation of damage control procedures, derating, and demanning.

(b) Objective and Scope. There is a need to reduce repair and operating costs, as well as minimize unexpected major structural failures, and to reduce unnecessary or misdirected requirements for inspection and repair. In this regard, therefore, there is a need to identify the degree of structural degradation that justifies repair, as well as determine the appropriate degree of repair. Also, there is a similar need for determining when to derate or remove from service.

(c) Necessary Tasks. Necessary tasks would include evaluating current inspection techniques for determining structural degradations; evaluating the effect of various degrees of corrosion; evaluating the effect of various sizes of out-of-roundness, dings, bends, degrees of collapse, and cracks, on the load-carrying capacity; evaluating the effect of various repair procedures on the load-carrying capacity and flexibility for various materials and structural shapes; evaluating the current structural analysis techniques and identify their limitations; developing new in-service evaluation techniques that are based on the above tasks; and testing and evaluating these new techniques.

LIFETIME STRUCTURAL INTEGRITY MANAGEMENT OF MOBILE MARINE STRUCTURES

(a) Problem Definition. At present, many mobile marine structures are designed by one firm, built by another, owned by a third, and operated by a fourth. Over the lifetime of a structure there may be many owners, operators, and yards involved in conversions and/or repair work. Furthermore, these structures are operated over different towing routes and service areas carrying various cargo load distributions under different environmental loading conditions. A system for managing a structure over its life is needed.

(b) Suggested Approach. A feasible approach for this study would be to convene a task group to consider systems from aerospace, pressure vessel, nuclear power, bridges and buildings, and other disciplines for technology transfer of lifetime structural integrity management. The study should include economic factors and provide an example of how the "cradle-to-grave" system can be used in the marine industry.

ON GROSS ERRORS

(a) Problem Definition. This study is concerned with determining ways for coping with gross errors. It is generally assumed that a large fraction of catastrophic failures are attributable to gross errors. This might be defined as any decision, however trivial it might appear, that can lead to actual or potential disaster. Gross errors may occur in design codes and/or analysis and design including interpretation of codes, fabrication, inspection, or operation.

(b) Scope and Approach. The study might include a survey of recorded disasters in marine, civil engineering, and aerospace fields to identify and classify underlying errors. Many such disasters are extensively documented. One possible strategy for avoidance of gross errors might be to set up, for a major project, an elite task force comprised of a small group of able and knowledgeable individuals to oversee the safety of the project throughout its design, fabrication, and operation phases.

An initial feasibility study might include a conference or workshop on gross errors that would identify the types of skill and attributes required in such a team, and procedures to be employed.

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