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Practical Application of a New Advanced Dynamic Based Hull Structural Strength Design and Evaluation Criteria

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Abstract

A presentation is offered summarizing the technical features of a new dynamic based hull structural strength design and evaluation criteria for tankers developed by the American Bureau Shipping as the most significant update of the traditional classification strength criteria in decades. The paper focuses on how this new criteria, utilizing engineering first principles, can be applied in a practical day-to-day design setting. This is in the form of a dedicated software applications system for use on IBM-compatible personal computers and engineering workstations. The procedures involved in applying the software system to the design and evaluation of tanker structures is discussed.

Introduction

The criteria typically employed by industry to design the hull structure of large commercial vessels are those published by the major international classification societies. Representatively, criteria, as offered by the American Bureau of Shipping, are essentially semi-empirical, experience-based standards reflecting over 130 years of successful practical application [1]. Over the past 20 years the industry has experienced dramatic changes in vessel design, particularly in terms of vessel size and arrangement, optimization of structure based on computer aided design, and material usage. Many of these design features fall outside the experience base of the existing strength criteria. As a result the traditional primary structural failure mode of concern, yielding, has expanded to include the modes of buckling and fatigue, which may control the design. Hence, buckling and fatigue can no longer be assumed to be accounted for via implied safety margins of the existing criteria. As there is no consistent and rational basis for extending the existing criteria into these new areas a new basis must be established.

In recognition of these concerns, in 1990 ABS undertook a major research and development effort, as part of its overall RULES 2000 initiative, to completely recast its hull structure criteria based on a first principles engineering approach. This work has been facilitated by many of the new methods and tools that have also been developed over the last 20 years, and is based in large part on the design by analysis approach that has been of increasing interest in recent years. Once developed these criteria have been tested, calibrated and verified against the wealth of experience embodied in the traditional strength criteria.

ABS has now completed the first phase of this project by issuing to industry for trial use its strength and fatigue guides for tankers [2,3] as the ABS SafeHull System for Tankers. The theoretical development of the criteria embodied in the SafeHull System has been well documented in recent publications to industry [4]. Having developed the technical basis for such criteria the focus now must be on how such criteria can effectively be applied in a practical design situation. Because of the relative complexity of the criteria to that of the traditional criteria a software system has been specially developed to complement and facilitate the application of the criteria. This paper will center on the procedures involved in the day-to-day use of these new criteria through the software applications system. By way of introduction a summary of the criteria itself will first be offered along with an example of the validity of the criteria.

Strength Criteria

Basic Principles

The objective of this R&D effort has been to develop a new engineering first principles based hull structural strength criteria. This criteria has been designed to allow a more realistic, comprehensive, technically consistent, integrated and yet flexible approach to quantify the loads and stresses in a ship's structure as well as the requirements of the structure to resist these loads. The criteria has also been formulated and fully documented to easily accommodate future research findings and adjustments warranted from actual service experience. The short-term goal has been to provide industry with a design tool as well as one for assessing structures throughout their service lives. In the long-term the flexibility of the current deterministic format provides an intermediate step and sound foundation towards a reliability-based strength criteria.

A few of the more novel features of the criteria are:

Dynamic Loads: The fundamental basis to the new criteria is the determination of realistic dynamic loads including hydrodynamic, inertial and sloshing loads. Additionally, the criteria provides the unique solution to the realistic combination of these component loads in a complete and integrated manner.

Net Ship: Traditionally, hull strength has been assessed based on the uncorroded condition of the structure. The impact of corrosion on strength over the life of the vessel has been ignored. In the new criteria the nominal corrosion margins expected over the life of the vessel are removed and the strength requirements are based on this reduced condition. Thus, the criteria helps ensure safer structures throughout a vessel's life, not just in its as-built condition.

Fatigue: Through extensive application of detailed spectral fatigue analyses on ships ABS has established a thorough experience base from which criteria have been derived to allow accurate screening of the fatigue life characteristics of structural details. Based on the cumulative damage theory in conjunction with appropriate S-N data this is an original and unique tool for the industry.

Integrated Approach: The new criteria employ an approach to assure the systematic and integrated development of a vessel design through determination of the realistic dynamic loads, establishment of minimum initial scantlings (strength criteria) for individual structural elements, followed by a thorough assessment of the primary failure modes of concern: yielding, buckling and fatigue (strength assessment) for the overall structural system. The loads are all fully integrated into both the strength criteria and assessment. All necessary information, data and equations are provided both in the strength and fatigue guides as well as in the software application system. Explicit guidelines are provided for all necessary analyses to ensure consistent application.

As noted in the previous item the criteria is essentially divided into three key elements: generation of realistic loads, strength criteria, and strength assessment. These areas are briefly elaborated upon in the following.

Load Criteria

The load components considered in the new criteria are:

1) global hull-girder loads including both static still water and wave induced dynamic loads,

2) static and dynamic components of the internal pressures of liquid in the tanks, and

3) external hydrodynamic pressure and its distribution over the ship length and girth.

The magnitude of each load component is defined as the "nominal design load". In order to obtain the combined load effects, a set of design load cases is derived, where the dominant load component and simultaneously occurring load components are combined in the appropriate manner. See Section 3 of [2].

Strength Criteria

The strength criteria is to allow the derivation of initial scantlings during the preliminary design phase in terms of both local and hull girder requirements established in conjunction with the specified load and failure criteria. This differs from traditional criteria in that much greater emphasis is placed on the treatment of local structure in addition to overall hull-girder strength. This is to account for the increased use of high tensile steels and thus the related concerns of local buckling and fatigue compared to the traditional use and characteristics of mild steel.

The initial design scantling selection criteria are applicable to double hull tankers ranging from 190 to 500 meters in length having a length-to-beam ratio not less than 5 and a breadth-to-depth ratio equal to or less than 2.5. The criteria development focus has been on double hull configurations considering the ongoing industry trend in this area. However, explicit guidance for single hull configurations is also included along with basic guidance on mid-deck configurations. The criteria include requirements for plating, longitudinal and other stiffeners, longitudinal girders and floors in the double bottom, and the main supporting members.

The initial scantlings obtained using the strength criteria are considered initial design minimum values. These need to be verified via a detailed stress analysis and assessment as described below. See Section 4 of [2] for details of the initial scantling strength criteria.

Strength Assessment

As noted above the initial scantlings must be verified via detailed stress analyses and assessment of the structure as an integrated system. The stress analyses provide not only an added degree of assurance of the vessel's safety but the analyses also provide useful insight that may help to monitor the condition of the as-built structure. The strength assessment of the structure covers the failure modes of yielding, buckling and fatigue. Additionally, the ultimate hull-girder strength in the intact and assumed damaged condition is also considered. The results of these stress analyses and strength assessment serve as a basis for the judicious and rationalized increase in scantlings above the initial minimum values as needed.

The stress analyses are carried out using finite element analyses (FEA) for both 3-D global and 2-D fine-mesh models. Detailed modeling guidelines have been developed to maintain a uniform level of quality in the analyses that is required to arrive at a meaningful comparison of results. Much of the FEA has been automated through the software system. This will be further described below.

Details of the failure criteria and strength assessment can be found in Section 5 of [2].

Comparison with Existing Designs and Criteria

In introducing any new strength criteria it is important to demonstrate that the criteria has been appropriately calibrated and verified against current criteria and practice. A detailed comparison is offered in [4]. In summary, a comparison of the initial minimum scantlings of the new criteria versus those of the as-built vessel are illustrated in Figure 1. The comparison shows that Guide values are essentially comparable to those required by the present 1993 ABS Rules. The variations reflect the redistribution of material in the hull girder as found in applying the new criteria. Some of these values would be expected to increase as a result of the subsequent strength assessment. A similar comparison of fatigue lives is offered in [5].

In addition to the criteria itself [2] a comprehensive overview of the new strength criteria is presented in [4].

Description of Software Applications System

The software applications system that has been developed in parallel with the Strength and Fatigue Guides is a necessary component of the overall ABS SafeHull System because of the first principles format of the new criteria. As the criteria is no longer in the traditional form of simplified formulas and tables the software is needed to make the criteria a practical tool for use in day-to-day design situations. While this is a significant departure from conventional application of classification criteria it is in keeping with modern technology commonly in use by the industry worldwide.

The design loads, for example, are given as distributed functions over the hull structure in terms of the location of interest as well as the principal geometry of the vessel. Similarly the formulas used to assess strength involve many more variables than the old format.

The software system is available to industry as part of the overall SafeHull System. This provides greater consistency in the application of the criteria and will greatly facilitate both the design and evaluation processes. Both of these attributes should also enhance the safety of the structure by eliminating the guess work related to judging the quality and consistency of the software and analysis methods used by the designer in the design and evaluation processes.

Software Platforms

The software is designed to run on IBM personal computers (PC's) and compatibles running version 5.0 or higher of the industry standard DOS operating system. PC's using 386-based CPU's are considered the minimum acceptable platform for the development of initial scantlings (See Phase A analysis, below). A math coprocessor is also optional for this phase of the analysis. For the Phase B analysis, which involves performance of finite element analyses, a 486-based PC is recommended and a math coprocessor is required.

The PC was selected as the development platform for a number of reasons, among which is the ready worldwide availability and affordability of these machines. The PC platform also allows many of the advancements in personal computer technology to be utilized in enhancing the capabilities of the software. Recognizing that the engineering workstation is also a standard design tool, ABS is currently working on the migration of the SafeHull System applications software to the workstation environment.

System Architecture

The software applications system is comprised of a suite of interactive programs for the design and analysis of tanker structures. In addition to the engineering analysis programs, routines are also provided expressly for the streamlining of the voluminous input data required for the detailed analytical modeling of a vessel. With user-friendliness a key issue in the development, these input data preparation programs have been developed to make extensive use of interactive on-screen color VGA graphics, graphical HPGL format reports, and active mouse and cursor key control among others. The goal of this input approach has been to make the data input as straightforward and intuitive as possible, minimizing the need for companion user's manuals. This emphasis on streamlining of the input is in large part due to the issue of productivity. With the computational ability of today's PC's the actual calculation time for many of the engineering modules can be quite short. Thus, most of the time for the analysis is found to be associated with the human interface. Therefore, every effort has been placed on reducing this time.

The system features a pull-down menu system that is organized to lead the user through the analyses in a systematic step-by-step manner. The options available in the top level menu include capabilities for the user to set up a specific system configuration for their site. The input and output files are created automatically based on the project and vessel names specified by the user. This internal file management helps enhance the integrity of the vessel-specific files, which is important considering the number of data files can grow quite large.

To enhance the flexibility of the system a more traditional "batch" type input scheme using a text editor is also built-in as an alternative option for users more comfortable with this input approach.

Integration

The software system can be installed and utilized as a fully integrated, stand-alone system. This includes all of the data preparation and analyses for determination of the initial scantlings as well as the analyses for the strength assessment. The one exception is the execution of the FEA calculation itself. The FEA solver provided with the SafeHull System is the PC-based GIFTS FEA package. While this is a separate system the execution of the FEA calculation can be called directly from the SafeHull System software, streamlining the overall flow of the analyses.

Alternatively, the software system has been structured in a modular fashion with the intention of permitting users to integrate the SafeHull System software into their existing applications. This is primarily in terms of FEA systems that a designer may already have established in-house. ABS can provide appropriate neutral data files for modeling, loading of the structure and post-processing to assist users in integrating the SafeHull System software with their FEA system. The format of these files has been generated to be consistent with requirements for NASTRAN. Other FEA systems can be used with the SafeHull system. However, the important common element in any SafeHull related analysis is the use of ABS specified loads. These loads are required to ensure the accuracy of analysis results.

Methods of Applications

The primary use of the software, and the new criteria in general, focuses on the design and evaluation of new tanker designs. Therefore, the system can be applied by designers in developing the initial scantlings for a tanker through the full strength assessment of the hull structure leading into the detailed design stage. Subsequent to this stage the design is submitted for ABS review for classification. ABS employs the SafeHull System criteria and software to perform an evaluation of the design. The fact that the designer has this tool available that ABS will also employ in the review process obviously helps the designer in knowing early in the process whether there could be problems in compliance of the structure with class requirements. This prior knowledge will also aid in streamlining the class review process by minimizing the number of amendments required to the submitted design.

In addition to the application of the software system to the design and evaluation of new designs, ABS is continuing to develop the services employing the system for the assessment of existing vessels. The criteria will enable a sound technical basis for the assessment of existing tanker structures and provide users with detailed information such as critical areas that should be monitored in the hull.

For system description purposes the application of the system to new vessel design and evaluation is focussed on in the following sections.

Flow of Analysis

The overall flow of the SafeHull System applications software is shown in Figure 2. The analysis can be divided into two major phases: Phase A - determination of initial minimum scantlings and assessment of fatigue, and Phase B - strength assessment of the primary failure modes of concern. These two phases are structured to be followed in an iterative manner. Phase A is performed and repeated as necessary to develop initial scantlings that meet the requirements of the criteria. Once these requirements are satisfied the strength assessment is performed iteratively until the overall structural system meets the failure criteria for yielding, buckling and ultimate strength specified in the Strength Guide.

The flow of the system has been developed to follow that of the classic design spiral for ships. While each designer has their own unique design process, it is felt that the details of the system described below will demonstrate its utility in individual situations.

Analysis Procedure: Phase A - Initial Scantlings

This phase of the SafeHull System software allows performance of the calculations necessary to determine the hull structural scantlings required to satisfy Section 3 - "Load Criteria", Section 4 - "Strength Criteria", and the first level of strength assessment, fatigue, from Section 5 - "Strength Assessment" of the Strength Guide [2]. The scantlings from Phase A are considered "initial" scantlings as they must still pass the strength assessment of Phase B, described below. It is estimated that experienced users of the software can perform a complete iteration of the Phase A analysis in a 2 to 3 day period. With the ease of use and speed of this analysis it is expected that this analysis will be a very useful tool during bidding and preliminary design phases.

The following describes the individual steps of the analysis for Phase A as shown in Figure 2.

Modeling of Hull Geometry

The first module of the Phase A analysis is used to generate the geometric model of the vessel midship section (Figure 3). The user specifies the principal dimensions, structural configuration and relevant geometric parameters. The parameters include the positioning of all longitudinal material, namely: plating and stiffeners for deck, bottom, sideshell and longitudinal bulkhead regions. The graphic user interface is used extensively in this module for ease of input. Two modes of input are provided, a user defined input mode and an automatically generated mode. The user defined mode is designed to allow the user to input specific plate and stiffener data based on a design configuration that is well planned or has already been developed (Figure 4). The automatic mode is provided for instances where the general configuration is known but specifics have not yet been developed. It must be reiterated that this module is strictly for modeling of the geometric configuration only. After the input is completed the associated engineering calculation is executed to complete the required geometric model. Once completed, this information is referenced automatically throughout the analysis whenever geometric data for the vessel is required, such as when initially developing and subsequently assessing the scantlings applied to the geometric configuration.

Definition of Tanks and Holds

Once the geometry is developed the boundaries of the cargo holds and ballast tanks are defined as a first step in developing the internal loading for the vessel. This is facilitated again by a graphical user interface (Figure 5). The mouse can be used to choose the tank type from a displayed on-screen library and then the corresponding space can be selected directly from the midship cross section, also displayed on-screen. The loading patterns for the required load cases (Figure 6) are then defined completing the input required to calculate the dynamic loads.

Generation of Dynamic Loads

By completing the definitions of the hull envelope and internal spaces the calculation of the loading for the required eight loading cases becomes a push button process. The previously defined geometric information along with the loading criteria imbedded in the software are utilized in developing the loading. Once the engineering module is executed the file containing the loading information is maintained internally for automatic reference through the initial scantling requirement check, and as a basis for the detailed loadings used in the FEA and strength assessment.

Assignment or Development of Offered Scantlings for Midship Section

At this point in the process the user has defined all of geometric configurations of the design and calculated the dynamic loads for the required load cases. The individual scantlings associated with the plates and stiffeners is now input. These are the offered scantlings that the designer has developed based on previous experience or represents a first iteration estimate to be checked using the criteria.

Plate thickness input is very straightforward through directly typing in the thickness for each strake in the midship section. Input of the scantlings for the stiffeners is necessarily more complex. However, this step is simplified through the use of a library of stiffener and end connection data. This library can be generated by the user through a built-in utility. Thus, the user can develop a personalized library appropriate for the standard stiffener and end connection details used in their particular applications. The library can then be used for subsequent SafeHull applications. From the library the user can use the graphical interface to point and click on the list of stiffeners and end connections to assign the appropriate scantlings to the previously defined geometry.

A significant enhancement to the software in this area will help simplify use of the software system as a design tool. A routine is currently under development that will be included to allow the user to have the software automatically develop an initial estimate of the plate thicknesses and stiffener sizes based on criteria values and internally specified typical design parameters. This would provide the user with a rational starting point for detailed development of the midship section scantlings.

The final input for this segment of the Phase A analysis are the still water bending moments. If this information has been calculated by the user the software system provides for this information to be input and employed in the analysis. If the values for the hogging and sagging still water bending moments are unknown the analysis will employ appropriate criteria-defined default values.

An interim step provided to the user at this juncture in the analysis is the calculation of the offered section modulus properties. This is another push button operation upon completion of the above input. In addition to the necessity of this information for the overall SafeHull analysis this calculation is seen as a simplified section modulus calculator for general use beyond the direct application of the software for SafeHull purposes.

Assignment of Offered Scantlings for Main Supporting Members

The input of the scantlings for the structural main supporting members can be the most tedious segment of input for the entire Phase A analysis. This is due to the complexity and variety of these structural members, which cover deck transverses, deck girders, side transverses, webs and girders on bulkheads, struts and transverse bulkheads. Here again the graphical user interface has been designed to make this input as intuitive and straightforward as possible.

Determination of Initial Minimum Scantlings

With all of the preceding input entered and preliminary calculations completed the next module is used to compute the overall properties of the midship section modulus and scantlings of the structural members with respect to the strength criteria. The midship section modulus is assessed for compliance with the hull-girder strength criteria and the individual longitudinal and transverse structural members are judged against the strength criteria based on the nominal loads acting at each location per the load criteria.

The output of this module is presented in tabular form and shows the comparison of offered versus required scantlings for each element of the structure. This output can be viewed directly on-screen or printed in hard copy form. Should the results show that the offered scantlings do not meet the minimum hull-girder or local criteria requirements the user would at this point reiterate on the preceding process by either adjusting the basic geometry or by increasing the offered scantlings.

Once the initial scantlings fully comply with the SafeHull System strength criteria for both local and hull-girder requirements the user is ready to proceed with the detailed strength assessment of the failure modes.

Fatigue Strength Assessment

The module of the Phase A analysis that is an exception from the balance of the phase is the fatigue assessment. While the other modules pertain to the determination of initial scantlings the fatigue assessment is actually the first step of the strength assessment of the failure modes. The fatigue assessment is included in Phase A because of the manner in which it is performed. By this stage in the overall analysis the required input for fatigue has already been input for the most part as portions of preceding input data. Therefore, the fatigue assessment becomes another push-bottom action after a very limited amount of input to define the end connection types for the stiffeners of interest. The calculated fatigue life characteristics of the structural details can then be viewed either on-screen or printed in tabular form. Should any of the fatigue lives be too short the user can iterate from the appropriate point in Phase A to take the most effective corrective action. This is again an advantage of the modular nature of the SafeHull System software as it allows re-entry at any point in the process rather than mandating a complete restart of the overall analysis.

Analysis Procedure: Phase B - Strength Assessment

The Phase B procedure for the SafeHull System is structured for performing the analyses required for the strength assessment of the initial scantlings obtained from the Phase A analysis. The Strength Guide Section 5 - "Strength Assessment" is to check the structure with respect to the failure modes of yielding, buckling and ultimate strength. The distinguishing characteristic of Phase B is the required performance of a Finite Element Analysis to determine the deflections and stresses for input to the failure criteria. Both three-dimensional and two-dimensional models are analyzed using a supplied FEA solver resulting in a complete, fully integrated system.

Phase B consists of seven steps consisting of:

1. initial setup,
2. generation of the global 3-D 3-tank length model,
3. loading and solution for the 3-D model,
4. strength assessment for the 3-D model,
5. generation of the fine-mesh 2-D models,
6. loading and solution for the 2-D models, and
7. strength assessment for the 2-D models.

The procedure and software is again designed to allow modular usage. Users can iterate over a particular step, a group of steps or the entire Phase B process. To provide a uniform and consistent method of analysis for the strength assessment FEA detailed guidance is provided in [6]. The precepts in this guidance are automated in the software system to streamline the procedure and execution time. It is estimated that experienced users of the software can perform a complete iteration of the Phase B analysis in a period on the order of 2 to 3 weeks. This analysis is seen as an effective tool for use in contract and detailed design phases.

The following provides an overview of the key elements of the Phase B process as shown in Figure 2.

Initial Setup

The initial setup step is effectively the link between the data generated in Phase A and the passage of the pertinent portions of this data to the analyses of Phase B. The necessary data is that needed to calculate loads according to the criteria. This includes principal dimensions, web frame spacing, tank descriptions and tank arrangements. This step is currently being streamlined with the objective of making this link transparent to the user.

FEA Modeling

Several FEA models are required for the analysis. One 3-D global FEA model is needed consisting of the midship 3-tank length of the tanker made up of longitudinal members, transverse members and springs at each end of the model. Subsequent to the global analysis, selected 2-D fine-mesh models of transverse webs or horizontal girders, or longitudinal ring frames are required. Creating these FEA models is the most time consuming process of the entire SafeHull analysis.

Three routines have been developed for the software system to help streamline the generation of the 3-D and 2-D models. Each routine is oriented to a specific structural area. One is used in building the longitudinal members of the 3-D 3-tank length model. A second is for building transverse members of the 3-D model or 2-D fine-mesh transverse members. And the third is an alternative technique for building 2-D fine-mesh transverse web models. In general, all of the routines employ the same simple model generation concept. The concept uses the direct modeling technique rather than using a composite technique. In the direct modeling technique the basic set up is to define nodal points in space. Elements are then generated by connecting the nodal points. The FEA model is made up of rod, beam, triangular and quadrilateral elements. Rod elements connect two nodal points, triangular elements connect three corner points, and quadrilateral elements connect four corner points. Each element is assigned a specific material and dimension. Examples are illustrated in Figure 7.

The mesh sizes to be used for the FEA models have been specified in the guidance in a manner to ensure that the results from the analysis are reasonable with respect to those used in developing the criteria itself. For the 3-D 3-tank length model the mesh size is equal to the spacing of the transverse web frames. For the 2-D fine-mesh analysis the mesh sizes used are equal to the stiffener spacing.

Loading

After the structural model is generated the next step in the process is to apply the loads to the structure. The loads include hull-girder loads, external wave loads and internal tank loads. These dynamic-based loads are automatically generated by a set of loader programs and then converted into the FEA system as point loads.

The loading routines are made up of a group of programs: 3-D loading for the eight required loads cases, 3-D loading for two sloshing load cases, 2-D transverse web loading, 2-D horizontal girder loading, and 2-D longitudinal ring loading. Each 2-D loading program includes the boundary displacement interface between the 3-D and 2-D models. Use of these routines ensure that the this critically important step in the analysis is executed in a consistent and accurate manner.

FEA Solver

The FEA solver built into the software system is the PC-based GIFTS basic package. A number of batch commands are built into the SafeHull software to permit the 3-D and 2-D analyses to be run directly. This integrated package is offered as an effective and inexpensive FEA solver available as part of the SafeHull System. GIFTS is not offered as a package to supplant a designer's existing FEA system and as such its use is not mandated by ABS. Existing systems can be integrated with SafeHull to take advantage of these systems' more elaborate features.

Strength Assessment for Yielding and Buckling

Post-processors for the FEA are provided to examine the results of the 3-D and 2-D analyses in terms of the strength of individual structural members for the failure modes of yielding and buckling. The solved FEA model includes displacements (Figure 8) at each nodal point, and stresses at each element. The stresses that are obtained from these FEA results are the primary and secondary stresses. In order to perform the strength assessment, it may be necessary to calculate the additional bending stresses induced by the local loads. Therefore, a set of criteria post-processing programs is included to permit full execution of the tasks specified in Section 5 of the Strength Guide.

The results of the strength assessment are presented in tabular form for review to judge the viability of the scantlings. If inadequacies are found at each step of the strength assessment the process must be repeated to adjust the structure and scantlings appropriately to meet the failure criteria requirements specified in the Strength Guide.

Conclusion

ABS views the SafeHull System for Tankers as a significant technological breakthrough relative to the rational, comprehensive, consistent and integrated nature of the new strength criteria and supporting software system. The system has been designed to be incorporated into the day-to-day design process of designers to allow them to more thoroughly and rapidly assess a variety of designs. Thus a design can be more completely developed resulting in more efficient production of the structure. Since the software applications system will also be employed by ABS in the review of designs for classification, structures developed by designers using the SafeHull software can expect virtually pre-approved scantlings, which will streamline the classification review process. Using the new first principles-based criteria more durable vessels can be produced. Ones that have an improved margin of safety and more effective use of material. Steel weight is expected to be nearly the same as that required by the existing criteria, however, that steel will be more appropriately distributed through the hull girder into the most critically stressed areas. Identification and subsequent monitoring of these critical areas will permit more efficient maintenance planning through the vessel's life.

ABS is continuing to enhance the software system and continuing developments are ongoing for the overall SafeHull System. The SafeHull System for Bulk Carriers is scheduled to be released to industry in the near future. Follow-on developments are also planned for other major vessel types such as containerships and gas carriers. As the current release for tankers is being offered to industry in a trial use mode comments and feedback from application of the system to practical situations is particular valuable and welcomed by ABS to ensure a useful tool for industry.

Acknowledgment

The authors would like to thank the Ship Structures Committee and SNAME for inviting ABS to present this paper. We would also like to recognize the many engineers in ABS who have contributed so much effort to the development of the new strength criteria over the last three years and also the engineers who have developed the software applications system. We would particularly like to thank Ping Liao for his contributions on the Phase B portion of this presentation. Additionally, we would like to thank the project management for their support of and contributions to this presentation, namely: Don Liu, John Conlon, Hsao Chen and Faith Lee.

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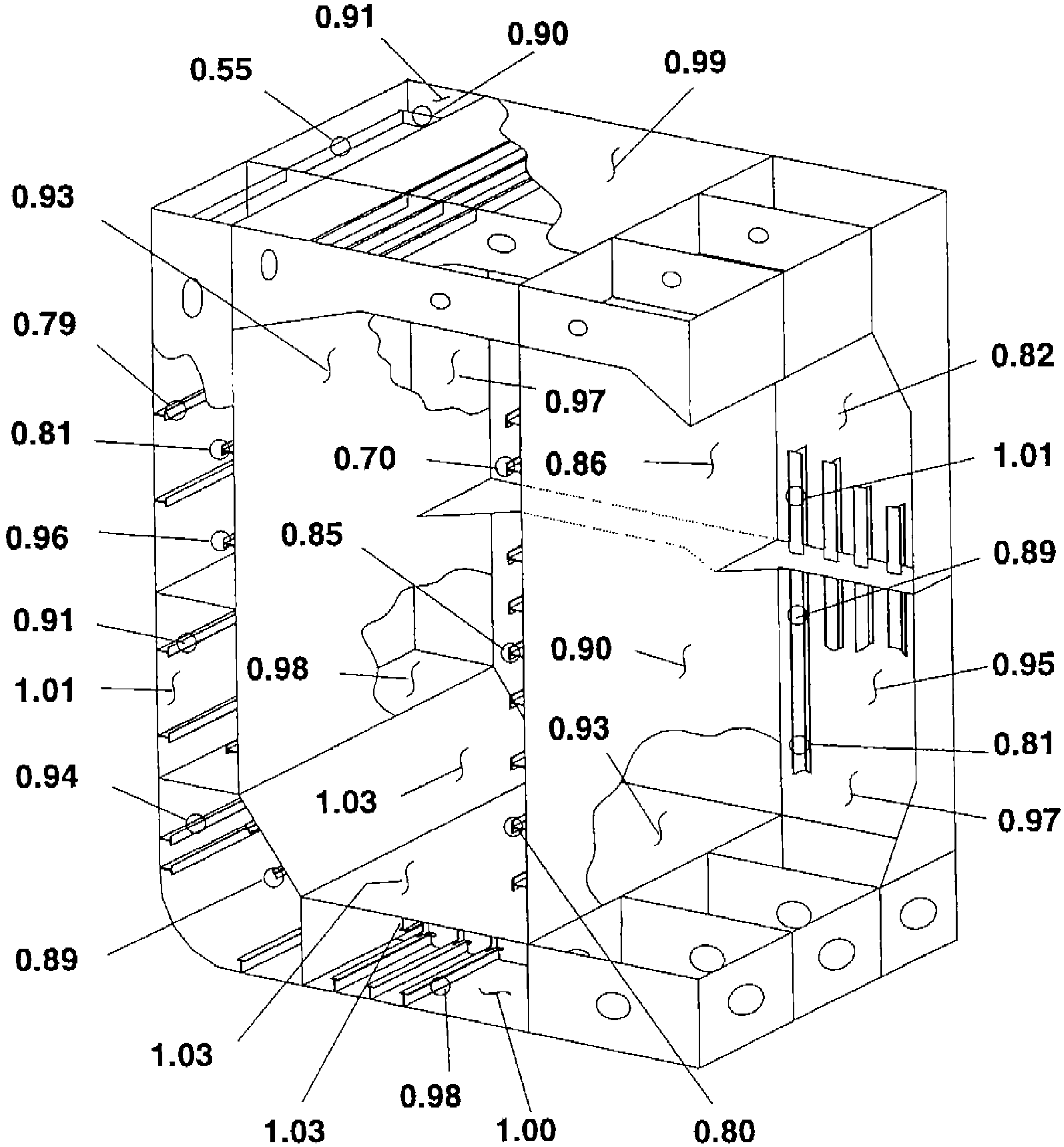


Values shown are ratios of Guide to offered scantlings.
Values over 1.00 represent increased scantlings compared to existing criteria.

Figure 1
Comparison of Guide Initial Scantlings Versus As-Built Scantlings

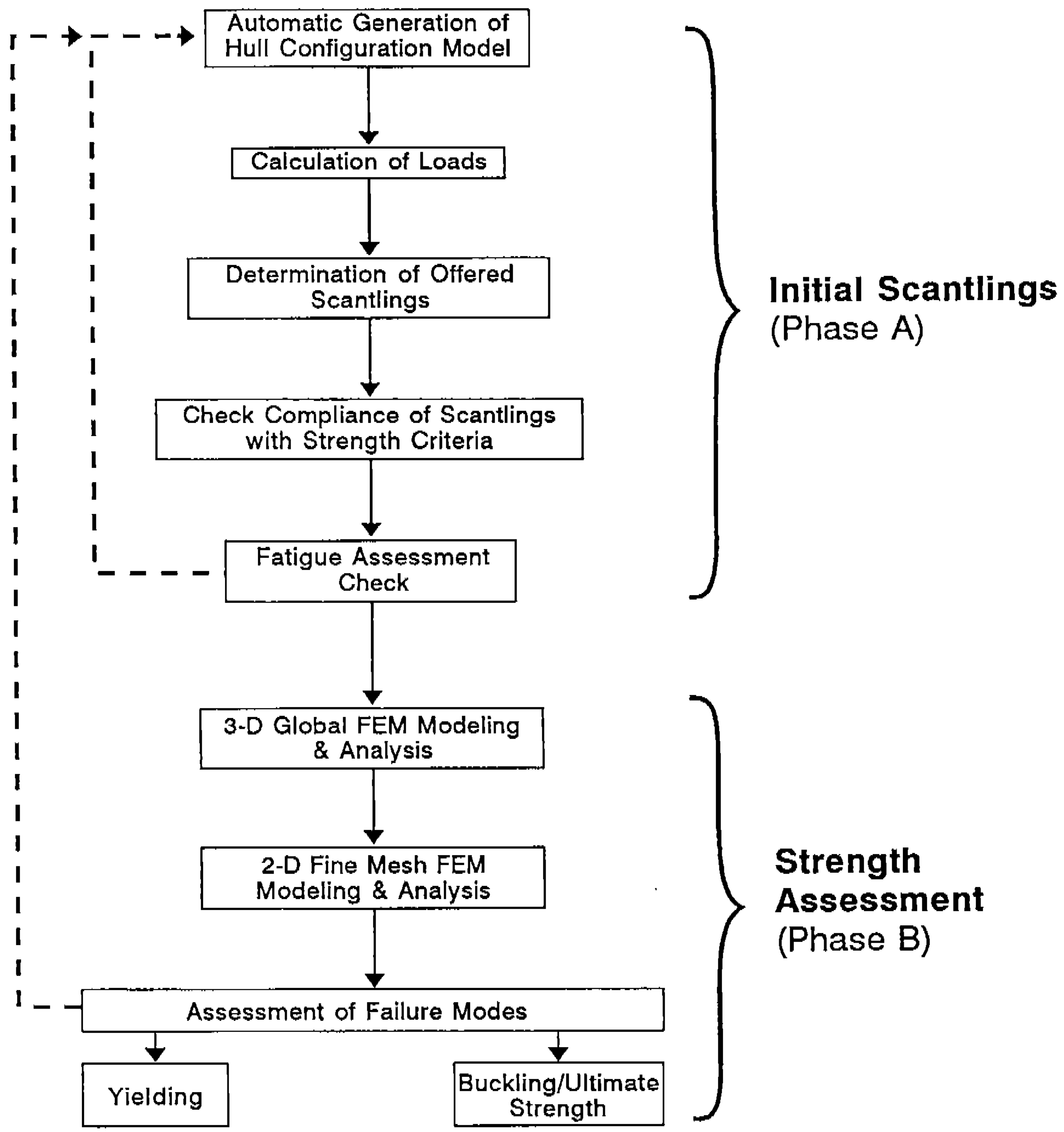
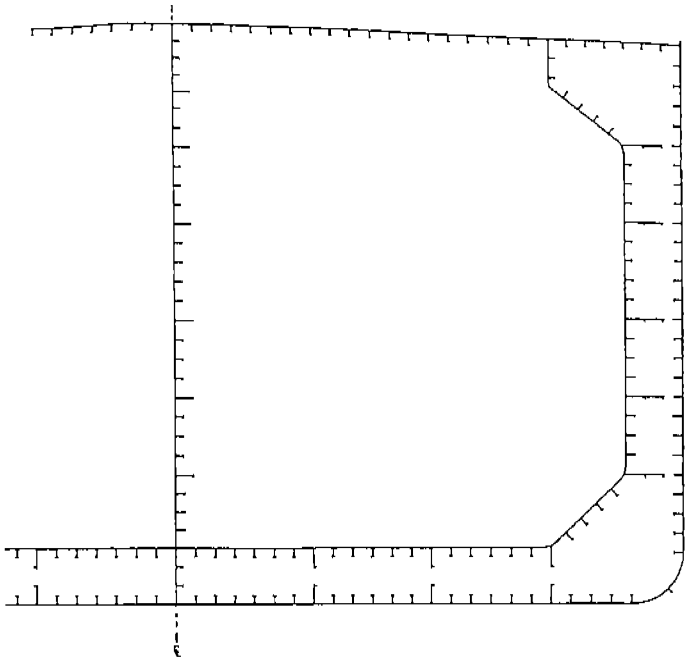
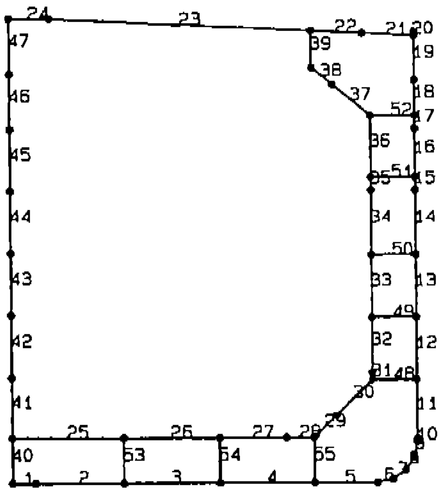


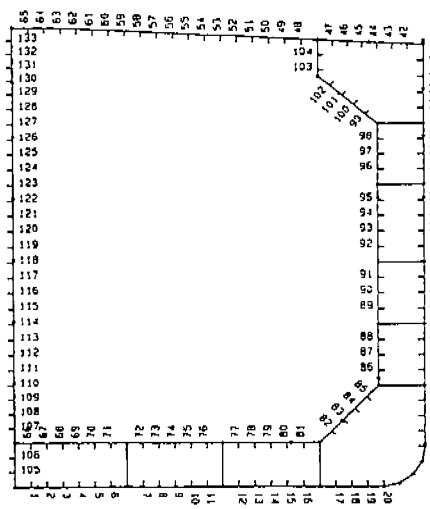
Figure 2
Procedure for Application of SafeHull System Software
in the Design and Evaluation of Tanker Structures



Typical Midship Section



Plates



Stiffeners

Analytical Model

Figure 3
Sample Midship Section and Associated SafeHull System Analytical Model

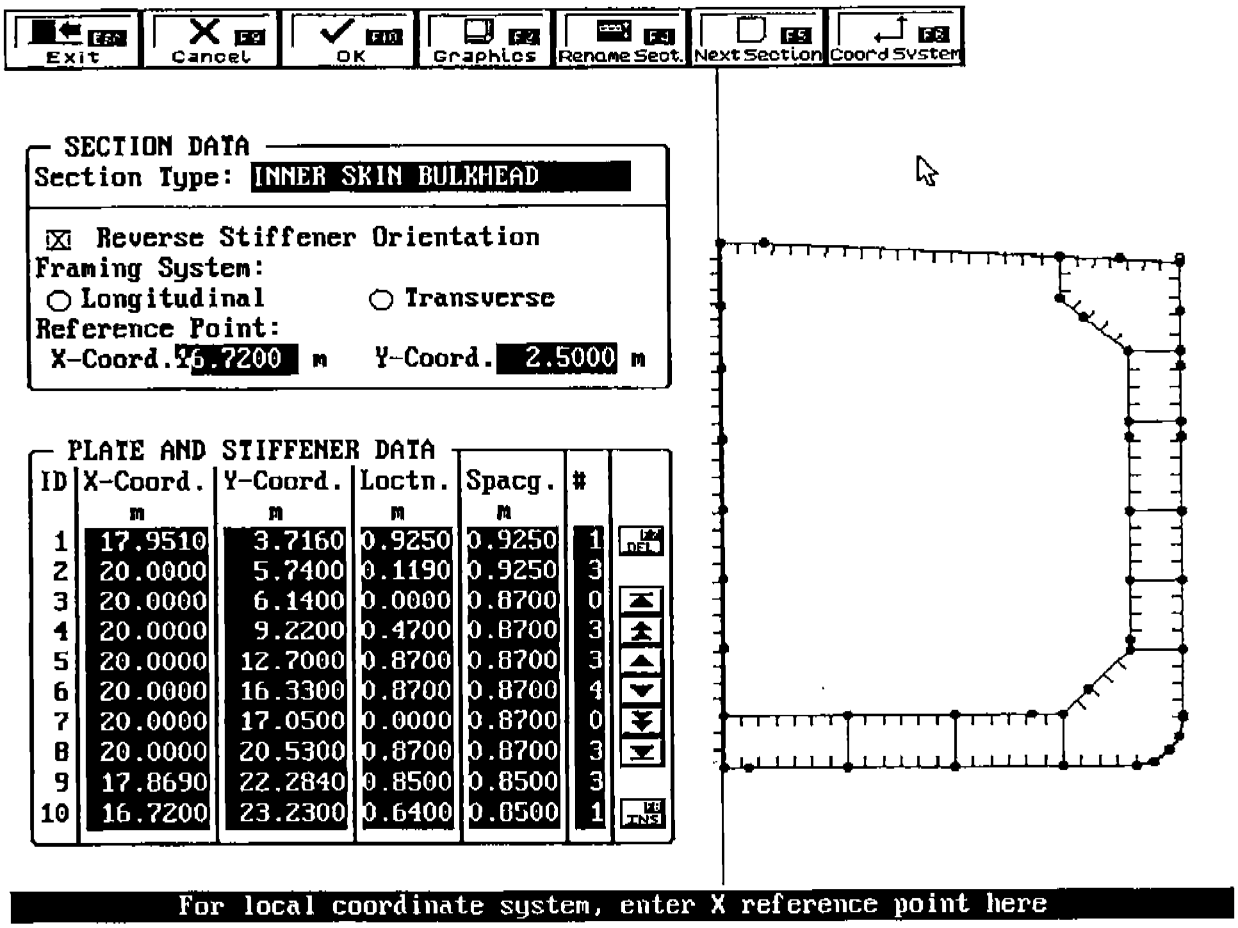


Figure 4
Computer Screen Showing Interactive Definition
of Midship Section Geometry

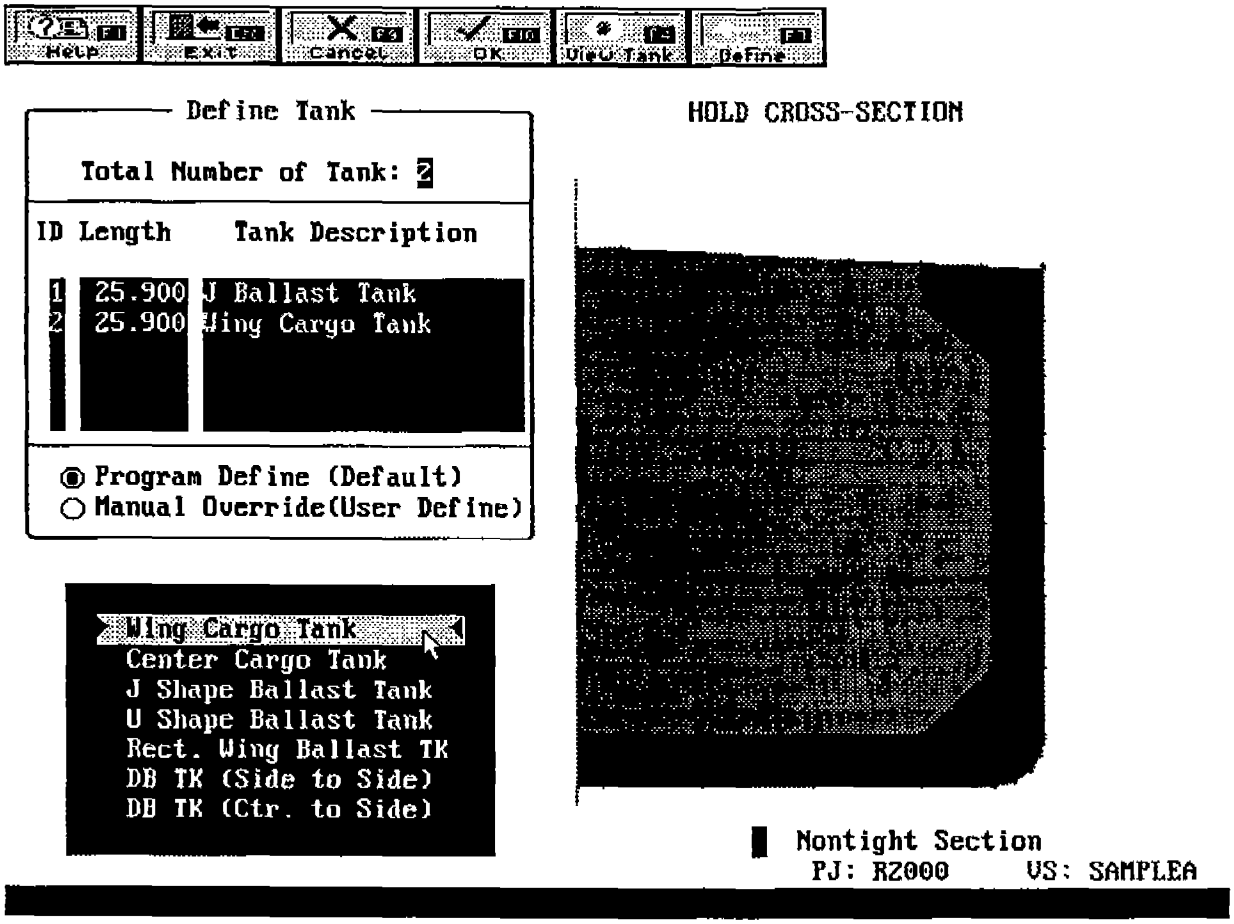


Figure 5
Computer Screen Showing Interactive Definition
of Ballast and Cargo Tanks

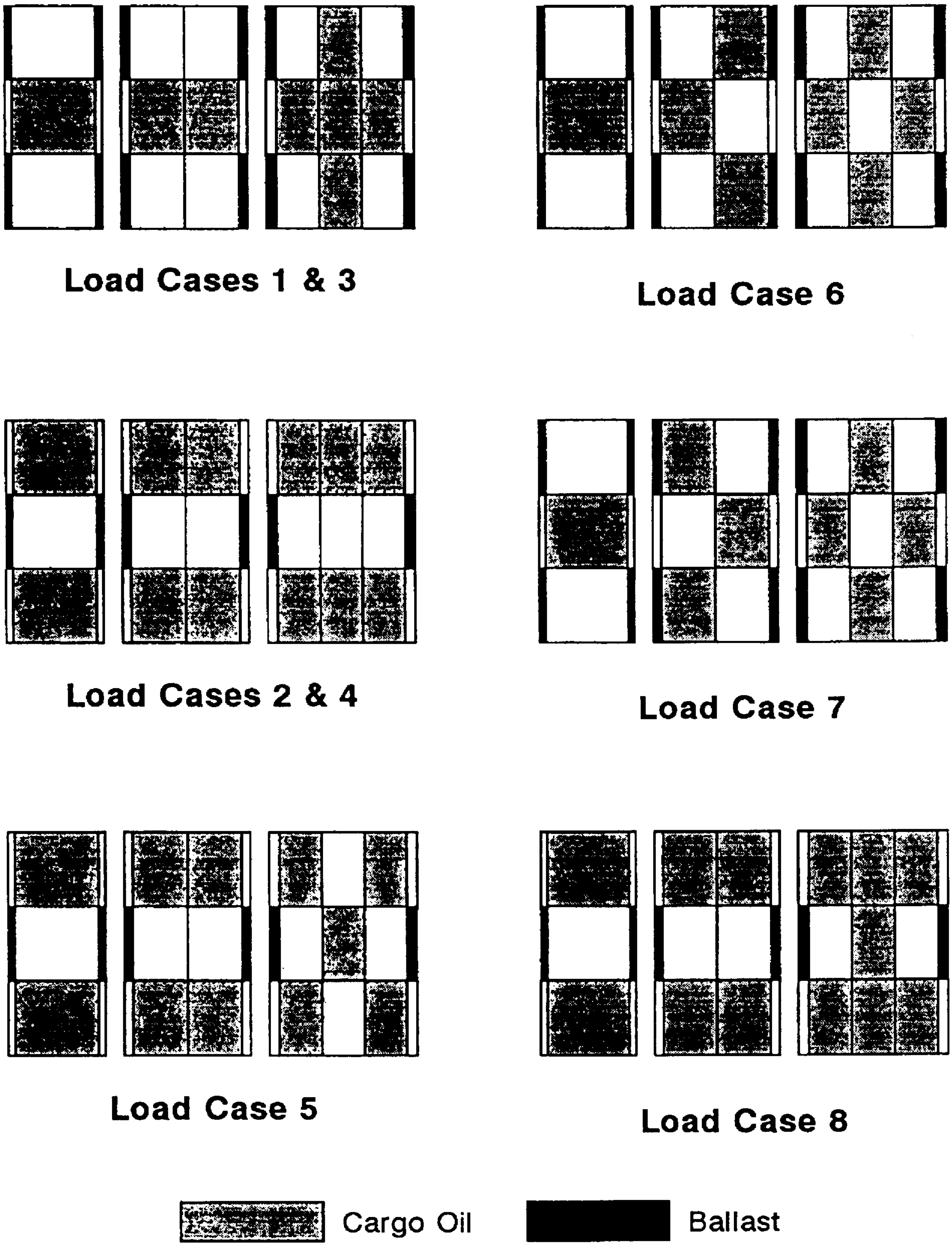


Figure 6
Typical Required Loading Patterns for Analyses

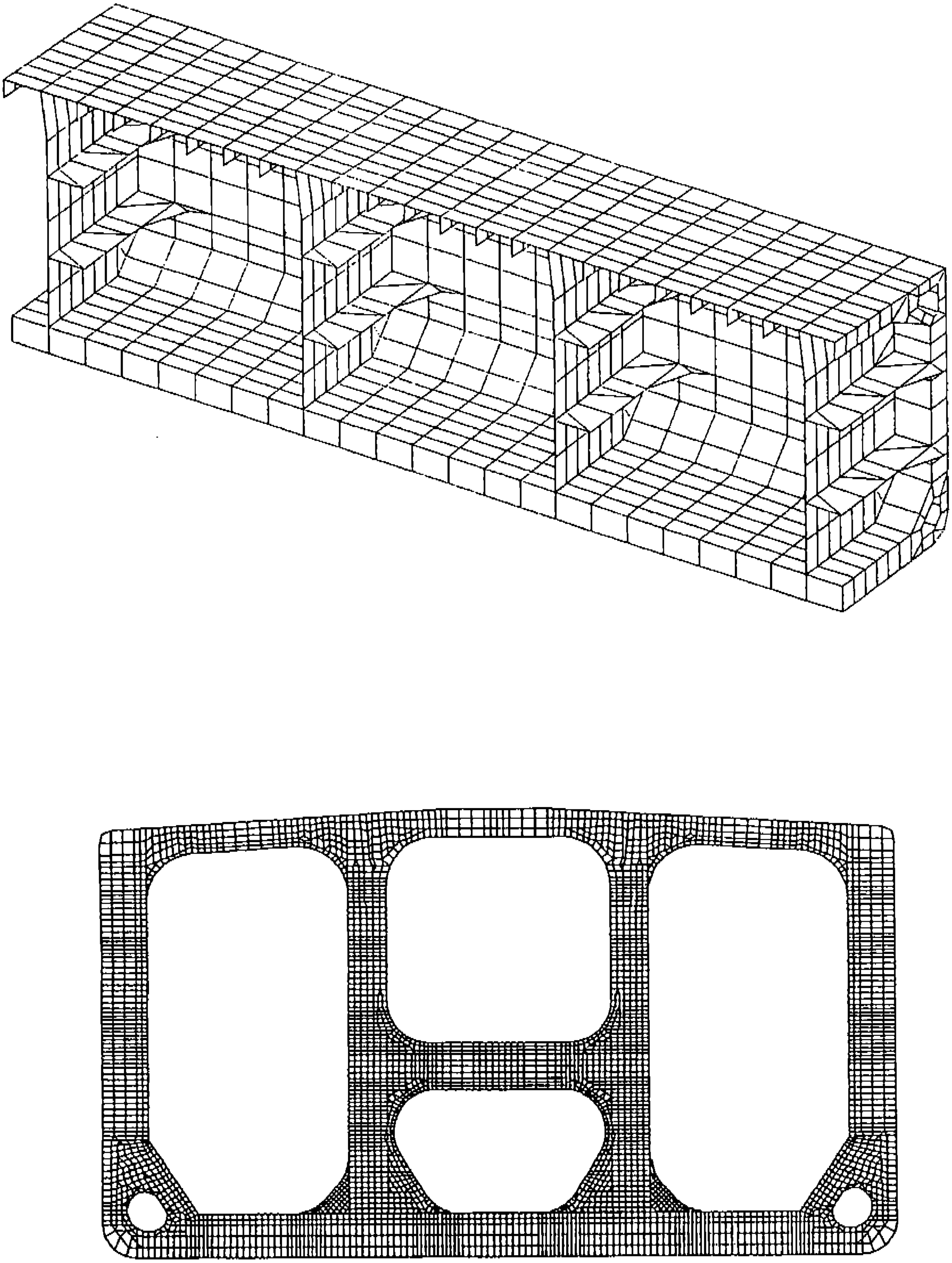


Figure 7
Representative 3-D and 2-D FEA Models Generated by Automated SafeHull System Routines

Top View: Undeflected Structure

Bottom View: Deflected Structure in Oblique Sea Condition

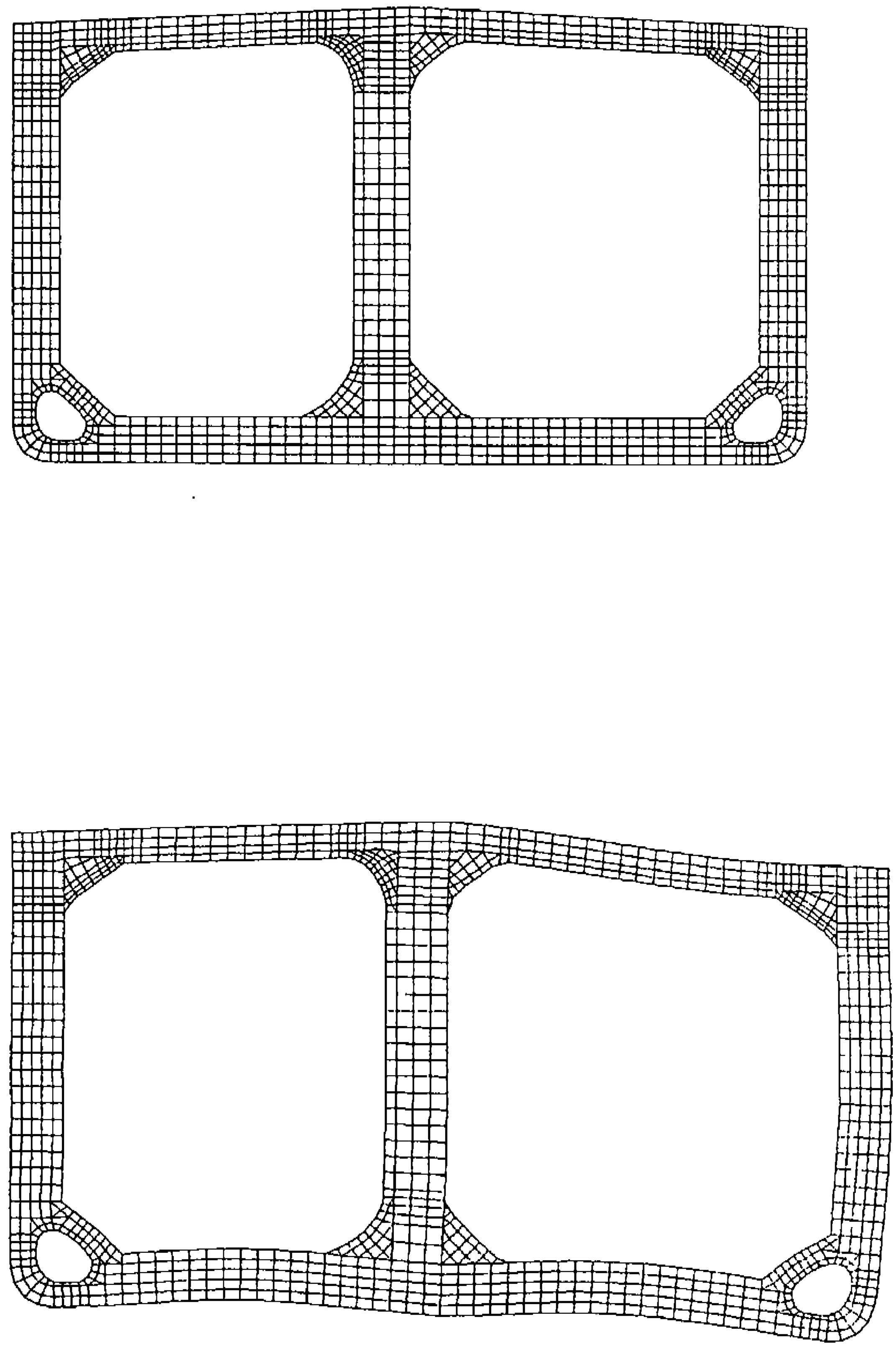


Figure 8
Representative Deflection Plot from Finite Element Analysis