DELIVERABLE #1

PROJECT WHITE PAPER

NVR Strength Criteria Implementation into MAESTRO Finite Element Analysis Application

NSRP Ship Design & Material Technologies Panel Project
(ATI Award No. #2010-388)
Cleared Internally under Case No. DS-TCS015

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DISCLAIMER: The specific implementation of the MAESTRO FEA Application (including incorporation of NVR Strength criteria) described herein has not been reviewed, tested or endorsed by the U.S. Navy, nor have the requisite Government verification, validation and accreditation steps been completed that would enable direct application on any Navy program.

Introduction

National Shipbuilding Research Program

The National Shipbuilding Research Program (NSRP) was created by U.S. shipyards at the Navy's request to reduce the cost of building and maintaining U.S. Navy warships. NSRP is a collaboration of several major U.S. shipyards focused on industry-wide implementation of solutions to common cost drivers. The program targets solutions to consensus priority issues identified by the Navy shipbuilding community and industry in undertaking R&D efforts that exhibit a compelling business case to increase warship affordability by improving U.S. shipbuilding and ship repair efficiency. Solutions include both leverage of best commercial practices and creation of industry-wide initiatives with aggressive technology transfer to, and buy-in by, multiple U.S. shipyards.[a]

The mission of NSRP is to manage and focus national shipbuilding and ship repair research and development funding on technologies that will reduce the cost of ships to the U.S. Navy and other National Security Customers by leveraging best commercial practices and improving the efficiency of the U.S. shipbuilding and ship repair industry. Provide a collaborative framework to improve ship-related technical and business processes. [a]

Panel Projects

Within the NSRP, there are 10 panels that correspond to narrow technical and/or process areas while being aligned to the broader major initiatives of the NSRP Strategic Investment Plan. The Executive Control Board typically sets aside a modest amount of money each year to fund relatively small (less than $100k), short-term (12 months or less) projects recommended by the Panel Chairs. This project, *NVR Strength Criteria Implementation into MAESTRO FEA Application*, represents one of the Panel Projects that was awarded in March 2010. Details of the Panel Project and Scope can be found in later sections of this report.

Panel Project Scope & Team Approach

The objective of this NSRP SDMT Panel project was to implement the Naval Vessel Rules' (NVR) structural strength criteria (i.e. NVR Table 7 1-3-4/4.1, Reference [b]) as an integrated structural evaluation criteria *set* within the global ship-oriented finite element analysis (FEA) computer program MAESTRO. Industry and government experts participated in the application of the NVR's by defining requirements, exercising, and testing this new technology, and were to identify any additional developments that would make the structural direct analysis process, in the context of NVR strength criteria, more efficient.

DRS Defense Solutions, LLC, Advanced Marine Technology Center (DRS AMTC), a division of DRS Training & Control Systems, LLC was the acting prime contractor. The following organizations participated as sub-contractors under the direction of DRS AMTC: NSWCCD Code 6510, General Dynamics Bath Iron Works (GDBIW), Huntington Ingalls Industries (Ingalls), and American Bureau of Shipping Naval Engineering Department (ABS NED). These participants understood that the development of this new technology would address an industry need that was currently not being met for classing vessels under the NVRs.

The goals of this panel project were to address the NVR structural direct analysis requirements of the US Navy, industry shipyards and ABS by implementing the NVR structural strength criteria in the finite element analysis computer program MAESTRO and create functionality to better facilitate the processing/post-processing of the strength criteria results. Achieving these objectives would enable the US Navy, industry, and ABS to more quickly apply the NVR structural criteria to new ship designs, design evaluations, as well as for assessing repairs, changes, and through-life condition of naval ships.

Project Background and Benefits

Past NSRP projects (e.g., *Improved Methods for Generation of Full-Ship Simulation/Analysis Methods* and *The Scantling Approval Process* [a]) addressed important elements and processes associated with today's ship structural design in the context of direct analysis and ABS classification. The panel project proposed herein was aimed to complement both of these projects. The *Improved Methods for Generation of Full-Ship Simulation/Analysis Methods* project focused on *creating* analysis models while the project described herein focused on *processing/post-processing* (specifically the NVR strength criteria). The panel project proposed herein also complemented the *Scantling Approval Process* project by focusing on Naval Ships classed under the *NVRs* as opposed to those classed under the *SVRs*. Further, the identification of needs from both *submitter* (shipyards) and *reviewer* (ABS/NSWCCD 6510) of NVR classed naval ships should assist in improving the efficiencies of scantling approval, which was precisely the subject the *Scantling Approval Process* project addressed.

Class requirements regarding direct analysis, specifically strength criteria, in many cases are not integrated into FEA applications. It becomes the responsibility of the engineering analyst to use internal organizational processes (e.g., spread sheets and macros) to first extract structural response results (i.e. deformations/stresses) and to second perform external strength calculations. Finally, the engineering analyst must post-process these results within the context of the global FEA model, which can also be difficult, time-consuming and error prone. Recent ship acquisitions exercising this process with the Naval Vessel Rules, e.g., US Navy's DDG-1000, could have benefitted from this projects proposed criteria integration. All future ships requiring NVR classification (e.g., USCG's Offshore Patrol Cutter) will also have to complete this process and will therefore benefit from this new technology.

Further, this project provided an opportunity for industry stakeholders to advance the discussions for more efficient ship structural design techniques and assessment procedures. The US Navy ship design and assessment community has long term requirements to improve tools and techniques in this area that are aimed to better define future ship design performance standards.

Project Methods and Procedures

Software development at DRS AMTC follows the agile development process. All modern software development practices, especially agile development methodologies such as the Unified Process (UP) and eXtreme Programming, advocate design and implementation protocols that emphasize the need for iterative cycles of planning, requirements analysis, design, coding, and acceptance testing. The agile process produces software quickly, and adapts easily to changes in requirements, allowing the customer to stay involved with the project as the software matures. This software development process was employed by DRS AMTC to successfully implement the NVR strength criteria and incorporate any additional user needs identified during the development process.

An industry expert from NSWCCD Code 6510 was responsible for defining requirements (e.g., stress recovery), performing NVR algorithm implementation checks, and reporting findings to correct any errors or inconsistencies. Industry experts from GDBWI and Ingalls were responsible for defining requirements (e.g., stress recovery), testing and verifying the criteria implementation, the software usability, and reporting findings to correct any errors or inconsistencies. Finally, industry experts from ABS NED were tasked with reviewing team member's input (e.g., stress recovery), testing/exercising the software to establish "design review" documentation needs and processing/post-processing needs and report findings to improve the classification process. Figure 1 summarizes the team members and their primary role in the project. The inputs of all team members were cycled within the team to develop a consensus for implementation.

Organization	Primary Role/Responsibility
DRS DS, AMTC	Prime Contractor/NVR Implementation
NSWCCD 6510	Requirements, Testing, & Documentation
ABS	Requirements & Testing
GD BIW	Testing & Feedback
Huntington Ingalls Industries	Testing & Feedback

Figure 1. Team Approach

NVR Background

Since 1998, ABS has worked with the US Navy to develop the Naval Vessel Rules, the first guidelines of which were available in mid-2004, ABS (2004). The Rules effectively follow the traditional Navy design approach using the quasi-static analysis of bending moments developed by the US Navy and the addition of a probabilistic approach to determine hull girder bending. The Rules require a finite element analysis and fatigue analysis for all new ships. Unique and special load cases may be considered based on full description and justification in common with all rules. Reference [c].

Photo Citation: http://www.popsci.com/scitech/gallery/2006-10/navys-invisible-warship

For this project, the latest release version, January 2010, of the NVRs were used. The NVRs are governed by a "**DISTRIBUTION STATEMENT D**" statement, which authorizes only Department of Defense (DoD) and U.S. DoD contractors the ability to gain access to the Rules. The NVR Parts cover general provisions, all aspects of hull, mechanical and electrical systems, and materials and welding. For this particular project, the focus was on ***Part 1 Hull and Structures*** [b]. In particular, the project was focused on the ***Acceptance Criteria*** found under ***Section 6 Analysis Methods*** (see Figure 2). This project does not focus on scantling checks (e.g., proportional requirements or minimum plate thickness) outside of ***Section 6 Analysis Methods/3 Finite Element Analysis/3.4 Acceptance Criteria***. Therefore, this project had a very specific focus, and attempted to address only one particular work activity within the Classification process of the NVRs. Future projects should be pursued to address remaining work activities within the Classification process of the NVRs.

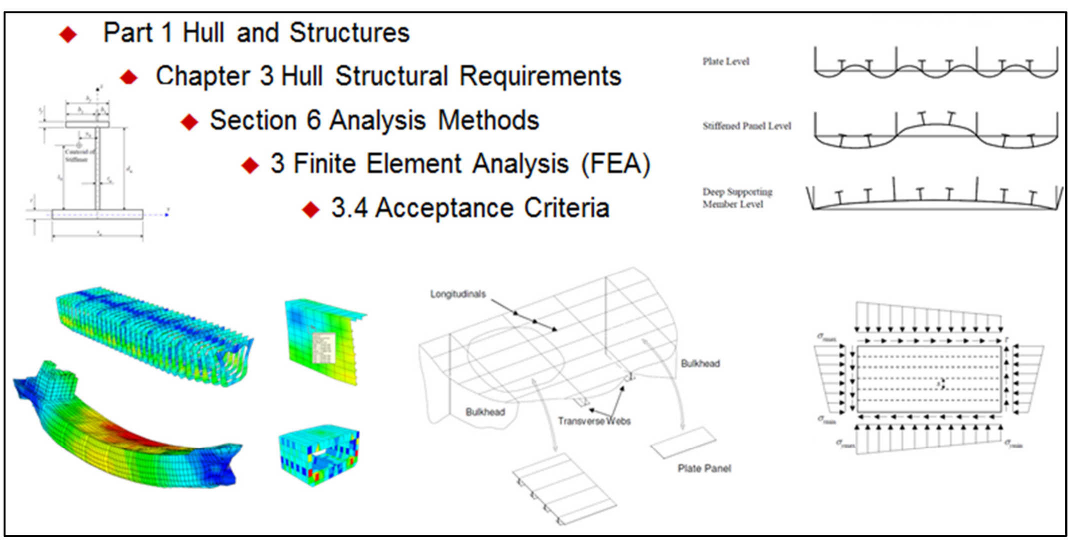


Figure 2. Project Focus

Structural Engineering Practices for NVR Classification

General Issue and Background

The functional and detail structural design of ship structures in accordance with the NVRs invokes a blend of prescriptive rules and first principal analyses. The codified combination of these two approaches can be difficult to implement in a single physics based analysis (e.g., direct structural finite element analysis and strength assessment). The NVR effectively conveys NAVSEA's prior design basis, the Design Data Sheets, and further imposes direct analysis. The design agents (shipyards) and review organization (ABS) have attempted to implement both analyses with computer based physics models. This trend to physics based models (or direct analysis) is driven by the need to quantify performance levels, the availability of 3-D models, an expectation of greater accuracy, and the skill set of the engineering population. Two developmental efforts are required to efficiently complete the transition to direct analysis: calibration of design load - limit state pairs, and process optimized software. NAVSEA generally holds responsibility for calibrating design loads and limit states to achieve desired levels of performance. Software development to improve the defined processes is the responsibility of industry.

Problems with Acceptance Criteria

The NVR only presents novel acceptance criteria for ultimate hull girder strength and fatigue analysis. For the other load cases, the limit states developed in the various Design Data Sheets are referenced in the NVR. These limit states and their stress interaction formulae, have been republished in the NVR. Due to their heritage in the DDS as hand calculation criteria, the limit states are awkward to invoke against the results from finite element analysis (FEA). The NVR stress values are in terms of members and panels; many of the local models evaluated during detail design are of a much finer resolution. Consequently, comparing FEA results to NVR Table 7 1-3-4/4.1 can be subject to interpretation. The table was originally developed for nominal member stress and the FEA models report local values. The mismatch between local and member stress results can lead to disputed Class review comments.

Problems with Processing and Post-processing Acceptance Criteria

Class requirements regarding direct analysis, specifically strength criteria, in many cases are not integrated into FEA applications. It becomes the responsibility of the engineering analyst to use internal organizational processes (e.g., spread sheets and macros) to first extract structural response results (i.e. deformations/stresses) and to second perform external strength calculations. Further, the analyst must post-process these results within the context of the global FEA model, which can also be difficult, time-consuming and error prone.

Solutions

Ship Structure Committee studies such as SSC-446, *Comparative Study of Naval and Commercial Ship Structure Design Standards* [d], begin to address the need for continuously evolving design standards that evolve with ship structural research and analysis methods. Specifically, SSC-446 stated the following project objectives:

> *The expectation is that such an assessment will be of benefit in identifying 'best practices' that incorporate latest models of structural behavior and that are adequately validated by theory and experimentation. These best practices could then be applied to*

> *new designs and to in-service assessments of existing ships; either on a ship-specific basis or through the development of new, unified structural design criteria. The project is intended to address these broader objectives.* [d]

Further activity in this area is needed so industry can adequately address the need for more efficient ship structural design techniques and assessment procedures. The US Navy ship design and assessment community has long term requirements to improve tools and techniques in this area to better define future ship design performance standards.

The focus of this project was to address the specific need of US Navy and industry by implementing current design standards (i.e., for naval vessels) inside of the design and assessment tool MAESTRO. The notion of the project was to extend MAESTRO's existing and comprehensive structural *strength assessment* analysis paradigm (described in the following sections) to include NVR Criteria.

Technical Approach

In the following sections, a description is provided for the reader to understand the basic capability background of MAESTRO as well as its product model framework architecture. Further, this background information is intended to provide the reader with an understanding of how the project objective (i.e., NVR strength criteria implementation) fit into an existing, and well established, strength assessment paradigm within MAESTRO. Two key aspects to this MAESTRO strength assessment paradigm, namely Evaluation Patch creation and Stress Recovery, are expanded upon for a more complete understanding of the NVR Strength Criteria implementation.

Distribution of the NVR Implementation

As stated previously, the NVRs are a "Distribution Statement D" document; therefore, the NVR documents and the software implementation of the NVRs are governed by the following stipulations:

- The NVR will not be shared with any subcontractors working on this NSRP panel project task who are not verified to be certified U.S. contractors.
- The NVR will not be shared with any foreign elements of DRS unless the necessary export license is approved via the U.S. State Department.
- Only "U.S. Person" (as defined in the ITAR regulations) will be allowed access to the NVR or NVR criteria as part of the execution of this task.
- The MAESTRO article of software (i.e., Dynamic Link Library, *NVR DLL* file) will not be kept on, or accessed through a web site, or transmitted via unencrypted electronic means.
- The MAESTRO article of software (i.e. Dynamic Link Library, *NVR DLL* file) will be considered a "Defense Article" in accordance with Sec 120.7 of the ITAR regulations, and access to it will be controlled accordingly.
- DRS AMTC will not make the MAESTRO article of software (i.e. Dynamic Link Library, NVR DLL file) available for commercial sale without obtaining NAVSEA 05D approvals of the individual entities to which sale is proposed. It is understood that such sales will be treated no differently than a determination to release the NVR Rules themselves. If sale to any non-U.S. entities is proposed, an export license must additionally be obtained.

The MAESTRO software does not include any of the NVR materials and will only facilitate the usage of the *NVR DLL* file. These NVR implementation stipulations provided by NAVSEA, were agreed upon, with specific language to accurately characterize the distribution of the MAESTRO article of software (i.e. Dynamic Link Library, *NVR DLL* file).

MAESTRO Software System & *Open* Product Model Architecture

MAESTRO (**M**ethod for **A**nalysis, **E**valuation, and **STR**uctural **O**ptimization) is a design, analysis, and evaluation tool specifically tailored for floating structures and has been fielded as a commercial product for over 20 years and has a world-wide user base. MAESTRO's history is rooted in rationally-based structural design, which is defined as a design directly and entirely based on structural theory and computer-based methods of structural analysis (e.g., finite element analysis). MAESTRO core components are: rapid coarse-mesh finite element modeling, ship-based loading, finite element analysis, limit state analysis (e.g., at the hull girder level, stiffened panel level, and local member level), and design evaluation (Figure 3).

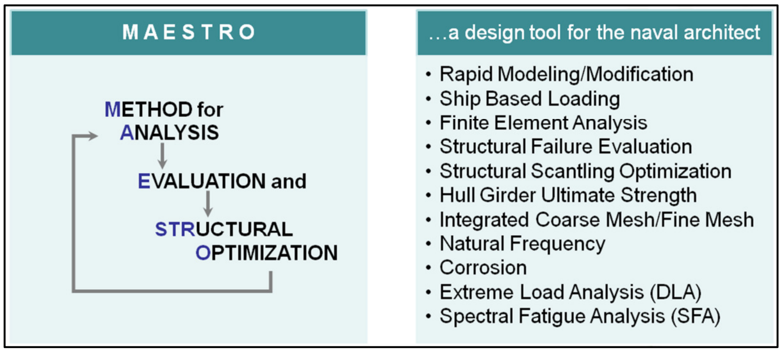


Figure 3. MAESTRO Core Capability

The core capability of MAESTRO is part of a larger *open* product model framework as shown in Figure 4. This *open* framework allows the interfacing (i.e., data input and data output) of MAESTRO with a variety of ship structural design and life-cycle assessment technologies for several technical domains including, but not limited to: Structural Life-cycle Assessment, Underwater Shock Assessment, Fatigue Analysis and Assessment, Hydrodynamic Loads Analysis, Ultimate Hull Girder Strength Assessment, and Ship Salvage Assessment. The implementation of the NVR Strength Criteria (i.e., the objective of this panel project) is one example of a particular US Navy toolset or methodology that can be interfaced with this *open* product model framework.

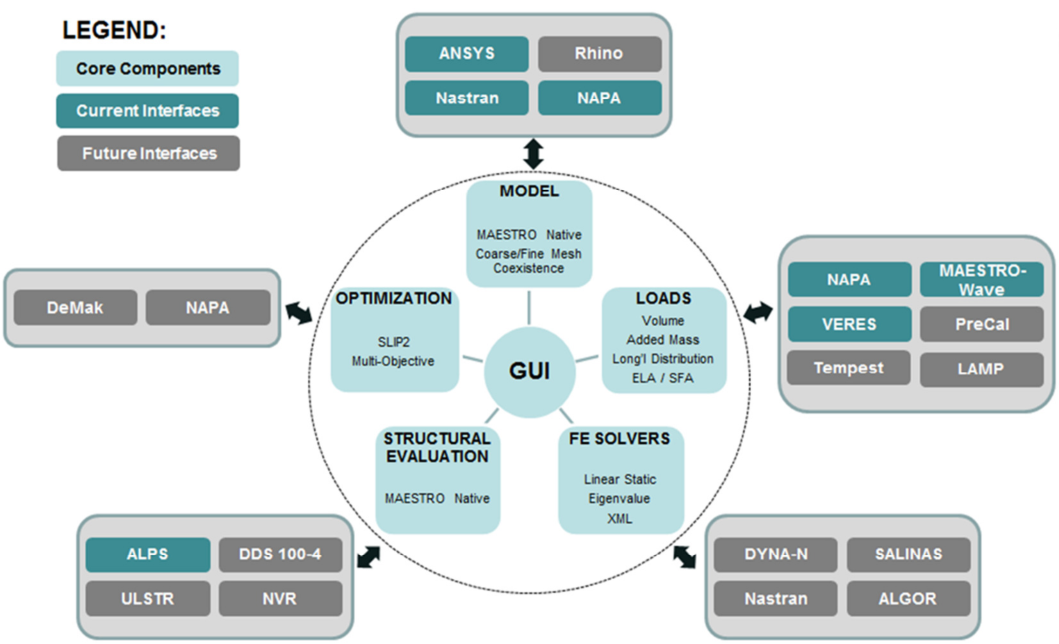


Figure 4. MAESTRO *Open* Product Model Framework

The Finite Element Analysis (FEA) Process

The overall FEA process in MAESTRO can be decomposed into key activities and individually examined. These activities are introduced in Figure 5 and discussed in detail in the following sections. The intent for discussing these key activities in the context of the MAESTRO application is to provide the reader with enough background to clearly understand how the implementation of the NVR Strength Criteria was completed.

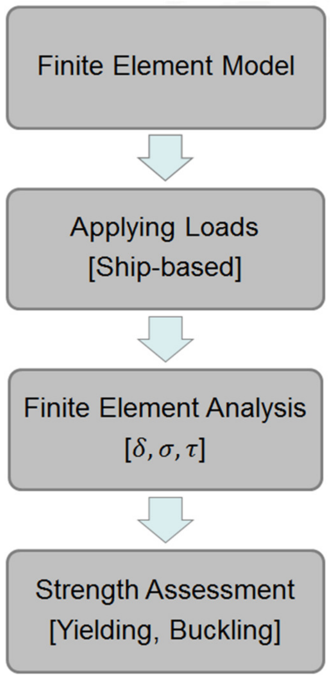


Figure 5. Key FEA Activities

Finite Element Model (FEM)

The first step in the FEA process is creating the model, which consist of nodes and finite elements. In the design of large structures such as ships, it is usually advisable to divide the task into a few distinct subtasks in order to maintain a good overview and control of the model generation. Most large structures can be reduced to several levels of component structures for which the design and analysis is relatively independent. Such a structure can best be modeled by subdividing it into a hierarchy of parts, down to the *module* level, and then constructing each module using a three-dimensional mesh of nodes and appropriate groupings of finite elements. As shown in Figure 6, the MAESTRO structural modeling is organized in two levels: modules and substructures.

Of particular interest in this model hierarchy, is the composition of the *module*. The module typically consists of a distinct segment of the ship (e.g., cargo holds in commercial ships or watertight subdivisions in naval ships). The definition of the module is helpful for this because they are ideal high-level building blocks and, in the parallel midbody of a tanker, bulker, or submarine, only one module (i.e., one cargo hold or compartment) needs to be built and then copied. Finally, within this module, the definition of the *strake* (see Figure 7) is used to capture and retain critical information (e.g., breadth between stiffeners, span of longitudinals, frames, or girders) for the process of strength assessment.

This concept of a strake, and the recovery/retaining of the strength assessment parameters are further extended to the concept of a MAESTRO Evaluation Patch.

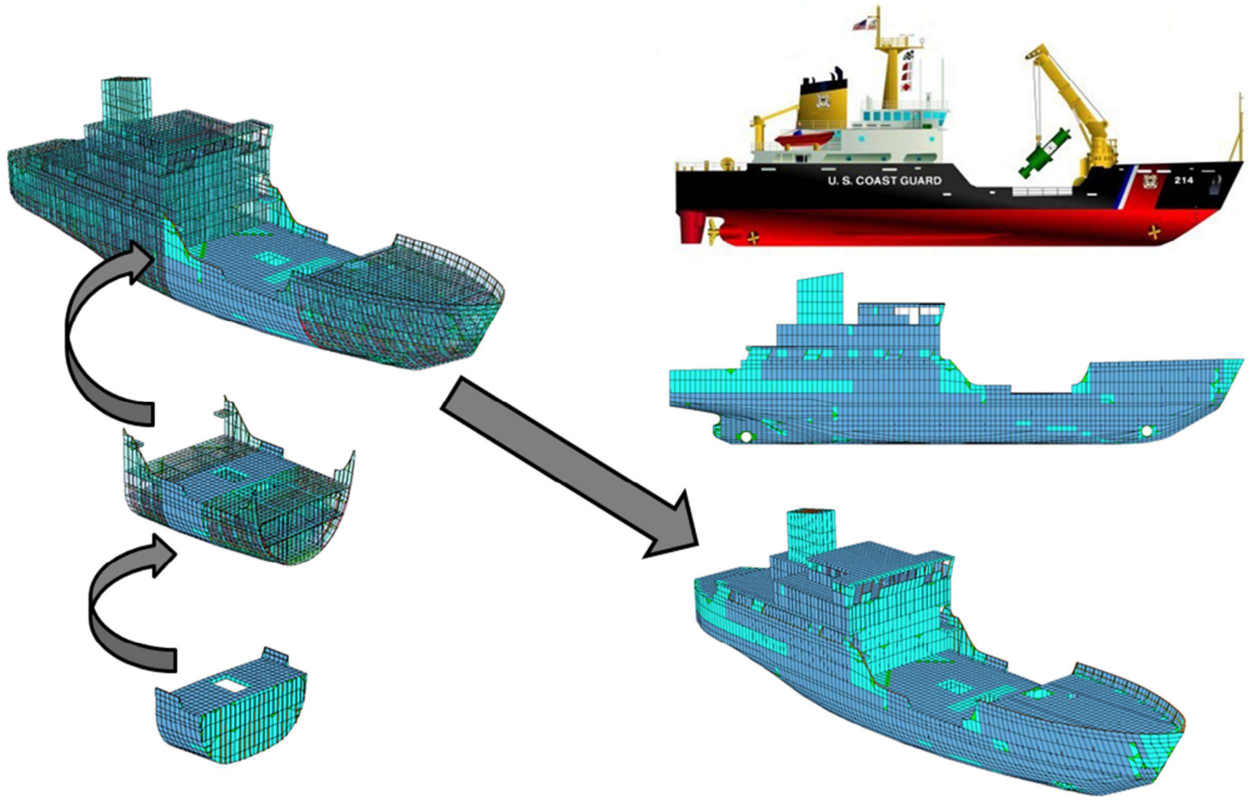


Figure 6. MAESTRO Model Hierarchy

The Evaluation Patch (E-patch) is a collection of elements with its boundary supported by bulkheads or beams. An E-patch can also be a single element. In traditional MAESTRO, an E-patch was a lengthwise *strake* panel or a few strake panels, if the section per bay was defined as greater than one. The evolution of the E-patch in MAESTRO eliminated this strict definition, freeing the analyst to create more refined FEMs, as sometimes is required. These E-patches are defined automatically (see the *quilted* colors in Figure 8; each color represents an automatically generated E-patch) by MAESTRO or can be defined manually by the user. Each E-patch can be subsequently reviewed for the recovered strength assessment parameters (see Figure 9). Later sections will discuss how stresses are utilized in this E-patch paradigm.

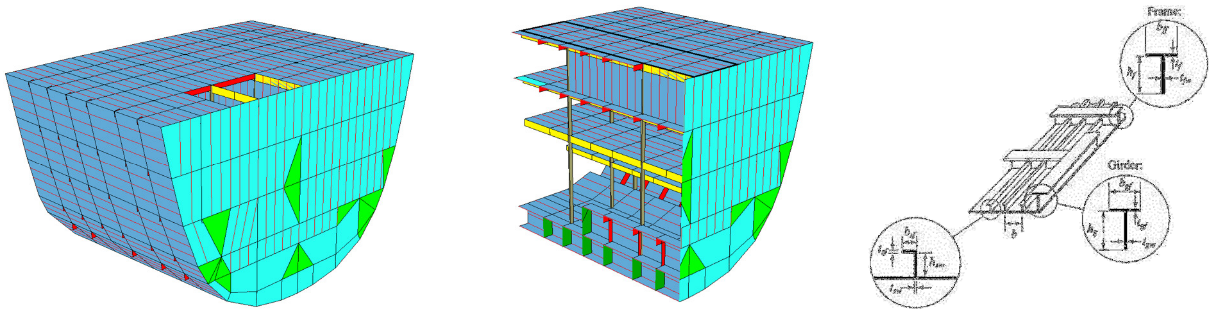


Figure 7. MAESTRO Module, Strake, and Strength Assessment Parameters

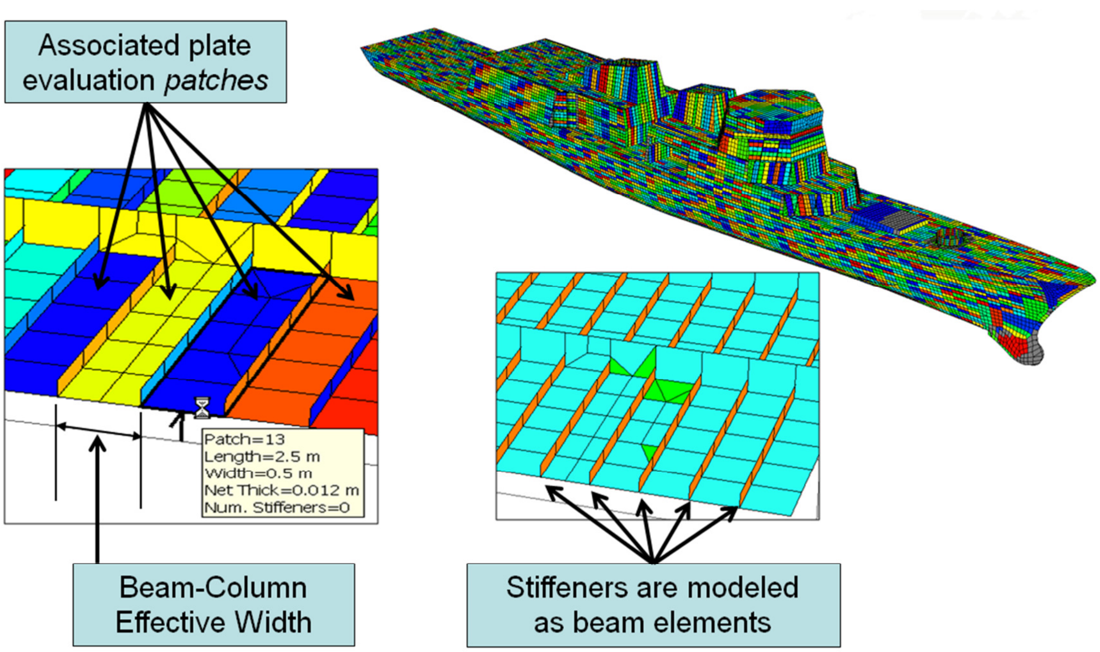


Figure 8. Evaluation Patch for Entire Ship

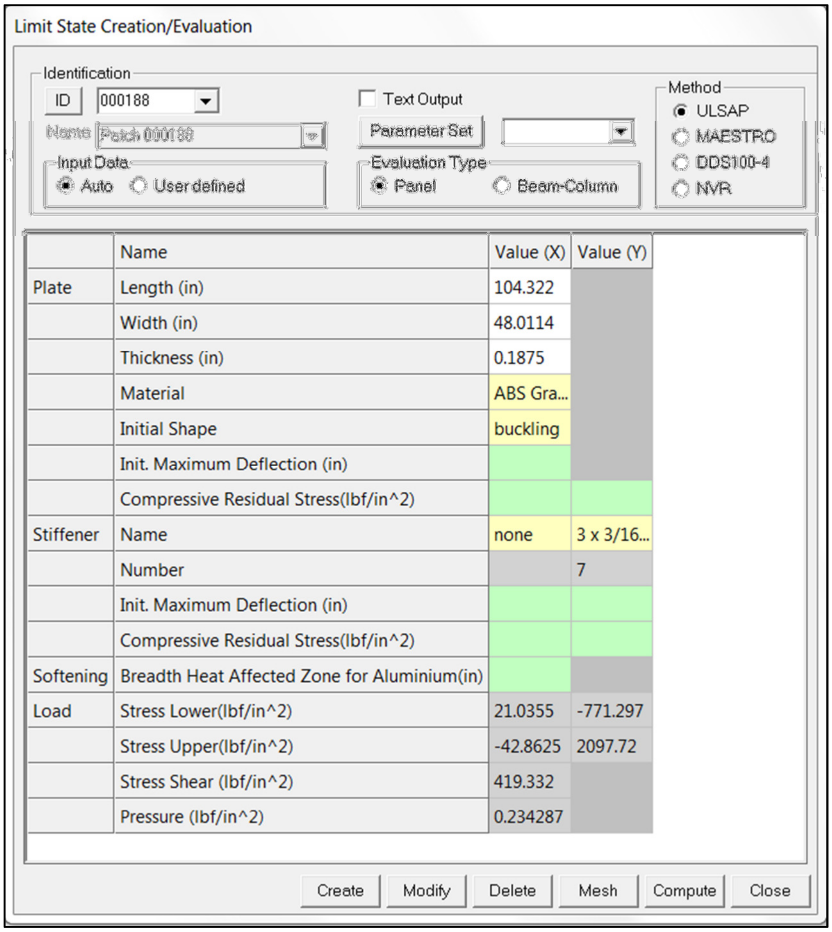
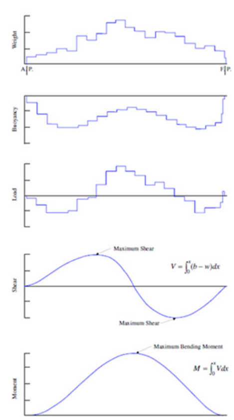


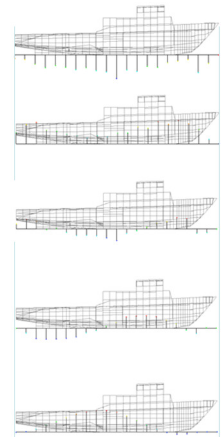
Figure 9. Individual Evaluation Patch Details (via MAESTRO dialog)

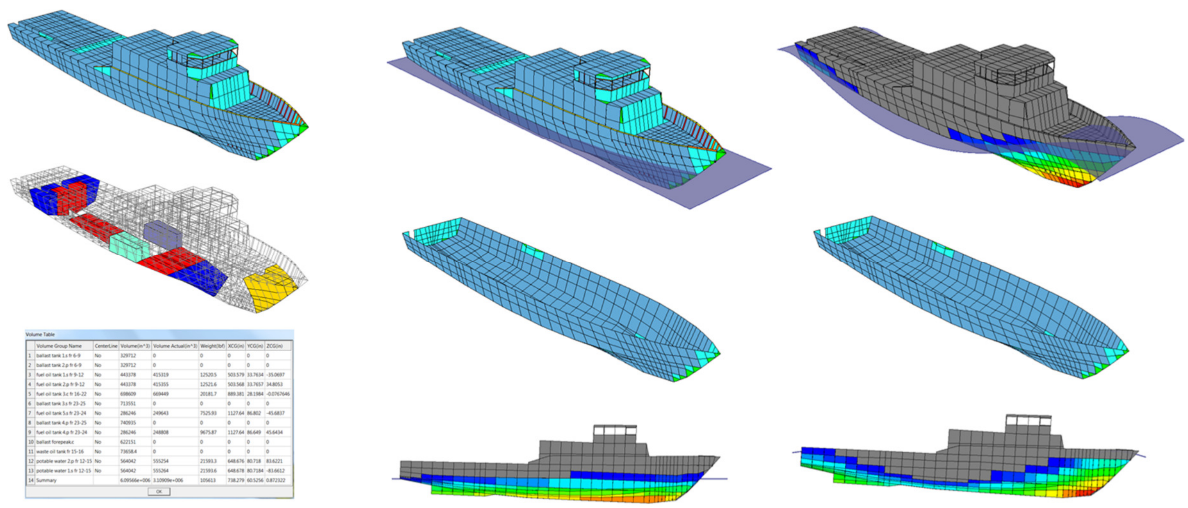
Applying Loads (Ship-based)

The next step in the FEA process (refer to Figure 5) is the application of loads. Loads are a prerequisite to structural response analysis and design. The correct application of loads is a critical factor to sound structural design assessment. In some ways, the correct application of loads is most important. In ship design, there are several common load “patterns” that need to be considered (e.g., Basic Loads-Live Loads/Dead Loads/Liquid Tank Loads, Sea Environment-Hull Girder Loads/Sea Loads/Ship Motion Loads, Operational Loads-Slamming/Flooding/Docking, and Combat Environment-Shock/Air blast/Weapons Effects). Although MAESTRO has the capability to accurately model these different load patterns, it should be noted that the analyst must use sound engineering judgment to determine what loads (e.g., “rule based” versus “first-principle based”) can be combined in a particular *load case*. Rule based loads must be distinguished as such and not combined with first-principle loads. Loads that are not generated *within* (e.g., computed hydrodynamic loads) MAESTRO can be imported and used for analyzing extreme global load structural responses.

Photo Citation: *www.globalsecurity.org*

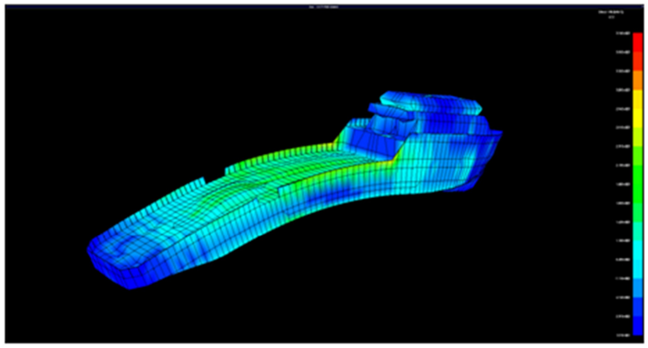






Finite Element Analysis (δ, σ, τ)

The next step in the FEA process (refer to Figure 5) is to determine the overall structural response, which entails calculating (i.e., using finite element methodologies) the effects of the Basic, Sea Environment, Operational, and Combat Environment loads (but not all of these combined) on the overall structure. This step in the FEA process computes deformations and stresses (see Figure 10).



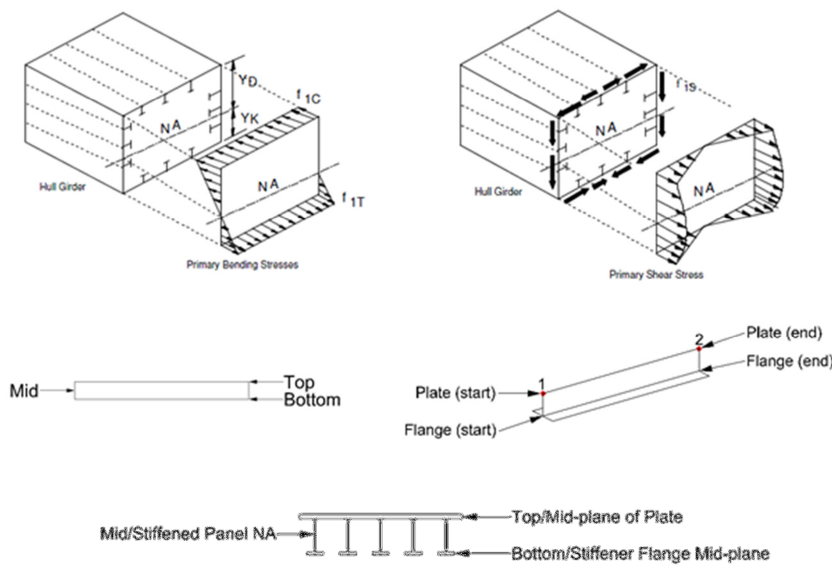


Figure 10. Sample Deformation and Stress Calculations

The types of stresses calculated by MAESTRO are of significant importance when conducting strength assessment. Depending on the type of strength assessment being addressed (e.g., f_t = tensile axial stress for NVR Strength Criteria 4.1a Tension), MAESTRO is required to recover and use the appropriate calculated stress. The appropriate recovered stress calculated by MAESTRO is used for application to the NVR Table 7 1-3-4/4.1 (Reference [a]). Determining what calculated stresses are appropriate, was a significant portion of the project activity. Inputs from individual team members were captured and the resulting consensus was included in the final implementation. This is described in the second project deliverable (i.e., the *Implementation Manual*). Determining the appropriate stress to be used required an in-depth understanding of MAESTRO's calculated stresses, the NVR strength criteria, and the intent of the particular NVR strength criterion.

Strength Assessment (Yielding, Buckling)

The final step in the FEA process (refer to Figure 5) is to perform comprehensive strength assessment, which includes evaluating yielding (σ_Y,τ_Y) and buckling ($\sigma_{cr}, \tau_{cr} \sigma_u \tau_u$) failure modes. For a given ship structural system and pertinent loading conditions, the calculated stresses must not be greater than the limits prescribed and/or computed for these failure modes.

Adequacy Parameters as a Measure of Safety

For the structural system to be deemed safe under a given load condition, the load effect *Q* must remain below the limiting value Q_L. The load effect (*Q*) is the calculated stress(es) found during the FEA. Depending on the specific criterion, Q can represent f_t or $f_t + f_b$. The limiting value (Q_L) is specified and/or calculated by MAESTRO in accordance with *Table 7 (1-3-4/4.1) Strength Criteria* of the NVRs [b]. Expressed mathematically, the requirement specified in *1-3-4/4.1*, is $Q < Q_L$ and a strength ratio can be defined as follows:

$$R = \frac{Q}{Q_L}$$

By expressing the requirement in a strength ratio, the safety requirement then becomes $R < 1$. Each of these requirements specified in *1-3-4/4.1* [b] constitutes a constraint on the ship structural system. For easier post-processing and evaluation, MAESTRO expresses this constraint in the form of a parameter called the Adequacy parameter, denoted by $g(R)$ and is defined as:

$$g(R) = \frac{1 - R}{1 + R}$$

The advantage of using an adequacy parameter of the strength ratio is that g always lies within the normalized limits of -1 and +1, whereas R ranges from 0 to ∞. Specifically, $g(R) \rightarrow 1$ as $R \rightarrow 0$ either as a result of a very small load or a very large limiting value (Q_L) and at the other extreme, $g(R) \rightarrow -1$ as $R \rightarrow \infty$ either as a result of a very large load or a very small limiting value (Q_L). Each of these adequacy parameters, as specified in *1-3-4/4.1* [b], is available by way of Results menu after NVR evaluation is executed when the solver is launched.

Strength Ratios as a Measure of Safety

The structural system measure of safety can also be expressed in terms of a Strength Ratio, which is simply the load effect (Q) divided by the limiting value (Q_L). Historically, the US Navy structural design community has used the strength ratio as a measure of structural adequacy. Therefore, MAESTRO's NVR strength assessment included exposing the computed strength ratios to the user.

Evaluation Patch (E-patch)

To properly perform this strength assessment, the true stiffened panel, stanchion and/or beam column are located in the FEM. MAESTRO does this by automatically searching the entire FEM and collects (if necessary) multiple finite elements (plates or beams) so the true boundary conditions and true structural spans are represented and used (if required) in automatically calculating the limiting value for all ship structural members in the FEM. This strength assessment entity (i.e., the Evaluation Patch or E-patch) was discussed and described in the *Finite Element Model* section, see Figure 8. As stated previously, the individual E-patch parameters can be reviewed and/or modified individually using a MAESTRO accessed dialog, see Figure 9.

Technical Approach Summary

The above describes, in general terms, the FEA process and strength assessment approach/methodology in MAESTRO. A more detailed description of the NVR Strength Assessment implementation and sample calculations can be found in the Implementation Manual as well as the Application and User Guide. The strength assessment implementation undertaken for this NSRP panel project focused on *Table 7 (1-3-4/4.1)* of the NVRs. There are a total of 16 equations, hence design constraints (i.e., limiting values, Q_L), that were codified for MAESTRO implementation. These 16 parameters cover a variety of load cases and associated structural element entities as described in the Implementation Manual.

Project Deliverables

A number of project deliverables were identified for the panel project. The following sections summarize the deliverables.

Project White Paper

The Project White Paper provides a description of all activities and team member contributions for the project as well as the background, methodologies, and technical approaches carried out to accomplish the stated goals of the project. Earlier DRAFTS of the Project White Paper included Appendices that captured team member inputs in their entirety; however, it was decided amongst the participating team members that including these full Appendices with the final Project White Paper would have been redundant. In essence, the Project White Paper is a high level description of the project as a whole. Technical details are captured in the *Implementation Manual*, the *Example Manual*, and the *MAESTRO Help Manual*.

Implementation Manual

The Implementation Manual provides a technical description of the available stresses and criterion computed, recovered, and exposed by MAESTRO's NVR strength criteria software implementation. As a prerequisite to the Implementation Manual, the user should understand the fundamental concepts to MAESTRO's finite element modeling processes and terms, model integrity checks, loading processes, and stress results. This document is governed by a DISTRIBUTION STATEMENT D classification.

Application User Guide and Examples

The Application User Guide and Examples provides a technical description of how to access the MAESTRO NVR Implementation software, process, and post-process the NVR strength criteria using finite element analysis methodologies. This document is governed by a DISTRIBUTION STATEMENT D classification.

Future NSRP Project Topics

This NSRP Panel Project addressed a focused need within the US Naval structural design community. Potential Topics to pursue include:

- Extend and/or evolve the strength criteria (Table 7 1-3-4/4.1) to be more appropriate for FEA methods. This should include a review of current literature/approaches.
- What can be learned from past JTDs.
- MAESTRO implementation of NVR 1-3-3 Load Criteria to facilitate the application of loads.
- Development of a NVR Software Program that performs calculations in accordance with Part 1 Hull and Structures.

References

[a] National Shipbuilding Research Program (http://www.nsrp.org/)
[b] ABS Rules for Building and Classing Naval Vessels, January 2010, Part 1 Hull and Structures
[c] ISSC committee V.5: Naval Ship Design, 16th International Ship and Offshore Structures Congress, 20-25 August 2006
[d] Ship Structure Committee, Report No. SSC-446, *Comparative Study of Naval and Commercial Ship Structure Design Standards*, March 21, 2007