

Naval Surface Warfare Center Carderock Division

West Bethesda, MD 20817-5700

NSWCCD-65-TR-2023/05 April 2024

Platform Integrity Department

Technical Report

Hull 3000 Design and Modeling

by

Christian A. Castillo, Tyler W. Rea, Rose E. Shayer, Gavin R. Fidanza,
Richard C. Henes, Kariann B. Vander Pol, Mark A. Rodriguez, and
Dr. Paul A. Lara



Distribution Statement A. Approved for public release: distribution is unlimited.

Naval Surface Warfare Center Carderock Division

West Bethesda, MD 20817-5700

NSWCCD-65-TR-2023/05 April 2024

Platform Integrity Department

Technical Report

Hull 3000 Design and Modeling

by

Christian A. Castillo, Tyler W. Rea, Rose E. Shayer, Gavin R. Fidanza,
Richard C. Henes, Kariann B. Vander Pol, Mark A. Rodriguez, and
Dr. Paul A. Lara

Distribution Statement A. Approved for public release: distribution is unlimited.

REPORT DOCUMENTATION PAGE				<i>Form Approved</i> <i>OMB No. 0704-0188</i>	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) 22-Apr-2024		2. REPORT TYPE Final		3. DATES COVERED (From - To) 11 March 2022 - 19 July 2023	
4. TITLE AND SUBTITLE Hull 3000 Design and Modeling				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER 633461DS700	
6. AUTHOR(S) Christian A. Castillo, Tyler W. Rea, Rose E. Shayer, Gavin R. Fidanza, Richard C. Henes, Kariann B. Vander Pol, Mark A. Rodriguez, and Dr. Paul A. Lara				5d. PROJECT NUMBER W81EWF23429269	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES) Naval Surface Warfare Center Carderock Division 9500 Macarthur Boulevard West Bethesda, MD 20817-5700				8. PERFORMING ORGANIZATION REPORT NUMBER NSWCCD-65-TR-2023/05	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) High Performance Computing Computational Research and Modernization Program Office Engineering Acquisition Tools 7701 Telegraph Rd and Environments Alexandria, VA 22315-3864				10. SPONSOR/MONITOR'S ACRONYM(S) HPCMP CREATE	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Distribution Statement A. Approved for public release: distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT In fiscal years 2022 and 2023, Naval Surface Warfare Center, Carderock Division (NSWCCD) Ship Structural Modeling and Simulation Branch (Code 651) designed structural scantlings and developed a geometric and finite element model for use in public-releasable research and development projects. NSWCCD used only the American Bureau of Shipping Marine Vessel Rules 2022 criteria to develop structural scantlings. NSWCCD created a high-fidelity geometric model, utilizing parametric modeling methods to make the model as versatile as possible. The primary purpose of this model is to capture global hull-girder ship response for dynamic hull whipping analysis.					
15. SUBJECT TERMS ABS naval ship design, structural scantlings, high-fidelity full-ship modeling, parametric modeling, finite element modeling, hull girder ship response, NESM, UNDEX					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 54	19a. NAME OF RESPONSIBLE PERSON Christian Castillo
a. REPORT UNCLASSIFIED	b. ABSTRACT UNCLASSIFIED	c. THIS PAGE UNCLASSIFIED			19b. TELEPHONE NUMBER (include area code) (301) 227-5074

This page intentionally left blank.

Contents

Contents	v
Figures.....	vi
Tables.....	vi
Preface.....	viii
1. Executive Summary	1
2. Introduction.....	2
2.1 Purpose.....	2
2.2 Background.....	2
3. Methods, Assumptions, and Procedures	6
3.1 ABS MVR Design	6
3.1.1 Bow Scantlings	9
3.1.2 Midship Scantlings.....	10
3.1.3 Stern Scantlings	11
3.1.4 Stanchions	13
3.2 Modeling Process.....	13
3.2.1 Parametric Modeling Explanation	13
3.2.2 Mesh Generation.....	17
3.2.3 Mesh Description	19
3.2.4 Mesh Quality.....	22
4. Results and Discussion	24
5. Conclusions.....	27
5.1 Deliverables	27
6. References.....	28
Appendix Design Calculation Worksheets	29
A.1 Plate-Stiffener Panel Design Checks	29
A.2 Stanchions	32
A.3 Bow Section Buckling Checks.....	33
A.4 Midship Section Buckling Checks.....	36
A.5 Stern Section Buckling Checks.....	39
A.6 References.....	42

Figures

	<i>Page</i>
Figure 1. Hull 3000 Hull Form.	3
Figure 2. Centerline Profile of Hull 3000.	3
Figure 3. Hull 3000 Full-Load Weight Curve.	4
Figure 4. ABS MVR Wave (1) Shear Force and (2) Bending Moment Diagrams.....	7
Figure 5. Bow Longitudinal Scantlings	9
Figure 6. Midship Longitudinal Scantlings	11
Figure 7. Stern Longitudinal Scantlings	12
Figure 8. Hull 3000 Module Breakdown: (1) Module 1, (2) Module 2, (3) Module 3, and (4) Module 4	14
Figure 9. Typical Frame Sketch.....	15
Figure 10. Hull 3000 (1) Seed Part and (2) Module 1 Master Part.....	16
Figure 11. Parametric Modeling in SolidWorks: (1) Equation Editor and (2) Stiffener Block.....	17
Figure 12. Parametric Modeling Name Convention: (1) Part-Naming Generator and (2) Acronym Meaning	17
Figure 13. Hull 3000 FEM.....	18
Figure 14. Hull 3000 FEM CL Profile.....	19
Figure 15. Midship Meshing Scheme	20
Figure 16. Element Growth.....	21
Figure 17. Rigid Element Transition	22
Figure 18. Hull 3000 Element Quality Contours: (1) Jacobian and (2) Aspect Ratio	23
Figure 19. FEM Mass Distribution	25
Figure 20. 1-Node Vertical Bending Mode	26

Tables

	<i>Page</i>
Table 1. Hull 3000 Characteristics.....	4
Table 2. Longitudinal Loads and Strength Checks.....	8
Table 3. Bow Transverse Scantlings.....	10
Table 4. Midship Transverse Scantlings.....	11
Table 5. Stern Transverse Scantlings.....	12
Table 6. Hull 3000 Stanchions.....	13
Table 7. Element Growth Summary	21
Table 8. Element Summary.....	24
Table 9. Property and Material Summary.....	24
Table 10. Hull 3000 Displacement Comparison.....	24

Table 11. Mass Distribution Bins	25
Table A1. Bow Section Plate-Stiffener Panel Design Checks.....	29
Table A2. Midship Section Plate-Stiffener Panel Design Checks	30
Table A3. Stern Section Plate-Stiffener Panel Design Checks.....	31
Table A4. Stanchion Buckling Checks	32
Table A5. Bow Section – Main Deck Buckling Checks.....	33
Table A6. Bow Section – 2nd Deck Buckling Checks	34
Table A7. Bow Section – Platform and Keel Buckling Checks	35
Table A8. Midship Section – Main Deck Buckling Checks	36
Table A9. Midship Section – 2nd Deck Buckling Checks	37
Table A10. Midship Section – Platform and Keel Buckling Checks	38
Table A11. Stern Section – Main Deck Buckling Checks.....	39
Table A12. Stern Section – 2nd Deck Buckling Checks	40
Table A13. Stern Section – Platform and Keel Buckling Checks	41

Preface

The Structures and Composites Division (Code 65) of the Platform Integrity Department at the Naval Surface Warfare Center, Carderock Division (NSWCCD) performed the work described in this report between March 2022 and July 2023. The High Performance Computing Modernization Program Office (HPCMP) to the Computational Research and Engineering Acquisitions Tools and Environments Program (CREATE) funded the work as part of the CREATE SHIPS task under program element number 633461DS700.

1. Executive Summary

In fiscal years (FYs) 2022 and 2023, Naval Surface Warfare Center, Carderock Division (NSWCCD) Ship Structural Modeling and Simulation Branch (Code 651) designed structural scantlings and developed a geometric and finite element model (FEM) for use in public-releasable research and development projects. NSWCCD used only the American Bureau of Shipping (ABS) Marine Vessel Rules (MVR) 2022 criteria to develop structural scantlings to facilitate their public release. NSWCCD created a high-fidelity geometric model, utilizing parametric modeling methods to make the model as versatile as possible. The primary purpose of this model is to capture global hull-girder ship response for dynamic hull whipping analysis. The FEM includes multiple element types, such as beams, shells, and rigids, and a notional, point mass distribution for the entire length of the ship. The FEM was under 500,000 elements making the model easier to transfer between users or onto remote systems and quicker for analysis. It also passed Jacobian and aspect ratio element quality criteria.

2. Introduction

The following sections provide the purpose, applicability, and background of Hull 3000.

2.1 Purpose

The purpose of Hull 3000 is to be a general, publicly releasable FEM of a naval-like surface ship for use in analyses that do not require ship response as a criterion of their analysis. Although designed to ABS MVR criteria (ABS, 2022b) to ensure reasonable surface ship behavior, this does not mean Hull 3000 should be used for any sort of strength or performance benchmarking, structurally speaking. Hull 3000 was built to reasonably simulate global, hull girder ship response for dynamic hull whipping.

Hull 3000 can be used to help in the development of engineer workflows, testing of finite element analysis (FEA) codes or hydrocodes, used as a common hull in working groups that can be shared easily across government and non-government entities, etc. The desired outcome of Hull 3000 is to promote collaboration within the Navy/DOD, academia, and international partner communities.

2.2 Background

In FY10, NSWCCD Code 65 developed a preliminary model of Hull 3000 (Amanuel et al., 2010). The hull form for the model was developed using early designs for the concept Joint High Speed Sealift (JHSS) ship using the baseline bulb from Cusanelli (2007).

NSWCCD developed concept-level scantlings for the hull using various U.S. Navy design tools, such as the Large Amplitude Motions Program (LAMP), the Method for Analysis Evaluation and Structural Optimization (MAESTRO), and the Ultimate Strength (ULTSTR) program, to supplement typical ABS Naval Vessels Rules (NVR). Figure 1, Figure 2, and Table 1 summarize the final ship arrangement, characteristics, and load curves presented by Amanuel et al. (2010).

The report by Amanuel et al. (2010) includes the full-load weight curve, as well as the full-load hog, sag, and stillwater shear force and bending moment curves, as shown in Figure 3.

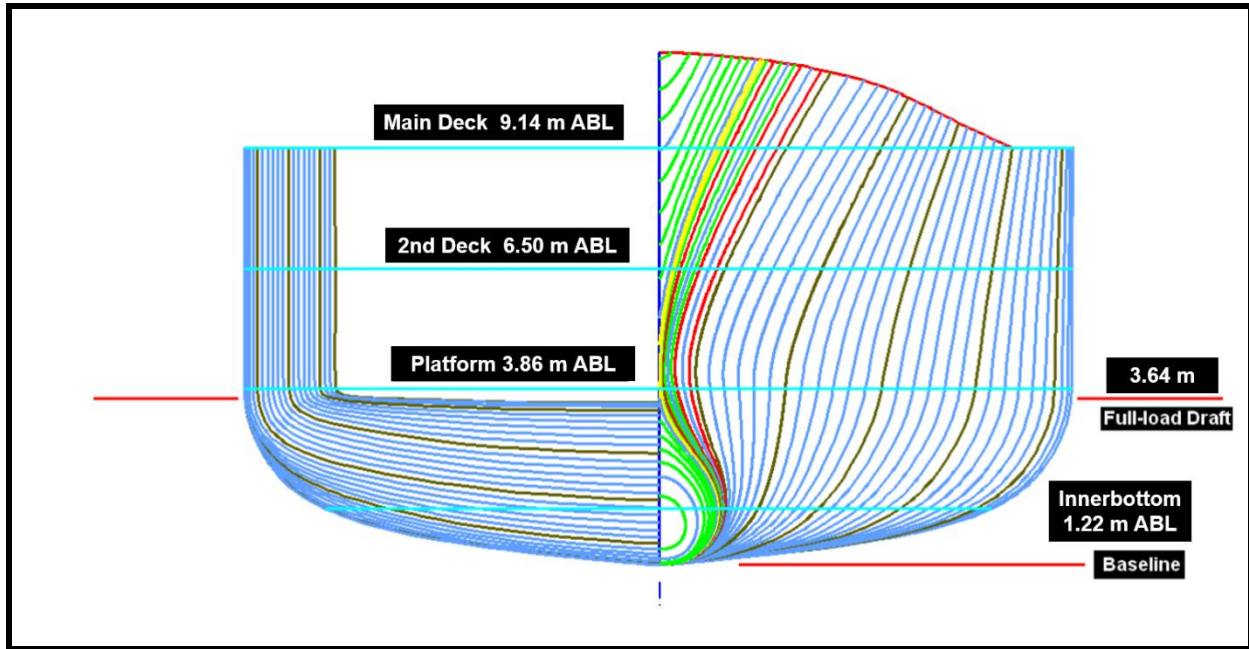


Figure 1. Hull 3000 Hull Form. Reprinted from *Damaged Ship Recoverability Study*, NSWCCD-65-TR-2010/18, p. 6, by Y. Amanuel et al., 2010, Naval Surface Warfare Center, Carderock Division.

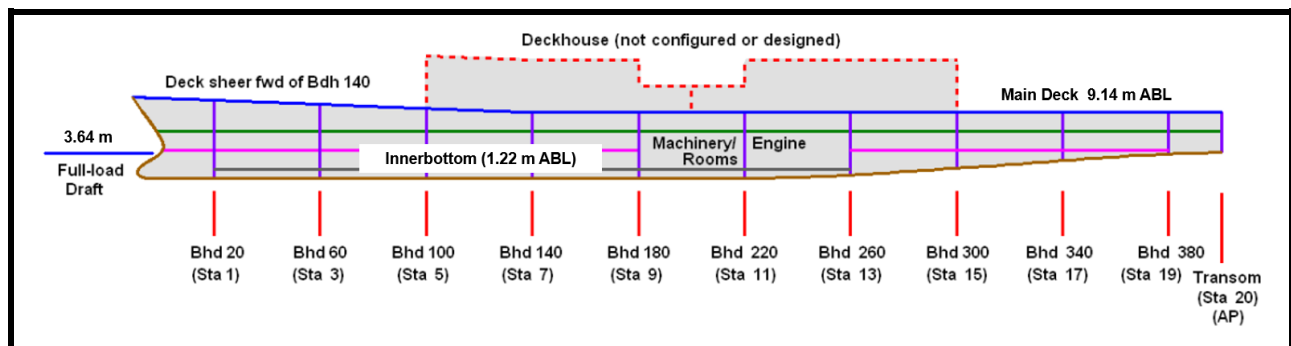


Figure 2. Centerline Profile of Hull 3000. Reprinted from *Damaged Ship Recoverability Study*, NSWCCD-65-TR-2010/18, p. 6, by Y. Amanuel et al., 2010, Naval Surface Warfare Center, Carderock Division.

Table 1. Hull 3000 Characteristics

Ship Characteristics	ft	m
Length Between Perp	400.00	121.92
Overall Length	410.67	125.17
Full Load Draft	11.94	3.64
Beam (at midships)	50.00	15.24
Depth (at midships)	30.00	9.14
Deck Spacing	8.67	2.64
Main Deck Height ABL	30.00	9.14
2nd Deck Height ABL	21.33	6.50
Platform Height ABL	12.67	3.86
Innerbottom Height ABL	4.00	1.22
Frame Spacing	6.67	2.03
Station Spacing	20.00	6.10

Note: Table adapted from *Damaged Ship Recoverability Study*, NSWCCD-65-TR-2010/18, by Y. Amanuel et al., 2010, Naval Surface Warfare Center, Carderock Division.

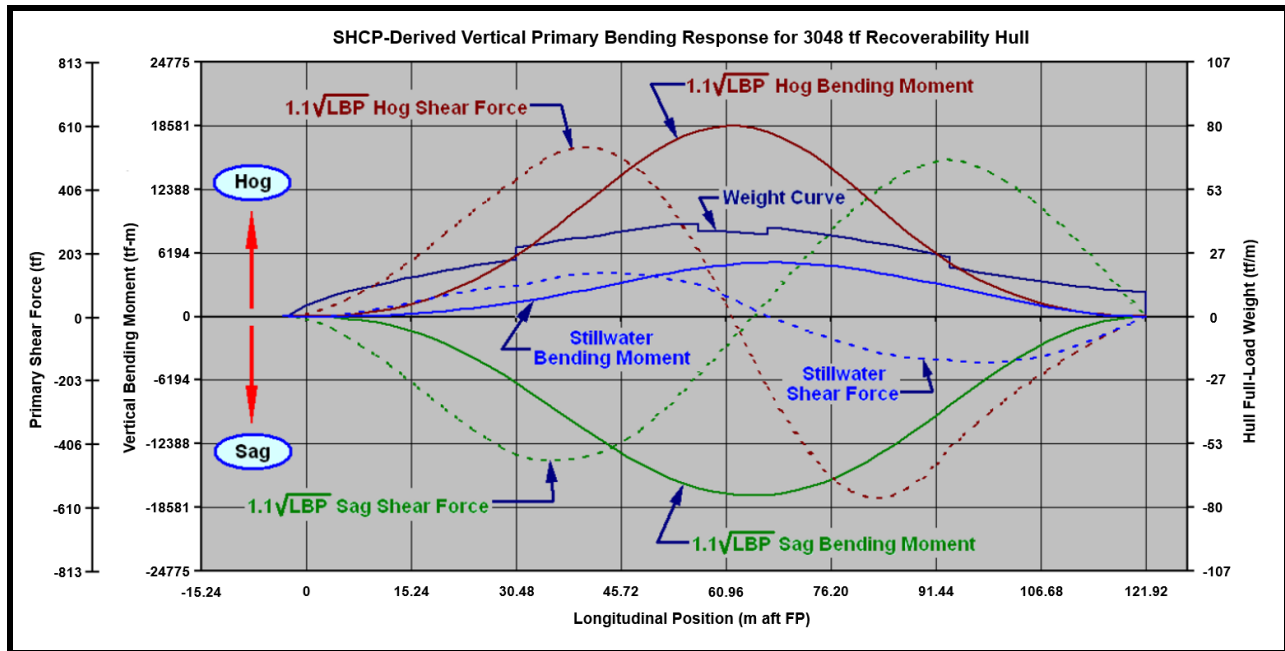


Figure 3. Hull 3000 Full-Load Weight Curve. Reprinted from *Damaged Ship Recoverability Study*, NSWCCD-65-TR-2010/18, p. 7, by Y. Amanuel et al., 2010, Naval Surface Warfare Center, Carderock Division.

In FY22, NSWCCD Code 651 used the Amanuel report (Amanuel et al., 2010) as a starting point for developing a new design of the Hull 3000 to ABS MVR standards (ABS, 2022b), so that it could be publicly released. The hullform (Cusanelli, 2007). and ship characteristics summarized in Table 1 were not changed and fed into the ABS criteria as ship characteristics. The redesign effort would reach only the level of preliminary design, as a complete design was

not necessary for the purposes of the Hull 3000 model, see Section 2.1 for details. As such, only three section scantlings, bow, midship, and stern, were designed to ABS criteria. The bow section is defined at station 5, the midship section at station 10, and the stern section at station 15.

The model was organized and meshed to generate all 2D plate elements and a combination of 1D beam elements and hybrid built-up plate/beam elements that defined frames and stiffeners. The midship compartment (station 9 to 11) included built-up plate webs for all stiffeners with beam flanges. The model was verified before delivery by assuring FEM connectivity using the MODCHK tool and performing modal analysis to ensure that the global response of the ship lies within typical frequency ranges of ships. MODCHK results are not provided in this report as all but the element quality checks came back with empty results and it would be tedious and unhelpful to present users with hundreds of lines of output. For element quality checks, see Section 3.2.4 and Figure 18.

3. Methods, Assumptions, and Procedures

The following sections provide the methods, assumptions, and procedures used to generate the ABS MVR (ABS, 2022b) design and the resulting FEM.

3.1 ABS MVR Design

The open-source ABS MVR criteria (ABS, 2022b) were used to design new Hull 3000 structural scantlings. This criteria was selected because a commercial criteria was required to support the design goal was to produce a reasonably robust publicly releasable ship model with sufficient hull girder strength that would be viewed as a preliminary design. There were key elements missing in the model, such as compartment and equipment arrangements, a detailed weight report, and no superstructure (represented only in an increase in the longitudinal weight curve over a representative length); however, these elements were not required for this study because they are assumed not to affect the hull girder strength. The model of the design was created using flexible parametric modeling methods to support future design iterations; see Section 3.2 for modeling details.

As stated previously, the Hull 3000 MVR design did not modify the hullform (Cusanelli, 2007). and ship characteristics from those summarized in Table 1. The key assumed parameters were fed into the ABS criteria as ship characteristics to determine the hull scantlings.

The design process for the Hull 3000 scantlings, as per ABS 3-2-A4, included a longitudinal hull girder assessment (gross section capacity), local checks for shell, deck, and transverse frame plate-stiffener panel sizing, including buckling of longitudinal members (ABS, 2022b), and a stanchion buckling capacity assessment. Shear capacity was not checked except for in the longitudinal plate-stiffener buckling checks. Three sections of the ship were checked for bending strength: the bow, midship and stern. The bow section was defined at station 5, the midship section at station 10, and the stern station at station 15 (see Figure 2).

The full-load wave shear and bending moments from the Amanuel report (Figure 3) were not derived using ABS rules and proved to be generally less conservative than ABS-derived values, therefore the required shear load and bending moments were calculated in accordance with the ABS rules. The ABS rules 3-2-1/3.5 require stillwater shear and bending moments as inputs; therefore, the stillwater shear and bending moment diagrams (Figure 3) were used to derive the ABS shear and bending moment diagrams (ABS, 2022b). The derived diagrams are in Figure 4; note the x-axis is oriented from left to right, aft/forward.

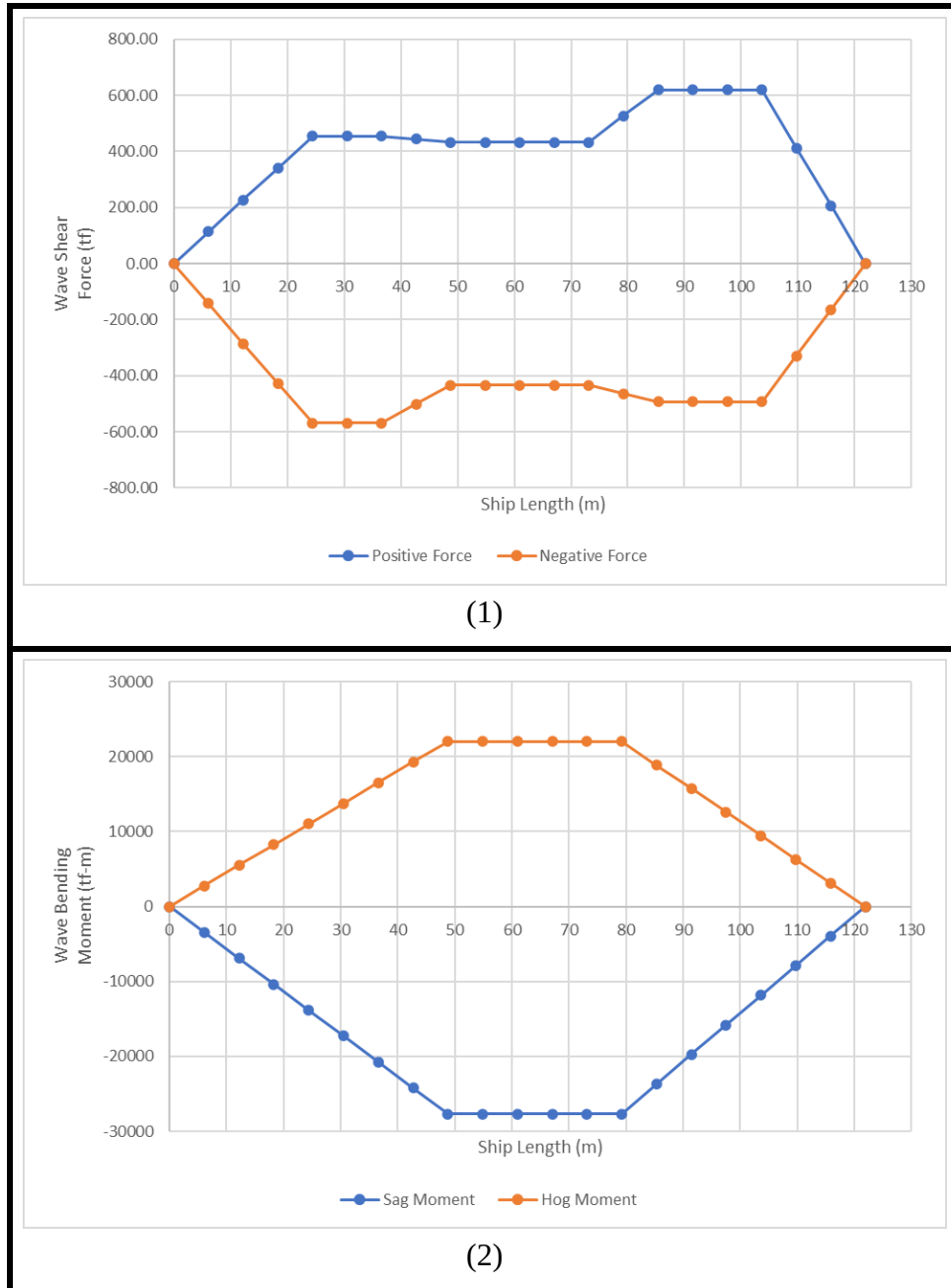


Figure 4. ABS MVR Wave (1) Shear Force and (2) Bending Moment Diagrams

Rather than calculate the maximum allowable and applied stresses of the hull girder, ABS MVR requires the minimum section modulus (ABS 3-2-1/3.7.1) and moment of inertia (ABS 3-2-1/3.7.2) to be less than or equal to the hull girder section properties at midships (except where ABS 3-2-1/3.7.3 applies) (ABS, 2022b). The section modulus requirements can be lessened, as described in ABS 3-2-1/5.3, as H36 steel (similar to AH/DH/EH-36 steel) is being used throughout the ship, ($Q = 0.72$); however, the moment of inertia requirements were not allowed to be relaxed, as per ABS 3-2-1/5.1 (ABS, 2022b). The wave shear and bending moments, minimum properties, and the hull girder properties are summarized in Table 2.

Table 2. Longitudinal Loads and Strength Checks

Loads	Bow	Midship	Stern
Stillwater Shear Force (tf)	-121.9	71.1	101.6
Positive Shear Force (3-2-1/3.5.3) (tf)	618.7	433.1	453.8
Negative Shear Force (3-2-1/3.5.3) (tf)	-493.2	-433.1	-569.2
Stillwater Moment (tf-m)	1548.5	5264.7	3406.6
Sag Moment (3-2-1/3.5.1) (tf-m)	-19763.1	-27668.3	-17292.7
Hog Moment (3-2-1/3.5.1) (tf-m)	15747.0	22045.9	13778.7
Requirements	Bow	Midship	Stern
SM_{req} (3-2-1/3.7.1(a)) cm^2-m	11945.9	18460.2	11602.7
SM_{req} (3-2-1/3.7.1(b)) cm^2-m	N/A	24659.8	N/A
SM_{hts} (3-2-1/5.3) cm^2-m	8601.1	17755.1	8354.0
I_{req} (3-2-1/3.7.2) cm^2-m^2	N/A	90286.0	N/A
SM (Hull Girder) cm^2-m	15861.9	23798.3	14154.5
I (Hull Girder) cm^2-m^2	81333.9	115727.8	58641.2
% SM_{hts}/SM	54%	75%	59%
% I_{req}/I	N/A	78%	N/A

For areas outside of midships (middle 0.4 length of the ship), the minimum required section modulus calculated in ABS 3-2-1/3.7.1(a) is the only section property checked against the the hull girder's section per ABS 3-2-1/3.7.3 (ABS, 2022b). Additionally, the platform deck was assumed to not be longitudinally continuous, and therefore not included in the section property calculations of the hull girder. It was, however, checked to satisfy plate-stiffener and buckling requirements (see Appendix).

The hull girder cross-sections contain at least a 22 % margin over the existing longitudinal strength requirements. This is because the majority of the structure was governed by local loads, as discussed in the following sections of this report.

3.1.1 Bow Scantlings

The scantlings shown in Figure 5 and listed in Table 3 summarize the final design of Hull 3000 for stations 5 and forward. Note that all stiffeners are equally spaced in their respective bays. The frame spacing was maintained from the Amanuel report, as identified in Table 1. The section's plate-stiffener panels were checked; see Appendix for the calculation results for minimum plate-stiffener sizing and the critical plate-stiffener buckling checks.

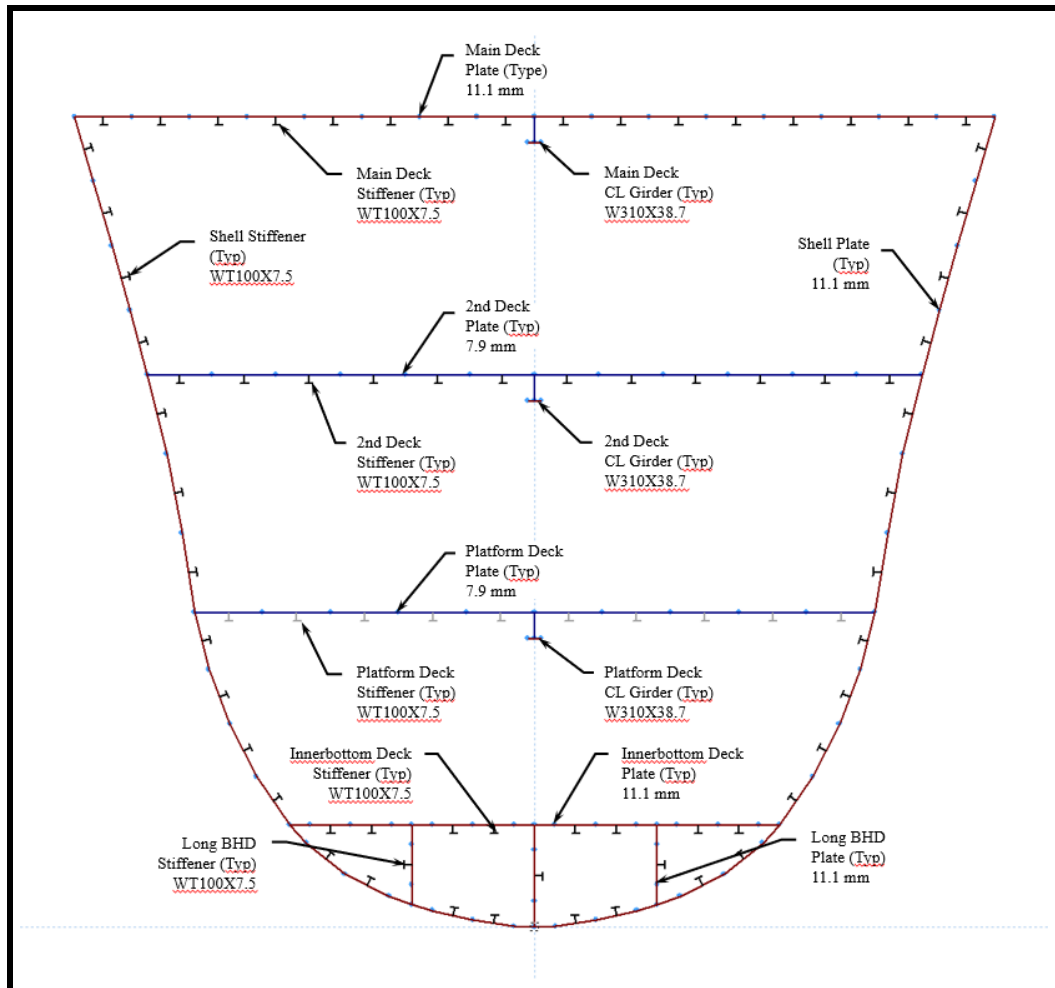


Figure 5. Bow Longitudinal Scantlings

Table 3. Bow Transverse Scantlings

Transverse Deck Frames	
Location	Shape
Main	WT155X10.5
2nd	WT155X10.5
Platform	WT155X10.5
Transverse Shell Frames	
Location between Decks	Shape
Main-2nd	WT155X10.5
2nd-Platform	WT155X10.5
Platform-Innerbottom	WT155X10.5

3.1.2 Midship Scantlings

The scantlings shown in Figure 6 and listed in Table 4 summarize the final design of Hull 3000 between stations 5 and 13 (where the continuity of structure at station 10 ends; see section 3.1.3 for further explanation). Note that all stiffeners are equally spaced in their respective bays. The frame spacing was maintained from the Amanuel report, as identified in Table 1. The section's plate-stiffener panels were checked; see Appendix for the calculation results for minimum plate-stiffener sizing and the critical plate-stiffener buckling checks.

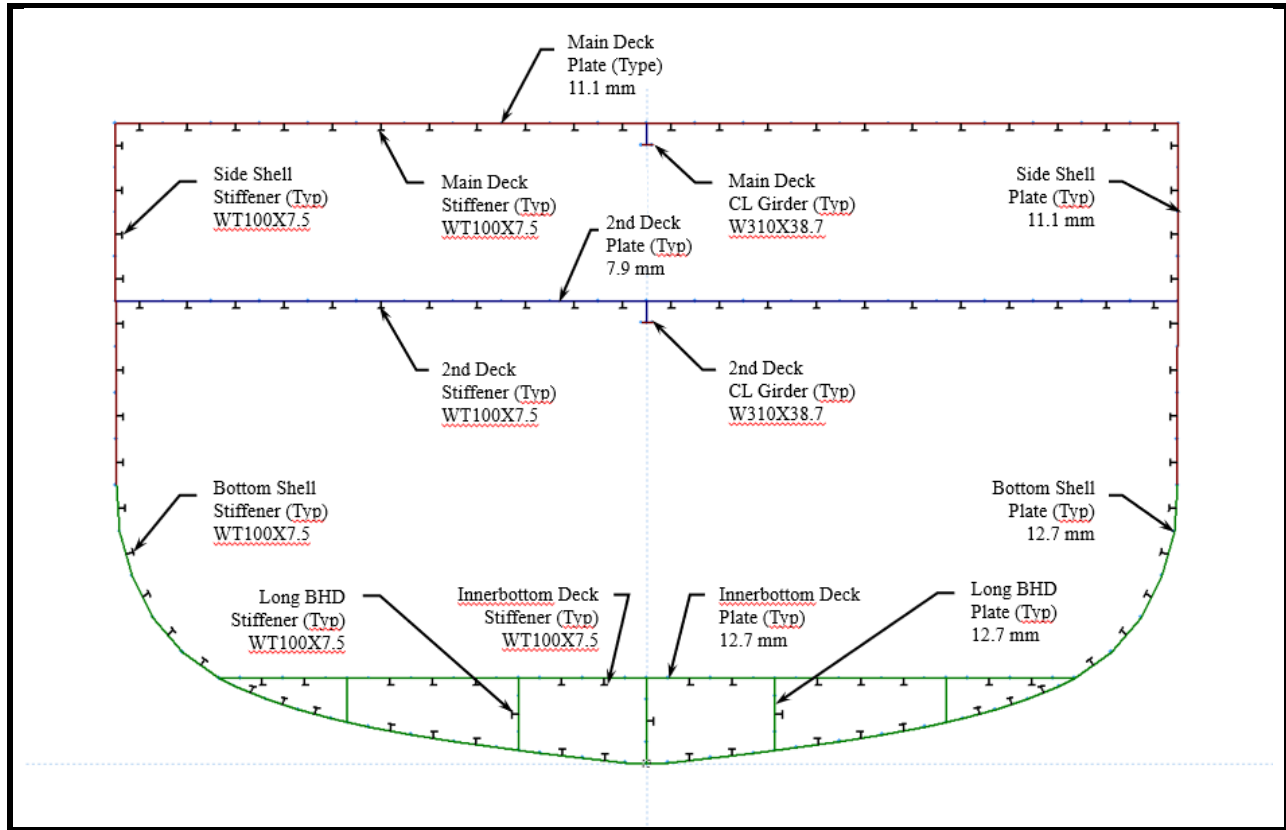


Figure 6. Midship Longitudinal Scantlings

Table 4. Midship Transverse Scantlings

Transverse Deck Frames	
Location	Shape
Main	WT205X19.4
2nd	WT180X16.45
Transverse Shell Frames	
Location between Decks	Shape
Main-2nd	WT155X10.5
2nd-Platform	WT155X10.5
Platform-Innerbottom	WT155X10.5

3.1.3 Stern Scantlings

The scantlings shown in Figure 7 and listed in Table 5 summarize the final design of Hull 3000 for station 13 and all stations aft. Station 15 is where the stern scantlings were checked; however, the continuity of structure begins at 13 and thus the scantlings were applied slightly forward. Note that all stiffeners are equally spaced in their respective bays. The frame spacing was maintained from the Amanuel report, as identified in Table 1. The section's plate-stiffener panels were checked; see Appendix for the calculation results for minimum plate-stiffener sizing and the critical plate-stiffener buckling checks.

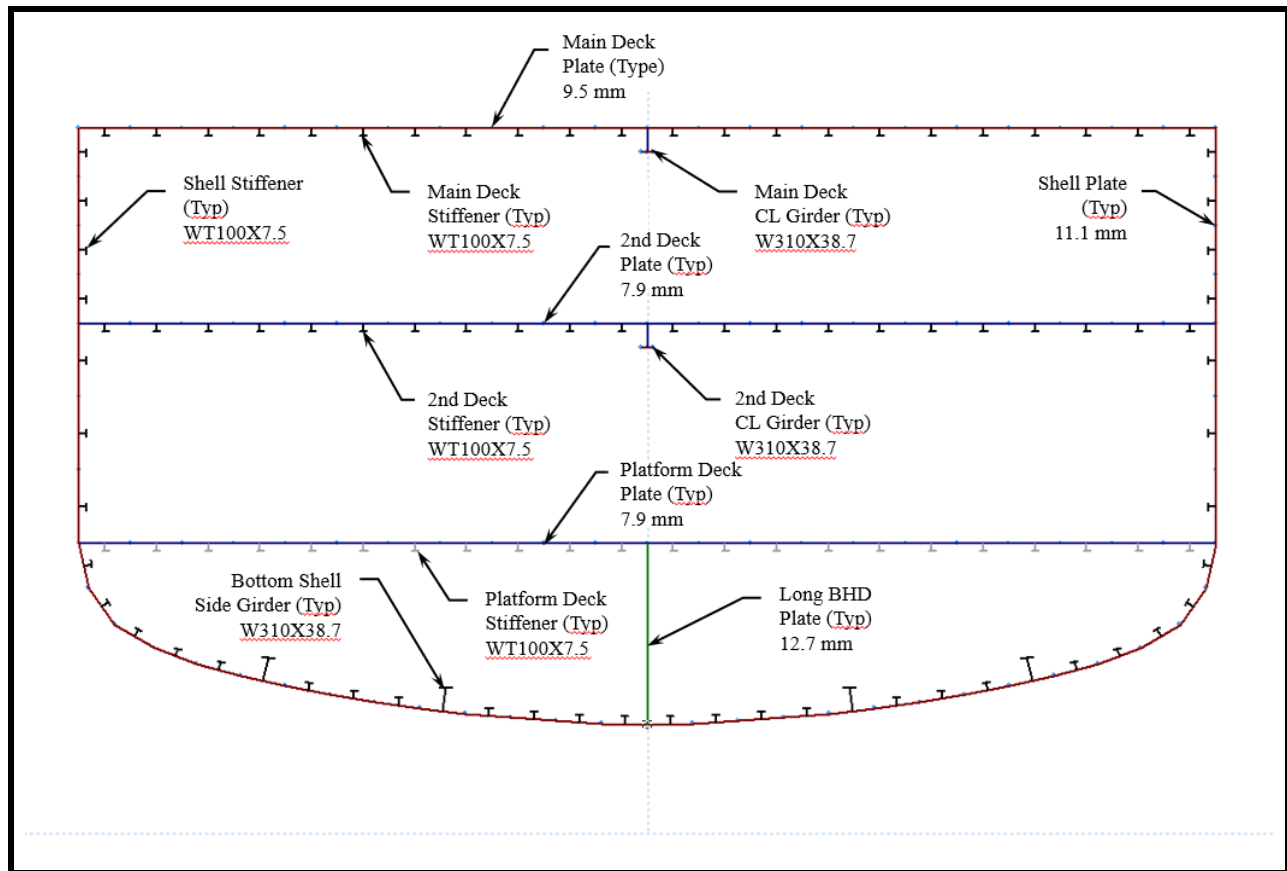


Figure 7. Stern Longitudinal Scantlings

Table 5. Stern Transverse Scantlings

Transverse Deck Frames	
Location	Shape
Main	WT205X19.4
2nd	WT180X16.45
Platform	WT180X16.45
Transverse Shell Frames	
Location between Decks	Shape
Main-2nd	WT155X10.5
2nd-Platform	WT155X10.5
Platform-Keel	WT155X10.5

3.1.4 Stanchions

The stanchions were designed in accordance with ABS MVR 3-2-8/3 (ABS, 2022b). There are two equally spaced stanchions per compartment, extending from the top of the lower deck to the bottom centerline girder on the deck above. Table 6 summarizes the stanchions used for the ship, where the “Location” column refers to what decks the stanchions are between. For example, the ship has four decks (main, 2nd, platform, and innerbottom), except at midships where the platform deck is no longer continuous, resulting in a slenderer column between the 2nd deck and the innerbottom. See Appendix for a summary of the buckling checks for all stanchions.

Table 6. Hull 3000 Stanchions

Stanchions	
Location	Shape
Main-2nd	Pipe200XS
2nd-Platform	Pipe250XS
Platform- Innerbottom	Pipe350XS
2nd-Innerbottom	Pipe350XS

3.2 Modeling Process

Parametric modeling methods were used to build the geometry for Hull 3000, utilizing the computer-aided design (CAD) program SolidWorks 2020. There were multiple benefits of using parametric modeling including: it could be used for both small and large models, it was designed to standardize and produce a well-organized geometric model that could be leveraged for automation, and, most importantly for FEM development, produced geometry that could be easily imported into FE pre/post-processors that required few edits and little effort to prep the surfaces to be meshed. Having a model that could be dynamically changed would also allow for future augmentations to be made quickly for any study that needed a purpose-built model.

3.2.1 Parametric Modeling Explanation

The Hull 3000 geometry model was created using parametric modeling methods and tools developed in Code 651. These methods include the use of commercially available tools like SolidWorks 2020 and Hypermesh 2020 as well as custom tools and methods developed internally. Parametric modeling enabled work on the geometry to start before the design of the internal structure was completed, then modify structural parameters to match the internal design when it was finalized. The structural design was being iterated as the ship model was being built, and the final size and thicknesses were being fed back to the modeler to implement, using the parametric modeling techniques described in the following paragraphs.

The modeling methods included a few major aspects; first, modules. The model was broken up into a set of modules at natural structural divisions, i.e., stations 5, 10, and 15; see Figure 8. Each of these modules is then modeled separately allowing for varied levels of fidelity, building in parallel, and a model organization that can be used for automation.

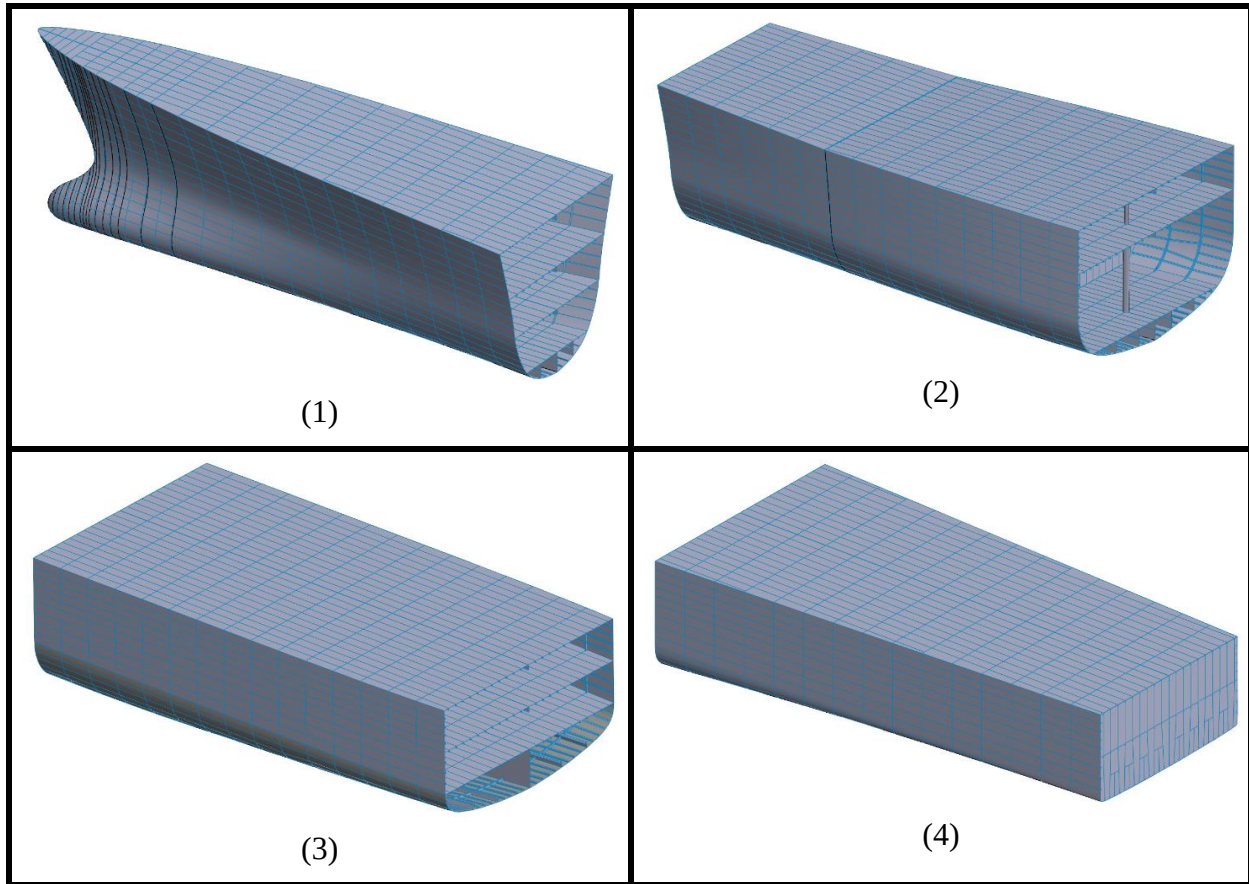


Figure 8. Hull 3000 Module Breakdown: (1) Module 1, (2) Module 2, (3) Module 3, and (4) Module 4

Code 651's methods break modeling parameters into three groups: global-level parameters, compartment-level parameters, and mesh parameters. In the case of Hull 3000, the global-level parameters were set before modeling began as a part of the project tasking. As a result, these ship characteristics were built directly into the model without parameterization. However, the compartment-level parameters were not yet determined when the geometry model was created. They were defined by utilizing the way SolidWorks 2020 organizes its multi-file models. SolidWorks 2020 uses two major file types for model building, the part file and the assembly file; the part file being the lower of the two that is linked to the assembly file. The specific file structure used for this project was to make an assembly file for each module with three part files in each module assembly. The seed part is at the top of the part file hierarchy where the global parameters are defined, containing all the cardinal planes (decks, stations, longitudinal) and the hull form. The master part is next in the hierarchy, containing the transverse bulkhead and frame planes and their respective sketches; see Figure 9 for an example. The lowest parts in the hierarchy are the child parts; these contain every structural component on the ship, including the shell, deck, and bulkhead plating, all the way down to stiffeners and brackets. Figure 10 shows the Hull 3000 seed part and, for example, the module 1 master part.

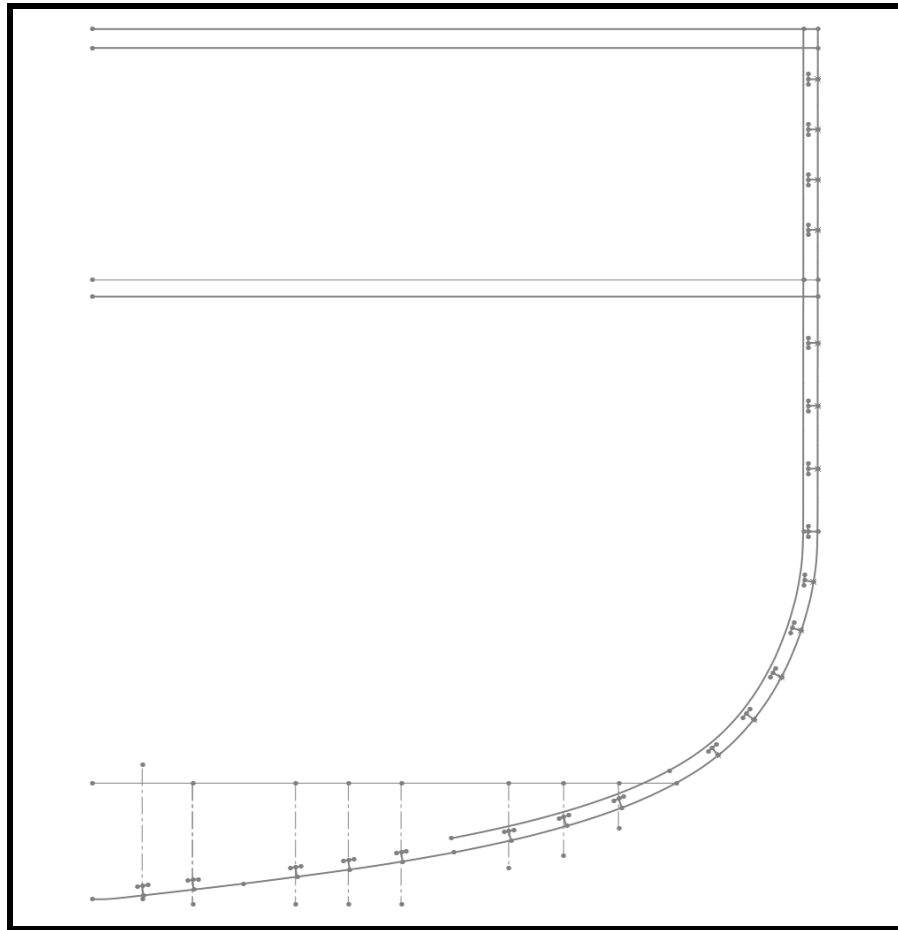


Figure 9. Typical Frame Sketch

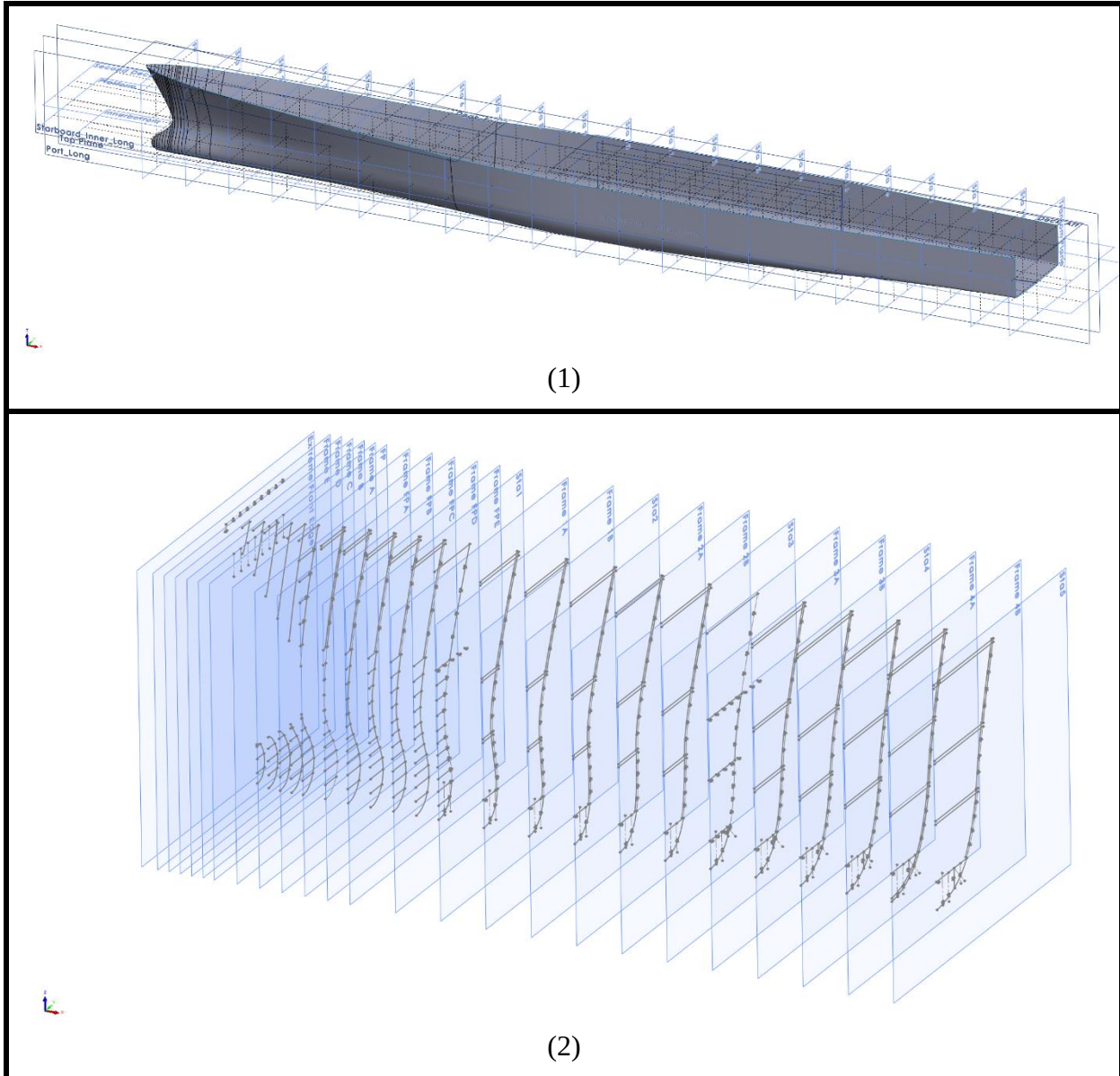


Figure 10. Hull 3000 (1) Seed Part and (2) Module 1 Master Part

SolidWorks 2020 has several parametric modeling tools that were utilized to build a parameterized version of the Hull 3000. The primary function of SolidWorks 2020 is that it is an equation-based geometry modeling software. So, all its geometry can be changed and edited by changing relationships, equations, and variables that define the surfaces. Figure 11 shows examples of the part equation manager and a SolidWorks 2020 part, known as a block, that is used as a template for all standard shapes. These tools were utilized in the master part frame sketches (see Figure 9) and were used to describe the depth of frame stiffeners and the shape and size of all deck and shell stiffeners.

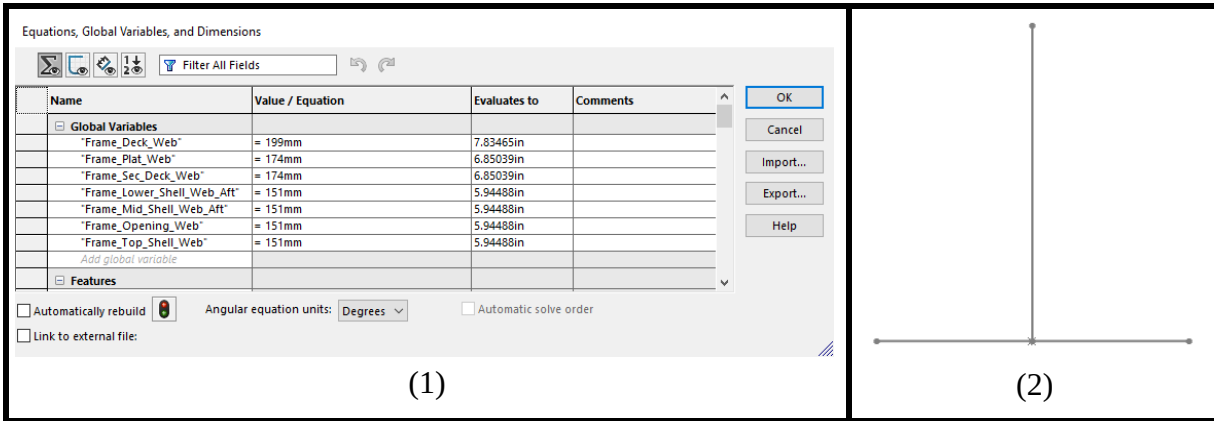


Figure 11. Parametric Modeling in SolidWorks: (1) Equation Editor and (2) Stiffener Block

A part-naming convention created in NSWCCD Code 651 allows for automation in the mesh generation process that functions as mesh parameters. When the structural design was finalized, these parameters were entered into the geometry model to create a final geometry model that was exported to a FE preprocessor, in this case Hypermesh 2020. Figure 12 is an example of a typical part name and the corresponding acronym meaning.

Auto-Generated Name:			
4-SP-PLT-10-HSS-(Shell_Plating)			
Name Component	Value	Notes	
Module Number	4	Module 4	
Assembly Class	SP	Shell & Superstructure Plating	
Three Letter Structure ID	PLT	Plate	
Part Thickness	10	Comma for Decimal	
Part Material	HSS	From Code 651 Material Database	
Part Delineator	Shell_Plating	Unique Description of the Structure & Location	

(1)

SP	Shell & Superstructure Plating	PLT	Plate
DP	Deck, Roof, & Innerbottom Plating	WEB	Web
FP	Frame & Transverse Bulkhead Plating	FLG	Flange
LP	Longitudinal Bulkhead, Girder, and Breasthook Plating	FBR	Flat Bar
SS	Shell & Superstructure Stiffeners	TEE	Tee (Uniform Thickness)
DS	Deck, Roof, & Innerbottom Stiffeners	ANG	Angle (Uniform Thickness)
FS	Frame & Transverse Bulkhead Stiffeners	CHA	Channel (Uniform Thickness)
LS	Longitudinal Bulkhead & Girder Stiffeners	STU	Square Tube (Uniform Thickness)
CD	Connection Details	RTU	Rectangular Tube (Uniform Thickness)
FD	Foundations Details	BAR	Round Bar
ST	Stanchions	BLB	Bulb Flange
SD	Special Details (Catch-All)	PIP	Round Pipe
		CHK	Chock
		DET	Detail (Catch-All)

(2)

Figure 12. Parametric Modeling Name Convention: (1) Part-Naming Generator and (2) Acronym Meaning

3.2.2 Mesh Generation

The mesh was created using Hypermesh 2020 in the centimeter-gram-seconds (CGS) unit system (derived force units in dynes). Hull 3000 was able to be quickly meshed with good quality elements. The element quality parameters used to determine mesh acceptability were the Jacobian, the aspect ratio, and the minimum number of elements along built-up stiffener webs.

All elements in the model must have Jacobians of 0.4 or greater. Although aspect ratio does not capture the true element quality of an element, i.e., how well the element will perform during analysis, it is a good idea to have aspect ratio limits as a means of grading mesh growth and for determining whether growth should be carried for a longer distance or if the change in element size should be decreased. The entire FEM should have no more than 5 % of elements above an aspect ratio of 3.0.

For stiffeners that have their webs modeled using shells, the minimum number of elements through the depth must be no less than two. Two elements are the minimum as typical, conservative post-processing is done with zero output averaging across an element, i.e., no gradient. Thus to see any change in element reaction across a web, at least two elements are required. Additionally, when using linear element formations, as exclusively used in the Hull 3000 model, having only one element across an edge will likely result in an overly stiff approximation of local behavior, at least two elements are needed to capture real world parabolic motion.

For the initial structural model, a low-element count model that was easy to handle and that did not take significant computing power to exercise was required. Also, some detail was desired near midships for a better representation of hull girder response. Thus, a refined midship compartment would be made with all stiffener webs meshed with shells and all flanges with bar elements. All other deck and shell stiffeners and all bulkhead stiffening outside of the refined compartment would be made with bar elements. With these parameters set, the goal was to create a full ship FEM with less than 500,000 elements. Additionally, a variety of element types were desired to exercise various tools (shells, bars, etc.). See Figure 13 and Figure 14.

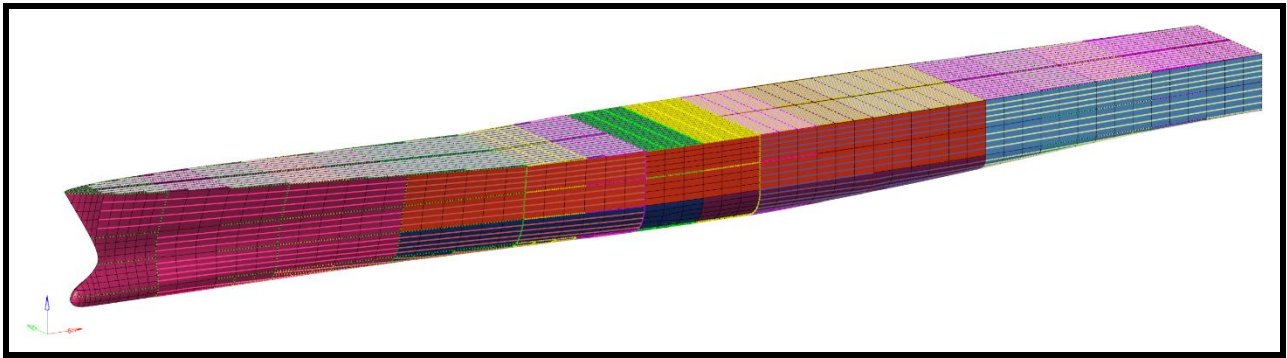


Figure 13. Hull 3000 FEM

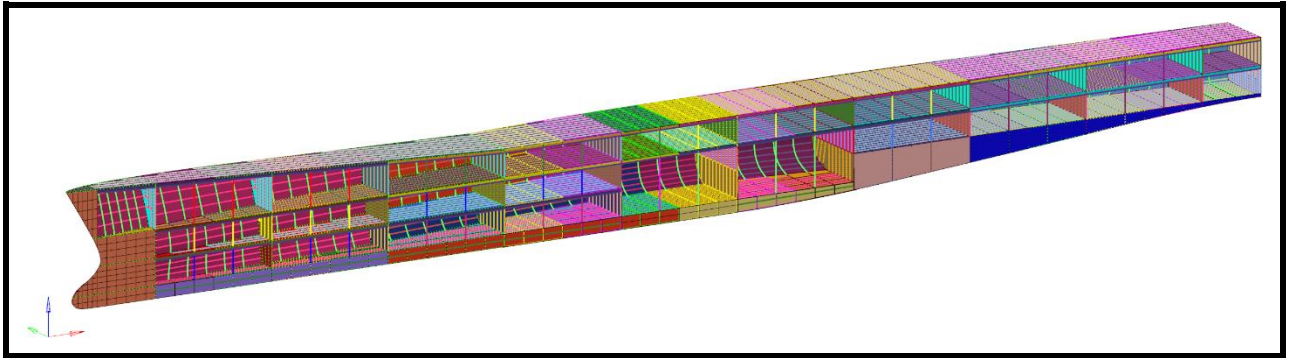


Figure 14. Hull 3000 FEM CL Profile¹

3.2.3 Mesh Description

To achieve a smaller element count, a progressive mesh growing out from the midship compartment (stations 9-11) was created. The smallest components are the deck and shell stiffeners (WT100X7.5); since two elements through the web is required, an element size of 5 cm was used for the midship compartment. To thin out this section, an aspect ratio of 3.0 was used to allow the longer edge to be 15 cm. To create an orderly mesh, with minimum contrivance, a meshing scheme going from within to without was determined to generate a good mesh, i.e., the smallest components (deck and shell stiffeners) were meshed first, then the decks, followed by the shell, to create a banded type of mesh (the longer dimension of any given element being orientated in the global x-axis). Figure 15 shows a representative portion of the midship meshing scheme where at least two elements through webs can be observed.

¹ Hull 3000 is longitudinally oriented in the x-axis (red arrow in Figure 13 and Figure 14). The corresponding y- and z-axes are represented by the green and blue arrows, respectively.

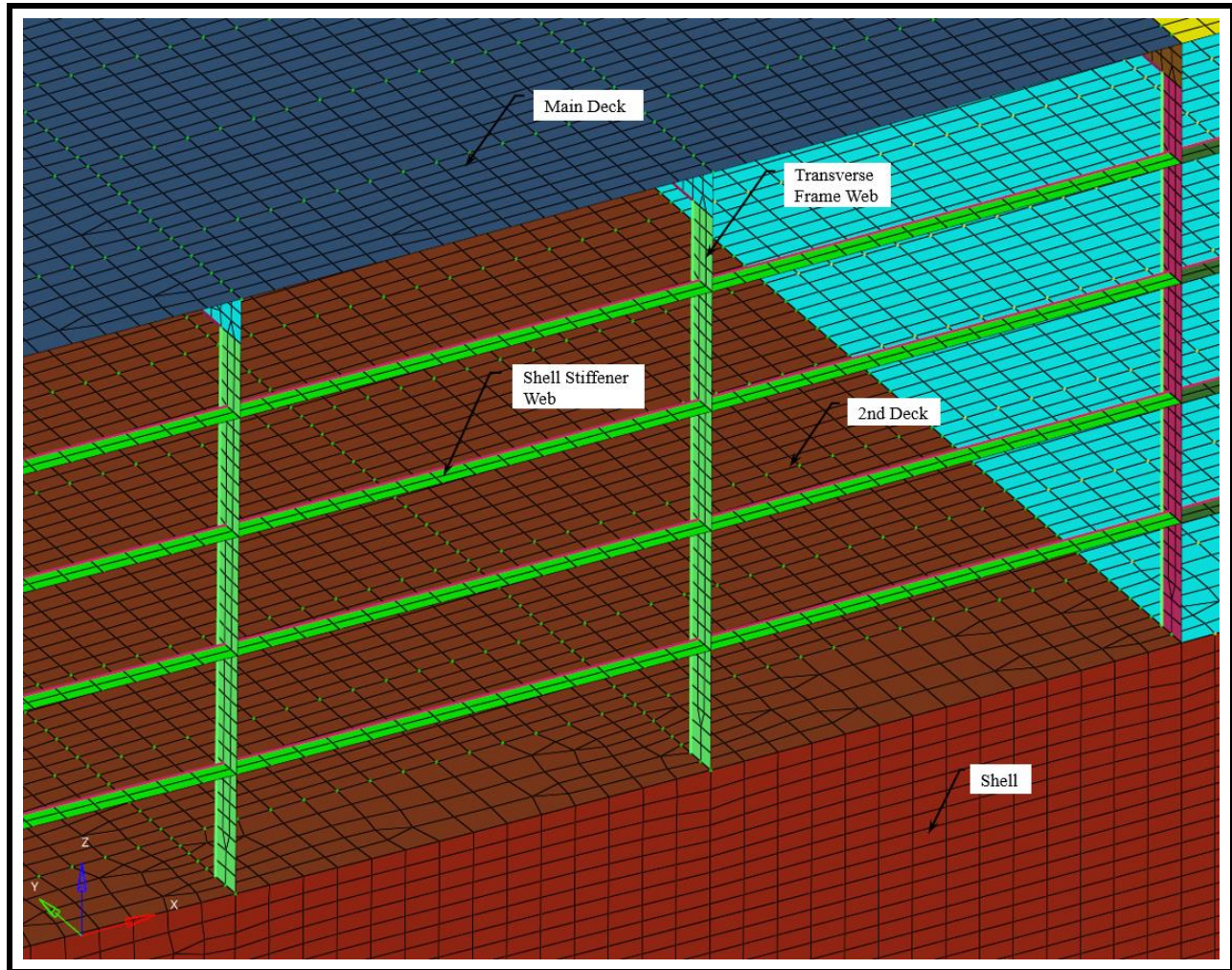


Figure 15. Midship Meshing Scheme

Forward and aft of the middle compartment, the element size was grown to 15 cm with 1.0 aspect ratio, to match the longest dimension in the refined section previously discussed, then 30 cm with aspect ratio of 1.0 to further coarsen the model. Outside of the refined section between stations 9 and 11, all deck and shell stiffeners were transitioned to bar elements. Figure 16 shows the mesh transition from 15x15 cm to 30x30 cm mesh and Figure 17 shows the transition of the refined mesh to the 15x15 cm mesh. The overall mesh sizing scheme is summarized in Table 7.

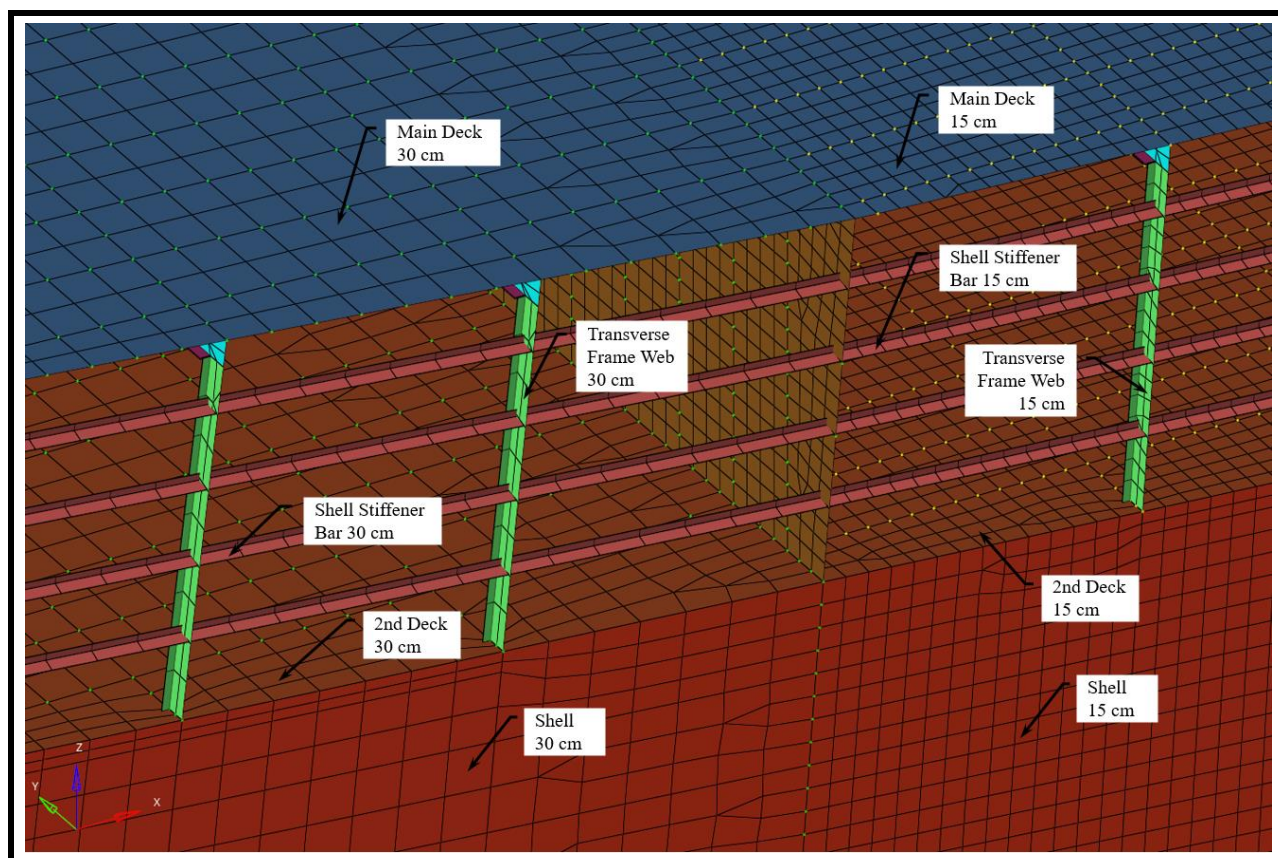


Figure 16. Element Growth

Table 7. Element Growth Summary

Stations	Min Elem Size (cm)	Aspect Ratio
Stem-7	30	1.0
7-9	15	1.0
9-11	5	3.0
11-13	15	1.0
13-20	30	1.0

To transition from stiffeners made with the shell/bar combination to bar element only, transition rigid elements (all degrees of freedom turned on) were used to tie the unshared nodes to each other, shown in Figure 17.

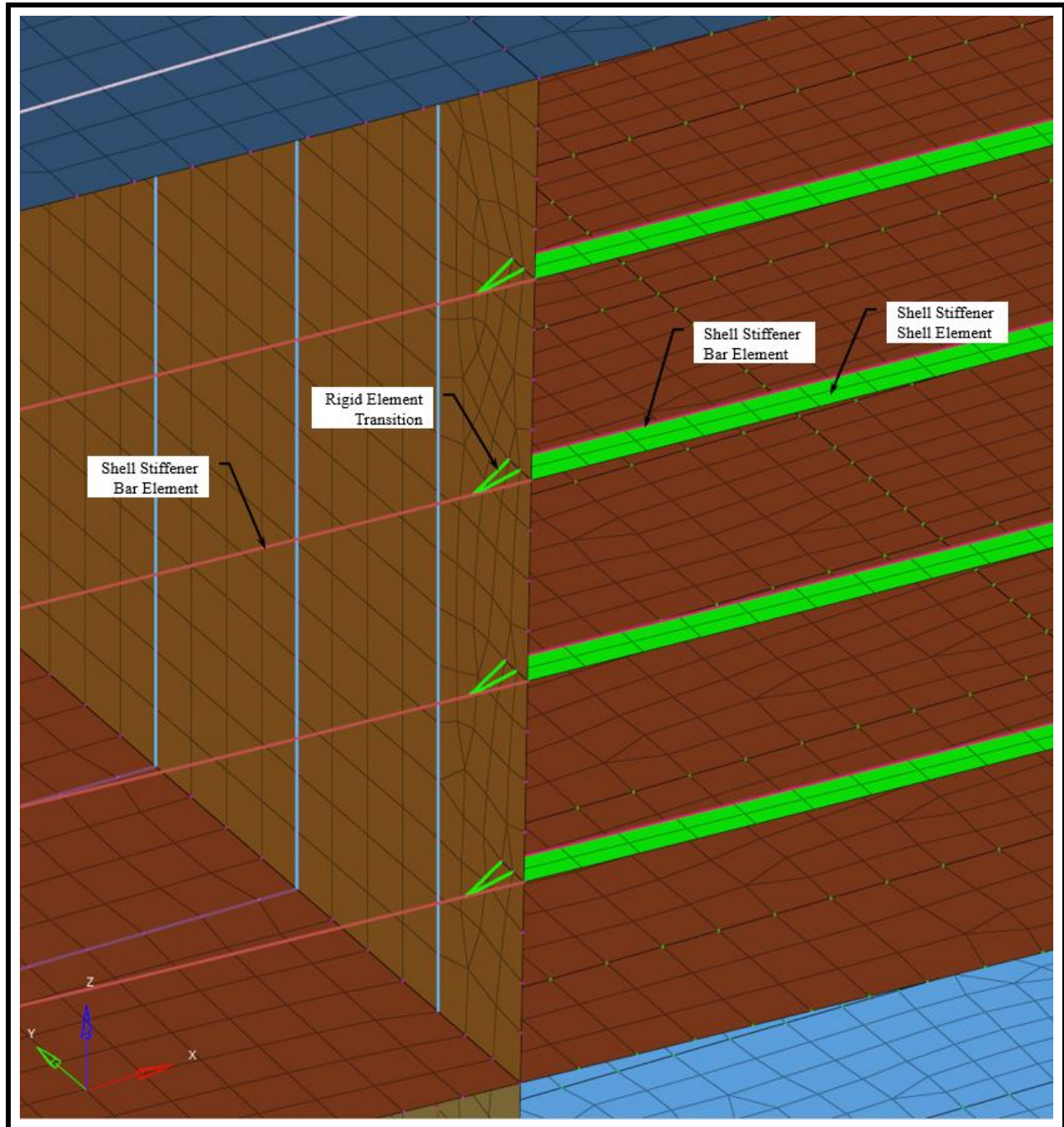


Figure 17. Rigid Element Transition

3.2.4 Mesh Quality

Hypermesh 2020 calculates the Jacobian in the traditional way, perfect element quality being unity and zero or less being broken. Figure 18 shows the Jacobian contour, with zero elements below 0.4, and the aspect ratio contour, with only 5 % of elements above 3.0.

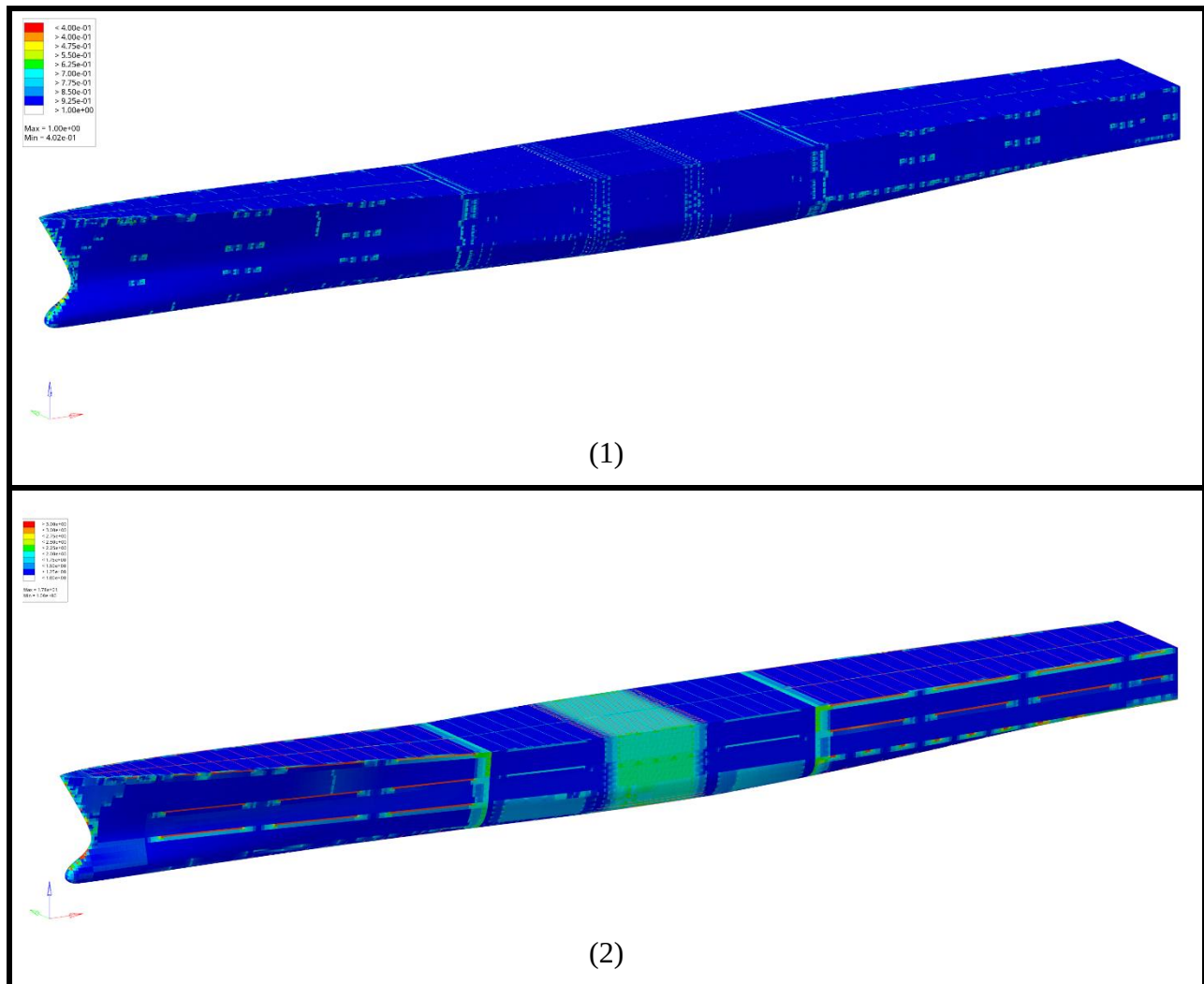


Figure 18. Hull 3000 Element Quality Contours: (1) Jacobian and (2) Aspect Ratio

4. Results and Discussion

Utilizing the meshing techniques described in section 3.2.2, a FEM with under 500,000 elements was created. Table 8 and Table 9 summarize the type and number of elements, properties, and materials used.

Table 8. Element Summary

Element	Type	Amount
Shell	PSHELL	336526
Bar	PBARL	75317
Mass	CONM2	69072
Rigids	RBE2	192
Total:		481107

Table 9. Property and Material Summary

Collector	Amount	Typical Name
Property	160	1-SP-PLT-1,11-AH36-(Foreward_Shell_Plating)
Material	1	AH36

A longitudinal mass distribution was added to the Hull 3000 FEM to support future model runs and model checking. The notional mass distribution was the full-load weight curve in Figure 3. Once the original was digitized, the full-load curve was integrated to confirm that it resulted in the stated full-load displacement. The differences are summarized in Table 10.

Table 10. Hull 3000 Displacement Comparison

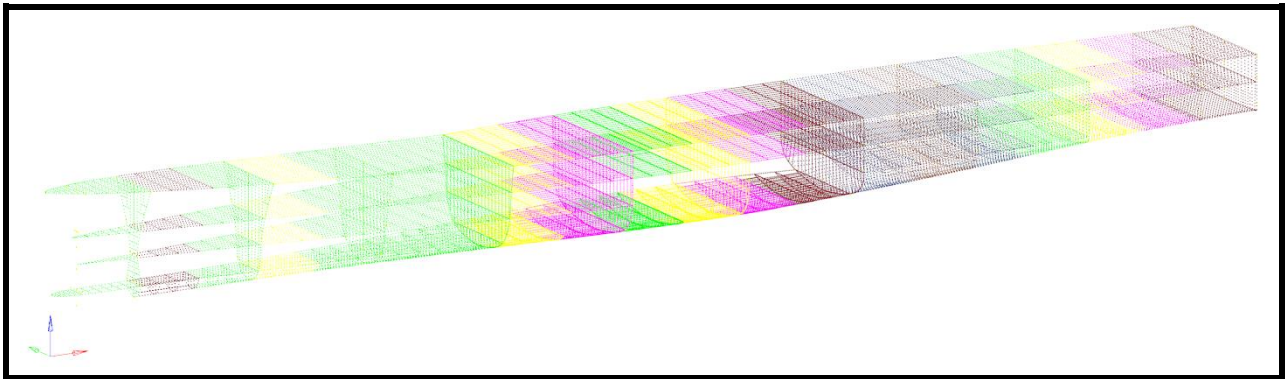
US (L-tons)			Metric (tf)		
Design	FEM	% Difference	Design	FEM	% Difference
2975.3	2971.9	0.12%	3023.0	3019.6	0.11%

Having good correlation, the weight curve was binned into 20 groups by stations. Each bin's full-load weight was calculated from the digitized data. Then the model was grouped in Hypermesh 2020 and each bin's structural weight was determined using the built in tool. The difference was calculated per bin to obtain the nonstructural mass that was added to the model. Table 11 summarizes the nonstructural weight required per bin.

Table 11. Mass Distribution Bins

Location	Full Load Weight (tf)	Structural Weight (tf)	Nonstructural Weight (tf)
Stem-Sta 1	54.12	39.35	14.77
Sta 1-2	75.96	25.42	50.54
Sta 2-3	99.75	32.70	67.05
Sta 3-4	120.55	31.99	88.56
Sta 4-5	139.08	41.68	97.40
Sta 5-6	184.56	41.67	142.89
Sta 6-7	200.95	53.83	147.12
Sta 7-8	216.64	50.83	165.81
Sta 8-9	232.41	64.49	167.92
Sta 9-10	225.08	50.64	174.44
Sta 10-11	213.41	62.44	150.97
Sta 11-12	221.89	51.37	170.52
Sta 12-13	206.83	58.65	148.18
Sta 13-14	189.27	50.77	138.50
Sta 14-15	169.82	57.93	111.89
Sta 15-16	130.95	43.79	87.16
Sta 16-17	105.22	48.16	57.06
Sta 17-18	89.98	38.97	51.01
Sta 18-19	75.92	42.11	33.81
Sta 19-20	67.17	34.26	32.91

Single point masses were added to only the stiffened nodes (nodes where stiffeners meet plate) on the decks, transverse bulkheads, and the shell plating inside the innerbottom. Figure 19 shows the mass distribution in the FEM; note each color represents a different bin of mass elements.

**Figure 19. FEM Mass Distribution**

A modal analysis was performed to verify that the mode did not contain disconnected elements and to confirm that the model's fundamental frequency is within typical surface ship range. The modal analysis was setup with no constraints and to output 20 modes. For brevity,

only the first, nonrigid body mode is shown in Figure 20. The 1-node vertical bending mode is typically the first nonrigid body mode for monohull ships, mode 7, with a natural frequency typically in the range of 2-5 Hz. As can be seen in Figure 20, the Hull 3000's 1-node vertical bending mode was mode 7 with a natural frequency of approximately 2.27 Hz. This shows that the Hull 3000's hull girder reacts in typical surface ship behavior. Special note should be paid, however, to the low natural frequency that the ship vibrates at as this indicates the ship is relatively less stiff. This can also be observed by the relatively large displacement of the midship decks, a response not typically observed in naval craft of similar size, further indicating a relatively less stiff design. However, as priorly stated, the current Hull 3000 design represents a preliminary design looking only at primary hull girder strength for a marine vessel, not a full design of a naval vessel. If Hull 3000 was a ship being designed for eventual deployment, the current design would have to be more refined. However, Hull 3000 sufficiently behaves like a surface ship to be used for the purposes of this study, as listed in section 2.1.

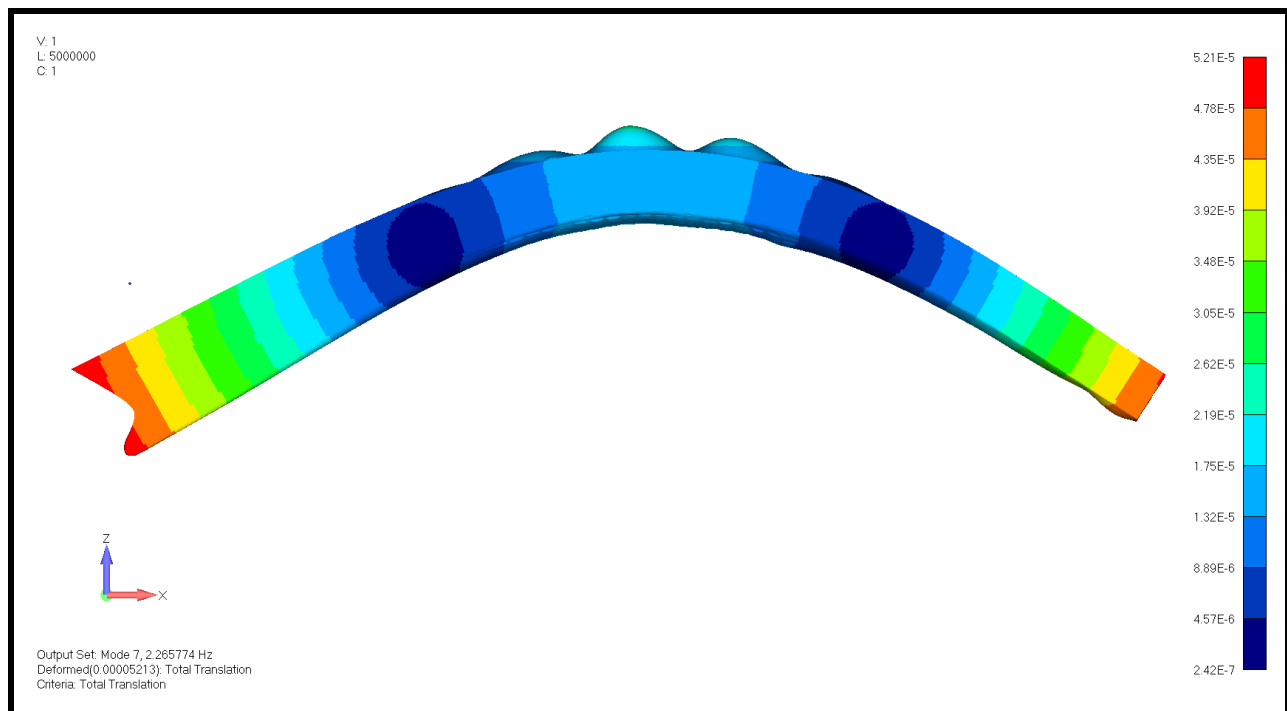


Figure 20. 1-Node Vertical Bending Mode

5. Conclusions

Hull 3000 is a high-fidelity, parametric geometric model, capable of rapid modification, and a well-organized, lightweight, multiuse FEM. The structural design satisfies preliminary hull girder strength requirements using the publicly available design resource, ABS MVR (ABS, 2022b) and is a reasonably representative ship structure for development of engineer workflows, testing of finite element analysis (FEA) codes or hydrocodes. Additional development of the Hull 3000 design would be required prior to using it for any strength or performance benchmarking with regards to structure.

Because a publicly releasable U.S. Navy hull form and the open-source ABS MVR (ABS, 2022b) design criteria were used to design the structural scantlings, Hull 3000 is a public-release design and model under Department of Defense (DoD) Distribution Statement A (Office of the Under Secretary of Defense for Research and Engineering, 2023), making it possible for NSWCCD and the U.S. Navy at large to demonstrate current and in-development capabilities to the public, academia, and international communities.

5.1 Deliverables

The result of this study resulted in the final deliverable version and contents:

Hull3000_v1.3_2023-01-30

- *Hull3000_Info.txt*
- *Hull3000_v1.3_2023-01-30.hm*
- *Hull3000_v1.3_2023-01-30.modfem*
- *Hull3000_v1.3_2023-01-30.nas*

Modal 20 subdirectory

- *Hull3000_Modal20_01.dat*
- *hull3000_modal20_01.f04*
- *hull3000_modal20_01.f06*
- *hull3000_modal20_01.log*
- *hull3000_modal20_01.op2*

6. References

- Amanuel, Y., Devine, E. A., Engle, A. H., Lien, V., Noe, M., Rosborough, J., & Shannohan, E. (2010). *Damaged ship recoverability study* (NSWCCD-65-TR-2010/18). Naval Surface Warfare Center, Carderock Division.
- American Bureau of Shipping. (2022a). *Part 2: Rules for materials and welding*. Rules for Building and Classing Marine Vessels.
- American Bureau of Shipping. (2022b). *Part 3: Hull construction and equipment*. Rules for Building and Classing Marine Vessels.
- American Institute of Steel Construction (2017). *AISC Steel Construction Manual* (15th Edition).
- Cusanelli, D. S. (2007). *Joint high speed sealift (JHSS) baseline shaft & strut (Model 5653) Series 1: Bare hull resistance, approved resistance, and alternative bow evaluations*. Naval Surface Warfare Center, Carderock Division.
- Femap (2021) [Computer software]. Siemens Digital Industries Software.
- Hypermesh (2020) [Computer software]. Altair Engineering.
- Office of the Under Secretary of Defense for Research and Engineering (2023). *Distribution Statements on DoD Technical Information* (DoD Instruction 5230.24). United States Department of Defense.
- SolidWorks (2020) [Computer software]. Dassault Systèmes.

Appendix Design Calculation Worksheets

This appendix presents Table A1 through Table A13, which show the worksheets used to design Hull 3000 to American Bureau of Shipping (ABS) MVR Part 3 (ABS, 2022b) criteria. All material data is taken from ABS MVR Part 2 (ABS, 2022a), and all shape section properties are taken from the American Institute of Steel Construction Steel Construction Manual (2017) Shapes Database.

A.1 Plate-Stiffener Panel Design Checks

Table A1. Bow Section Plate-Stiffener Panel Design Checks

Analysis Inputs			Member Inputs			Plating Calculation Checks				Member Calculation Checks		
Type	Name	$t_{PLT, INPUT}$ (mm)	Type	Shape	S_x (cm ³)	b_e (mm)	$t_{PLT, CALC}$ (mm)	Controlling Load Case	Thickness Ratio	SM_{REQ} (cm ³)	Controlling Load Case	SM Ratio
Deck-Long	Main deck longs	11.1	T	WT100X7.5	313.068	635	6.424	Hydrostatic	1.728	38.657	Hydrostatic	8.099
Deck-Long	Main deck L6	11.1	T	WT100X7.5	313.068	635	6.424	Hydrostatic	1.728	38.657	Hydrostatic	8.099
Deck-Long	Main deck CL girder	11.1	I-T	W310X38.7	1213.453	635	6.424	Hydrostatic	1.728	154.627	Hydrostatic	7.848
Deck-Long	2nd deck longs	7.9	T	WT100X7.5	299.214	635	6.021	Hydrostatic	1.312	33.383	Hydrostatic	8.963
Deck-Long	2nd deck L6	7.9	T	WT100X7.5	299.214	635	6.021	Hydrostatic	1.312	33.383	Hydrostatic	8.963
Deck-Long	2nd deck CL girder	7.9	I-T	W310X38.7	1149.013	635	6.021	Hydrostatic	1.312	133.531	Hydrostatic	8.605
Deck-Long	Platf deck longs	7.9	T	WT100X7.5	283.514	635	5.589	Hydrostatic	1.413	37.725	Hydrostatic	7.515
Deck-Long	Platf deck L6	7.9	T	WT100X7.5	283.514	635	5.589	Hydrostatic	1.413	37.725	Hydrostatic	7.515
Deck-Long	Platf deck CL girder	7.9	I-T	W310X38.7	1079.508	635	5.589	Hydrostatic	1.413	150.899	Hydrostatic	7.154
Deck-Long	Innerbottom longs	11.1	T	WT100X7.5	399.322	635	9.726	Inner Bottom	1.141	83.266	Tank	4.796
Side Shell-Long	Main-2nd deck long upper	11.1	T	WT100X7.5	400.242	635	9.774	Hydrostatic	1.136	56.312	Hydrostatic	7.108
Side Shell-Long	Main-2nd deck long lower	11.1	T	WT100X7.5	400.242	635	9.774	Hydrostatic	1.136	56.312	Hydrostatic	7.108
Side Shell-Long	2nd-Platf deck long upper	11.1	T	WT100X7.5	400.242	635	9.774	Hydrostatic	1.136	70.247	Hydrostatic	5.698
Side Shell-Long	2nd-Platf deck long upper	11.1	T	WT100X7.5	400.242	635	9.774	Hydrostatic	1.136	105.132	Hydrostatic	3.807
Bottom Shell-Long	Platf-IB deck long upper	11.1	T	WT100X7.5	416.64	635	10.7	Hydrostatic	1.037	117.274	Hydrostatic	3.553
Bottom Shell-Long	Platf-IB deck long upper	11.1	T	WT100X7.5	416.64	635	10.7	Hydrostatic	1.037	117.274	Hydrostatic	3.553
Bottom Shell-Long	Tank 2 long upper	11.1	T	WT100X7.5	416.64	635	10.7	Hydrostatic	1.037	117.274	Hydrostatic	3.553
Bottom Shell-Long	Tank 2 long lower	11.1	T	WT100X7.5	416.64	635	10.7	Hydrostatic	1.037	121.985	Hydrostatic	3.416
Bottom Shell-Long	Tank 1 long upper	11.1	T	WT100X7.5	416.64	635	10.7	Hydrostatic	1.037	128.858	Hydrostatic	3.233
Bottom Shell-Long	Tank 1 long lower	11.1	T	WT100X7.5	416.64	635	10.7	Hydrostatic	1.037	130.665	Hydrostatic	3.189
Deck-Trans	Main deck transv	11.1	T	WT155X10.5	1318.384	2032	6.424	Hydrostatic	1.728	910.548	Hydrostatic	1.448
Deck-Trans	2nd deck transv	7.9	T	WT155X10.5	1270.462	2032	6.021	Hydrostatic	1.312	786.323	Hydrostatic	1.616
Deck-Trans	Platf transv	7.9	T	WT155X10.5	1214.017	2032	5.589	Hydrostatic	1.413	761.656	Hydrostatic	1.594
Side Shell-Trans	Main-2nd deck transv	11.1	T	WT155X10.5	1565.89	2032	9.774	Hydrostatic	1.136	223.615	Hydrostatic	7.003
Side Shell-Trans	2nd-platf transv w/ deep shell stiff	11.1	T	WT155X10.5	1565.89	2032	9.774	Hydrostatic	1.136	141.996	Hydrostatic	11.028
Bottom Shell-Long	Platf-IB transv w/ deep shell stiff	11.1	T	WT155X10.5	1597.613	2032	10.7	Hydrostatic	1.037	634.411	Hydrostatic	2.518

Note: Where hydrostatic is listed as the governing load case, it is the ABS-determined plating thickness or section modulus.

Table A2. Midship Section Plate-Stiffener Panel Design Checks

Analysis Inputs			Member Inputs			Plating Calculation Checks				Member Calculation Checks		
Type	Name	$t_{PLT, INPUT}$ (mm)	Type	Shape	S_x (cm ³)	b_k (mm)	$t_{PLT, CALC}$ (mm)	Controlling Load Case	Thickness Ratio	SM_{REF} (cm ³)	Controlling Load Case	SM Ratio
Deck-Long	Main deck longs	11.1	T	WT100X7.5	313.068	635	6.424	Hydrostatic	1.728	42.057	Hydrostatic	7.444
Deck-Long	Main deck L6	11.1	T	WT100X7.5	313.068	635	6.424	Hydrostatic	1.728	42.057	Hydrostatic	7.444
Deck-Long	Main deck CL girder	11.1	I-T	W310X38.7	1213.453	635	6.424	Hydrostatic	1.728	168.229	Hydrostatic	7.213
Deck-Long	2nd deck longs	7.9	T	WT100X7.5	313.068	635	6.424	Hydrostatic	1.23	34.875	Hydrostatic	8.977
Deck-Long	2nd deck L6	7.9	T	WT100X7.5	313.068	635	6.424	Hydrostatic	1.23	34.875	Hydrostatic	8.977
Deck-Long	2nd deck CL girder	7.9	I-T	W310X38.7	1213.453	635	6.424	Hydrostatic	1.23	139.502	Hydrostatic	8.698
Deck-Long	Platf deck longs	7.9	T	WT100X7.5	296.911	635	5.956	Hydrostatic	1.326	37.725	Hydrostatic	7.87
Deck-Long	Platf deck L6	7.9	T	WT100X7.5	296.911	635	5.956	Hydrostatic	1.326	37.725	Hydrostatic	7.87
Deck-Long	Platf deck CL girder	7.9	I-T	W310X38.7	1138.6	635	5.956	Hydrostatic	1.326	150.899	Hydrostatic	7.545
Deck-Long	Innerbottom longs	12.7	T	WT100X7.5	431.675	635	11.726	Inner Bottom	1.083	77.796	Tank	5.549
Side Shell-Long	Main-2nd deck long upper	11.1	T	WT100X7.5	399.364	635	9.728	Hydrostatic	1.141	56.312	Hydrostatic	7.092
Side Shell-Long	Main-2nd deck long lower	11.1	T	WT100X7.5	399.364	635	9.728	Hydrostatic	1.141	56.312	Hydrostatic	7.092
Side Shell-Long	2nd-IB deck long upper	11.1	T	WT100X7.5	399.364	635	9.728	Hydrostatic	1.141	56.687	Hydrostatic	7.045
Bottom Shell-Long	2nd-IB deck long upper	12.7	T	WT100X7.5	423.793	635	11.162	Hydrostatic	1.138	117.274	Hydrostatic	3.614
Bottom Shell-Long	Tank 3 long upper	12.7	T	WT100X7.5	423.793	635	11.162	Hydrostatic	1.138	117.274	Hydrostatic	3.614
Bottom Shell-Long	Tank 3 long lower	12.7	T	WT100X7.5	423.793	635	11.162	Hydrostatic	1.138	117.274	Hydrostatic	3.614
Bottom Shell-Long	Tank 2 long upper	12.7	T	WT100X7.5	423.793	635	11.162	Hydrostatic	1.138	117.274	Hydrostatic	3.614
Bottom Shell-Long	Tank 2 long lower	12.7	T	WT100X7.5	423.793	635	11.162	Hydrostatic	1.138	119.18	Hydrostatic	3.556
Bottom Shell-Long	Tank 1 long upper	12.7	T	WT100X7.5	423.793	635	11.162	Hydrostatic	1.138	122.165	Hydrostatic	3.469
Bottom Shell-Long	Tank 1 long lower	12.7	T	WT100X7.5	423.793	635	11.162	Hydrostatic	1.138	123.525	Hydrostatic	3.431
Deck-Trans	Main deck transv	11.1	T	WT205X19.4	2069.613	2032	6.424	Hydrostatic	1.728	1892.575	Hydrostatic	1.094
Deck-Trans	2nd deck transv	7.9	T	WT180X16.45	1749.516	2032	6.424	Hydrostatic	1.23	1569.397	Hydrostatic	1.115
Deck-Trans	Platf deck transv	7.9	T	WT180X16.45	1655.296	2032	5.956	Hydrostatic	1.326	1455.101	Hydrostatic	1.138
Side Shell-Trans	Main-2nd deck transv	11.1	T	WT155X10.5	1564.013	2032	9.728	Hydrostatic	1.141	141.996	Hydrostatic	11.014
Side Shell-Trans	2nd-Platf transv w/ deep shell stiff	11.1	T	WT155X10.5	1564.013	2032	9.728	Hydrostatic	1.141	141.996	Hydrostatic	11.014
Bottom Shell-Trans	Platf-IB transv w/ deep shell stiff	12.7	T	WT155X10.5	1609.2	2032	11.162	Hydrostatic	1.138	488.009	Hydrostatic	3.297

Note: Where hydrostatic is listed as the governing load case, it is the ABS-determined plating thickness or section modulus.

Table A3. Stern Section Plate-Stiffener Panel Design Checks

Analysis Inputs			Member Inputs			Plating Calculation Checks				Member Calculation Checks		
Type	Name	t _{PLT,INPUT} (mm)	Type	Shape	S _x (cm ³)	b _s (mm)	t _{PLT,CALC} (mm)	Controlling Load Case	Thickness Ratio	SM _{REQ} (cm ³)	Controlling Load Case	SM Ratio
Deck-Long	Main deck longs	9.5	T	WT100X7.5	313.068	635	6.424	Hydrostatic	1.479	43.28	Hydrostatic	7.233
Deck-Long	Main deck L6	9.5	T	WT100X7.5	313.068	635	6.424	Hydrostatic	1.479	43.28	Hydrostatic	7.233
Deck-Long	Main deck CL girder	9.5	I-T	W310X38.7	1213.453	635	6.424	Hydrostatic	1.479	173.122	Hydrostatic	7.009
Deck-Long	2nd deck longs	7.9	T	WT100X7.5	290.99	635	5.792	Hydrostatic	1.364	36.164	Hydrostatic	8.046
Deck-Long	2nd deck L6	7.9	T	WT100X7.5	290.99	635	5.792	Hydrostatic	1.364	36.164	Hydrostatic	8.046
Deck-Long	2nd deck CL girder	7.9	I-T	W310X38.7	1112.173	635	5.792	Hydrostatic	1.364	144.657	Hydrostatic	7.688
Deck-Long	Platf deck longs	7.9	T	WT100X7.5	275.608	635	5.38	Hydrostatic	1.468	37.725	Hydrostatic	7.306
Deck-Long	Platf deck L6	7.9	T	WT100X7.5	275.608	635	5.38	Hydrostatic	1.468	37.725	Hydrostatic	7.306
Side Shell-Long	Main-2nd deck long upper	11.1	T	WT100X7.5	400.242	635	9.774	Hydrostatic	1.136	56.312	Hydrostatic	7.108
Side Shell-Long	Main-2nd deck long lower	11.1	T	WT100X7.5	400.242	635	9.774	Hydrostatic	1.136	56.312	Hydrostatic	7.108
Side Shell-Long	2nd-Platf deck long upper	11.1	T	WT100X7.5	400.242	635	9.774	Hydrostatic	1.136	59.504	Hydrostatic	6.726
Side Shell-Long	2nd-Platf deck long upper	11.1	T	WT100X7.5	400.242	635	9.774	Hydrostatic	1.136	94.373	Hydrostatic	4.241
Bottom Shell-Long	Platf-Keel shell longs	11.1	T	WT100X7.5	416.64	635	10.7	Hydrostatic	1.037	117.274	Hydrostatic	3.553
Bottom Shell-Long	Platf-Keel shell girders	11.1	I-T	W310X38.7	1866.14	635	10.7	Hydrostatic	1.037	469.097	Hydrostatic	3.978
Bottom Shell-Long	Platf-Keel shell girders	11.1	I-T	W310X38.7	1866.14	635	10.7	Hydrostatic	1.037	469.097	Hydrostatic	3.978
Bottom Shell-Long	Platf-Keel shell longs	11.1	T	WT100X7.5	416.64	635	10.7	Hydrostatic	1.037	117.274	Hydrostatic	3.553
Deck-Trans	Main deck transv	9.7	T	WT205X19.4	2069.613	2032	6.424	Hydrostatic	1.51	1832.811	Hydrostatic	1.129
Deck-Trans	2nd deck transv	7.9	T	WT180X16.45	1620.873	2032	5.792	Hydrostatic	1.364	1531.46	Hydrostatic	1.058
Deck-Trans	Platf transv	7.9	T	WT180X16.45	1531.732	2032	5.38	Hydrostatic	1.468	1369.327	Hydrostatic	1.119
Side Shell-Trans	Main-2nd deck transv	11.1	T	WT155X10.5	1565.89	2032	9.774	Hydrostatic	1.136	141.996	Hydrostatic	11.028
Side Shell-Trans	2nd-platf transv	11.1	T	WT155X10.5	1565.89	2032	9.774	Hydrostatic	1.136	141.996	Hydrostatic	11.028
Bottom Shell-Trans	Platf-keel transv	11.1	T	WT155X10.5	1597.613	2032	10.7	Hydrostatic	1.037	740.235	Hydrostatic	2.158
Bottom Shell-Trans	Platf-keel transv	11.1	T	WT155X10.5	1597.613	2032	10.7	Hydrostatic	1.037	613.392	Hydrostatic	2.605
Bottom Shell-Trans	Platf-keel transv	11.1	T	WT155X10.5	1597.613	2032	10.7	Hydrostatic	1.037	613.766	Hydrostatic	2.603

Note: Where hydrostatic is listed as the governing load case, it is the ABS-determined plating thickness or section modulus.

A.2 Stanchions

Table A4. Stanchion Buckling Checks

Typical main to 2nd deck stanchion			Typical 2nd to platf deck stanchion			Typical platf to IB deck stanchion			Engine room stanchion		
Permissible Load	Units	Notes	Permissible Load	Units	Notes	Permissible Load	Units	Notes	Permissible Load	Units	Notes
k	1.848	(MTS units) For AH36 steel	k	1.848	(MTS units) For AH36 steel	k	1.848	(MTS units) For AH36 steel	k	1.848	(MTS units) For AH36 steel
H,deck	4.12554	m Deck height at 1 frame fwd Sta 2	H,deck	2.641702	m	H,deck	2.641702	m	H,deck	5.283403	m
d,girder	0.31	m W310X38.7	d,girder	0.31	m W310X38.7	d,girder	0.31	m W310X38.7	d,girder	0.31	m W310X38.7
L	3.81554	m	L	2.331702	m	L	2.331702	m	L	4.973403	m
r	7.34	cm Pipe200XS	r	9.25	cm Pipe250XS	r	12.2	cm Pipe350XS	r	12.2	cm Pipe350XS
A	76.8	cm ² Pipe200XS	A	97.4	cm ² Pipe250XS	A	124	cm ² Pipe350XS	A	124	cm ² Pipe350XS
n	0.918	(MTS units) For AH36 steel	n	0.918	(MTS units) For AH36 steel	n	0.918	(MTS units) For AH36 steel	n	0.918	(MTS units) For AH36 steel
Wa	105.2773	tf	Wa	157.4563	tf	Wa	207.3961	tf	Wa	182.7477	tf
L/r	51.98283	Applicable	L/r	25.20758	Applicable	L/r	19.11231	Applicable	L/r	40.7656	Applicable
Calculated Load	Units	Notes	Calculated Load	Units	Notes	Calculated Load	Units	Notes	Calculated Load	Units	Notes
n	0.715	(MTS units) For AH36 steel	n	0.715	(MTS units) For AH36 steel	n	0.715	(MTS units) For AH36 steel	n	0.715	(MTS units) For AH36 steel
b	7.62	m tributary breadth	b	7.62	m tributary breadth	b	7.62	m tributary breadth	b	7.62	m tributary breadth
s	4.064203	m tributary length	s	4.064203	m tributary length	s	4.064203	m tributary length	s	4.064203	m tributary length
h	3.8	m	h	6.441702	m	h	9.083403	m	h	6.441702	m
W	84.14339	tf	W	142.6386	tf	W	201.1338	tf	W	142.6386	tf
%W/Wa	80%	PASS	%W/Wa	91%	PASS	%W/Wa	97%	PASS	%W/Wa	78%	PASS

A.3 Bow Section Buckling Checks

Table A5. Bow Section – Main Deck Buckling Checks

Main Deck (Top Fiber)				Main Deck (Top Fiber)			
E	2.06E+05	N/mm2	Young's elastic modulus	E	2.06E+05	N/mm2	Young's elastic modulus
3.1 Elastic Buckling of Plates				3.1 Elastic Buckling of Plates			
3.1.1 Compression				3.1.1 Compression			
t	11.1	mm	Plate thickness	t	11.1	mm	Plate thickness
tk	2	mm	Standard deduction in plate	tk	2	mm	Standard deduction in plate
tb	9.1	mm	Net plate thickness	tb	9.1	mm	Net plate thickness
s	635	mm	Short side of plate	s	635	mm	Short side of plate
l	2032	mm	Long side of plate	l	2032	mm	Long side of plate
c	1.21	-	For tee stiffeners	c	1.21	-	For tee stiffeners
ψ	1	-	Assume no stress variation across panel	ψ	1	-	Assume no stress variation across panel
m	4	-	Plating with stiffis parallel to comp stress	m	4	-	Plating with stiffis parallel to comp stress
σE,p	152.30	N/mm2	Elastic buckling stress of plate	σE,p	152.30	N/mm2	Elastic buckling stress of plate
3.1.2 Shear				3.1.2 Shear			
kt	5.73	-		kt	5.73	-	
τE,p	218.20	N/mm2	Elastic buckling shear stress of plate	τE,p	218.20	N/mm2	Elastic buckling shear stress of plate
3.3 Elastic Buckling of Longitudinals for WT100X7.5				3.3 Elastic Buckling of Longitudinals for W310X38.7			
3.3.1 Column Buckling without Rotation of the Cross Section				3.3.1 Column Buckling without Rotation of the Cross Section			
Ia	6.23E+02	cm4	Inertia of plate-stiffener	Ia	1.44E+04	cm4	Inertia of plate-stiffener
A	67.335	cm2	Area of plate-stiffener	A	91.24794	cm2	Area of plate-stiffener
l	2.032	m	Span length	l	2.032	m	Span length
c1	1000	-		c1	1000	-	
σE,s	461.31	N/mm2	Elastic buckling stress of stiffener	σE,s	7868.57	N/mm2	Elastic buckling stress of stiffener
3.3.2 Torsional Buckling Mode for WT100X7.5				3.3.2 Torsional Buckling Mode for W310X38.7			
tw	4.32	mm	Web thickness	tw	5.84	mm	Web thickness
twk	2	mm	Standard deduction in web	twk	2	mm	Standard deduction in web
twb	2.32	mm	Web net thickness	twb	3.84	mm	Web net thickness
tf	5.21	mm	Flange thickness	tf	9.65	mm	Flange thickness
tfk	2	mm	Standard deduction in flange	tfk	2	mm	Standard deduction in flange
tfb	3.21	mm	Flange net thickness	tfb	7.65	mm	Flange net thickness
d	100	mm	Depth of stiffener	d	310	mm	Depth of stiffener
hw	96.79	mm	Height of web	hw	302.35	mm	Height of web
bf	100	mm	width of flange	bf	165	mm	width of flange
s	635	mm	Stiffener spacing	s	635	mm	Stiffener spacing
c2	1000000	-		c2	1000000	-	
c3	0.0001	-		c3	0.0001	-	
c4	0.000001	-		c4	0.000001	-	
np	0.66	-		np	0.66	-	
kp	0.34	-	Not to be less than zero	kp	0.34	-	Not to be less than zero
C	64.85	-		C	86.57	-	
It	0.15	cm4	St. Venant's inertia for flanged shapes	It	2.96	cm4	St. Venant's inertia for flanged shapes
Ip	370.85	cm4	Polar inertia for flanged shapes	Ip	15076.78	cm4	Polar inertia for flanged shapes
Iw	2506.02	cm6	Warping constant for tee shapes	Iw	261789.35	cm6	Warping constant for tee shapes
K	0.02	-		K	0.00	-	
m	1	-	number of half waves	m	1	-	number of half waves
σE,tor	371.78	N/mm2	Elastic buckling torsional stress of stiffener	σE,tor	870.81	N/mm2	Elastic buckling torsional stress of stiffener
3.3.3 Web and Flange Buckling for WT100X7.5				3.3.3 Web and Flange Buckling for W310X38.7			
σE,web	449.74	N/mm2	Elastic buckling stress of stiffener web	σE,web	126.27	N/mm2	Elastic buckling stress of stiffener web
bf/tf	9.6	PASS	Flange buckling check	bf/tf	8.5	PASS	Flange buckling check
5 Critical Buckling Stresses				5 Critical Buckling Stresses			
5.1 Compression				5.1 Compression			
σF	355	N/mm2	Yield strength of AH36	σF	355	N/mm2	Yield strength of AH36
σC,p	152.30	N/mm2	Critical buckling stress of plate	σC,p	152.30	N/mm2	Critical buckling stress of plate
σC,s	286.70	N/mm2	Critical buckling stress of stiffener	σC,s	351.00	N/mm2	Critical buckling stress of stiffener
σC,tor	270.26	N/mm2	Critical buckling torsional stress of stiffener	σC,tor	318.82	N/mm2	Critical buckling torsional stress of stiffener
σC,web	284.95	N/mm2	Critical buckling stress of stiffener web	σC,web	126.27	N/mm2	Critical buckling stress of stiffener web
5.3 Shear				5.3 Shear			
τF	204.96	N/mm2	Shear strength of AH36	τF	204.96	N/mm2	Shear strength of AH36
τC,p	156.83	N/mm2	Critical buckling shear stress of plate	τC,p	156.83	N/mm2	Critical buckling shear stress of plate
7 Working Stress				7 Working Stress			
7.1 Longitudinal Compressive Stress				7.1 Longitudinal Compressive Stress			
Msw	15190.35	kN-m	Still water moment	Msw	15190.35	kN-m	Still water moment
Mws	-193875.69	kN-m	Sag wave moment	Mws	-193875.69	kN-m	Sag wave moment
In	813338900	cm4	Hull girder inertia	In	813338900	cm4	Hull girder inertia
y	4.574	m	Distance from NA to extreme upper fiber	y	4.574	m	Distance from NA to extreme upper fiber
Q	0.72	-	Steel strength reduction factor	Q	0.72	-	Steel strength reduction factor
c5	100000	-		c5	100000	-	
σa	100.48	N/mm2	Applied compressive stress due to sag	σa	100.48	N/mm2	Applied compressive stress due to sag
7.3.1 Ships without Effective Longitudinal Bulkheads				7.3.1 Ships without Effective Longitudinal Bulkheads			
y1	302.55	cm	Distance from NA to first moment centroid	y1	302.55	cm	Distance from NA to first moment centroid
A1	3427.29	cm2	Area of first moment	A1	3427.29	cm2	Area of first moment
ms	1036937.07	cm3	First moment at the bottom of main deck plate	ms	1036937.07	cm3	First moment at the bottom of main deck plate
ts	1.11	cm	Side shell thickness at main deck	ts	1.11	cm	Side shell thickness at main deck
Fsw	1471.50	kN	Shear force due to still water	Fsw	1471.50	kN	Shear force due to still water
Fwn	6069.64	kN	Maximum negative shear force	Fwn	6069.64	kN	Maximum negative shear force
c6	10	-		c6	10	-	
τa	43.31	N/mm2	Applied compressive shear stress due to sag	τa	43.31	N/mm2	Applied compressive shear stress due to sag
CHECKS				CHECKS			
%σa/σC,p	66%	PASS	Plate compression capacity	%σa/σC,p	66%	PASS	Plate compression capacity
%σa/σC,s	35%	PASS	Stiffener compression capacity	%σa/σC,s	29%	PASS	Stiffener compression capacity
%σa/σC,tor	37%	PASS	Stiffener torsion capacity	%σa/σC,tor	32%	PASS	Stiffener torsion capacity
%σa/σC,web	35%	PASS	Stiffener web compression capacity	%σa/σC,web	80%	PASS	Stiffener web compression capacity
%τa/τC,p	28%	PASS	Plate shear capacity	%τa/τC,p	28%	PASS	Plate shear capacity

Table A6. Bow Section – 2nd Deck Buckling Checks

2nd Deck			2nd Deck		
E	2.06E+05 N/mm2	Young's elastic modulus	E	2.06E+05 N/mm2	Young's elastic modulus
3.1 Elastic Buckling of Plates			3.1 Elastic Buckling of Plates		
3.1.1 Compression			3.1.1 Compression		
t	7.9 mm	Plate thickness	t	7.9 mm	Plate thickness
tk	2 mm	Standard deduction in plate	tk	2 mm	Standard deduction in plate
tb	5.9 mm	Net plate thickness	tb	5.9 mm	Net plate thickness
s	635 mm	Short side of plate	s	635 mm	Short side of plate
l	2032 mm	Long side of plate	l	2032 mm	Long side of plate
c	1.21 -	For tee stiffeners	c	1.21 -	For tee stiffeners
ψ	1 -	Assume no stress variation across panel	ψ	1 -	Assume no stress variation across panel
m	4 -	Plating with stiffeners parallel to comp stress	m	4 -	Plating with stiffeners parallel to comp stress
σ _{E,p}	64.02 N/mm2	Elastic buckling stress of plate	σ _{E,p}	64.02 N/mm2	Elastic buckling stress of plate
3.1.2 Shear			3.1.2 Shear		
kt	5.73 -		kt	5.73 -	
τ _{E,p}	91.72 N/mm2	Elastic buckling shear stress of plate	τ _{E,p}	91.72 N/mm2	Elastic buckling shear stress of plate
3.3 Elastic Buckling of Longitudinals for WT100X7.5			3.3 Elastic Buckling of Longitudinals for W310X38.7		
3.3.1 Column Buckling without Rotation of the Cross Section			3.3.1 Column Buckling without Rotation of the Cross Section		
I _a	6.23E+02 cm4	Inertia of plate-stiffener	I _a	1.44E+04 cm4	Inertia of plate-stiffener
A	67.335 cm2	Area of plate-stiffener	A	91.24794 cm2	Area of plate-stiffener
l	2.032 m	Span length	l	2.032 m	Span length
c ₁	1000 -		c ₁	1000 -	
σ _{E,s}	461.31 N/mm2	Elastic buckling stress of stiffener	σ _{E,s}	7868.57 N/mm2	Elastic buckling stress of stiffener
3.3.2 Torsional Buckling Mode for WT100X7.5			3.3.2 Torsional Buckling Mode for W310X38.7		
tw	4.32 mm	Web thickness	tw	5.84 mm	Web thickness
twk	2 mm	Standard deduction in web	twk	2 mm	Standard deduction in web
twb	2.32 mm	Web net thickness	twb	3.84 mm	Web net thickness
tf	5.21 mm	Flange thickness	tf	9.65 mm	Flange thickness
tfk	2 mm	Standard deduction in flange	tfk	2 mm	Standard deduction in flange
tfb	3.21 mm	Flange net thickness	tfb	7.65 mm	Flange net thickness
d	100 mm	Depth of stiffener	d	310 mm	Depth of stiffener
hw	96.79 mm	Height of web	hw	302.35 mm	Height of web
bf	100 mm	width of flange	bf	165 mm	width of flange
s	635 mm	Stiffener spacing	s	635 mm	Stiffener spacing
c ₂	1000000 -		c ₂	1000000 -	
c ₃	0.0001 -		c ₃	0.0001 -	
c ₄	0.000001 -		c ₄	0.000001 -	
np	0.65 -		np	0.65 -	
kp	0.35 -	Not to be less than zero	kp	0.35 -	Not to be less than zero
C	102.93 -		C	123.62 -	
I _t	0.15 cm4	St. Venant's inertia for flanged shapes	I _t	2.96 cm4	St. Venant's inertia for flanged shapes
I _p	370.85 cm4	Polar inertia for flanged shapes	I _p	15076.78 cm4	Polar inertia for flanged shapes
I _w	2506.02 cm6	Warping constant for tee shapes	I _w	261789.35 cm6	Warping constant for tee shapes
K	0.03 -		K	0.00 -	
m	1 -	number of half waves	m	1 -	number of half waves
σ _{E,tor}	376.08 N/mm2	Elastic buckling torsional stress of stiffener	σ _{E,tor}	870.91 N/mm2	Elastic buckling torsional stress of stiffener
3.3.3 Web and Flange Buckling for WT100X7.5			3.3.3 Web and Flange Buckling for W310X38.7		
σ _{E,web}	449.74 N/mm2	Elastic buckling stress of stiffener web	σ _{E,web}	126.27 N/mm2	Elastic buckling stress of stiffener web
bf/tf	9.6 PASS	Flange buckling check	bf/tf	8.5 PASS	Flange buckling check
5 Critical Buckling Stresses			5 Critical Buckling Stresses		
5.1 Compression			5.1 Compression		
σ _F	355 N/mm2	Yield strength of AH36	σ _F	355 N/mm2	Yield strength of AH36
σ _{C,p}	64.02 N/mm2	Critical buckling stress of plate	σ _{C,p}	64.02 N/mm2	Critical buckling stress of plate
σ _{C,s}	286.70 N/mm2	Critical buckling stress of stiffener	σ _{C,s}	351.00 N/mm2	Critical buckling stress of stiffener
σ _{C,tor}	271.22 N/mm2	Critical buckling torsional stress of stiffener	σ _{C,tor}	318.82 N/mm2	Critical buckling torsional stress of stiffener
σ _{C,web}	284.95 N/mm2	Critical buckling stress of stiffener web	σ _{C,web}	126.27 N/mm2	Critical buckling stress of stiffener web
5.3 Shear			5.3 Shear		
τ _F	204.96 N/mm2	Shear strength of AH36	τ _F	204.96 N/mm2	Shear strength of AH36
τ _{C,p}	91.72 N/mm2	Critical buckling shear stress of plate	τ _{C,p}	91.72 N/mm2	Critical buckling shear stress of plate
7 Working Stress			7 Working Stress		
7.1 Longitudinal Compressive Stress			7.1 Longitudinal Compressive Stress		
M _{sw}	15190.35 kN-m	Still water moment	M _{sw}	15190.35 kN-m	Still water moment
M _{ws}	-193875.69 kN-m	Sag wave moment	M _{ws}	-193875.69 kN-m	Sag wave moment
I _n	813338900 cm4	Hull girder inertia	I _n	813338900 cm4	Hull girder inertia
y	1.375 m	Distance from NA to extreme upper fiber	y	1.375 m	Distance from NA to extreme upper fiber
Q	0.72 -	Steel strength reduction factor	Q	0.72 -	Steel strength reduction factor
c ₅	100000 -		c ₅	100000 -	
σ _a	41.67 N/mm2	Applied compressive stress due to sag	σ _a	41.67 N/mm2	Applied compressive stress due to sag
7.3.1 Ships without Effective Longitudinal Bulkheads			7.3.1 Ships without Effective Longitudinal Bulkheads		
y ₁	302.55 cm	Distance from NA to first moment centroid	y ₁	302.55 cm	Distance from NA to first moment centroid
A ₁	3427.29 cm2	Area of first moment	A ₁	3427.29 cm2	Area of first moment
M _s	1036937.07 cm3	First moment at the bottom of main deck plate	M _s	1036937.07 cm3	First moment at the bottom of main deck plate
ts	1.11 cm	Side shell thickness at main deck	ts	1.11 cm	Side shell thickness at main deck
F _{sw}	1471.50 kN	Shear force due to still water	F _{sw}	1471.50 kN	Shear force due to still water
F _{wn}	6069.64 kN	Maximum negative shear force	F _{wn}	6069.64 kN	Maximum negative shear force
c ₆	10 -		c ₆	10 -	
τ _a	43.31 N/mm2	Applied compressive shear stress due to sag	τ _a	43.31 N/mm2	Applied compressive shear stress due to sag
CHECKS			CHECKS		
%σ _{oa/oc,p}	65% PASS	Plate compression capacity	%σ _{oa/oc,p}	65% PASS	Plate compression capacity
%σ _{oa/oc,s}	15% PASS	Stiffener compression capacity	%σ _{oa/oc,s}	12% PASS	Stiffener compression capacity
%σ _{oa/oc,tor}	15% PASS	Stiffener torsion capacity	%σ _{oa/oc,tor}	13% PASS	Stiffener torsion capacity
%σ _{oa/oc,web}	15% PASS	Stiffener web compression capacity	%σ _{oa/oc,web}	33% PASS	Stiffener web compression capacity
%τ _{a/τc,p}	47% PASS	Plate shear capacity	%τ _{a/τc,p}	47% PASS	Plate shear capacity

Table A7. Bow Section – Platform and Keel Buckling Checks

Platform			Keel (Bottom Fiber)				
E	2.06E+05	N/mm2	Young's elastic modulus	E	2.06E+05	N/mm2	Young's elastic modulus
3.1 Elastic Buckling of Plates			3.1 Elastic Buckling of Plates				
3.1.1 Compression			3.1.1 Compression				
t	7.9	mm	Plate thickness	t	11.1	mm	Plate thickness
tk	2	mm	Standard deduction in plate	tk	2	mm	Standard deduction in plate
tb	5.9	mm	Net plate thickness	tb	9.1	mm	Net plate thickness
s	635	mm	Short side of plate	s	635	mm	Short side of plate
l	2032	mm	Long side of plate	l	2032	mm	Long side of plate
c	1.21	-	For tee stiffeners	c	1.21	-	For tee stiffeners
ψ	1	-	Assume no stress variation across panel	ψ	1	-	Assume no stress variation across panel
m	4	-	Plating with stiffis parallel to comp stress	m	4	-	Plating with stiffis parallel to comp stress
σE,p	64.02	N/mm2	Elastic buckling stress of plate	σE,p	152.30	N/mm2	Elastic buckling stress of plate
3.1.2 Shear			3.1.2 Shear				
kt	5.73	-		kt	5.73	-	
τE,p	91.72	N/mm2	Elastic buckling shear stress of plate	τE,p	218.20	N/mm2	Elastic buckling shear stress of plate
3.3 Elastic Buckling of Longitudinals for WT100X7.5			3.3 Elastic Buckling of Longitudinals for WT100X7.5				
3.3.1 Column Buckling without Rotation of the Cross Section			3.3.1 Column Buckling without Rotation of the Cross Section				
Ia	6.23E+02	cm4	Inertia of plate-stiffener	Ia	6.23E+02	cm4	Inertia of plate-stiffener
A	67.335	cm2	Area of plate-stiffener	A	67.335	cm2	Area of plate-stiffener
l	2.032	m	Span length	l	2.032	m	Span length
c1	1000	-		c1	1000	-	
σE,s	461.31	N/mm2	Elastic buckling stress of stiffener	σE,s	461.31	N/mm2	Elastic buckling stress of stiffener
3.3.2 Torsional Buckling Mode for WT100X7.5			3.3.2 Torsional Buckling Mode for WT100X7.5				
tw	4.32	mm	Web thickness	tw	4.32	mm	Web thickness
twk	2	mm	Standard deduction in web	twk	2	mm	Standard deduction in web
twb	2.32	mm	Web net thickness	twb	2.32	mm	Web net thickness
tf	5.21	mm	Flange thickness	tf	5.21	mm	Flange thickness
tfk	2	mm	Standard deduction in flange	tfk	2	mm	Standard deduction in flange
tfb	3.21	mm	Flange net thickness	tfb	3.21	mm	Flange net thickness
d	100	mm	Depth of stiffener	d	100	mm	Depth of stiffener
hw	96.79	mm	Height of web	hw	96.79	mm	Height of web
bf	100	mm	width of flange	bf	100	mm	width of flange
s	635	mm	Stiffener spacing	s	635	mm	Stiffener spacing
c2	1000000	-		c2	1000000	-	
c3	0.0001	-		c3	0.0001	-	
c4	0.000001	-		c4	0.000001	-	
np	0.65	-		np	0.85	-	
kp	0.35	-	Not to be less than zero	kp	0.15	-	Not to be less than zero
C	102.93	-		C	51.66	-	
It	0.15	cm4	St. Venant's inertia for flanged shapes	It	0.15	cm4	St. Venant's inertia for flanged shapes
Ip	370.85	cm4	Polar inertia for flanged shapes	Ip	370.85	cm4	Polar inertia for flanged shapes
Iw	2506.02	cm6	Warping constant for tee shapes	Iw	2506.02	cm6	Warping constant for tee shapes
K	0.03	-		K	0.02	-	
m	1	-	number of half waves	m	1	-	number of half waves
σE,tor	376.08	N/mm2	Elastic buckling torsional stress of stiffener	σE,tor	370.29	N/mm2	Elastic buckling torsional stress of stiffener
3.3.3 Web and Flange Buckling for WT100X7.5			3.3.3 Web and Flange Buckling for WT100X7.5				
σE,web	449.74	N/mm2	Elastic buckling stress of stiffener web	σE,web	449.74	N/mm2	Elastic buckling stress of stiffener web
bf/tf	9.6	PASS	Flange buckling check	bf/tf	9.6	PASS	Flange buckling check
5 Critical Buckling Stresses			5 Critical Buckling Stresses				
5.1 Compression			5.1 Compression				
σF	355	N/mm2	Yield strength of AH36	σF	355	N/mm2	Yield strength of AH36
σc,p	64.02	N/mm2	Critical buckling stress of plate	σc,p	152.30	N/mm2	Critical buckling stress of plate
σc,s	286.70	N/mm2	Critical buckling stress of stiffener	σc,s	286.70	N/mm2	Critical buckling stress of stiffener
σc,tor	271.22	N/mm2	Critical buckling torsional stress of stiffener	σc,tor	269.92	N/mm2	Critical buckling torsional stress of stiffener
σc,web	284.95	N/mm2	Critical buckling stress of stiffener web	σc,web	284.95	N/mm2	Critical buckling stress of stiffener web
5.3 Shear			5.3 Shear				
τF	204.96	N/mm2	Shear strength of AH36	τF	204.96	N/mm2	Shear strength of AH36
τc,p	91.72	N/mm2	Critical buckling shear stress of plate	τc,p	156.83	N/mm2	Critical buckling shear stress of plate
7 Working Stress			7 Working Stress				
7.1 Longitudinal Compressive Stress			7.1 Longitudinal Compressive Stress				
Msw	51647.19	kN-m	Still water moment	Msw	51647.19	kN-m	Still water moment
Mwh	154478.49	kN-m	Hog wave moment	Mwh	154478.49	kN-m	Hog wave moment
In	813338900	cm4	Hull girder inertia	In	813338900	cm4	Hull girder inertia
y	1.267	m	Distance from NA to extreme upper fiber	y	5.128	m	Distance from NA to extreme upper fiber
Q	0.72	-	Steel strength reduction factor	Q	0.72	-	Steel strength reduction factor
c5	100000	-		c5	100000	-	
σa	41.67	N/mm2	Applied compressive stress due to sag	σa	129.95	N/mm2	Applied compressive stress due to sag
7.3.1 Ships without Effective Longitudinal Bulkheads			7.3.1 Ships without Effective Longitudinal Bulkheads				
y1	302.55	cm	Distance from NA to first moment centroid	y1	302.55	cm	Distance from NA to first moment centroid
A1	3427.29	cm2	Area of first moment	A1	3427.29	cm2	Area of first moment
ms	1036937.07	cm3	First moment at the bottom of main deck plate	ms	1036937.07	cm3	First moment at the bottom of main deck plate
ts	1.11	cm	Side shell thickness at main deck	ts	1.11	cm	Side shell thickness at main deck
Fsw	-1373.40	kN	Shear force due to still water	Fsw	-1373.40	kN	Shear force due to still water
Fwn	-5584.07	kN	Maximum negative shear force	Fwn	-5584.07	kN	Maximum negative shear force
c6	10	-		c6	10	-	
τa	39.96	N/mm2	Applied compressive shear stress due to sag	τa	39.96	N/mm2	Applied compressive shear stress due to sag
CHECKS			CHECKS				
%σoa/σc,p	65%	PASS	Plate compression capacity	%σoa/σc,p	85%	PASS	Plate compression capacity
%σoa/σc,s	15%	PASS	Stiffener compression capacity	%σoa/σc,s	45%	PASS	Stiffener compression capacity
%σoa/σc,tor	15%	PASS	Stiffener torsion capacity	%σoa/σc,tor	48%	PASS	Stiffener torsion capacity
%σoa/σc,web	15%	PASS	Stiffener web compression capacity	%σoa/σc,web	46%	PASS	Stiffener web compression capacity
%τa/τc,p	44%	PASS	Plate shear capacity	%τa/τc,p	25%	PASS	Plate shear capacity

A.4 Midship Section Buckling Checks

Table A8. Midship Section – Main Deck Buckling Checks

Main Deck (Top Fiber)			Main Deck (Top Fiber)		
E	2.06E+05 N/mm ²	Young's elastic modulus	E	2.06E+05 N/mm ²	Young's elastic modulus
3.1 Elastic Buckling of Plates			3.1 Elastic Buckling of Plates		
3.1.1 Compression			3.1.1 Compression		
t	11.1 mm	Plate thickness	t	11.1 mm	Plate thickness
tk	2 mm	Standard deduction in plate	tk	2 mm	Standard deduction in plate
tb	9.1 mm	Net plate thickness	tb	9.1 mm	Net plate thickness
s	635 mm	Short side of plate	s	635 mm	Short side of plate
l	2032 mm	Long side of plate	l	2032 mm	Long side of plate
c	1.21 -	For tee stiffeners	c	1.21 -	For tee stiffeners
ψ	1 -	Assume no stress variation across panel	ψ	1 -	Assume no stress variation across panel
m	4 -	Plating with stiffers parallel to comp stress	m	4 -	Plating with stiffers parallel to comp stress
σ _{E,p}	152.30 N/mm ²	Elastic buckling stress of plate	σ _{E,p}	152.30 N/mm ²	Elastic buckling stress of plate
3.1.2 Shear			3.1.2 Shear		
kt	5.73 -		kt	5.73 -	
τ _{E,p}	218.20 N/mm ²	Elastic buckling shear stress of plate	τ _{E,p}	218.20 N/mm ²	Elastic buckling shear stress of plate
3.3 Elastic Buckling of Longitudinals for WT100X7.5			3.3 Elastic Buckling of Longitudinals for W310X38.7		
3.3.1 Column Buckling without Rotation of the Cross Section			3.3.1 Column Buckling without Rotation of the Cross Section		
I _a	6.23E+02 cm ⁴	Inertia of plate-stiffener	I _a	1.44E+04 cm ⁴	Inertia of plate-stiffener
A	67.335 cm ²	Area of plate-stiffener	A	91.24794 cm ²	Area of plate-stiffener
l	2.032 m	Span length	l	2.032 m	Span length
c ₁	1000 -		c ₁	1000 -	
σ _{E,s}	461.31 N/mm ²	Elastic buckling stress of stiffener	σ _{E,s}	7868.57 N/mm ²	Elastic buckling stress of stiffener
3.3.2 Torsional Buckling Mode for WT100X7.5			3.3.2 Torsional Buckling Mode for W310X38.7		
tw	4.32 mm	Web thickness	tw	5.84 mm	Web thickness
twk	2 mm	Standard deduction in web	twk	2 mm	Standard deduction in web
twb	2.32 mm	Web net thickness	twb	3.84 mm	Web net thickness
tf	5.21 mm	Flange thickness	tf	9.65 mm	Flange thickness
tfk	2 mm	Standard deduction in flange	tfk	2 mm	Standard deduction in flange
tfb	3.21 mm	Flange net thickness	tfb	7.65 mm	Flange net thickness
d	100 mm	Depth of stiffener	d	310 mm	Depth of stiffener
hw	96.79 mm	Height of web	hw	302.35 mm	Height of web
bf	100 mm	width of flange	bf	165 mm	width of flange
s	635 mm	Stiffener spacing	s	635 mm	Stiffener spacing
c ₂	1000000 -		c ₂	1000000 -	
c ₃	0.0001 -		c ₃	0.0001 -	
c ₄	0.000001 -		c ₄	0.000001 -	
np	0.61 -		np	0.61 -	
kp	0.39 -	Not to be less than zero	kp	0.39 -	Not to be less than zero
C	66.60 -		C	89.72 -	
I _t	0.15 cm ⁴	St. Venant's inertia for flanged shapes	I _t	2.96 cm ⁴	St. Venant's inertia for flanged shapes
I _p	370.85 cm ⁴	Polar inertia for flanged shapes	I _p	15076.78 cm ⁴	Polar inertia for flanged shapes
I _w	2506.02 cm ⁶	Warping constant for tee shapes	I _w	261789.35 cm ⁶	Warping constant for tee shapes
K	0.02 -		K	0.00 -	
m	1 -	number of half waves	m	1 -	number of half waves
σ _{E,tor}	371.98 N/mm ²	Elastic buckling torsional stress of stiffener	σ _{E,tor}	870.82 N/mm ²	Elastic buckling torsional stress of stiffener
3.3.3 Web and Flange Buckling for WT100X7.5			3.3.3 Web and Flange Buckling for W310X38.7		
σ _{E,web}	449.74 N/mm ²	Elastic buckling stress of stiffener web	σ _{E,web}	126.27 N/mm ²	Elastic buckling stress of stiffener web
bf/tf	9.6 PASS	Flange buckling check	bf/tf	8.5 PASS	Flange buckling check
5 Critical Buckling Stresses			5 Critical Buckling Stresses		
5.1 Compression			5.1 Compression		
σ _F	355 N/mm ²	Yield strength of AH36	σ _F	355 N/mm ²	Yield strength of AH36
σ _{c,p}	152.30 N/mm ²	Critical buckling stress of plate	σ _{c,p}	152.30 N/mm ²	Critical buckling stress of plate
σ _{c,s}	286.70 N/mm ²	Critical buckling stress of stiffener	σ _{c,s}	351.00 N/mm ²	Critical buckling stress of stiffener
σ _{c,tor}	270.30 N/mm ²	Critical buckling torsional stress of stiffener	σ _{c,tor}	318.82 N/mm ²	Critical buckling torsional stress of stiffener
σ _{c,web}	284.95 N/mm ²	Critical buckling stress of stiffener web	σ _{c,web}	126.27 N/mm ²	Critical buckling stress of stiffener web
5.3 Shear			5.3 Shear		
τ _F	204.96 N/mm ²	Shear strength of AH36	τ _F	204.96 N/mm ²	Shear strength of AH36
τ _{c,p}	156.83 N/mm ²	Critical buckling shear stress of plate	τ _{c,p}	156.83 N/mm ²	Critical buckling shear stress of plate
7 Working Stress			7 Working Stress		
7.1 Longitudinal Compressive Stress			7.1 Longitudinal Compressive Stress		
M _{sw}	51647.19 kN-m	Still water moment	M _{sw}	51647.19 kN-m	Still water moment
M _{ws}	-271425.97 kN-m	Sag wave moment	M _{ws}	-271425.97 kN-m	Sag wave moment
I _n	1157278000 cm ⁴	Hull girder inertia	I _n	1157278000 cm ⁴	Hull girder inertia
y	4.863 m	Distance from NA to extreme upper fiber	y	4.863 m	Distance from NA to extreme upper fiber
Q	0.72 -	Steel strength reduction factor	Q	0.72 -	Steel strength reduction factor
c ₅	100000 -		c ₅	100000 -	
σ _a	92.35 N/mm ²	Applied compressive stress due to sag	σ _a	92.35 N/mm ²	Applied compressive stress due to sag
7.3.1 Ships without Effective Longitudinal Bulkheads			7.3.1 Ships without Effective Longitudinal Bulkheads		
y ₁	342.51 cm	Distance from NA to first moment centroid	y ₁	342.51 cm	Distance from NA to first moment centroid
A ₁	4573.42 cm ²	Area of first moment	A ₁	4573.42 cm ²	Area of first moment
m _s	1566431.11 cm ³	First moment at the bottom of main deck plate	m _s	1566431.11 cm ³	First moment at the bottom of main deck plate
t _s	1.11 cm	Side shell thickness at main deck	t _s	1.11 cm	Side shell thickness at main deck
F _{sw}	1471.50 kN	Shear force due to still water	F _{sw}	1471.50 kN	Shear force due to still water
F _{wn}	6069.64 kN	Maximum negative shear force	F _{wn}	6069.64 kN	Maximum negative shear force
c ₆	10 -		c ₆	10 -	
τ _a	45.98 N/mm ²	Applied compressive shear stress due to sag	τ _a	45.98 N/mm ²	Applied compressive shear stress due to sag
CHECKS			CHECKS		
%σ _{oa} /σ _{c,p}	61% PASS	Plate compression capacity	%σ _{oa} /σ _{c,p}	61% PASS	Plate compression capacity
%σ _{oa} /σ _{c,s}	32% PASS	Stiffener compression capacity	%σ _{oa} /σ _{c,s}	26% PASS	Stiffener compression capacity
%σ _{oa} /σ _{c,tor}	34% PASS	Stiffener torsion capacity	%σ _{oa} /σ _{c,tor}	29% PASS	Stiffener torsion capacity
%σ _{oa} /σ _{c,web}	32% PASS	Stiffener web compression capacity	%σ _{oa} /σ _{c,web}	73% PASS	Stiffener web compression capacity
%τ _a /τ _{c,p}	29% PASS	Plate shear capacity	%τ _a /τ _{c,p}	29% PASS	Plate shear capacity

Table A9. Midship Section – 2nd Deck Buckling Checks

2nd Deck			2nd Deck		
E	2.06E+05 N/mm2	Young's elastic modulus	E	2.06E+05 N/mm2	Young's elastic modulus
3.1 Elastic Buckling of Plates			3.1 Elastic Buckling of Plates		
3.1.1 Compression			3.1.1 Compression		
t	7.9 mm	Plate thickness	t	7.9 mm	Plate thickness
tk	2 mm	Standard deduction in plate	tk	2 mm	Standard deduction in plate
tb	5.9 mm	Net plate thickness	tb	5.9 mm	Net plate thickness
s	635 mm	Short side of plate	s	635 mm	Short side of plate
l	2032 mm	Long side of plate	l	2032 mm	Long side of plate
c	1.21 -	For tee stiffeners	c	1.21 -	For tee stiffeners
ψ	1 -	Assume no stress variation across panel	ψ	1 -	Assume no stress variation across panel
m	4 -	Plating with stiffeners parallel to comp stress	m	4 -	Plating with stiffeners parallel to comp stress
σ _{E,p}	64.02 N/mm2	Elastic buckling stress of plate	σ _{E,p}	64.02 N/mm2	Elastic buckling stress of plate
3.1.2 Shear			3.1.2 Shear		
kt	5.73 -		kt	5.73 -	
τ _{E,p}	91.72 N/mm2	Elastic buckling shear stress of plate	τ _{E,p}	91.72 N/mm2	Elastic buckling shear stress of plate
3.3 Elastic Buckling of Longitudinals for WT100X7.5			3.3 Elastic Buckling of Longitudinals for W310X38.7		
3.3.1 Column Buckling without Rotation of the Cross Section			3.3.1 Column Buckling without Rotation of the Cross Section		
I _a	6.23E+02 cm4	Inertia of plate-stiffener	I _a	1.44E+04 cm4	Inertia of plate-stiffener
A	67.335 cm2	Area of plate-stiffener	A	91.24794 cm2	Area of plate-stiffener
l	2.032 m	Span length	l	2.032 m	Span length
c ₁	1000 -		c ₁	1000 -	
σ _{E,s}	461.31 N/mm2	Elastic buckling stress of stiffener	σ _{E,s}	7868.57 N/mm2	Elastic buckling stress of stiffener
3.3.2 Torsional Buckling Mode for WT100X7.5			3.3.2 Torsional Buckling Mode for W310X38.7		
tw	4.32 mm	Web thickness	tw	5.84 mm	Web thickness
twk	2 mm	Standard deduction in web	twk	2 mm	Standard deduction in web
twb	2.32 mm	Web net thickness	twb	3.84 mm	Web net thickness
tf	5.21 mm	Flange thickness	tf	9.65 mm	Flange thickness
tfk	2 mm	Standard deduction in flange	tfk	2 mm	Standard deduction in flange
tfb	3.21 mm	Flange net thickness	tfb	7.65 mm	Flange net thickness
d	100 mm	Depth of stiffener	d	310 mm	Depth of stiffener
hw	96.79 mm	Height of web	hw	302.35 mm	Height of web
bf	100 mm	width of flange	bf	165 mm	width of flange
s	635 mm	Stiffener spacing	s	635 mm	Stiffener spacing
c ₂	1000000 -		c ₂	1000000 -	
c ₃	0.0001 -		c ₃	0.0001 -	
c ₄	0.000001 -		c ₄	0.000001 -	
np	0.66 -		np	0.66 -	
kp	0.34 -	Not to be less than zero	kp	0.34 -	Not to be less than zero
C	101.83 -		C	122.03 -	
I _t	0.15 cm4	St. Venant's inertia for flanged shapes	I _t	2.96 cm4	St. Venant's inertia for flanged shapes
I _p	370.85 cm4	Polar inertia for flanged shapes	I _p	15076.78 cm4	Polar inertia for flanged shapes
I _w	2506.02 cm6	Warping constant for tee shapes	I _w	261789.35 cm6	Warping constant for tee shapes
K	0.03 -		K	0.00 -	
m	1 -	number of half waves	m	1 -	number of half waves
σ _{E,tor}	375.95 N/mm2	Elastic buckling torsional stress of stiffener	σ _{E,tor}	870.91 N/mm2	Elastic buckling torsional stress of stiffener
3.3.3 Web and Flange Buckling for WT100X7.5			3.3.3 Web and Flange Buckling for W310X38.7		
σ _{E,web}	449.74 N/mm2	Elastic buckling stress of stiffener web	σ _{E,web}	126.27 N/mm2	Elastic buckling stress of stiffener web
bf/tf	9.6 PASS	Flange buckling check	bf/tf	8.5 PASS	Flange buckling check
5 Critical Buckling Stresses			5 Critical Buckling Stresses		
5.1 Compression			5.1 Compression		
σ _F	355 N/mm2	Yield strength of AH36	σ _F	355 N/mm2	Yield strength of AH36
σ _{c,p}	64.02 N/mm2	Critical buckling stress of plate	σ _{c,p}	64.02 N/mm2	Critical buckling stress of plate
σ _{c,s}	286.70 N/mm2	Critical buckling stress of stiffener	σ _{c,s}	351.00 N/mm2	Critical buckling stress of stiffener
σ _{c,tor}	271.20 N/mm2	Critical buckling torsional stress of stiffener	σ _{c,tor}	318.82 N/mm2	Critical buckling torsional stress of stiffener
σ _{c,web}	284.95 N/mm2	Critical buckling stress of stiffener web	σ _{c,web}	126.27 N/mm2	Critical buckling stress of stiffener web
5.3 Shear			5.3 Shear		
τ _F	204.96 N/mm2	Shear strength of AH36	τ _F	204.96 N/mm2	Shear strength of AH36
τ _{c,p}	91.72 N/mm2	Critical buckling shear stress of plate	τ _{c,p}	91.72 N/mm2	Critical buckling shear stress of plate
7 Working Stress			7 Working Stress		
7.1 Longitudinal Compressive Stress			7.1 Longitudinal Compressive Stress		
M _{sw}	51647.19 kN-m	Still water moment	M _{sw}	51647.19 kN-m	Still water moment
M _{ws}	-271425.97 kN-m	Sag wave moment	M _{ws}	-271425.97 kN-m	Sag wave moment
I _n	1157278000 cm4	Hull girder inertia	I _n	1157278000 cm4	Hull girder inertia
y	2.221 m	Distance from NA to extreme upper fiber	y	2.221 m	Distance from NA to extreme upper fiber
Q	0.72 -	Steel strength reduction factor	Q	0.72 -	Steel strength reduction factor
c ₅	100000 -		c ₅	100000 -	
σ _a	42.18 N/mm2	Applied compressive stress due to sag	σ _a	42.18 N/mm2	Applied compressive stress due to sag
7.3.1 Ships without Effective Longitudinal Bulkheads			7.3.1 Ships without Effective Longitudinal Bulkheads		
y ₁	342.51 cm	Distance from NA to first moment centroid	y ₁	342.51 cm	Distance from NA to first moment centroid
A ₁	4573.42 cm2	Area of first moment	A ₁	4573.42 cm2	Area of first moment
m _s	1566431.11 cm3	First moment at the bottom of main deck plate	m _s	1566431.11 cm3	First moment at the bottom of main deck plate
ts	1.11 cm	Side shell thickness at main deck	ts	1.11 cm	Side shell thickness at main deck
F _{sw}	1471.50 kN	Shear force due to still water	F _{sw}	1471.50 kN	Shear force due to still water
F _{wn}	6069.64 kN	Maximum negative shear force	F _{wn}	6069.64 kN	Maximum negative shear force
c ₆	10 -		c ₆	10 -	
τ _a	45.98 N/mm2	Applied compressive shear stress due to sag	τ _a	45.98 N/mm2	Applied compressive shear stress due to sag
CHECKS			CHECKS		
%σ _{oa/oc,p}	66% PASS	Plate compression capacity	%σ _{oa/oc,p}	66% PASS	Plate compression capacity
%σ _{oa/oc,s}	15% PASS	Stiffener compression capacity	%σ _{oa/oc,s}	12% PASS	Stiffener compression capacity
%σ _{oa/oc,tor}	16% PASS	Stiffener torsion capacity	%σ _{oa/oc,tor}	13% PASS	Stiffener torsion capacity
%σ _{oa/oc,web}	15% PASS	Stiffener web compression capacity	%σ _{oa/oc,web}	33% PASS	Stiffener web compression capacity
%τ _{a/τc,p}	50% PASS	Plate shear capacity	%τ _{a/τc,p}	50% PASS	Plate shear capacity

Table A10. Midship Section – Platform and Keel Buckling Checks

Platform			Keel (Bottom Fiber)				
E	2.06E+05	N/mm2	Young's elastic modulus	E	2.06E+05	N/mm2	Young's elastic modulus
3.1 Elastic Buckling of Plates			3.1 Elastic Buckling of Plates				
3.1.1 Compression			3.1.1 Compression				
t	7.9	mm	Plate thickness	t	12.7	mm	Plate thickness
tk	2	mm	Standard deduction in plate	tk	2	mm	Standard deduction in plate
tb	5.9	mm	Net plate thickness	tb	10.7	mm	Net plate thickness
s	635	mm	Short side of plate	s	635	mm	Short side of plate
l	2032	mm	Long side of plate	l	2032	mm	Long side of plate
c	1.21	-	For tee stiffeners	c	1.21	-	For tee stiffeners
ψ	1	-	Assume no stress variation across panel	ψ	1	-	Assume no stress variation across panel
m	4	-	Plating with stiffis parallel to comp stress	m	4	-	Plating with stiffis parallel to comp stress
σE,p	64.02	N/mm2	Elastic buckling stress of plate	σE,p	210.57	N/mm2	Elastic buckling stress of plate
3.1.2 Shear			3.1.2 Shear				
kt	5.73	-		kt	5.73	-	
τE,p	91.72	N/mm2	Elastic buckling shear stress of plate	τE,p	301.67	N/mm2	Elastic buckling shear stress of plate
3.3 Elastic Buckling of Longitudinals for WT100X7.5			3.3 Elastic Buckling of Longitudinals for WT100X7.5				
3.3.1 Column Buckling without Rotation of the Cross Section			3.3.1 Column Buckling without Rotation of the Cross Section				
Ia	6.23E+02	cm4	Inertia of plate-stiffener	Ia	6.23E+02	cm4	Inertia of plate-stiffener
A	67.335	cm2	Area of plate-stiffener	A	67.335	cm2	Area of plate-stiffener
l	2.032	m	Span length	l	2.032	m	Span length
c1	1000	-		c1	1000	-	
σE,s	461.31	N/mm2	Elastic buckling stress of stiffener	σE,s	461.31	N/mm2	Elastic buckling stress of stiffener
3.3.2 Torsional Buckling Mode for WT100X7.5			3.3.2 Torsional Buckling Mode for WT100X7.5				
tw	4.32	mm	Web thickness	tw	4.32	mm	Web thickness
twk	2	mm	Standard deduction in web	twk	2	mm	Standard deduction in web
twb	2.32	mm	Web net thickness	twb	2.32	mm	Web net thickness
tf	5.21	mm	Flange thickness	tf	5.21	mm	Flange thickness
tfk	2	mm	Standard deduction in flange	tfk	2	mm	Standard deduction in flange
tfb	3.21	mm	Flange net thickness	tfb	3.21	mm	Flange net thickness
d	100	mm	Depth of stiffener	d	100	mm	Depth of stiffener
hw	96.79	mm	Height of web	hw	96.79	mm	Height of web
bf	100	mm	width of flange	bf	100	mm	width of flange
s	635	mm	Stiffener spacing	s	635	mm	Stiffener spacing
c2	1000000	-		c2	1000000	-	
c3	0.0001	-		c3	0.0001	-	
c4	0.000001	-		c4	0.000001	-	
np	0.65	-		np	0.47	-	
kp	0.35	-	Not to be less than zero	kp	0.53	-	Not to be less than zero
C	102.93	-		C	53.13	-	
It	0.15	cm4	St. Venant's inertia for flanged shapes	It	0.15	cm4	St. Venant's inertia for flanged shapes
Ip	370.85	cm4	Polar inertia for flanged shapes	Ip	370.85	cm4	Polar inertia for flanged shapes
Iw	2506.02	cm6	Warping constant for tee shapes	Iw	2506.02	cm6	Warping constant for tee shapes
K	0.03	-		K	0.02	-	
m	1	-	number of half waves	m	1	-	number of half waves
σE,tor	376.08	N/mm2	Elastic buckling torsional stress of stiffener	σE,tor	370.46	N/mm2	Elastic buckling torsional stress of stiffener
3.3.3 Web and Flange Buckling for WT100X7.5			3.3.3 Web and Flange Buckling for WT100X7.5				
σE,web	449.74	N/mm2	Elastic buckling stress of stiffener web	σE,web	449.74	N/mm2	Elastic buckling stress of stiffener web
bf/tf	9.6	PASS	Flange buckling check	bf/tf	9.6	PASS	Flange buckling check
5 Critical Buckling Stresses			5 Critical Buckling Stresses				
5.1 Compression			5.1 Compression				
σF	355	N/mm2	Yield strength of AH36	σF	355	N/mm2	Yield strength of AH36
σc,p	64.02	N/mm2	Critical buckling stress of plate	σc,p	205.37	N/mm2	Critical buckling stress of plate
σc,s	286.70	N/mm2	Critical buckling stress of stiffener	σc,s	286.70	N/mm2	Critical buckling stress of stiffener
σc,tor	271.22	N/mm2	Critical buckling torsional stress of stiffener	σc,tor	269.95	N/mm2	Critical buckling torsional stress of stiffener
σc,web	284.95	N/mm2	Critical buckling stress of stiffener web	σc,web	284.95	N/mm2	Critical buckling stress of stiffener web
5.3 Shear			5.3 Shear				
τF	204.96	N/mm2	Shear strength of AH36	τF	204.96	N/mm2	Shear strength of AH36
τc,p	91.72	N/mm2	Critical buckling shear stress of plate	τc,p	170.15	N/mm2	Critical buckling shear stress of plate
7 Working Stress			7 Working Stress				
7.1 Longitudinal Compressive Stress			7.1 Longitudinal Compressive Stress				
Msw	51647.19	kN-m	Still water moment	Msw	51647.19	kN-m	Still water moment
Mwh	216269.89	kN-m	Hog wave moment	Mwh	216269.89	kN-m	Hog wave moment
In	1157278000	cm4	Hull girder inertia	In	1157278000	cm4	Hull girder inertia
y	0.420	m	Distance from NA to extreme upper fiber	y	4.281	m	Distance from NA to extreme upper fiber
Q	0.72	-	Steel strength reduction factor	Q	0.72	-	Steel strength reduction factor
c5	100000	-		c5	100000	-	
σa	41.67	N/mm2	Applied compressive stress due to sag	σa	99.11	N/mm2	Applied compressive stress due to sag
7.3.1 Ships without Effective Longitudinal Bulkheads			7.3.1 Ships without Effective Longitudinal Bulkheads				
y1	342.51	cm	Distance from NA to first moment centroid	y1	342.51	cm	Distance from NA to first moment centroid
A1	4573.42	cm2	Area of first moment	A1	4573.42	cm2	Area of first moment
ms	1566431.11	cm3	First moment at the bottom of main deck plate	ms	1566431.11	cm3	First moment at the bottom of main deck plate
ts	1.11	cm	Side shell thickness at main deck	ts	1.11	cm	Side shell thickness at main deck
Fsw	-1373.40	kN	Shear force due to still water	Fsw	-1373.40	kN	Shear force due to still water
Fwn	-5584.07	kN	Maximum negative shear force	Fwn	-5584.07	kN	Maximum negative shear force
c6	10	-		c6	10	-	
τa	42.42	N/mm2	Applied compressive shear stress due to sag	τa	42.42	N/mm2	Applied compressive shear stress due to sag
CHECKS			CHECKS				
%σoa/σc,p	65%	PASS	Plate compression capacity	%σoa/σc,p	48%	PASS	Plate compression capacity
%σoa/σc,s	15%	PASS	Stiffener compression capacity	%σoa/σc,s	35%	PASS	Stiffener compression capacity
%σoa/σc,tor	15%	PASS	Stiffener torsion capacity	%σoa/σc,tor	37%	PASS	Stiffener torsion capacity
%σoa/σc,web	15%	PASS	Stiffener web compression capacity	%σoa/σc,web	35%	PASS	Stiffener web compression capacity
%τa/τc,p	46%	PASS	Plate shear capacity	%τa/τc,p	25%	PASS	Plate shear capacity

A.5 Stern Section Buckling Checks

Table A11. Stern Section – Main Deck Buckling Checks

Main Deck (Top Fiber)			Main Deck (Top Fiber)		
E	2.06E+05 N/mm ²	Young's elastic modulus	E	2.06E+05 N/mm ²	Young's elastic modulus
3.1 Elastic Buckling of Plates			3.1 Elastic Buckling of Plates		
3.1.1 Compression			3.1.1 Compression		
t	9.7 mm	Plate thickness	t	9.7 mm	Plate thickness
tk	2 mm	Standard deduction in plate	tk	2 mm	Standard deduction in plate
tb	7.7 mm	Net plate thickness	tb	7.7 mm	Net plate thickness
s	635 mm	Short side of plate	s	635 mm	Short side of plate
l	2032 mm	Long side of plate	l	2032 mm	Long side of plate
c	1.21 -	For tee stiffeners	c	1.21 -	For tee stiffeners
ψ	1 -	Assume no stress variation across panel	ψ	1 -	Assume no stress variation across panel
m	4 -	Plating with stiffers parallel to comp stress	m	4 -	Plating with stiffers parallel to comp stress
σ _{E,p}	109.04 N/mm ²	Elastic buckling stress of plate	σ _{E,p}	109.04 N/mm ²	Elastic buckling stress of plate
3.1.2 Shear			3.1.2 Shear		
kt	5.73 -		kt	5.73 -	
τ _{E,p}	156.22 N/mm ²	Elastic buckling shear stress of plate	τ _{E,p}	156.22 N/mm ²	Elastic buckling shear stress of plate
3.3 Elastic Buckling of Longitudinals for WT100X7.5			3.3 Elastic Buckling of Longitudinals for W310X38.7		
3.3.1 Column Buckling without Rotation of the Cross Section			3.3.1 Column Buckling without Rotation of the Cross Section		
I _a	6.23E+02 cm ⁴	Inertia of plate-stiffener	I _a	1.44E+04 cm ⁴	Inertia of plate-stiffener
A	67.335 cm ²	Area of plate-stiffener	A	91.24794 cm ²	Area of plate-stiffener
l	2.032 m	Span length	l	2.032 m	Span length
c ₁	1000 -		c ₁	1000 -	
σ _{E,s}	461.31 N/mm ²	Elastic buckling stress of stiffener	σ _{E,s}	7868.57 N/mm ²	Elastic buckling stress of stiffener
3.3.2 Torsional Buckling Mode for WT100X7.5			3.3.2 Torsional Buckling Mode for W310X38.7		
tw	4.32 mm	Web thickness	tw	5.84 mm	Web thickness
twk	2 mm	Standard deduction in web	twk	2 mm	Standard deduction in web
twb	2.32 mm	Web net thickness	twb	3.84 mm	Web net thickness
tf	5.21 mm	Flange thickness	tf	9.65 mm	Flange thickness
tfk	2 mm	Standard deduction in flange	tfk	2 mm	Standard deduction in flange
tfb	3.21 mm	Flange net thickness	tfb	7.65 mm	Flange net thickness
d	100 mm	Depth of stiffener	d	310 mm	Depth of stiffener
hw	96.79 mm	Height of web	hw	302.35 mm	Height of web
bf	100 mm	width of flange	bf	165 mm	width of flange
s	635 mm	Stiffener spacing	s	635 mm	Stiffener spacing
c ₂	1000000 -		c ₂	1000000 -	
c ₃	0.0001 -		c ₃	0.0001 -	
c ₄	0.000001 -		c ₄	0.000001 -	
np	0.76 -		np	0.76 -	
kp	0.24 -	Not to be less than zero	kp	0.24 -	Not to be less than zero
C	71.41 -		C	89.01 -	
I _t	0.15 cm ⁴	St. Venant's inertia for flanged shapes	I _t	2.96 cm ⁴	St. Venant's inertia for flanged shapes
I _p	370.85 cm ⁴	Polar inertia for flanged shapes	I _p	15076.78 cm ⁴	Polar inertia for flanged shapes
I _w	2506.02 cm ⁶	Warping constant for tee shapes	I _w	261789.35 cm ⁶	Warping constant for tee shapes
K	0.02 -		K	0.00 -	
m	1 -	number of half waves	m	1 -	number of half waves
σ _{E,tor}	372.52 N/mm ²	Elastic buckling torsional stress of stiffener	σ _{E,tor}	870.82 N/mm ²	Elastic buckling torsional stress of stiffener
3.3.3 Web and Flange Buckling for WT100X7.5			3.3.3 Web and Flange Buckling for W310X38.7		
σ _{E,web}	449.74 N/mm ²	Elastic buckling stress of stiffener web	σ _{E,web}	126.27 N/mm ²	Elastic buckling stress of stiffener web
bf/tf	9.6 PASS	Flange buckling check	bf/tf	8.5 PASS	Flange buckling check
5 Critical Buckling Stresses			5 Critical Buckling Stresses		
5.1 Compression			5.1 Compression		
σ _F	355 N/mm ²	Yield strength of AH36	σ _F	355 N/mm ²	Yield strength of AH36
σ _{c,p}	109.04 N/mm ²	Critical buckling stress of plate	σ _{c,p}	109.04 N/mm ²	Critical buckling stress of plate
σ _{c,s}	286.70 N/mm ²	Critical buckling stress of stiffener	σ _{c,s}	351.00 N/mm ²	Critical buckling stress of stiffener
σ _{c,tor}	270.42 N/mm ²	Critical buckling torsional stress of stiffener	σ _{c,tor}	318.82 N/mm ²	Critical buckling torsional stress of stiffener
σ _{c,web}	284.95 N/mm ²	Critical buckling stress of stiffener web	σ _{c,web}	126.27 N/mm ²	Critical buckling stress of stiffener web
5.3 Shear			5.3 Shear		
τ _F	204.96 N/mm ²	Shear strength of AH36	τ _F	204.96 N/mm ²	Shear strength of AH36
τ _{c,p}	137.73 N/mm ²	Critical buckling shear stress of plate	τ _{c,p}	137.73 N/mm ²	Critical buckling shear stress of plate
7 Working Stress			7 Working Stress		
7.1 Longitudinal Compressive Stress			7.1 Longitudinal Compressive Stress		
M _{sw}	33418.77 kN-m	Still water moment	M _{sw}	33418.77 kN-m	Still water moment
M _{ws}	-169641.23 kN-m	Sag wave moment	M _{ws}	-169641.23 kN-m	Sag wave moment
I _n	586411900 cm ⁴	Hull girder inertia	I _n	586411900 cm ⁴	Hull girder inertia
y	3.589 m	Distance from NA to extreme upper fiber	y	3.589 m	Distance from NA to extreme upper fiber
Q	0.72 -	Steel strength reduction factor	Q	0.72 -	Steel strength reduction factor
c ₅	100000 -		c ₅	100000 -	
σ _a	83.38 N/mm ²	Applied compressive stress due to sag	σ _a	83.38 N/mm ²	Applied compressive stress due to sag
7.3.1 Ships without Effective Longitudinal Bulkheads			7.3.1 Ships without Effective Longitudinal Bulkheads		
y ₁	228.88 cm	Distance from NA to first moment centroid	y ₁	228.88 cm	Distance from NA to first moment centroid
A ₁	3967.36 cm ²	Area of first moment	A ₁	3967.36 cm ²	Area of first moment
m _s	908063.12 cm ³	First moment at the bottom of main deck plate	m _s	908063.12 cm ³	First moment at the bottom of main deck plate
t _s	1.11 cm	Side shell thickness at main deck	t _s	1.11 cm	Side shell thickness at main deck
F _{sw}	1471.50 kN	Shear force due to still water	F _{sw}	1471.50 kN	Shear force due to still water
F _{wn}	6069.64 kN	Maximum negative shear force	F _{wn}	6069.64 kN	Maximum negative shear force
c ₆	10 -		c ₆	10 -	
τ _a	52.60 N/mm ²	Applied compressive shear stress due to sag	τ _a	52.60 N/mm ²	Applied compressive shear stress due to sag
CHECKS			CHECKS		
%σ _{oa} /σ _{c,p}	76% PASS	Plate compression capacity	%σ _{oa} /σ _{c,p}	76% PASS	Plate compression capacity
%σ _{oa} /σ _{c,s}	29% PASS	Stiffener compression capacity	%σ _{oa} /σ _{c,s}	24% PASS	Stiffener compression capacity
%σ _{oa} /σ _{c,tor}	31% PASS	Stiffener torsion capacity	%σ _{oa} /σ _{c,tor}	26% PASS	Stiffener torsion capacity
%σ _{oa} /σ _{c,web}	29% PASS	Stiffener web compression capacity	%σ _{oa} /σ _{c,web}	66% PASS	Stiffener web compression capacity
%τ _a /τ _{c,p}	38% PASS	Plate shear capacity	%τ _a /τ _{c,p}	38% PASS	Plate shear capacity

Table A12. Stern Section – 2nd Deck Buckling Checks

2nd Deck			2nd Deck		
E	2.06E+05 N/mm2	Young's elastic modulus	E	2.06E+05 N/mm2	Young's elastic modulus
3.1 Elastic Buckling of Plates			3.1 Elastic Buckling of Plates		
3.1.1 Compression			3.1.1 Compression		
t	7.9 mm	Plate thickness	t	7.9 mm	Plate thickness
tk	2 mm	Standard deduction in plate	tk	2 mm	Standard deduction in plate
tb	5.9 mm	Net plate thickness	tb	5.9 mm	Net plate thickness
s	635 mm	Short side of plate	s	635 mm	Short side of plate
l	2032 mm	Long side of plate	l	2032 mm	Long side of plate
c	1.21 -	For tee stiffeners	c	1.21 -	For tee stiffeners
ψ	1 -	Assume no stress variation across panel	ψ	1 -	Assume no stress variation across panel
m	4 -	Plating with stiffeners parallel to comp stress	m	4 -	Plating with stiffeners parallel to comp stress
σ _{E,p}	64.02 N/mm2	Elastic buckling stress of plate	σ _{E,p}	64.02 N/mm2	Elastic buckling stress of plate
3.1.2 Shear			3.1.2 Shear		
kt	5.73 -		kt	5.73 -	
τ _{E,p}	91.72 N/mm2	Elastic buckling shear stress of plate	τ _{E,p}	91.72 N/mm2	Elastic buckling shear stress of plate
3.3 Elastic Buckling of Longitudinals for WT100X7.5			3.3 Elastic Buckling of Longitudinals for W310X38.7		
3.3.1 Column Buckling without Rotation of the Cross Section			3.3.1 Column Buckling without Rotation of the Cross Section		
I _a	6.23E+02 cm4	Inertia of plate-stiffener	I _a	1.44E+04 cm4	Inertia of plate-stiffener
A	67.335 cm2	Area of plate-stiffener	A	91.24794 cm2	Area of plate-stiffener
l	2.032 m	Span length	l	2.032 m	Span length
c ₁	1000 -		c ₁	1000 -	
σ _{E,s}	461.31 N/mm2	Elastic buckling stress of stiffener	σ _{E,s}	7868.57 N/mm2	Elastic buckling stress of stiffener
3.3.2 Torsional Buckling Mode for WT100X7.5			3.3.2 Torsional Buckling Mode for W310X38.7		
tw	4.32 mm	Web thickness	tw	5.84 mm	Web thickness
twk	2 mm	Standard deduction in web	twk	2 mm	Standard deduction in web
twb	2.32 mm	Web net thickness	twb	3.84 mm	Web net thickness
tf	5.21 mm	Flange thickness	tf	9.65 mm	Flange thickness
tfk	2 mm	Standard deduction in flange	tfk	2 mm	Standard deduction in flange
tfb	3.21 mm	Flange net thickness	tfb	7.65 mm	Flange net thickness
d	100 mm	Depth of stiffener	d	310 mm	Depth of stiffener
hw	96.79 mm	Height of web	hw	302.35 mm	Height of web
bf	100 mm	width of flange	bf	165 mm	width of flange
s	635 mm	Stiffener spacing	s	635 mm	Stiffener spacing
c ₂	1000000 -		c ₂	1000000 -	
c ₃	0.0001 -		c ₃	0.0001 -	
c ₄	0.000001 -		c ₄	0.000001 -	
np	0.65 -		np	0.65 -	
kp	0.35 -	Not to be less than zero	kp	0.35 -	Not to be less than zero
C	102.93 -		C	123.62 -	
I _t	0.15 cm4	St. Venant's inertia for flanged shapes	I _t	2.96 cm4	St. Venant's inertia for flanged shapes
I _p	370.85 cm4	Polar inertia for flanged shapes	I _p	15076.78 cm4	Polar inertia for flanged shapes
I _w	2506.02 cm6	Warping constant for tee shapes	I _w	261789.35 cm6	Warping constant for tee shapes
K	0.03 -		K	0.00 -	
m	1 -	number of half waves	m	1 -	number of half waves
σ _{E,tor}	376.08 N/mm2	Elastic buckling torsional stress of stiffener	σ _{E,tor}	870.91 N/mm2	Elastic buckling torsional stress of stiffener
3.3.3 Web and Flange Buckling for WT100X7.5			3.3.3 Web and Flange Buckling for W310X38.7		
σ _{E,web}	449.74 N/mm2	Elastic buckling stress of stiffener web	σ _{E,web}	126.27 N/mm2	Elastic buckling stress of stiffener web
bf/tf	9.6 PASS	Flange buckling check	bf/tf	8.5 PASS	Flange buckling check
5 Critical Buckling Stresses			5 Critical Buckling Stresses		
5.1 Compression			5.1 Compression		
σ _F	355 N/mm2	Yield strength of AH36	σ _F	355 N/mm2	Yield strength of AH36
σ _{c,p}	64.02 N/mm2	Critical buckling stress of plate	σ _{c,p}	64.02 N/mm2	Critical buckling stress of plate
σ _{c,s}	286.70 N/mm2	Critical buckling stress of stiffener	σ _{c,s}	351.00 N/mm2	Critical buckling stress of stiffener
σ _{c,tor}	271.22 N/mm2	Critical buckling torsional stress of stiffener	σ _{c,tor}	318.82 N/mm2	Critical buckling torsional stress of stiffener
σ _{c,web}	284.95 N/mm2	Critical buckling stress of stiffener web	σ _{c,web}	126.27 N/mm2	Critical buckling stress of stiffener web
5.3 Shear			5.3 Shear		
τ _F	204.96 N/mm2	Shear strength of AH36	τ _F	204.96 N/mm2	Shear strength of AH36
τ _{c,p}	91.72 N/mm2	Critical buckling shear stress of plate	τ _{c,p}	91.72 N/mm2	Critical buckling shear stress of plate
7 Working Stress			7 Working Stress		
7.1 Longitudinal Compressive Stress			7.1 Longitudinal Compressive Stress		
M _{sw}	33418.77 kN-m	Still water moment	M _{sw}	33418.77 kN-m	Still water moment
M _{ws}	-169641.23 kN-m	Sag wave moment	M _{ws}	-169641.23 kN-m	Sag wave moment
I _n	586411900 cm4	Hull girder inertia	I _n	586411900 cm4	Hull girder inertia
y	0.948 m	Distance from NA to extreme upper fiber	y	0.948 m	Distance from NA to extreme upper fiber
Q	0.72 -	Steel strength reduction factor	Q	0.72 -	Steel strength reduction factor
c ₅	100000 -		c ₅	100000 -	
σ _a	41.67 N/mm2	Applied compressive stress due to sag	σ _a	41.67 N/mm2	Applied compressive stress due to sag
7.3.1 Ships without Effective Longitudinal Bulkheads			7.3.1 Ships without Effective Longitudinal Bulkheads		
y ₁	228.88 cm	Distance from NA to first moment centroid	y ₁	228.88 cm	Distance from NA to first moment centroid
A ₁	3967.36 cm2	Area of first moment	A ₁	3967.36 cm2	Area of first moment
M _s	908063.12 cm3	First moment at the bottom of main deck plate	M _s	908063.12 cm3	First moment at the bottom of main deck plate
ts	1.11 cm	Side shell thickness at main deck	ts	1.11 cm	Side shell thickness at main deck
F _{sw}	1471.50 kN	Shear force due to still water	F _{sw}	1471.50 kN	Shear force due to still water
F _{wn}	6069.64 kN	Maximum negative shear force	F _{wn}	6069.64 kN	Maximum negative shear force
c ₆	10 -		c ₆	10 -	
τ _a	52.60 N/mm2	Applied compressive shear stress due to sag	τ _a	52.60 N/mm2	Applied compressive shear stress due to sag
CHECKS			CHECKS		
%σ _{oa} /σ _{c,p}	65% PASS	Plate compression capacity	%σ _{oa} /σ _{c,p}	65% PASS	Plate compression capacity
%σ _{oa} /σ _{c,s}	15% PASS	Stiffener compression capacity	%σ _{oa} /σ _{c,s}	12% PASS	Stiffener compression capacity
%σ _{oa} /σ _{c,tor}	15% PASS	Stiffener torsion capacity	%σ _{oa} /σ _{c,tor}	13% PASS	Stiffener torsion capacity
%σ _{oa} /σ _{c,web}	15% PASS	Stiffener web compression capacity	%σ _{oa} /σ _{c,web}	33% PASS	Stiffener web compression capacity
%τ _a /τ _{c,p}	57% PASS	Plate shear capacity	%τ _a /τ _{c,p}	57% PASS	Plate shear capacity

Table A13. Stern Section – Platform and Keel Buckling Checks

Platform			Keel (Bottom Fiber)		
E	2.06E+05 N/mm2	Young's elastic modulus	E	2.06E+05 N/mm2	Young's elastic modulus
3.1 Elastic Buckling of Plates			3.1 Elastic Buckling of Plates		
3.1.1 Compression			3.1.1 Compression		
t	7.9 mm	Plate thickness	t	11.1 mm	Plate thickness
tk	2 mm	Standard deduction in plate	tk	2 mm	Standard deduction in plate
tb	5.9 mm	Net plate thickness	tb	9.1 mm	Net plate thickness
s	635 mm	Short side of plate	s	635 mm	Short side of plate
l	2032 mm	Long side of plate	l	2032 mm	Long side of plate
c	1.21	For tee stiffeners	c	1.21	For tee stiffeners
ψ	1	Assume no stress variation across panel	ψ	1	Assume no stress variation across panel
m	4	Plating with stiffis parallel to comp stress	m	4	Plating with stiffis parallel to comp stress
σE,p	64.02 N/mm2	Elastic buckling stress of plate	σE,p	152.30 N/mm2	Elastic buckling stress of plate
3.1.2 Shear			3.1.2 Shear		
kt	5.73		kt	5.73	
τE,p	91.72 N/mm2	Elastic buckling shear stress of plate	τE,p	218.20 N/mm2	Elastic buckling shear stress of plate
3.3 Elastic Buckling of Longitudinals for WT100X7.5			3.3 Elastic Buckling of Longitudinals for WT100X7.5		
3.3.1 Column Buckling without Rotation of the Cross Section			3.3.1 Column Buckling without Rotation of the Cross Section		
Ia	6.23E+02 cm4	Inertia of plate-stiffener	Ia	6.23E+02 cm4	Inertia of plate-stiffener
A	67.335 cm2	Area of plate-stiffener	A	67.335 cm2	Area of plate-stiffener
l	2.032 m	Span length	l	2.032 m	Span length
c1	1000		c1	1000	
σE,s	461.31 N/mm2	Elastic buckling stress of stiffener	σE,s	461.31 N/mm2	Elastic buckling stress of stiffener
3.3.2 Torsional Buckling Mode for WT100X7.5			3.3.2 Torsional Buckling Mode for WT100X7.5		
tw	4.32 mm	Web thickness	tw	4.32 mm	Web thickness
twk	2 mm	Standard deduction in web	twk	2 mm	Standard deduction in web
twb	2.32 mm	Web net thickness	twb	2.32 mm	Web net thickness
tf	5.21 mm	Flange thickness	tf	5.21 mm	Flange thickness
tfk	2 mm	Standard deduction in flange	tfk	2 mm	Standard deduction in flange
tfb	3.21 mm	Flange net thickness	tfb	3.21 mm	Flange net thickness
d	100 mm	Depth of stiffener	d	100 mm	Depth of stiffener
hw	96.79 mm	Height of web	hw	96.79 mm	Height of web
bf	100 mm	width of flange	bf	100 mm	width of flange
s	635 mm	Stiffener spacing	s	635 mm	Stiffener spacing
c2	1000000		c2	1000000	
c3	0.0001		c3	0.0001	
c4	0.000001		c4	0.000001	
np	0.76		np	0.78	
kp	0.24	Not to be less than zero	kp	0.22	Not to be less than zero
C	84.93		C	58.50	
It	0.15 cm4	St. Venant's inertia for flanged shapes	It	0.15 cm4	St. Venant's inertia for flanged shapes
Ip	370.85 cm4	Polar inertia for flanged shapes	Ip	370.85 cm4	Polar inertia for flanged shapes
Iw	2506.02 cm6	Warping constant for tee shapes	Iw	2506.02 cm6	Warping constant for tee shapes
K	0.03		K	0.02	
m	1	number of half waves	m	1	number of half waves
σE,tor	374.04 N/mm2	Elastic buckling torsional stress of stiffener	σE,tor	371.06 N/mm2	Elastic buckling torsional stress of stiffener
3.3.3 Web and Flange Buckling for WT100X7.5			3.3.3 Web and Flange Buckling for WT100X7.5		
σE,web	449.74 N/mm2	Elastic buckling stress of stiffener web	σE,web	449.74 N/mm2	Elastic buckling stress of stiffener web
bf/tf	9.6 PASS	Flange buckling check	bf/tf	9.6 PASS	Flange buckling check
5 Critical Buckling Stresses			5 Critical Buckling Stresses		
5.1 Compression			5.1 Compression		
σF	355 N/mm2	Yield strength of AH36	σF	355 N/mm2	Yield strength of AH36
σc,p	64.02 N/mm2	Critical buckling stress of plate	σc,p	152.30 N/mm2	Critical buckling stress of plate
σc,s	286.70 N/mm2	Critical buckling stress of stiffener	σc,s	286.70 N/mm2	Critical buckling stress of stiffener
σc,tor	270.77 N/mm2	Critical buckling torsional stress of stiffener	σc,tor	270.09 N/mm2	Critical buckling torsional stress of stiffener
σc,web	284.95 N/mm2	Critical buckling stress of stiffener web	σc,web	284.95 N/mm2	Critical buckling stress of stiffener web
5.3 Shear			5.3 Shear		
τF	204.96 N/mm2	Shear strength of AH36	τF	204.96 N/mm2	Shear strength of AH36
τc,p	91.72 N/mm2	Critical buckling shear stress of plate	τc,p	156.83 N/mm2	Critical buckling shear stress of plate
7 Working Stress			7 Working Stress		
7.1 Longitudinal Compressive Stress			7.1 Longitudinal Compressive Stress		
Msw	33418.77 kN-m	Still water moment	Msw	33418.77 kN-m	Still water moment
Mwh	135168.68 kN-m	Hog wave moment	Mwh	135168.68 kN-m	Hog wave moment
In	586411900 cm4	Hull girder inertia	In	586411900 cm4	Hull girder inertia
y	1.694 m	Distance from NA to extreme upper fiber	y	4.143 m	Distance from NA to extreme upper fiber
Q	0.72	Steel strength reduction factor	Q	0.72	Steel strength reduction factor
c5	100000		c5	100000	
σa	48.70 N/mm2	Applied compressive stress due to sag	σa	119.11 N/mm2	Applied compressive stress due to sag
7.3.1 Ships without Effective Longitudinal Bulkheads			7.3.1 Ships without Effective Longitudinal Bulkheads		
y1	228.88 cm	Distance from NA to first moment centroid	y1	228.88 cm	Distance from NA to first moment centroid
A1	3967.36 cm2	Area of first moment	A1	3967.36 cm2	Area of first moment
ms	908063.12 cm3	First moment at the bottom of main deck plate	ms	908063.12 cm3	First moment at the bottom of main deck plate
ts	1.11 cm	Side shell thickness at main deck	ts	1.11 cm	Side shell thickness at main deck
Fsw	-1373.40 kN	Shear force due to still water	Fsw	-1373.40 kN	Shear force due to still water
Fwn	-5584.07 kN	Maximum negative shear force	Fwn	-5584.07 kN	Maximum negative shear force
c6	10		c6	10	
τa	48.53 N/mm2	Applied compressive shear stress due to sag	τa	48.53 N/mm2	Applied compressive shear stress due to sag
CHECKS			CHECKS		
%βoa/σc,p	76% PASS	Plate compression capacity	%βoa/σc,p	78% PASS	Plate compression capacity
%βoa/σc,s	17% PASS	Stiffener compression capacity	%βoa/σc,s	42% PASS	Stiffener compression capacity
%βoa/σc,tor	18% PASS	Stiffener torsion capacity	%βoa/σc,tor	44% PASS	Stiffener torsion capacity
%βoa/σc,web	17% PASS	Stiffener web compression capacity	%βoa/σc,web	42% PASS	Stiffener web compression capacity
%τa/τc,p	53% PASS	Plate shear capacity	%τa/τc,p	31% PASS	Plate shear capacity

A.6 References

American Bureau of Shipping. (2022a). *Part 2: Rules for materials and welding*. Rules for Building and Classing Marine Vessels.

American Bureau of Shipping. (2022b). *Part 3: Hull construction and equipment*. Rules for Building and Classing Marine Vessels.

American Institute of Steel Construction (2017). *AISC Steel Construction Manual* (15th Edition).

