

# Automated Modelling of Ship Structures in Early Ship Design Phase

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## ABSTRACT

### Automated Modelling of Ship Structures in Early Ship Design Phase

By **PERUMANA THOMAS Hans**

3D modelling is a process which takes several months during the initial design phase. In addition to the initial time period taken to generate the model, every minor change in subsequent design or calculation demands for a modification in the 3D model. These problems seek for automation in such model generation which can have a significant impact on man-hours saved in the early design phases.

The New version of NAPA Designer recently incorporated the possibility to access and edit the 3D model with the help of integrated scripting platform by C#. This upgrade gives the user a wide range of opportunities to customise the 3D model as per user requirements and specifications.

The objective of this thesis is to automate the 3D modelling of ship steel structures like plates and structural elements, using the scripting language platform offered in the new “NAPA Designer”. The execution of those scripts can automatically generate vertical walls based on imported GAP drawing in .dxf format. It is also equipped to create primary and secondary elements on to those generated surfaces based on minimum manual inputs. For accurate model generation considerations have been given to ignore the overlapping of stiffeners with girders or any walls. Local modification of modelling is also automated in case of comments from class/client. The codes have been checked and verified to ensure functionality and diversity with various structural elements and types.

With the implementation of these codes, the steel structural model is generated at an early stage of the basic design, which helps the user to carry out accurate finite element global strength analysis of the vessel by exporting the meshed structural model from NAPA. This model can also be used to generate CAD structural and plan drawings with precision and quality for class submission.

**Keywords:** Structural Modelling, Early Design Phase, Automation, NAPA

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## **LIST OF ABBREVIATIONS**

1. CAD: Computer aided Design
2. CAM: Computer aided Manufacturing
3. FEA: Finite element Analysis
4. FEM: Finite element modelling
5. GAP: General arrangement plan
6. LNG: Liquefied natural gas
7. MODU: Mobile Offshore Drilling Units
8. F E M: Finite Element Method
9. GAP: General Arrangement Plan
10. CNC: Computer Numerical Control
11. API: American Petroleum Institute
12. SOLAS: Safety of Life at Sea
13. IACS: International Association of Classification Societies
14. HVAC: Heating, ventilation, and air conditioning
15. SPS: Special Purpose Ship
16. ACV: Air Cushion Vessel

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## DECLARATION OF AUTHORSHIP

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## 1. INTRODUCTION

Shipping industry is currently considered to be the largest means of transport all across the world. International shipping carries 90% of the world's trade and hence is considered as lynchpin of the world economy. Shipping now a days is used for recreational, oil and gas, commercial and military purposes. The possibilities and applications of shipping industries are increasing every year based on the current world requirements. The implementation of LNG Carriers for LNG transport, air cushion vessels (ACV) or hovercraft for military purposes, MODU (Mobile offshore drilling units) to create cheap and faster drilling are some examples.

According to the statistics as shown in Figure 1, the necessity of almost all types of ships remained constant or progressive during the period from 2008 to 2017. These progressive figures are maintained during a period where a huge economic blow hit the shipping industry. Hence, this clearly indicates the high demand of shipping industry for the present world in any circumstances.

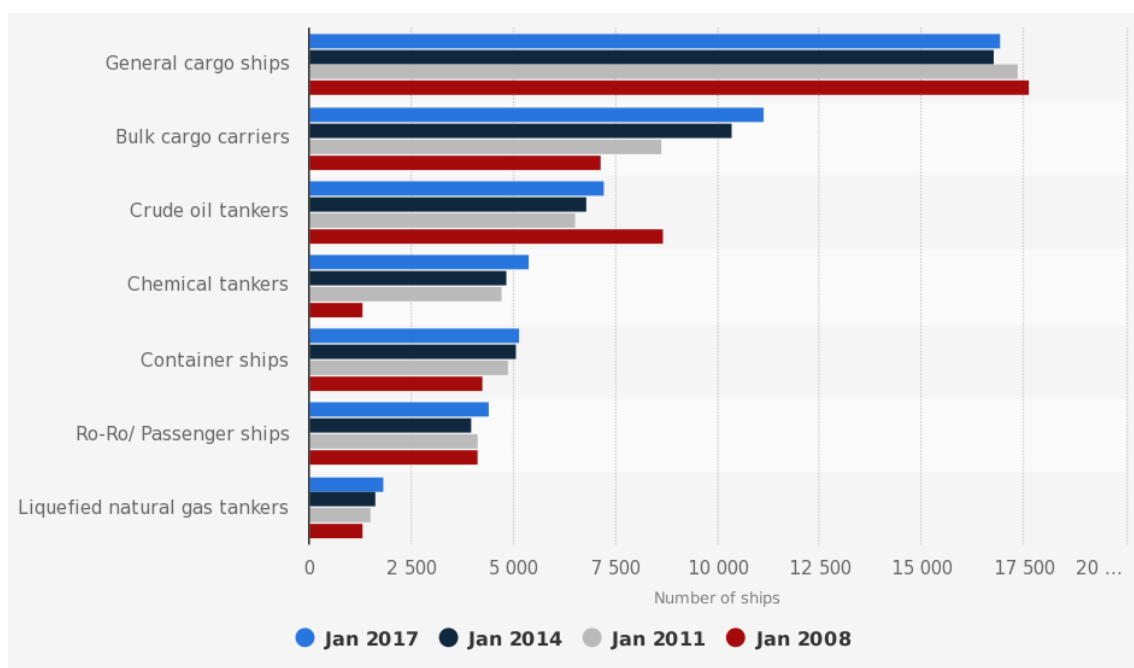


Figure 1: Statistics showing numbers of ships in demand from 2008 to 2017 [1]

The ship construction is a vast process which takes months or years of discussions, calculations, document preparations, approvals and production at the end. The whole ship building process can be categorized mainly into two segments (a) design phase and (b) production.

Design is a very substantial and vital stage in shipbuilding as it lies as the bridge between client requirements and final product, which in this case is a ship. The ship design itself comprises of various stages based on the documents dealt within each stage. Ship design contain of design spiral, which is a loop of all the major tasks the design stage undergoes during its progress towards production. Pictorial representation of design spiral is shown in Figure 2.

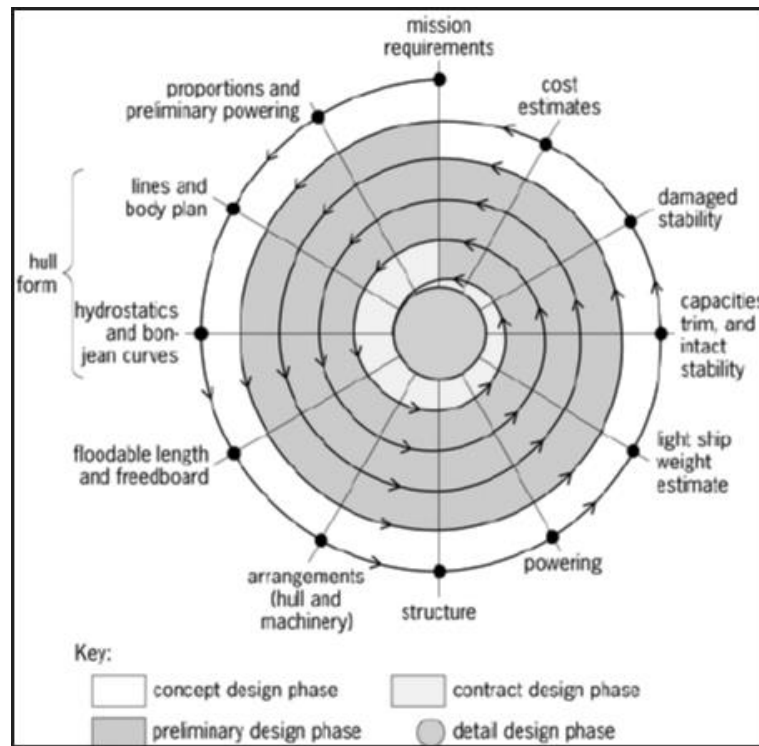


Figure 2: Design Spiral in Shipbuilding Industry [2]

As shown in Figure 2, the design stage in ship building is categorized into four (4) major phases:

1. Concept design phase
2. Preliminary design phase
3. Contract design phase
4. Detail design phase

As shown in Figure 2, the design spiral contains of several loops which indicates the different iterations the ship design has to undergo. Once you start with the design process and at some moment you had to make some major changes in initial ship particulars or any such major parameters then loop will be terminated and design spiral will be started from the beginning. This is the reason why decisions in initial design phases are very critical. And due to this importance, each and every step-in early design phase is taken very carefully and much consideration, so to eliminate possible errors. Any automation or any means to make



calculations faster with good accuracy is always welcomed in early design phase as it will save a huge amount of time.

### **1.1. General Overview of the Topic**

This thesis is based on a kind of automation which needs to be implemented in early design phase. The topic is focused on automating the 3D modelling of ship structures in early design phase by which a plenty of time can be saved. Now a days in shipbuilding industry, 3D models are used for various tasks like drawing generation, 3D visualization, model export for FEA, model export for stability calculation and many other uses. So, by making the structure model generation faster the whole ship design process will be shortened and thereby the shipbuilding process in complete will be faster.

The user who will be using this automation process generally will be a shipyard or design office who handle the design process and 3D modelling. So, hereafter the term user is defined for anyone who will be dealt with 3D structure modelling like shipyard, design office or any freelance modellers.

This thesis is done in collaboration with M V Werften GmbH, where the practical works are carried out. For executing this task, the 3D modelling software used in M V Werften which is NAPA Designer is utilized. The new NAPA Designer is integrated with the script editor, which will help the user to access and modify the model using scripting. So, this automation is made to happen with the help of the scripting platform provided in NAPA Designer. The scripting language used in NAPA is Microsoft generated C# which is having access to its general C# libraries, in addition to the special NAPA library.

So, by implementing this automation the 3D model generation will be more spontaneous and easier. By making the 3D structure model so early, user can export a meshed finite element model for finite element analysis. This finite element model can be used in any of the FE software to evaluate the global strength of the ship at an early design stage. This gives the user more flexibility to handle the structure design in preliminary and detail design phase with more freedom based on the initial global strength results.

### **1.2. Scope of the Topic**

The scope of this thesis is a rapid 3D structure model generation in the early phase of design. A rapid generation of 3D structure model based on general arrangement plan and structural details

at early design stage is vital. So, the focus would be on generating a 3D structure model with ship structural parts like decks, bulkheads, other walls and structural members like stiffeners, primary members etc.

3D structure model generated using this method will be exported to any finite element software for global strength analysis. So, the main aim will be to generate a 3D structural model with all structural members which will be influential in global strength like plates, secondary and primary members. So, structural details such as brackets, cut-outs, end cuts etc. will not be given much attention during this stage. By implementing this tool, the shipyard can realize about its margin of safety in global strength at very early stage of design. This will give the shipyard its freedom in structural design and structural arrangements during basic and detail design.

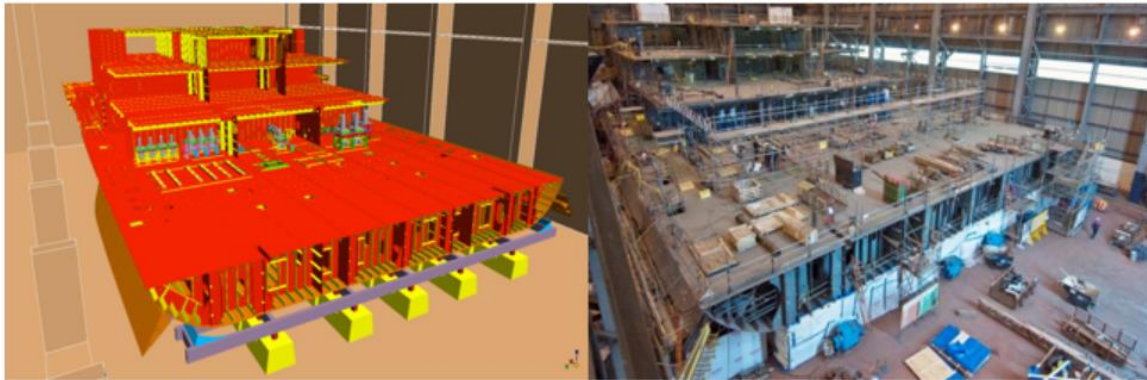


Figure 3: 3D Model generated in line with production [3]

The model generated as part of this thesis work is expected to have the following features for compliance with the current user requirements:

- Horizontal decks need to be generated.
- Generated horizontal decks should be trimmed within hull boundaries.
- From general arrangement plan CAD drawings prepared during concept design stage, vertical walls or bulkheads needs to be generated.
- As bulkheads with similar structure type within a portion of ship is subjected to similar stress range, the structural details and structural stiffening on those bulkheads will be similar. So, taking this into account, a selection criterion should be generated so that bulkheads with COG (centre of gravity) coming inside bounding box made of vertical, transverse and longitudinal limits is possible. For example, longitudinal bulkhead within lower decks between  $0.4L$  to  $0.6L$  is expected to expose to same global and local

loads and hence the thickness and stiffeners in all such bulkheads in that region will be same.

- Stiffeners should be generated on every frame and girders on web frames. The direction on which the stiffeners and girder should be created should be manually given.
- Transverse girders should be always made at web frame. While, longitudinal girders on decks and vertical girders on transverse bulkhead should be generated at required locations, as it could be non-symmetric and random.
- Provision should be taken to eliminate stiffeners when stiffener and girder overlaps. This will occur only when both stiffener and girder is of same stiffening type.
- Provision should be taken to eliminate stiffeners/girder where stiffener/girder and bulkheads overlaps. This will occur only when vertical stiffening system is followed for stiffeners/girders.

This is achieved using the NAPA steel software so to generate a script template driven modelling which could be a substantial time saving method at the early design stage for ships. The NAPA steel is a system orientated towards modelling of steel structures during concept and basic design. The NAPA Designer (new NAPA steel) offers a feature for its users to customize the model with its scripting platform.

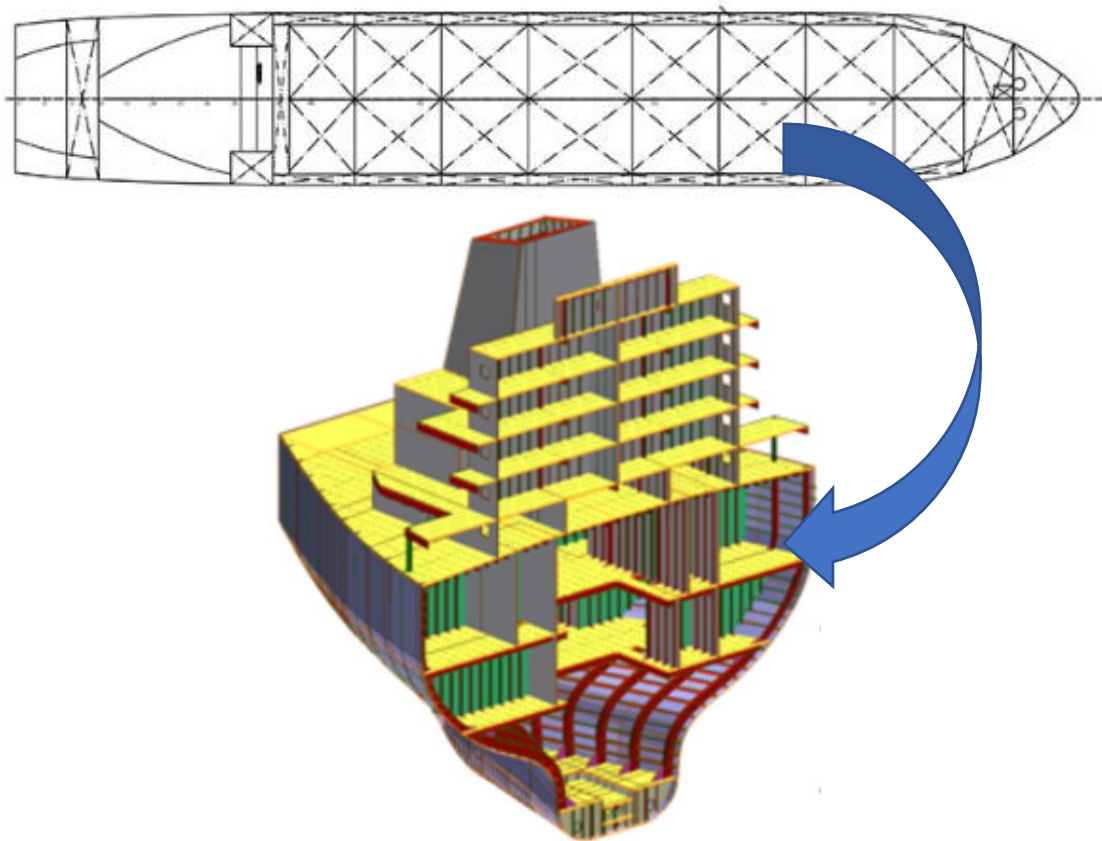


Figure 4: 2D CAD general arrangement plan is converted to a 3D structural model

The requirement also demands to maintain the exact dimension of plate structure as in the 2D drawings in the generated 3D model. In addition to that it also calls for maintaining the size of the primary and secondary stiffening as given in the 2D drawing. All these requirements have to be made automatically for individual structural members based on the imported 2D drawings. So, by successfully executing these processes a substantial amount of time saving can be achieved.

### 1.3. Methodology

Generally, during early design phase only limited information will be available about the ship. During preliminary design phase, basic drawings like general arrangement plan, lines plan and capacity plan are prepared. Also, structural details like stiffener size, plate thickness and girder size etc. are prepared, further to the scantling calculation. So, the 3D structural model should be generated with these set of limited available data.

For generating 3D structural model, general arrangement plan (GAP) and hull form are required as pre-requisites. Hull form can be generated using the lines plan prepared during early design phase. This thesis work will be done using NAPA Designer. So, the methodology for the execution of thesis work is done considering the tools and features offered by NAPA.

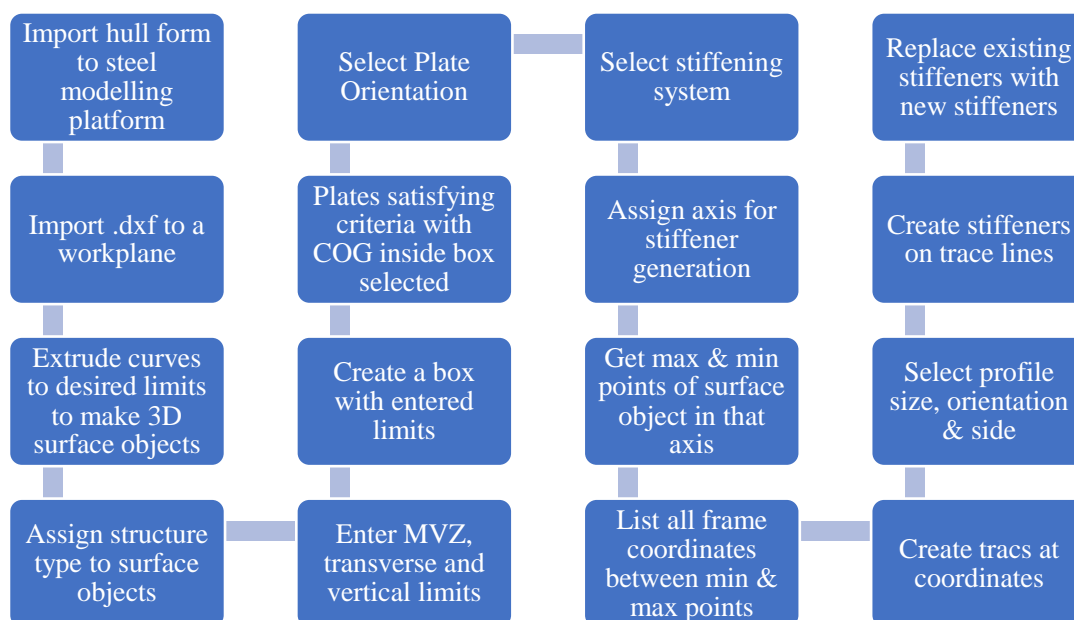


Figure 5: Flow chart showing the planned procedure for 3D model generation

Once the pre-requisites are available, then the general arrangement plan (GAP) in CAD format need to be imported into NAPA Designer. The curves from imported general arrangement plan

will be extruded within minimum and maximum limit to make 3D surfaces. Similarly, horizontal decks will be generated in required vertical heights. Structure type like LBH, TBH\_WT, DECK etc. will be assigned to each surface.

The longitudinal, vertical and transverse limits will be manually given. Using these limits, a bounding box will be generated and surfaces with centre of gravity (COG) coming inside bounding box with any specific structure type are selected. Maximum and minimum points of the selected surfaces will be selected. Coordinate values for each frame between minimum and maximum points will be selected. Based on the stiffening direction, trace lines will be generated at coordinate values. Stiffener will be generated on each trace line. This will be repeated with a loop function to generate stiffener in all trace line in that surface.

When existing stiffeners on a surface need to be replaced with a new stiffener, the existing stiffener is deleted by maintain the trace lines. The new stiffener will be assigned at trace line. This can be repeated for all selected surfaces using the help of a loop function.

## **1.4. Software Used**

### **1.4.1. *NAPA Designer***

The practical works for this thesis is done in a 3D modelling software named NAPA. The NAPA is having an integrated tool to carry out several structural tasks named NAPA Designer. NAPA Designer is a software feature which enables us to model plates, structural elements and other structural parts. It also features generation of structural drawing, meshing of structural model for FE software export, outfit design and numeric data for weight, COG, weld length, BOM and other functionalities. This NAPA Designer is the new version of old NAPA structural software called NAPA steel. Majority of this thesis had been carried out in NAPA Designer as our goal is to automate the structure modelling.

NAPA has been the preferred partner for industry's leading organizations for several decades. NAPA for design incorporates state of the art hull surface and 3D model definition with advanced hydrodynamic, stability and structural design software tools, thus enabling the handling of all aspects of an efficient design at the early design stages in a single software system.

#### **1.4.2. *Microsoft Excel***

Microsoft Excel is used to generate a NAPA input template which will contain the details of the structural members for the surface objects. This excel is made up with drop down option for selecting the structural element size, material, orientation and stiffening type. This is down to reduce the human error which may lead to abort the execution of the process.

Excel provide various features which make the data input very easier. In such a way using various functions of excel an output format is generated which can be completed used as an input to NAPA Designer script for execution without any further modifications.

## 2. MOTIVATION

### 2.1. Early Design Stage & Important Considerations

The ship construction involves with many participants during the period of its construction. It includes mainly the ship owner's, owner's representative, shipyard or manufacturer, design office, classification society etc... The ship construction process is involved of two major stages where first one is the ship design and latter one is ship production or construction.

The shipbuilding process starts with the owner's requirement which is read and agreed by a shipyard. The mission requirements listed by ship owners are based on the current and future market scenario and expectations, which will define the parameters and specifications of the ship. Shipyard makes a quotation for the project satisfying most of the owner's requirements, with all basic details they going to execute on the project with a preliminary technical specification. Once the owner and shipyard come in a conclusion with the basic design and final estimated cost, then the ship design phase is initiated. The design office then comes into the picture to proceed with the calculations and drawing so to ensure the best out for the final product.

The development of a new ship design is carried out in four (4) various design stages or phases.

**1. CONCEPT DESIGN PHASE** – The key objective of this design phase is to arrive at the feasibility of the project in terms of technical compliance with client requirements.

During this stage the aim is to create a baseline concept of the new vessel that satisfies the shipowner's requirements. During this stage, a Preliminary General Arrangement Plan (GAP), outline specification and a short description of the vessel with main parameters and components (e.g. location of ER, cranes, cargo holds, location of deckhouse) are prepared. In order to carry out the Concept Design it is necessary to define the following items:

- Types of cargo intended for transport
- Required cargo capacity
- Restrictions for main dimensions, if any
- Required service speed
- Endurance
- Classification Society and ship class rules

- Required number of cabins
- Cargo handling equipment
- Type of hatch covers
- Other requirements based of type of vessels

**2. CONTRACT DESIGN PHASE** - The key objective of this design phase is to arrive at the costing of the project.

Contract design phase aim to develop a detailed contract including schedules, plans and specifications necessary to calculate the cost of the vessel and to finalize the contract with a shipyard. Contractual documentation included of corresponding documents:

- Contract Specification
- Steel and Lightship weights
- Contract General Arrangement
- Midship Section

**3. PRELIMINARY DESIGN PHASE** - The key objective of this design phase is to plan the project for proper execution.

This design phase consists of a vast amount of major decisions and further to which a lot of calculations and documentation on which huge number of man-hours will be spend. After signing the contract with a shipyard, it is possible to carry out the Technical Design which contains all drawings, documents and calculations to be approved by a class society, national authority and shipowner.

This phase will finalize main parameters of the intended vessel by proven calculations. The documents which will be majorly covered or prepared during this phase consist of following:

- General Arrangement Plan
- Requirement Specification
- Lines Plan
- Midship section
- Tank Arrangement Plan
- Engine Room Arrangement



- Accommodation Layout
- Naval architectural calculations
- Steel Plans
- Engine Room Arrangement
- Outfitting for cargo operation

**4. DETAIL DESIGN PHASE-** The key objective of this design phase is construction of the vessel based on the design.

After finalizing with the basic design, detail design will be started which contains precise engineering solutions and give an easier understanding of designed items. The 3D model utilized in the detail design includes all relevant information necessary to follow up with Production design in shipyard. The generation of production design documents are made in line with the shipyard facilities and schedules, and hence generally this stage in ship design is done primarily by shipyard itself. The major documents or processes during this stage are:

- Structural or profile list
- Pipe isometrics
- Workshop drawing
- Nesting plan and part drawings
- Bending templates

The concept and contract design phases can be named together as the early design phase. The decisions made during the early design phases are very vital and crucial. A small mistake or error happened during the early design phase could lead to large amount of rework if it is identified during basic or detail design stages. Hence, it could be said that early design phase is a backbone for the overall design phase.

In the same way, any automation or template made during the early design phase, to make the calculations, modelling or any other task faster will be saving a huge amount of manhours. These automations will reduce the time taken for rework because of some early design phase errors.

## 2.2. History of the Topic

Ship design is a process which need to be executed considering lot of factors based on market and client requirement. Some of the main considerations and factors during the ship design phases are listed in Figure 6.

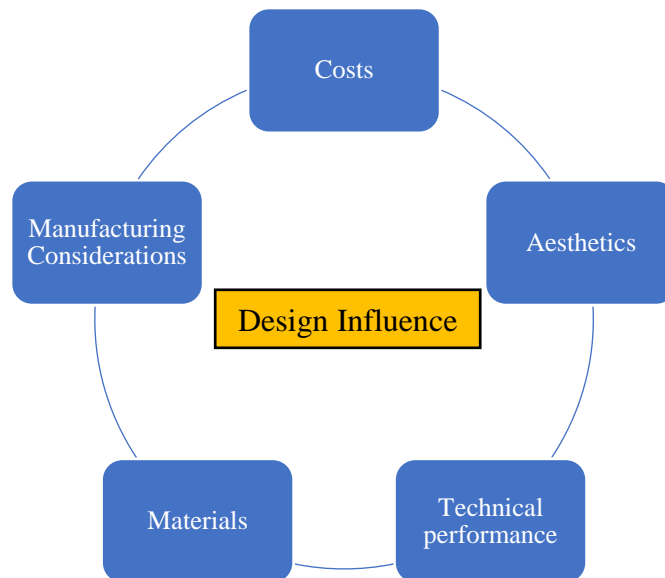


Figure 6 : Factors influencing the Ship Design

[5] During the detail design stage the use of a ship 3D model is very common, while the basic design is still generally based on 2D drawings in many organizations, although it is the stage where most of the costs are compromised which implies long design periods, repetition of relevant work in subsequent stages and potential for multiple design inconsistencies. This all leads to a major increase in costs and a low production performance.

Awareness of this situation and due to marketing and commercial reasons 3D tools have been introduced recently in the initial design stage. Implementation of 3D model creation at early design stage is so helpful to maintain an updated model all throughout the construction period and saves a lot of time.

The ship design process is involved with several factors that develop various aspects of engineering. This process is a sequential phenomenon where input of a stage can be an output from earlier stage. Non-exhaustive list of tasks involved are shown in Figure 7.

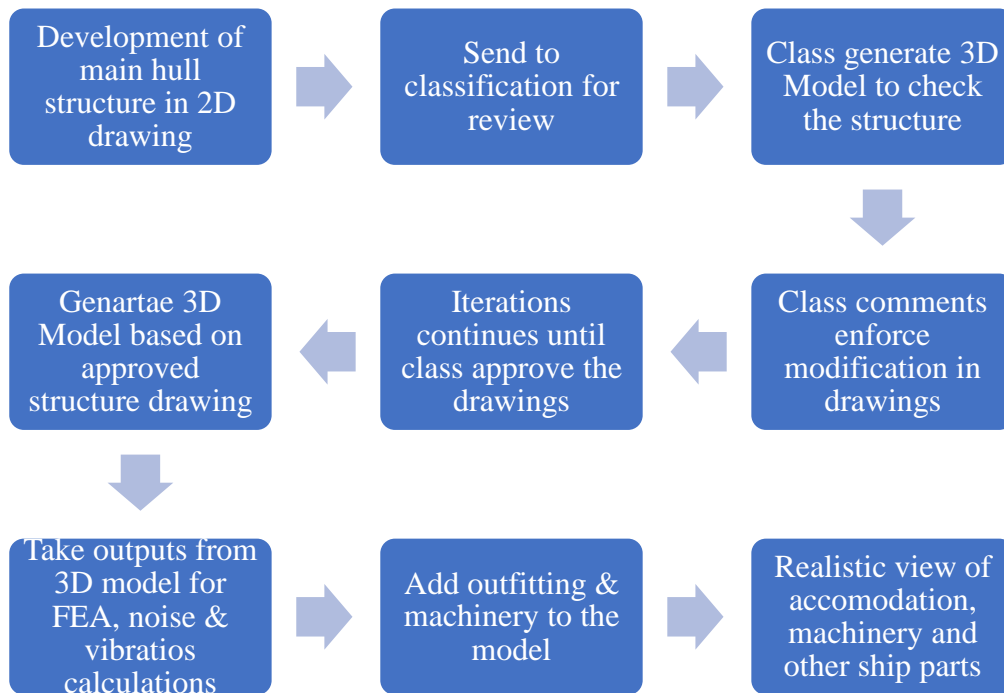


Figure 7: Work flow occurs in design department.

As an alternative to this traditional method, the new approach of generating 3D model at the early design stage is implemented now a days. This is mainly aimed to reduce the rework that could occur due to classification society comments. This 3D models are capable to generate 2D structural drawings with class standards for approval. This 3D model update goes in line with the construction at yard and hence any required drawings can be generated at any time of construction period. So, this 3D model lies as a bridge between the basic design and production phase at the same time. Although at first sight it is a time-consuming process concerning the whole-time span of design process it saves a huge amount of time.

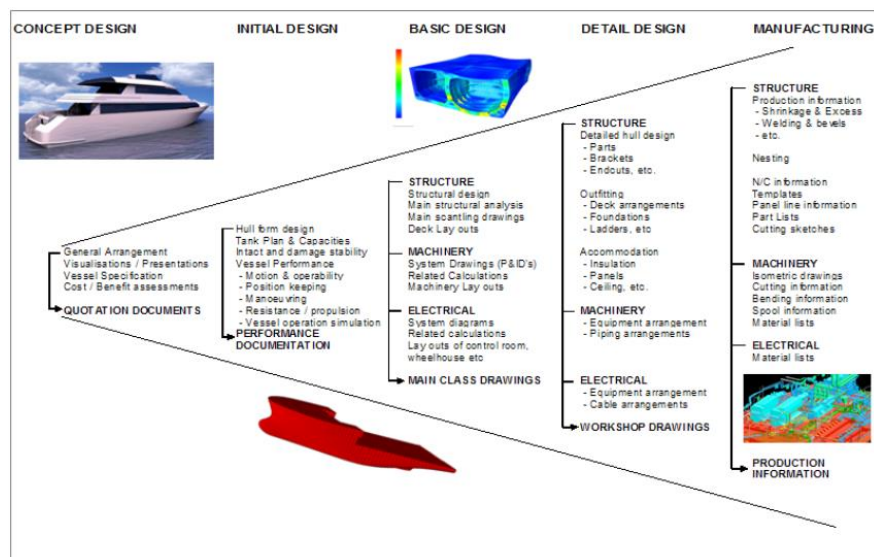


Figure 8 : Design stages in ship design process from quotation stage to manufacturing [3]

Large Shipyards has lot of technologies which they generally use to fasten the ship building process as they will have a queue of orders to complete. Shipbuilding is an industry where always innovations happens and implemented for a more efficient and comprehensive vessel.

Modern shipbuilding makes considerable use of prefabricated sections. Entire multi-deck segments of the hull or superstructure will be built elsewhere in the yard, transported to the building dock or slipway, then lifted into place. This is known as "block construction". The most modern shipyards pre-install equipment, pipes, electrical cables, and any other components within the blocks, to minimize the effort needed to assemble or install components deep within the hull once it is welded together. [6]. Figure 9 is a simple visual representation of block construction.

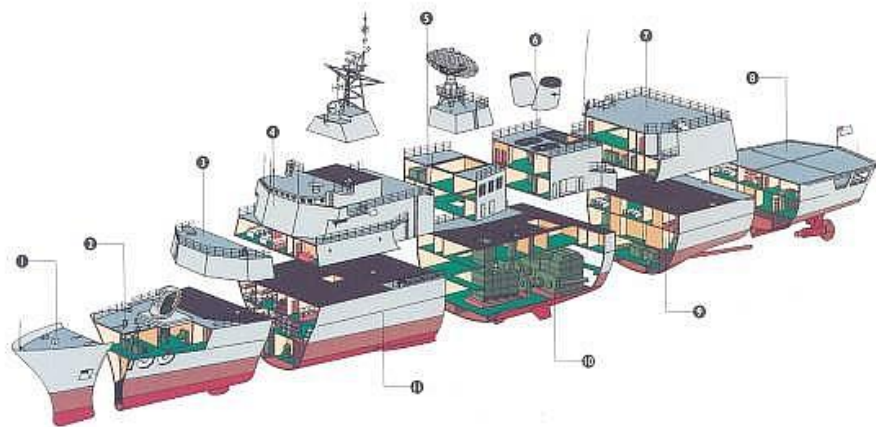


Figure 9: Example of block construction in a shipyard

### 2.3. Challenges Enforced for Development

Earlier when 3D model was initially implemented into basic design stage the available software in market had limited capabilities. Due to this, the advantages of using 3D model at early stage was questioned due to the short time period available to submit information to client to grab the project. So many consider 2D approach as a feasible method during this period neglecting the fact of rework or complete variation in later stage if the project is sanctioned. But the truth is that at this stage though the time is short, the demand and quality of information expected is high. So, considering the above fact, the 3D approach ensures the quality and avoid errors and inconsistencies inherent to the 2D approach.

Also, earlier separate software packages were used for different functions like drawing preparation, modelling, outfitting, stability calculations, finite element analysis and many other

tasks. So, different models were used for all this software and it was always difficult to bring on all the models updated all the time. Such cross-linking between multiple software platforms were not always smooth and it led to plenty of rework. So, a single platform for all these functionalities is a feasible solution to get rid of this situation. Many modern 3D modelling software packages offer this feature where a base model is maintained and separate models are exported from this base model for carrying out their respective tasks.

Nowadays, a lot of very advanced 3D Model software like NAPA, Aveva Marine, Poseidon, Cadmatic etc... It includes a wide range of design and computational capabilities like stability model for hydrostatic calculations, structural compliance with class rules, export model for FEM software and 2D structural and plan drawing extraction in line with class standards. All these functions are linked to a single model which will reduce the inconsistency between models in various software. This was one of the main features seeking for development in early design stage.

Earlier, the 3D model generation was a time-consuming process where it used to take around 2 months of effort by 2-3 designers. By automating the modelling process which is made as part of this thesis work, the whole process is made faster. The same 3D model which will be generated with the help of the code will take maximum of 3-4 days for a designer.

## **2.4. Domain for Development**

Considering the whole shipbuilding process, various functionalities or processes still calls for development to make the process more user friendly and automated. It is because of the difficulties in automating such tasks without human interference. Ships are a one of a kind industrial product (custom product) rather than mass production in industries like automobile. Therefore, it is difficult to automate various stages where human supervision is required.

Though this limitations in developing various tasks exist, still it is possible to make some of the very specific intermediate works automated to make the process faster. This thesis is focused on such a scope where some automation can be used to make the design process quicker.

In this thesis work, the main focus is given on automating the 3D model generation in CAD/CAM software. There are a lot of such 3D model generating CAD/CAM software packages are available in market. CAM software provides the output in a format which is

required for manufacturing facilities like CNC codes, production drawings, detailing etc. The CAM software provide a platform where the user can use a single platform to manage the whole shipbuilding process. Such software packages are involved from initial design till detailed design which completely lies very close with production.

So, by implementing this thesis work, the 3D structure model generation will be automated and by which a rapid 3D model will all important structural member in its required arrangement can be obtained. This model can be meshed using the features offered by some of the CAM software packages. Earlier meshing was possible only with finite element (FE) software, but now it is possible with the CAM software packages. This is something which happened as part of development.

Earlier structural and plan drawing were made by dedicated CAD (Computer aided design) software like AutoCAD. But now a days as part of development in industry and by the usage of 3D modelling software theses CAD software usage is minimized. Now a days, these 3D modelling software models itself is capable enough to provide any structural or plan drawings.

Model for stability calculating defining compartment and detailing about its water and weather tightness properties is now a days exported from the same 3D modelling software packages.

All these advancements happened as a part of development in shipbuilding and ship design industry. But for all these processes, a base model is required which will be generated in the CAM software. This model generation used to take around 2 months of hard work by 2-3 structural designers. Though the use of such a model is very helpful in further stages of ship design and production phases, the time taken for that model generation was quite comparatively high. So, this thesis is focused to reduce the time taken for generating the 3D structure model using such software packages, which here in this thesis is accomplished using NAPA.

### 3. BACKGROUND STUDY

#### 3.1. Literature Survey

The number of software available for ship design and analysis is increasing every year. Each one of them are competing to be the best in the market satisfying every need for users. A lot of research and development is done by each of these software developers to make it more user friendly and faster. Now-a-days the focus has been shifted to combine different software together to carry out various functions together under a software package. In order to be the best in the market, they make these functions in compliance with class rules, which will make the class approvals faster which is the main focus for a design department or a shipyard. Figure 10 demonstrate the different class software and FEM packages on to which the 3D model can be exported from NAPA Steel for structural analysis with respect to class rules.

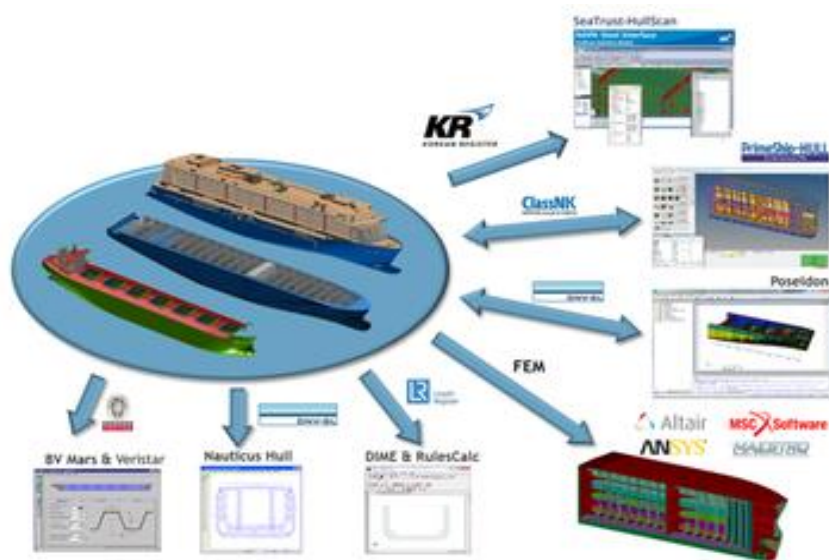


Figure 10: NAPA interface to structural rule check [16]

CAD (Computer aided design) packages have the functionality of generating the geometry and design. Whereas CAM (Computer aided manufacturing) package are used to achieve actual output required by manufacturing facilities like CNC codes, detailing, production drawings, bill of material etc. As their names impicates CAD is used for design and drawing generation whereas CAM is used for manufacturing processes and functionalities which are related to manufacturing.

The advantage of CAM packages is that it has a single platform to organize the whole ship building process starting from its basic design to production details. But some CAD/CAE

software packages like NAPA, FORAN generate a 3D structure model from which model can be transferred to stability software packages for hydrostatic calculations. This same model can be meshed and exported to any Finite Element packages like Nastran, Ansys etc. for structural analysis. Because of these features currently most of the big organizations use combination of such CAD/CAE/CAM packages to streamline their design process.

In a research paper written by Dundara Djani, Bocchetti Dario, Kuzmanovic Obrad, Zanic Vedran, Andric Jerolim and Prebeg Pero [21] they develop a new innovative concept for a shipyard to optimize various design-oriented analyses tools used by them to be brought under a platform to make the design loop easier and faster. They combine various software used by different disciplines in design office together to make a fully integrated CAD/CAM solution named TRIDENT which is based on product database developed at that shipyard called CADD5i.

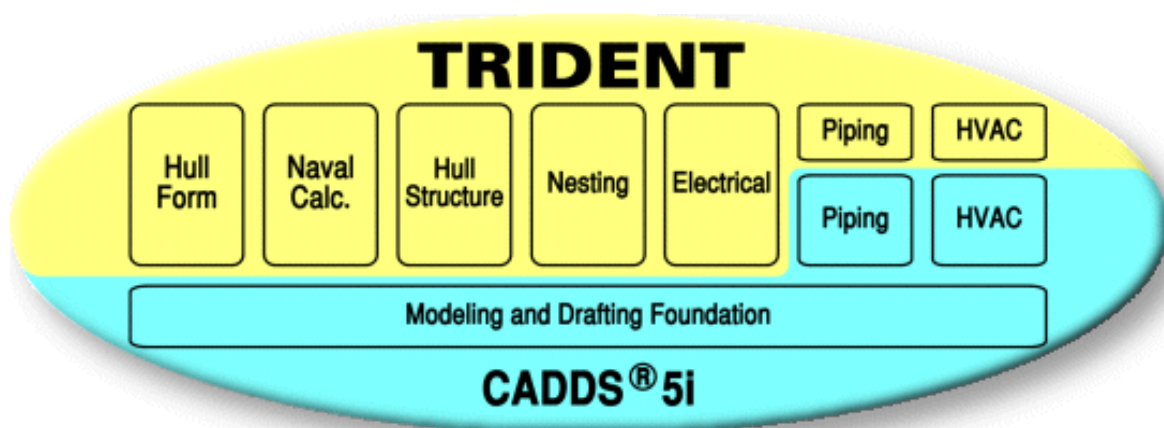


Figure 11: TRIDENT

Using TRIDENT environment, they carried out hull form and naval architecture calculation modules in the early design phase. In addition to general hull form module functionalities, the naval calculations include hydrostatics, intact and damage stability, launching, tonnage, sounding tables, capacity, loading conditions, ship resistance calculations and seakeeping behaviours.

Lloyd's Register Data Interface Management System (DIME) is a system allowing translation between CAD/CAM ship models which is capable to mesh and generate the geometry which is required for structural analysis. In research paper by Pegg [22] and Robert [23] a more



detailed information regarding DIME along with LR/MARTECH suite which is a tool used for naval ship design is explained.

Similarly, in a research paper by Zanic [24], a frame work for linking NAPA steel used as CAD/CAM platform, Mastero used as an analysis software and Octopus which is used as an optimization code to generate ship design for general cargo ship is explained.

All the papers explain about combining various software serving different functionalities together to make the design process easier. As various software packages are available, linking them together are done as separate research works. It is impossible to use the same procedure to combine the functionalities of various software packages because of the differences in the features they provide.

But customizing the software with script-based system is recently coming up to make the design process faster. Many software developers now provide an API script platform which could be used by the user to access and modify the model and automate the repeated functions which generally takes lot of manhours. A research paper by Ruy [25] explain about a python based automated system developed in Tribon M3 to generate cut-outs in structural members. Based on the prepared list of specific cut-out locations and their topologies cut-outs will be automatically generated in the ship product model further to the execution of the code.

Similarly, an XML based approach used to connect the initial ship steel design made by German design package E4 to DNV structural assessment package Nauticus Hull is explained in a research paper made by Rox and Astrup [26].

All the methods mentioned above which are used in customizing the software using the data interface technologies like Python script, XML and other databases indicate the value of including standard data storage routines.

Lot of software are available which are offering the features of customization and multi-task capability. Some of the major such type of software are listed in Table 1.

Name	Structural Modeling Capabilities
Autoship	Structural member definition via SQL/AutoCAD approach, nesting, lofting.
AVEVA Marine	Integrated structural design and detailed design/production package, with other naval architecture features as well.
BVB Café	Features easy definition of structure on top of imported geometry, basic calculations, and extensive FEM import/export.
CADDS 5	PTC's discrete manufacturing CAD/CAM platform. Focused on detailed steel and outfitting design. Includes lifecycle links via PTC's Optegra.
Design for Sea/ Catia	Specialized marine tools built into more general CAD/manufacturing software. Supports initial design, FEM analysis, and links to lifecycle applications.
FORAN	Comprehensive naval architecture package. Supports initial vessel design and structural detailing. Links to ship production and PLM management
Maxsurf	Supports initial structural design and built-in FEM analysis with beam/plate tool Multiframe. Links to other disciplines such as seakeeping, resistance, and stability.
NAPA	Basic through detailed design and production, including pre/post FEM processing capability.
Nupas- Cadmatic	Marine-focused modelling suite with extensive tools for steel definition and production. Includes LCM links via its "eShare" module, which can also share design data from other packages.
ShipConstructor	3-D detailed design CAD/CAM model for structure and outfitting built on top of AutoCAD and SQL.
SMART 3D	Intergraph's latest iteration of what was originally Intelliship, then SmartMarine 3D. Supports detailed steel design and manufacturing, strong links to process and outfitting/piping from co-focus on plant design.

Table 1: Various CAD/CAM software used in ship design

### 3.2. Background Study of Similar 3D Modelling Software

Table 1 indicates the various CAM software packages generally used in ship design process. Each one of them vary with the other one based on the features they are capable of. The user chooses the software which provide the best output on the functionalities on which they are more concentrated and based on their commercial values. As most of these software developers

provide free training for its new users the knowledge in such software are not of any consideration. Some of the software packages with their functionalities and features are explained in below sections.

### **3.2.1. SEANAPTIC**

Seanaptic gives solution for fast 3D modelling of parametric marine structures for weight assessment, FEA pre-processing or boosting the efficiency of established basic and production engineering systems. Seanaptic is having two software application where first one is Seanaptic AI and the second one is Seanaptic for Rhino.

When a large set of ship database, then using the Seanaptic AI it is possible to predict some major information in very early stage of design for new projects. It can provide user with information like weight estimation, cost and man-hours prediction, hydrodynamic coefficients, power requirements, scantling and bill of materials. Its artificial intelligence and machine learning engine reduce tedious initial manual calculations and compile design parameters straight into basic design phase.

Seanaptic for Rhino is a plug-in for Rhino which is used to model ship structures efficiently. Using the advanced automatic algorithms, the modelling process is accelerated. It is also capable to generate 2D drawings from 3D model which makes the design phase faster. Seanaptic model can give the user data like centre of gravity, weight and bill of material for procuring. This output can be obtained in a table format report. This software is very useful in design phase as 3D model and results obtained from it can be generated by concept design phase, instead of basic design phase.

This 3D model can be exported in multiple formats to Rhino and various software for carrying out functions like detailed modelling, class drawing generation, model for Finite element analysis (FEA) and weight distribution. The 3D model is linked permanently to the 2D drawings format and hence it is possible to export latest 2D drawing any time during the design stage very easily and quick. Consideration has been taken to avoid repetitive work by automation. Since it is a plug-in for Rhino modelling method is kept very much similar to Rhino and hence no special training is required for Rhino users. Seanaptic is flexible enough so that the user can combine parametric and non-parametric elements in the same model.

In Seanaptic, every 3D object is connected to a 2D curve when it will be exported to obtain the general arrangement plan (GAP). Objects can be created at constant coordinates, create using

rhino and then export to Seanaptic or generate based on imported parent surface. The plate will be assigned default thickness and material unless specified by the user. Based on the limits assigned, each parent surfaces will be trimmed within the limits either implicitly or explicitly. By defining the seams, surfaces are split into multiple plates with different or same thickness. Structural objects like stiffeners, plate cut outs and openings etc... are defined to plates to get the structural 3D model in line with the real ship hull.

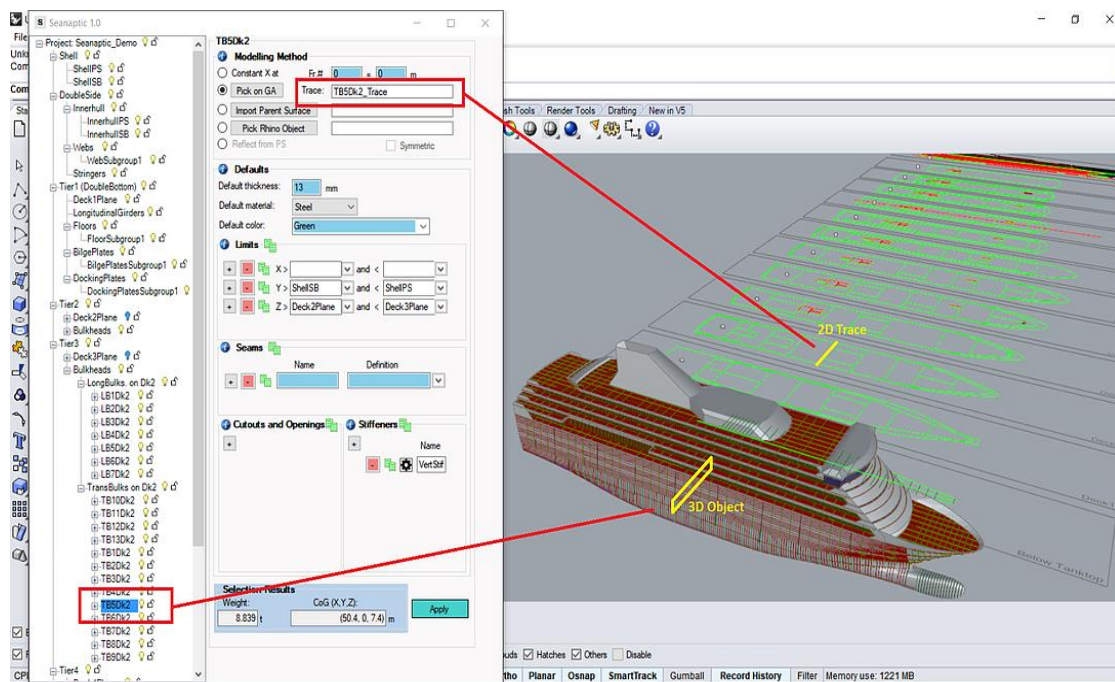


Figure 12: Seanaptic Modelling [17]

### 3.2.2. POSEIDON

POSEIDON is an integrated software for ship hull structure strength assessment developed by classification society DNV-GL. This software also makes the ship design process a much more efficient phase by its compact yet powerful modelling functions and comprehensive analysis capabilities. Being a class generated software, its compromises and managed to bring up the most relevant and seeking needs in ship design phases, taking necessary feedbacks and developments areas from design associated groups like naval architects, engineering companies and yards.

POSEIDON has a design and dimensioning tool which can be used throughout the ship design process. It is used for the modeling of ship structures, which evaluates the scantling for all structural elements in longitudinal and transverse, according to local and global loads. For determining the scantling, it carries out yield, fatigue and buckling checks. It is a very user-

friendly software which can be used with very less training and no specific finite modelling technical knowledge is required for operating or modelling in this. The 2-D modeling approach in the form of hull cross sections help to generate a quicker structure concept model. Full 3D model is generated using extruding a midship section with few modifications. So initially a midship section is modelled and then it is extended in ship length and then modified where necessary, to generate a 3D model. So, the 3D modeling functions are not restricted to the midship region, instead they are used for a complete 3D model generation of the ship. Aft and fore part section will be modelled either separately or with some modification in generated midship section itself. This makes the model generation very faster (possible in 1-3 days) and also make it possible to model complex ship structures in a spontaneous way. So, modelling of symmetric as well as non-symmetric hull structures is possible. Even modelling of ship hulls of ice class is possible using this software platform.

It is also capable of determine initial scantlings automatically. As mentioned earlier, since it is a classification society overlooked software it complied will all rule sets and ship types for 100A5 hull types and CSR hulls. It is a capable to define loads manually and conduct direct analysis using finite element methods. It is equipped with a tool for the assessment of hatch covers.

POSEIDON with all above stated features is capable to make the ship production faster and reduce the structural designing cost. It will improve the ship quality by optimising the structural material weigh distribution and by making the design approvals faster by quick electronic drawing and document generation using its features. Software is so generated that multiple time data entry is not required. The inputs data are stored and reused for further necessities. Structural strength analysis is integrated with all relevant necessary calculations for local and global strength with fatigue, yield and buckling strength checks. All set of load cases and condition are automatically updated on case by case basis. It is also made in such a way that rapid model changes can be incorporated and further to that a full re-analysis can be made quickly to obtain an optimum design. It is recently implemented to import full model from NAPA steel along with returning of results.

### **3.2.3. FORAN**

FORAN is a system used for the design and construction of marine structures. It enhances all aspects of design in a fully integrated manner as it is used in every stage involves in the design and production of a marine structure.

FORAN is equipped with key features like it is open to other systems and applications, focuses on automation, suitable from concept to detail design or construction, capable for advanced and fast modelling, can be used for any types of marine or offshore structures.

FORAN is a CAD/CAM/CAE system used for marine design. It stores all the information of a product used by various disciplines in shipbuilding in a single database. It's 3D Model visualization capability, interface with product model, virtual reality, interface with lifecycle management systems and interface with FEM tools makes the design phase very efficient and faster and also a useful tool for various shipbuilding stake holders.

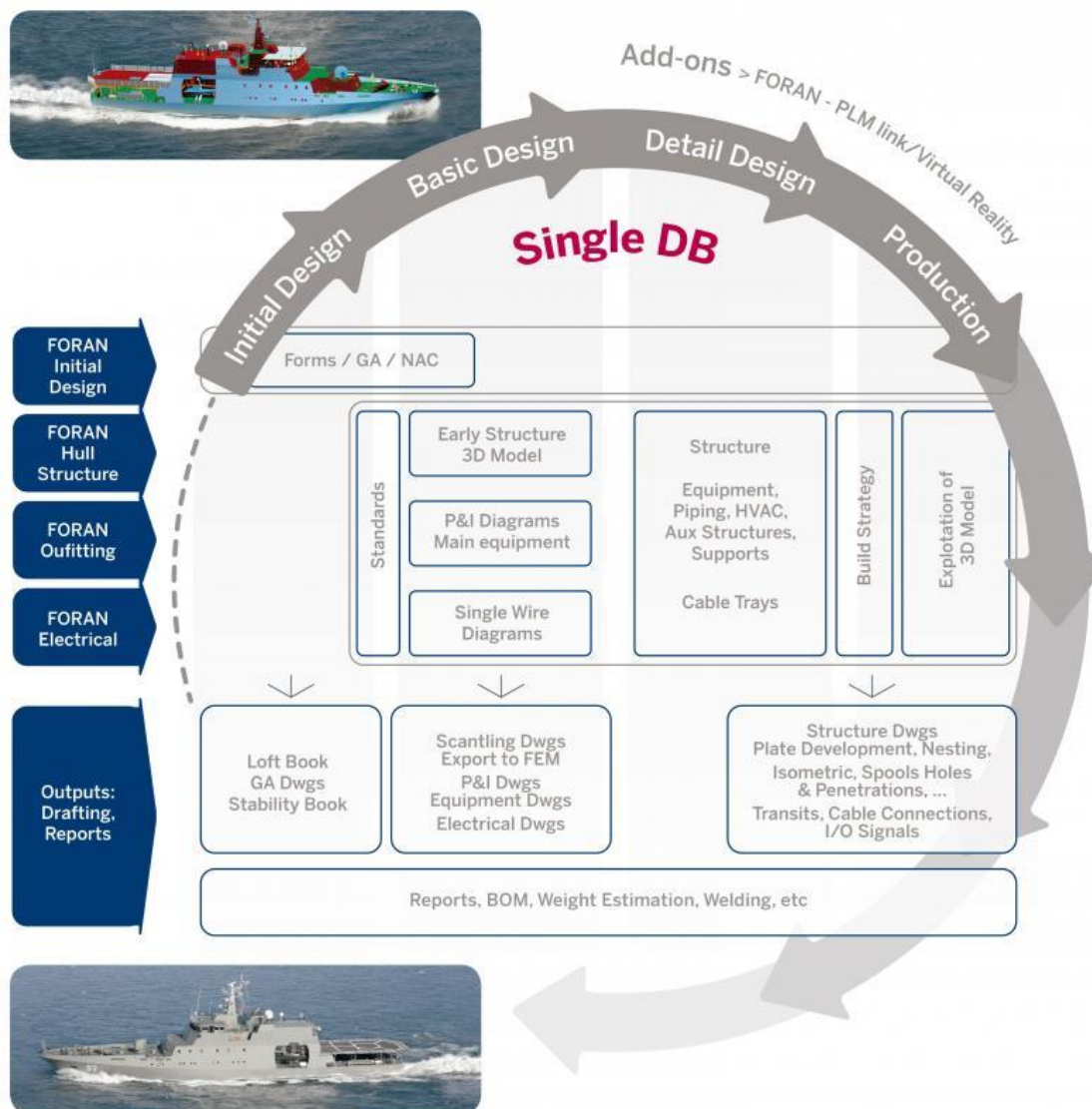


Figure 13: FORAN design stage flowchart [18]

FORAN is capable of generating or customizing the following functionalities:

- Defining ship layout adjusting volume and spaces of the ship

- Generate any kind of hull form or modify it based on external form file
- Initial design phase naval architecture calculations
- Rapid 3D model in early design phase
- Possible to define ship structures with only primary elements and place main pieces of equipment in their final or approximate position
- Material list and estimation of actual weights in early design phase
- Possible to define detail model by every disciplinary in ship design
- Possible to define every structure element, equipment and machinery positioning, HVAC, supports, auxiliaries, electronics and electrical design
- Possible to extract all necessary information required for production and assembly
- 2D-3D transparency
- Automatic generation of customized shop floor information reduces cost of material and labour and improve production quality
- Brings up design team coordination by collaborative engineering between various stake holders in design and production departments

FORAN is capable of advanced technologies like data management, surface and structure (solid) modeling and 3D visualization. It is also capable of sharing engineering information with PLM, MRP and ERP systems, finite element tools and other CAE software. It is capable to export in multiple formats like such as DWG, DXF, IGES, STEP, VDA, VRML and XML. FORAN is equipped with advanced optimization features for production or manufacturing technologies like plate cutting and marking, plate bending using line heating or roll, panel lines, welding robots, profile marking, dimensional control, grinding; painting and pipe cutting and bending.

#### **3.2.4. NAPA**

[19] NAPA has been the preferred partner for industry's leading organizations for several decades. NAPA for Design incorporates state of the art hull surface and 3D model definition with advanced hydrodynamic, stability and structural design software tools, thus enabling the handling of all aspects of eco-efficiency at the early design stages in a single software system.

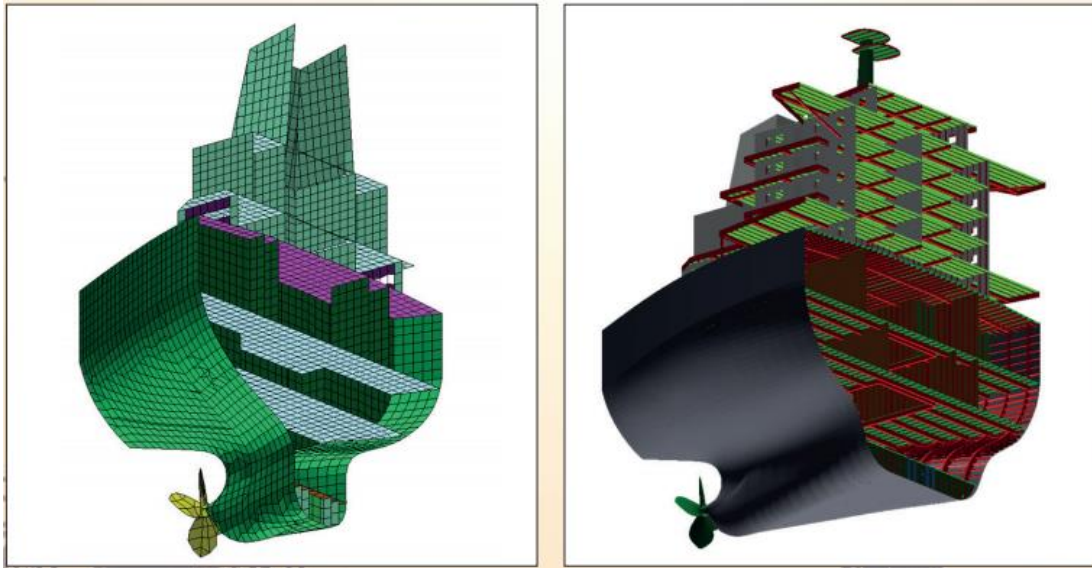


Figure 14: Meshed model to export to FE package and normal 3D structural model

- **NAPA Contract Design**

[16] NAPA helps us to generate an optimal design very quickly in the concept phase which helps shipyards an upper hand to win the contracts. It can generate optimal contract design solution for any types and size of floating vessels.

Obtaining an optimum contract design solution before contract is a great step for shipyards. It can create an entire ship's 3D model quickly and easily including the surfaces and compartments.

The obtained design satisfies relevant naval architectural analysis and assurance of technical feasibility. It also gives the opportunity to have swift and facile modification of design and geometry changes due to class comments. It also enables unequalled speed of displaying design variations for time-efficient identification of the optimal solution. NAPA statutory compliance and NAPA Steel provide a seamless continuation of the design work in the basic and detail design phases.

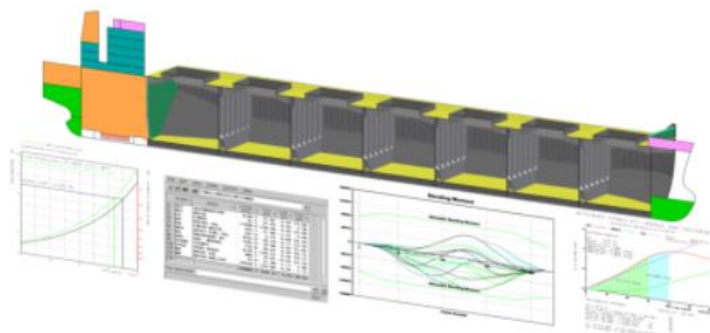


Figure 15 : NAPA Contract Design



### • NAPA Statutory Compliance

Shipyards and Naval Architects are in need of precise calculation for stability and strength now a day. NAPA's statutory analysis tools with its strong product model, speed and accurate calculation engine became a de facto standard for the shipbuilding industry. NAPA provides a good comprehensive list of stability criteria covering most of the existing statutory requirements. It also enables us to define any existing or future criteria for stability.

NAPA statutory compliance dealt with the intact and damage stability evaluation for required regulations. It can also comply with SOLAS 2009 and SPS code. It also contains of MSC.245(83) for cross flooding calculations.

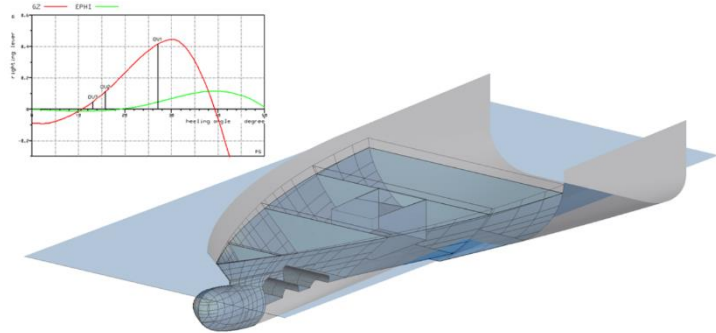


Figure 16: NAPA statutory compliance

It also abides by IACS longitudinal strength including shear force calculations and MARPOL 73/78 regulations. It also comprises in generating limiting GM/KG curves and freeboard and tonnage computation.

### • NAPA Hull form and Performance

NAPA offers the finest art tools available in market for the hull form generation and optimization throughout the entire design procedure. The hull design methodology provides us a good quality hull form exceeding the difficulties of conventional system while still maintain the precision needed for final fairing work to customize based on special designer requirements.

NAPA's unique hull design methodology gives the user better control and flexibility while still doesn't forget to maintain the accuracy required for the final fairing work. It is combined with several support hull design methods like real 3D topological surface modelling, local and global transformations, parametric definitions and more. It is integrated with a performance prediction tool for hull design evaluation. It can also predict power required using empirical method or CFD computations. It can also perform seakeeping behaviours of the hull form in all 6 degrees of freedom (DOF).

It also contains with manoeuvring simulations based on IMO resolution A.751(18) along with circle, zig-zag, crash stop, man over board and station keeping calculations.

It can also compute the wave resistance calculation based on an integrated computerized fluid dynamics (CFD) viscous flow or potential flow solver.

Also blessed with the capability of finding the optimum floating position

and trim curves with the computerized fluid dynamics (CFD) Manager tool. It can also do multi-objective genetic algorithms to handle any kind of optimization task.

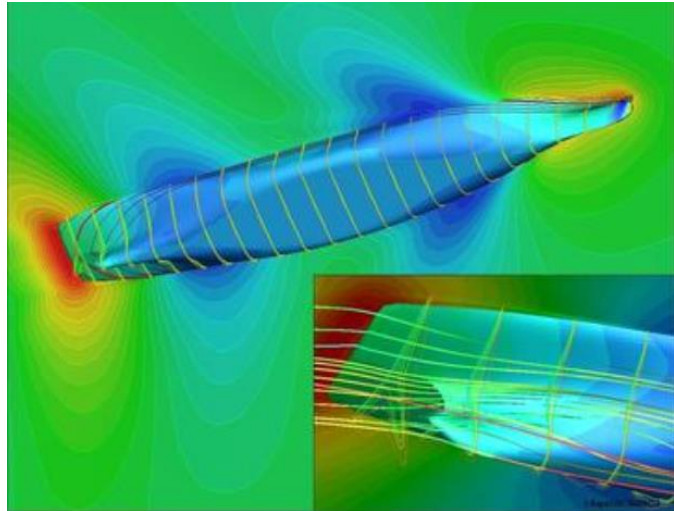


Figure 17: NAPA Hull form

#### • NAPA Steel

NAPA steel is one of the leading structural design software presently used by the leading shipyards and design consultancies all across the world. It provides a new level of swift and flexible structural design with all its perfections. Further, NAPA Steel serves as a database for numerous design levels and is seamless in integration with production and outfitting systems.

It is used as a good friend by the designers from the beginning of design process to increase productivity by using an integrated 3D model. It helps to save a significant amount of time in creating finite element mesh from the structural model. It also gives an accurate and fast scantling analysis with compliance with any common class rules presently in action. Also, rapid

and flexible model variations provide possibilities for optimization and studying multiple design alternatives in shorter time. Automatic generation of 2D drawings from the NAPA Steel model eliminates typical inconsistencies between drawings while the model is frequently changing.

In addition, integration of structural

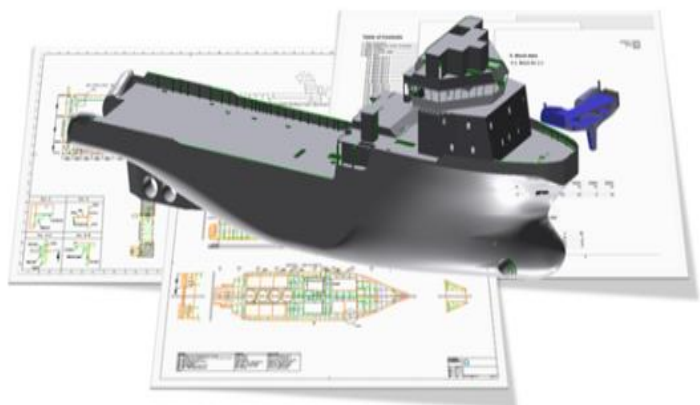


Figure 18: Napa Steel

model with outfitting design systems enable us to start the 3D outfitting design months earlier in the design process with higher quality information. The possibility to export production design drawings enables a good way to bring the production exactly in line with the design.

NAPA steel can generate a wide range of outputs which can be used further for various other calculations or analysis. It can generate weight and centre of gravity, bill of materials, welding lengths and painting areas.

It can also perform production planning, cost estimation and drawing generation. It also offers the opportunity to export the 3D structural model to outfitting and production design systems. It can also exchange data regarding scantling analysis and model for FEM with classification society. It is capable to automatically idealize and generate FEM Mesh which can be exported to FEM solvers such as Nastran or Ansys. It has IGES and DXF interfaces for linking to a wide variety of general CAD systems such as AutoCAD.

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## 4. GENERAL STRUCTURE CONCEPT

### 4.1. Structural Elements

The ship hull structure design is quite important technically as well as economically as it caters around 20% of the ship's total cost. The structural design in ships is based on the forces being applied and strength of the ships.

When a ship is operated in open waters, it is subjected to various load conditions which may cause deformations and create stress. A structural designer who designs the ship structures should be aware of all the loads which that ship could come across during its designed life span. He should be aware of the load magnitude, frequency of occurrence, behaviour with time period and distribution pattern.

When explaining about the load distribution in ship structures, the load applied by external or internal factors is transmitted gradually from local structural members to an adjacent bigger supporting member. These loads are transferred in the order from deck to side and then to bottom primary members and they are then cancelled by the external water pressure acting on bottom plates and structural members.

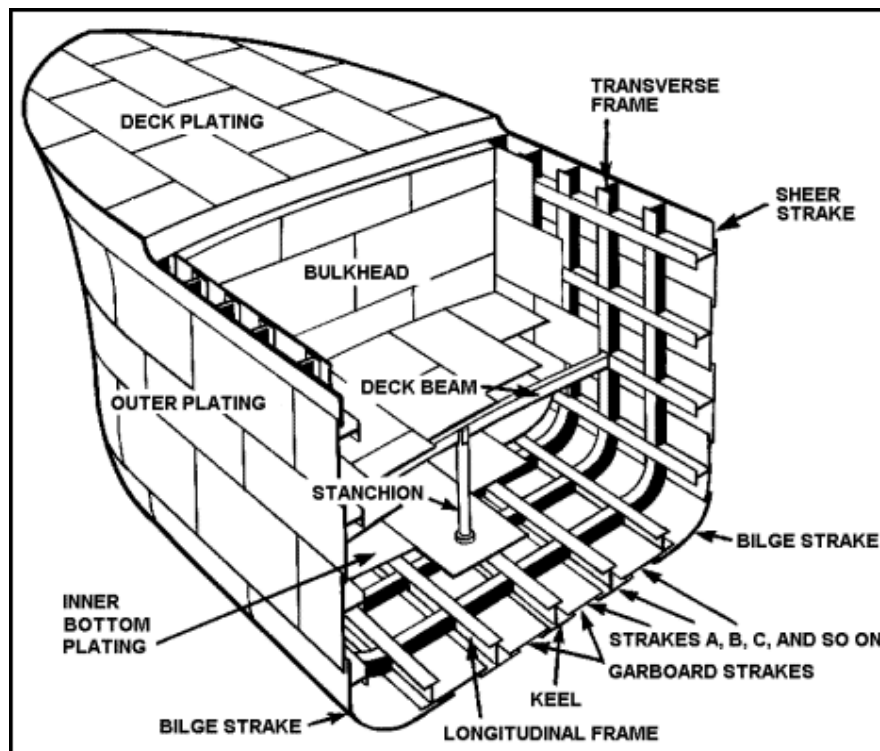


Figure 19: Ship Structural Elements [11]

All these structural members need to be designed so to resist the loads exerted on ship externally and internally. The design of structural members should be well planned so that the load should be transferred properly without failure of any structural members. Each structural member and their connection to the adjacent members should be designed so to ensure smooth load transfer without any hinderance. The various types of loads acting on a ship hull structure can be listed as follows:

- Longitudinal strength loads – The loads acting on a ship which could bend ship longitudinally like a beam or girder and create stress on longitudinal members because of its slender profile. Overall strength of ship's hull is estimated by the structural rigidity of the hull against the longitudinal loads which are represented as bending moment, shear force and torsional moments. These loads are global loads which means the loads are carried or transmitted along ship's length. Longitudinal strength loads can be categorized in two categories, where early one is static load which is due to inequalities of weight and buoyancy of hull and latter one is the dynamic load which is induced by waves.
- Transverse strength loads – the loads acting on the transverse members and create structural distortion of a cross section. The loads include weight of cargo, hydrostatic pressure on bottom and side shell, ballast tank pressure etc... These loads are also global loads which is transmitted along ship's breadth.
- Local strength loads – The local loads affect the local structural members like plates, stiffeners, girders and connections between stiffeners or girders. This loads generally are concentrated local area loads which is distributed within the local structural members.

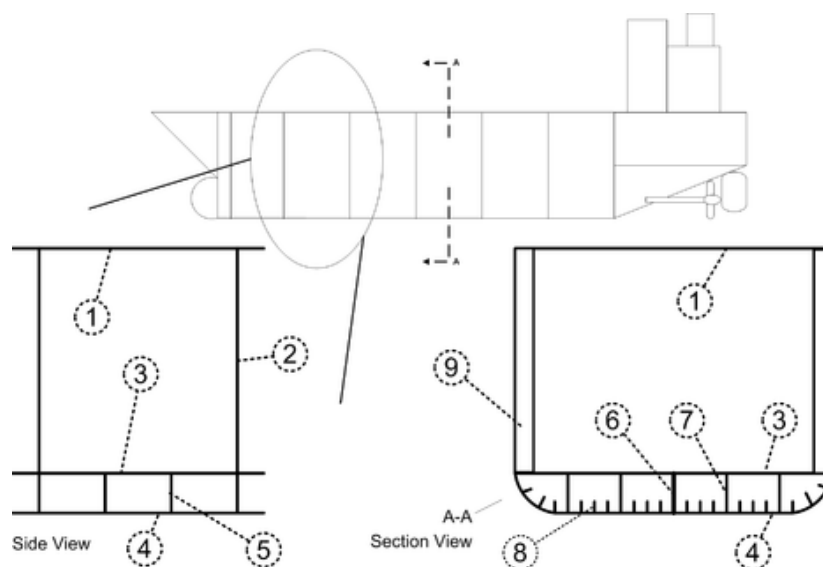


Figure 20 : Structural elements in a Ship Hull [20]

Figure 20 presents the key structural elements in a ship hull. The numbered structural elements in the figure are given with their names below:

- 1) Deck plating (a.k.a. Main Deck, Weather deck or Strength Deck)
- 2) Transverse bulkhead
- 3) Inner bottom shell plating
- 4) Hull bottom shell plating
- 5) Transverse frame (1 of 2)
- 6) Keel frame
- 7) Keelson (longitudinal girder) (1 of 4)
- 8) Longitudinal stiffener (1 of 18)
- 9) Hull side beam

The important components or sections that should be considered during the structural design of a ship are described below:

#### **4.1.1. Reference Framing System**

The ship design is initiated with 2D plan view where a local coordinate system to relate the ship components dimensionally is required. The local coordinate system should be in X and Y axes where X axis lies in line with the ship length and Y axis along ship breadth. Similarly, when the ship design comes to 3D modelling in CAD software, a reference framing system in X, Y and Z directions is defined. In this case X and Y lies in the same longitudinal and transverse directions and Z direction lies vertically.

#### **4.1.2. Stiffening types**

Some major types of stiffening system used in ship building are:

- 1) Longitudinal stiffening system: In this stiffening system the secondary members will be lied in longitudinal direction. This stiffening system is used generally to carry longitudinal loads.

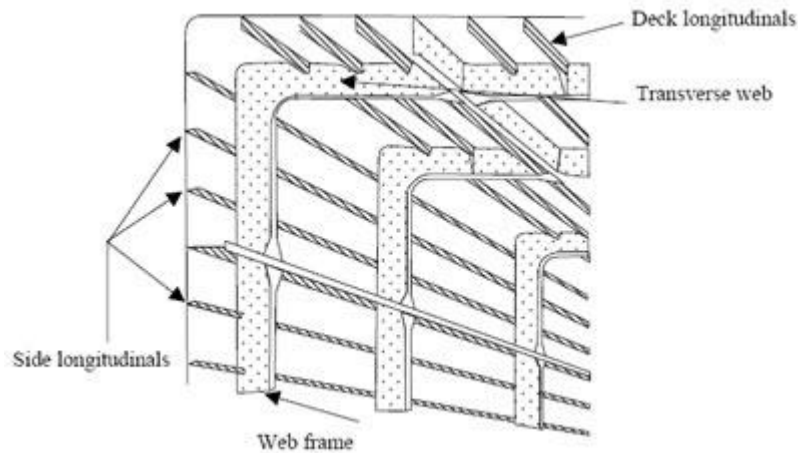


Figure 21: Longitudinal stiffened system [8]

- 2) Transverse stiffening system: In this stiffening system the secondary members will be aligned in transverse direction. This stiffening system is used generally to carry transverse and torsional loads.

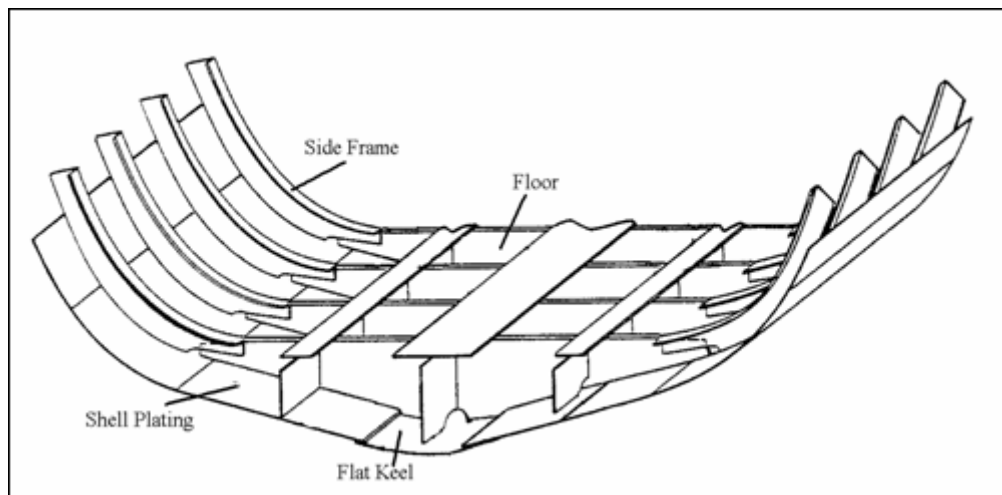


Figure 22: Transverse stiffened side shell [9]

- 3) Vertical stiffening System: In this stiffening system the secondary members will be aligned in vertical direction. This stiffening system is used generally to transverse loads from above deck to lower deck smoothly. Vertical girders, vertical stiffeners, pillars, stations are some examples of this type of stiffening system.

For Example: in multi deck vessels when deck loads are very high, they need to be transferred propel to lower decks and for such cases vertical stiffening system is used. This method is followed in ship accommodation areas also.



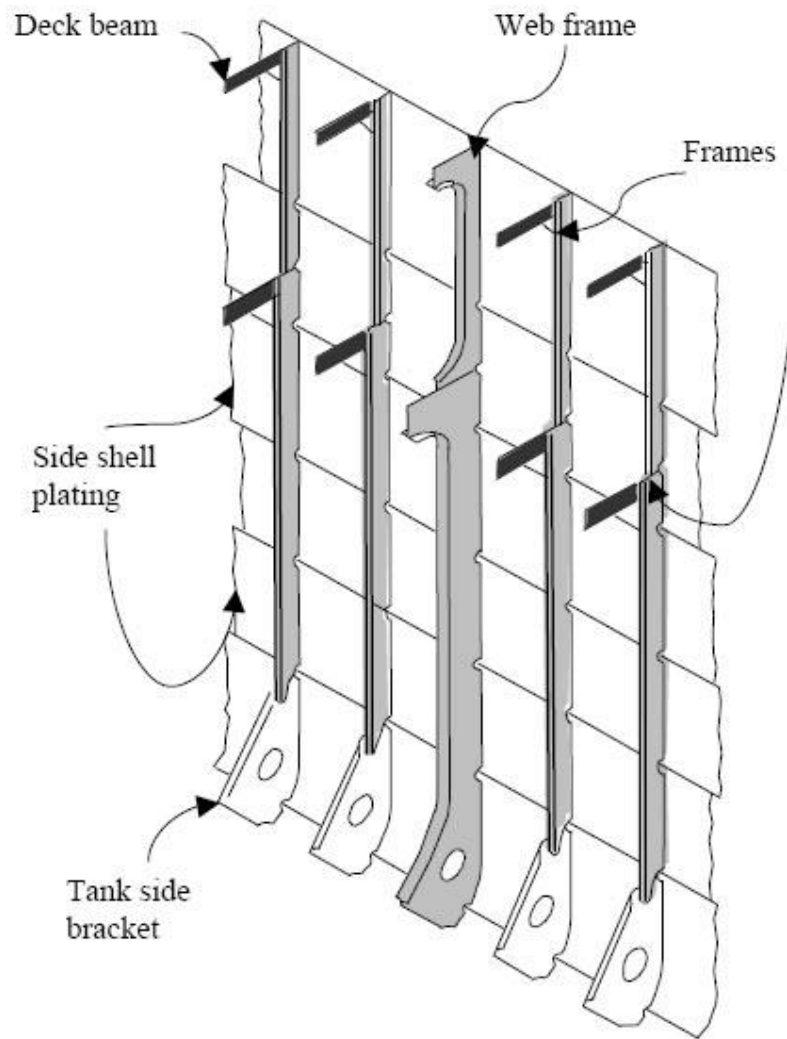


Figure 23: Vertical stiffening system – Side Shell [10]

- 4) Mixed/Combined stiffening system: This is a practical case of stiffening system generally followed in ship building. The ship is exposed to various kinds of loads and some loads are very prominent in some areas. So, when the ship structurally is designed according to the loads active in each area, stiffening type will be different everywhere. So, this type of stiffening system can be seen very common in ship building industry now a days.

For Example: Figure 24 is a midship section view of a bulk carrier which is in general a proper example for combined stiffening system. From Figure 24 it can be visualized that the deck and bottom plates are longitudinally stiffened and sides are transversely stiffened.

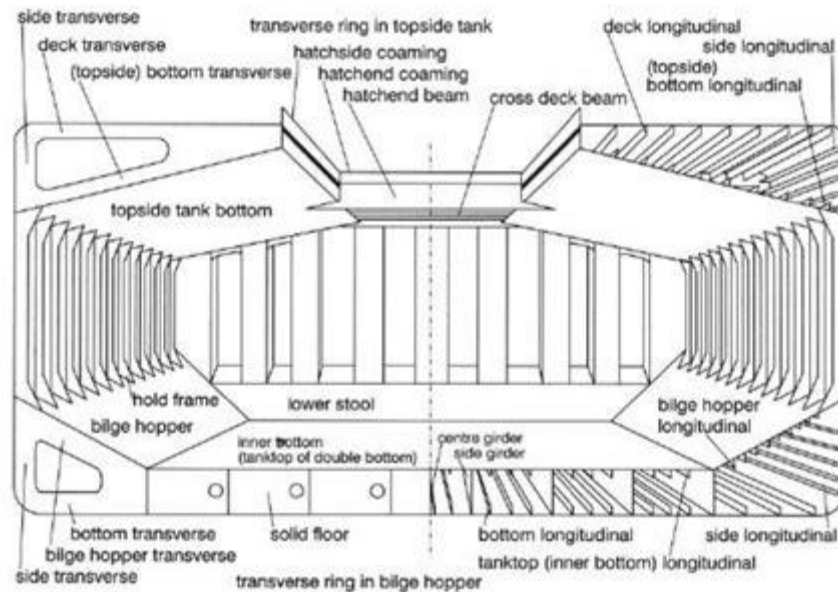


Figure 24: Combined stiffening system [10]

#### 4.1.3. Sub division

Ship's hull is sub divided into watertight compartments which is called compartments. Proper subdivision is very crucial for ship's stability in a damaged condition. This sub divisions are kept watertight so to retain buoyancy of ship's hull when hull is damaged. The watertightness restricts to extend the damage into further compartments and hence regulate the damage without extending into adjacent compartments and also save the ship from overall collapse. The ship's hull can be said to be sub divided by longitudinal and transverse bulkheads or floors, horizontal decks, hull boundaries, double bottom etc.

The ability of a ship to survive a flooding caused by grounding or collision can be measured by subdivision index. If the attained subdivision index A is more than Required subdivision index R then the ship can be said to be stable to withstand the flooding happened by respective damage.

Classification rules and Statutory standards have given specific limits in horizontal, vertical and transverse directions, which needs to be satisfied so to ensure ship's safety. The classification rules also seek to maintain a minimum number of bulkheads in the ship based on the ship length. The decks also act as a sub division boundary in many of the cases. Double bottom is also considered to be a case of deck sub division where minimum double bottom height and no of longitudinal watertight girders are specified by class. Double bottom design

is considered very crucial in ship design as it is very much depending on the ship stability and watertightness.

This sub division limits are heavily related damage stability limits are hence complying with those limits in early design stage is generally ensured by the designers. For example, as per IMO regulations longitudinal extent is 3% of LBP + 3 meters, transverse extent is  $B/5$  and vertical extent is limitless.

#### 4.1.4. Plates

Plate in ship building is generally a rectangular shaped steel with certain thickness value. The plates are used as the shell of a ship. ‘Hard outer covering is the dictionary meaning for the word shell. Plates are given all around the ship to provide water and weather tightness and also provide longitudinal strength to the ship.

In a real ship case it has plates in deck, side and bottom. But they are categorized to further names based on their position and function. Keel plating, shear strakes, garboard strake, deck plating, side plating and bottom plating are some common types of plating seen in ships.

Plates are very much prone to bending when they are subjected to lateral pressures. Also, plates are vulnerable to buckling when they are subjected to compression or shear. So, plates are to be designed so to withstand these pressure cases without failure. When plates of very small thickness are subjected to real ship loads it could fail very easily. Hence the plate thickness needs to be very much high to sustain these loads. So as an alternative to this solution generally a combination of stiffeners and girders to make it a plate panel which will withstand all these loads are provided.

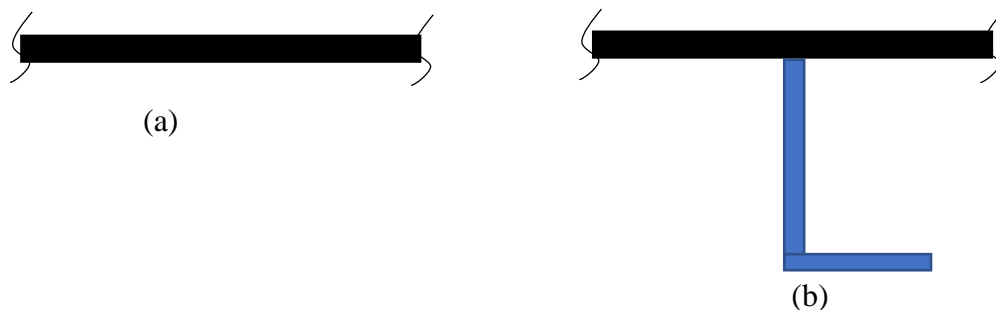


Figure 25: (a) unstiffened plate & (b) stiffened plate

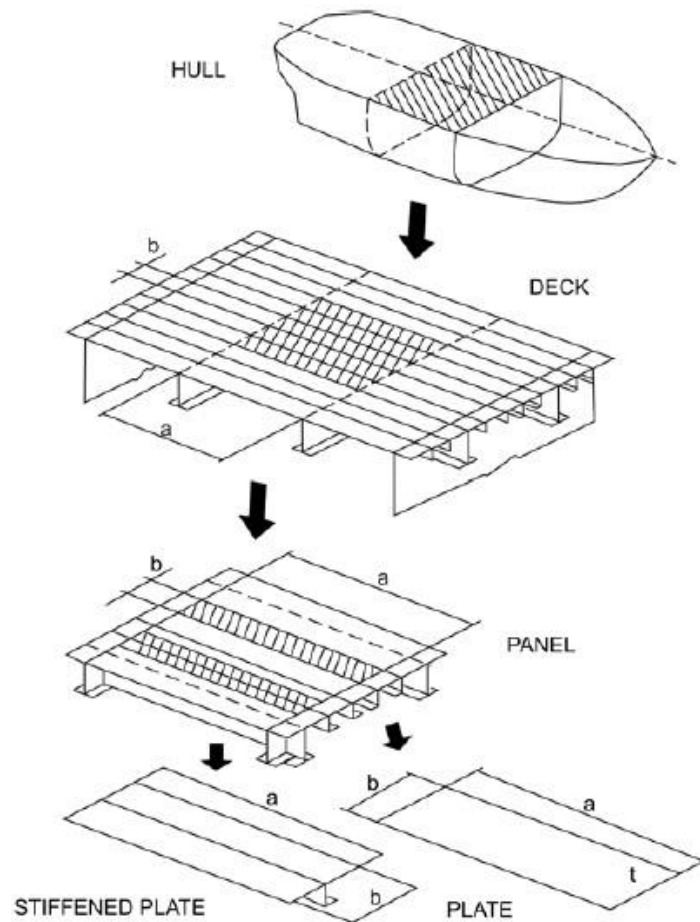


Figure 26: unstiffened plate & stiffened plate panel is ship structural arrangement [11]

#### 4.1.5. Stiffeners

Stiffeners are a kind of beams used in ships which increase the load bearing capacity of the plate they are attached and avoid that plate structure from bending. Stiffeners are secondary structural plates or sections which are attached to the plates to stiffen them against any kind of out of plane deformations by external loads. The plate of the stiffeners which is connected to the plates are called web. The plates of parts connected to the web at its other end could be called as flange.

The stiffeners are used to control the local buckling of plate when they are subjected to compression or shear. When the plates stay along the cross section to withstand the buckling is very less and it could be very vulnerable to buckling failure. So, to avoid this failure condition either the thickness of plate need to be increased or else a stiffener with higher cross section need to be provided. Increasing the thickness is not a feasible solution as it will increase the ship's dead weight very much. So, by adding stiffeners to these plates the cross section that

contribute to buckling is more and hence the slender plates combined with relatively small stiffener increase the resistance to local buckling drastically.

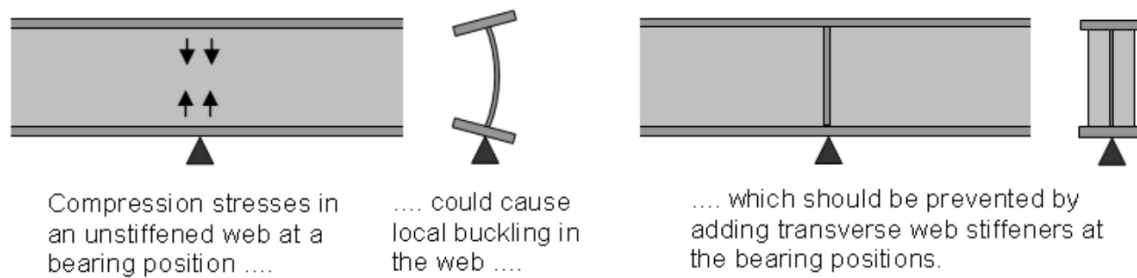


Figure 27: Behaviour of a stiffened and unstiffened web to local buckling [12]

Some general kind of stiffeners used in ship building are L angles, Holland profiles (HP) or bulbs, T angles, flat bars, box or closed stiffener etc. Flat bars are a kind of stiffener which is not having a flange. Holland profile or bulb is a kind of stiffener where the flange is fused and concentrated at the end of the web.

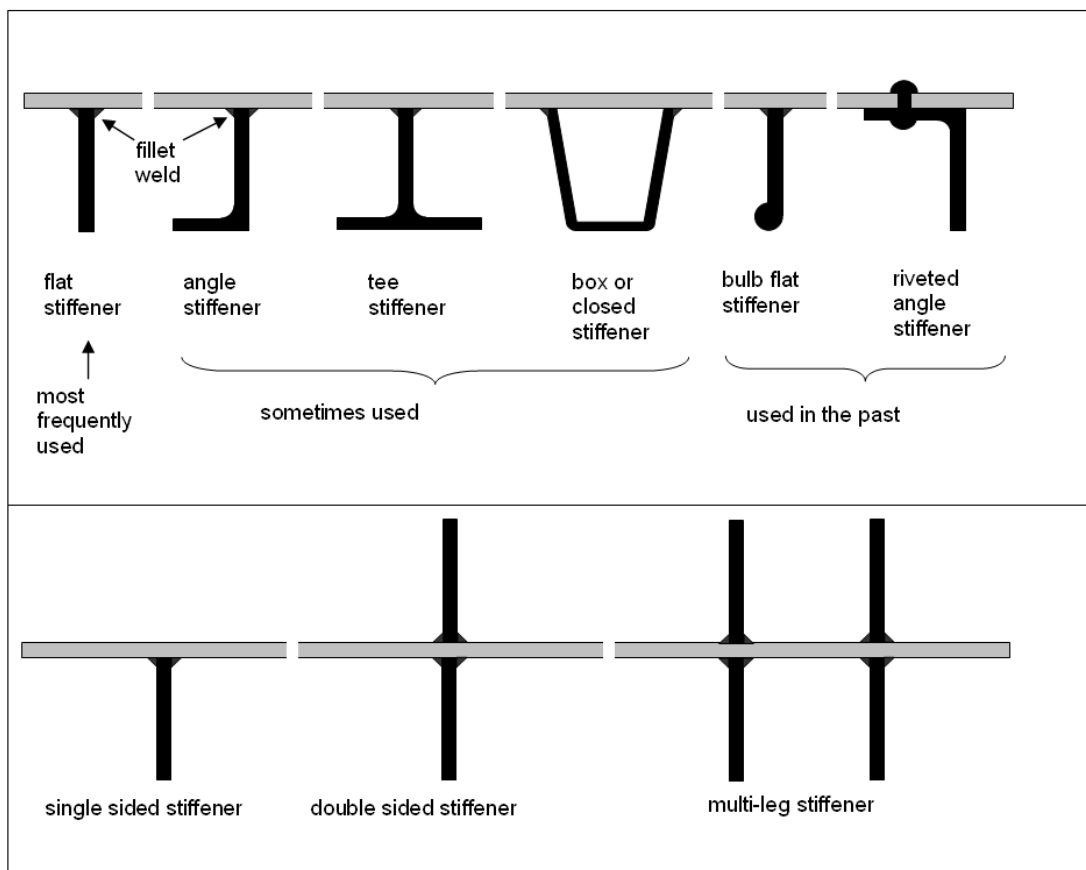


Figure 28: Different type of stiffeners [12]

The stiffeners are designed so to avoid any kind of distortion or crack. For this, a specific ratio between height of web, thickness of web and flange, breadth of flange etc. is made after

research and is followed for stiffener design. Following these standards every international engineering organizations has their own set of standard profiles or stiffeners. Generally, these standard set of stiffeners are available to purchase from in market, but big shipyards used to manufacture these standard stiffeners by themselves to reduce the steel cost.

The extend of stiffeners are limited between the adjacent primary members. For longitudinally stiffened deck, the longitudinal stiffeners on decks are continuous only between the adjacent transverse girders or webs. For a transverse stiffened plate panel, the transverse stiffeners are continuous only between the longitudinal girders.

#### 4.1.6. Girders, Webs

Girders or Web are primary structural plates or sections which are attached to the plates to stiffen them against global loads and bending moments. These structural members are given to maintain the structural rigidity of the whole structural when subjected to local and global loads. These members carry the loads from secondary members or stiffeners are then transfer then to adjacent primary members.

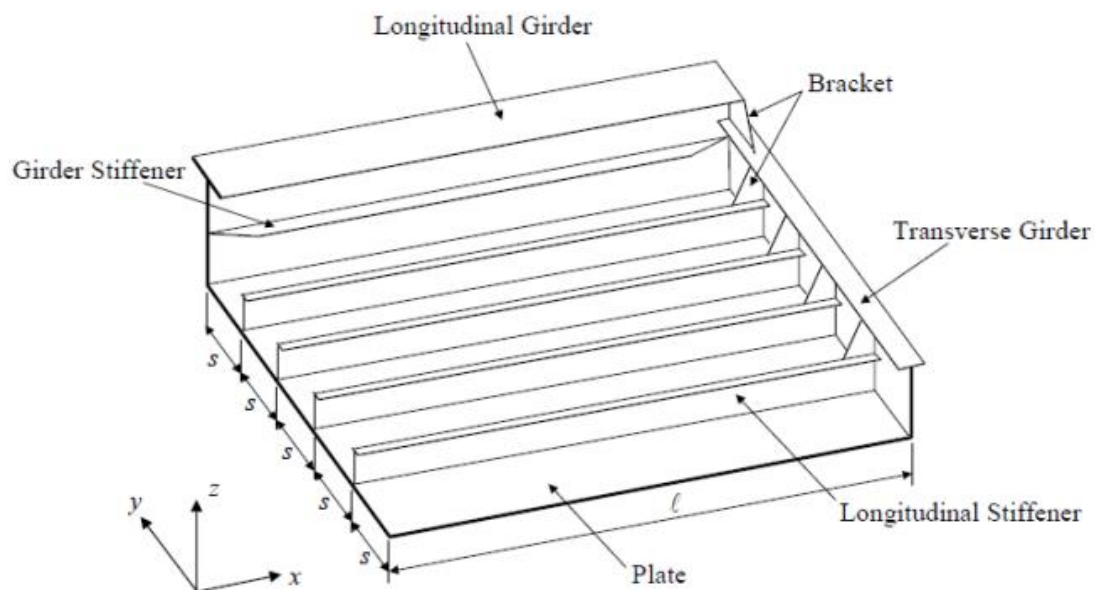


Figure 29: Stiffened panel with plate, stiffener, transverse and longitudinal girders [13]

The load transfer in ship structure is maintained mainly by these girders and webs. For a longitudinally stiffened ship, the local loads due to deck cargo in decks and hydrostatic and hydrodynamic loads acting on side and bottom are carried initially by stiffeners. These will create stresses on stiffeners which will be transferred to adjacent girder. So, in case of a

longitudinally stiffened vessel, the longitudinal stiffeners will transfer stresses to the adjacent transverse girders or webs. These webs will transverse stresses to the adjacent longitudinal girders and side vertical frames. Longitudinal girders transfer the stresses to the adjacent transverse bulkhead vertical girders. The stresses from vertical girders in transverse bulkhead and vertical side frames in side shell will be transferred to bottom structural arrangement. This is how the load transfer occur in ship structures. This load transfers are happening based on the size of structural members and their continuity.

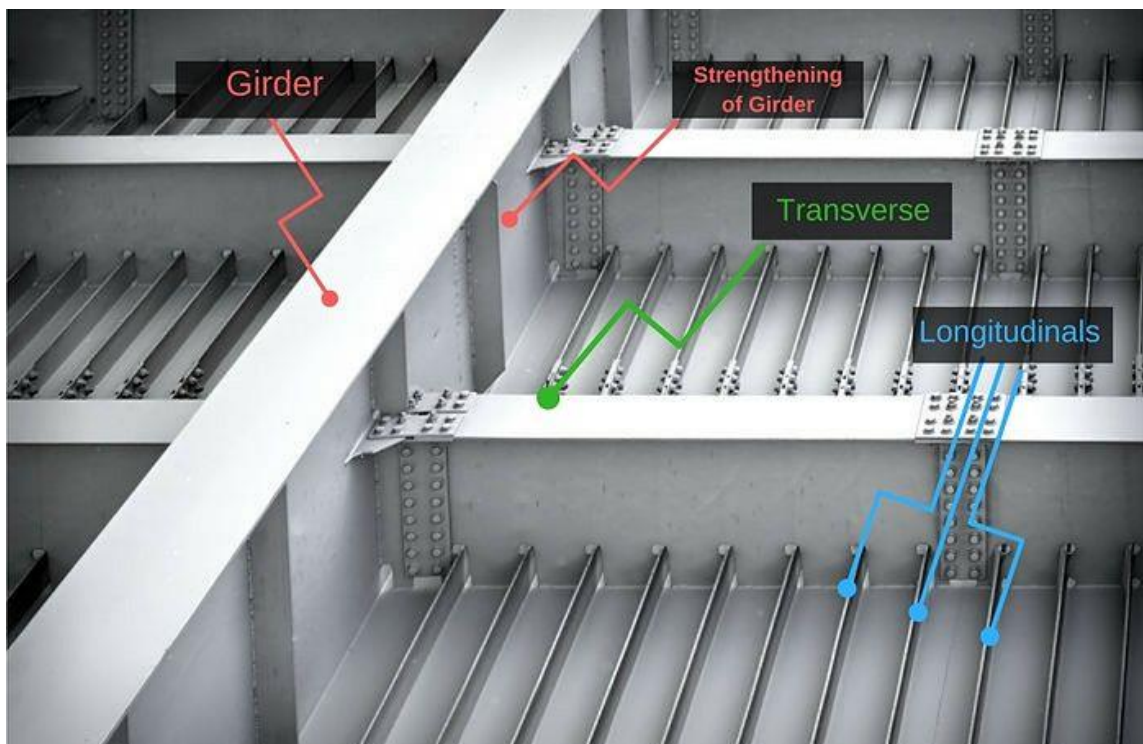


Figure 30: Stiffeners and Girders in a real ship case [14]

Small structural members will transfer the stresses to bigger structural members connected to them at the ends. When a structural member is breaking at its ends or not continuous after the adjacent connecting member then it can be said that the member is not carrying the stresses in that member any further after that joint. In such cases the member is assumed to transfer the stresses occupied in them to the adjacent primary member. When the structural member connected at the ends are of same size then the load is partially distributed between both members which is the phenomenon behind grillage design. The extend or continuity of webs in a longitudinally stiffened ship lies between two adjacent longitudinal girders and extend or continuity of longitudinal girders in a longitudinally stiffened vessel stay between the transverse bulkheads.

#### **4.1.7. Bulkheads**

Bulkheads are vertical partitions of ship hull transversely or longitudinally. These bulkheads divide the ship into different compartments. Some bulkheads made of steel have structural influence. Bulkheads in addition to its sub division property and water tightness during flooding it also serve as transverse and longitudinal strength member, resistance against racking, fire resistance and ship structural stiffness against torsion and deformations.

Water pressure increase with depth and hence in a tank the maximum water pressure will be at the bottom of the tank. So, the strength of the bulkhead should be increasing toward the bottom. So, considering the above fact either the thickness is increased or higher scantlings are provided toward bottom of the bulkhead.

Different kind of bulkheads seen in ships are

1. Watertight - Watertight bulkhead divide ship into watertight compartment where no water leakage or transfer occur through them, unless any damage happens in such bulkheads. The door, cut-outs, opening etc. in such bulkheads will be closed with watertight closing arrangements to ensure its water tightness.
2. Non-watertight – Bulkhead which serve as partitions for accommodation, separate store compartments or engine casing are some kind of non-watertight bulkhead. They don't have the ability to make the compartments watertight or any closing arrangements on such bulkheads doesn't need to follow any such standards to make it watertight.
3. Oil tight or tank bulkheads – Bulkheads which serve as the boundary for fuel tanks or liquid cargoes are coming under this category. They need to provide the watertight property to ensure safety of flammable and drinkable cargoes they may handle. Any small leakages from tanks like fuel or lube oil tanks can cause big disasters. Hence classification societies are also given special attention and additional allowances to such oil tight or tank bulkheads.

Classification societies has done proper study to investigate the necessity of transverse bulkhead in all ship form and they implemented rules to calculate minimum number of transverse bulkheads each ship type require based on their length. Longitudinal bulkheads extending along its length by minimum of 40% in its midship area is considered to be contributing to longitudinal strength. Such bulkheads are designed with special consideration taking those global loads also into account along with local loads they may be subjected to.



Collision bulkhead is a type of transverse bulkhead which is the foremost bulkhead in any ship. It is designed to control progressive propagation of water in the event of a collision from upfront. The collision bulkhead is also designed with special consideration and safety factor and they have around 12% more thickness than other watertight bulkheads. Position for collision bulkhead is to be done within a specific length from forward perpendicular which is specified by various classification rules.

Corrugated bulkhead is a kind of bulkhead which have corrugated plating. They are generally used where welded stiffeners needs to be eliminated and weight reduction is concerned. Corrugated plates are equivalent to plane plates with stiffeners. Bulk carriers, general cargo ship and tankers generally use corrugated bulkhead for easy cargo handling. In transverse direction the troughs in corrugated bulkhead is kept vertical but in longitudinal direction troughs are kept horizontal so to contribute to longitudinal strength.

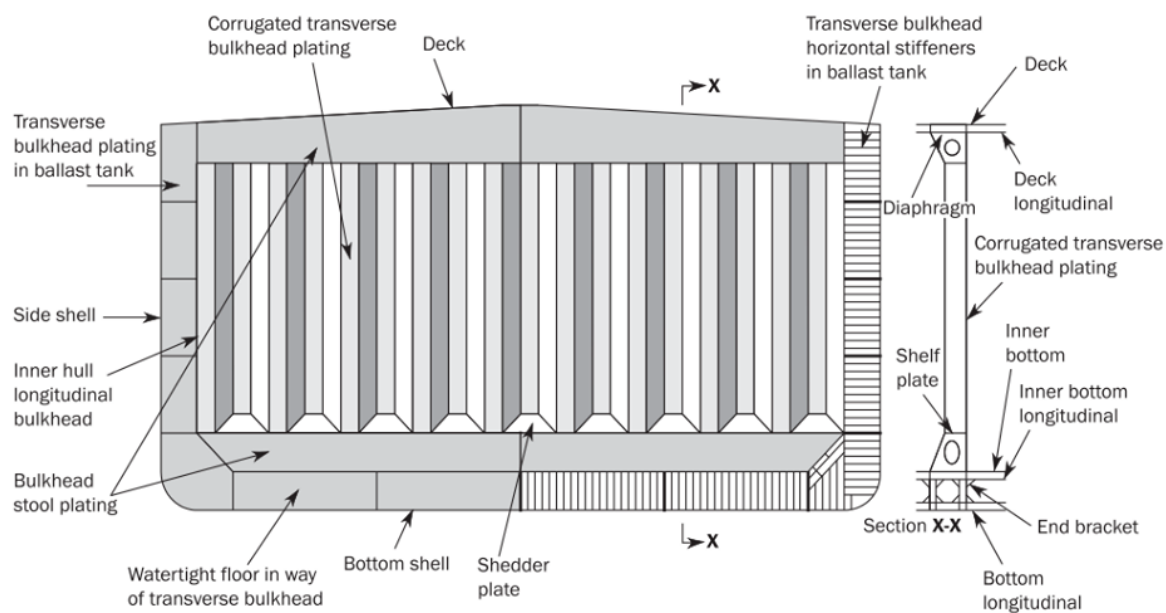


Figure 31: Corrugated bulkhead [15]

## 4.2. Structural design

For structural design using any 3D structure modelling software the user needs to be familiar with the terms used in the software. There are special terminologies used for each element in structural models. These terminologies are very necessary to understand to differentiate between their functions and features offered to the structural elements. Some of the main

terminologies used and very much adequate to understand this thesis paper further is explained below.

- **Material:** Material denotes the grade of any metal or composite. Here in this thesis material denotes the grade of the steel used for ship production. Every material will have different composition and physical properties. Because of this reason material will have different strength values like, yield strength and ultimate strength.

A	EH32
B	AH36
D	DH36
AH32	EH36
DH32	FH36
EH32	AH40
AH36	DH40
DH36	EH40
EH36	FH40
FH36	

Figure 32: Steel material grades generally used in ship building

As shown in Figure 32 the material grade is denoted for example as A, AH32, AH36 and AH40. This indicate the steel with different tensile strength values. H stands for high tensile steel. The yield and tensile strength values for some of these steel grades is as shown in Figure 33.

**Mechanical properties:**

Grade	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)
A, B, D, E	400-520	≥235	≥22
AH32, DH32, EH32, FH32	440-570	≥315	≥22
AH36, DH36, EH36, FH36	490-630	≥355	≥21
AH40, DH40, EH40, FH40	510-660	≥390	≥20

Figure 33: Yield and tensile strength for various steel grades

- **Structure Type:** The walls or decks in a ship model will be of some kind of structure type based on its location, orientation, purpose etc. This structure type is followed to categorize the surfaces. Ship design, production and operations are done by multiple persons, different organizations and from different countries. So, for a proper communication between all

these people in any case of discussion ship terminologies should be available for each part in a ship. For example, a watertight transverse bulkhead at Frame location 40 (TBH\_WT #40) and longitudinal bulkhead at 4m off centreline in starboard direction (LBH 4.0S) gives a clear idea for anyone involved with shipping industry to location them very easily. Figure 34 shows different types of structure types generally used in ship industry.

TRANSBHD		
TBH_WT	LBH	BOTTOM
TRANSBHD	LBH_WT	BOUNDARY
TRANSCORBHD	LNGHCOAMING	BRACKET
TRANSLSTOOLTOP	MD	DECK
TRANSLWRSTOOL	PILLAR	DGI_WT
TRANSUPRSTOOL	SHELL	FLOOR
TRANSUSTOOLBTM	SI	FLOOR_WT
TTOP	SIDE	GIRDER
WEB	SI_WT	GIRDER_WT
WEB_WT	TBH	INNERSKINBHD

Figure 34: Different structure types used

- **Object:** Object is a term used for walls or deck in a 3D ship model. Objects are not capable to contain any structural properties. So, objects won't have any thickness, structure type, material grade etc.
- **Surface Object:** Surface objects is a term used to define the walls or decks with any structural properties. So once objects are converted to surface objects, they get the license to contain structural properties like thickness, structure type, material grade. Figure 35 shown the structural properties a surface object can contain.

The screenshot shows a 'Properties' window with a dark theme. At the top, there's a dropdown menu set to 'All (1)'. Below it, the 'General' section is expanded, showing fields for Name, Area, Center of Gravity, and Labels. The 'Structure' section is also expanded, showing a dropdown for Structure Type, a field for Default Thickness, and a field for Default Material.

Figure 35: Sample for list of details available for a Main Object under arrangement

- **Structural member/Steel object:** Structural member or steel object is any structural stiffening members used in ship design. Stiffeners, girders, pillars are some main examples of structural members. Stiffeners, girders and pillars with different cross-sections are also considered as different structural elements.

FB100X8	FB100X8
FB150X15	FB100X10
FB150X20	FB100X15
FB200X10	FB150X10
FB200X15	FB150X15
FB200X20	FB150X20
FB250X25	FB200X10
FB300X20	FB200X15
FB300X25	FB200X20
FB300X30	FB250X25

Figure 36: Flat bars available in steel library

300X10/150X15	L100X75X7
400X10/150X15	L150X75X9
450X7/100X10	L180X90X9
450X10/150X15	L200X90X9X15
500X7/100X10	L250X90X10.5X15
600X12/200X20	L300X100X10.5X15
800X15/200X20	L350X120X11.5X18
1000X15/250X25	
1200X18/300X30	

Figure 37: T sections and angles available in steel library

HP220X12	HP160X9	HP140X8
HP240X10	HP180X9	HP80X7
HP240X12	HP180X10	HP100X6
HP260X12	HP200X10	HP120X6
HP280X10	HP200X12	HP120X7
HP280X12	HP220X10	HP140X7
HP300X12	HP220X12	HP140X8
HP320X12	HP240X10	HP140X9
HP340X12	HP240X12	HP160X8

Figure 38: Holland profile or bulb available in steel library

- **Arrangement:** Arrangement is a feature which provide the structural license for the surface objects making them capable to contain any structural member. Once surface objects are listed under arrangement then it is eligible to conceive any structural members.

## 5. SOFTWARE UTILIZATION

As discussed earlier this thesis work is orientated for 3D structure modelling automation. For executing this task, any of the 3D structure modelling software used in ship design industry is required. Or this thesis work NAPA Designer which is one of the most popular and leading 3D structural modelling software available on date is chosen. In below sections, a brief description is given on how NAPA software is influenced in ship design phases and what are the main features and functions which NAPA undertake in ship design. Also, some brief description about the new C# scripting platform offered in NAPA Designer is discussed below.

### 5.1. Role of Napa in Ship Design

NAPA Steel provides an interactive 3D structural modelling interface. NAPA Steel is one of the forerunners in ship structural design technology. NAPA steel software can be used at both the initial design stage and detailed design stage. NAPA steel is proficient enough to handle fast design changes while providing detailed results for each design stage.

The same mode of NAPA steel can be used by Naval Architects and structural designers throughout the design process with class rule checks, finite element model generation, generate plan approval drawings and weight estimation, thus reducing the design time in general. [6]

Many of the leading ship building firms expects to reduce around 30% of time and man hours in ship structural design by the implementation of NAPA steel software. Further development and customization of NAPA steel can be made in-house or in collaboration with NAPA to obtain a further reduction in those percentage. [7]

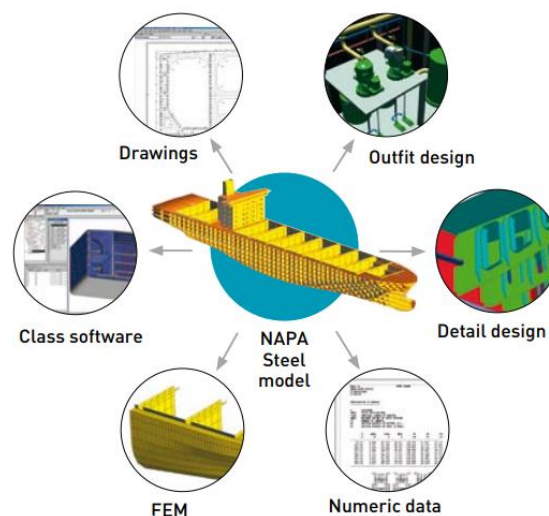


Figure 39: NAPA Steel model applications [16]

NAPA always tries to keep the software updated with the changing market requirements which makes it the best choice at any period for last few decades. New versions and updates are made upon changing classification rules, international standards and technological advancements. The updates will eliminate duplication between software systems and reduce the work needed to ensure designs are compliant with the new rules.

NAPA structural design calculations are harmonized with Bureau Veritas' Mars2000, PrimeShip-Hull from Napa parent company ClassNK, Lloyd's Register's RulesCalc as well as DNV GL's Poseidon and Nauticus Hull programs. This makes the NAPA software results an alternative to those leading classification requirements which makes it easy for classification society and shipyards for easier review and approval of calculations and drawings.

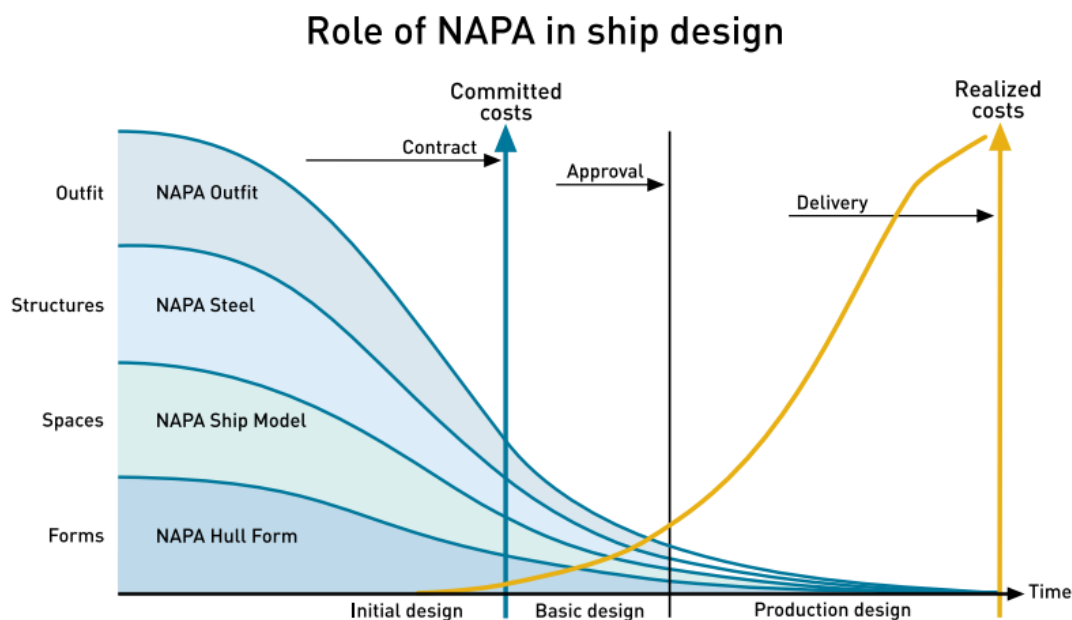


Figure 40: Role of various NAPA software in ship design in ship design process [16]

## 5.2. NAPA Designer scripting concept

C# is a modern object-oriented, general-purpose programming language, created and developed by Microsoft in the .NET platform. C# is a high-level language that is similar to Java and C++. The C# language is distributed together with a special environment on which it is executed, called the Common Language Runtime (CLR). CLR programs are portable and, once written they can function with little or no changes on various hardware platforms and operating systems. The C# scripting language used in NAPA is having access to its general C# libraries, in addition to the special NAPA library.

This NAPA library features various functions which help the user to access, assign, modify and deleted various elements in NAPA model. So, by this user have the full control over the modelling which help them to create a user required model by implementing everything they need. The console feature in this help the user to understand any exemption cases or location the line in the script where the execution is aborted. NAPA offers a help file which can be used to understand what each function performs and what type of input variable is required and what type of variable will be returned by such functions.

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## 6. WORK-FLOW

Before executing any task, a detailed work plan is required. In the same way a work plan is generated for the successful completion of this project as well. Work plan should be a path between what user have, what are the data available and what user want, which is the expected output in this case.

Work plan should contain different phases which will be carried out and list of activities which will be executed during each phase. Before initiating the project, the only available data for this task are 3D hull form and 2D GAP drawing in CAD format. The project is divided into five different phases:

1. Extrusion Tool to generate vertical walls – During this phase, the available .dxf format GAP drawing is imported and then the curves in GAP is extruded in required axis to generate 3D walls or surface objects.
2. Generation of Horizontal Decks – During this phase, horizontal decks are generated at required vertical heights and then trimmed within the 3D hull boundaries. Generated horizontal decks are also a type of surface objects.
3. Listing the structural details for surface objects – During this phase, a spreadsheet is generated which will be filled with details of structural elements which is to be provided to surface objects.
4. Automatic generation of structural members on surface objects based on spreadsheet input – During this phase, structural elements like stiffeners and girders are generated on surface objects as per the input given in spreadsheet list.
5. Substituting the existing stiffeners with new stiffener type – During this phase, any of the existing stiffeners on the surface objects will be replaced with a new stiffener type.

The various phases of this project can be briefly represented using Figure 41 to Figure 44. The pictorial representation gives a better understanding about the procedure.

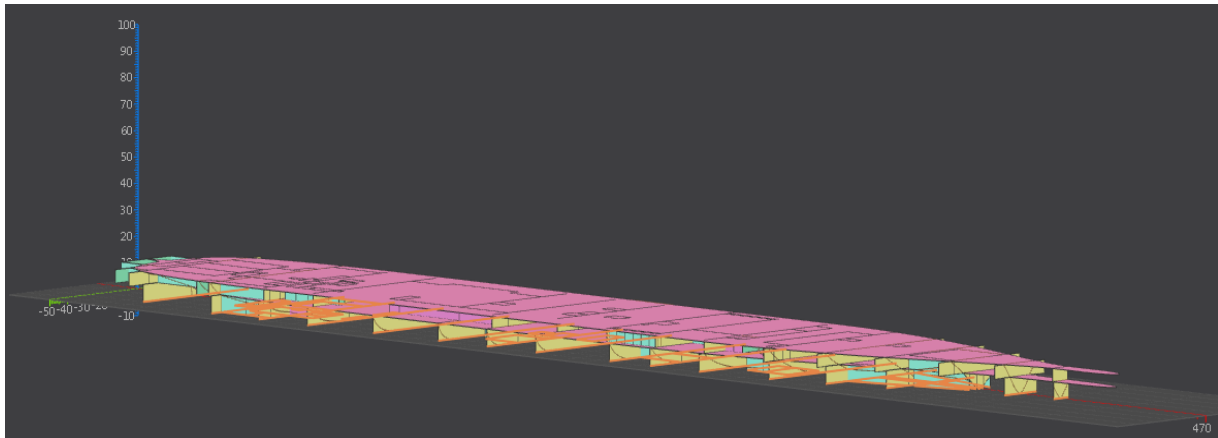


Figure 41: Extruded walls generated and horizontal decks trimmed with hull boundaries

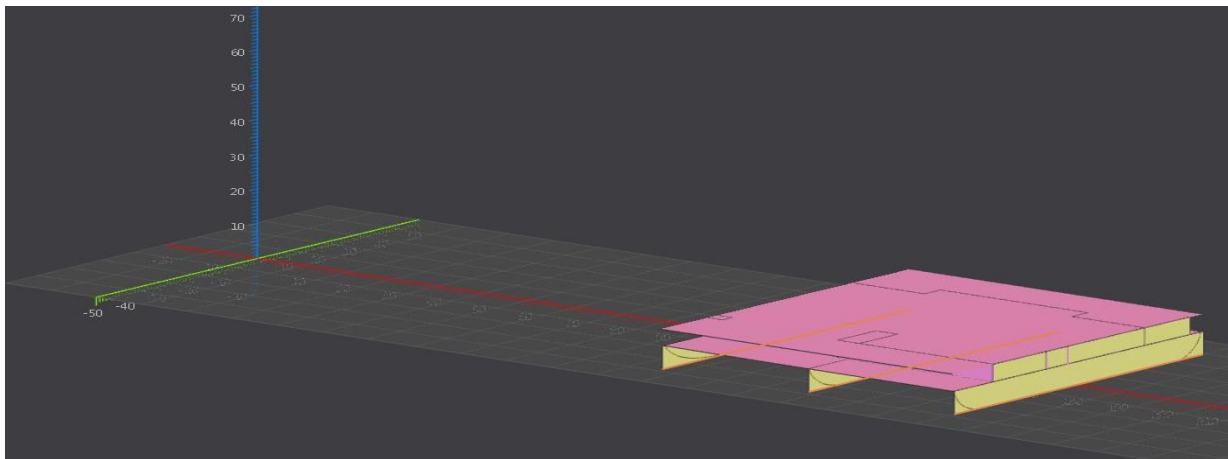


Figure 42: Selecting surface objects with COG inside the bounding box made by given limits

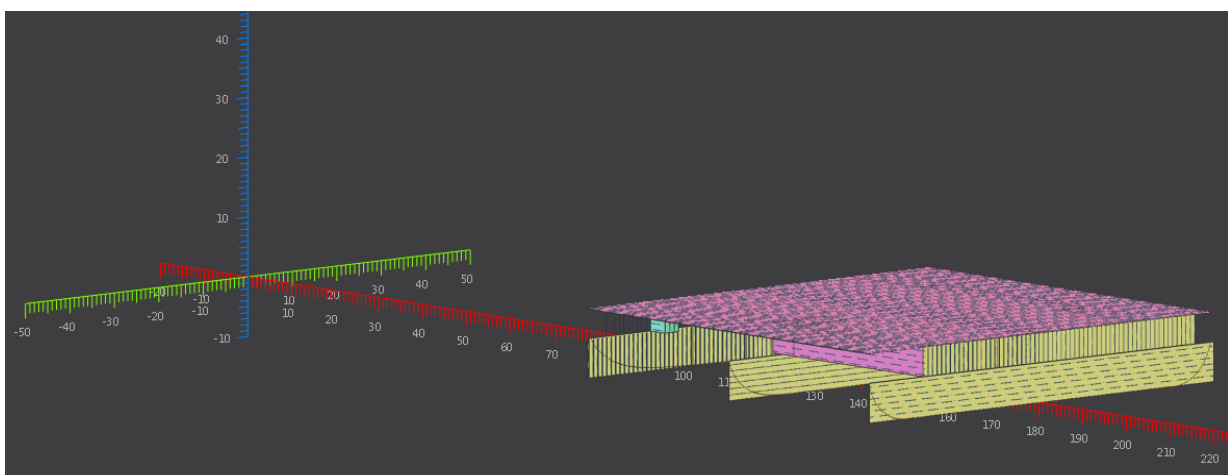


Figure 43: Adding stiffeners to the selected surface objects

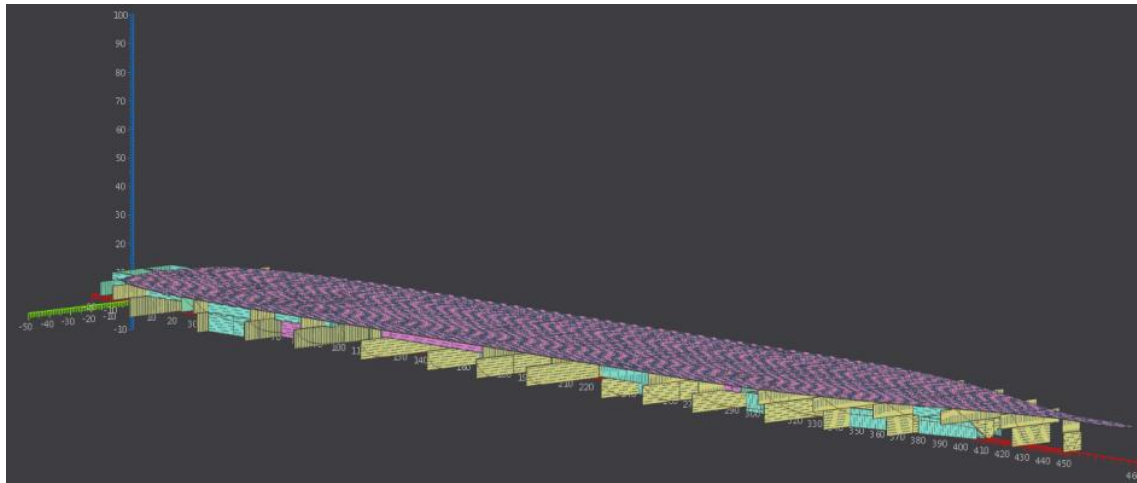


Figure 44: Repeat the selection process and assigning stiffener to surface objects all over ship

In below sections, each step involved in generating this automated 3D structure model is explained in a detailed manner. As discussed above the whole process is categorized into 5 stages and under each stages the sub tasks conducted are also described.

## 6.1. Extrusion Tool to generate vertical walls

### 6.1.1. Create 3D Ship Hull in the NAPA Hull Form

The most notable structural entity of the ship is the hull form. The NAPA hull form feature gives the user the ability to create a precise 3D hull form. It also helps the user to optimize the hull design any time during the design stages. Fairing of hull form to get a precise hull neglecting the difficulties of conventional systems like baton and baton weight is very much used now a days. Implementation of such methods will lead to accurate results along meeting the special design requirements.

A 3D hull form is the primary requirement. A hull model meeting hydrodynamic and seakeeping requirement is essential as it would eliminate or reduce the need for further changes to the design. Thus, based on basic parameters like length, breadth, depth, draft, displacement, block coefficient and with references of existing hull forms of similar ship types, the new hull form is generated.

### 6.1.2. Create a 3D reference framing system

Once the hull form is ready, it can be imported to NAPA Designer. To import an external model or drawing to NAPA designer, a reference point or reference plane is required. For generating this reference system, a framing system can be generated as shown in Figure 45. This framing

system input window gives a platform for the user to enter the longitudinal, transverse, vertical and web framing system details as shown in Figure 45.

**Reference Dimensions**

Description	Value	Key	Status
Reference length	315.0879	LRUF	Calculated
Reference breadth	46.4	BRUF	Calculated
Design draught	9.2	TDRL	Given
Reference point	151544	XRUF	Calculated
Seawater density	1.025	BHD	Initial
Shell thickness	0.015	SHEL	Given
Keel	0.01	KEEL	Initial
Largest frame	128	XMBD	Given
Aft perpendicular	0	AP	Given
Fore perpendicular	315.0879	FP	Calculated
Aft end	-12.6	XMBN	Calculated
Fore end	332.46	XMAX	Calculated
Length over all	345.06	LOA	Calculated
Maximum breadth	57	BMAX	Given
Maximum draught	0	TMAX	Undefined
Subdivision draught	0	HSD	Undefined
Total height	60	HMAX	Given

**Arrangement naming**

Description	Value	Key	Status
Ref. surface arrangement	23.00.08.002	REF	Given
Compartments arrangement	SKTP	ARR	Given
Structure arrangement		STR	Given
Opening arrangement		OPR	Given
Equipment arrangement		EQP	Given
Ref. lightweight version		LGV	Given

**Key Objects**

Description	Value	Key	Status
Stem curve	STERN	STRN	Given
Stem curve	STEM	STEM	Given
Midship section	FRM	FRM	Given
Moulded hull	HULL	MOUL	Given
Hydrostatic hull	HULL	HYDR	Given
Stability hull	STABHULL	STAB	Given
Damage hull	DAMHULL	DAMA	Given
Tonnage hull	TONHULL	TONH	Given
Hull label	HULL	HLBL	Given
Bulkhead deck	BHDECK	BHDE	Given
Main deck	BHDECK	MDCK	Given
Lateral profile	PROFILE	PRCF	Given
Margin line	MARGINLINE	MARG	Given
Draught marks aft	DRMA	DRMA	Given
Draught marks fore	DRMF	DRMF	Given
Visibility limit	PROFILE	PRCV	Given

**Control and Conventions**

Description	Value	Key	Status
Polygonization tolerance	0.001	DMTO	Given
Max. open length		DMAX	Given

**Frame Systems**

**X - Transverse (frames)**

Start frame	Spacing [m]	Distance from frame zero [m]
64	0.75	43.2
68	0.7	46.2
72	0.675	49
144	0.75	97.8
148	0.7	100.6
152	0.675	103.4
224	0.7	152
228	0.75	154.8
232	0.675	157.8
304	0.7	206.4
308	0.75	209.2
312	0.675	212.2
384	0.7	260.8
388	0.75	263.6
392	0.675	266.6
452	2.7	307.1

**X - Web**

Start web	Spacing [m]	Distance from web zero [m]
4		

**Y - Longitudinal**

Start long	Spacing [m]	Distance from long zero [m]
-6	0.6	-22.8
-26	0.6	-15.6
-14	0.6	-8.4
-3	0.6	-1.8
3	0.6	1.8
14	0.6	8.4
26	0.6	15.6
38	0.6	22.8

**Z - Vertical**

Start vert	Spacing [m]	Distance from vert zero [m]
0.6		

Figure 45: NAPA Designer - Reference framing system data input window

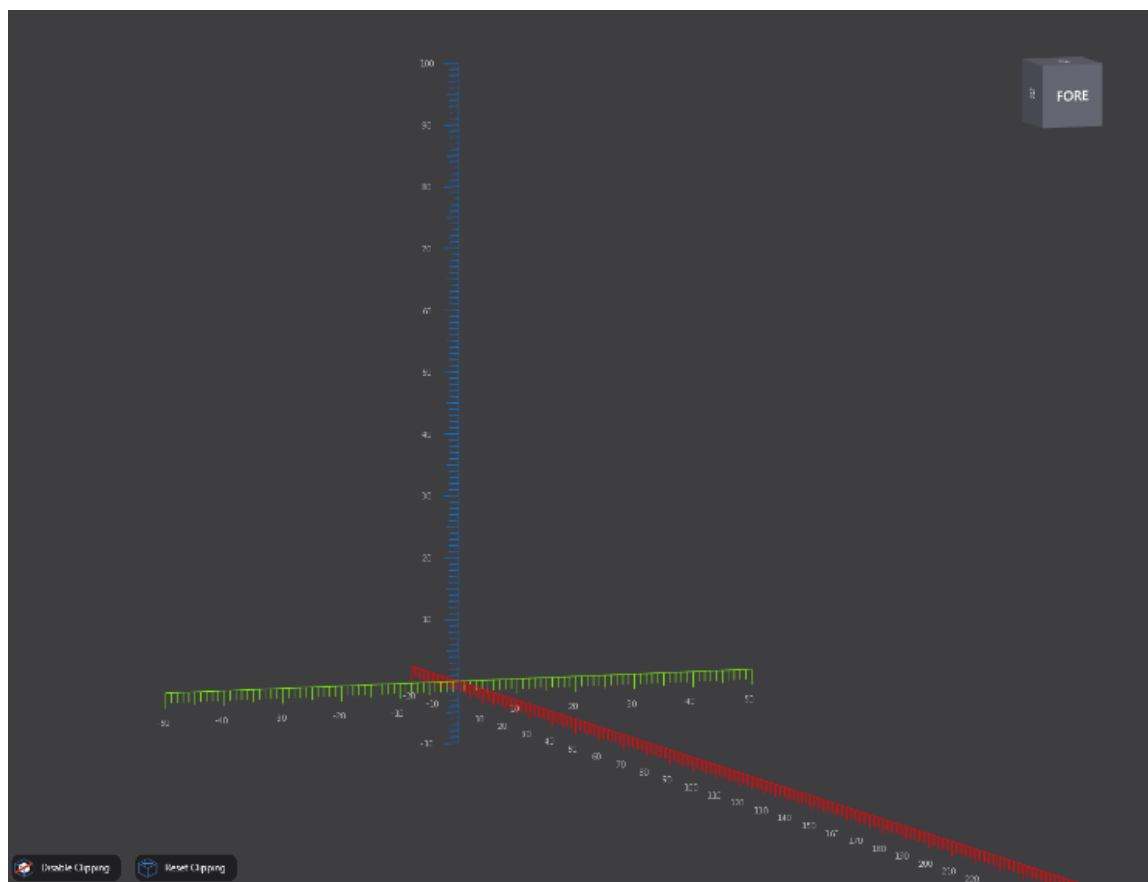


Figure 46: 3D Reference Framing System

This reference frame system is extensively used and is vital in creating the 3D model later. Workplane in this software is a flat plane surface either parallel or inclined to any of the axis which is considered to be the working plane. This reference system can be used to create workplane in any of the axis easily. This reference system is also used as reference to generate stiffeners or girders, which is explained in detail later in section 6.4.4

### **6.1.3. Import .dxf Format AutoCAD drawing into NAPA Designer**

Once the external hull form is available as in normal ship design phase, the internal divisions are considered. The internal divisions will be comprised of all transverse and longitudinal bulkheads, non-watertight steel walls and other steel structural separations based on classification rules and statutory standards. Thus, these internal divisions in each deck are marked up as separate AutoCAD drawings like in conventional design phases.

NAPA Designer gives the possibility to import any AutoCAD drawing in .dxf format. NAPA imported drawing should be so arranged that the drawing contains plan or elevations view of a single deck only. Each line imported into NAPA Designer from 2D AutoCAD drawing will be saved as a polyline. So, this imported drawing is inserted to a user defined reference plane here in NAPA called as workplane. For example, once the 2D drawing is ready workplane can be set at  $Z=0$  axis. This will create a XY Plane at  $Z=0$  on to which the plan view from 2D drawing is imported and saved in NAPA Designer.

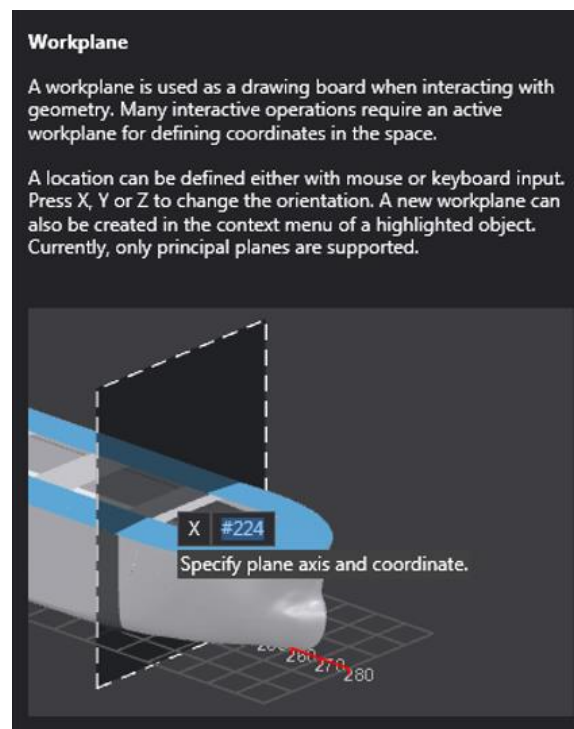


Figure 47: Description of Workplane from NAPA Designer

The plan view drawing generated in AutoCAD in .dxf format should contain only continuous straight lines. Any breaks or overlapping will be taken as it is, when they are imported to NAPA Designer. The ship hull boundaries are not required in the AutoCAD drawing as the surfaces generated by extruding the imported lines will be trimmed with the 3D hull boundaries which were already generated in NAPA Hull form.

#### **6.1.4. Extrude the Polylines to Create Surfaces**

Further to the above step, the lines in AutoCAD drawings are saved as polylines in NAPA Designer. These polylines are extruded within a specific limit in required directions to generate surfaces. NAPA itself is having a feature for extrusion in NAPA Designer. But extrusion with this feature can be done only individually for every polyline, which is a time-consuming process. Hence, the multiple extrusions are achieved together using a script by which all the selected polylines can be extruded within specified minimum and maximum limits. For example, if one needs to extrude polylines in frame no #56, #9, #168, #LONGI 3.75m, #LONGI -7m in Z direction (vertical) between vertical limits 4m and 7m measured from base line, these can be achieved successfully by executing the script.

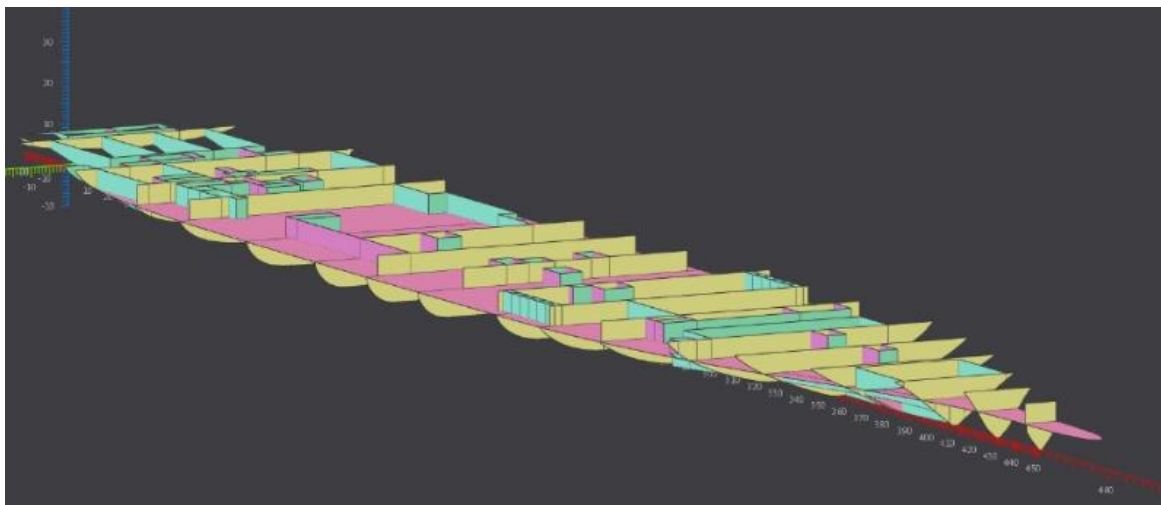


Figure 48: Extruded polylines turned into vertical surfaces in Deck 2

#### **6.1.5. Convert Objects into Surface Object**

Objects in NAPA are composed of just surfaces which do not contain any structural properties. Hence, the extruded surface (called as object) need to be changed into surface object so that it is possible to obtain properties like thickness, material and structure type. With the help of a loop function each of the created objects are converted into Surface Object using the function 'CreateSurfaceObject'. Once an object is changed to surface object then it is possible to assign

any structural properties like structural type, thickness and material. If no specific values are given then default values will be assigned to the surface objects.

#### 6.1.6. Assigning Structure type to surface objects

Once the surface object is generated, the structure type for each of those surface objects needs to be provided. This stage hasn't been automated as part of this thesis. It is very difficult to categorize what type of structure type each of those elements have. For example, a longitudinally aligned bulkhead has multiple possibilities as its structure type like LBH (longitudinal bulkhead), LBH\_WT (longitudinal watertight bulkhead), SIDE (side plating), SHELL (shell plating), INNERSKINBHD (inner bulkhead) etc. So, deciding the structure type among a list of such possibilities cannot be automated and hence needs manual intervention.

So, structure type for each surface objects are manually assigned which will help the user in further stages to select surface objects based on structure type. Since surface objects with same structure type will contain similar properties it will be easier to assign additional structural details to them.

LBH	TBH_WT	BOTTOM
LBH_WT	TRANSBHD	BOUNDARY
LNGHCOAMING	TRANSCORBHD	BRACKET
MD	TRANSLSTOOLTOP	DECK
PILLAR	TRANSLWRSTOOL	DGI_WT
SHELL	TRANSUPRSTOOL	FLOOR
SI	TRANSUSTOOLBTM	FLOOR_WT
SIDE	TTOP	GIRDER
SI_WT	WEB	GIRDER_WT
TBH	WEB_WT	INNERSKINBHD

Figure 49: List of structure types available in NAPA Designer

#### 6.1.7. Make Surface Objects under “Arrangement”

Categorize surface objects under “Arrangement” to make it eligible to conceive further structural properties like stiffeners, bracket, cut-outs etc. By bringing the surface object under arrangement the license is obtained to access and modify the surface objects. This gives a wide range of freedom for the programmer to modify the surface object so as to match-up with the real design standards and practical scenarios.

## 6.2. Generation of Horizontal Decks

### 6.2.1. Create Horizontal Decks in Required Vertical Heights

Although sub division using the deck was mentioned in section 6.1.3, procedure and concept used to create horizontal deck have not been clearly explained. A script was created for the same to generate horizontal decks in every required vertical height. To reduce manual work, consideration has been given in the script to trim the created decks within the hull boundaries. This is practically done using the function ‘CreateObject’. These generated surfaces are converted from objects into surface objects using the above steps through the function ‘CreateSurfaceObject’. Further they are brought under the “Arrangement” to add more structural properties like stiffeners, cut-outs etc.

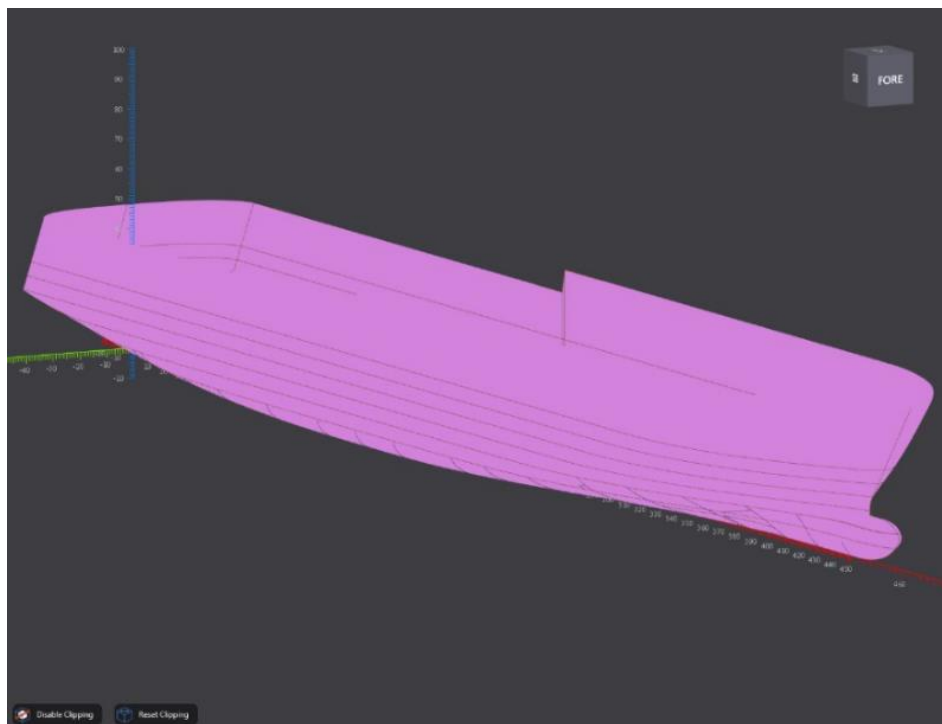


Figure 50: Horizontal deck created cropped within hull boundaries

## 6.3. List the structural details for surface objects in spreadsheet

### 6.3.1. Input of Table Content on to Script

Once the required surface objects are generated, then it is eligible to accommodate structural properties. Hence, once surface objects are created, all the structural properties of each of the surface objects are provided. Giving structural properties separately for every surface object is a time-consuming task. But for ship design in general, the structural members remain same for all structural types within a specific area. Using this phenomenon, one can assign a structural



property for a selected set of surface objects based on a criterion. Some example for selection of surface object based on criteria is given below.

Example 1: Stiffeners on all longitudinal bulkhead (LBH) between Deck 3 (5 meters) and Deck 4 (8 meters) in Main Vertical Zone 3 (MVZ 3) is HP160x9

Deck 3, MVZ 3	LBH	Z>5, Z<8, X>60, X<120	HP160x9	A
---------------	-----	-----------------------	---------	---

Example 2: Stiffener on Surface object with surface type Transverse bulkhead (TBH) coming between vertical height 2m to 9m and Main Vertical Zone 1 and 4 (MVZ 1& MVZ4) is DH32

Deck 1, MVZ 3	TBH	Z>0, Z<2.5, X>60, X<120	L150x90x8	DH32
---------------	-----	-------------------------	-----------	------

The above example is a simple representation of an idea which is planned to be implemented in the script. In order to improve the process efficiency and increase the automation, a spreadsheet is generated which takes a complete set of manual input from the spreadsheet to script in a transferable format. The spreadsheet contains an input section which needs to be manually provided. It also contains an output section where all the contents which were provided earlier are available and can be completely copied into the script and so that it can be executed to generate the final output.

Limits & Structural Type						Stiffener				
Sl. No	M V Z	Z min	Z max	Y min	Y max	Type	Orientation	Mould ed	Mater ial	Profile Size
1	2	4.0	7.0	-25.0	25.0	LBH	VERTICAL	FRONT	AH32	FB150X10
2	3	0.0	4.0	-25.0	25.0	LBH_WT	LONGITUDINAL	FRONT	A	HP140X8
3	1	0.0	4.0	-25.0	25.0	TRANSBHD	VERTICAL	FRONT	A	L150X75X9
4	1	4.0	7.0	-25.0	25.0	TBH	TRANSVERSE	FRONT	A	FB100X8
5	3	0.0	4.0	-25.0	25.0	TRANSBHD	TRANSVERSE	FRONT	D	HP140X8
6	1	4.0	7.0	-25.0	25.0	LBH_WT	LONGITUDINAL	BACK	A	L100X75X7
7	2	0.0	4.0	-25.0	25.0	DECK	LONGITUDINAL	FRONT	AH32	L150X75X9
8	3	4.0	7.0	-25.0	25.0	TRANSBHD	VERTICAL	FRONT	AH32	L150X75X9
9	2	5.5	7.0	-25.0	25.0	DECK	LONGITUDINAL	FRONT	A	L150X75X9
10	2	0.0	4.0	-25.0	25.0	TRANSBHD	VERTICAL	FRONT	AH32	L100X75X7

Table 2: Format for Structure Details of stiffener manually inserted in spreadsheet

As shown in Table 2, the vertical longitudinal and transverse limits are manually inserted and based on those limits all surface objects with structure type as in the table will be selected. These selected surface objects will be assigned with stiffener type provided respectively in the

table. These generated stiffeners will follow the structural properties like type of stiffening, material grade and orientation of stiffener on which face of the surface object.

The spreadsheet also contains the same format as stiffener for entering structural details of the girders which need to be assigned to the surface objects. The only additional details which need to be provided for girders are the location of girders on the surface object. This is because of the asymmetric girders positioned in ships in real case.

Limits & Structural Type							Girder				
Sl. No	M VZ	Z min	Z max	Y min	Y max	Type	Orientation	Moulded	Material	Girder Size	Girder Location
1	2	4.0	7.0	-25.0	25.0	LBH	VERTICAL	FRONT	A	300X10/150X15	
2	3	0.0	4.0	-25.0	25.0	LBH_WT	VERTICAL	FRONT	AH36	500X7/100X10	
3	1	0.0	4.0	-25.0	25.0	TRANSBHD	VERTICAL	FRONT	A	400X10/150X15	6.0,-6.0
4	1	4.0	7.0	-25.0	25.0	TBH	VERTICAL	BACK	A	300X10/150X15	3.0
5	3	0.0	4.0	-25.0	25.0	TRANSBHD	VERTICAL	FRONT	A	450X7/100X10	
6	1	4.0	7.0	-25.0	25.0	LBH_WT	VERTICAL	BACK	AH32	300X10/150X15	
7	2	0.0	4.0	-25.0	25.0	DECK	LONGITUDINAL	FRONT	A	450X10/150X15	3.0,6.0,12.0,15.0
8	3	4.0	7.0	-25.0	25.0	TRANSBHD	TRANSVERSE	FRONT	A	450X10/150X15	0.0,3.0,9.0,15.0
9	2	5.5	7.0	-25.0	25.0	DECK	TRANSVERSE	FRONT	AH36	450X10/150X15	
10	2	0.0	4.0	-25.0	25.0	TRANSBHD	VERTICAL	FRONT	A	300X10/150X15	0.0,3.0,-3.0,9.0,-9.0,-15.0,15.0

Table 3: Format for Structure Details of girder manually inserted in spreadsheet

The stiffeners or girders can be generated longitudinally, transversely or vertically. This is decided based on the orientation of plate and the type of stiffening which is required in respective areas based on loads acting over that region. The type of stiffening in each of these regions is decided based on the type of loads that are majorly transferred to these stiffeners.

Hence, regardless of the stiffening system chosen, the stiffeners or girders will be generated in line with the frames in that axis. Figure 51 denotes a simple example of how a vertically stiffened transverse bulkhead looks in NAPA Designer. It can be noticed the stiffeners and girders are generated in frames only. Also, the girders are not symmetric, which is a real case

in ship building. Because of this reason an additional option is given in girder section to specify the location where the girders are needed. The coordinates for the port side and starboard side girder need to be specified separately. For this, the distance from the centre line to the girder location should be specified in meters (+ve for port and -ve for starboard). The right end corner column in Table 3, denotes the same.

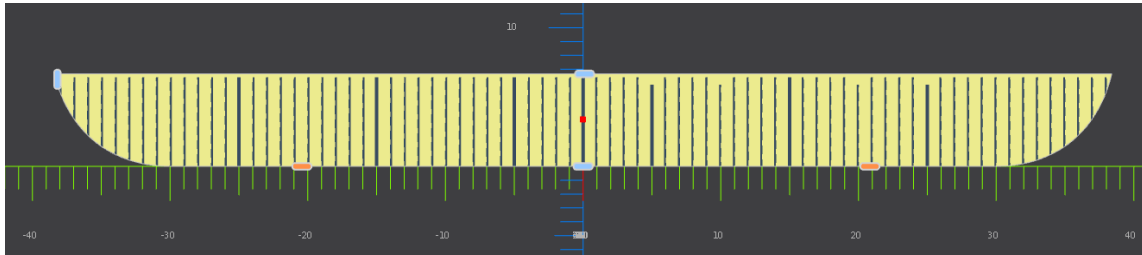
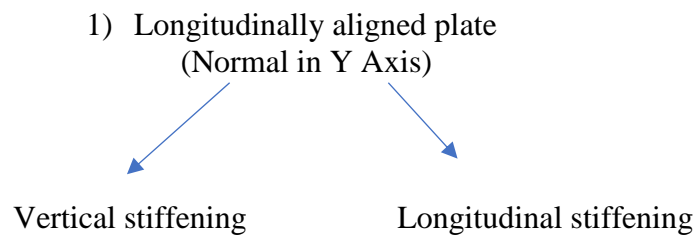
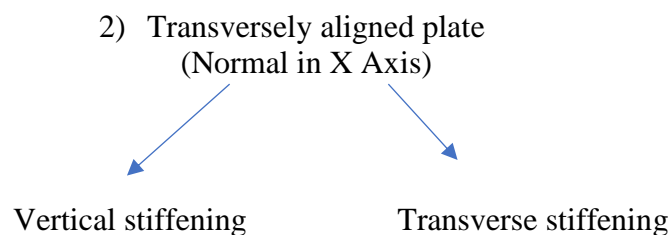


Figure 51: Stiffeners generated in line with the frame system (transverse frame system)

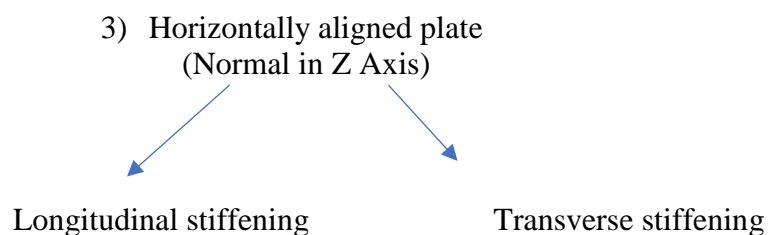
From Table 2 and Table 3, it is clear that the orientation for stiffeners or girders are provided manually. But based on the orientation of plate the stiffening types are limited. Various possible types of stiffening based on plate orientation are shown below.



Example: Longitudinal bulkhead (LBH), Longitudinal double bottom Girder



Example: Transverse bulkhead, Double bottom floor, collision bulkhead



Example: Decks, tween decks, double bottom, forecastle deck

For example, a longitudinal bulkhead in lower decks is very much prone to global longitudinal loads. In such a case, out of the two possible types of stiffening one has to go with longitudinal stiffening, so that the longitudinal global loads are carried and properly transferred through the stiffeners. In this manner, the stiffening type in every part of ship is decided.

## **6.4. Automatic generation of structural members**

### **6.4.1. *Select Surface Objects Within Specific Boundary Limits***

Once the surface objects are categorized under “arrangement” and structural details of stiffeners and girders are available for required surface objects then those structural elements can be assigned to the respective surface objects. For implementing this, a code is generated to select surface objects enclosed in a specified boundary limit. Selection criteria is set based on the position of centre of gravity. With these criteria, all surface objects with centre of gravity coming inside the bounding box formed by limits will be selected. This will solve the selection issues for the surface object extending two main vertical zones or lies in two bounding boxes.

For example: surface objects inside  $Z < 7$ ,  $Z > 4$  and Main Vertical Zones 4 – In this case all surface objects with centre of gravity inside the rectangular bounding box generated by the above given limits will be selected.

This selection of surface objects inside a bounding box can be filtered using the structure type also. By using this filter, only the surface objects with specified structure type and enclosed within the boundary limits will get selected. If no structure type is specified, all surface objects inside the boundary limits will be selected. In the next stage these selected surfaces objects will be assigned to respective stiffeners or girders. This will be explained in detail in further steps.

For example, consider the case of surface objects inside  $Z < 7$ ,  $Z > 4$  and Main Vertical Zones 4 with structure type ‘TRANSBHD’. In this case all surface objects with structure type only as transverse bulkhead and centre of gravity inside the rectangular bounding box generated by the above given limits will be selected.

### **6.4.2. *Assign Given Type of stiffening to Surface Objects under Selection Criteria***

Once the selection of surface objects is done successfully, the kind of stiffening types that need to be given on to those selected objects can be assigned. As shown in Table 4, the kind of stiffening for stiffeners required for surface objects selected within limits are defined. Similar description is given for girders separately.

Sl. No	MVZ	Z <sub>min</sub>	Z <sub>max</sub>	Y <sub>min</sub>	Y <sub>max</sub>	Type	Orientation	Moulded	Material	Profile Size
1	2	4.0	7.0	-25.0	25.0	LBH	LONGITUDINAL	FRONT	AH32	FB150X10

Table 4: Structure Details of stiffener for surfaces objects with structure type as LBH within limits

The mentioned stiffening type can be assigned to the surface objects using a code. In the above example, all the selected surface objects with structure type longitudinal bulkhead within limits is supposed to have vertical stiffeners as shown in Table 4. So, further after the implementation of the code, it will return the axis and location, where the trace needs to be generated based on stiffening type. It will return the axis and location details for every trace which is supposed to come in that surface object. Once the traces are generated in those locations as described in next step, further to that these steps will be repeated for every surface object selected using the selection criteria.

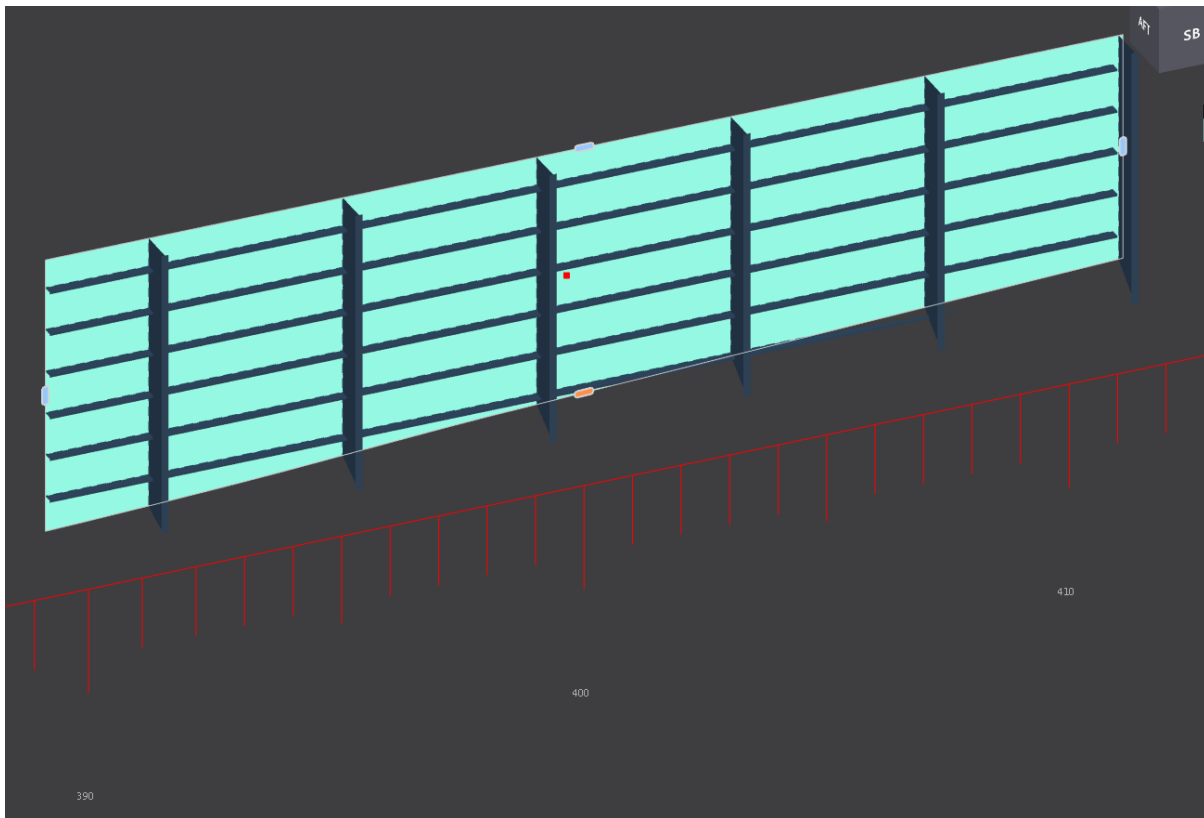


Figure 52: Longitudinal stiffened bulkhead with vertical girders in every 4<sup>th</sup> frame or web frame generated as per the spreadsheet details shown in Table 4

### 6.4.3. Create Trace on the Surface Objects

Once the surface object within the specified boundary limit is selected and the axis and location details are obtained for the trace from the above step, every surface object needs to be selected individually to generate traces. Traces are generated so to lay down the route for stiffeners in the surface object where they should be created.

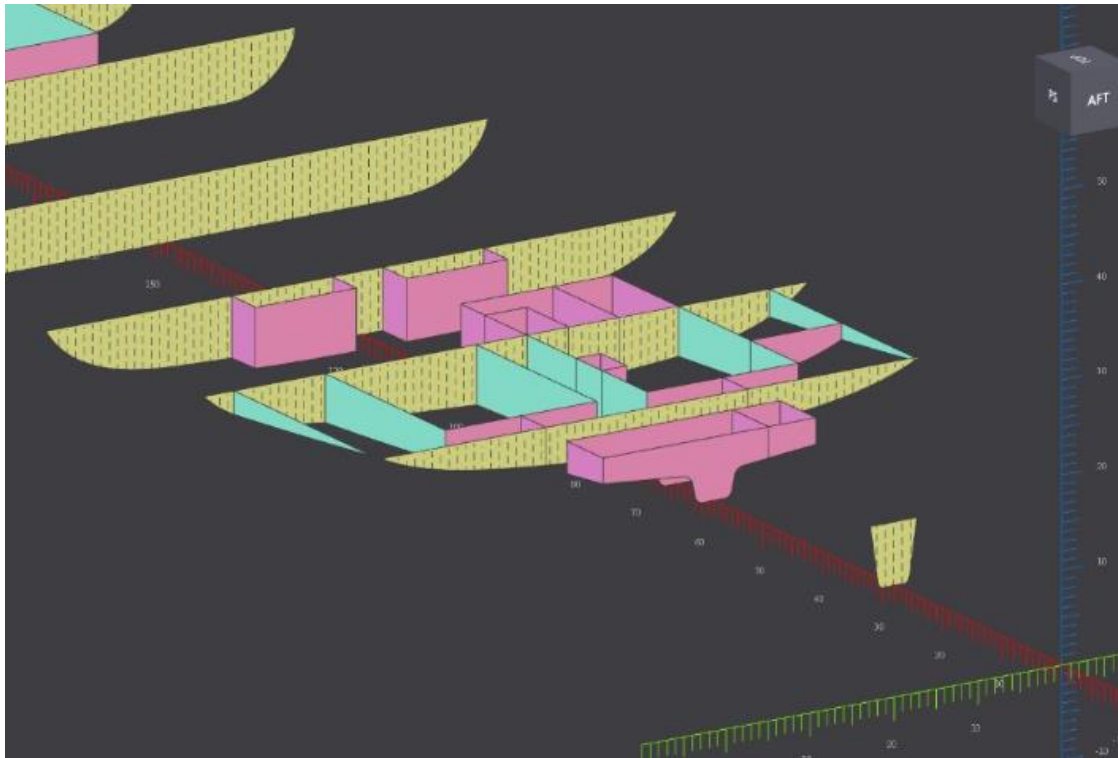


Figure 53: Vertical traces created in all surface objects with structure type TRANSBHD

Figure 53 is a graphical representation of surface objects with structure type 'TRANBHD' selected within some bounding limits assigned with traces generated based on vertical stiffening system. As seen in Figure 53, the traces generated in the above case lies in line with the transverse frames system. For trace generation, details of axis and location from above step for every selected surface object have already been gathered. Traces generated are limited within the surface object boundaries. Traces are not extended outside surface object boundaries. From Figure 53 it can be seen that surface objects are cropped with hull boundaries and the generated traces also lie within the same boundaries.

When stiffener and girder stiffening system are similar, there will be duplication of traces at locations where girders will be generated. So, in order to avoid duplication, the stiffening type for girder and stiffener will be compared and if both of them have the same stiffening type, code is capable to skip trace generation at locations where girder will be created.

#### 6.4.4. Create Stiffener or Girders on the Surface Objects

Once the traces are generated stiffener or girder can be generated on surface objects. Stiffeners or girders will be generated in trace lines created. But for creating them some details regarding the stiffener or girder are needed. For this, the profile size, profile direction, profile material and profile side (moulded) on the surface objects needs to be provided. Front side represents the face of the surface object directed towards centre line, baseline and midship. Table 5 is an example of structural details provided for stiffener.

Sl. No	MVZ	Z <sub>min</sub>	Z <sub>max</sub>	Y <sub>min</sub>	Y <sub>max</sub>	Type	Orientation	Moulded	Material	Profile Size
1	3	2.0	5.0	-25.0	25.0	TBH	VERTICAL	FRONT	A	L150X75X9

Table 5: Structure Details of stiffener for surfaces objects with structure type as TBH within limits

Once the structural details for stiffener and the traces on surface object are obtained, stiffeners can be generated on trace lines as per the details. Every trace line will be selected individually and a stiffener with associated structural details will be generated with base of stiffener lying on the trace line. This will repeat for every trace line generated on the surface object.

The screenshot shows a 'Properties' dialog box with the following fields and values:

- Name:** S:GDCX60N1IS/SO.DK3\_DXF\_133
- Structure:**
  - Profile:** L (selected), L150X75X9
  - Material:** AH32
  - Side:** FRONT (selected), BACK
  - Web Direction:** Default
  - Priority:** 0
  - Start Angle(degrees):** 0
  - Flange Reflection:** ☐
  - Start Endcut:** (dropdown)
  - End Endcut:** (dropdown)
  - Start Limit:** (input)
  - End Limit:** (input)
  - Location:** Y=-3.6
  - Center of Gravity:** (280.00; -3.58; 5.50)
  - Cross Section Area (cm²):** 19.44
  - Length (m):** 3
  - Weight (T):** 0.046
- Custom Properties:**
  - New property... (input)
  - New value... (input)

Figure 54: Sample List of details available for a Steel Object or Structural Member

Once a surface object is completed with stiffener generation in every trace, this procedure will be repeated to the next selected surface objects. Similarly, every surface object under selection will be filled with stiffeners on their trace lines. Once every surface object under a selection criterion is completed, this procedure will repeat to the next selection criteria and their surface objects. In this way, all the cases given in the spreadsheet input will be executed and every surface object coming under those selection criteria will be generated with stiffeners or girders.

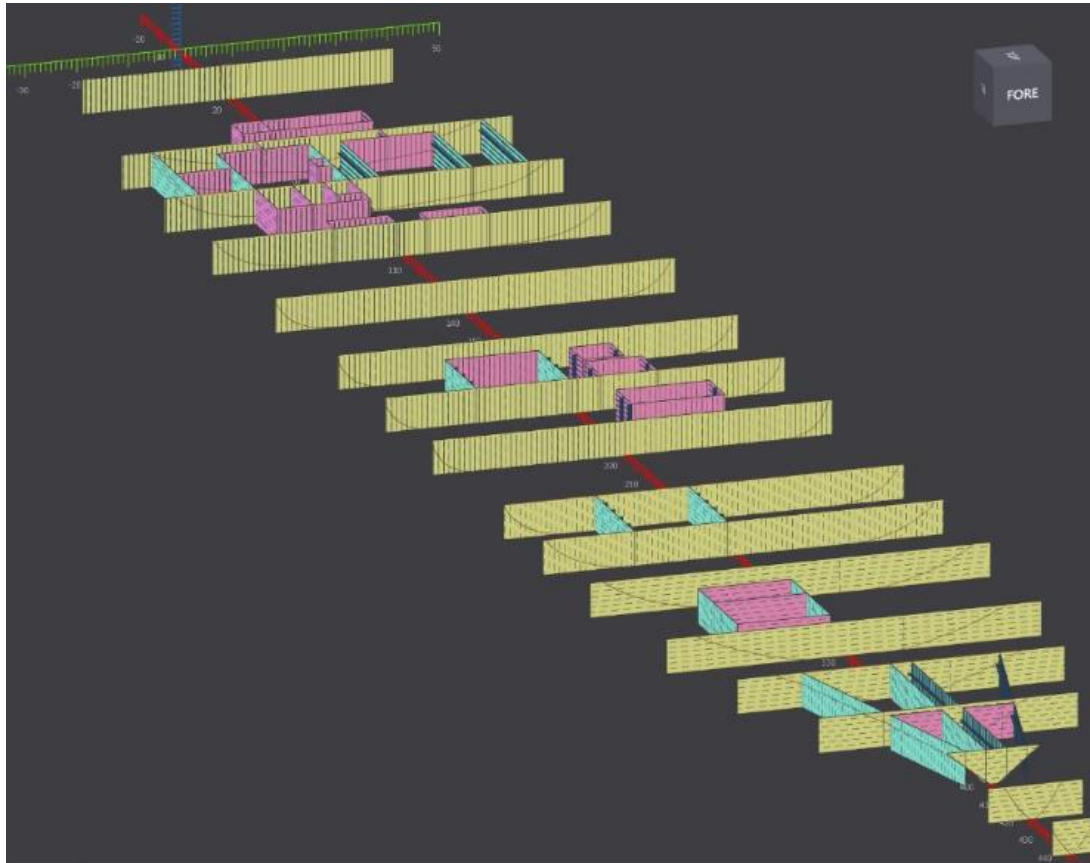


Figure 55: Final model with every surface object with their respective stiffeners and girders

## 6.5. Substituting the existing stiffeners with a new stiffener type

The structural members given on surface objects may need to be changed many times during the design stages. The classification society comments, production facility limitations and unavailability of the structural member for procurement are some of the reasons which could lead for such changes. In such cases, one may need to modify the 3D model as well.

The software provides the possibility for the user to select and then change structure element type individually for every stiffener using the icons in its toolbar. But selecting each profile individually and modifying them is a time consuming and hectic for designers. So, a code is generated to select surface objects with similar structure type within an area, which generally



have the same structural members. Once the selection is done, the existing stiffeners are first deleted from the surface objects retaining the trace lines. Then in next stage the new stiffener type provided will be generated on surface objects at every trace line. This process will occur repeatedly for every surface object which are under selection.

This is an easier way to modify the 3D model upon some classification society or owner comments to meet the structural stiffness of the ship. This will help the user to generate modified 3D structural model incorporating class comments very rapidly.

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## 7. EVALUATION OF THE RESULT

The special considerations taken care during the 3D model generations are discussed under this section. In order to meet the scope of the thesis model generation underwent through numerous hurdles and complications. Major problems that were observed during the model generation are listed in section 7.1. Solution for the problems are found in such a way that the reoccurrence of these challenges are minimized. Under section 7.2 the model generated as a result of this thesis work is evaluated with the initial requirements.

### 7.1. Special Considerations taken for automating the structure modelling

- Based on the stiffening type given in spreadsheet input, the type of stiffening will be decided for stiffeners and girders individually. When both stiffener and girder are provided with the same stiffening system, then, care is taken to avoid overlapping with a console statement. This will help the user to have a list of all locations where the stiffeners are eliminated.

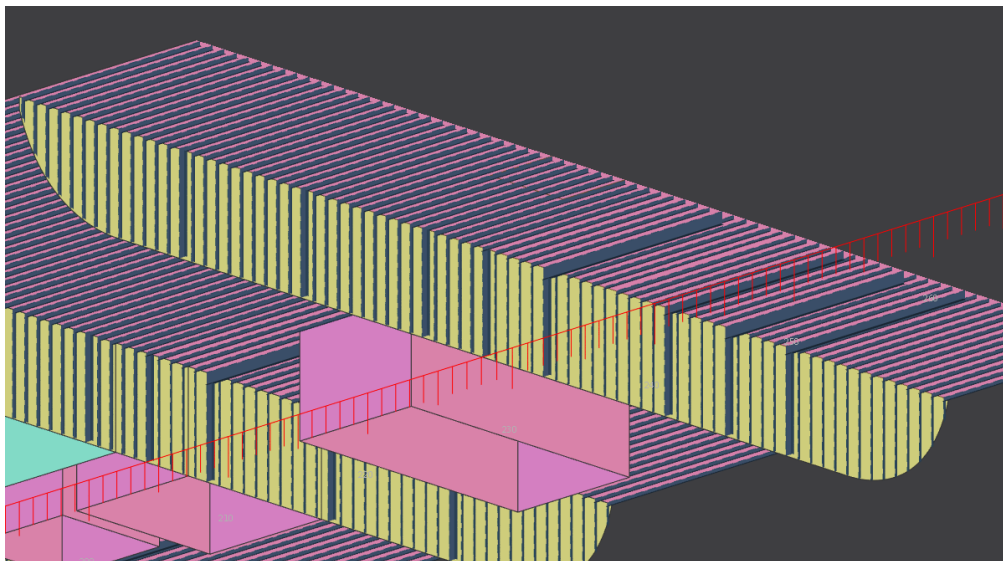


Figure 56: Overlapping of stiffeners at girder locations eliminated

- When stiffeners or girders overlap with any main objects, stiffeners or girders are eliminated with a console statement. This will happen only when the stiffener or girder will have vertical stiffening type. In such cases the trace line for stiffener or girder and the surface object edge could overlap. Figure 57 is an example of such a situation where the stiffener is eliminated at surface object intersection point.

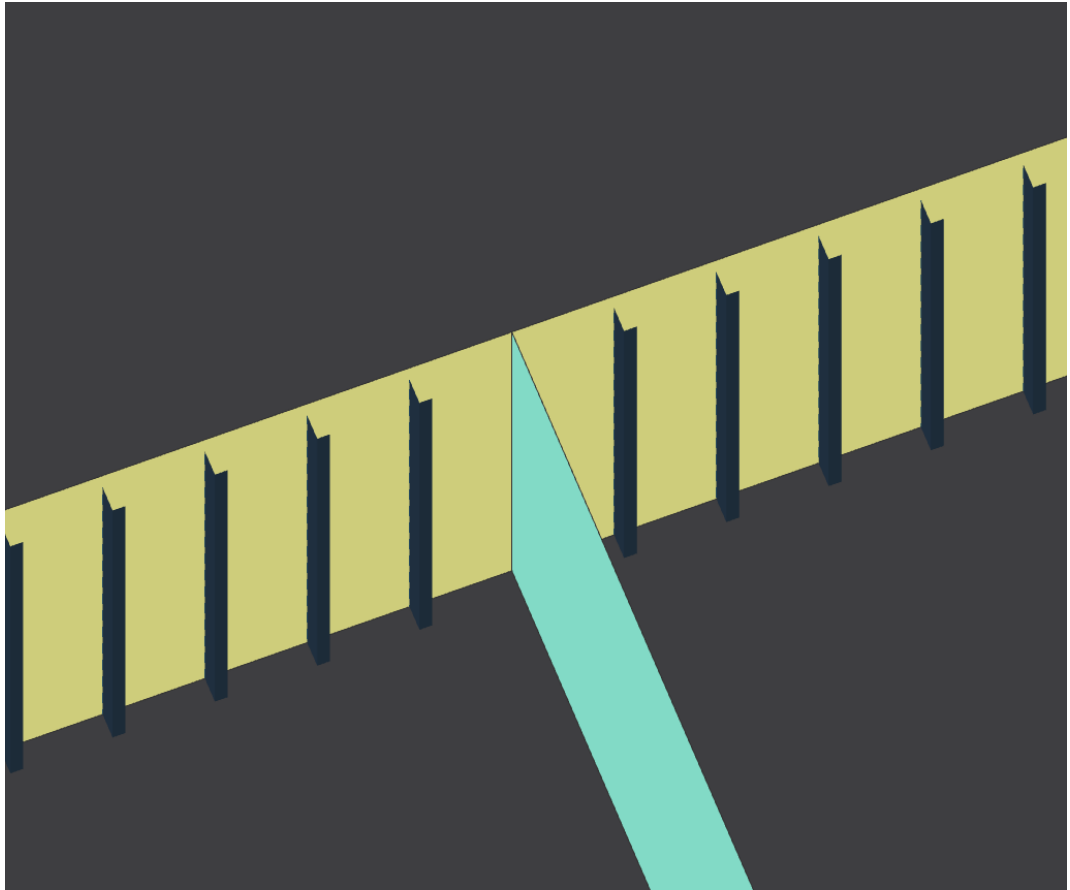


Figure 57: Overlapping of stiffeners at surface object intersection eliminated

- Because of plate orientation (facing forward or aft ward), the minimum and maximum point in terms of coordinates may not be uniform in the whole model. For example, a forward-facing plate would be having its maximum point in the starboard side while an aft facing plate would have the maximum point at port side. So, in order to ignore this error which would occur because of the plate orientation the minimum and maximum values in such cases needs to swapped.
- Coordinates of all frames coming between minimum and maximum points will be selected for trace generation. The numerical values of co-ordinates are rounded to 5 decimal points in order to avoid out of frame stiffener generations.
- In ship's reference framing system, in addition to normal longitudinal frames there would be web frames which generally repeat after every 3, 4 or 5 normal frames. This is decided by the user during the structural arrangement. Transverse girders or webs are generally generated at every web frame. But longitudinal girders or vertical girders may not be having a regular pattern or symmetry like transverse girders.

Hence, a feature is offered so that the longitudinal girders or vertical girders can be assigned to surface object at desired location.

- When a stiffener or girder intersects with another stiffener or girder, they will have some common intersecting area. But in reality, any one of them will be snipped at the flange of the other member. The one which will be snipped is decided based on the continuity of members for load transfer. For example, in a case where vertical stiffener in a vertical transverse bulkhead is connected to the longitudinal stiffener in deck, a longitudinal stiffener will be continuous and vertical stiffener will be snipped. This is because the load transfer happens from deck stiffeners to vertical stiffeners in bulkhead. Figure 58 & Figure 59 are clear examples of snipped stiffener at intersection point.

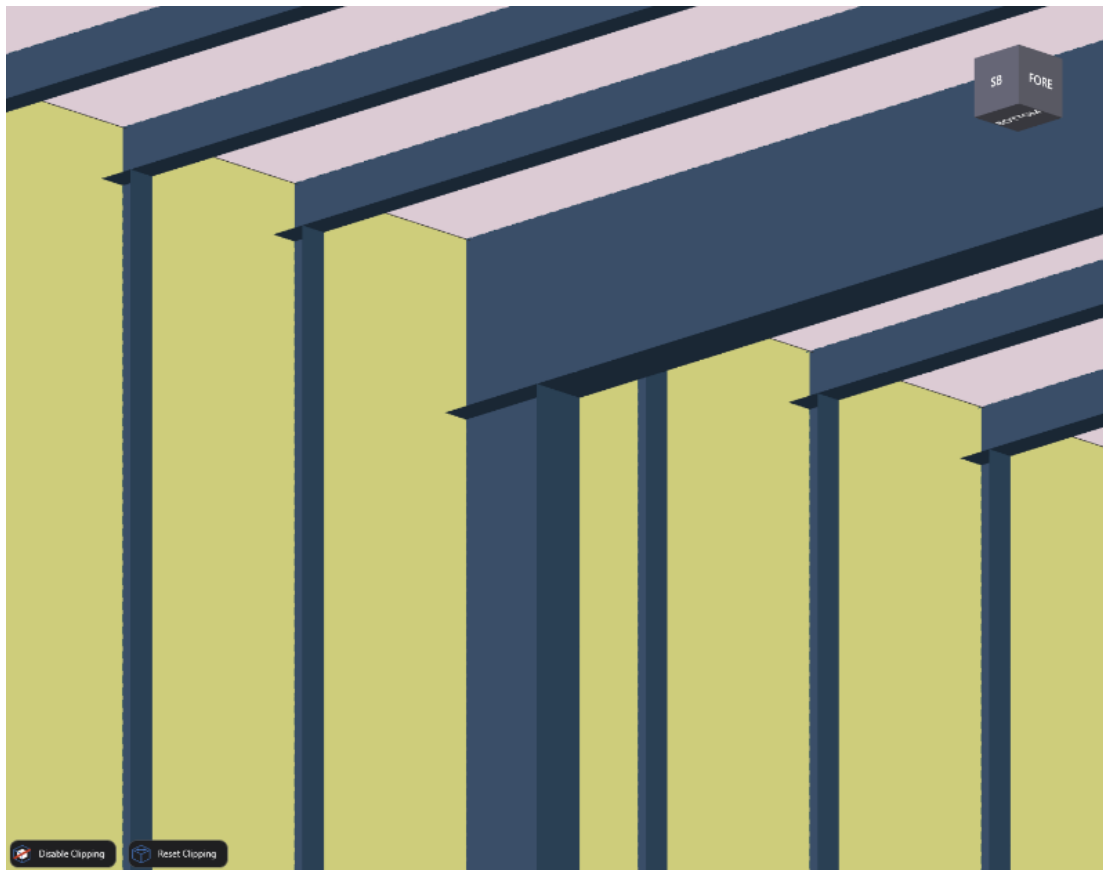


Figure 58: Stiffener & girder ends cut at intersection points with deck members

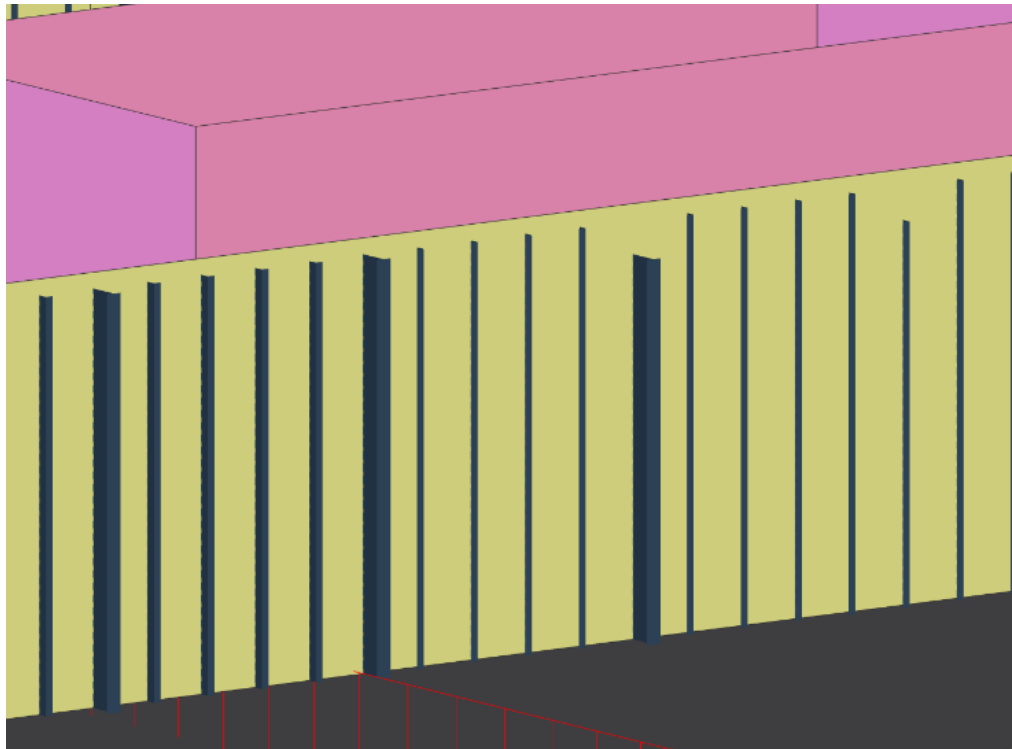


Figure 59: Stiffeners and Girders with end cuts hiding the connection with deck members

- The stiffener orientation is kept as default, facing the reference line in framing axis. The reference lines for various axis lies longitudinally at midship, transverse at centre line and vertically at baseline. So, if the structural element orientation needs to be in different direction than the default case, then it should be manually changed.

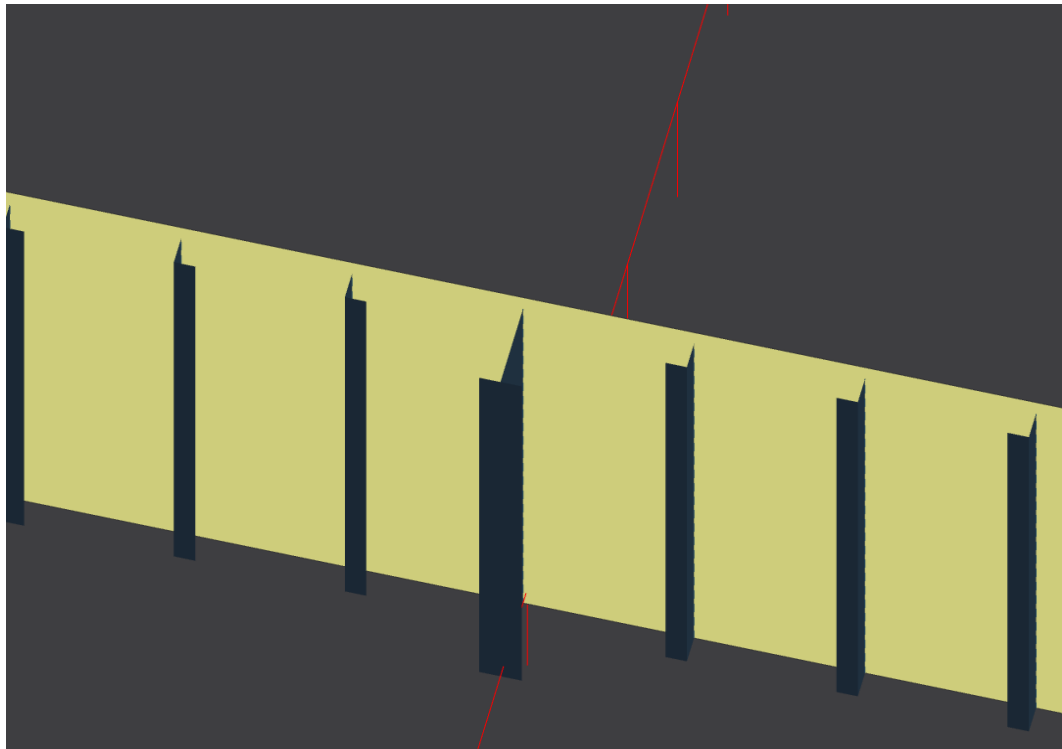


Figure 60: Orientation of Stiffeners in port and starboard side towards centre line

- While implementing automated steel structure modelling, only profiles available in steel library can be generated. If the profile size to be assigned is not listed in the steel library, the automatic modelling operation will abort.
- Error in the .dxf imported CAD file will lead to a lot of manual work in modelling. Hence the drawing that is imported should be proper and error free to avoid such extra manual work in later stage. If the bulkheads or surfaces are not in line with frames then girders or stiffeners generated in adjacent surface object could overlap partially. Figure 61 is a clear example of such an error case.

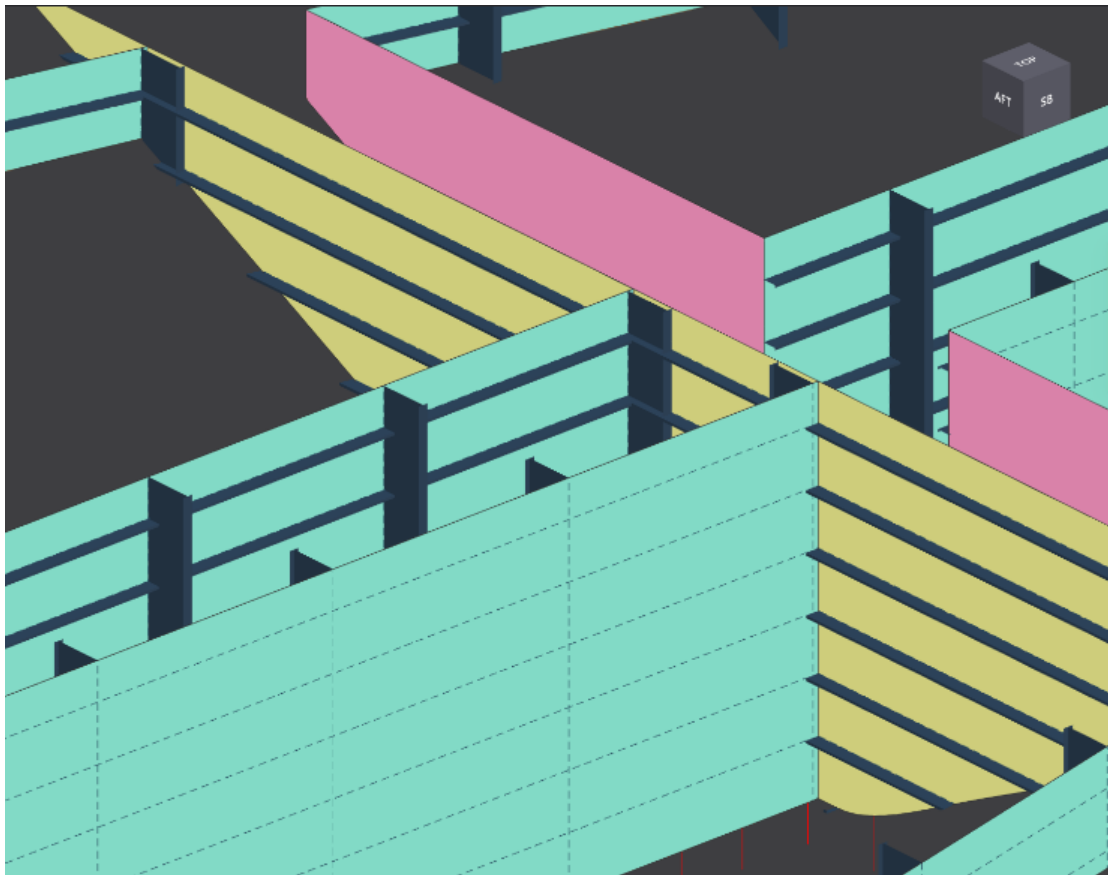


Figure 61: Partial overlapping of vertical girder with non-frame aligned TRANBHD

Even a minute variation of surfaces from frames could lead to such geometric problems. This cannot be exempted automatically as it is not overlapping completely.

## 7.2. Review of result

The 3D structure model obtained further to the implementation of various codes generated as part of this thesis exactly meets the needs of the user. Figure 62 is a representation of a single deck with structural members generated using the script implementation. Similarly, a ship

consists of multiple decks which is also assigned with structural members using the script but not shown pictorially because of the complexity that it entails. The model which will be generated with the help of the codes earlier used to take around two months of effort by 2-3 designers. Using the implemented code, it may take maximum of 3-4 days for a designer to achieve the same model using the scripts.

The aim was to automate the process to generate the 3D structure model very rapidly so as to generate a FEM model from it for global strength analysis. So rather than the small structural details like brackets, scallops etc. the main purpose was to generate a quick 3D model with all its structural members like stiffeners, girders, pillars which could influence the global strength. In that sense the quality of the model generated is good enough for rough global strength analysis in early design phase. So, by implementing this the shipyard can get its margin of safety in global strength at very early stage of design. This will give the shipyard its freedom in structural design and arrangements during preliminary and detail design. The details of structural members which need to be assigned to surface objects are provided using a spreadsheet named 'NAPA Input' for error-free data entry.

The 3D structure model generated using this method contains the following features:

- Horizontal decks are trimmed within hull boundaries.
- Vertical walls or objects are generated as per the general arrangement plan.
- Surface objects are assigned with default thickness and material grade.
- Selection of surface object based on COG (centre of gravity) coming inside bounding box
- Stiffeners are generated on assigned axis at every frame. Girders are created on web frames. It can be created either vertically, horizontally or transversely.
- Longitudinal girders on decks and vertical girders on transverse bulkhead can be generated at required locations.
- Transverse girders on decks and vertical girders on longitudinal bulkhead will be generated at every web frame.
- When stiffener and girder overlaps, stiffeners are eliminated at that location.
- When stiffener and surface object overlaps, stiffeners are eliminated at that location.
- Vertical stiffeners have snipped ends where they are connected to deck stiffeners. Same with the case of girders too.



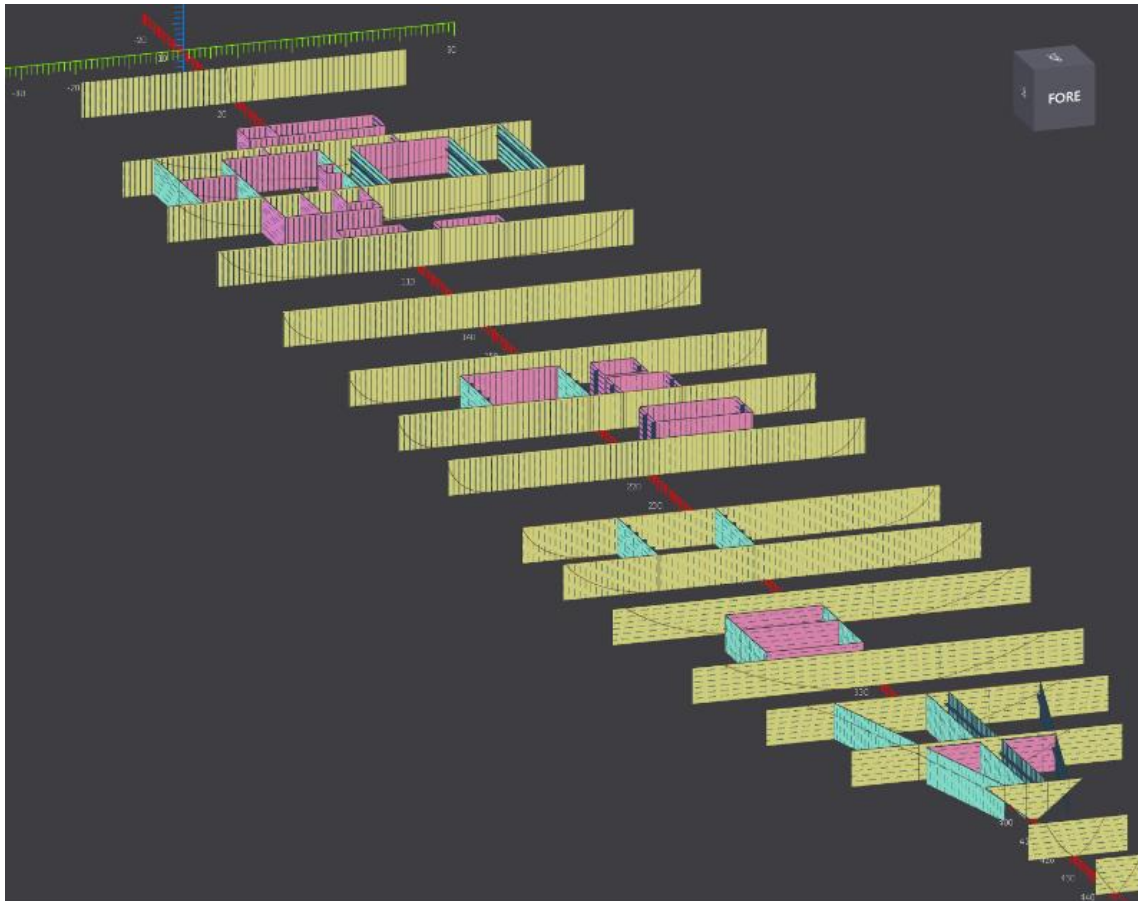


Figure 62: Final 3D structure model after the execution of automated modelling in NAPA

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## 8. SUMMARY & FUTURE DEVELOPMENTS

### 8.1. Summary

The aim of this thesis work was to automate the process of generating a 3D structure model of a ship at early design stage. So, by generating such a 3D structure model very early during the design stage, a FE model can be exported to check the global strength of the vessel with the help of any FE software. This will help the shipyard to understand how much margin of safety is available for the ship in terms of its global strength and it helps them to design other associated structures with that consideration.

The code develops a 3D structural model with all important structural members associated with global strength like plating, primary and secondary members. Small structural members or detailing like brackets, tripping brackets, local stiffening etc. are not considered at this stage. But this same model is used later in design stage for detail 3D model generation. This model is exported for stability calculations and as meshed model for FE analysis.

The whole process associated with 3D model generation is summarized hereafter. As a prerequisite for this process, a 3D hull form and a general arrangement plan in CAD file is required. The CAD file is imported and curves from general arrangement plan is extruded to required vertical limits to generate walls called as objects. These objects are converted to surface objects to make them eligible to contain structural properties. Then horizontal decks are generated at required vertical heights and they are trimmed within hull boundaries to avoid anything protruding outside ship hull. These decks are also converted to surface objects. All these surface objects are brought under arrangement to assign structural members to them.

Before assigning the structural members like stiffeners and girders to surface objects, as a prerequisite a list of all structural members which will be assigned to each surface objects needs to be prepared. To achieve this, a tabular list in a spreadsheet is prepared with all details of structural members and the surface objects onto which they are to be allocated. Bounding box made by given limit in spreadsheet is used as selection criteria. So, by this selection criteria any surface objects with centre of gravity (COG) coming inside the bounding box will be selected. To these selected surface objects based on the stiffening type given in spreadsheet, trace lines need be generated. For generating the trace lines, the coordinate values where traces need to be generated are needed. For this, the minimum and maximum points of the surface object in the direction normal to stiffeners is calculated and coordinate values for all the frames

coming between minimum and maximum points need to be found. Once the coordinate values are available then trace lines will be generated in those coordinate values. For vertical stiffening vertical trace lines and for transverse stiffening transverse trace lines will be generated.

Once the trace lines are generated, respective stiffeners and girders will be assigned to those trace lines. This process will be repeated for each selected surface objects. Once all the surface objects under a selection criterion are finished with structural member allocation, this process is repeated for next selection criteria. This way it will repeat for all the cases given in the spreadsheet.

In any case, one can easily change the structural member given on a surface object or list of surface object under a selection criterion. For this the selection criteria will be executed and selection of surface objects will be made. Then the structural element in the surface objects will be deleted maintaining the trace lines. Hereafter, the new stiffener type which need to be assigned will be generated in all the trace lines in the surface object. By this way any change in structural members can be made to alter the 3D structure model that were generated in later stages.

## **8.2. Recommendation for Future Developments**

The implemented automation entails considerable time saving to the tune of several manhours. Considerable improvements are however still possible. Some of those improvements which could be developed to make the early design phase 3D structural modelling even faster are highlighted below.

### **8.2.1. *Categorizing the surface objects under arrangement automatically***

Currently the surface objects are brought under arrangement manually. Surface objects are brought under arrangement to make them licensed to take any structural elements like stiffener or girders.

But there are difficulties in automating this stage. This is because generally different users want different type of categorization or listing for their convenient usage. So, this categorization tree is made manually and then under “arrangement” different categories and sub categories are created and then it is possible to drag and put all the required surface object under every sub category type. This decision of which all plates should go under which sub category is decided by the user, and can vary for various users.

So, by implementing a feasible category tree chart which is convenient for large percentage of the users and then implanting a method to bring surface objects under each sub categories automatically can still save much more time.

### ***8.2.2. Possibility to Input structural members which are out of steel library***

Currently only structural elements like stiffeners, girders, pillars or other types which are available in the steel library are used as part of this automation process. Any custom structural element type cannot be used in the process which will terminate the code execution.

So, a method should be implemented to take a custom structural member with any cross section or any shape and implant them to the surface objects at trace lines. This process will give the user more flexibility for the modelling phase to go in line with real production situation, without any compromises.

### ***8.2.3. Input brackets of specific type based on the connection types and types of element which are connected***

Implementing this task will save considerable time further from detail design phase on modelling. Brackets are assigned for smooth load transfer between the structural members.

There are special calculations to estimate the size, thickness and required weld length to ensure the safety of the bracket and proper load transfer between structural members. Further to this calculation, these bracket sizes are manually assigned in between structural members. But automating this process will save a lot of manhours during design phase.

Generally, the bracket types are same when similar structural elements are joined. But this may vary with location longitudinally, transversely or vertically. However, it is safe to conclude that within a specific region for same connection types the bracket sizes and type will be same. Using this assumption, a method to assign stiffeners between same connection types coming in a specific region in ship can be generated. By repeating this process throughout the ship, a detailed model can be generated quickly. Any special cases can be changed manually, which will take only a fraction of the time considering the whole process of bracket generation.

Though the time range that can be saved by this method cannot be predicted exactly now, a minimum of 50%-time saving can be expected using this method. This process helps to shorten the detail model generation process also.

**8.2.4. *Providing the scallops in girders where stiffeners are passing through***

This process can be implemented in a manner similar to the bracket generation. Wherever stiffeners of similar cross-sectional area are passing through girders, a method can be made to make scallops or cut-outs in that location on girders. This process will also save a substantial amount of time during detail design process.

**8.2.5. *Substituting existing stiffeners on a bulkhead with multiple new stiffener types***

Currently using this method any existing stiffeners on a bulkhead can be replaced with a new stiffener type. But it is not possible to use the automation when a bulkhead needs to be assigned with multiple stiffeners. So, by generating a method for attaining this, the user can get closer to the real case scenario.

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