WP 3 / Activity 3.2.

Ro-Pax Ferry Structural Model

Prepared by:

University of Rijeka - Faculty of Engineering

Tehnomont Shipyard Pula Ltd

Summary

1. INTRODUCTION

METRO is the acronym for the *Maritime Environment-friendly TRanspOrt systems*, a project supported by the European Commission under the Interreg V-A Italia-Croatia2014-2020 programme. The project aims to improve the sustainability of the environment in the field of maritime transport, through multimodal and green solutions, with special emphasis on tourist connections in the North Adriatic. From a logistical point of view, the goal of the project would be achieved through the definition of new routes between the ports of the North Adriatic, and a study on the adaptation of electricity supply infrastructure in smaller ports. Considering from a technological point of view, one of the goals of the project is the development of hybrid ships of short and medium sailing range. Of interest are the ferry with mutual loading and unloading ramps at both ends, so called double ended, and the Ro-Pax ferry (passenger and vehicle transport ship), which are the most common types of coastal navigation ships in the Adriatic. The route between Brestova and Porozina was chosen for the double ended ferry, while the route between Split and Ancona was chosen for the Ro-Pax ferry. The Faculty of Engineering University of Rijeka (RITEH) participates in the METRO project within the work package WP3 "Hybrid Vessels Study and Demonstrators", which also includes the Università degli studi di Trieste, Wärtsilä Italia S.p.A. and Tehnomont shipyard Pula d.o.o. The activities of the RITEH as a project partner are closely related to ship design, and especially relate to the structure and hydrodynamics of the hull of the ferries. Within the process of conceptual designs of ships, one of the basic activities is the design of the structure, which should, within the first round of the design spiral define the basic structural layout, preliminary dimensions of all structural elements as a basis for estimating mass and cost of materials and hull construction. In the standard commercial procedure, the next step would be the preparation of complete classification documentation, and after that, the eventual selection of investors/owner and the signing of the contract, and the workshop documentation. As this is a research project, so the investor / shipowner is unknown, the project did not aim to prepare a workshop or complete classification documentation, nor its confirmation by the classification society. By agreement of the ship design partners on the project, it was decided to make a structural analysis of the complete structure of both ships, and the goal was to check the global strength and confirm the calculation of the dimensions of structural elements from the point of view of bending and buckling. The remaining structural design assesment activities, such as fatigue assessment and ultimate strength calculation, have been omitted as they belong to the final, detailed structure assessment. It should be noted that this scope of work, modeling and structural analysis of complete hulls, is not common at this stage of the conceptual design, due to the high consumption of human and computer resources, but it is still done because there is a lack of data to assess the load capacity of superstructures. The analysis of the structure is based on the initial calculations of the structure made by Tehnomont shipyard Pula d.o.o and in which the structural elements on the central section (main frame) of both ships are defined. Based on these data, the remaining parts of the structure were defined and dimensioned at the RITEH.

For this purpose, the rules and regulations of the Bureau Veritas classification society (BV rules for Steel Ships, July 2019), [1], together with the MARS2000 software package of the same classification society were used for scantling verification.

Since the entire process of structural analysis consists of two major groups of tasks, the report is divided into two parts. The first part, for each vessel separetely, entitled *Ro-Pax ferry structural model*, includes a presentation of the methodology for creating a computer model, and a presentation of individual structural units of the 3D computer model of both ships. The second document entitled *Global FE Strength Analysis of Ro-Pax Ferry* is a more demanding part of the procedure and includes scantling calculations and validation against bending and buckling, geometry meshing, modeling of loads and boundary conditions and analysis of the obtained results. In order to create the geometry of the computer model, the software package RHINOCEROS [2] was used, while LS-DYNA [3] was used as a preprocessor, solver and postprocessor for linear static strength analysis including mutual file communication.

2. VESSEL STRUCTURAL ARRANGEMENT

The second designed vessel presented is a Ro-Ro passenger ship, Figure 1, compliant with SOLAS regulations for Short International Voyages (excluding US waters), in accordance with builder's standards and to comply with the listed Rules and Regulations. The Vessel is a twin screw, twin rudder, dual fuel-driven ship of welded steel construction incl. superstructure and wheelhouse, with one cargo deck and one hoistable deck for cars. The hull with bulbous bow, transom stern, twin skegs and with lines so designed to ensure good seaworthiness and good maneuverability. The hull under the freeboard deck is divided into sufficient watertight compartments, to satisfy damage stability as well as SRtP requirements according to the SOLAS regulations. The vessel shall have a capacity of abt. 630 lm for trailers or area of abt. 2020 m^2 for cars and transporters on the level of main garage decks. In addition to that, the area of abt. 1865 m^2 for cars on hoistable car deck is ensured. Further it will accommodate abt. 1340 passengers and 75 crew members. The cargo section consists of fully enclosed main cargo hold suitable for storing of trucks and other wheeled cargoes, as well as hoistable car deck for stowage of cars only. Loading and unloading of wheeled cargo is performed by two ramps, one stern and other bow with hinged arms. All vehicle decks are designed to carry vehicles with fuel in their own tanks. Hull of the vessel is divided on following main compartments: fore and aft peak, double bottom / side tanks, engine rooms. The double bottom is extended between fore and aft peak bulkheads and subdivided as shown in General Arrangement Plan. Double bottom is provided in engine rooms for storage of water, lubricating oil and other service tanks. Equipment for cargo are; one stern ramp for loading/unloading cars and trucks on/from Main Garage Deck, one bow ramp with bow doors for loading/unloading cars and trucks on/from Main Garage Deck, one stern ramp for passenger's entrance leading to the passenger decks by stairways or elevators, and one hoistable car deck in Main Garage space for stowage of cars only. The vessel including its hull, machinery and equipment is to be constructed in accordance with the Rules of the Classification Society of Bureau Veritas to obtain the following Class notations: I ✠HULL ✠MACH; Ro-Ro Passenger Ship, Unrestricted navigation, SRTP, POWERGEN(DUALFUEL), ✠AUT-UMS, ✠SYS-NEQ, ELECTRIC HYBRID (PM, ZE), MON-SHAFT, INWATERSURVEY.

The hull is arranged with transverse watertight subdivision below main deck. Passenger deck and Main deck are supported by transverse frames. Pillars are arranged in the service spaces below the Main deck and in the superstructure in order to minimize steel weight and structure height. The cargo area is arranged without pillars. Structural arrangement is based on longitudinal framing system. Transverse framing system is arranged for superstructure sides. Bilge keels 2 x HP320, abt. 35% of length. Frame spacing is 800 mm. Main transverse frame spacing is 3200 mm. Longitudinal stiffener spacing on decks is generally 600 mm. Material main hull in general is mild steel (MS). Cargo area will have one (1) fixed deck and one (1) hoistable deck for Ro-Ro cargo. Cargo hold is made as fully enclosed Ro-Ro space. The vessel shall have efficient drive through facility and shall incorporate vehicle access by the bow as well as by the stern. Therefore, bow ramp with suitable bow door and stern ramp will be implemented for facilitated loading/unloading. The vehicle decks and ramps is designed considering appropriate loads.

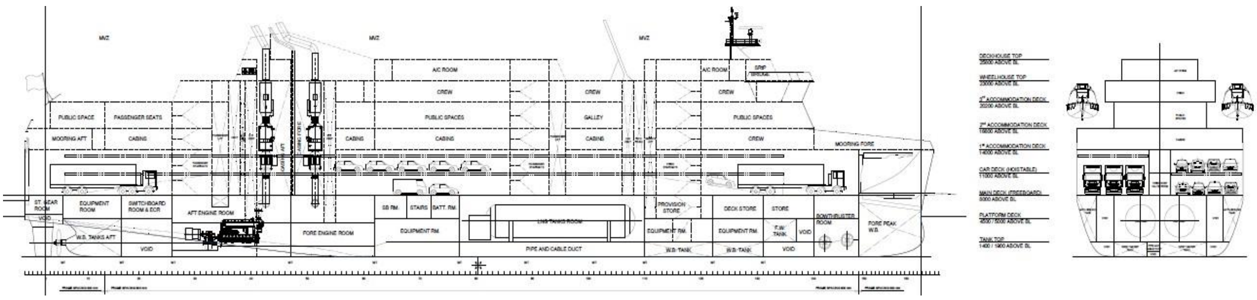

Figure 1 *General arrangement plan of Ro-Pax ferry*

The front and sides of superstructures and deckhouses is to be extra stiffened wherever necessary by racking bulkheads. The funnel will be made of steel plates and properly stiffened from the inside. The top plate will have a hatch, passages for exhaust gas pipes and water drain at the after end.

Table 1 *Ro-Pax ferry main particulars*

Length, overall	129.27	m
Length, between perpendiculars	124.45	m
Breadth, moulded	23.60	m
Hull depth to freeboard deck (midship)	8.00	m
Draught, scantling	5.60	m
Draught, design	5.25	m
Deadweight (at scantlings draught)	abt.2240	t
Deadweight (at design draught)	abt.1400	t
Gross tonnage	15040	GT
Main engines MCR	2x4000	kW @ 750 rpm
Design speed (design draught)	abt.15.5	knots
Maximum trial speed (design draught)	16.1	knots

3. METHODOLOGY OF BUILDING A 3D COMPUTER MODEL OF THE STRUCTURE

Modelling the structure for FEM analysis differ from the standard structural modelling for basic and detail production. In order to prepare graphical and surface model of the ship some necessary simplifications needed to be made and model was adjusted to easily mesh the surfaces and proceed with the structural analysis. The following chapters will briefly explain the process of modelling using any 3D modelling software. Similar concept was taken for Double ended ferry as well as the Ro-Pax ship. Only difference is the level of details on the double ended ferry, where secondary stiffening structure was also modelled.

3.1. Graphic and surface model

Base line documentation for the 3D modelling for FEM will always be hull shape, general arrangement drawing and midship section drawing. Using the information from these drawings, an engineer is capable of creating the 3D project space in which ship will be created. First, the reference planes (frame planes, deck planes, and longitudinal planes) were created, forming the project similar to [4].

Upon completion of the project setup, the hull shape was inserted into the model. Following the methodology presented in Figure 2, and adopted to FEM modelling, first hull plating and decks were created using the available 3D software for modelling of the vessels. Secondly, watertight bulkheads and longitudinal bulkheads were modelled. After the bulkheads, all primary structure was modelled (deck girders and beams as well as web frames and floors). Structure was modelled from double bottom to the wheelhouse deck, creating the structure one deck at the time. In order to prepare the model for meshing, all plates needed to be cut at the intersections and prepared for meshing. All major openings were created, but not the manholes, lightning holes in floors and beams and doors in the bulkheads. In case of double ended ferry, the hull and deck longitudinals were also modelled, thus creating the structure from first two stages of modelling presented on figure 4 while structural details were not modelled.

In case of limited input (case of Ro-Pax vessel) only midship section drawing and general arrangement drawing were used. In case of double ended ferry some of the classification documentation and additional documents were available at the time of the modelling so the structure was modelled with much more details.

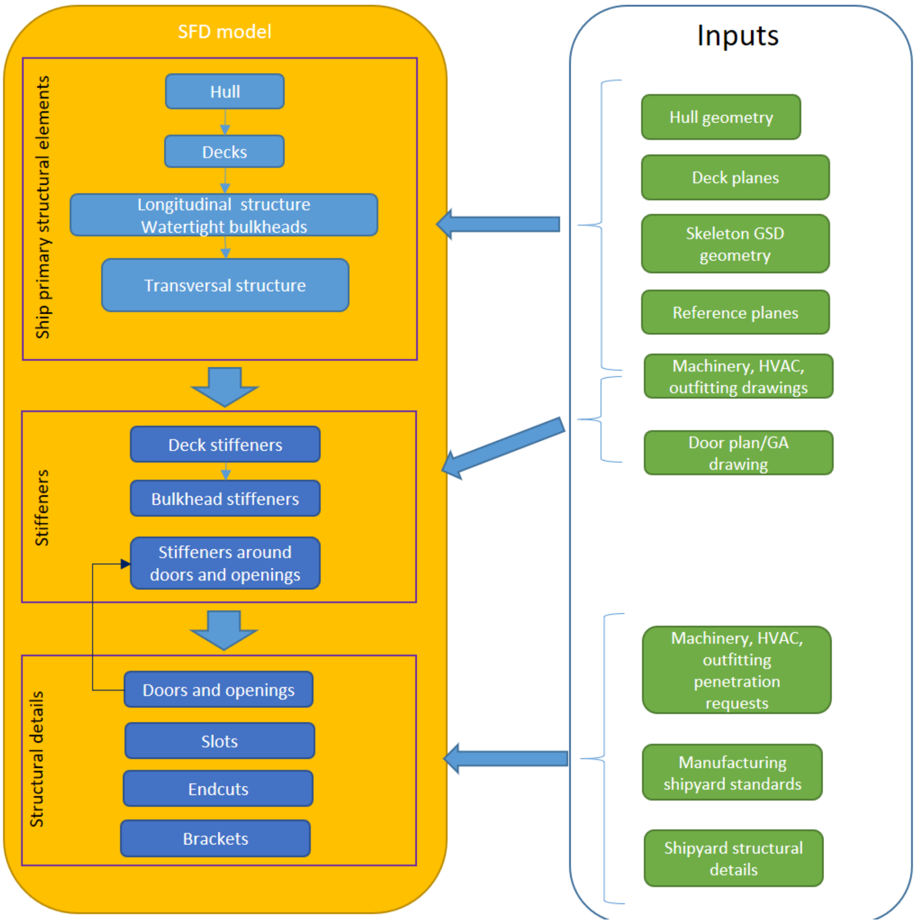

Figure 2 *Modelling sequence of ship structure using the 3D Experience SFD app [5]*

3.2. Structural details and simplifications

As described above, simplifications needed to be made. There were no brackets slots and endcuts of the profiles. Structural details were avoided if possible. Flat bars as flanges on the composite beams and girders as well as web frames were not modelled. In case the stiffeners were modelled, some simplifications were made. The stiffeners were presented as flat bar even though they were actually bulb profiles. The section modulus of these flat bar stiffener was adjusted (by altering dimensions of the flat bar) to fit the value of the referenced bulb profile. Doors and openings were not modelled if of standard dimensions. Only large deck and bulkhead openings were created. The plates were modelled square, radius modelled only if significant. The intention of these simplifications was to create geometry adjusted for easier meshing while maintaining the structural integrity of the model.

3.3. Referential documents

A list of the main documents used for this report, follows below.

Key Drawings

The project state has been defined according to the following drawings:

Technical description: ROPAX-METRO-Outline-REV2

General Arrangement Plan: ROPAX-METRO-GAP-REV2

Body Lines: METRO-RO-PAX-1101301-REV2

Midship section: METRO-RO-PAX-1200301-REV2-Midship section preliminary
METRO-Ropax-TRIM & STABILITY BOOK_REV1

Referential Notes

All procedures have been carried out in accordance with the following documents: - The BV Rule Edition, BV rules for Steel Ships, July 2019.

4. RO-PAX FERRY STRUCTURAL MODEL

The intention within this chapter is to present the entire geometry of the ship, Figure 3 and 4 through section rings, Figure 5, longitudinal sections, Figure 6, and horizontal plans / decks, as well as detail view on some particular structural units such as double bottom, Figure 7, engine room, Figure 8, side, Figure 9, decks and superstructure, Figures 10 to 19 and ship's ends, Figure 20, with all structural elements that are important for the analysis of global strength. These are all the primary elements, i.e. all the plating of the outer shell, decks and bulkheads, girders in the bottom (central girder, side girders, floors), stringers and web frames, underdeck side girders and deck transverses. Of the secondary elements, the calculation also includes the bottom, side and deck longitudinals, ordinary frames in the superstructure, pillars, and horizontal / vertical stiffeners are shown here. The scantlings of these elements, after calculation and checking against vertical bending moments and buckling, will be shown in another document titled *Global FE Strength Analysis of Ro-Pax Ferry*, together with the calculation results.

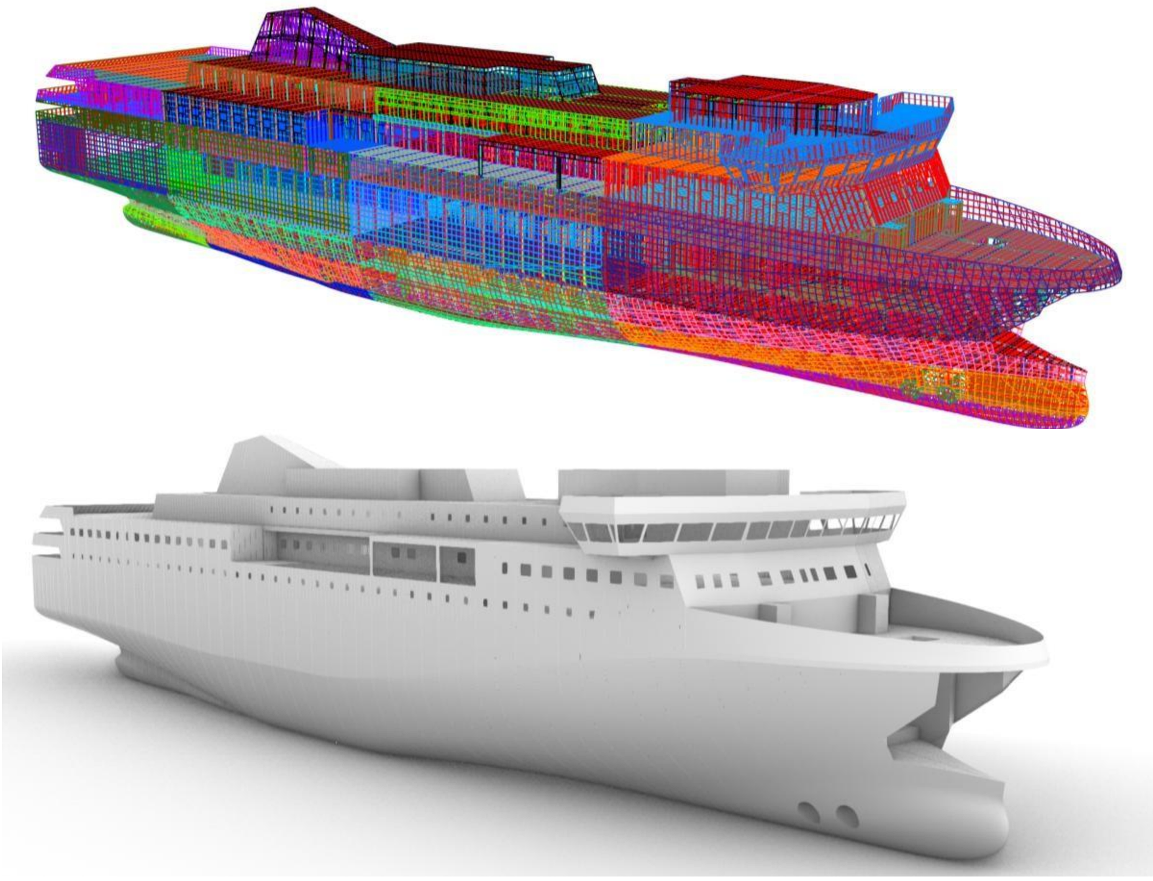

Figure 3 *Hull* 3D *geometry model of the whole ship, wireframe (top) and render (bottom)*

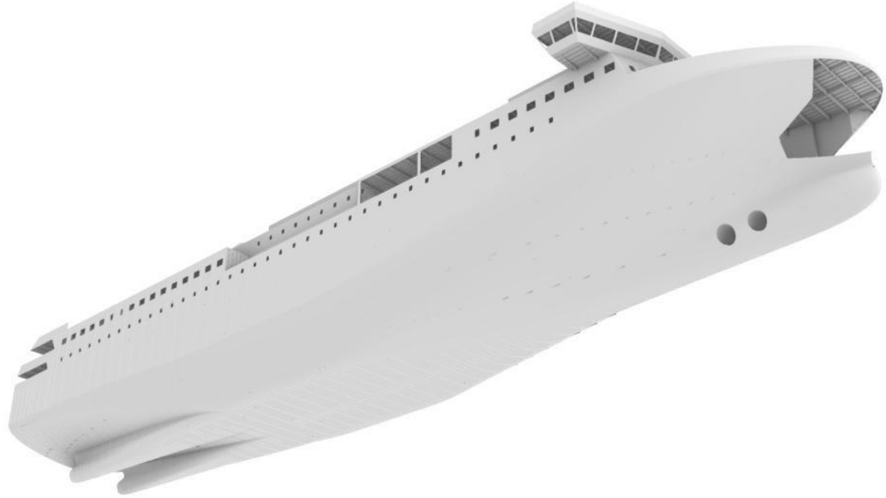

Figure 4 *Hull* 3D *geometry model of the whole ship, view from bellow*

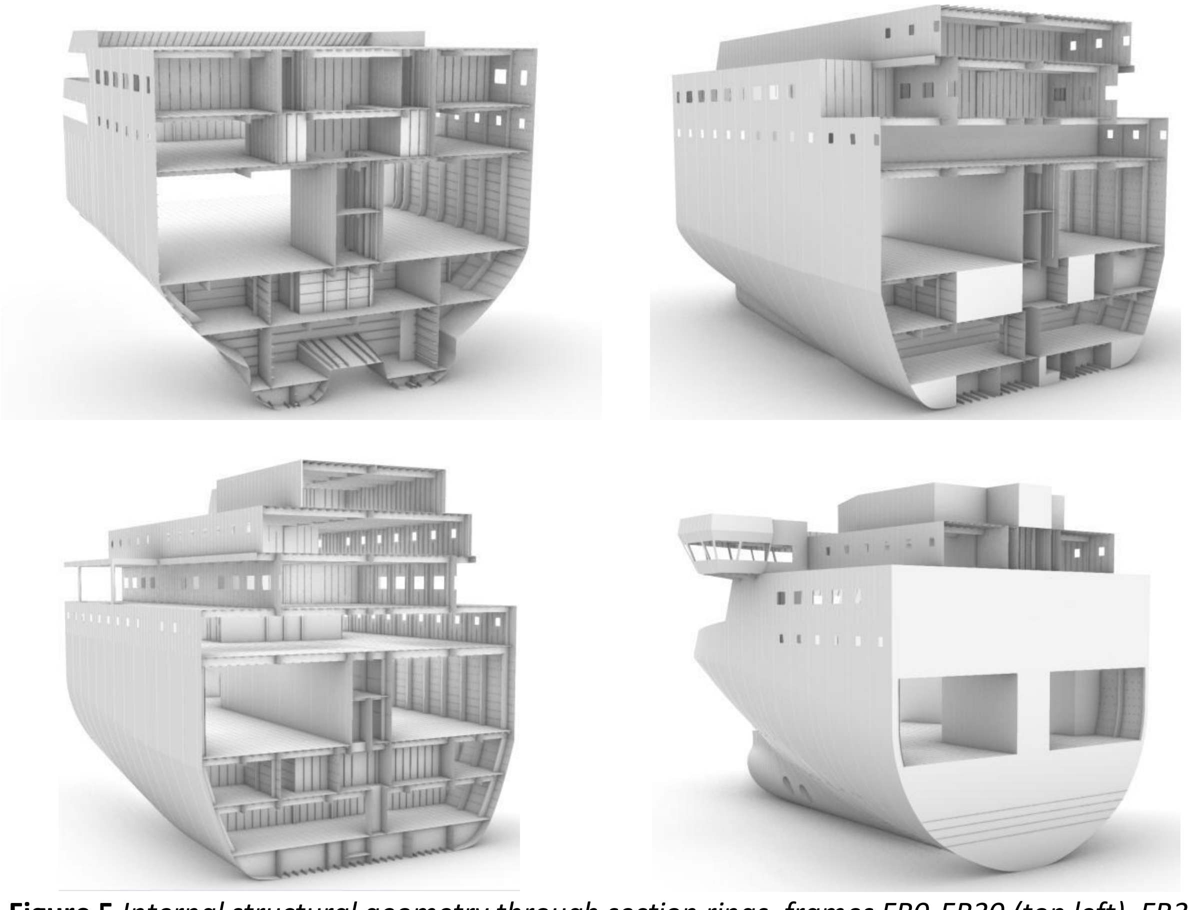

Figure 5 *Internal structural geometry through section rings, frames FR0-FR30 (top left), FR30-FR70 (top right), Fr70-Fr110 (bottom left) and Fr110-Fr130 (bottom right)*

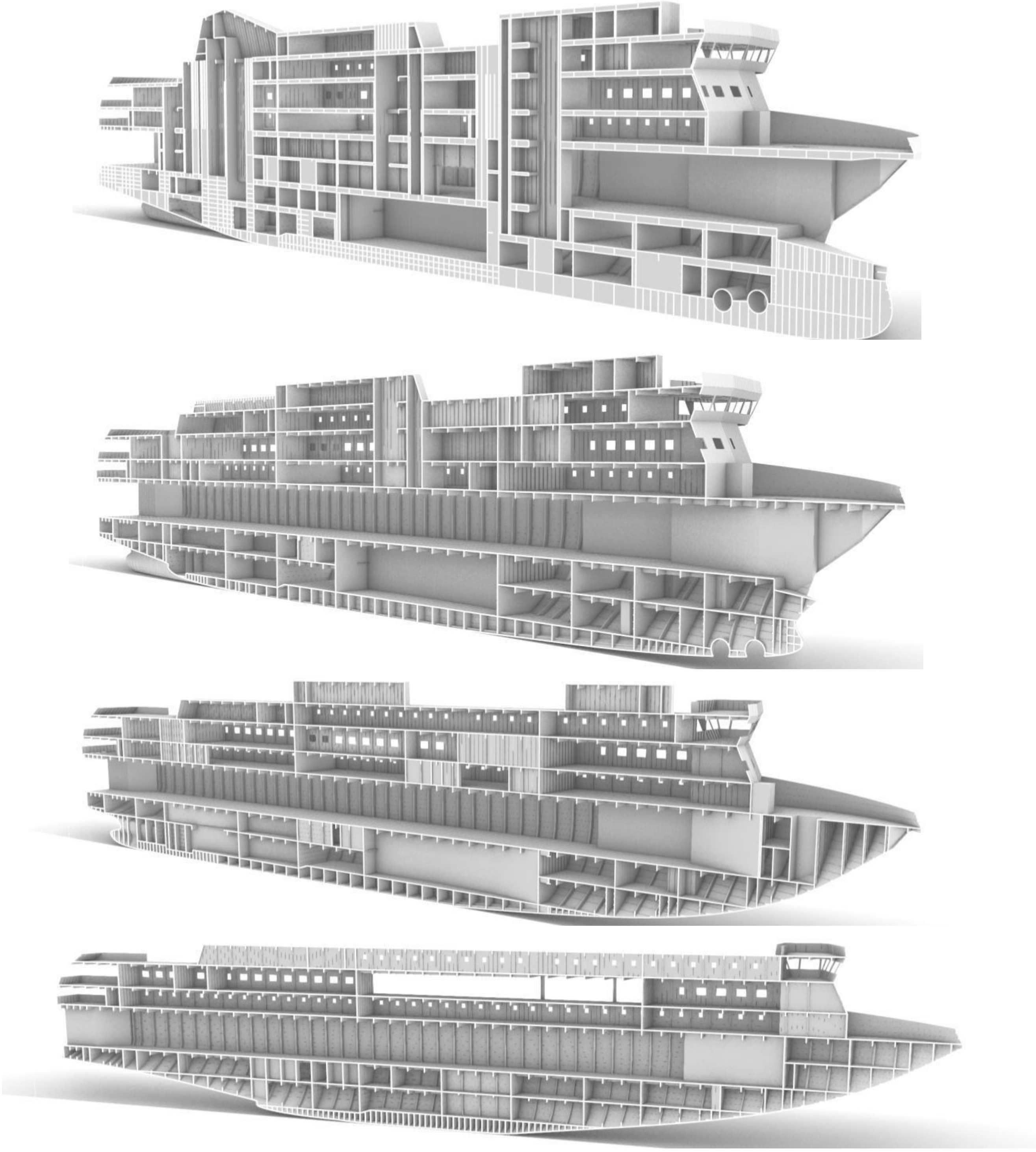

Figure 6 *Hull geometry model – longitudinal section in CL (top), 2400 PS from CL (middle top), 6600 PS from CL (middle bottom) and 9000 PS from CL (bottom)*

4.1. Double bottom structure

On tank top, bow thruster's room, equipment rooms, LNG tanks room and engine rooms are placed.

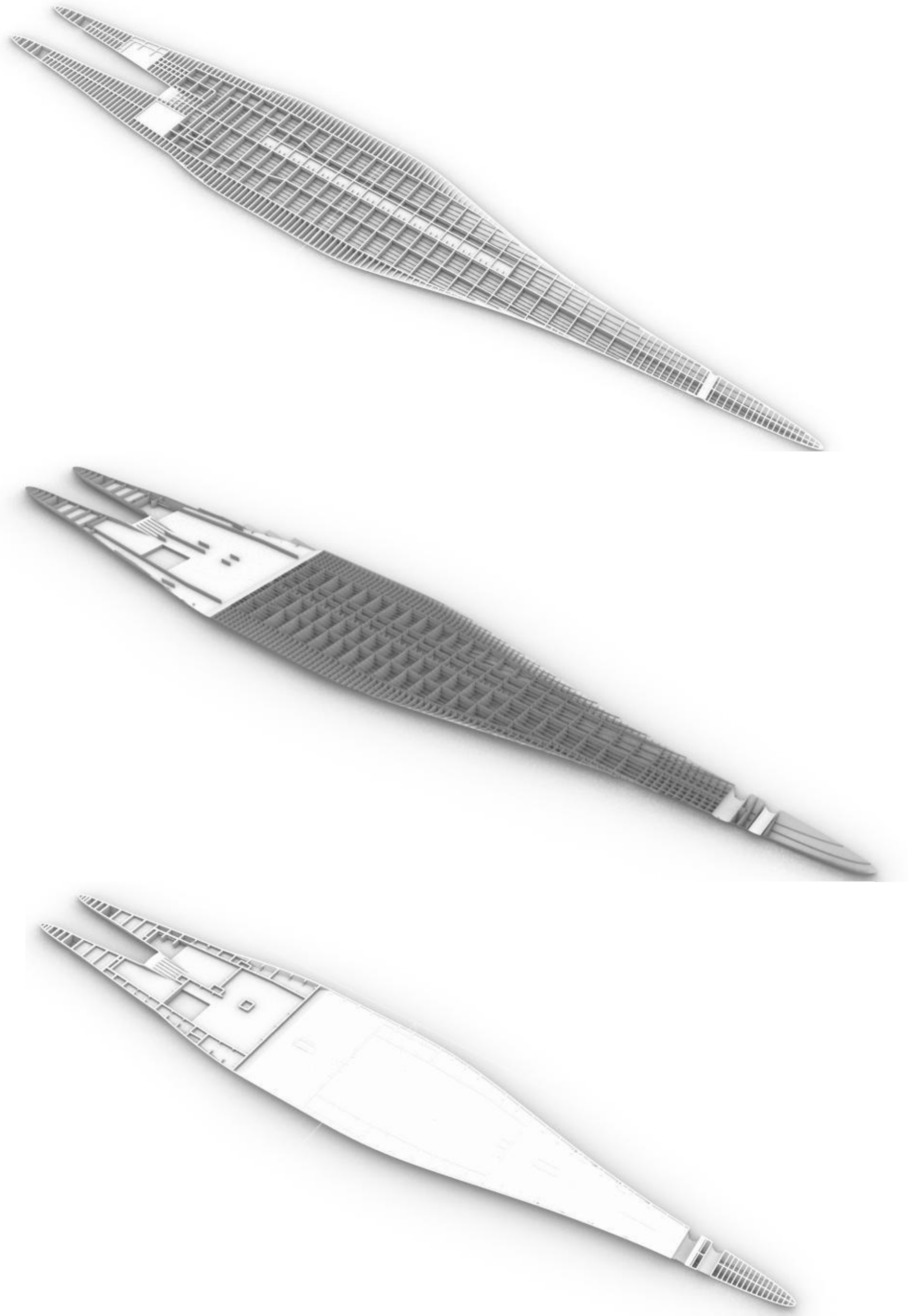

Figure 7 *Hull geometry model – double bottom 1400 above BL (top), tank top 1900 above BL (middle), and double bottom and tank top plating (bottom)*

4.2. Engine and LNG storage space structure

The engine and machinery rooms to be situated between the aft peak bulkhead and aft bow thruster room bulkhead. Side shell shall be supported by longitudinal and transverse frames and web frames, as appropriate. Structure in way of sea chests shall be strengthened. Double bottom will be arranged with solid floors at every frame and longitudinal girders or with longitudinally framed double bottom structure, where appropriate. Lubricating and fuel oil drain tanks shall be arranged in double bottom. Foundations for propulsion machinery shall be of welded construction throughout and arranged as virtually integrated part of the ship's primary structure by alignment with elements of such structure within the double bottom. Particular attention shall be given to the structure transmitting the propulsive thrust into primary structure. The necessary tanks and cofferdams shall be provided according to concept General Arrangement Plan and to be detailed during basic and detailed designs. The shaft bearings to be supported by welded steel foundations of suitable strength attached to the tank top. Upper deck and platforms shall be built on the longitudinal framing system. Pillars to be provided for supporting the engine casing and other appropriate structure and shall be in line with web frames.

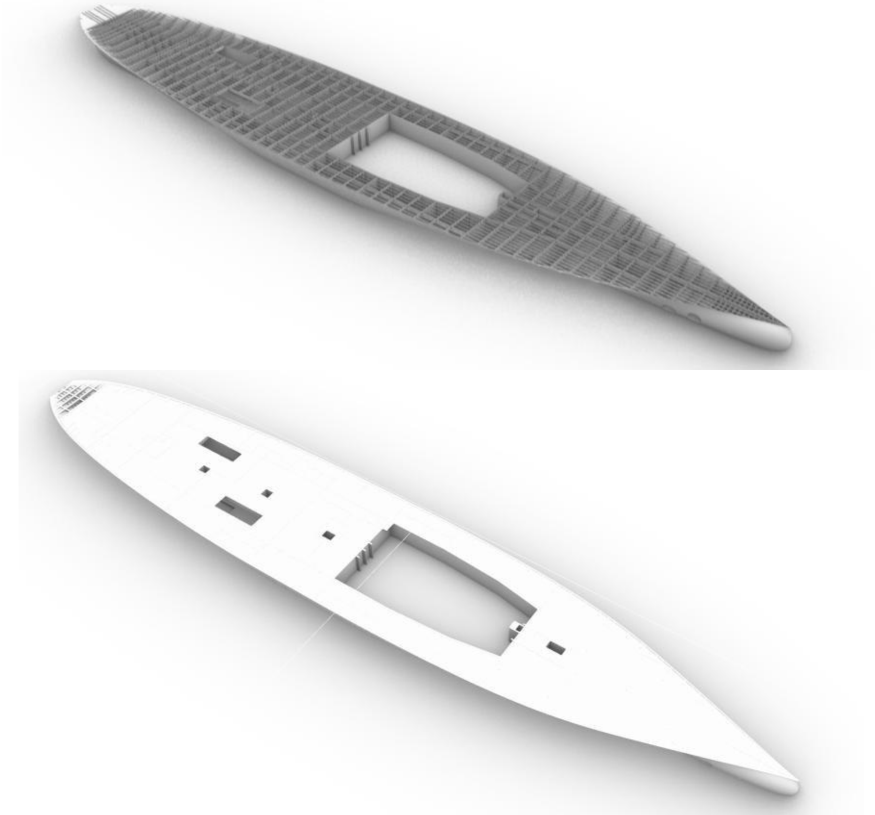

Figure 8 *Hull geometry model – platform deck structure 4500 above BL (top), with plating (bottom)*

4.3. Side structure

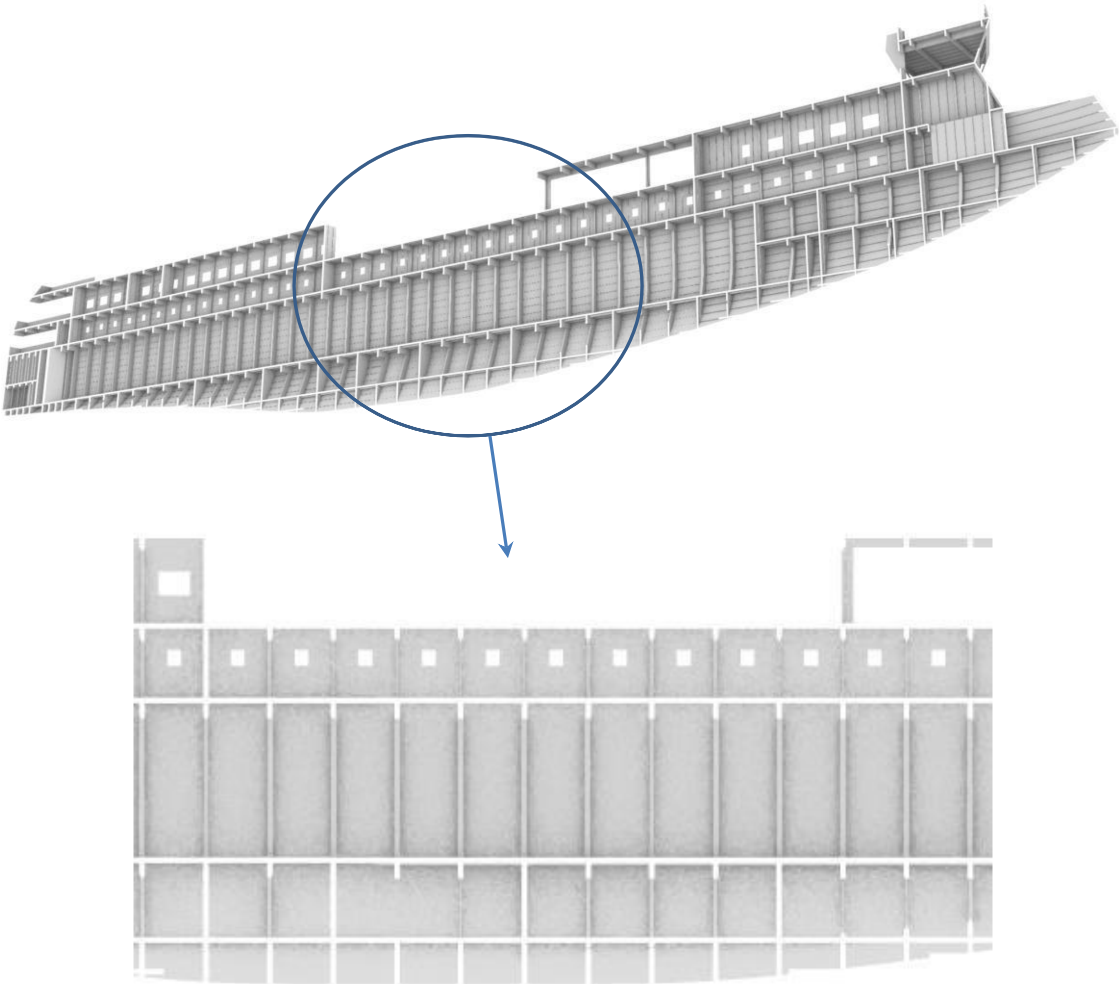

Figure 9 *Hull geometry model – side structure web frames with side longitudinals*

4.4. Decks and superstructure

The front and sides of superstructures and deckhouses is to be extra stiffened wherever necessary by racking bulkheads. Steel bulkheads shall be arranged around galley, provision rooms, stairways, cable/pipe trunk etc. in compliance with regulations. Internal bulkheads are plane type with vertical stiffeners or corrugated type where suitable. After tank top and platform deck where following spaces are organised; provision & deck stores, battery equipment rooms, engine & electric workshops, switchboard rooms, equipment room, steering gear rooms, there is main garage deck (freeboard) with ro-ro cargo space, A/C rooms, ventilation rooms, bunkers, shore connection room, garbage room, main stairway & lift spaces.

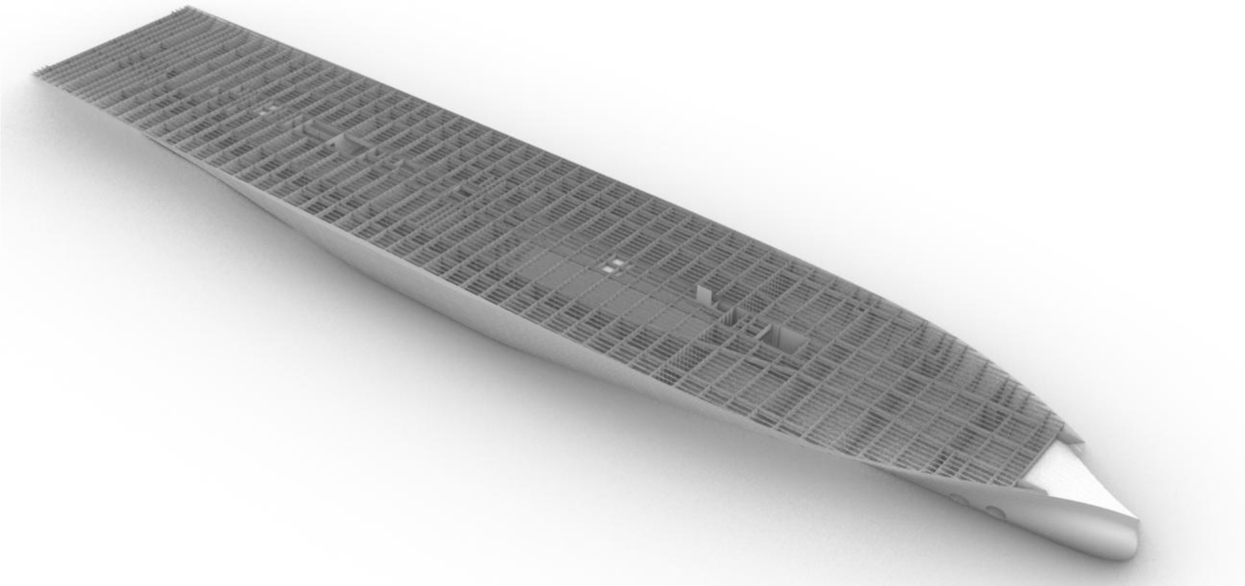

Figure 10 *Hull geometry model – main deck structure 8000 above BL*

Two hoistable car decks is provided, each of five panels (SB & PS). The end panels (4 pcs) shall also function as access ramps and shall be operable with a full load of cars. The ramp sections shall be designed with a maximum slope of 8 degrees. The material of the panels shall be steel. The panels shall be designed for the given design axle load. The deck and ramps are to be provided with portable railings. Stops are to be arranged for preventing cars from driving over the end of ramps.

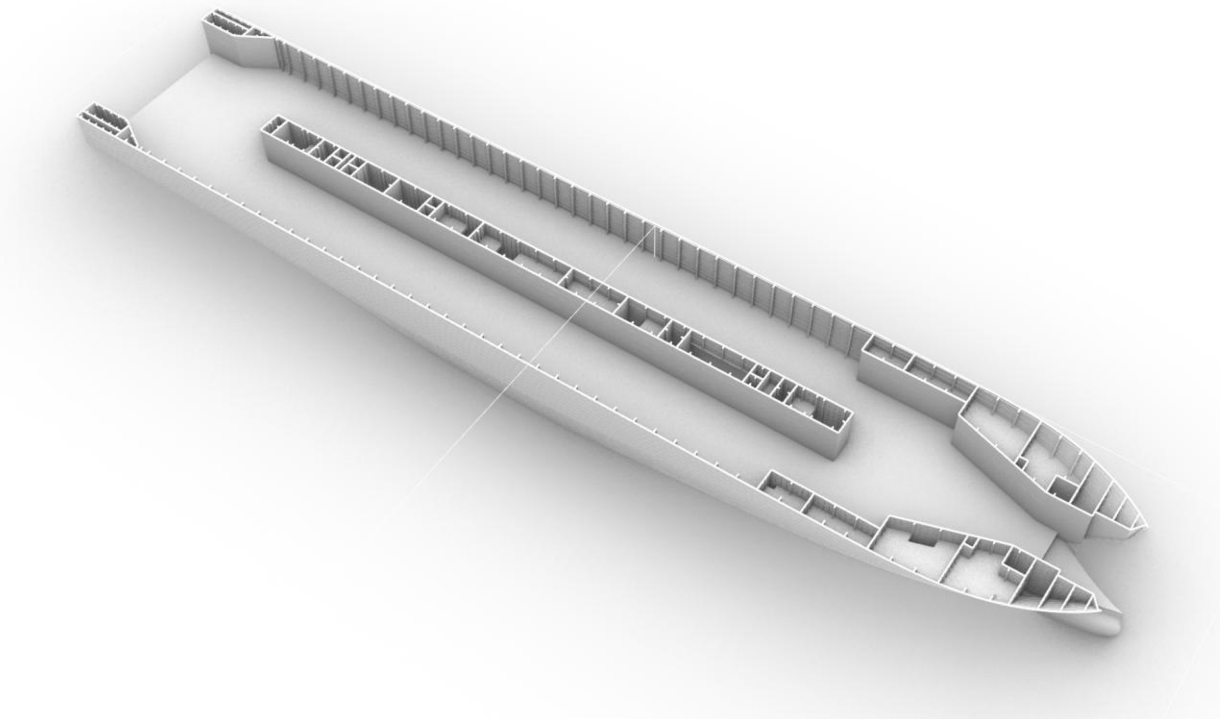

Figure 11 *Hull geometry model – cargo space*

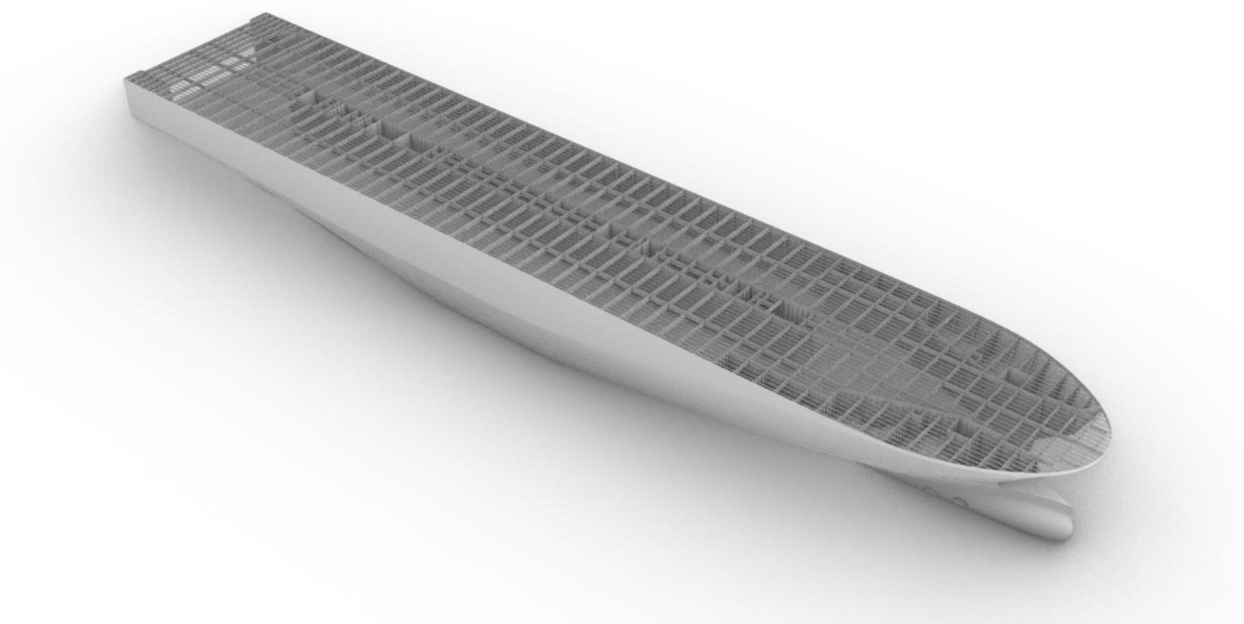

Figure 12 *1 st Accommodation deck structure: passenger & crew cabin spaces*

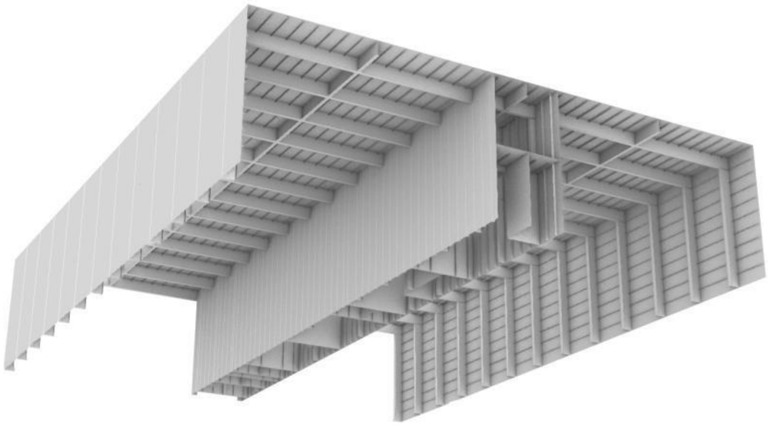

Figure 13 *Part of the 1st Accommodation deck structure, view from bellow*

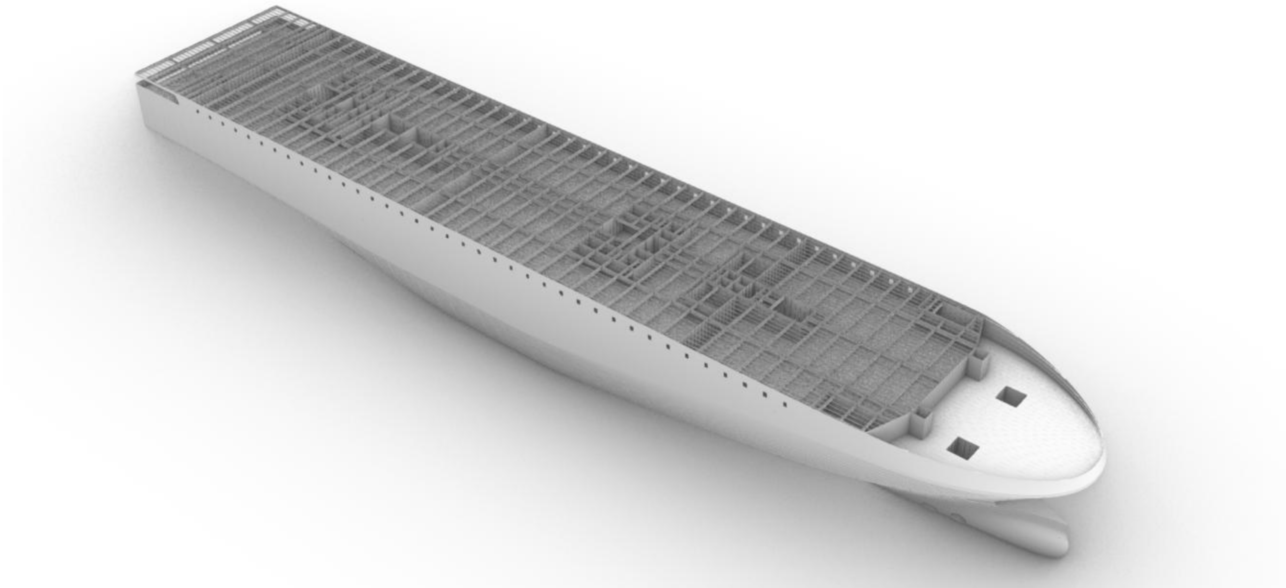

Figure 14 *2nd Accommodation deck structure: passenger public spaces, air seats spaces*

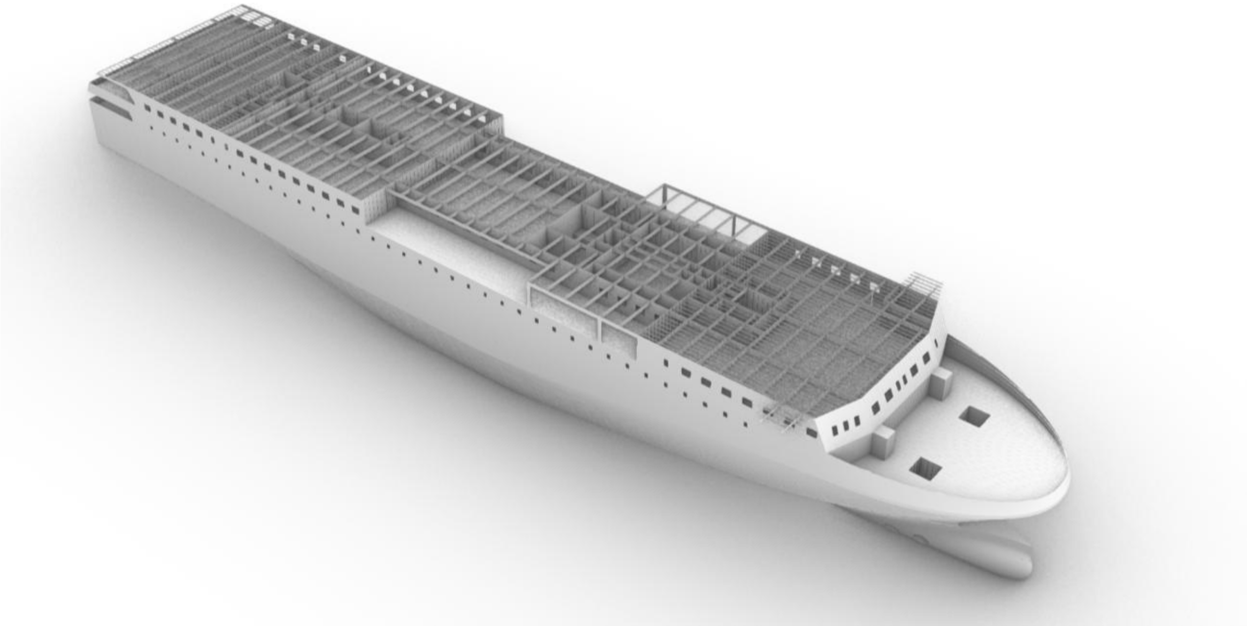

Figure 15 *3rd Accommodation deck structure: wheelhouse, crew cabin & public spaces, A/C rooms*

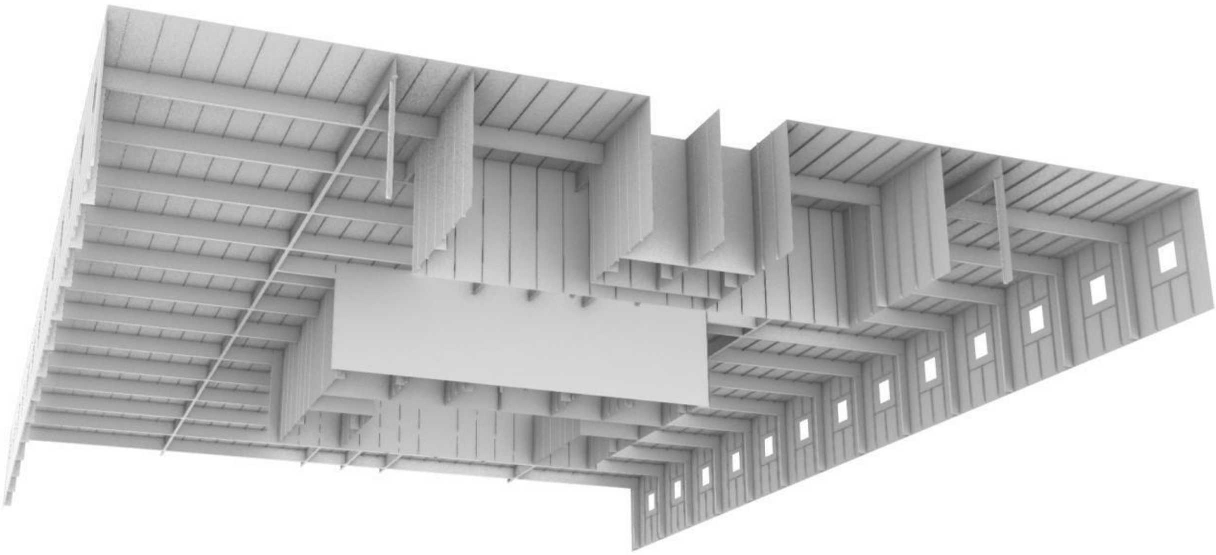

Figure 16 *Part of the 2nd Accommodation deck structure, view from bellow*

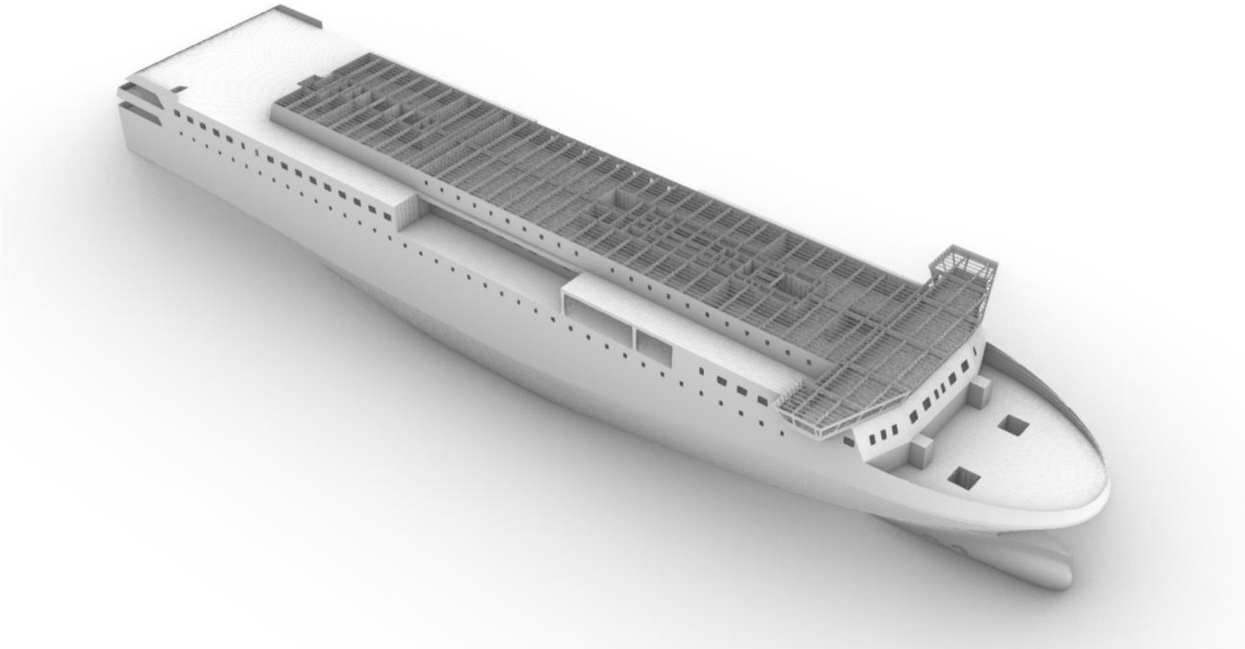

Figure 17 *Wheelhouse top structure: SRtP bridge, battery room, A/C rooms*

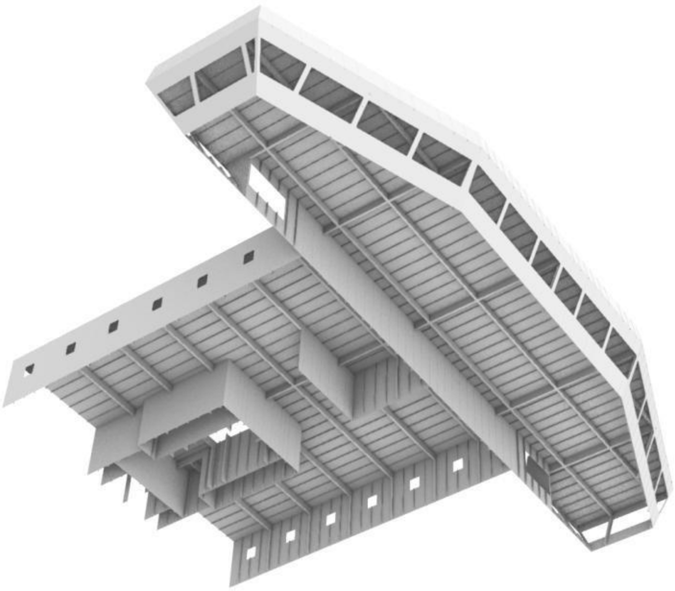

Figure 18 *Part of the Wheelhouse structure, view from bellow*

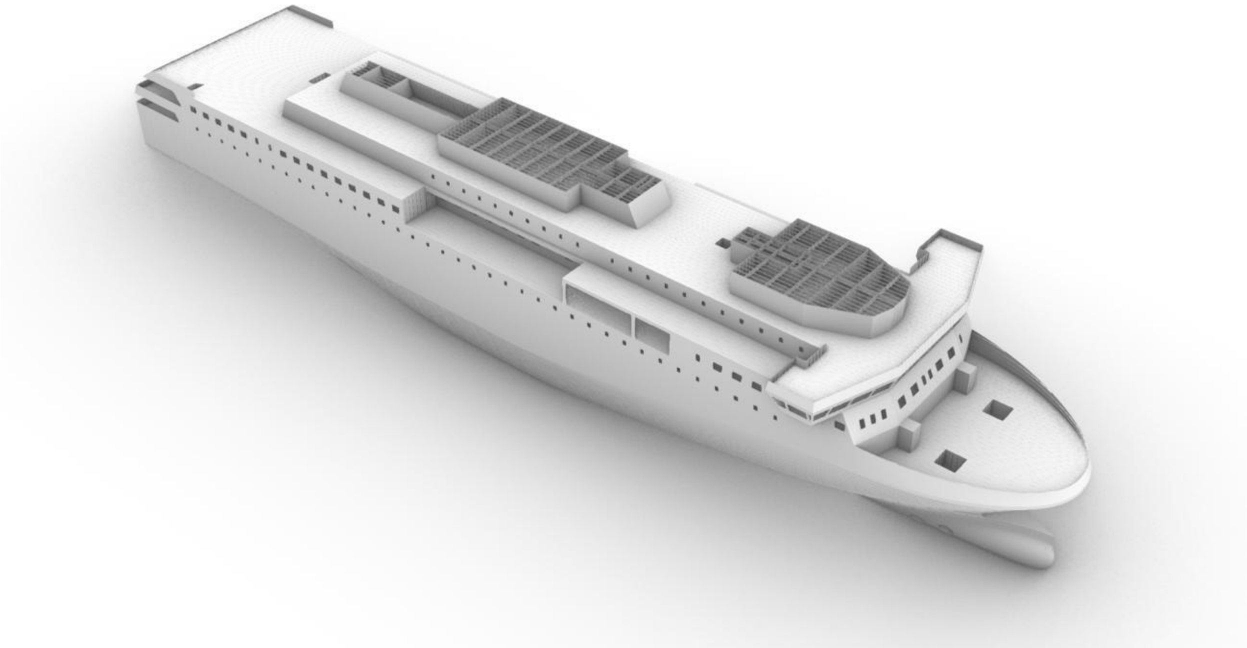

Figure 19 *Deck house top structure*

4.5. Ends structure

The afterbody extends to the after peak bulkhead and shall include decks, bulkheads and tanks. The stern is of transom type, shaped to accommodate stern ramp. The aft is fitted with two hydrodynamic shaped skegs incorporating the propulsion train with shaft bearings.

For cargo and passengers loading/unloading, the weathertight ramp operated by wire ropes with electric winch motors shall be arranged at stern. Clear width to be abt. 18 m, of which is 15 m clear driving width between kerbs for cargo shall be arranged (simultaneous loading/unloading of 5 trailer lanes). The clear driving height to be 4.80 m. The height of the opening to be clear driving height + extension due to maximum angle of the ramp. The maximum operation angle to be abt. 8 degrees at max. list of 3 degrees. The length of the ramp shall be abt. 7.5 m fitted with flaps of additional 2.0 m. The flaps shall be foldable and capable to be stowed in turndown position. The material of the ramps shall be steel. The ramps shall be designed for the given design axle load. The passenger walkway shall be fitted on SB side of stern ramp, with clear width of abt. 1.8 m.

The fore body between the aft bow thruster room bulkhead and the stem will include fore peak, chain locker and bow thruster space. The fore part of deck will be transversally framed and adequate reinforced in way of heavy equipment. The structure of the forepeak shall include shell with transverse framing, deep floors, stringers, panting beams and wash bulkhead.

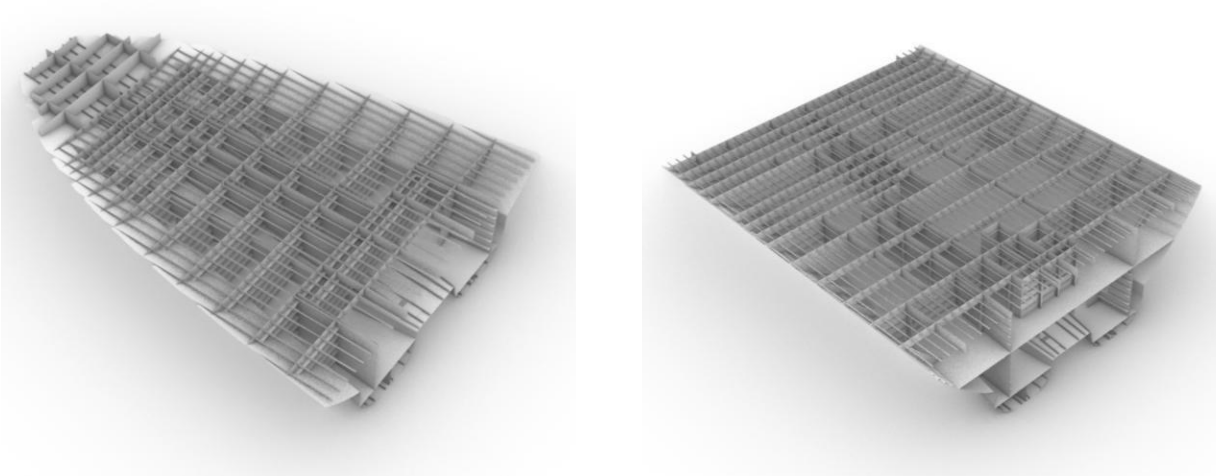

Figure 20 *Aft end structure bellow platform deck (left) and below main deck (right)*

Bow ramp & door for cargo and passengers loading/unloading, the weathertight ramp shall be operated hydraulically by two cylinders at each side and shall be secured by means of hydraulic self-securing locking devices. Clear width of 4.3 m to be ensured, of which is 3 m clear width between kerbs on ramps for cargo shall be arranged. The clear driving height to be 4.70 m. The height of the opening to be clear driving height + extension due to maximum angle of the ramp. The maximum operation angle to be abt. 8 degrees at max. list of 3 degrees. The length of the ramp shall be abt. 11.9 m fitted with flaps of additional 2.0 m. When the bow ramp is in its stowed position, it is utilized to double-up as the inner door and therefore seals the aperture forming a weathertight door in the collision bulkhead. It is divided in two main sections with dimensions abt. 5.0 + 6.9 m and an additional folding section with tapered end flaps, as shown on General Arrangement Plan. The material of the ramps shall be steel. The ramps shall be designed for the given design axle load. Portable handrails shall be arranged on each side. The bow doors shall form a weathertight part of the hull structure and shall be divided into two sections with an intermediate joint on the ship's centerline. Each section shall be attached to the hull by means of a hinged arm. The door shall be arranged to provide clear access for the bow ramp. Interlocks are to be arranged to prevent the bow ramp from being operated before the door is opened, and conversely that the doors cannot be closed until the bow ramp is fully closed.

5. CONCLUSION

In order to check and validate the global strength of the Ro-Pax ferry hull structure, geometric model of the structure of the entire ship was made, including the complete superstructure. In this first phase of structural analysis, special attention is paid to details that should facilitate or simplify, as much as possible, the next phase, which is the creation of a mesh of finite elements as a process of discretization of the structure. As the intention of the analysis is to check the strength of primary supporting members and to indicate areas or structural elements that require additional detailed local analysis, which, although not the subject of this report, could be performed with as little additional work of modeling and modifications. Namely, a change in some part of the basic geometry requires deleting the mesh, correcting the geometry and remeshing, which can be extremely complex and time demanding due to the connection with other structural elements. Therefore, an additional effort has been made here, i.e. an improvement over the standard technique of modeling a complete ship, in such a way that secondary elements, i.e. longitudinals, ordinary frames, pillars and bulkhead stiffeners, are included in the geometry model. In this way, a possible later analysis of local strength can be simpler from the point of view of time consumption for submodels and various forms of optimization.

In addition, the division of goemetry into certain units was taken into account, so that after meshing and analysis, tracking the elements and review of results would be easier. The method of load modeling was also taken into account, as well as the definition of limits for the use of the most uniform dimensions of finite elements. In such a way, at a later stage of design, structural optimisation could be easily achieved.

REFERENCES

[1] Bureau Veritas Rules for the classification of Steel Ships, June 2019, Part B Hull and Stability

[2] RHINOCEROS 6, https://www.rhino3d.com/support/

[3] ANSYS/LST, LS-DYNA R11, https://www.lstc.com/products/ls-dyna

[4] Bolf, D., Hadjina, M., Matulja, T. i Knapić, I. (2020). Implementation of Advanced Collaborative Platform for Project Based Learning in Naval Architecture Studies, Pomorski zbornik, Special edition (3), 217-226

[5] Bolf, D., Hadjina, M., Zamarin, A., Matulja, T. (2020). Methodology of Integrated Design of the Ship Structure and Production Using the 3D Experience Platform, Book of proceedings from 24th Symposium on the Theory and Practice of Shipbuilding (in memoriam prof. Leopold Sorta), 319-326