WP 3 / Activity 3.2.

Double-ended Ferry Structural Model

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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 assessment 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 separately, entitled *Double ended 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 Double Ended 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 first designed vessel presented is double ended car & passenger ferry intended for restricted waters operation in Croatia, Fig.1 and Tab. 1. The vessel has a capacity for 170 standard car units on an open upper car deck and a fully enclosed lower car deck, or a combination of 22 standard trailer units on the upper car deck and 40 cars on the lower car deck. The vessel has also capacity for up to 600 passengers.

The cargo space is arranged on the main deck as open ro-ro space and a closed ro-ro space below the main deck. The open ro-ro space with a clear height of 4.8 m, is intended for private cars as well as lorries, buses, trucks and trailers. The closed ro-ro space below main deck, with a clear height of 2.1 m, is intended for private cars and vans. The lower car deck is accessible from the main deck by two fixed ramps, one forward and one aft. Hydraulically operated weather tight car deck hatches are arranged to close the access ramps such that the upper car deck is free of any obstacles within vehicle parking areas when the hatches are closed. Vehicles may be loaded and unloaded to/from the vessel from both ends and via hydraulically operated ramps at each end. Below main deck the following service compartments are arranged: fore peak (ballast), fore thruster room, fore engine/equipment room with battery room, fresh water tanks, aft engine/equipment room, aft thruster room and aft peak (ballast). The vessel shall be designed, constructed and tested according to requirements and under the survey of Bureau Veritas (BV) (or other IACS member classification societies) with class notation: BUREAU VERITAS I ✠HULL ✠MACH, Aut 1, Ro-ro passenger ship, coastal area, ELECTRIC HYBRID (PM, ZE). The hull is arranged with transverse watertight subdivision below main deck. The Main deck is arranged with freeing ports as required by rules. 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. Deck camber is arranged on all open decks and tank top. Double bottom is arranged where practicable in the central part of the vessel. Bilge area is arranged without double bottom. Generally, longitudinal framing system is arranged for decks and side. Transverse framing system is arranged for superstructure sides. Bilge keels 2 x HP300, abt. 35% of length Frame spacing is 600 mm. Main transverse frame spacing is 3000 mm. Longitudinal stiffener spacing on decks is generally 600 mm. Material main hull in general is HTS 36 (High Tensile Steel grade 36) while material of the superstructure is MS (mild steel). Lower car deck hatches are hydraulically operated weathertight car deck hatches with dimensions of about 3600x13000 mm to be arranged forward SB and aft PS, at the lower car deck rampway in closed position, hatches shall be flush in line with the main deck. Hatches should be hinged on short edge and open towards bow/stern. A 2.3 m clear height shall be secured in open position and the clear width shall not be less than 3.0 meter. The hatches shall in general be built in same steel quality and dimensions as surrounding deck with necessary strengthening in highly loaded areas (i.e. hinge structures). For cargo and passengers loading/unloading, hydraulically operated ramps are arranged at each end. Hull clear width of 8.1 m, of which is 6.5 m clear width for cargo shall be arranged. The material of the ramps shall be steel. The ramps shall be designed for the design axle load. Railings shall be arranged on each side. Two fixed driving ramps from Main deck to Tank top, one forward and one aft, are arranged to access the lower hold. The fixed driving ramps below the hatches shall be shaped to secure small angles over knuckle lines. Minimum free width of doors in passenger areas is 1200 mm. Minimum free width in crew areas is 700 mm, but not to be less than 900 mm for main emergency escape routes. Weather tight doors for all entrances leading down below main deck, and arranged with a sill height according to Rules.

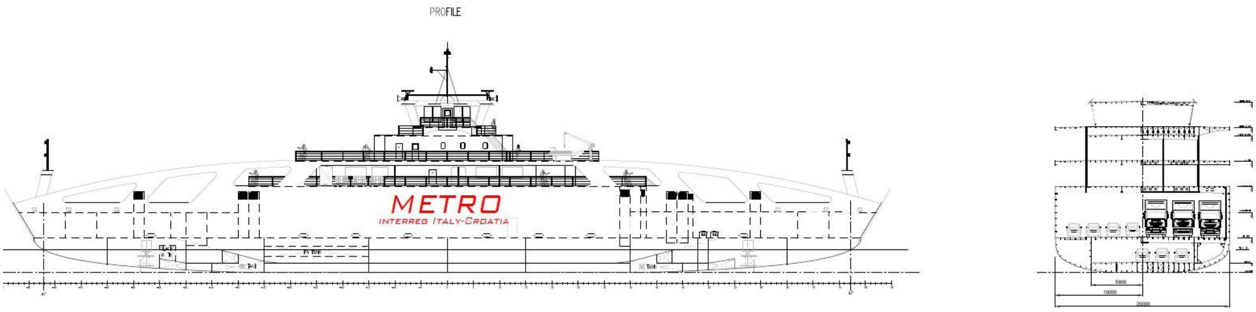


Figure 1 *General arrangement plan of double ended ferry*

Table 1 *Double ended ferry main particulars*

Length, overall	101.90	m
Length, between perpendiculars	92.70	m
Breadth, moulded	20.00	m
Hull depth to lower car deck (midship)	1.05	m
Hull depth to upper car deck (midship)	3.80	m
Draught,max (hull)	2.50	m
Draught, design (hull) abt.	2.30	m
Air draught	abt. 25.00	m
Deadweight (at max. draught)	abt.1000	t
Deadweight (at design. draught)	abt. 660	t
Gross tonnage	4860	GT
Design speed (design draught)	abt. 10	knots
Maximum speed (design draught)	abt. 12	knots

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

Modelling the structure for FEM analysis differs 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 adapted 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.

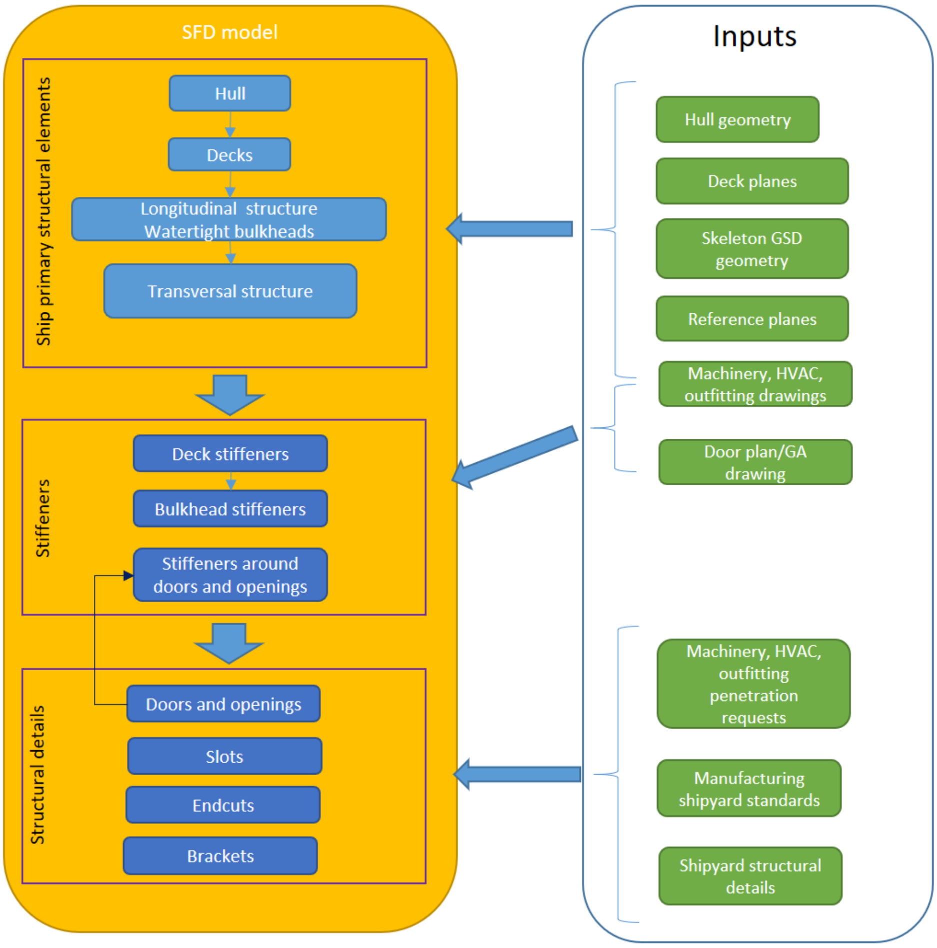


Figure 2 *Modelling sequence of ship structure using the 3D Experience SFD app [5]*

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: METRO-Double ended Ferry-Outline specification_REV2

General Arrangement Plan: METRO-DoubleEndedFerry-1101302-REV2-GAP

Body Lines: METRO-DoubleEndedFerry-1101301-REV2-Body Lines

Midship Section: METRO-double ended ferry-1200301-REV1-Midship section preliminary

METRO-Double ended Ferry-TRIM & STABILITY BOOK_REV1
METRO-Double ended Ferry-Weight estimation_REV2

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. DOUBLE ENDED FERRY STRUCTURAL MODEL

The intention within this chapter is to present the geometry of the entire ship presented by horizontal plans / decks from double bottom up to top of the wheelhouse, Figures 3 to 11, longitudinal section, Figure 12 and 13, and particular structural units; double bottom, side, deck, superstructure, ship's ends and engine room, Figures 14 to 24 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, strong girders in the bottom (central girder, side girders, floors), stringers and web frames, underdeck side girders and deck transverses. Regarding secondary elements, the calculation also includes bottom, side and deck longitudinals, ordinary frames in the superstructure, pillars, and horizontal / vertical stiffeners shown here. The scantlings of these elements, after calculation and checking against bending and buckling, will be shown in another document titled *Global FE Strength Analysis of Double Ended Ferry*, together with the calculation results.

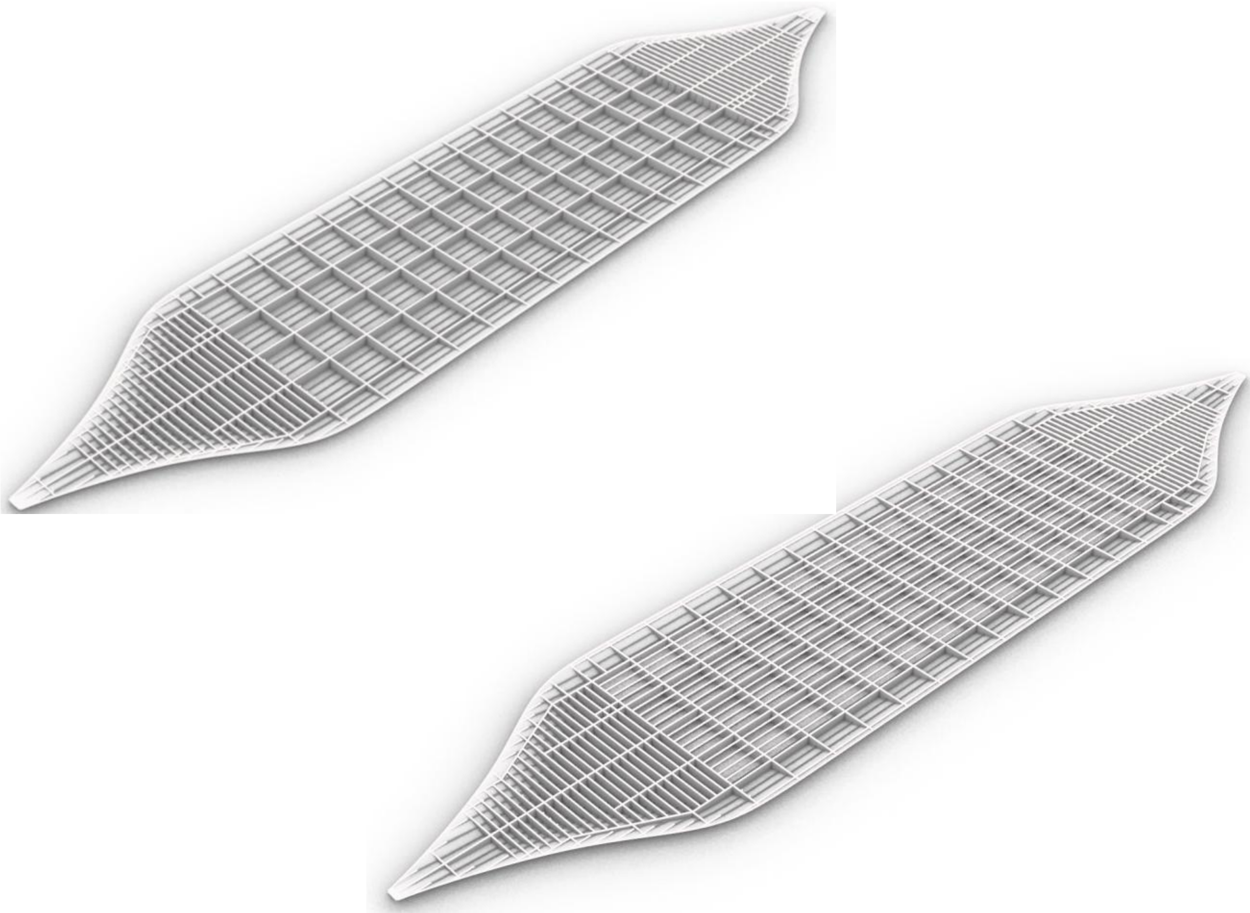


Figure 3 *Hull geometry model – double bottom bellow tank top (left) and with tank top longitudinals (right)*

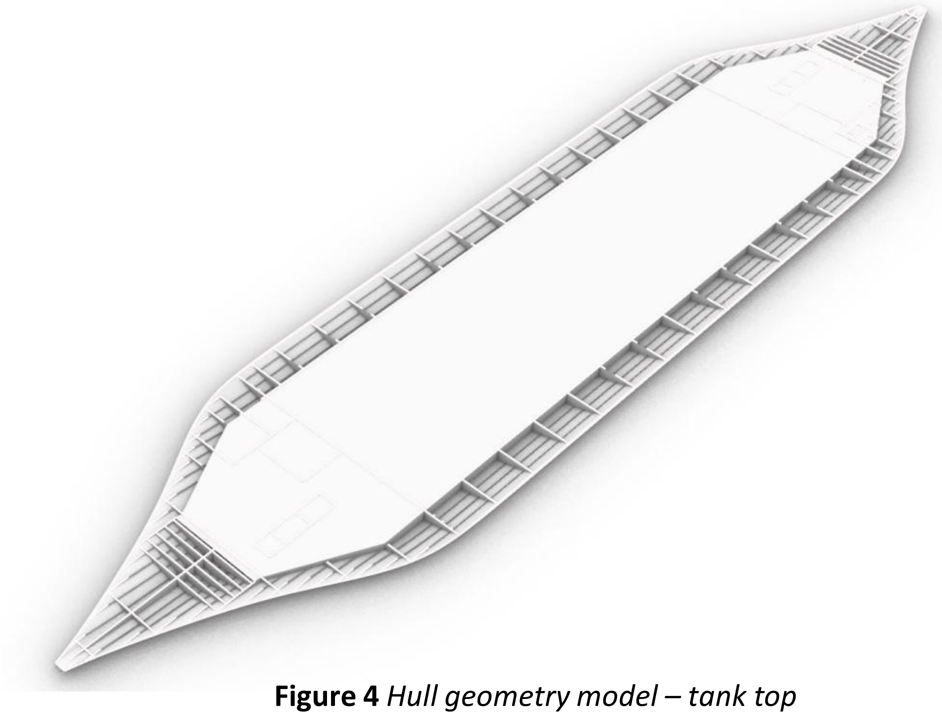


Figure 4 *Hull geometry model – tank top*

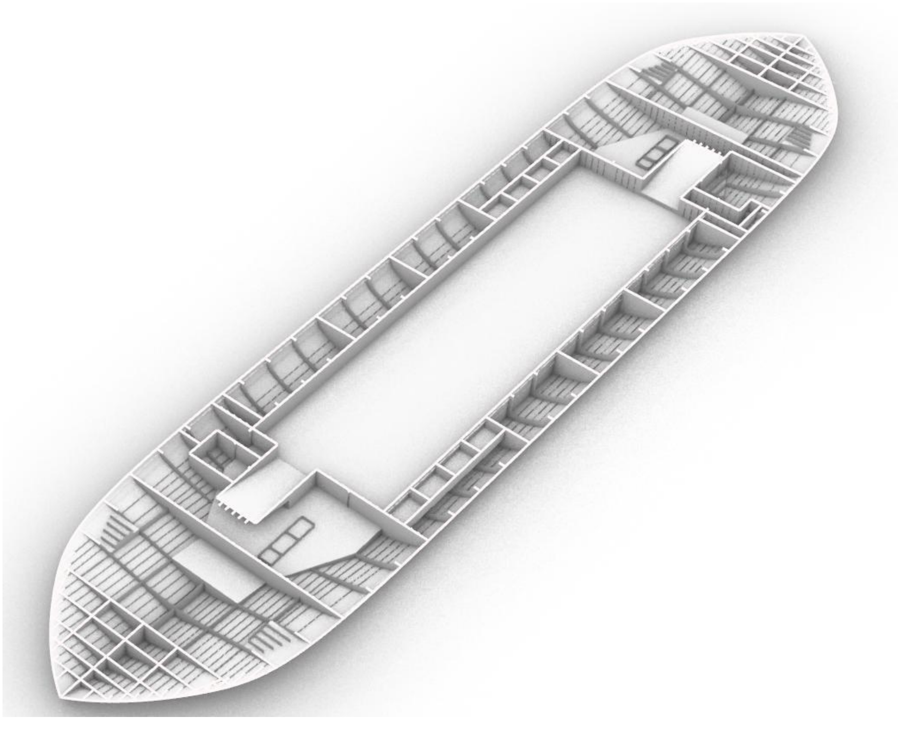


Figure 5 *Hull geometry model – structural arrangement bellows main deck*

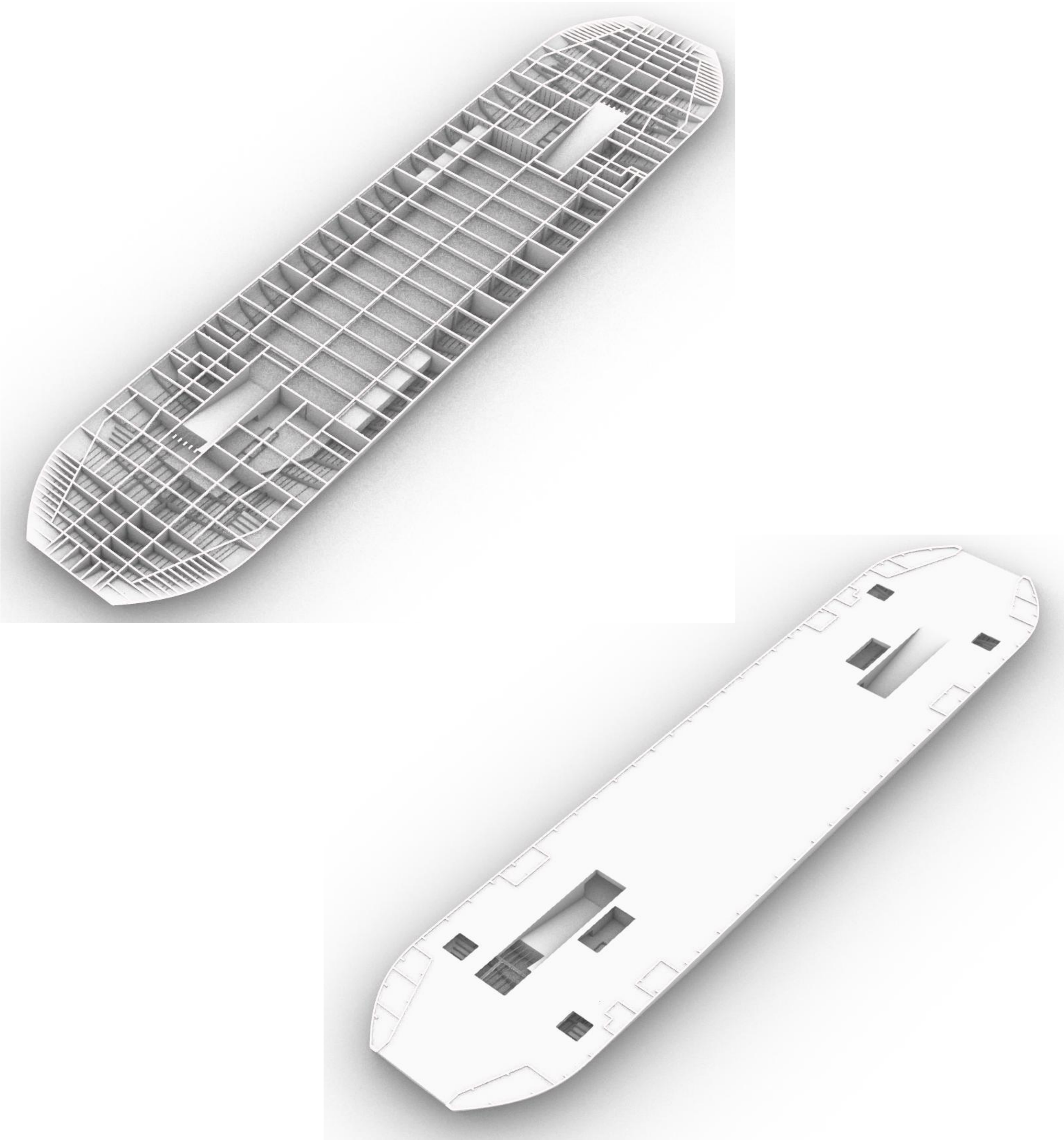


Figure 6 *Hull geometry model - structural arrangement bellows main deck with web frames (left) and main deck (right)*

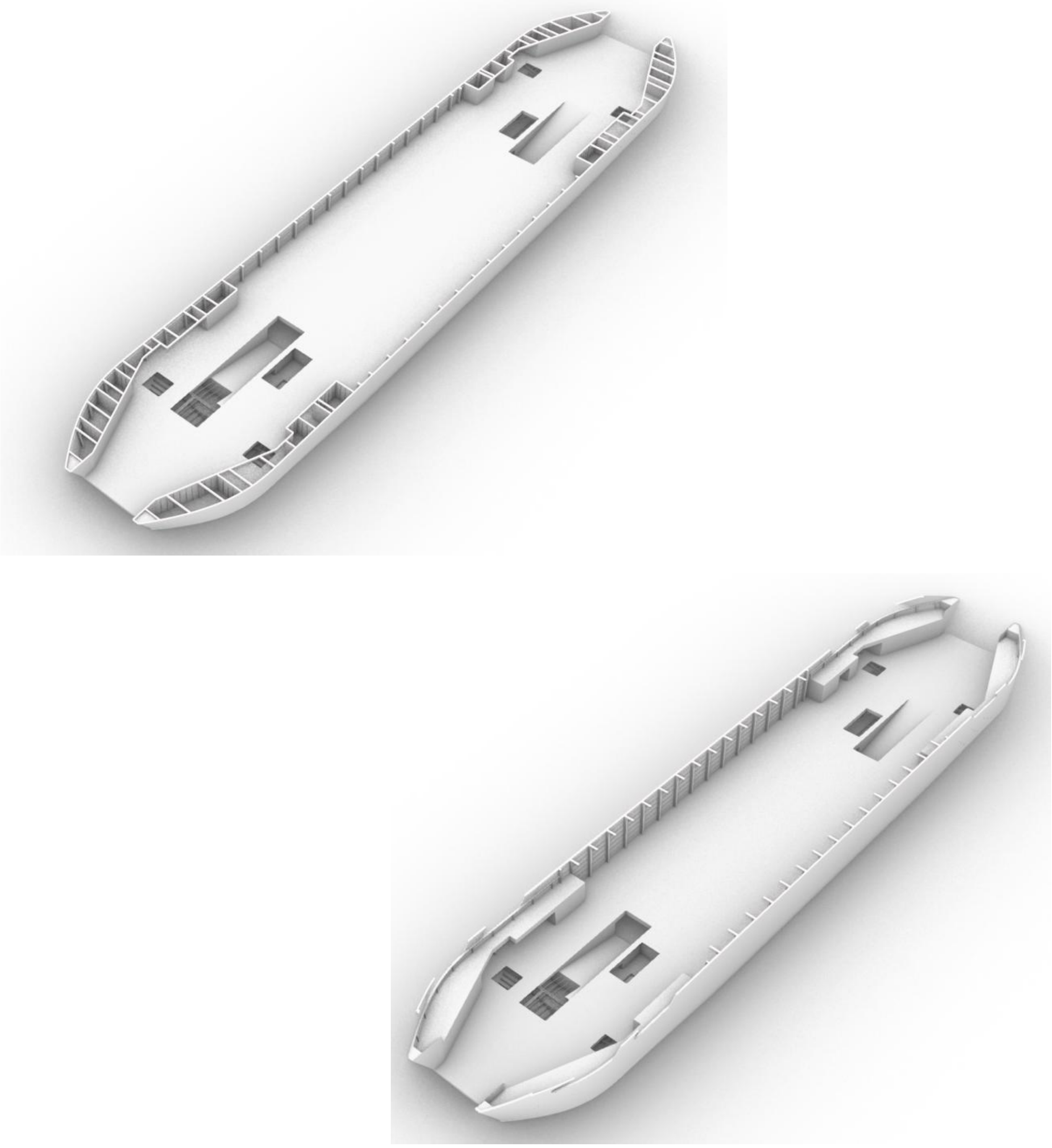


Figure 7 *Hull geometry model – side (left) and mooring deck (right)*

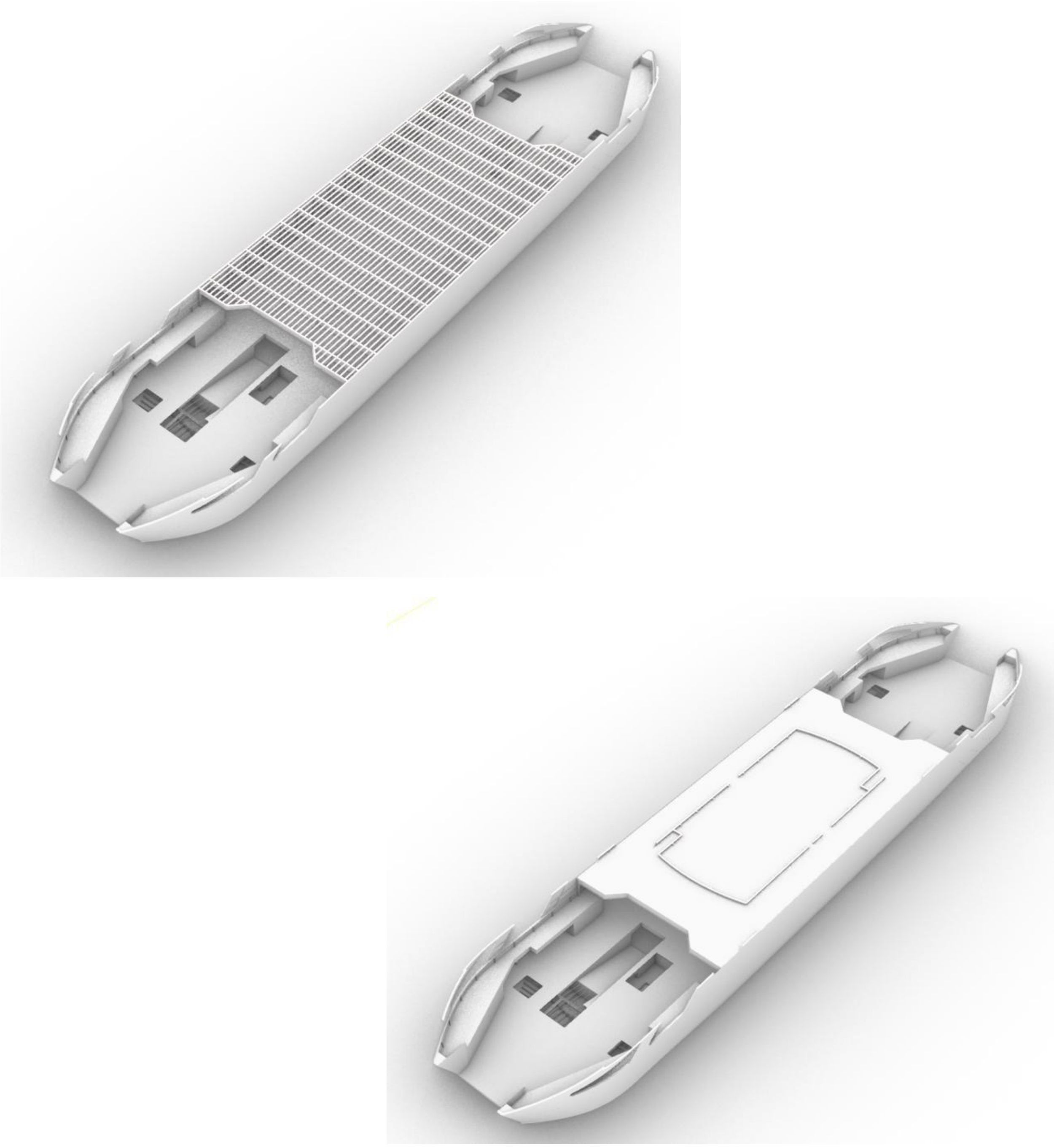
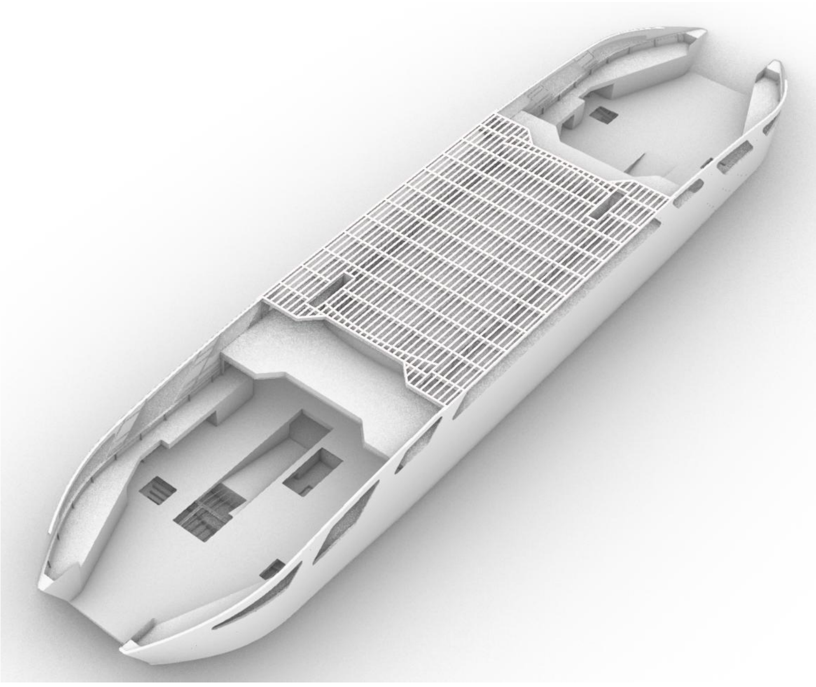


Figure 8 *Hull geometry model – structural arrangement of the passenger deck with deck transverses and longitudinals (left) and passenger deck plating (right)*



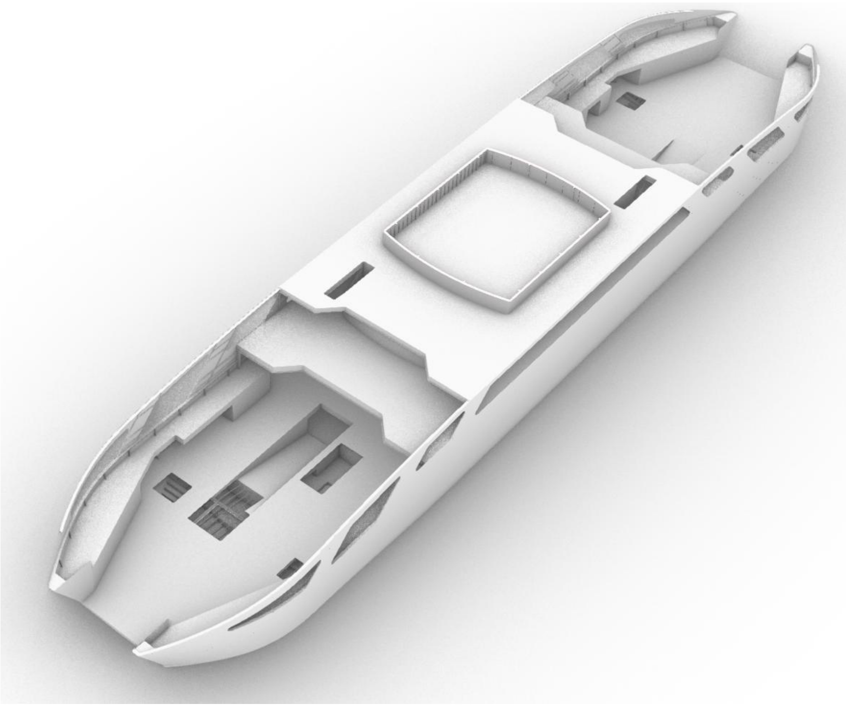
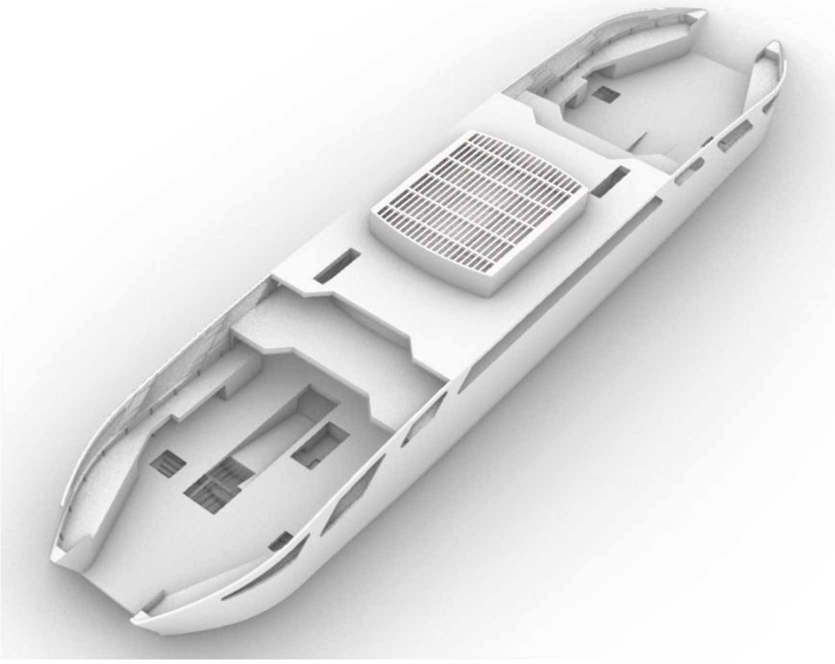


Figure 9 *Hull geometry model – structural arrangement of the sun deck with deck transverses and longitudinals (left) and sun deck plating (right)*



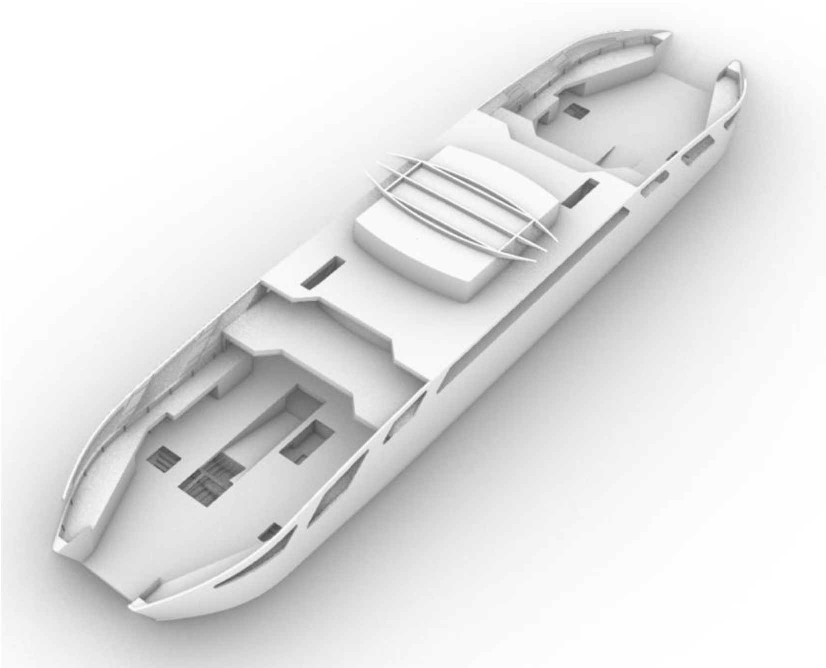


Figure 10 *Hull geometry model – superstructure top deck with deck transverses and longitudinals (left) and plating (right)*

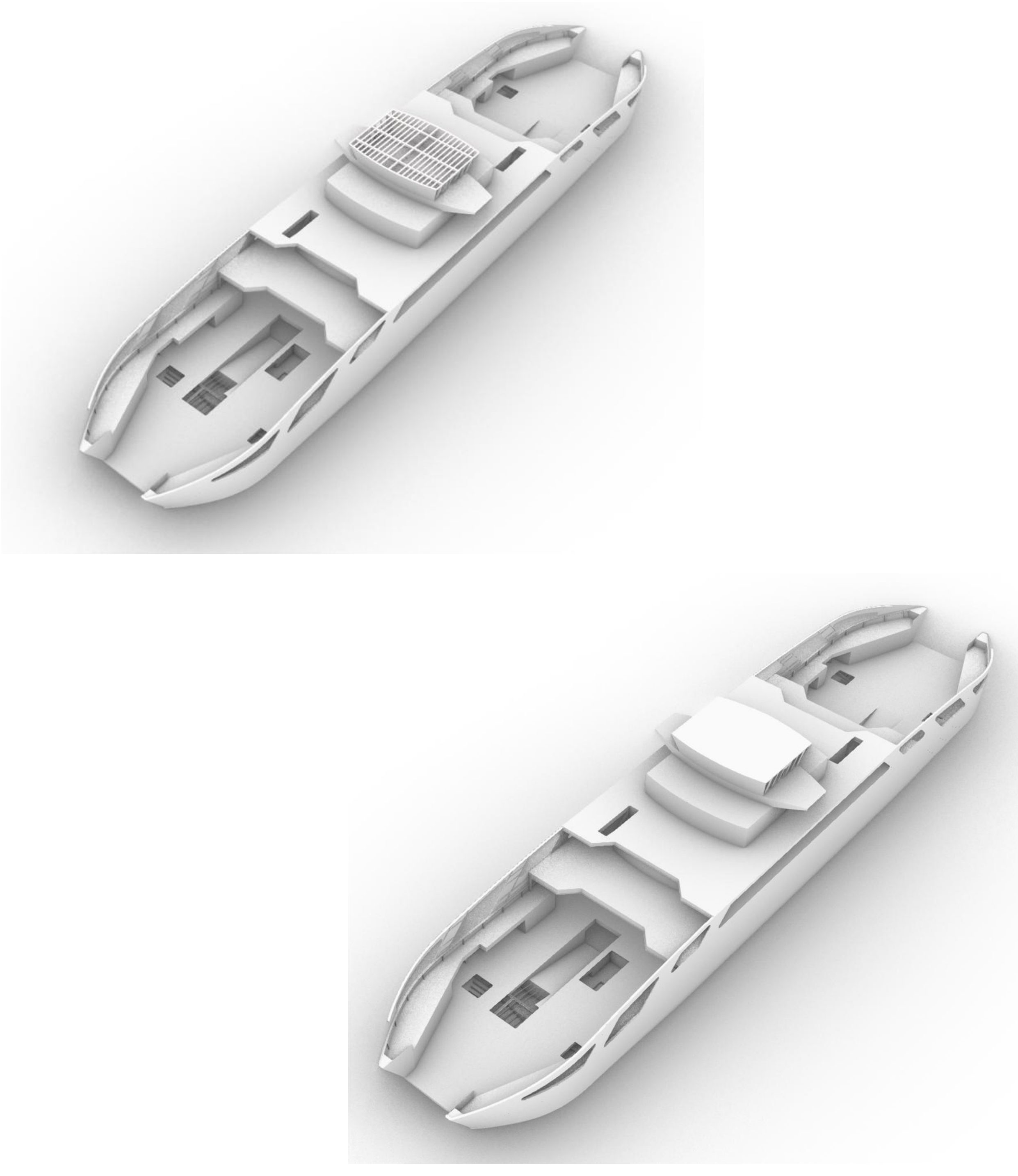


Figure 11 *Hull geometry model – wheelhouse internal structure (left) and wheelhouse top (right)*

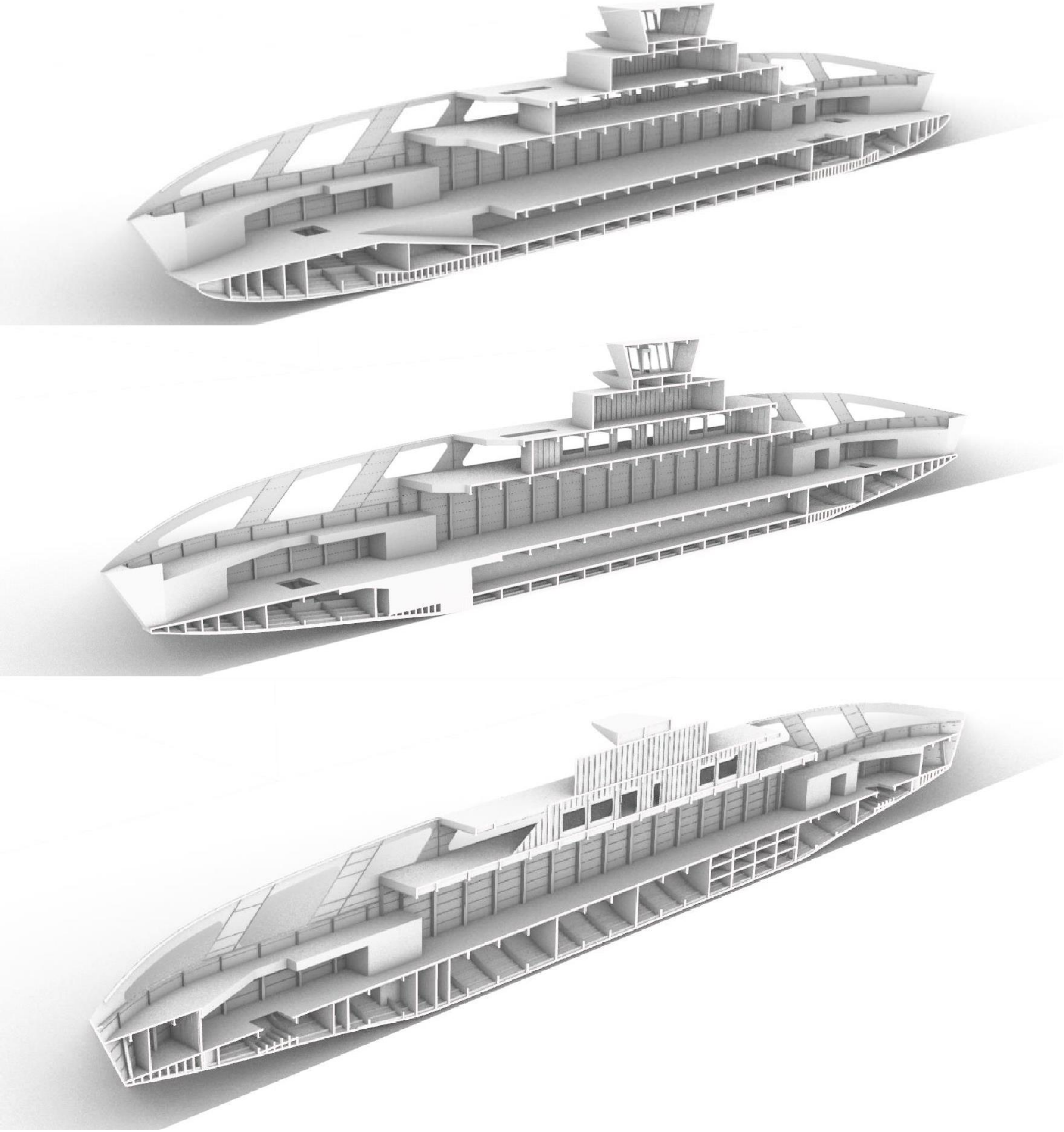


Figure 12 *Hull geometry model – longitudinal section in CL (top) 2400 from CL (middle) and 5900 from CL (bottom)*

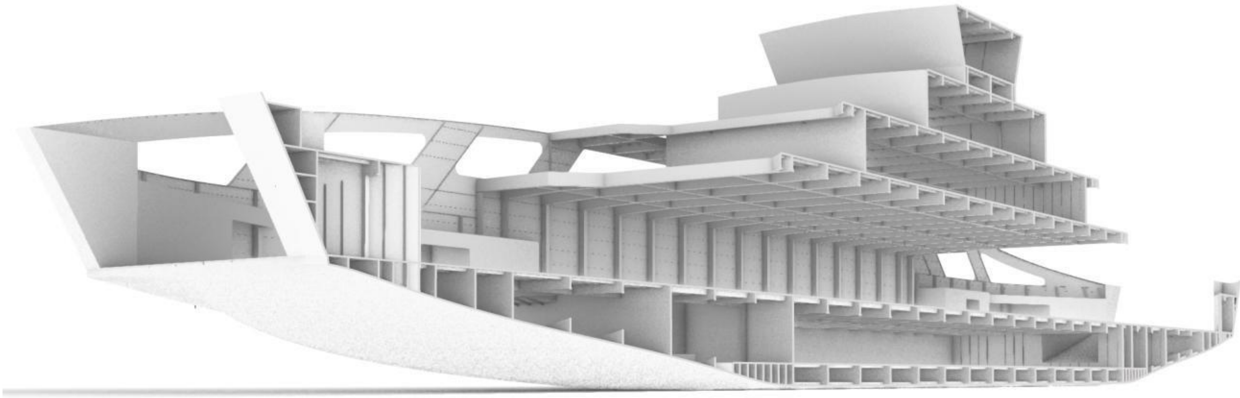


Figure 13 *Hull geometry model – isometric view from stern-bottom*

4.1. Double bottom structure

Double bottom structure (tank top deck) is longitudinally framed and consist of system of side girders and floors being support for tank top end bottom longitudinals.

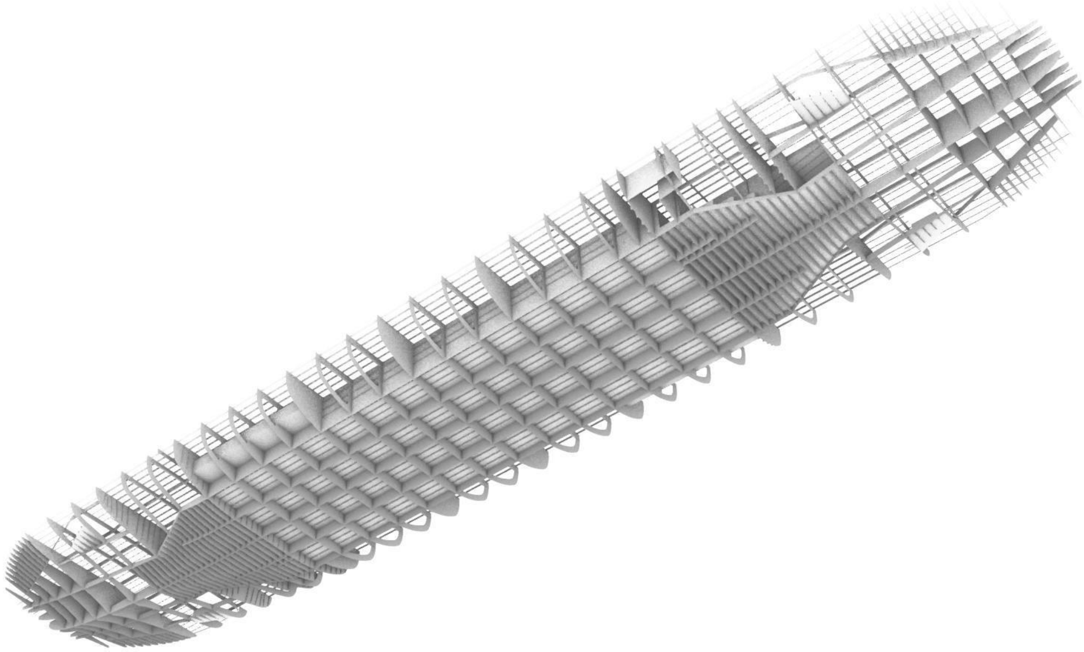


Figure 14 *Hull geometry model – double bottom girders and longitudinals, view from bellow*

4.2. Side structure

Side structure is longitudinally framed as well, with web frames being support for side longitudinals.

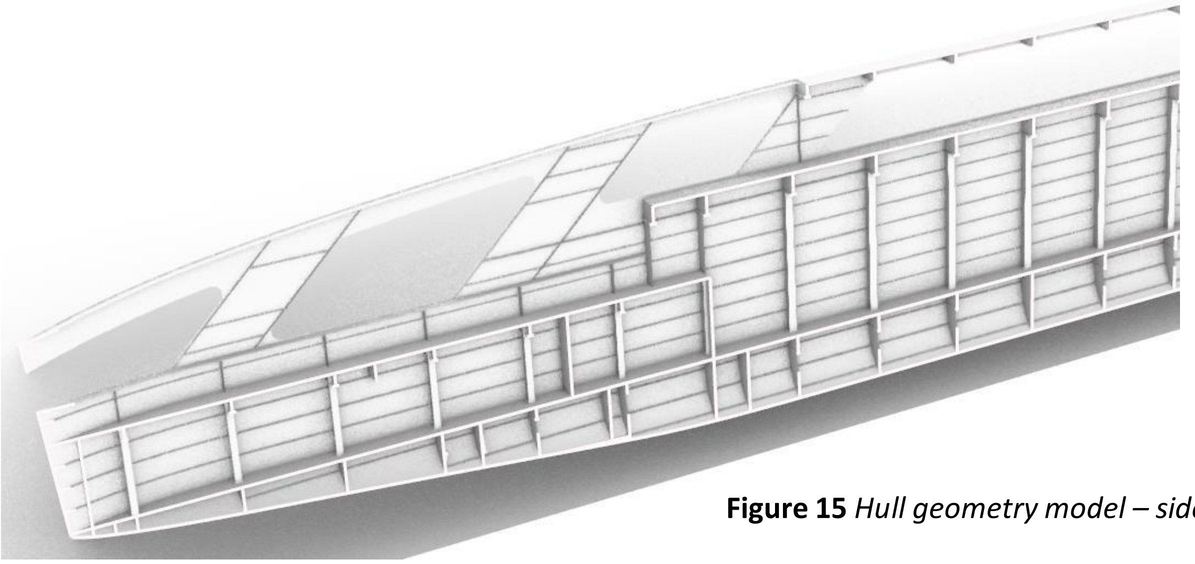


Figure 15 *Hull geometry model – side*

4.3. Decks and superstructure

Decks structures are longitudinally framed as well, with deck transverses being support for deck longitudinals. In order to reduce scantling of deck transverses, underdeck longitudinal girders are fitted.

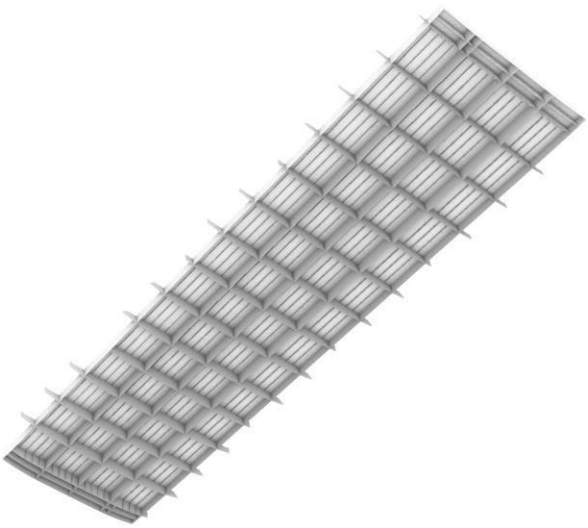


Figure 16 *Hull geometry model – tank top structure, view from bellow*

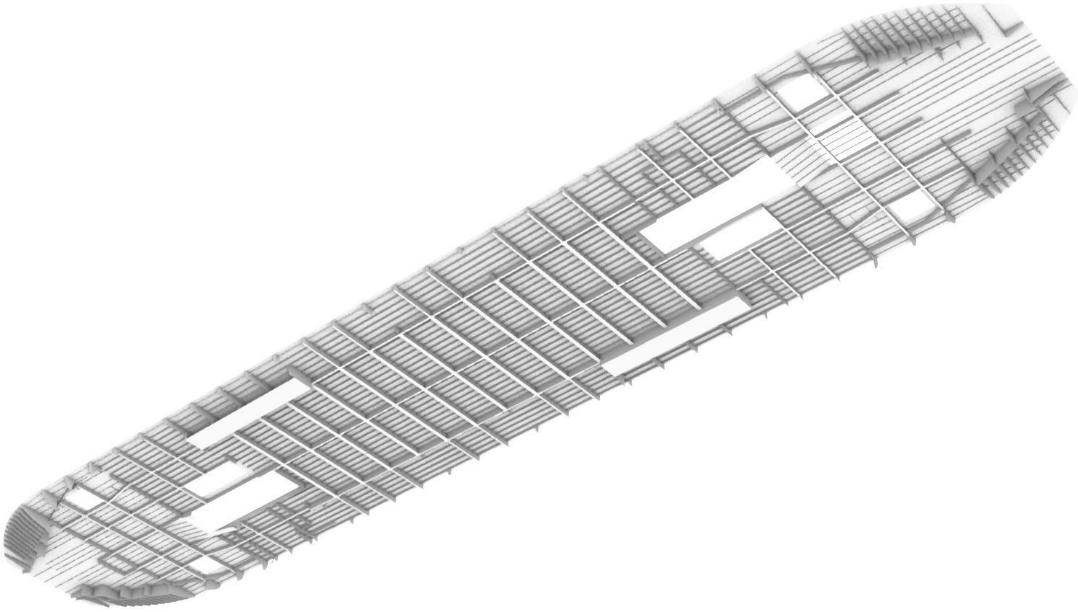


Figure 17 *Hull geometry model – main deck structure, view from bellow*

Below main deck the following service compartments are arranged: Fore peak (ballast), Fore thruster room, Fore Engine/equipment room with battery room, Fresh water tanks, Aft Engine/equipment room, Aft thruster room and Aft peak (Ballast).
Two fixed driving ramps from Main deck to Tank top, one forward and one aft, are arranged to access the lower hold. The fixed driving ramps below the hatches shall be shaped to secure small angles over knuckle lines.

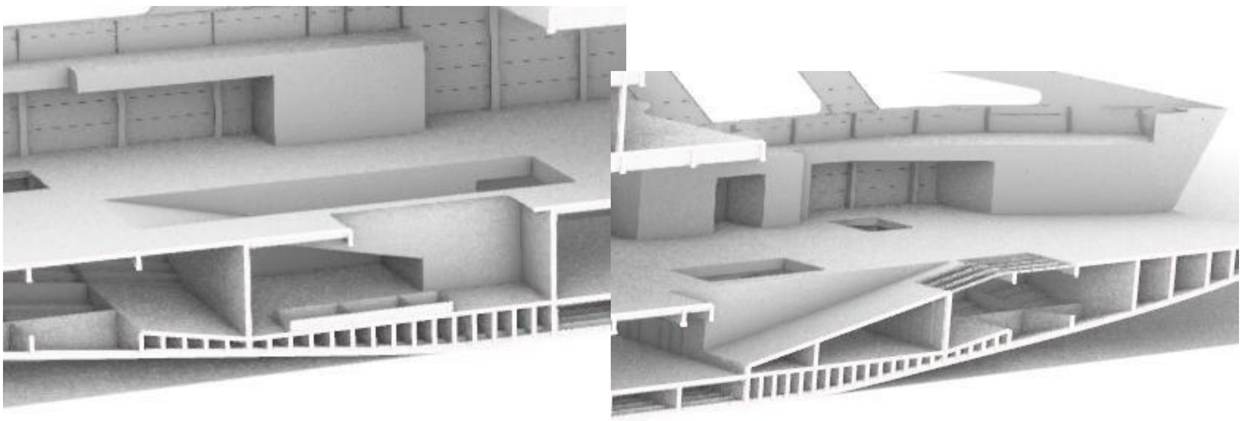


Figure 18 *Hull geometry model – for and aft driving ramps*

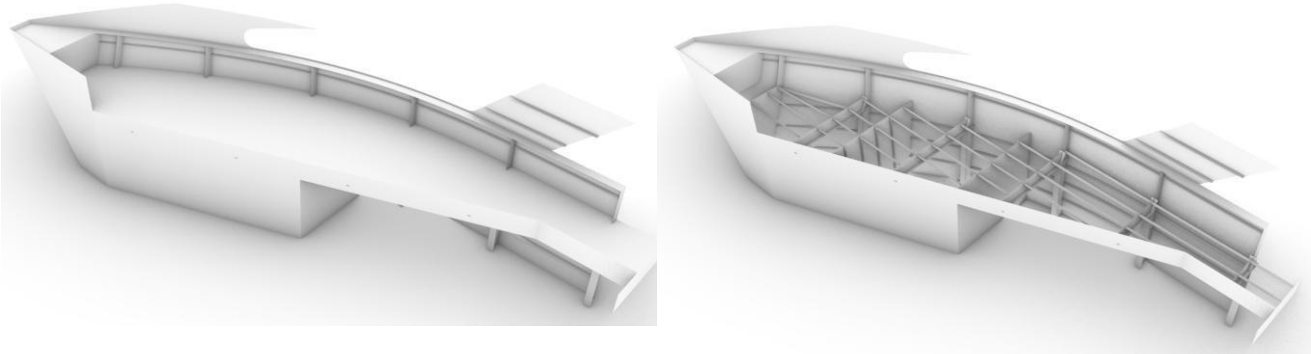


Figure 19 *Hull geometry model – mooring and anchoring equipment deck structure (left), with plating (right)*

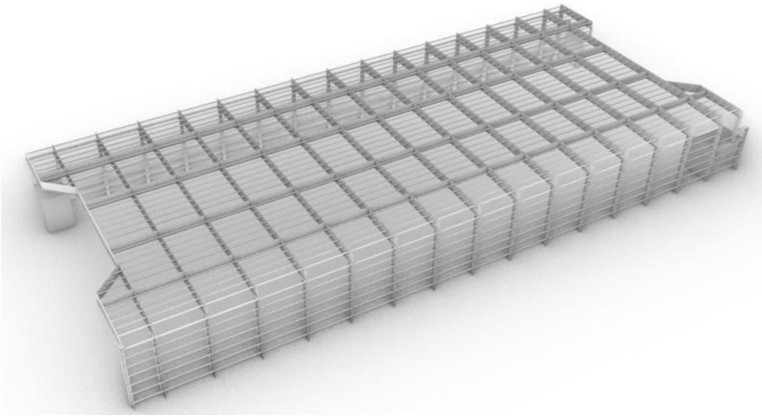


Figure 20 *Hull geometry model – passenger deck structure*

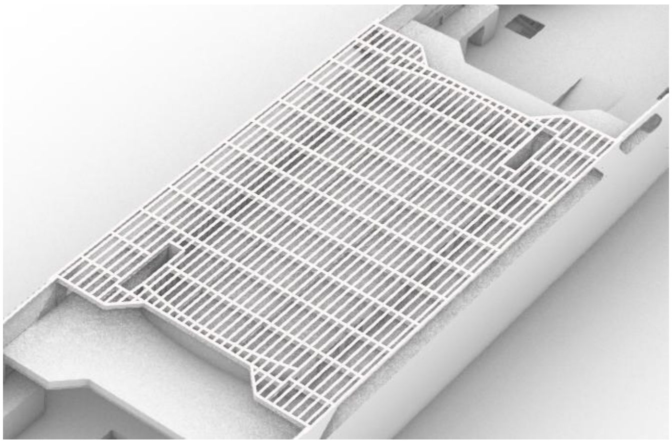


Figure 21 *Hull geometry model – passenger deck structure*

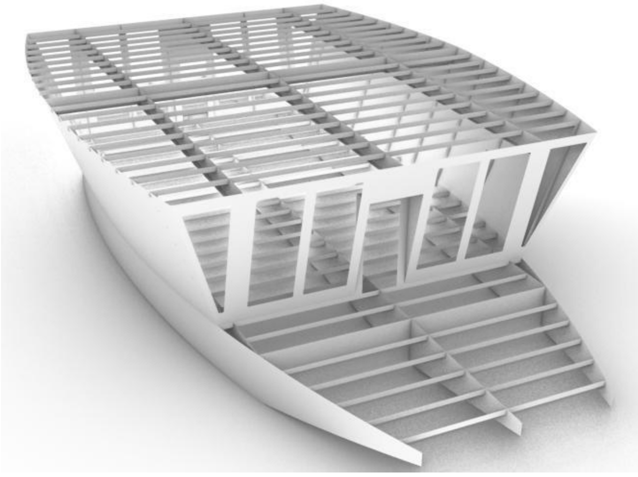


Figure 22 *Hull geometry model – wheelhouse deck and top structure*

4.4. Ends structure

For cargo and passengers loading/unloading, hydraulically operated ramps are arranged at each end. Hull clear width of 8.1 m, of which is 6.5 m clear width for cargo shall be arranged. The material of the ramps shall be steel. The ramps shall be designed for the design axle load. Railings shall be arranged on each side. Hull structure in way of bow / stern ramps is presented on Figure 23.

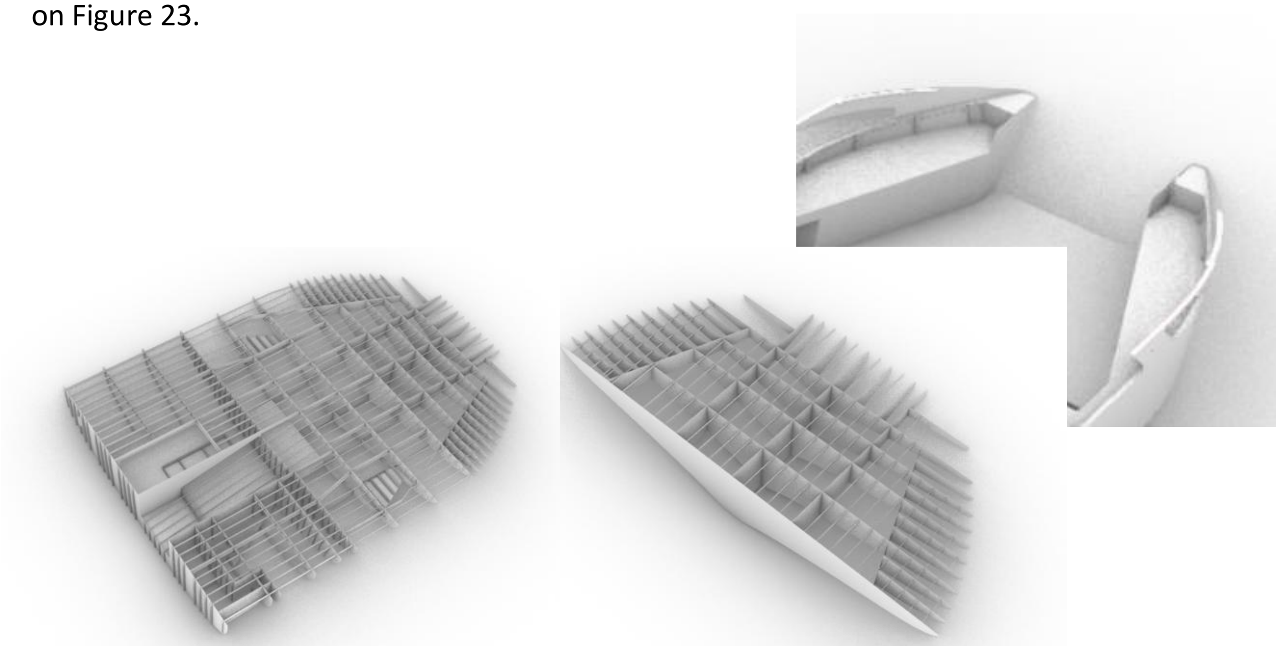


Figure 23 *Hull geometry model – ends structure, bow stern ramps*

4.5. Engine and battery space

In the fore engine room main components are main genset, battery room, switchboards and pumps. In the aft engine room main components are main genset, switchboards, sewage treatment and pumps. Main access to engine rooms is via stairs on the Main deck. Emergency exit is on opposite side of the stairs. Casings for ventilation are arranged at ship sides on PS and SB. The battery room is arranged within the fore engine room with A60 boundaries and with dedicated ventilation ducts. Main components in thruster rooms are thrusters with electric motors. Main access to these compartments is via stairs on the Main deck, with emergency exit on the opposite side. Due to heavy weights of the engines, battery and equipment located within engine rooms, double bottom structure in the engine room is additionally strengthened, Figure 24.

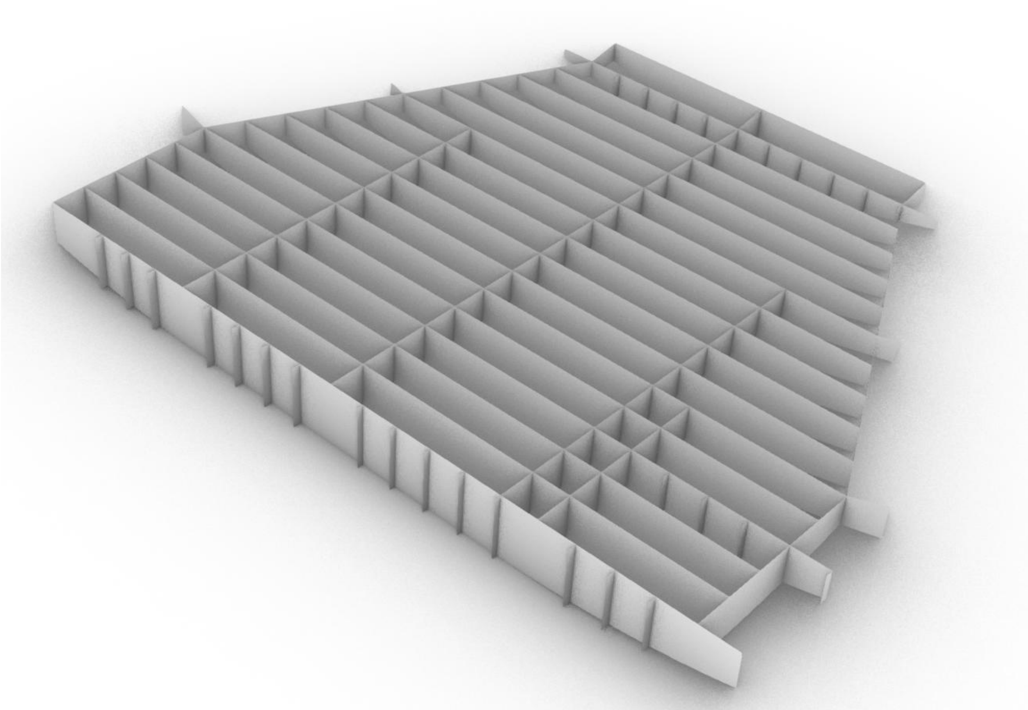


Figure 24 *Hull geometry model – engine and battery space, bottom girders*

5. CONCLUSION

In order to check and validate the global strength of the double ended ferry hull structure, a 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 geometry into certain units was taken into account, so that after meshing and analysis, the elements tracking and review of results was 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. Finally, the strength analysis will be made with the hypothesis that part of the superstructure participates in the calculation of the longitudinal strength, ie the partial efficiency of the superstructure in the stress response of the longitudinal primary elements. Therefore, the hull geometry with the superstructure was prepared in three modules; hull up to and including main deck, hull up to and including passenger deck, and hull with complete superstructure up to wheelhouse. The aim will be to assess the efficiency of superstructures based on monitoring the equivalent stress in some structural elements, which in the later phase of structure optimization could reduce the dimensions of some structural elements, and thus reduce the total mass of light ship.

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[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/

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