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Basic Design of an Innovative Semisubmersible Launching Platform for Load out of Floating Wind Turbines.

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by

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CONTENT

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ABSTRACT

In this paper are presented the basic design of a launching platform and the planning for the load-out and the launching operations of FOWT. The dimensioning of the barge has been done based on up to date FOWT types and dimensions. The barge is made entirely out of steel and in Table 1, its main dimensions can be seen. The hull can be seen in Figure 1 and in Annex 6, details regarding the draft can be found. The supports on the deck are made out of steel as well. Analysis regarding the intact stability of the barge during the operations and out of the operational time have been done. The influence of the displacement on the trim and heel has been observed with the goal of finding the optimum ballasting and de-ballasting sequences.

A representative port (Cadiz) has been selected to model the operation. The load-out and the launching operations have been simulated and planned according to the industry standard. Based on these results, the equipment used has also been decided. The capital and operational expenses have been forecasted. An approximate price of the barge's construction and price per operation have been presented.

Table 1. Main Dimensions of the Launching Platform

Length [m]	73.27
Beam [m]	80.56
Depth [m]	10.58
Minimum Draft [m]	0.416
Lightweight [t]	2315

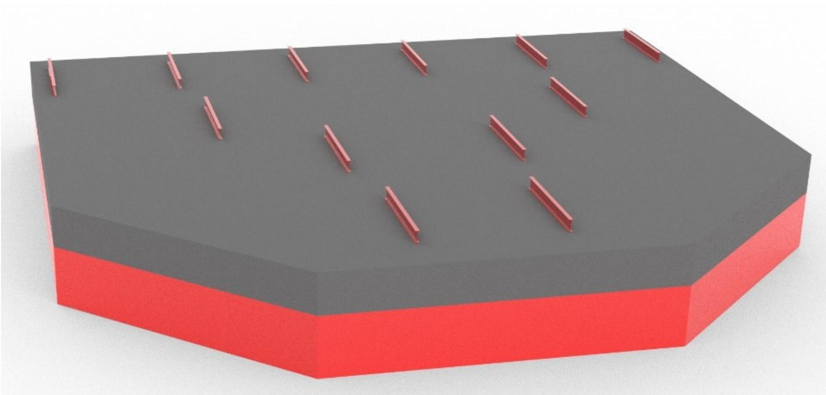

Figure 1. Designed Launching Platform

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1. INTRODUCTION

When discussing about the launching of a vessel or floating structure, one must talk about the launching place, the method that shall be used and the significant factors that have can have a strong impact on the launching process.

The launching place, or dock, is chosen based on the dimensions of the structure and the water depth needed for the launching process. This detail is decided in the first iteration based on the length and width of the structure. In the second and third iterations, it is checked if the depth of the water in the port is enough for the structure's draft and for the draft needed for the launching platform.

A dock is a structure used for launching floating structures. These structures are seen as possible solutions for launching floating platforms for the wind turbines as well. The docks are of 2 types, wet and dry. The wet dock is a body of water adjacent to a group of facilities used to handle boats or ships. (Wikipedia, n.d.)

Figure 2. *Granville Wet Dock. Available from https://marinas.com/view/marina/eycyj6_Granville_Wet_Dock_Granville_Low_Normandy_France*

However, even if the dock, be it wet or dry, provides shelter from big waves and reduces the loads imposed on the vessels and structures, there are still important factors that must be considered.

The wind speed and the tide level are two of the most important ones. The wind's effect on a structure can be dangerous. If the said structure is in the vanishing stability point and the wind was not properly considered during the design phases, it can lead to capsizing.

If the tide is not properly checked and the vessel lowers or raises too much below or above the quay level, the load-out process can become dangerous for both the crew and the structures' integrity. For these very reasons, the most important steps throughout the planning of a launching are choosing the proper time and weather window and ensuring the structure's stability.

It is also very important to mention the difference between the load-out and the load-in process. In the load-in process, the structure or pipes, or the component is transferred from the vessel or barge on the shore/quay. The load-out is the process of transferring the said structure or components from the quay/shore onto the vessel or barge.

The launching methods are presented in the chapter 2.

2. LAUNCHING METHODS

Usually, in the case of the wet dock type, the offshore construction is loaded on a semi-submersible heavy-lift vessel then launched. The launching process normally takes place at the quay. Among all the different types of semi-submersible heavy-lift vessels, the most cost-effective one is the nonself-propelled-type barge. Such a structure requires overall lower capital (building, maintenance and crew) and doesn't need annual machineries survey nor a safe manning certificate.

Figure 3. Semi-Submersible Heavy Lift Vessel Bluetech Finland. Available from: https://bluetechfinland.com/semi-submersible-heavy-lift-vessel/

The dry dock is a well-structured place in which vessels and boats and other structures are built, repaired or maintained. The unique trait of this type of structure is that it allows water to flood in for the manoeuvring of the vessels in and out of the dock. Once the ship is positioned properly in the flooded area, the gates close and the water is drained out. This process exposes the normally immersed part of the hull, to air and therefore, make it accessible for the maintenance and repair works (Wankhede, n.d.)

The later dock type can be separated into 5 kinds: Graving, Floating, Marine Rail Dock, Ship Lifts and Marine Mobile Lifts. Considering the present study, further will be presented and discussed the dock types that are fitted for the immersion of the launching platform.

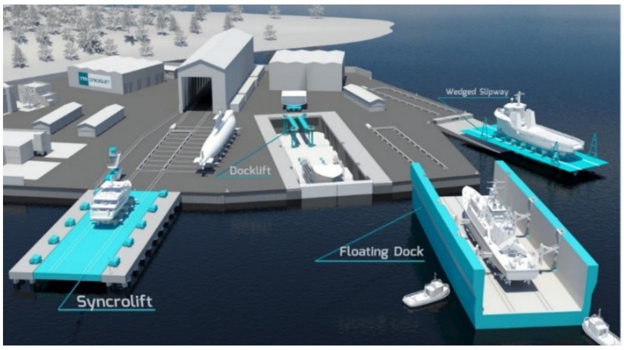


Figure 4. Docking Solutions (Syncrolift Shipyard Solutions)

The Graving dock is usually built onshore, in the proximity of the coastal waters. It is most of the time made out of solid concrete, in a rectangular shape and equipped with blocks, walls, and gates. After the area is flooded to the floater's minimum draft, the latter is towed with tugboats, to its previously determined position in the wind farm.


Figure 5. Fitzroy Graving Dock. Available from https://commons.wikimedia.org/wiki/File:Fitzroy_Graving_Dock_April_2018.jpg

The Floating dock is used mostly for the salvaging of a ships damaged to a point that prevents them to sail to the closest coastal dock. It is built in a "U" form, to provide a great stability both in the immersed and emersed cases. Its ability to immerse itself and emerge with almost imperceptible trim changes, turns it into a very interesting and practical solution. It is all the more practical considering that the floating dock can launch the platform at the designed position, reducing the need for tugboats to minimum.

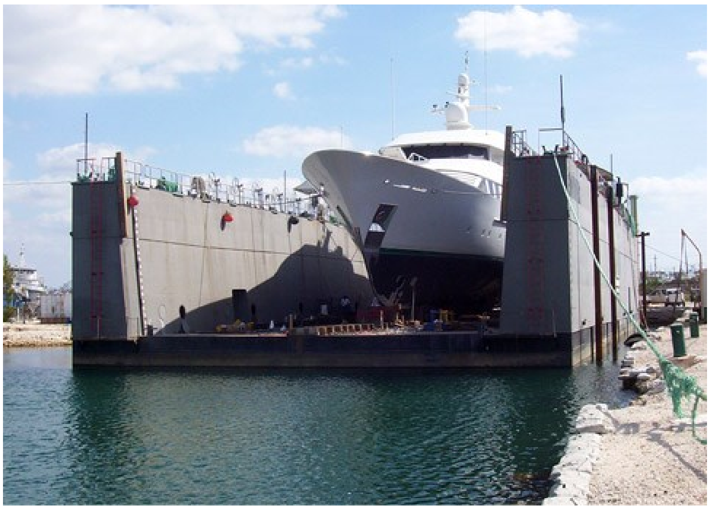


Figure 6. Heger Floating Dock. Available from: http://www.hegerdrydock.com/projects/floating10.html

The shiplift is a newer alternative to the previously described solutions. It is made of a platform and a number of hoists that lift and lower perfectly vertical the platform. This type of structure is used for drydocking and launching ships. One popular example of this type of dock is ***Syncrolift.*** (Wikpedia, 2013) This method is more expensive and favourable for ships with a slender to medium width, therefore it is not usually used in the launching process of floaters.

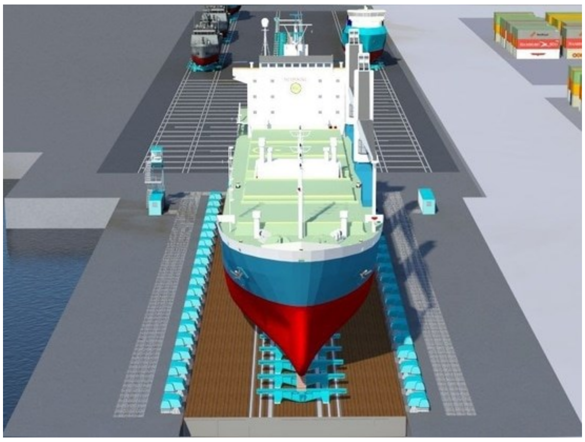


Figure 7. Syncrolift System. Available from: https://trends.nauticexpo.es/project-323624.html

2.1 Barge Load-out methods

2.1.1 Buoyancy Tanks

According to (Kojima, Cho, Yang, 2002), the typical barge-type semi-submersible heavy-lift vessels is equipped with four buoyancy tanks arranged in a symmetrical pattern at the corners. However, the layout or the number of tanks can change while carrying huge offshore constructions. By reducing the number of buoyancy tanks, one can increase the vessel's operational efficiency and reduce the contact damage risk while resulting in an asymmetrical layout out.

Figure 8. Malin Group Giant Semi-Submersible Vessel. Available from: https://www.heavyliftnews.com/giant-semi-submersible-lifting-barge-being-prepared-for-malin-group/

The vessel's ballast tanks are filled according to the ballasting procedure. The ballasting begins in one of the ship's extremities (aft or fore). Once the ship is grounded and the deck is at the predetermined depth under the water (the floater's minimum draft), the offshore construction starts floating by itself and it is towed by tugboats.

2.1.2 Piles

The barge is equipped with 4 piles, laid out symmetrically in fore-aft and starboard-portside. After loading the structure onto the barge, the piles are lowered and dug into the soil. The vessel is ballasted and lowered on the piles, until the water reaches the minimum draft of the offshore structure. Afterwards, the procedure is similar to the one before. The construction is towed by the tugboats. The advantage of this method is that it can be used in deeper water as well.

2.1.3 Non-Conventional Solutions

2.1.3.1 Reaction Barge

2 arms are installed on the quay or on a reaction barge, to provide lateral stability. The barge is positioned so the arms can be coupled on it as well. The reaction barge is ballasted for stability reasons and to ensure appropriate reaction force to the ship's possible motions. Considering that is very important for the arms to push the barge downwards at the same time, the arms can be hydraulic or connected. This will prevent the roll motion as well.

The barge is ballasted with respect to the ballasting procedure, while kept in place by the arms. Once the floater is afloat and towed by the tugboats, the de-ballasting process begins and the vessel is brought back to the surface.

This method has been used by Coremarine in the Load-out procedure for the Offshore structure UNDER (2200t Concrete Structure) in Norway.

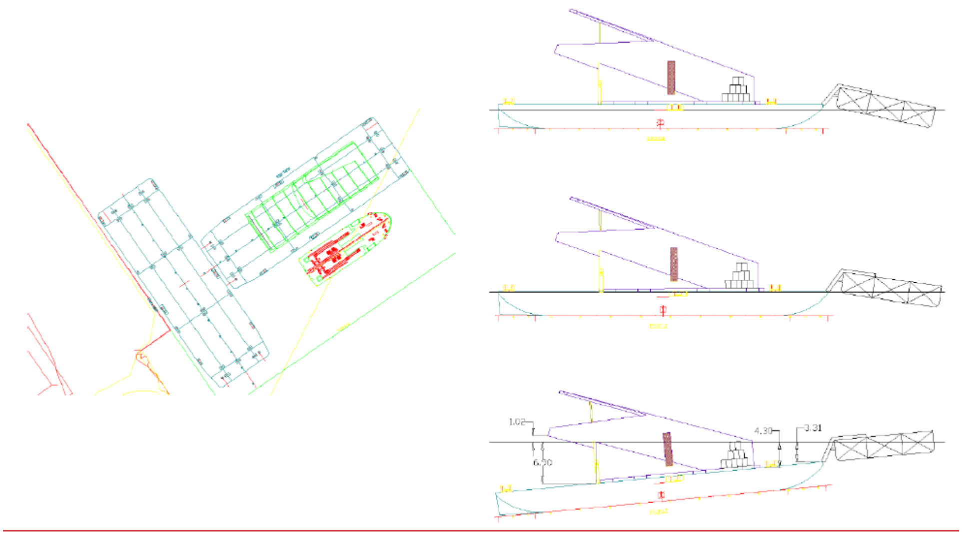


Figure 9. UNDER Load-out Method by Reaction Barge

2.1.3.2 Winches and tugboat

This solution implies the usage of 2 winches on the quayside and 1 winch on the tugboat. The 3 chains shall be in vertical position. The 2 winches on the quayside will be attached to 2 supports welded in the aft of the vessel as shown in the Figure 20while the one on the tugboat will be positioned in the fore of the ship, attached in a similar way to the ones in the aft.

This solution is very practical as it allows control over the trim and heel. The grounding and de-ballasting processes are controlled better through this method, which also helps in finishing the launching process in time and sometimes, even faster.

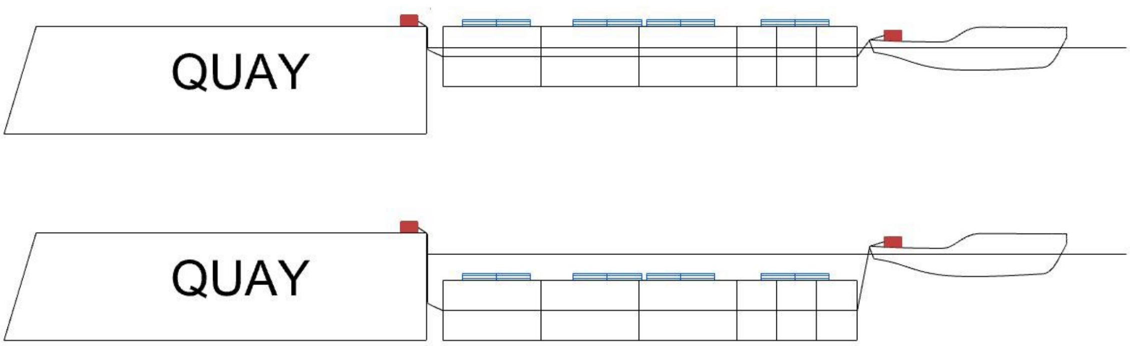


Figure 10. Proposed Solution for the Present Study. Side View

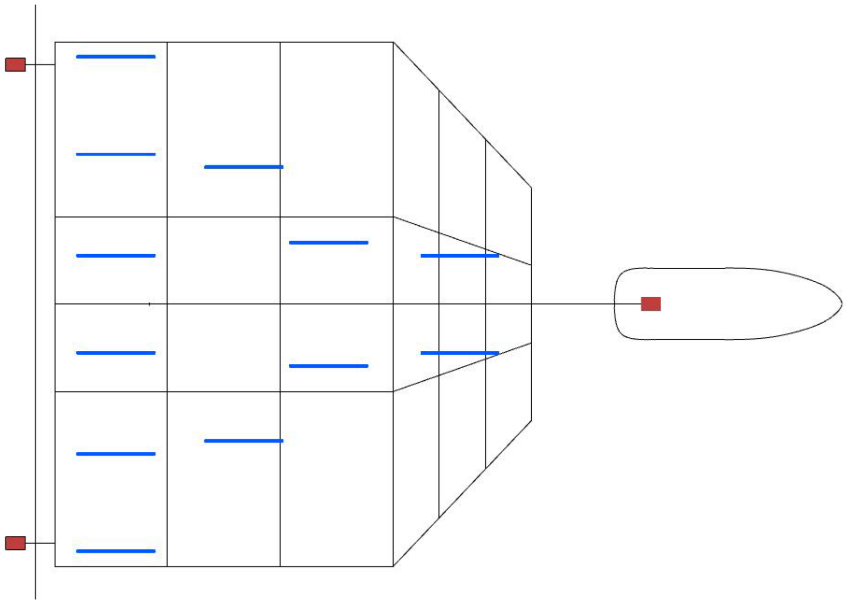


Figure 11 Proposed Solution for the Present Study. Top View

3. FLOATERS

The floaters' studied for this paper are developed for Wind Turbines of 10-15 MW. Several sources of information were used to obtain details regarding the floaters. After a careful analysis, it was decided to have as main focus the floaters for Wind Turbines of 12 MW.

3.1 Analyzed Floaters

6 floaters were studied, to get an approximation of the industry's structures' dimensions. The chosen structures are the ones shown in Table 2. The displacement presented in the table represents the total weight of the structures, with ballast included. As it can be noticed, VolturnUS is the most massive construction. The launching platform designed in the current paper will be based on the average dimensions of the studied floaters. The VolturnUS floater's dimensions considerably stand out compared to the others, therefore it shall be overlooked in the further considerations.

Table 2. Studied Floaters

Floater	L x W (m x m)	Displacement (t)	Draft (m)
OLAV OLSEN 50 (10 MW)	78.3 x 86.89	24096.7	22
NAUTILUS 50 (10 MW)	65.25 x 65.25	8137.1	14.447
VOLTURNUS (15 MW)	90.13 x 102.13	20711.15	20
WINDMOOR (12 MW)	67.8 x 76	14176.1	15.5
PRINCIPLE POWER	65.3 x 75.2	4100	20
IDEOL S.P. (12 MW)	61.5 x 61.5	10379.8	6

The floaters can be seen below, in the Figure 12. The order is as follows, from top left to bottom: Olav Olsen 50, Principle Power, Nautilus, IDEOL, VolturnUS and the model that will be the main focus for the stability analysis, WindMoor. The "WindMoor" floater was chosen in agreement with the project supervisor because of its interesting fabrication characteristics and public information available. It is a model that has been developed by the joint effort of the major wind developers.

Figure 12. Structures of Floaters Studied

The average dimension of the FOWT floaters selected is 67.6 m in length and 72.97 m in width. The launching platform, though, will need to be rather wider and longer than that. One of the main reasons is the safety of the floaters. Its dimensions need to overcome the ones of the floater it is carrying. It also needs to provide enough space for the extra equipment used during the operations.

During the load in and load out processes, the floaters aren't ballasted. Once the platform's deck is fully immersed and the water reaches the offshore structure, the latter must be stable and float. Therefore, the minimum draft of the structures must be found. The draft presented by the manufacturers is the operational one, therefore research was conducted to find the ballast mass. Based on the results of the said research, the needed draught was calculated. For the floaters that didn't have these data specified, an interpolation with structures made out of the same material (Steel or Concrete) was done.

Table 3. The minimum drafts obtained

Floater	Operational Draft (m)	Hull Weight (t)	Minimum Draft (m)	Material
Olav OLSEN 50 (10 MW)	22	13420	12.25	Concrete
NAUTILUS 50 (10 MW)	14.447	2696	4.79	Steel
VOLTURNUS (15 MW)	20	6454	6.23	Steel
WINDMOOR (12 MW)	15.5	4500	2.26	Steel
PRINCIPLE POWER	20	2500	6.12	Steel
IDEOL S.P. (12 MW)	6	7037	2.07	Concrete

4. BASIC DESIGN PHASES

For an offshore structure to be designed, the naval architect needs to pass through an iterative process shown in Figure 13. Among the members of the industry, it is also well known as the Basic Design Spiral. Most of the time, it is composed of 3 major phases: Concept Design, Feasibility Design and Full (Detail) Design. (Naval-architecture, 2014)

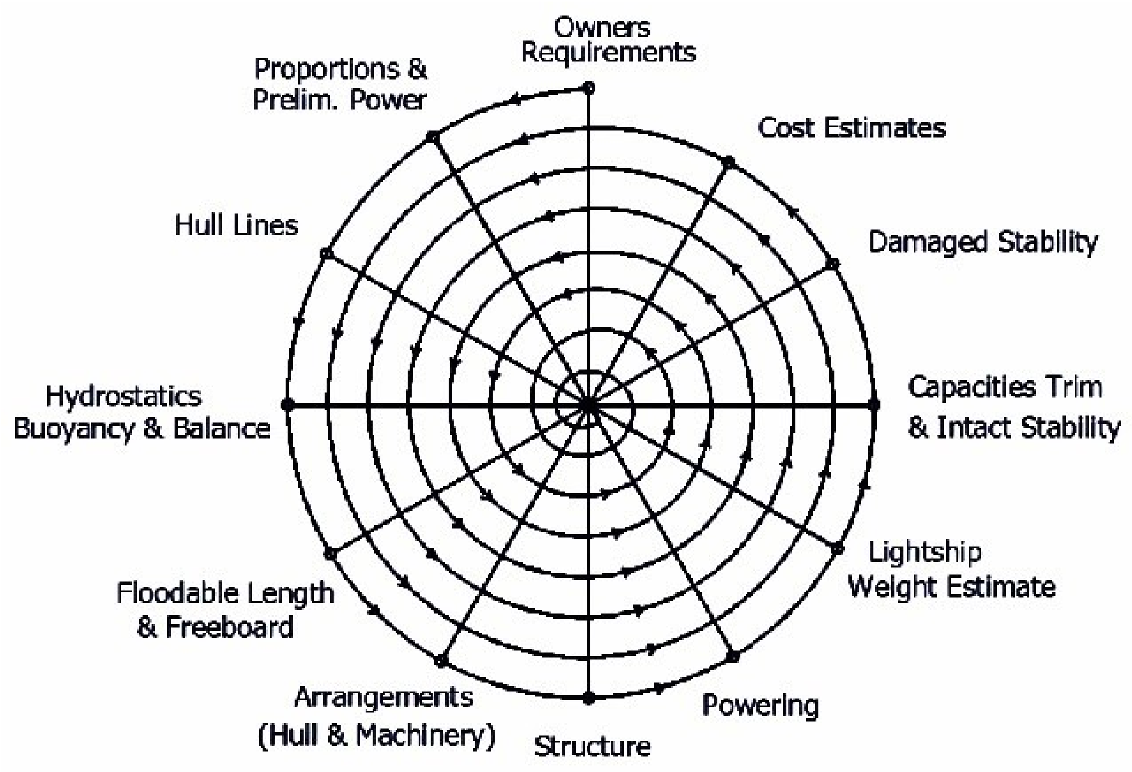


Figure 13. Basic Design Spiral from: http://naval-architecture.blogspot.com/2014/04/the-design-spiral.html

4.1 Mission Requirements

The concept of the launching platform is to fit any of the, now 5, floaters considered and to require as little steel as possible. As explained in the beginning, the platform will be a non-self-propelled barge. It is assumed that it will be used for the launching of several floaters, therefore it shall be built and not converted from another vessel. The Classification Society

Rules used for this project are the ones of DNV. All calculations and arrangements are done in accordance with the DNV and the flag rules.

4.2 Proportions

In the third chapter, it was explained that the dimensions need to be increased. Considering the various factors, the best-suited dimensions are the ones shown in Figure 9.

4.2.1 Shape

3 shapes were considered in the first place. The typical rectangular form and 2 trapezoidal forms. The later ones were differentiated by the width of the "small base". In Figure 14, the shapes can be noticed.

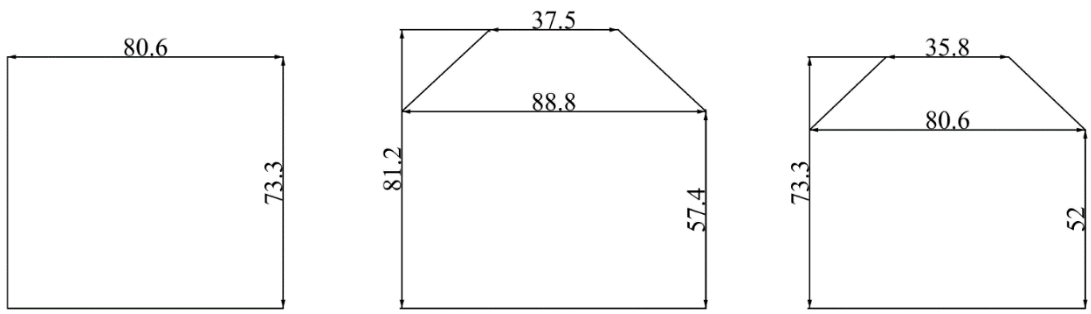


Figure 14. Barge Shapes 1, 2 and 3 (from left to right)

To take an accurate decision regarding which shape to choose, the areas were calculated. The results can be found in Table 4. As it can be seen, the smallest area is obtained in the third option. Considering it provides enough space on deck for the offshore constructions and that it also requires less material for building, this is the chosen model.

Table 4. Areas of the models

Barge Shape	Area (m^2)
1	5903
2	6606
3	5427

In the first place, only the shape of the barge was chosen. It took a few iterations before deciding on the dimensions presented in Figure 14. Once those were decided, a database of semi-submersible barges was created and it is found in Table 5.

Table 5. Semi-submersible vessels Database

Length (m)	Width (m)	Depth (m)	Draft (m)
90	40.7	7.5	6.1
110	45	6.1	4.84
159.24	45.5	9	6.113
137	36.6	7.6	5.8
152	38	9.15	6.92
140	57.05	8.54	6.3
164	65	10.2	6.6

Based on the data presented above, the full height and the draft were calculated through interpolation. These results are shown below, in Table 6. The barge's width is rather impressive and it requires a shipyard with a high width and with a wide entrance channel, for construction.

Table 6. Platform Dimensions

Length (m)	Width (m)	Depth (m)	Operational Draft (m)
73.27	80.56	10.58	6.569

The center of gravity (CoG) and the center of buoyancy (CoB) were calculated as well. The reference point (coordinates' center) was placed in the Center Line (CL), in the aft and at the draft. Their positions are shown in Table 7.

Table 7. Launching Platform's Center of Gravity and of Buoyancy Positions

Position (m)	X	Y	Z
CoG	-2.59	0	-1.273
CoB	-2.59	0	-3.278

4.3 Lines & Body Plan

The Body Plan and the 3D model were made by using Rhinoceros 7, with a license provided by Core-Marine.

In Figure 15 and Figure 16, the Transversal and Longitudinal Sections are seen as well as the waterlines. The distance at which each transversal section is found is provided in Table 8. Considering the shape of the barge, only 3 longitudinal sections in each board were created.

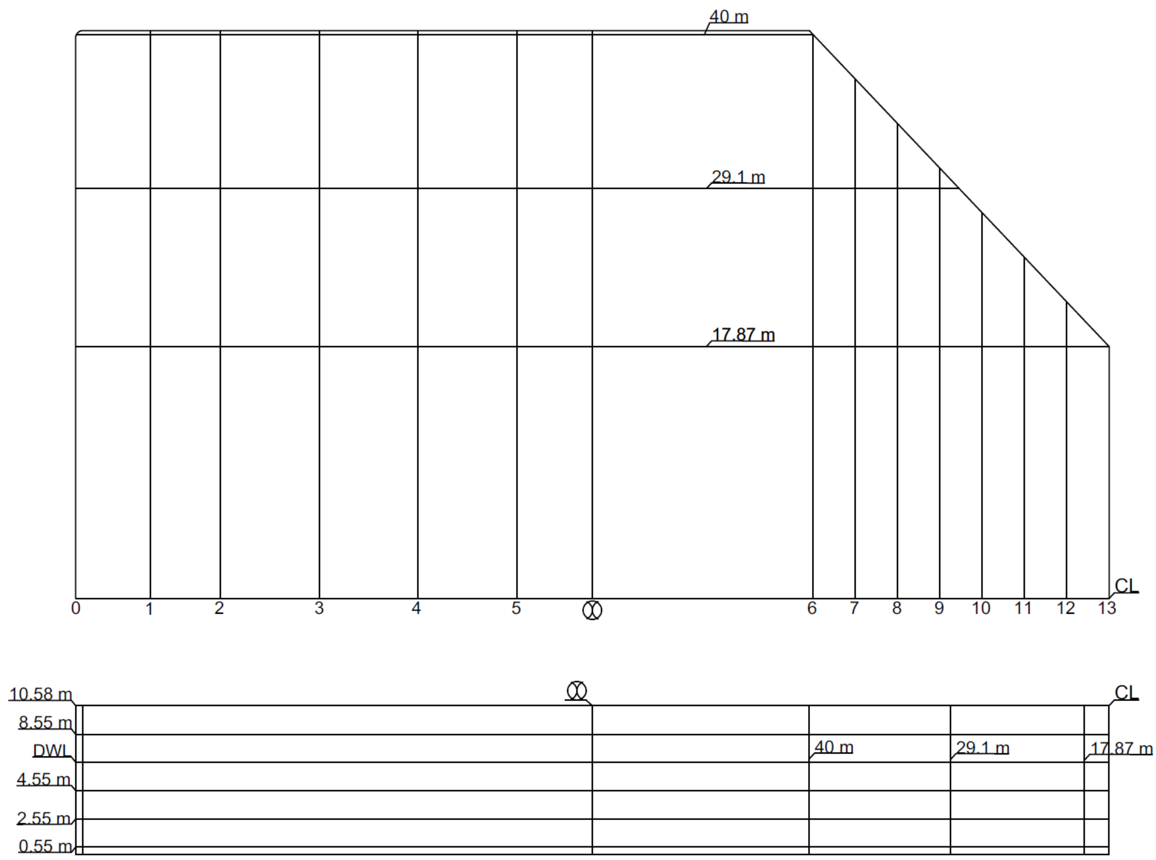


Figure 15. Body Plan. Longitudinal Sections and Waterlines.

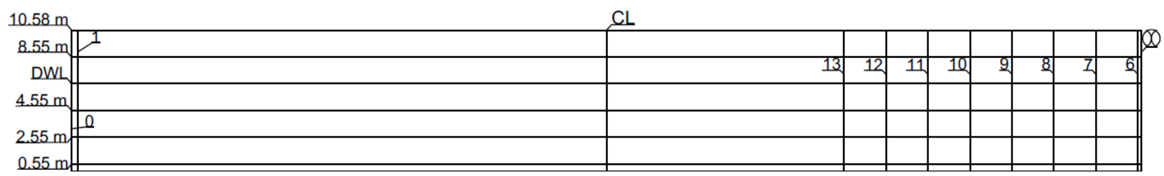


Figure 16. Body Plan. Front View. Transversal Sections and Waterlines.

Table 8. Transversal Sections

Transversal Section	Distance from Aft (m)
0	0
1	5.27
2	10.27
3	17.27

4	24.27
5	31.27
Midship	36.63
6	52.27
7	55.27
8	58.27
9	61.27
10	64.27
11	67.27
12	70.27
13	73.27

The transversal sections were placed in such a way that depicts properly the change in the shape of the barge in the fore extremity.

4.4 Arrangements

4.4.1. Supports

a) On Deck Supports

On the deck of the platform, supports are arranged in such a way to permit the passage of the SPMTs but also to support the floater's weight properly. At first, the supports type chosen was the cement ones. Normally, they have a simple, rectangular shape and the dimensions for the present paper are 6 m x 1.2 m x 1.5 m (L x W x H). The height was chosen to fit the height of the SPMTs. The concrete density was approximated to 2.4 t/m^3. Therefore, the weight of a support is 25.92 tons. Because of the offshore constructions' different forms and weights, different layouts and numbers of supports are needed.

The pressure on the deck is calculated with respect to the number of supports, their weight and considering the weight of the floater's hull. It is aimed to obtain a pressure between 10 and 20 $\left(\frac{t}{m^2}\right)$. In Table 9 the pressure obtained and the number of supports for each structure can be seen.

Table 9. Number of supports and the obtained pressure on the deck

Floater	Weight (t)	Nr. Supports	Total Weight (t)	Covered Area (m^2)	Pressure $\left(\frac{t}{m^2}\right)$
Olav Olsen	13420	114	16366	818	20
Nautilus	2696	30	3473	216	16
WindMoor	4501	55	5926	396	15
Ideol S.P.	7037	80	9111	576	16
Principle Power	2500	33	3355	238	14

One can easily see that the number of supports in the case of Olav Olsen's structure is significantly higher than in the other floaters' situations. If the number is reduced, the pressure on the barge's structure increases too much and leads to a high risk of damage to the launching platform. The solution found for this problem is to use steel supports, sea fastening grillage type. This offers higher structure resistance and less covered area, but it comes with a higher price as well.

In the Principle Power's floater, the number of supports is acceptable. However, the connecting bars cannot be placed on supports, out of structural integrity reasons. Therefore, the steel supports solution is also used in this case as well.

In Figure 17can be seen the arrangements by using cement supports. The number of supports is still too high, which would mean a very high number of sea-fastenings needed. In the end, the decision was changed and the chosen type of supports is the steel one. The form and dimensions of the steel supports can be seen in Figure 18, while in Figure 19 can be seen the steel supports arrangement for all floaters.

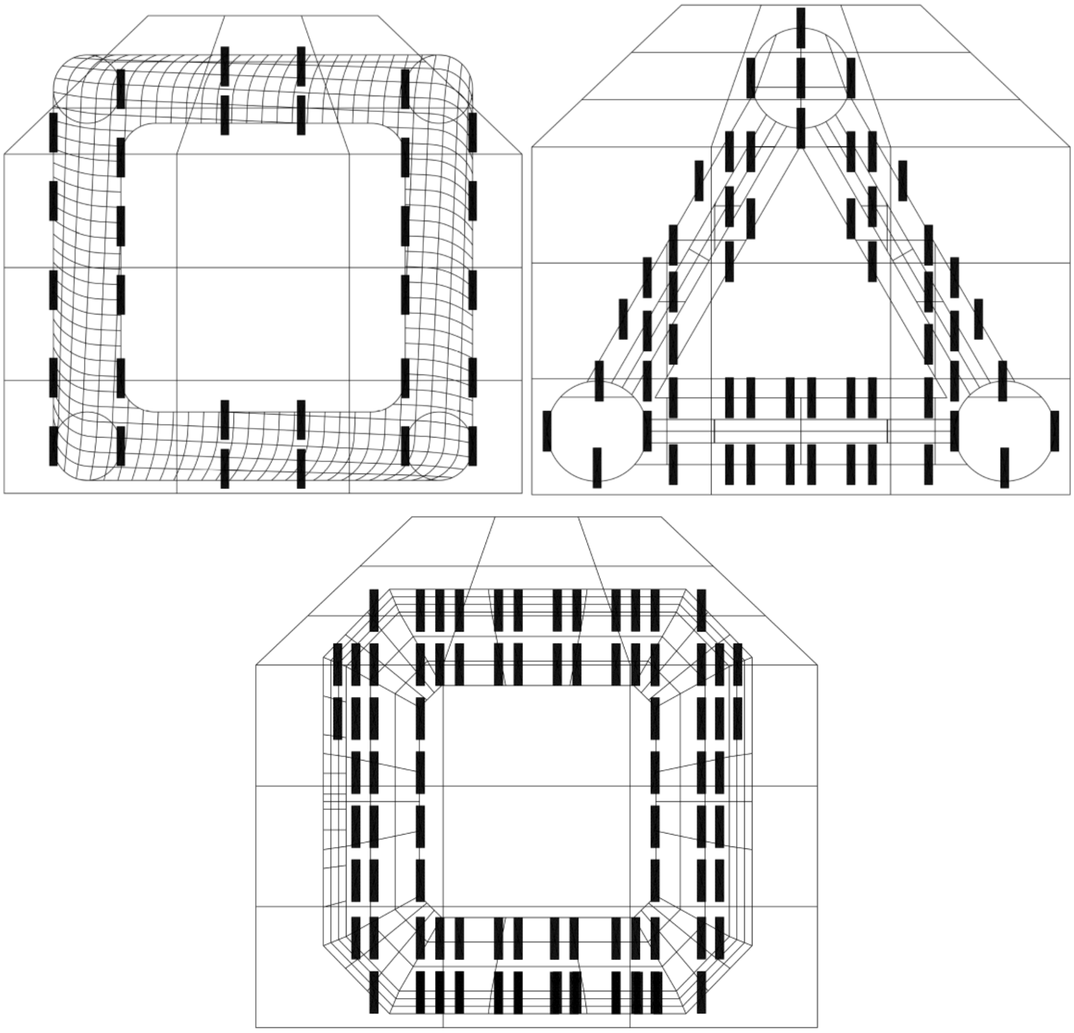


Figure 17. Cement Supports Arrangement for the Floaters Studied

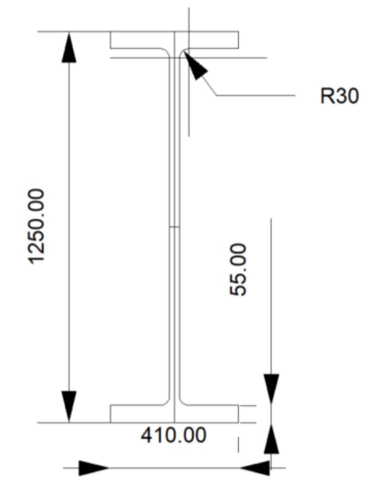
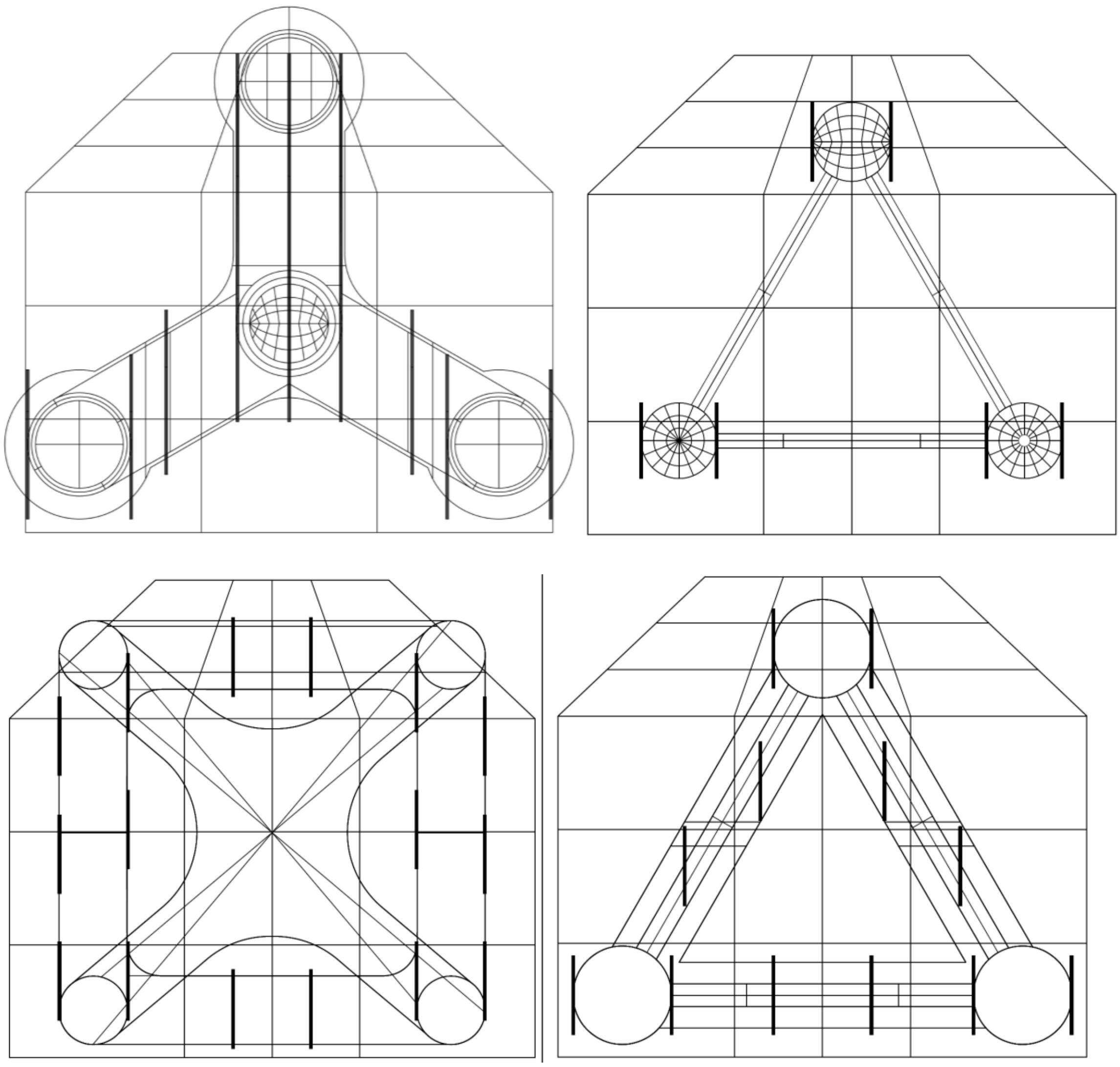


Figure 18. Steel Support Dimensions, in mm.



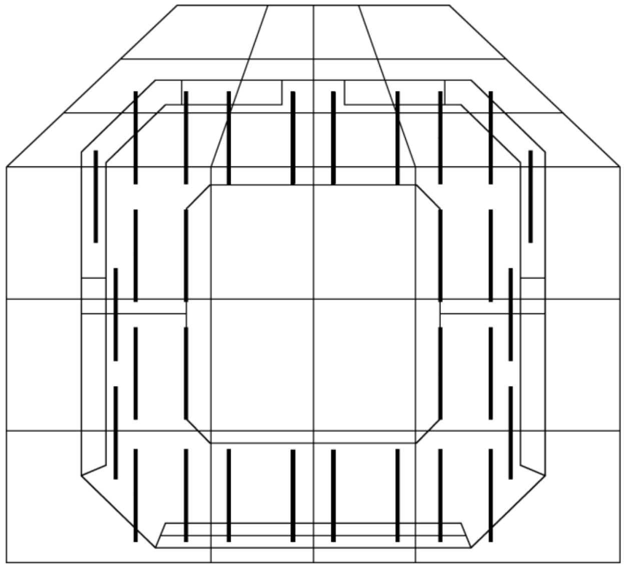


Figure 19. Steel Supports Arrangement for the Floaters Studied

Table 10. Number of supports

Floater	Nr. of cement supports	Nr. of steel supports
Olav Olsen	114	9
Principle Power	33	6
Nautilus	30	16
WindMoor	55	12
Ideol S.P.	80	32

As it can be easily noticed, this choice reduces the number of supports by, at least, half and it also offers a much better resistance of the structure under the load. The number of steel supports was not optimised, however in the case of Ideol, it can be highly reduced.

b) Winch Connection Supports

The barge is connected in total to 3 winches. 2 in the aft part and 1 in the fore. To ensure the integrity of the hull, the plate around the supports is reinforced. The supports are made from the same type of steel as the barge.

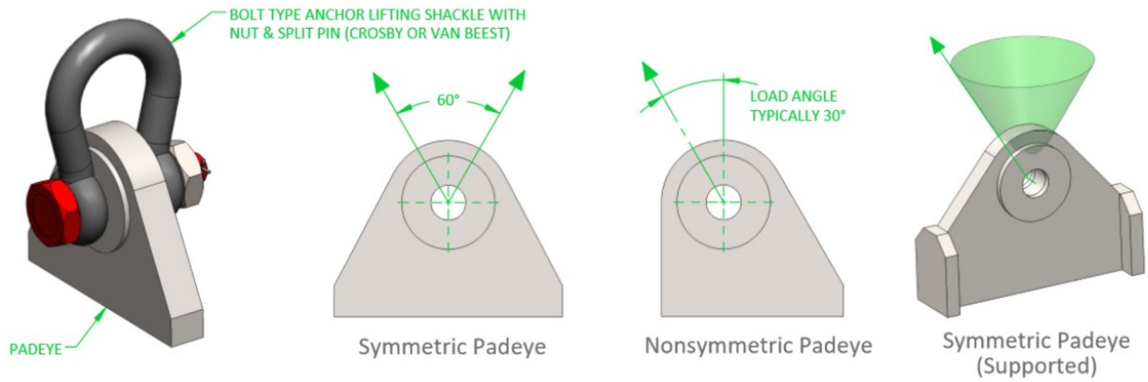


Figure 20. Padeye design from: https://technikdesign.co.uk/index.php/case-studies/padeye-design-guidelines/

4.4.2. Self-Propelled Modular Transporter

A self-propelled modular transporter is a heavy hauler platform with a long array of wheels. SPMTs are used for transporting massive heavy objects. They are used for transport in several industry sectors, from bridge constructions to offshore industry. Its use in the shipbuilding companies increased lately, as it is a cheaper solution than the gantry cranes.

One of the interests of this study, as stated before as well, is to reduce the costs. For this, research regarding the SPMTs manufacturers and the SPMTs they bring to the industry was done. The focus was mostly on the payload capacity. Higher payload capacity means fewer modular transporters needed for moving the floaters. That can also lead to a decrease in the transportation costs. The relevant results after the research are shown inTable 11.

Table 11. SPMTs Manufacturers and Models

SPMTs	Series	Payload (t)	Deadweight (t)	Dimensions (m)	
				L x W	H
Morello	SGD VCP4 ECN	1190	102	23 x 10	1.55 +- 0.7
Cometto	Eco1500 6/4	388	32	11.6 x 2.99	1.51 +- 0.3
TII Group	PPU Z390 + Z180	480/2880/5760	40/ 249/ 500	11.5 x 2.43	1.5 +- 0.3
	K25 H Scheuerle	250	20	9 x 3	1.175 +- 0.875

The choice was the PPU Z390 + Z180 of the TII Group, as it offers very practical options for the arrangement and a very good payload as well. One platform has 8 axle lines and up to 3 platforms can be connected in line.

In Figure 22. SPMTs arrangement for each floater, the arrangement of the SPMTs is shown for each floater considered in the study. For this, it was considered the possible critical points during the transport of the structures. The aim was for safety and stability of the offshore constructions.

Figure 21. SPMTs modules from TII Group, from: https://www.tii-group.com/products/self-propelled-transporters.html

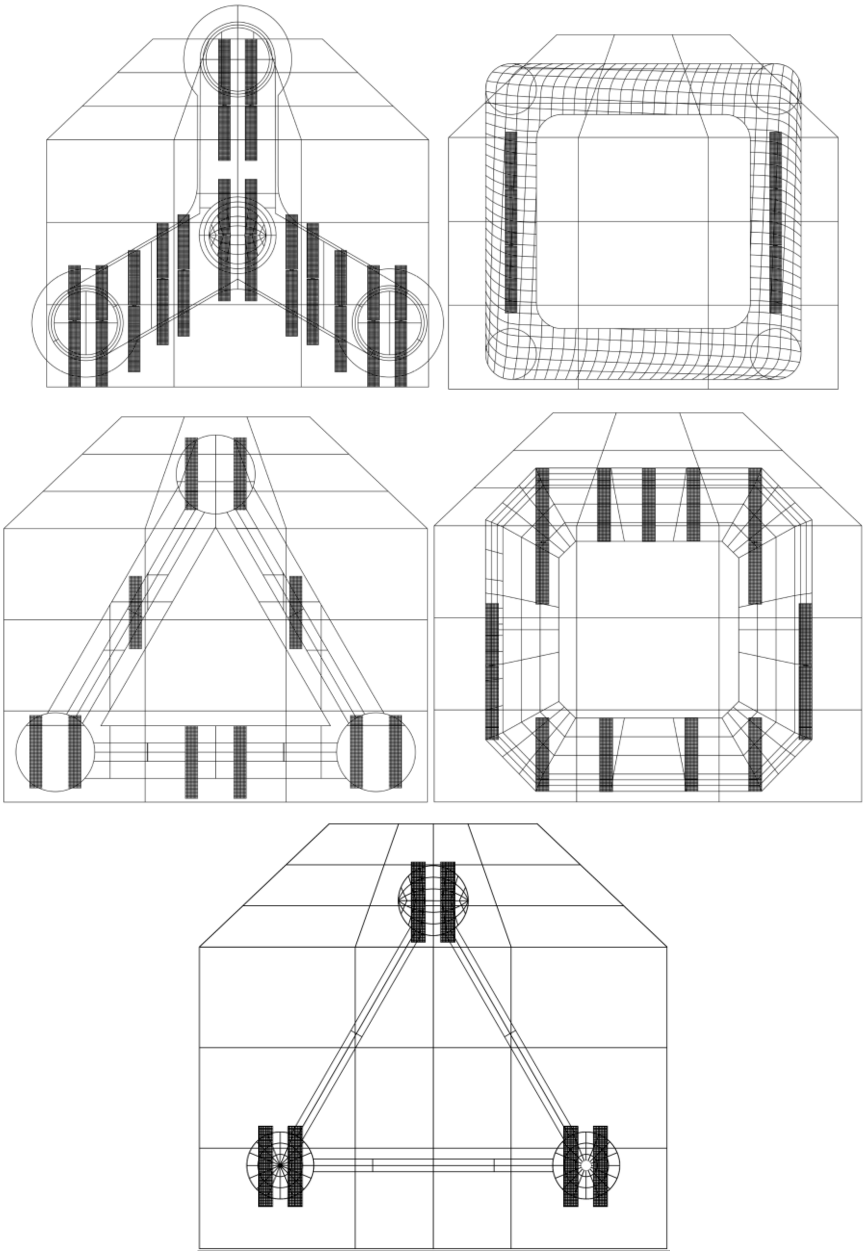


Figure 22. SPMTs arrangement for each floater

The supports and SPMT's arrangements were done with respect to each other. The formations presented in the figures above are the final results after 2 rounds of modifications. The modifications occurred as a result of changing the support type and dimensions.

4.4.3. Tanks Arrangement

The launching platform is submersible. In order to be immersed, the tanks must be filled with water to a previously defined level and in such a manner that will ensure that the trim and heel are equal to 0, or as close as possible. Of course, depending on the process's steps, the need for trim or heel may arise, but in that case, it will be a controlled inclination of the launching platform. Because the necessity for ballasting and de-ballasting will occur, a pump room is needed. For the design of this room, an inner „deck" was placed under the main deck at 2.5 m, in Tank 11. This way, the design shall provide enough space for the machineries and enough floodable space in the barge, to submerge it. In Figure 23, Figure 24 and Figure 25 can be seen the Bottom, Top and Side views of the tanks. From the figures presented below, it is obvious that there are different dimensions and volumes throughout the tanks. Therefore, this data is shown in Table 12, for a better understanding of the model.

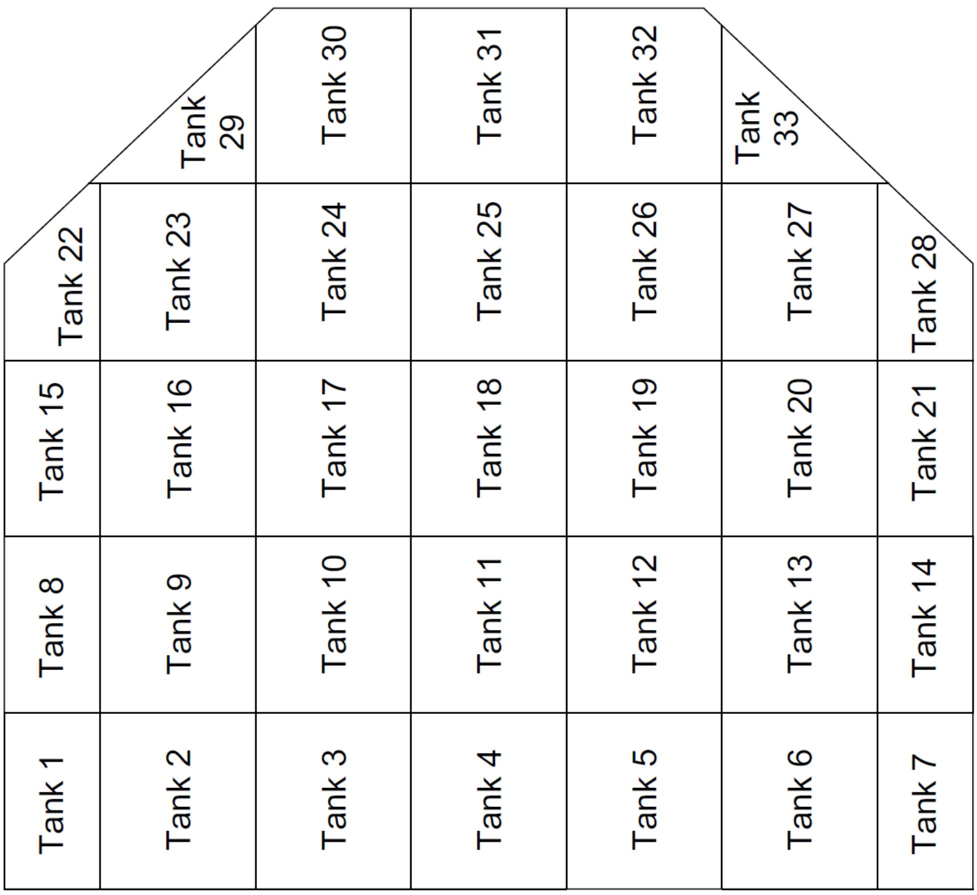


Figure 23. Tanks Arrangement. Bottom View

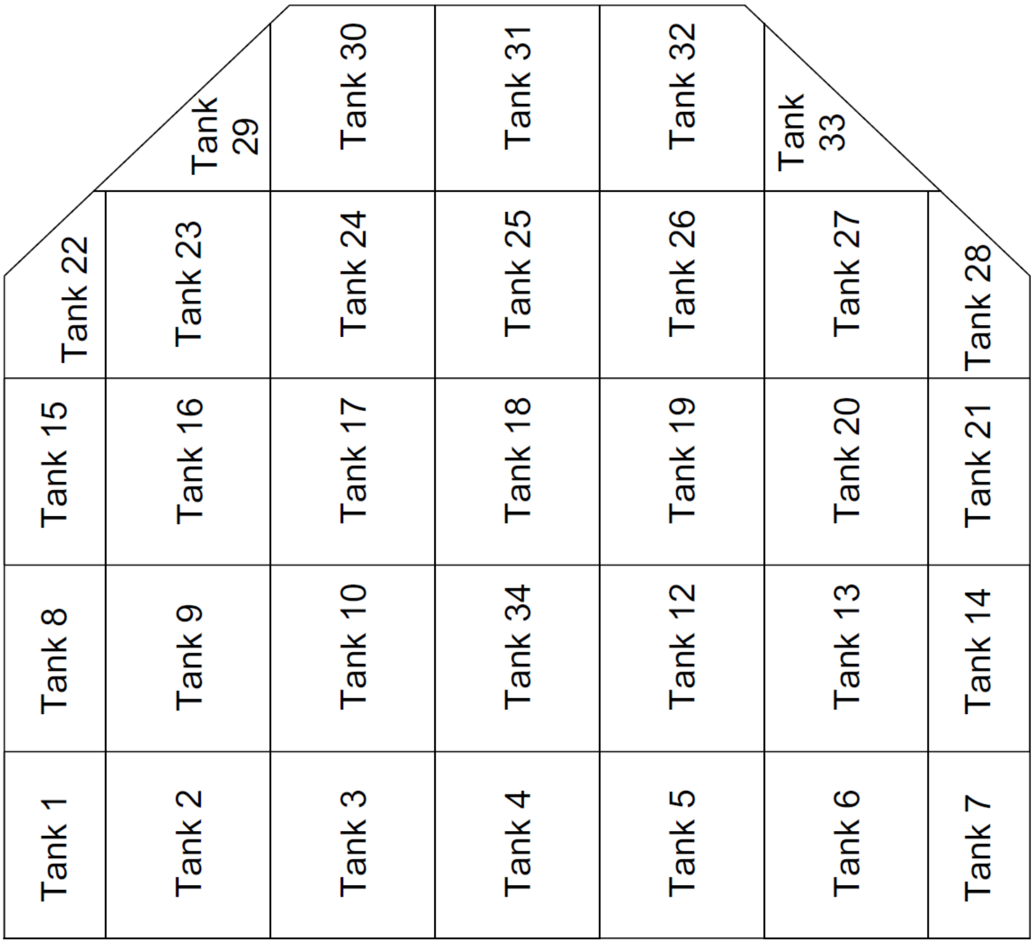


Figure 24. Tanks Arrangement. Top View

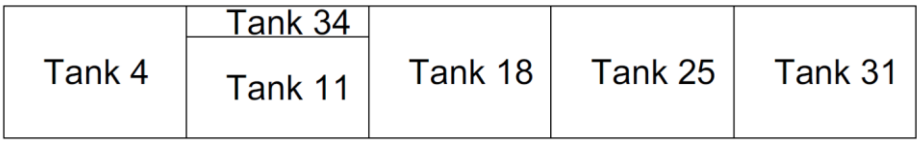


Figure 25. Tanks Arrangement. Side View

Table 12. Tanks Dimensions

Tanks Number	Length x Width x Height	Volume [m^3]
1, 7, 8, 14, 15, 21	14.66 x 7.95 x 10.58	1223,2
2, 3, 4, 5, 6, 9, 10, 12, 13, 16, 17, 18, 19, 20, 23, 24, 25, 26, 27	14.66 x 12.92 x 10.58	1981.65

22, 28	8/14.66 x 7.95 x 10.58	981.919
29, 33	13.2 x 13.9 x 10.58	952.161
30, 32	14.6 x 12.92 x 10.58	1962.11
31	14.6 x 12.92 x 10.58	1973.461
11	14.7 x 12.92 x 8.08	1515.106
34	14.7 x 12.92 x 2.5	400.504

4.4.4. Deck & Tank Access Openings

The access to the Pump Room is through 2 openings in the main deck. The dimensions were chosen to provide enough space for the person to pass without impediments. Around the openings, the structure is reinforced, to prevent cracks or even worse, the failure of the plate. The position is shown in Annex 1 and the details of the opening can be seen in Figure 26. The plate thickness is of 13 mm.

There is a hatch in the deck, above the pump room. It is done for the necessity of changing a pump or the pipes of the installations. The opening offers enough space for the equipment to be transferred inside the room without any problems. On the hatch door, there is also a small hatch. Through it, a hose is pulled and connected to the pump hatch installed on the tank 34's floor. It is used for filling the tank 11 with water.

The access into the tanks is done through a watertight door. The main door is placed in the aft of the pump room and gives way to vertical stairs. Each tank has at least 1 watertight door for the access, for the checks before starting the load-out and launching processes.

In Figure 29 and Figure 30 the doors are stairs depicted in brown, for better contrast.

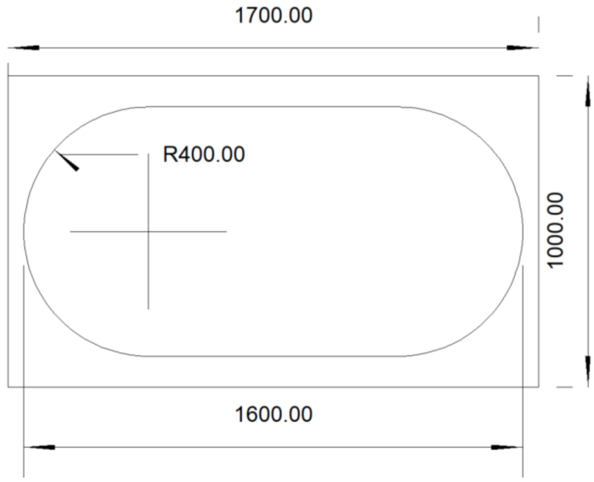


Figure 26. Pump Room Manhole. Dimensions in mm

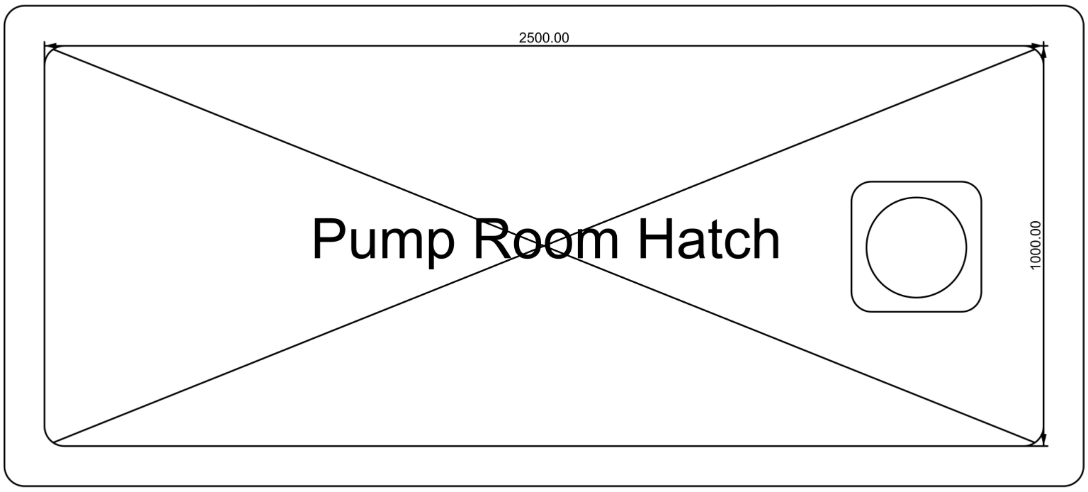


Figure 27. Pump Room Hatch Door. Dimensions in mm

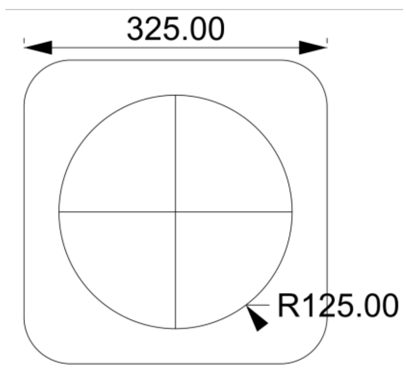


Figure 28. Tank Hatches for ballasting. Dimensions in mm

Figure 29. View from the Aft

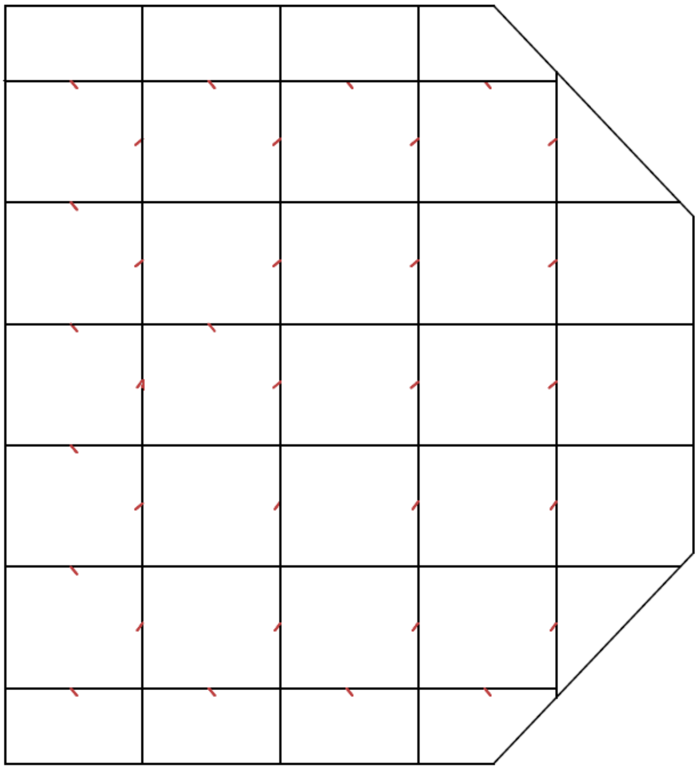


Figure 30. Top View of the Access Openings in tanks

4.4.5. Pumps

A pump is the device which moves either liquids or gases by using mechanical action. The latter is normally converted from electrical into hydraulic energy. There are several types of pumps onboard, a few of them being used for machinery cooling, supply of fluid for different operations, fire and sanitary supply and domestic freshwater supply. They are also classified as electrical pumps or diesel pumps.

After discussing with the client and checking the solutions available, the decision is made for electrical water pumps. Considering that the barge won't leave the port and the pumps can be connected to a power source on the quay through isolated cables, there is no need to set one up aboard. The entire pumping system is controlled remotely.

In Table 12, the volume of each tank is shown. By summing up, the total volume obtained is of 56695 m^3, out of which 56294.3 m^3 (the values are taken from Maxsurf, for a higher accuracy of the results) are for ballasting. In the case of a launching, when it needs to be submerged, the barge must be filled up. Here, 2 situations are possible. Either use pumps with a medium capacity for a longer number of hours or use high-capacity pumps for a significantly reduced period. However, the latter solution is adopted since it is more economical for the load-out and the launching operations to be done faster.

The tanks are classified into 2 classes: *gross ballast tanks* and *fine-tuning tanks*. Some tanks are ballasted completely by using portable pumps. This represents the "*gross ballast"* and the water level in those tanks won't suffer changes throughout the operations.

The submerging and the de-ballasting, trim and heel modifications are controlled through 14 tanks. These tanks are referred to as *"fine-tuning"* because all the operational steps are done through the remote control of the ballast levels in them.

The design concept for the pump system has 7 main pumps in the pump room and 1 back-up pump. Considering the dimensions and the geometry of the barge, it is obvious that the trim is more sensitive than the heel. The controlled tanks are situated longitudinally, close to the centerline. In Table 13 is shown the pump – tanks connection.

Table 13. Pump – Tanks correlation

Pump	Tanks
1	2 – 6
2	3 – 5
3	8 – 14
4	10 – 12
5	17 – 19
6	24 – 26
7	30 – 32

Based on the timeline and on the simulations done for the launching and load-out operations, it is recommended to use pumps with a capacity of 6000 m^3/h. A lower capacity, results in a longer duration of the operations.

4.4.6. Piping Lay-out

The pipes aboard serve different roles. While some are used for water intake and discharge, others are used for ventilation. Therefore, in this sub-sub chapter, the concept for the air system and for the pumping system shall be presented below.

a) Air System

During the ballasting of a tank, the pressure inside the accommodation must remain as constant as possible. For this, the air must have a way out of the tank, so the void can be filled. In this sense, each tank will have installed above the deck an air vent. (PRES VAC)

Figure 31. Air vent head type M4P with locking system, from: https://www.gomg.dk/presvac/product/air-vent-head-type-m4/

The de-ballasting is done by spilling the water in the tanks back into the sea and filling the void with air. In this sense, from the dock and through flexible pipes or umbilicals, compressed air is pushed into the air system pipes. However, according to the rule 4.3.4.3, the umbilicals used for air pressurisation of submerged vessels have to be connected to valves at the vessel's tanks. The valves at the end of the pipes are then pushed open by the pressure of the air and the air flows freely into the tanks. To ensure that this process can't be stopped by a failed valve, each pipe end has 2 valves through which the flow can enter the room.

In the Figure 32, it can be noticed the lay-out of the air system. The magenta lines represent the air pipes, the circles are the air vent heads on the deck and the structures on the side of the ships represent the system through which the flexible pipes will be attached to the air system onboard.

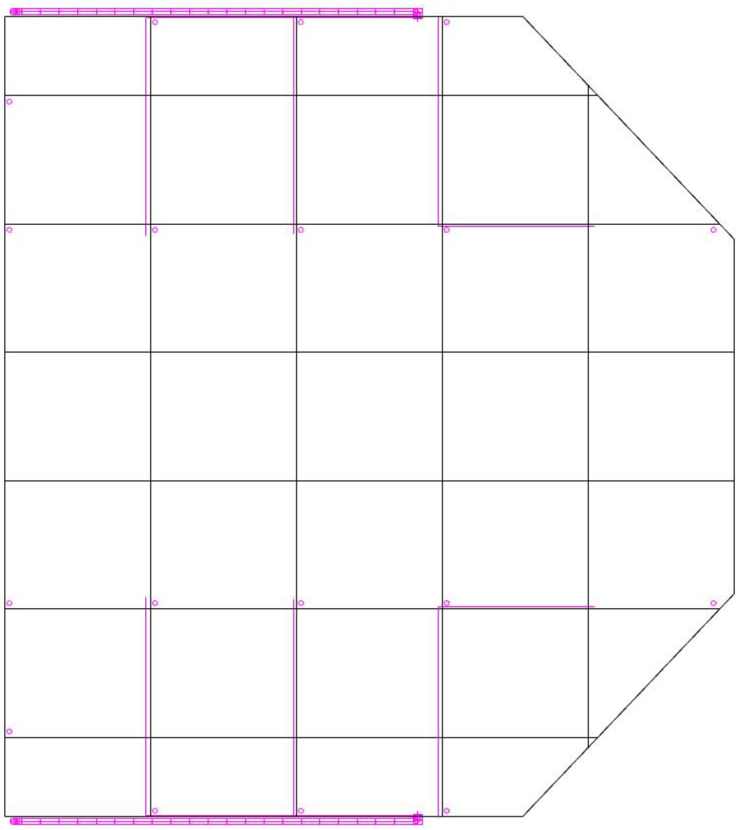


Figure 32. Top View of the Air System

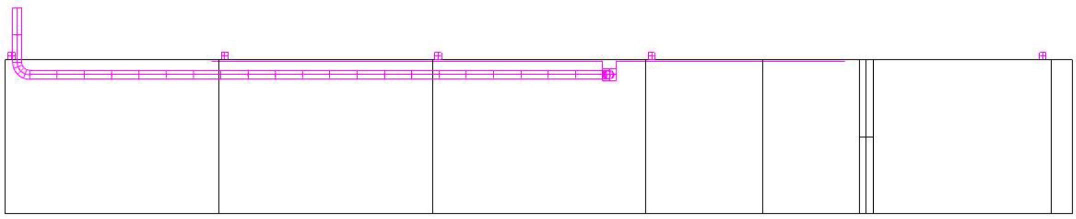


Figure 33. Side View of the Air System in the Pump Room and Tank 11

b) Ballast system

In Figure 34, Figure 35 and Figure 36, in gold lines, can be noticed the ballast system. The rectangular forms represent the vertical pumps while the lines represent the piping system. As it can be seen, the spare pump is connected to the installations of both main pumps. In the case that one pump fails, the spare pump takes its place.

The discharge pipes are installed at the top of the tanks, under the deck. The suction pipes, that enable the pumps to take water from the sea and to transfer it into tanks, are installed vertically. The whole piping system was done in such a way that the friction loss is reduced. Deciding the piping diagram is an iterative process, trying to find the most optimal solution. For the system presented below, 3 iterations were needed and optimisations can still be made. However, this is not the goal of the current study.

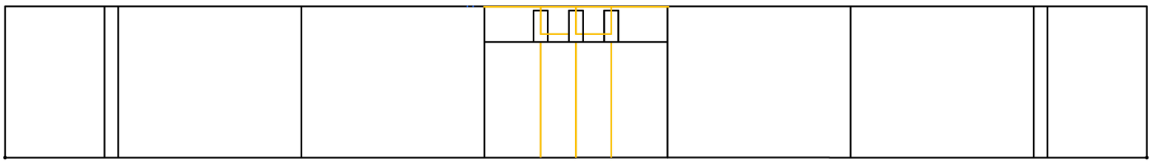


Figure 34. Front View of the Ballasting System

Figure 35. Side View of the Ballasting System

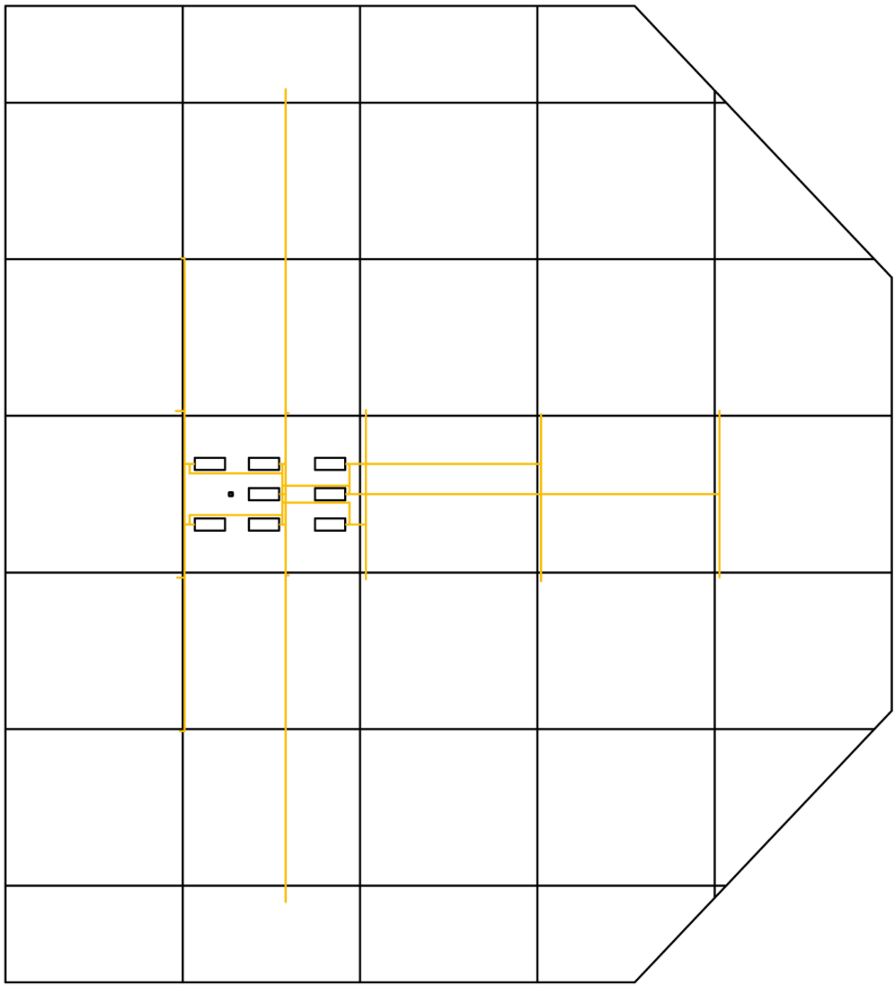


Figure 36. Top View of the Ballasting System

c) De-ballast system

The de-ballasting pipes are depicted in blue. The lay-out is rather similar as it was the option with the least pressure lost found at the moment. The pipes in this case are situated on the lower part of the tanks, close to the bottom. This way, water can be evacuated until the barge reaches the desired draft.

In the Figure 37, Figure 38 and Figure 39, the system is shown from all of the points of view and it can be seen that the pump is connected to the piping system and to the bottom of the barge. During the de-ballasting, the system is reversed and the pipe connected to the bottom becomes the discharge pipe while the pipes inside the tanks become suction pipes.

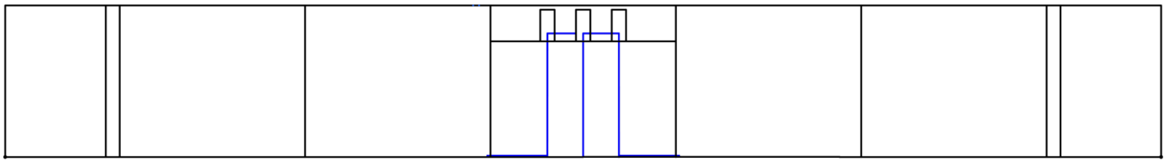


Figure 37. Front View of the De-ballasting System

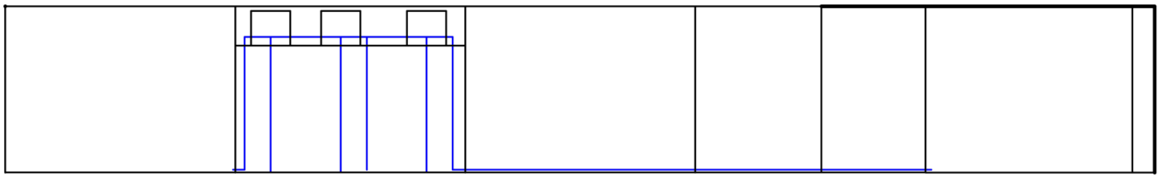


Figure 38. Side View of the De-ballasting System

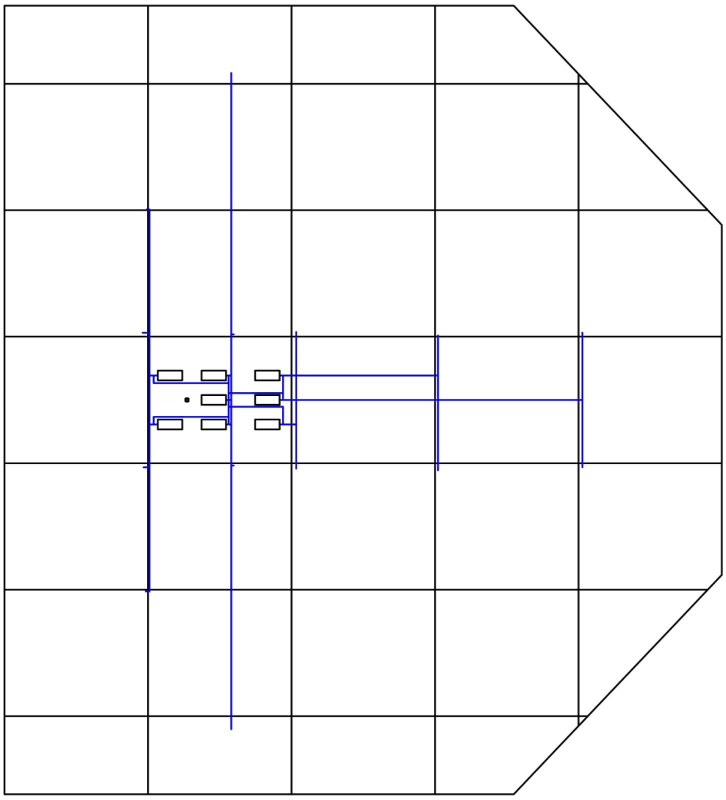


Figure 39. Top View of the De-ballasting System

4.4.7 General Arrangement

To sum up the previously shown arrangements and details, in the Annexes 1 and 2 are presented the General Arrangements of the Main Deck and of the Pump Room.

4.5 Structure

The structure of a ship is probably the most important part inside a ship. The global and the local strength of the vessel depends on it. However, in order to calculate it accurately and to make the proper decisions regarding the material, a few steps must be done previously. First, the class notation has to be decided so the naval architect will know what rules to follow. After, the static and dynamic pressures are calculated depending on the load case. In this type of calculations, the vessel is assumed to be a beam. Considering the loads, their type and their location on board, the bending moment and shear force that occur in the ship are calculated.

The structural elements, primary, secondary and tertiary, must be chosen in such a way that the barge has a resistance higher than the maximum Bending Moment (BM) and Shear Force (SF) obtained.

4.5.1 Class Notation

The Classification Societies assign "Class notations" to vessels, to help the naval architects in determining which rule requirements are applicable for their assignment.

A construction symbol must be assigned. DNV has 2 such symbols, one for vessels that are built under the supervision of DNV and one for the vessels built under the supervision of another class society that is recognized by DNV. The barge discussed in this study is going to be built under the DNV's supervision, therefore the construction symbol is "✠".

The main class notation that is assigned to ships with hull, systems, equipment and machinery that follows the class's requirements is **1A**. The entire design and systems were done according to the rules, therefore it is expected the same main class notation to be assigned.

In part 1 Chapter 2 Section 3 of the DNV rules, the Ship type notations are presented. According to the classifications provided by the class, the present project enters in the **Barge** class. However, for the scantling calculations, the rules for the „Semi-submersible heavy transport vessel" class are considered.

In Section 4, the class offers additional class nations that may or may not be mandatory. For the launching platform designed in the current paper, the cargo on the deck is very heavy. This requires a strengthened deck. According to the rules, the additional class shall be added, **DK**.

In Section 5, depending on the service area restrictions, the ship receives one more notation. The semi-submersible barge designed in this study won't leave the port, therefore it will receive the Service area notation **RE** (enclosed waters). As shown in the rules, that means that the corresponding significant wave height, H_s, in meters, is calculated as shown in Equation (1).

$$H_S = 0.4C_w \quad (1)$$

Where C_w is the wave coefficient. This coefficient is calculated and shown in the following pages.

In conclusion to this sub-chapter, the entire notation of the launching platform shall be **„✠ 1A Barge DK RE".**

4.5.2 Pressures and loads

The calculations and analysis presented were done just for the strength assessment. Static and dynamic load cases were considered and for accurate results of the BM and SF, Maxsurf Stability was used. The process is an iterative one and different drafts were considered, to obtain the worst case possible (highest BM and SF).

The loads that act on the barge can be classified into four categories:

- Hull Girder Loads
  - Still Water Loads
    - Vertical BM
    - Vertical SF
  - Dynamic Loads
    - Vertical BM
    - Vertical SF
    - Horizontal BM

- External Loads
    - Hydrostatic Pressure, P_S
    - Hydrodynamic Pressure, P_W
- Internal Loads
    - Static Liquid Pressure, P_{ls-3}
    - Dynamic Liquid Pressure, P_{ld}
- Wheel Loads

a) Still water hull girder Loads

The barge is not going at sea, therefore the calculations begin with the ***Vertical Bending Moment***. For the preliminary design stage, the permissible still water bending moments for both sagging and hogging in harbour water condition are recommended to be taken equal to the ones in seagoing condition. The unit is kNm.

Hogging conditions:

$$M_{sw-h-min} = f_{sw}[171C_w L^2 B(C_B + 0.7)10^{-3} - M_{wv-h-mid}] \quad (2)$$

Sagging conditions:

$$M_{sw-s-min} = -0.85 f_{sw}[171C_w L^2 B(C_B + 0.7)10^{-3} + M_{wv-s-mid}] \quad (3)$$

Where:

- f_{sw} is the distribution factor along the ship length
- $M_{wv-h-mid}$ and $M_{wv-s-mid}$ are the vertical wave bending moments for strength assessment amidships in the hogging respectively sagging conditions
- C_B = 0.919

The values for f_{sw} are calculated and presented in the Table 14. The graph shown in Figure 40 depicts the evolution of the factor.

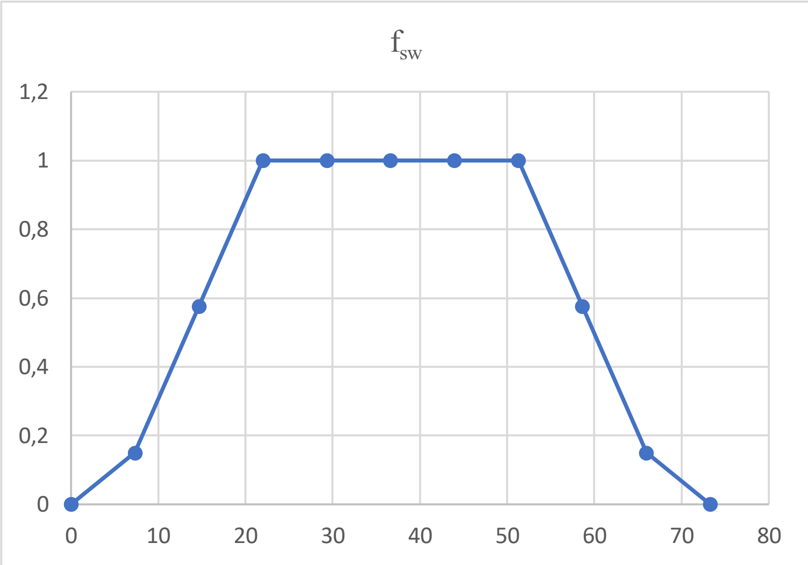


Figure 40. The distribution factor along the ship length, f_{sw}. Graph

Table 14. The distribution factor along the ship length's values for bending moment

f_{sw}	x[m]
0	0
0.15	7.327
0.575	14.654
1	21.981
1	29.308
1	36.635
1	43.962
1	51.289
0.575	58.616
0.15	65.943
0	73.27

The vertical still water shear force can be negative or positive. It is calculated as shown in Equations (4) and (5) , with respect to the absolute maximum of the bending moments in hogging and sagging conditions and it is expressed in kN.

$$Q_{sw-pos-min} = \frac{5\, f_{qs} M_{sw-min}}{L} \tag{4}$$

$$Q_{sw-neg-min} = \frac{-5\, f_{qs} M_{sw-min}}{L} \tag{5}$$

Where:

- M_{sw-min} is the absolute maximum mentioned above
- f_{qs} is the distribution factor along the ship length.

Its values are shown in Table 15 and the evolution is depicted in Figure 41.

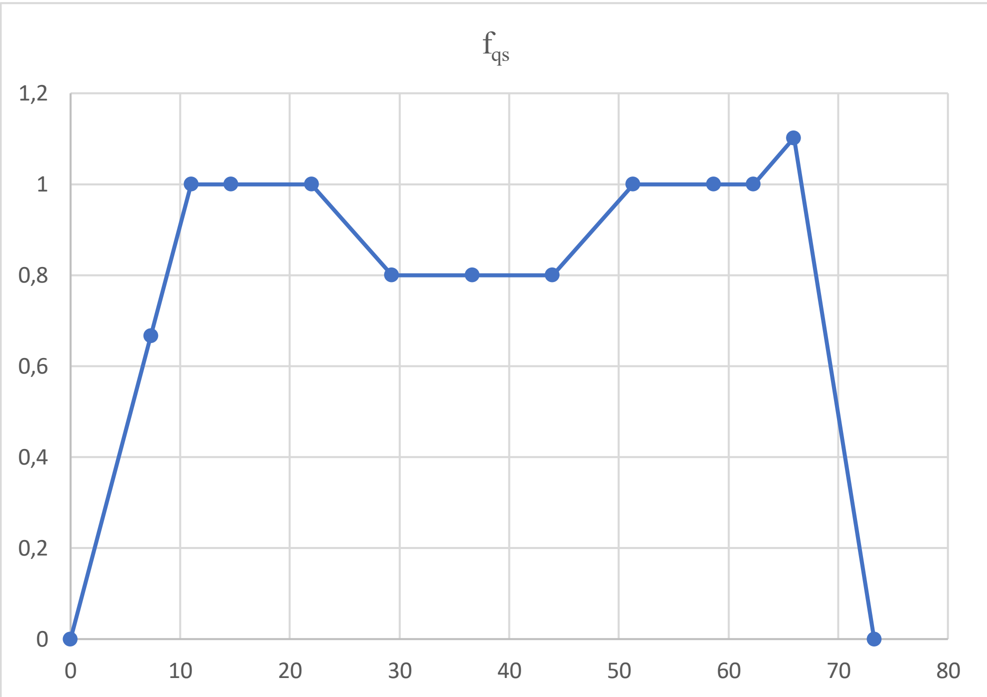


Figure 41. The distribution factor along the ship length, f_{qs}. Graph

Table 15. The distribution factor along the ship length's values for shear force

f_{qs}	x[m]
0	0
0.67	7.327
1	10.991
1	14.654
1	21.981
0.8	29.308
0.8	36.635
0.8	43.962
1	51.289
1	58.616
1	62.279
1.1	65.943
0	73.27

After doing the calculations, the values obtained for the still water hull girder loads are shown inTable 16.

Table 16. Still Water Loads. Results

Load	Value
$M_{sw-h-min}$	372111.91 [kNm]

$M_{sw-s-min}$	-309902 [kNm]
M_{sw-min}	372111.91 [kNm]
$Q_{sw-pos-min}$	20313.45 [kN]
$Q_{sw-neg-min}$	-20313.45[kN]

b) Dynamic hull girder Loads

As by the rules, the ***vertical wave BM***, at any longitudinal position, is calculated as:

Hogging condition:

$$M_{wv-h} = 0.19\frac{f_R}{0.85}f_{nl-vs}f_m f_p C_w L^2 B C_B \quad (6)$$

Sagging condition:

$$M_{wv-s} = -0.19\frac{f_R}{0.85}f_{nl-vs}f_m f_p C_w L^2 B C_B \quad (7)$$

Where:

- f_{nl-vh} = coefficient considering non-linear effects applied to hogging = 1
- f_{nl-vs} = coefficient considering non-linear effects applied to sagging = $0.5789\frac{C_B+0.7}{C_B}$
- f_R = factor related to the operational profile = 0.85
- f_p = 0.8
- f_m = 1

The ***vertical wave shear force*** is obtained by using the equations (8) and (9).

$$Q_{\mathrm{wv-pos}} = 0.52 f_{q-pos} f_p C_w L B C_B \quad (8)$$

$$Q_{wv-neg} = -(0.52 f_{q-neg} f_p C_w L B C_B) \quad (9)$$

Where:

- f_{q-pos} is the distribution factor along the ship length for positive wave shear force

- $f_{q\text{-}neg}$ is the distribution factor along the ship length for negative wave shear force

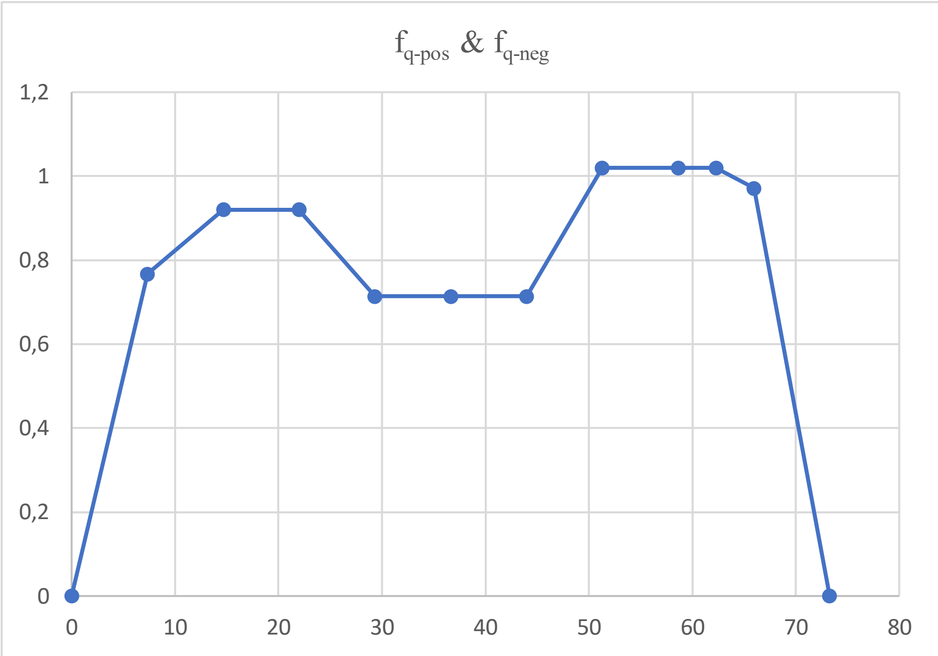


Figure 42. The distribution factor along the ship length for positive and negative wave shear force.

The horizontal wave bending moment is calculated as well.

$$M_{wh} = f_p\left(0.31 + \frac{L}{2800}\right) f_m C_w L^2 T_{LC} C_B \quad (10)$$

The results obtained for the dynamic water hull girder loads are shown in Table 17.

Table 17 . Dynamic Water Loads. Results

Load	Value
$M_{wv\text{-}h}$	378967.55 [kNm]
$M_{wv\text{-}s}$	-386488.8 [kNm]
M_{wh}	88044 [kNm]
$Q_{wv\text{-}pos}$	10104.96 [kN]
$Q_{wv\text{-}neg}$	-10104.96 [kN]

c) Hydrostatic Pressure

The hydrostatic pressure, or sea pressure, is calculated at any load point along the height of the barge. Because the barge in discussion is semi-submersible and the need to immerge it will occur, the load case draft considered is decided with respect to the water depth in the port. The results presented are presented inTable 18.

Table 18. Hydrostatic Pressure

Height [m]	Pressure [kN/m^2]
0	165.912
1	155.856
2	145.8
3	135.75
4	125.69
5	115.635
6	105.58
7	95.525
8	85.47
9	75.414
10	65.36
10.58	59.53

d) Hydrodynamic Pressure

The hydrodynamic pressures are normally calculated for each dynamic load case. However, the length of the barge is under 90 m. For this situation, the rule applied is 1.3.9, from Part 3 Chapter 4 Section 5. It mentions that for ships with L≤90 m, the ***envelope pressure*** shall be used instead of the hydrodynamic pressures for the dynamic load cases. The envelope pressure is obtained as the maximum between $P_{ENV\text{-}BS}$ and $P_{ENV\text{-}HS}$. The two terms are calculated as shown in the equations provided below.

$$P_{ENV-BS} = f_r f_3 \left(2 + \frac{55}{L}\right) f_{yz} C_w \tag{11}$$

$$P_{ENV-HS} = 5 f_r f_4 f_5 \left(1 - \frac{C_B}{3}\right) C_w \sqrt{\frac{1.2L - 15}{L}} \tag{12}$$

The external pressure is equal to the sum between the hydrostatic and hydrodynamic pressure. In theTable 19, the results for the external pressure on the deck, at the middle of the height of the ship and at the bottom are shown.

Table 19. External Pressure. Results

Component	Pressure [kN/m^2]
$P_{s\text{-}deck}$	59.53
$P_{s\text{-}middle}$	112.72
$P_{s\text{-}bottom}$	165.912
P_w	39.17
$P_{ex\text{-}deck}$	98.7
$P_{ex\text{-}middle}$	151.89
$P_{ex\text{-}bottom}$	205.082

e) Static Liquid Pressure

For the normal operations at harbor, the static pressure is calculated as

$$P_{ls-3} = \rho_L g (z_{top} - z) + P_0 \tag{13}$$

Where:

- ρ_L = the density of the liquid inside the tanks (sea water) = 1.025 t/m^3

- z_{top} = Z coordinate of the highest point of the tank = 10.58 m
- z = Z coordinate of the load point with respect to the reference coordinate system = 6.569 m
- P_0 = static pressure = 0.3L – 5 kN/m^2

f) Dynamic Liquid Pressure

As in the hydrodynamic pressure's case, the method of calculation is slightly different than normal, because of the length. The dynamic liquid pressure is obtained with respect to the envelope accelerations and the factors k_1 and k_2. It is also taken as the maximum of the equations (14)-(17).

$$P_{ld} = \rho_L\left[0.6a_{x-env}|x_0 - x| + 0.6a_{y-env}|y_0 - y| + 0.6a_{z-env}|z_0 - z|\right] \tag{14}$$

$$P_{ld} = \rho_L k_1[a_{x-env}|x_0 - x|] \tag{15}$$

$$P_{ld} = \rho_L k_2\left[a_{y-env}|y_0 - y|\right] \tag{16}$$

$$P_{ld} = 15 \tag{17}$$

Where:

- x_0, y_0, z_0 = x, y, z coordinates in the middle of the upper boundary of the tank
- k_1 = 2
- k_2 = 1.2

In the Table 20 can be seen the results for P_{ls-3}, P_{ld}, a_{x-env}, a_{y-env}, a_{z-env} and $P_{int.}$

Table 20. Internal Pressure. Results

Component	Value
a_{x-env}	1.83 m/s^2
a_{y-env}	8.12 m/s^2

a_{z-env}	0.633 m/s^2
P_{ls-3}	57.31 kN/m^2
P_{ld}	15 kN/m^2
P_{int}	72.31 kN/m^2

g) Wheel loads

The load-out process is done by transferring the floater onto the barge by using SPMTs. That means that pressure from the SPMTs will also occur. Therefore, the pressure that will act onto the deck must also be considered. For normal operations at harbor, the pressure is calculated as:

$$P_{wl-1} = \frac{Q}{n_0 a_1 b_1}\left(g + \frac{3}{\sqrt{Q}}\right)10^6 = 29.365\ kN/m^2 \qquad (18)$$

Where:

- Q = maximum axle load
- n_0 = number of loads areas on the axle
- a_1 = extent, in mm, of the load area parallel to the stiffeners
- b_1 = extent, in mm, of the load area perpendicular to the stiffeners

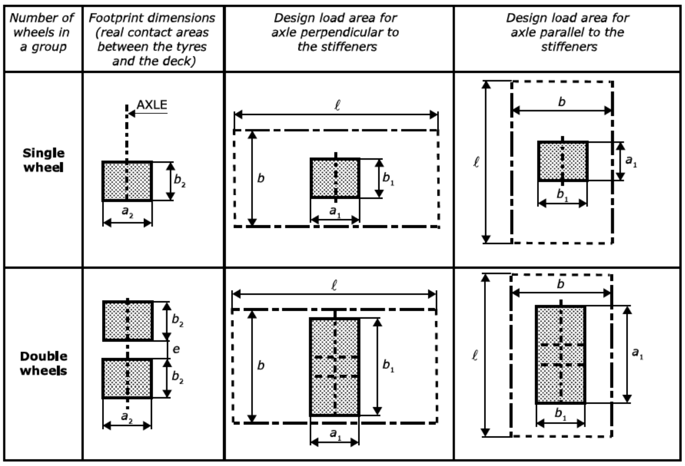


Figure 43. Definition of load area from DNV rules, Pt. 3 Ch. 10

4.5.3 Scantling Requirements

After calculating the pressures and the loads that the barge must withstand, the structure's properties are decided. Properties such as material, thickness, profile and dimensions of the supporting members. The Classification Societies usually give formulas to calculate the minimum thickness that should be adopted and the maximum shear and bending stresses. However, the final thickness is obtained with respect to the section modulus of the ship and to the shear and bending stresses' limits.

As shown previously, the pressures that act on the deck, on the bottom and on the lateral side of the barge are different. Therefore, the requirements for the plating and supporting members that are under the deck, on the bottom of the launching platform or on the side are different as well. In this part, the results obtained are presented.

The process of determining the proper values is an iterative one. For the results presented in the following pages, 4 iterations were needed.

a) Material Mechanical Properties

The material chosen for the structure, as well as the hull itself, is Steel. Depending on the choice of on-the-deck supports, draft and on the load on board (the SPMTs, the floater, the number of supports on the deck and the material they are made of), there are 2 possible choices for the steel grade.

In the worst combination of draft – support type and number – load on board, the Shear Force in Sagging conditions, goes up to 28959 kN. In this case, the second choice is the safer choice. However, all the design decisions were done so that situation can be avoided.

Both steel grade options are presented in Table 21.

In the present paper, the Steel grade A40 was chosen, as the results for the shear and bending stresses are below the permissible maximum limit.

Table 21. Mechanical Properties of the material

Steel grades	R_{eH}	R_m	k
A40-D40-E40-F40	390	510-660	0.68
A47-D47-E47-F47	460	570-720	0.62

b) Deck plating. Net thickness.

In the Part 3 Chapter 10 Section 5, DNV gives the formula for calculating the minimum of the next thickness, for the deck plating that's subjected to wheel loading. The value obtained is expressed in mm.

$$t = \frac{77.4\alpha_p\sqrt{k_w cbP}}{\sqrt{mC_a R_{eH}}} = 7.868 \text{ mm} \tag{19}$$

Where:

- α_p = coefficient = 0.8
- k_w = coefficient = 0.57
- c = load breath = 2430 mm
- b = extent of the load area perpendicular to the stiffeners, as seen in Figure 35 = 2430 mm
- P = design pressure calculated in equation 18 = 29.365 kN/ m^2

- m = bending moment factor = 8.64
- C_a = permissible bending stress coefficient for plate = 1.8
- R_{eH} = minimum specified yield stress = 390 N/mm^2

c) Stiffeners Minimum net section modulus

As per the rules, the net section modulus of the deck beams and longitudinals subjected to wheel loading must be at least:

$$Z = \frac{Pk_Z cdl_{bdg}}{mC_s R_{eH}} 10^{-3} cm^3 = 670939 cm^3 = 0.67 m^3 \qquad (20)$$

Where:

- k_z = coefficient dependent on the $\frac{b_1}{b}$ raport = 1
- d = load length = 2882.5 mm
- l_{bdg} = effective bending span = 300 mm
- C_s = permissible bending stress coefficient for the design load set being considered = 0.85

d) Web Plating Minimum thickness

The thickness of the deck stiffener's web is calculated as shown in equation(21). The value is a minimum, therefore it can be increased, as per the design need.

$$t_w = \frac{f_{shr} Pk_Z cd}{d_{shr} C_t \tau_{eH}} 10^{-3} mm = 7.95\ mm \qquad (21)$$

Where:

- f_{shr} = shear force distribution factor = 1
- d_{shr} = effective web depth of stiffener = 127 mm
- C_t = permissible shear stress coefficient for the design load set being considered = 0.9

The results presented until now are requirements about the deck and the stiffeners under the deck, as they have more loads acting on them. Further, the requirements of the rules in Part

3 Chapter 6 are presented and calculated. For this, the permissible maximum limits for the longitudinal and the shear stresses are shown in Table 22.

Table 22. Maximum permissible longitudinal and shear stresses

Stress	Value [N/mm^2]
$\sigma_{hg\text{-}perm}$	301.47
$\tau_{hg\text{-}perm}$	176.5

e) Plating minimum thickness requirements

In Table 23can be seen the values obtained as minimum required. They are function of the barge's length and of the material factor, k.

Table 23. Minimum plating thickness

Element		Thickness [mm]
Shell	Keel	8.02
	Bottom	6.6
Sideshell	From the upper end of bilge plating to T_{SC} + 4.6 m	6.15
	Elsewhere	4.6
Deck	Strength Deck	5.7
Inner Bottom		5.7
Bulkheads	Water Ballast tanks	5.41

For the plating subjected to the lateral pressures, the minimum thickness is calculated as shown in the equation(22). However, this time the values for α_p, b and C_a are different than before.

$$t = 0.0158\, \alpha_p b \sqrt{\frac{|P|}{C_a R_{eH}}} \tag{22}$$

Where:

- α_p = correction factor for the panel aspect ratio = 1
- b = breadth of plate panel = 775 mm
- C_a = permissible bending stress coefficient for plate

To calculate it properly, the design cases must be defined, depending on the structural member that is in focus. The analysis this time is done for the external shell and for the boundaries of water ballast tanks and ballast holds. Both these cases require the acceptance criteria to be AC-I. The pressures used in the calculation of the thickness are calculated as shown in the rules. The minimum thicknesses for the stiffened plating between tanks are presented in the Table 24.

Table 24. Minimum Lateral Plating thickness

Structural Member	Element	Thickness [mm]
External Shell	Longitudinal stiffened plating	4
Tank Boundaries	Longitudinal stiffened plating	5.5

The thickness to be adopted must be at least equal to the one obtained through calculations according to the rules. When there are different results for the same element, the minimum thickness is to be taken as the highest of the values obtained. Therefore, as a minimum for the external shell is considered 6.15 mm and for the bulkheads, 5.5 mm.

f) Primary supporting members (PSM) minimum thickness

Regarding the primary supporting members, the thicknesses are calculated with respect to their position to the center line. The girder in the center of the barge must be more resistant as all the other elements pass on the stress to it.

Table 25. Minimum PSM thickness

Element	Thickness [mm]
Bottom center line girder	6.8
Other bottom longitudinal girders	6
PSM in general	5.1

4.5.4 Scantling model

After the minimum thicknesses are calculated, the proper configuration is decided. Besides the results in part 4.6.4, one must decide the positions of the stiffeners and girders with respect to the section modulus as well. In this phase, the final thicknesses of the plating, the profile and the dimensions of the supporting members are decided, along with the number.

In the Table 26, the profiles can be seen and in the Table 27 the dimensions are presented, with respect to their positioning. The elements under the deck must be more resistant as more load and pressure are acting on them. The values adopted for the plating are presented in Table 28.

Table 26. Supporting members profiles

Position	Structural Member	Profile Type
Deck	Girder	T
	Stiffener	T
Side	Girder	I
	Stiffener	I
Bottom	Girder	I
	Stiffener	I

Table 27. Stiffener and Girders details

Position	Structural Member	Element	Height/ Width [mm]	Thickness [mm]	Number
Deck	Girder	Web	250	13	27
		Flange	100	13	
	Stiffener	Web	100	13	240
		Flange	100	13	
Side	Girder		150	10	6
	Stiffener		100	10	28
Bottom	Girder		150	10	27
	Stiffener		100	10	106

Table 28. Plating Dimensions

Plates	Sides	Width [m]	Thickness [mm]
Deck	SB	40.28	13
	PS	40.28	13
Side	SB	10.58	10
	PS	10.58	10
Bottom	SB	39.58	10
	PS	39.58	10
Keel		1.4	11

As it can be seen, the thicknesses are taken higher than the values obtained by using the DNV formulas. The decision to adopt these values was a conservative one, as the structure will provide more safety this way. In Figure 44, the 3D model of the internal structure of the barge is presented and in Figure 45, the 3D of the hull is shown. In Annex 3, the 2D drawing of the midship section is shown.

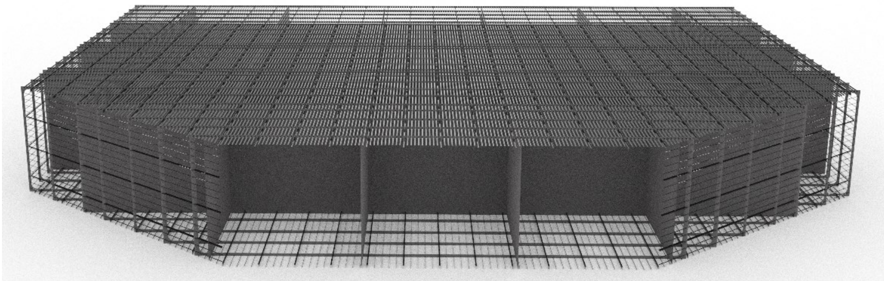


Figure 44. Internal Structure. 3D model

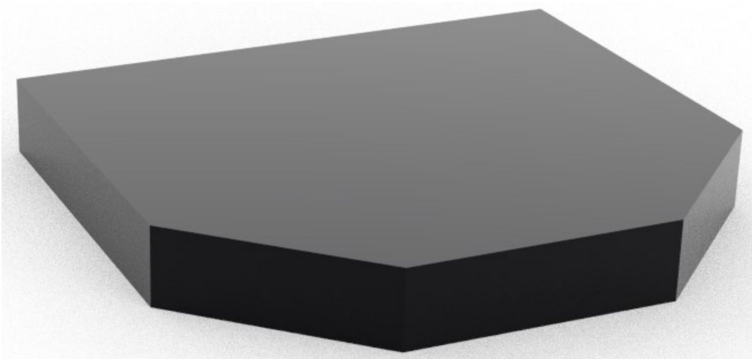


Figure 45. Hull in 3D

4.6 Lightweight & Load Cases

4.6.1 Lightweight

The lightweight of a vessel represents its displacement without liquids, cargo, passengers or crew. It is also known as light displacement or lightship.

After the structure is established, the 3D model is designed for a better approximation of the amount of steel used. The volume is obtained from Rhino and it is multiplied by the steel density chosen, in the present paper 8.03 t/m^3. In total, the result is 2118.25 tons. However, to these weights, the weight of the pipes, the pumps and the steel on-deck supports are added as well. Because the number of supports differs from floater to floater, the lightweight in each case is different.

Below are presented the results obtained for the lightweight, with the supports for WindMoor. As it can be seen, there is a very small trim towards the aft, which was expected.

Table 29. Lightweight loading case

Draft Amidships [m]	0,416
Displacement [t]	2315
Heel [deg]	0
Draft at FP [m]	0,413
Draft at AP [m]	0,419
Draft at LCF [m]	0,416
Trim (+ve by stern) [m]	0,006
WL Length [m]	73,274
Beam max extents on WL [m]	80,568
Wetted Area [m^2]	5536,224
Waterpl. Area [m^2]	5427,237
Prismatic coeff. (Cp)	0,914
Block coeff. (Cb)	0,919
Max Sect. area coeff. (Cm)	1
Waterpl. area coeff. (Cwp)	0,919
LCB from zero pt. (+ve fwd) [m]	-2,667
LCF from zero pt. (+ve fwd) [m]	-2,593
KB [m]	0,208
KG fluid [m]	5,362
BM_t [m]	1181,003

BM_L [m]	963,925
GM_t corrected [m]	1175,85
GM_L [m]	958,772
KM_t [m]	1181,211
KM_L [m]	964,133
Immersion (TP_c) [tonne/cm]	55,629
MT_c [tonne.m]	302,907
RM at 1deg = GM_t.Disp.sin(1) [tonne.m]	47506,24
Max deck inclination [deg]	0,0044
Trim angle (+ve by stern) [deg]	0,0044

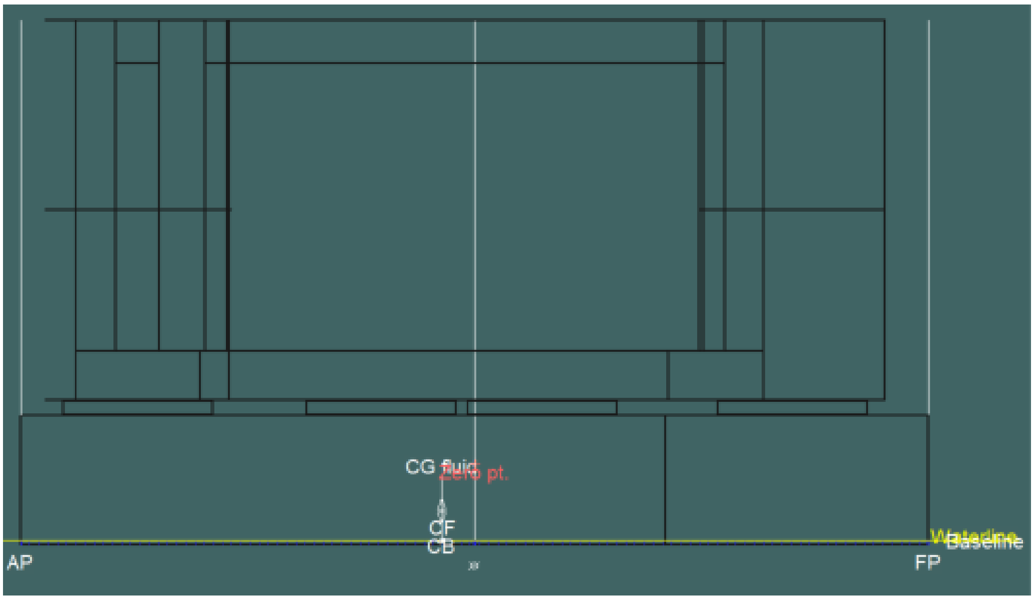


Figure 46. Load Case: Lightweight

4.6.2 Filled Tanks

The tanks are filled progressively to 25%, 50%, 75% and 100. The evolution of the trim, displacement and of the GM_T are observed closely. In the Figure 47 to Figure 50, the loadcases are shown graphically.

Table 30. 25%, 50%, 75% and 100% loading cases

Draft Amidships [m]	3,011	5,606	8,2	12,625
Displacement [t]	16740	31166	45591	60017
Heel [deg]	0	0	0	0
Draft at FP [m]	3,029	5,65	8,268	13,324
Draft at AP [m]	2,992	5,561	8,133	11,926
Draft at LCF [m]	3,009	5,602	8,196	12,447
Trim (+ve by stern) [m]	-0,037	-0,088	-0,135	-1,398
WL Length [m]	73,274	73,274	73,274	67,839
Beam max extents on WL [m]	80,568	80,568	80,568	75,971
Wetted Area [m^2]	6192,985	6812,858	7395,973	15904,514
Waterpl. Area [m^2]	5427,237	5427,241	5427,246	1917,237
Prismatic coeff. (Cp)	0,917	0,916	0,916	0,982
Block coeff. (Cb)	0,919	0,919	0,919	0,9
Max Sect. area coeff. (Cm)	1	1	1	0,989
Waterpl. area coeff. (Cwp)	0,919	0,919	0,919	0,372
LCB from zero pt. (+ve fwd) [m]	-2,526	-2,507	-2,503	-2,51
LCF from zero pt. (+ve fwd) [m]	-2,593	-2,593	-2,593	-9,357
KB [m]	1,505	2,801	4,098	5,426
KG fluid [m]	5,98	5,035	5,518	5,255
BM_t [m]	163,316	87,724	59,967	11,716
BM_L [m]	133,297	71,599	48,945	11,641
GM_t corrected [m]	158,841	85,49	58,547	11,887
GM_L [m]	128,822	69,366	47,524	11,813
KM_t [m]	164,821	90,525	64,065	17,14
KM_L [m]	134,802	74,401	53,043	17,065
Immersion (TP_c) [tonne/cm]	55,629	55,629	55,629	19,652

MT_c [tonne.m]	294,31	295,035	295,698	96,754
RM at 1deg = GM_t.Disp.sin(1) [tonne.m]	46406,92	46499,6	46584,22	12451,308
Max deck inclination [deg]	0,029	0,0689	0,1056	1,0927
Trim angle (+ve by stern) [deg]	-0,029	-0,0689	-0,1056	-1,0927

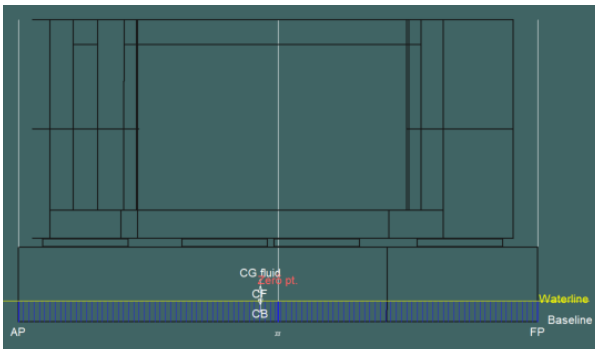


Figure 47. Load Case: 25% Filled Tanks

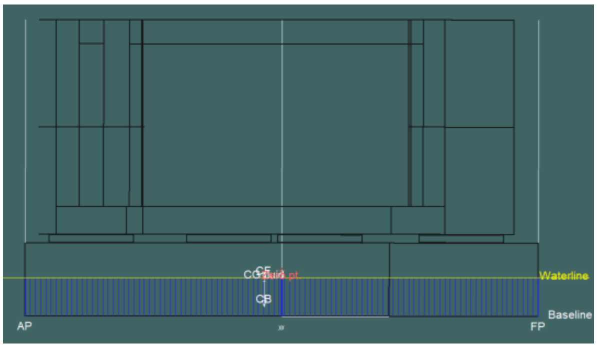


Figure 48. Load Case: 50% Filled Tanks

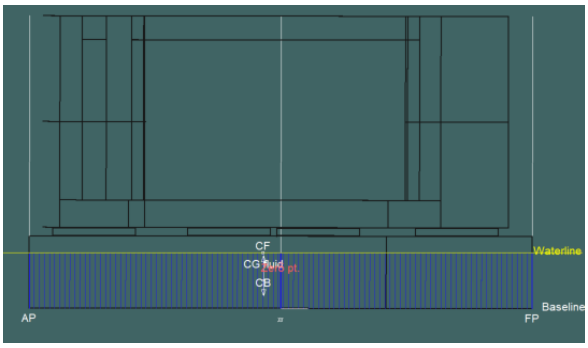


Figure 49. Load Case: 75% Filled Tanks

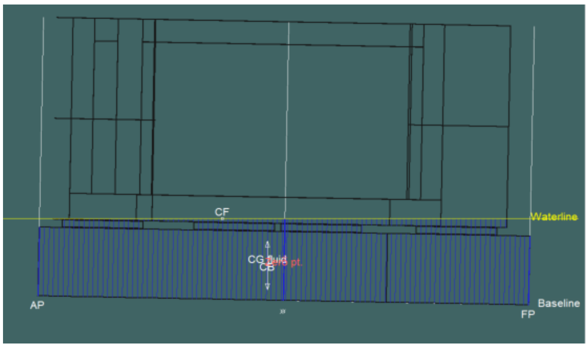


Figure 50. Load Case: 100% Filled Tanks

It can be noticed from the results in the Table 30, that the trim gets more accentuated as the loads in the tanks increase. However, in the first case, the draft was slightly higher in the aft extremity. Now, the higher draft is noticed in the fore part.

Unlike for the vessels that carry cargo, the draft of the present model can't be established based on the full load condition. The draft is considered the level at which the barge's stability is safe and the operational draft is decided based on the quay side's height.

4.6.2.1 Trim & Barge shape, GM_T & Displacement

a) Trim & Barge shape

The trim is influenced by different factors but in the present study, the most decisive factor is the shape of the fore part of the barge. The area reduction leads to trim that is an easy to solve the problem in the early ballasting stages but which becomes more and more problematic as the ballast level increases.

In the Figure 51 the graphical evolution of the trim is presented.

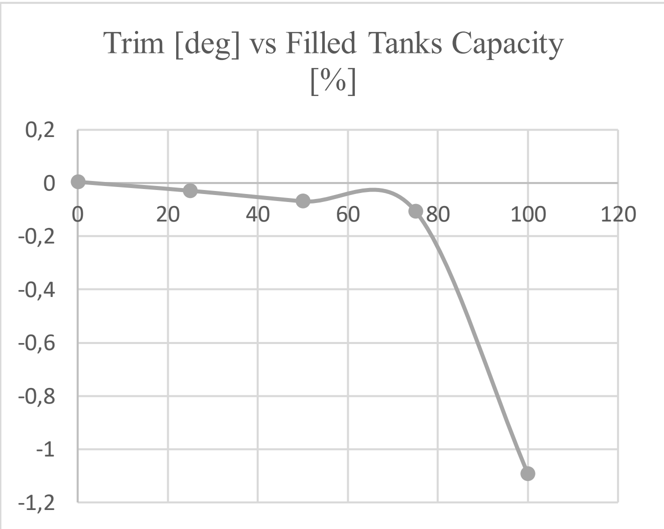


Figure 51. Trim Evolution

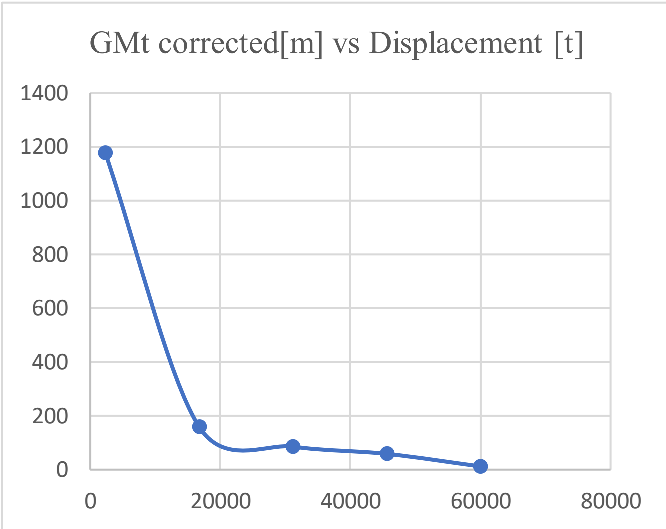


Figure 52. GM_T corrected evolution

b) GM_T vs Displacement

A vessel's transversal stability is very closely related to the GM_T. If the latter has a value too high, it shows that the ship has high chances of capsizing. This is usually caused by an improper load positioning on board or by a too shallow draft.

In the current study case, it is obvious that the barge is not stable when the tanks are empty. The value of the GM_T for the displacement of 2315 t is of 1175.85 m. This result shows that the ship should avoid being left with only 0.416 m of the draft (corresponding to the 0% filled tanks case).

4.7 Intact Stability

4.7.1 Intact Stability Criteria

DNV has no requirements regarding a barge's stability, except that it should satisfy the IMO 2008 IS Code Part B Ch.2.2 criteria.

4.7.2 Intact Stability Analysis of the Barge

The stability of the barge was verified for different situations. A few of them are shown in Table 31, while the others are shown in the upcoming pages. The analysis begins with the completely empty barge and then the normal tank filling cases. In all of the studied cases, the IMO criteria are passed and the barge is stable.

Table 31. Load Cases Analysed and the results obtained

Load Case	Max GZ [m]	Angle at Max GZ [deg]	Displacement [t]
0% Filled tanks	34.281	13.6	2315
25% Filled tanks	23.738	17.3	16741
50% Filled tanks	15.97	17.3	31164
75% Filled tanks	7.451	16.4	45586
Floater on deck, trim and heel = 0, operational draft	14.641	29.1	38117

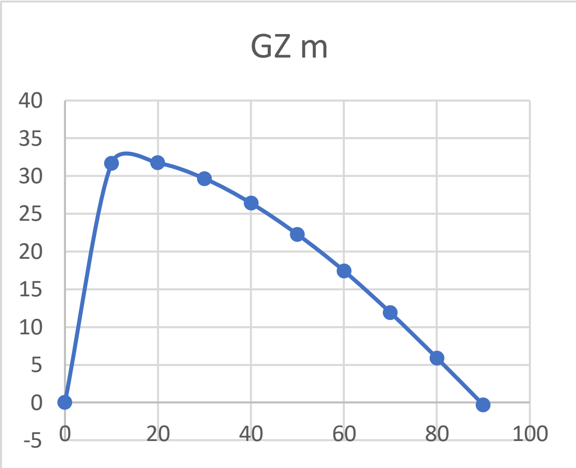


Figure 53. GZ for 0% Tanks Filled Load Case

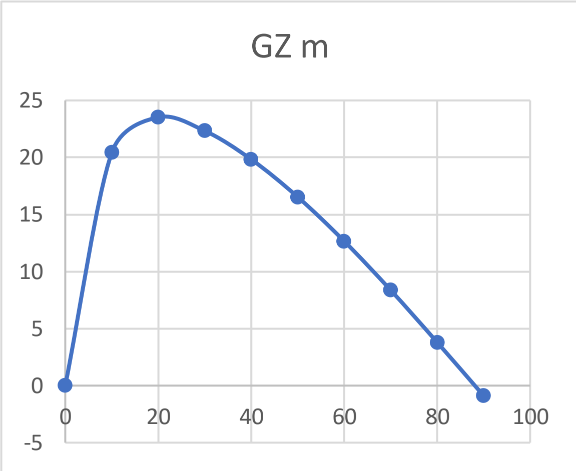


Figure 54. GZ for 25% Tanks Filled Load Case

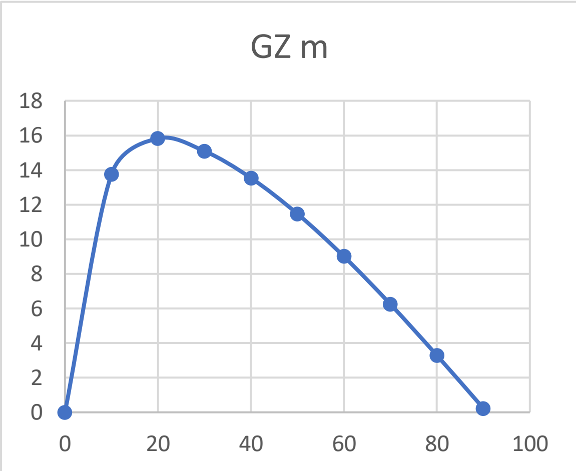


Figure 55. GZ for 50% Tanks Filled Load Case

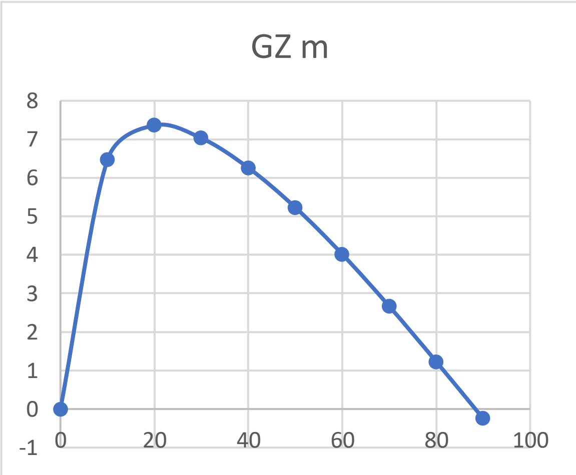


Figure 56. GZ for 75% Tanks Filled Load Case

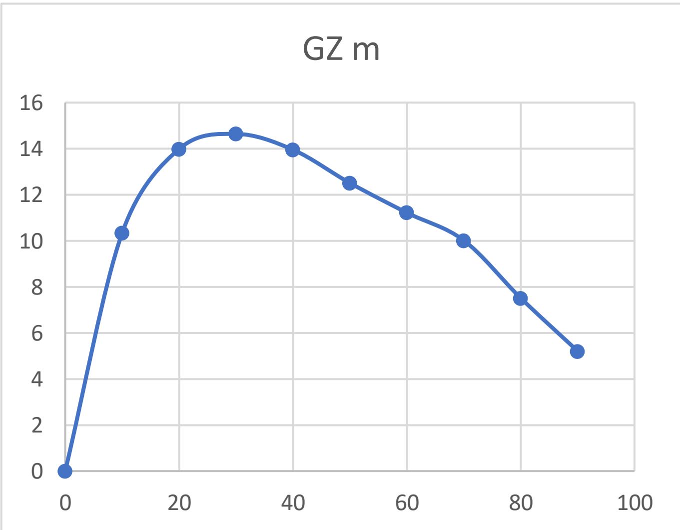


Figure 57. GZ for Floater on deck Load Case

4.8 Damage Stability

4.8.1 Damage Stability Criteria

For Barges, DNV does not require the Damage Stability analysis. However, it was done, to make sure that the launching platform remains on the positive side of the stability range. The possibility of an accident that would lead to the flooding of a compartment is rather insignificant, but it is an interesting exercise to see how it would affect the stability of the barge.

The compartments studied are:

- Compartments adjacent to the sea
- Compartments inside the structure, crossed by seawater filled pipes.

4.8.2 Damage Stability Analysis

a. Compartments adjacent to the sea

As it is required, the damage stability will be analysed for some of the compartments adjacent to the sea. For the present study, the tanks 2, 15, 22 and 30 were flooded each at a time. The influence of flooding on the heel, trim and on the angle at which the maximum GZ is obtained, as well as the value of GZ_{max} are shown in theTable 32.

Table 32. Damaged Stability Adjacent to the Sea Tanks

Tank Flooded	GZ_{max} [m]	GZ_{max} angle [deg]	Heel angle [deg]	Trim angle [deg]
Normal case	11.826	17.3	0	0
2	9.395	17.3	-1.1	1.44
15	9.99	17.3	-1	-0.0836
22	10.356	17.3	-0.8	-0.4243
30	10.833	17.3	-0.3	-0.9323

From Table 32, it is obvious that the tank with the highest influence on the trim and heel is the tank 2. The flooding of this tank leads to the biggest modification in the heel and trim angles. However, the barge has positive stability and the criteria are passed.

b. Compartments inside the structure (Tanks 10, 17, 24)

The damage stability analysis for the tanks inside the structure was conducted on the tanks 10, 17 and 24. The tanks were chosen based on their position. The tank 17 was chosen in the midship longitudinal area.

The Table 33 shows the results obtained, the same factors as in Table 32 being the focus.

Table 33. Damaged Stability Tanks inside the Structure

Tank Flooded	GZ_{max} [m]	GZ_{max} angle [deg]	Heel angle [deg]	Trim angle [deg]
Normal case	11.826	17.3	0	0
10	10.662	17.3	-0.4	0.4184
17	10.556	17.3	-0.4	-0.0951
24	10.553	17.3	-0.4	-0.6489

It is noticed that the decrease in the GZ_{max} value is less significant and that all flooding scenarios lead to a heel angle of -0.4 degrees. For the trim angle, the highest value is reached when tank 24 is flooded. This is caused by the geometry of the barge. The criteria are one again passed and the barge stability remains in the required range.

5. PLANNING

Any marine procedure requires a very careful and accurate planning, that will start in safe conditions and it will end in safe conditions as well. Because of this, several details and factors must be considered. For a better assessment of the possible risks and planning, the procedures are usually divided into sub-operations.

The planning of a complex operation tends to be quite an iterative process. If one aspect is not according to the rules or if it represents too high of a risk, the previous decisions are rechecked. It is possible to be needed to restart the entire planning process from step 1 if a solution is not found.

The planning process is presented in the following pages for each of the ports chosen, separately.

The first step is choosing an appropriate port. The water depth, channel dimensions and the tide range are checked. It is important for the port to offer enough depth for the launching operation, to have dimensions that fit the barge and a tide range that can be compensated by the pumps, in case of need.

5.1 Port

The port of **Cadiz** was chosen for the purpose of loading the barge, as its Entrance Channel is 200 m long and 100 m wide. Information about the height of the quay is not public, therefore the height was approximated. Based on the information from their site (Cadiz Puerto, n.d.), the water depth is of 13 m and the total height of the quayside should be around 19 m. The water depth is also considered as the Low Tide.

$$13 + 5.9 = 19 \; [\mathrm{m}] \tag{23}$$

5.1.1 Tidal Range in Cadiz

According to the report from the *Puertos del Estado* (Puertos del Estado, n.d.), the Mean Sea Level is at 173 cm above the Low Tide level and the minimum High Tide observed is of 61 cm. That means a total water depth of 15.34 m. This leads to the incapability of launching the Olav Olsen and Principle Power floaters, because of their minimum drafts. For these two platforms, the launching process must take place in another port, with a higher depth of water.

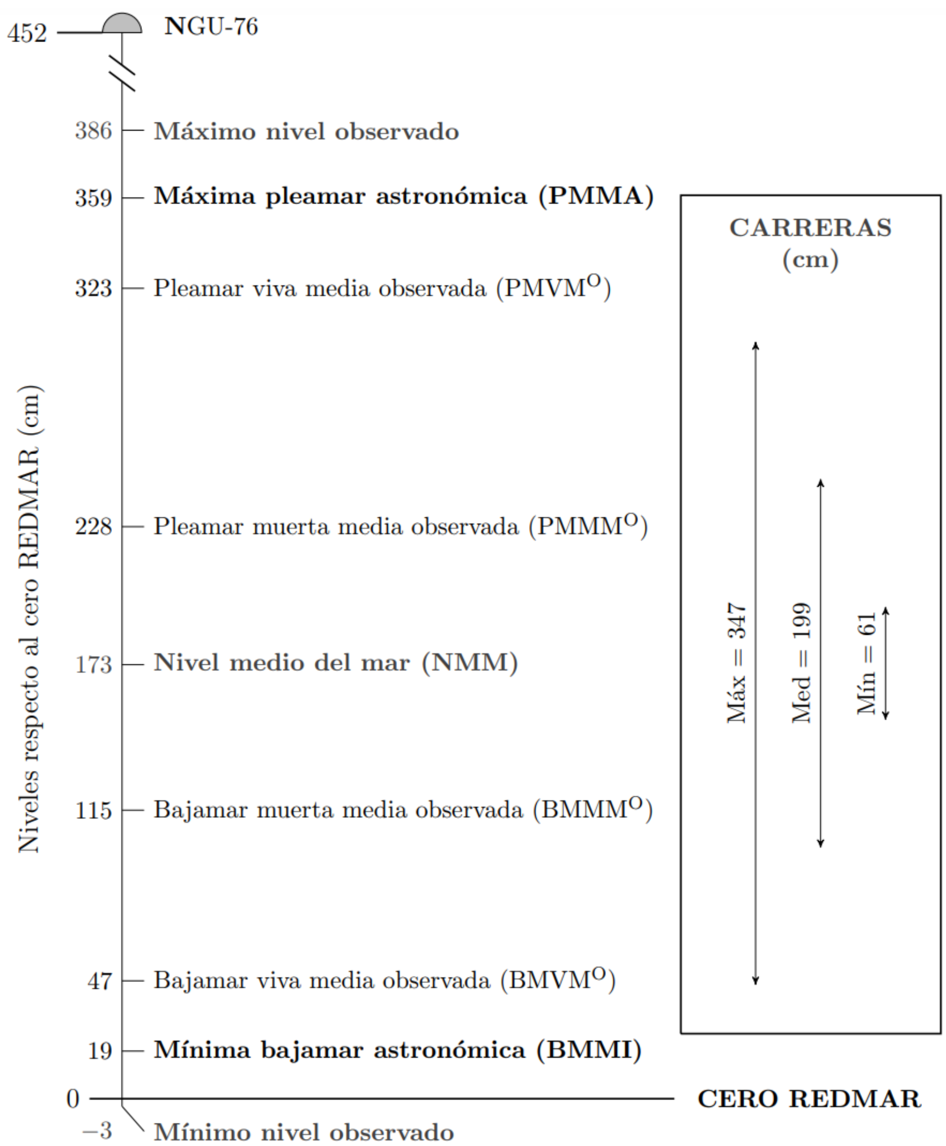


Figure 58. Water Levels Observed by the stations of Puertos del Estado, from: https://www.puertos.es/es-es/oceanografia/Paginas/portus.aspx

Meanwhile, for WindMoor, the water depth needed is of 14.04 m. To check if it is possible to launch the floater, the tide must be checked.

$$10.58 + 1.2 + 2.26 = 14.04 \text{ [m]} \quad (24)$$

During the load-out operations, the deck must be at the same level with the quay or as close to it as possible. This will help to reduce the period needed for the loading of the floater onto the deck and the risk of accidents or incidents during the load-out operation.

Table 34. Water Levels used for the analysis

Tide Type	Water Level (m)	Barge Draft (m)
Low Tide (LT)	13	4.58
Mean Sea Level (MSL)	14.73	6.31
Minimum High Tide (HT_{min})	15.34	6.92

The 13 m water depth is the astronomical low tide and it is unlikely to be reached.

The philosophy of the load-out and the launching operations is that if they can be done using the MSL and the HT_{min}, then the operations can be done any day, all around the year. Of course the other factors like the wind and the weather conditions must be taken into account.

An analysis of the tide was done for a period of a month and it was noticed that the time range between a low tide and a high tide is of about 6 hours.

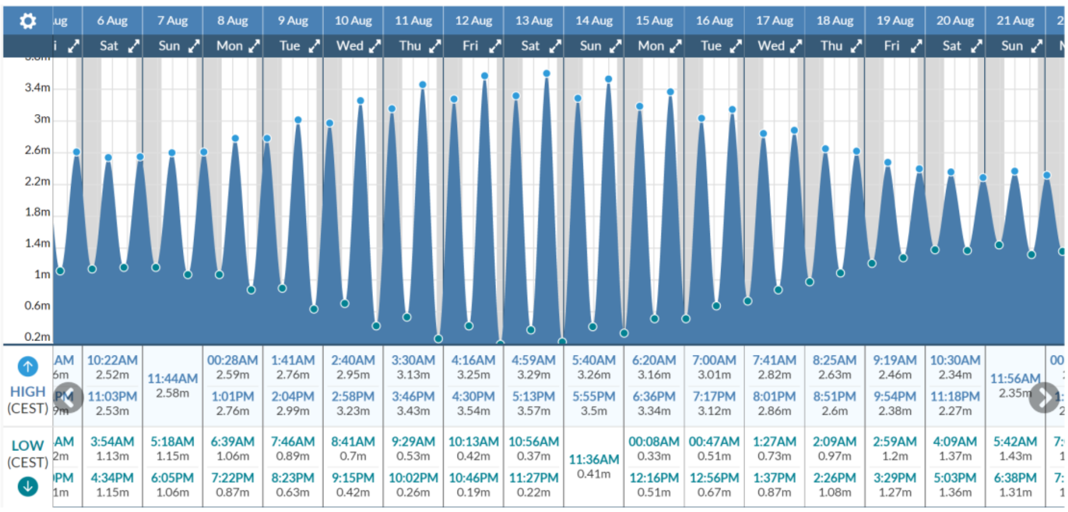


Figure 59. Tide for August 2022, Cadiz Port from: https://www.tide-forecast.com/locations/Cadiz-Spain/tides/latest

In the equation (24) it was shown that for the launch of the WindMoor floater, the water depth needed is of 14.04 m. That means that it can be launched even during the Mean Sea Level.

5.2 Load-out Operation

The period for such an operation should normally take around 1 h (Industry Standard, confirmed by supervisor). In order to ensure that the operation goes as smoothly and quickly as possible, it is decided to start the load-out in rising tide, closer to the moment of the tide peak.

After running several simulations and checking which would be the most optimal moment and the needed time frame for the load-out, it was concluded that the operation should be 40 minutes before the highest tide is reached and the entire process should take around 76 minutes. In Figure 60 is shown the timeline with respect to the tide level.

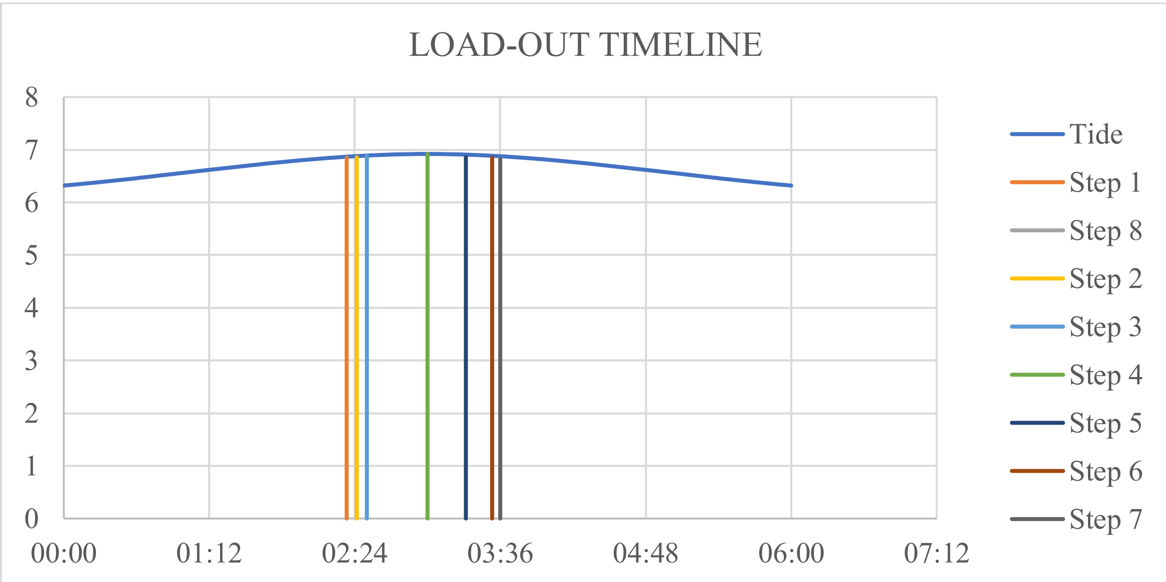


Figure 60. Load-out Timeline

The draft needed for the beginning of the operation is of 6.85 m. At this point and for a water level of 15.27 m, the barge is aligned with the quay.

The barge is fully ballasted in 14 tanks and it is brought up to 85% in the tank 31. In the Figure 61 is shown the barge on heel and trim 0, at the quay level. The load-out operation is done in 7 steps in the present paper.

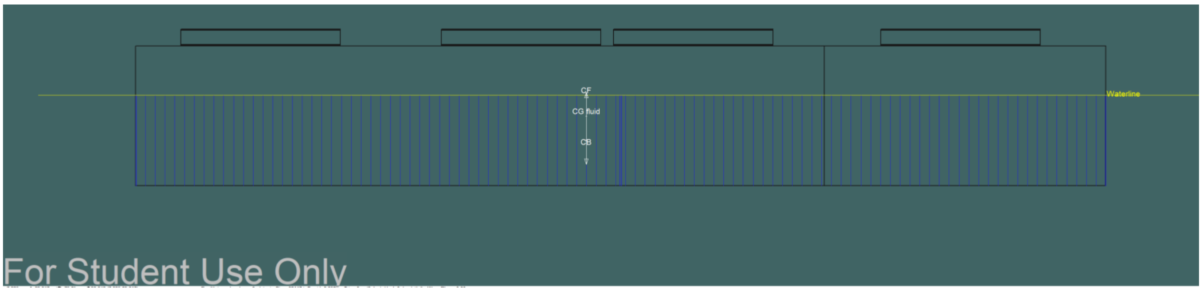


Figure 61. Barge at 6.85 m draft

Next, the floaters starts being loaded onto the deck. The presence of the SPMTs and of the floater, even if just partly, leads to a change in the ballast configuration. Further, the SPMT's keep moving forwards until the floater is in the position and lowered onto the supports. In the Table 35, 2 steps are considered during this part.

Table 35. Transfer of floater onto the deck

Case	Max GZ [m]	Max GZ angle [deg]
Ballasted barge	14.641	29.1
Floater loaded 25%	13.999	29.1
Floater loaded 50%	12.773	28.2
Floater 100% + SPMTs	12.916	25.5

The draft increases almost at the same time with the tide level, maintaining as much as possible the alignment with the quay. In the Figure 62 is shown the comparison of the stability between the analyzed steps.

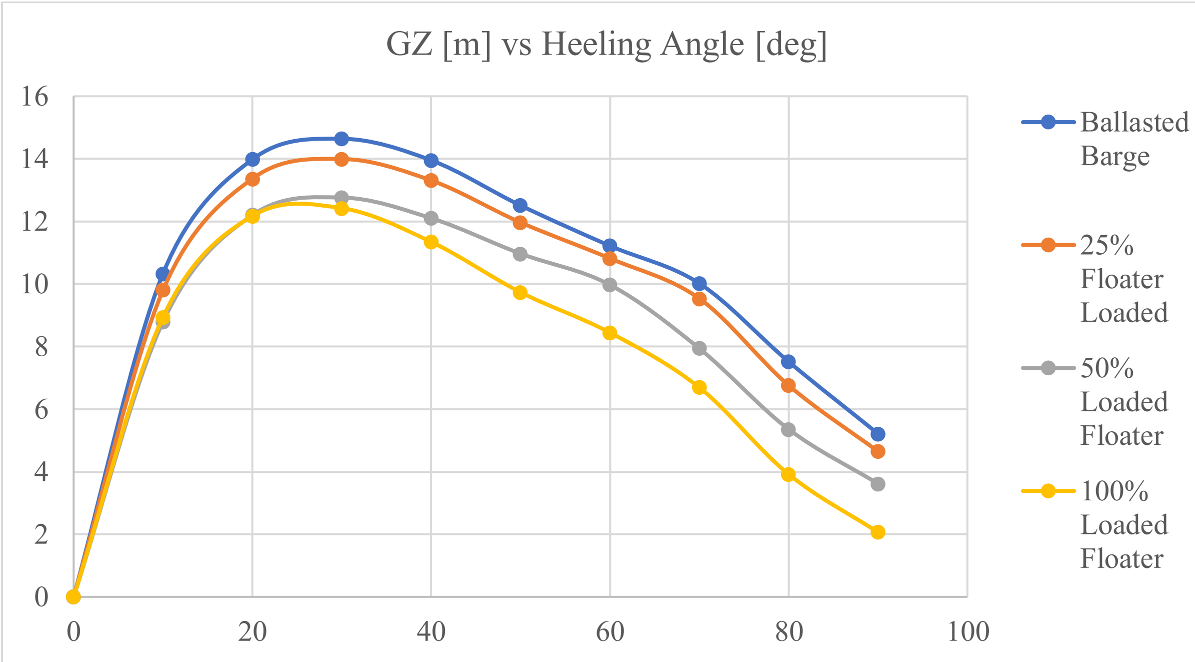


Figure 62. Graphic comparison of the stability throughout the transfer onto the deck

As it was expected, the presence of the variable loads on board decreases the stability. Even so, the assembly (barge + floater + SPTMs) presents good stability throughout the first half of the operation.

After the floater is lowered and positioned on the steel supports, it is the time to unload the SPMTs from the deck. As they move back towards the quay, the stability is checked at the same positions as previously. The new results obtained are presented in Table 36.

Table 36. SPMTs leaving the deck

Case	Max GZ [m]	Max GZ angle [deg]
Floater on position	12.928	25.5
SPMTs 60% off the deck	13.296	25.5
SPMTs 80% off the deck	13.418	26.4
SPMTs off	13.503	26.4

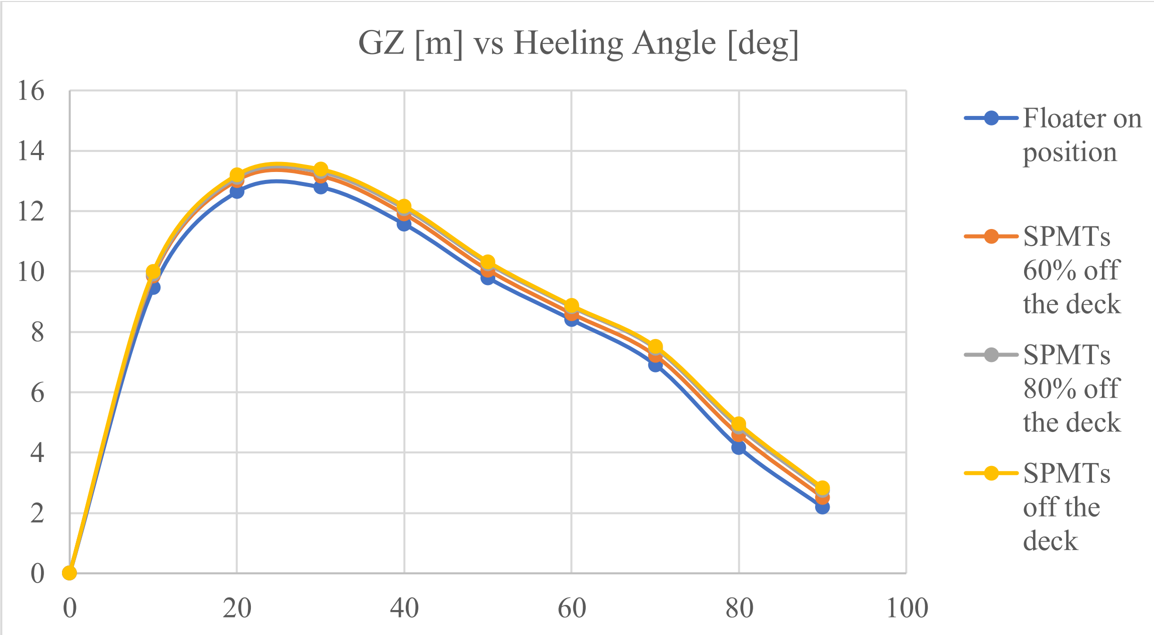


Figure 63. Graphic comparison of the stability after the floater's the transfer onto the deck

The ballasting is distributed in such a way that ensures the stability at all moments. There are no specifications in the rules regarding what the safe range is during the operations.

The Bending Moments and the Shear Forces are checked and verified if they don't exceed the limits required by the DNV rules. In Table 37, Table 38 and Table 39 are presented the results for Still Water, Hogging and Sagging.

Table 37. Bending Moments and Shear Forces for Still Water

Step	BM [kNm]	Shear Force [kN]
Ballasted barge	134547.24	8286.62
Floater loaded 25%	213451.54	-10934.42
Floater loaded 50%	80512.59	6119.35
Floater 100% + SPMTs	50366.95	6560.65
SPMTs 60% off the deck	-78953.34	6678.33
SPMTs 80% off the deck	-67852.21	5638.32
SPMTs off	-82366.05	5962.44

Table 38. Bending Moments and Shear Forces for Hogging

Step	BM [kNm]	Shear Force [kN]
Ballasted barge	60212.83	4971.97
Floater loaded 25%	138087.44	-7806.09
Floater loaded 50%	23477.12	4815.07
Floater 100% + SPMTs	-57594.46	-5609.4
SPMTs 60% off the deck	-153787.88	8669.08
SPMTs 80% off the deck	-138381.64	7639.38
SPMTs off	-153121.03	7953.19

Table 39. Bending Moments and Shear Forces for Sagging

Step	BM [kNm]	Shear Force [kN]
Ballasted barge	210038.83	11591.46
Floater loaded 25%	289119.66	14062.74
Floater loaded 50%	145785.66	-9208.45
Floater 100% + SPMTs	121170.97	9855.68
SPMTs 60% off the deck	43933.79	-4775.84
SPMTs 80% off the deck	60340.32	-5736.89
SPMTs off	49435.32	-5060.23

All the values are respecting the maximum limits for the bending and the shear stresses.

5.3 Launching Operation

In part 5.1.1, it was explained that for the launch of the floater, it is needed at least a water depth of 14.04 m, which means is smaller than the Mean Sea Level (14.73 m). This should mean that this operation can be done any day of the year, as well. However, analysis is still done and the results are presented in the following pages.

Like in the case of the load-out, the operation is done in raising tide. The period for this operation is of approximately 4 hours and 50 minutes.

Figure 64. Launching Timeline with respect to the tide

5.3.1 Launching concept

In the initial step, the barge is brought to a positive trim of almost 4.5 degrees. This allows the aft to be slowly submerged and the water to get on board. It is considered the optimal way for submerging the barge in a controlled way.

The second step is to slowly sink the barge, maintaining the inclination. The water raises higher on the deck and the floater starts touching the water. This step continues until the water level reaches the fore extremity.

The third step is to bring the barge on trim 0. At this point, the floater starts slowly to float but it is not stable enough.

In the fourth step, the barge is grounded in aft and in the fore, is supported by a winch. The goal is to keep the launching vessel on trim 0 or as close as possible to it.

The fifth and final step is bringing the barge back to the surface. The process is done in a similar way to the submerging, by using trim and carefully controlling the de-ballasting.

5.3.2 Ballasting

As mentioned in the Pump System sub-chapter, the submerging and the de-ballasting of the barge are done only by using the fine-tuning tanks. Even so, portable pumps are needed to get to the ballast configuration needed to start the launching. Starting from the ballast configuration of the last step in the load-out operation, the pumps are used to fill the tanks 15, 21, 22, 28 and 31. At the same time, through the pumping system, the tanks in the aft part of the barge are filled, maintaining the trim 0.

Once the tanks are filled, the portable pumps are retrieved and the trim depicted in Figure 65 is attained only by controlling the fine-tuning tanks.

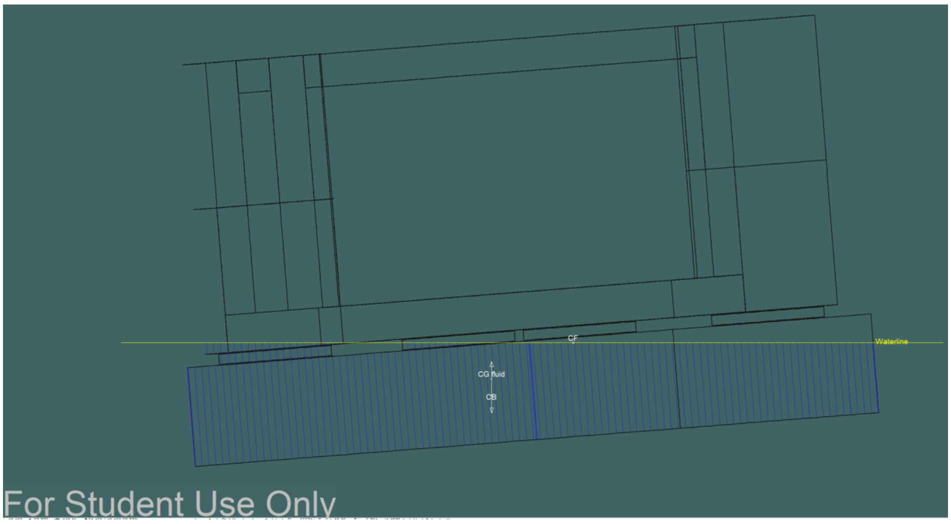


Figure 65. Ballasting Step 1

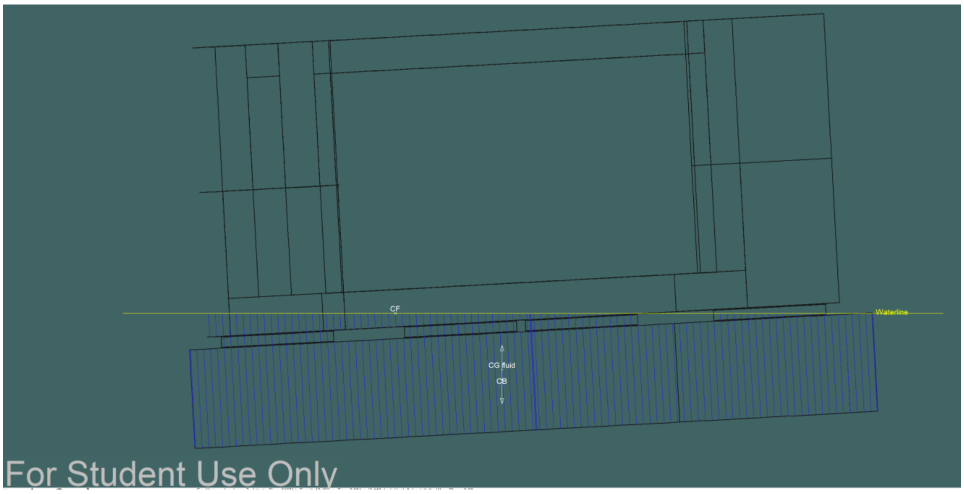


Figure 66. Ballasting Step 2

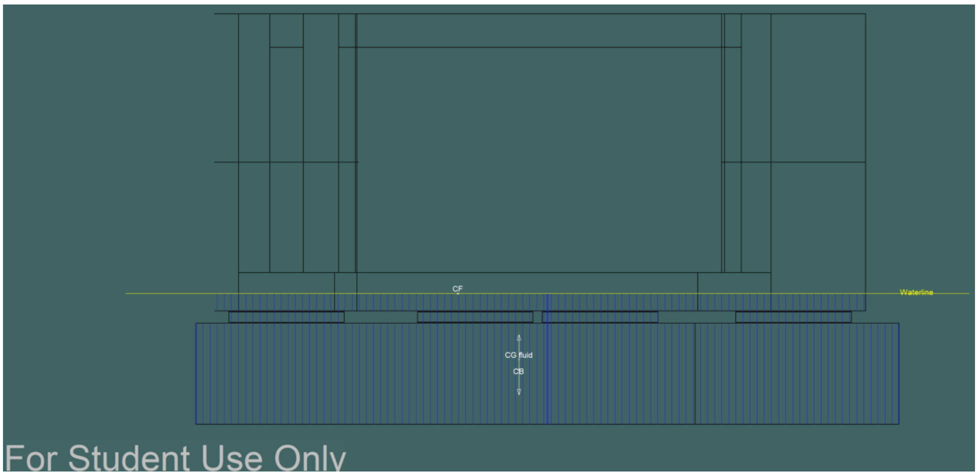


Figure 67. Ballasting Step 3

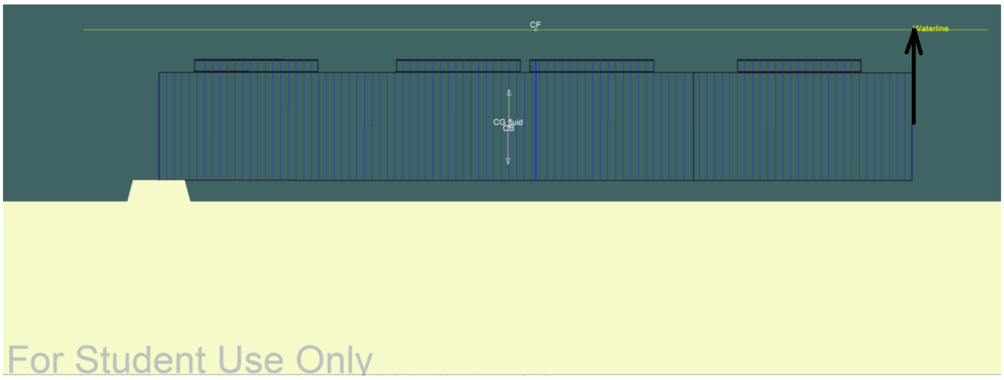


Figure 68. Ballasting Step 4 (Black arrow representing the reaction force of the tug-winch/grounding)

In this situation, the grounding is done by using the seabed. However, if the operation takes place in a port with a higher water depth, it is still possible. Considering that the project is thought for the launching of several floaters, it is more economical to prepare a grounding place.

For the winches system, the maximum tension was calculated based on the tide and the ballasting strategy. It was calculated for the final step, to obtain the maximum force needed and to ensure that the stability of the barge is maintained. The result is that the winches on the quay need a force under 100 t and the tug-winch needs a force under 25 t.

5.3.3 De-ballasting

For this part, just like for the ballasting, only the fine-tuning tanks are used. The de-ballasting process begins with the tanks in the fore extremity. A positive trim of 3.8 degrees is reached. At this point, the tension in the winch needs to be gradually lowered. The ideal case would be for it to drop at the same rate with the ballast in the tanks that are de-ballasted. The goal is to keep the same trim but without the action of the winch.

In the Figure 69, it is noticed that the fore part of the deck starts emerging from under the water. The tanks in the midship are de-ballasted gradually until the aft extremity of the deck raises to the water level. The tanks in the aft get de-ballasted until the barge reaches trim 0. Afterwards, the barge is de-ballasted until it reaches the 6.32 m draft once again.

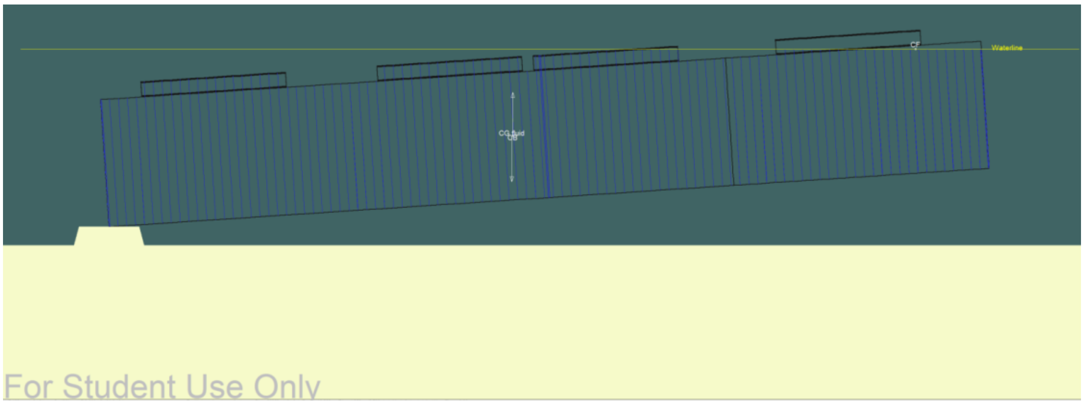


Figure 69. De-Ballasting Step 1

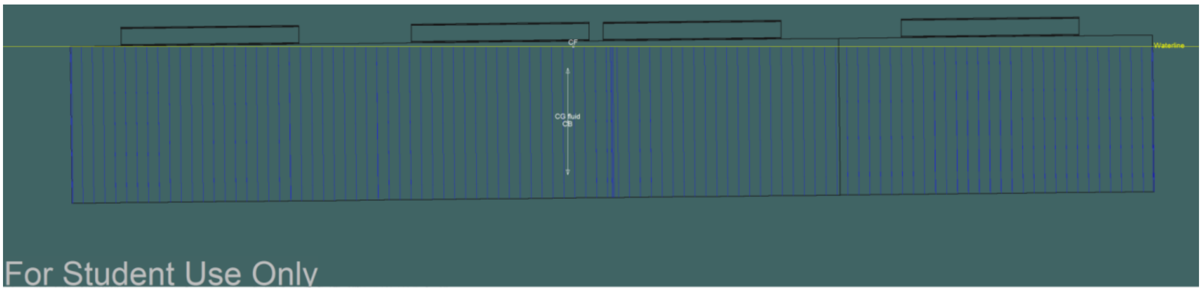


Figure 70. De-Ballasting Step 2

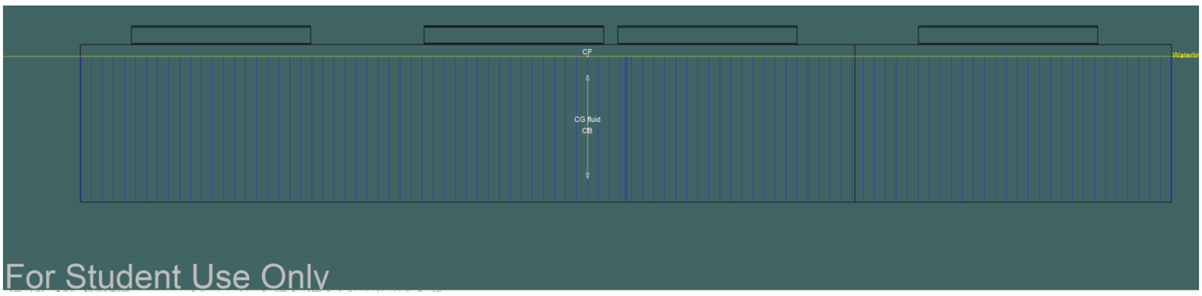


Figure 71. De-Ballasting Step 3

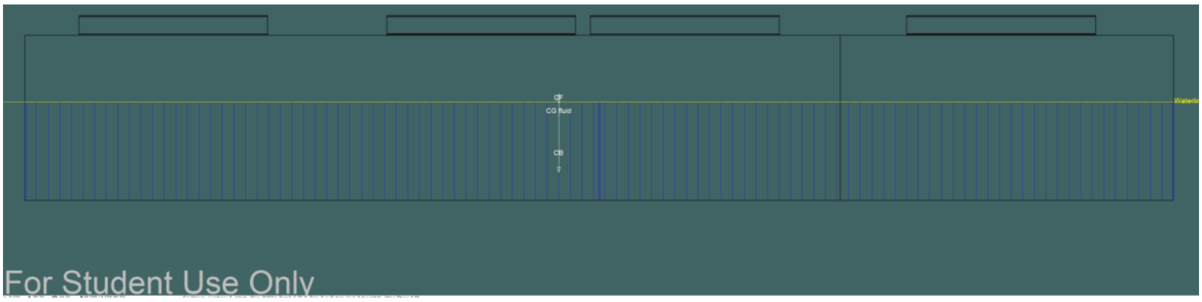


Figure 72. De-Ballasting Step 4

5.4 Sub-operations

5.4.1 The load-out

The load-out operation can be separated into different sub-operations, depending on the agreement between the shipyard project manager, the naval architect and the client's team. For the present project, the operation was parted in the following 12 steps:

1. The floater is loaded on the SPMTs and one last visual check of the quay and of the road to the quay is done.
2. The barge is put in position and connected to 2 winches on the quay a third one, on a tugboat, in the fore part of the launching platform.
3. The ramps for the SPMTs, between the quay and the barge, are installed.
4. The barge is ballasted until the deck reaches the same level as the quay and the SPMTs bring the floater on the quay.
5. Once the previously set moment for the beginning of the load-out is reached, the SPMTs start the transfer.
6. Transfer of 25% of the floater on the barge. Ballast is transferred from the aft fine tuning tanks into the fore ones.
7. Transfer of 60% of the floater on the barge. Ballast transfers continue.
8. Floater fully transferred onto the barge and the air valves on the deck are opened and de-ballasting begins.
9. Lowering the floater on the steel supports. Check the trim and the heel. Stop the be-ballasting.
10. Start ballasting, SPMTs 25% off the barge.
11. SPMTs 50% off the barge, the ballasting continues.

12. SPMTs completely off the barge, the barge is brought on trim 0 and the ballasting stops.

It was considered that the separation into smaller steps leads to fewer errors in the overall process.

5.4.2 The launching

The sub-operations for the launching operations in the present paper are:

1. Bring the mobile pumps on board and ballast the tanks in the fore. Tie the 2 tugboats to the floater.
2. Once the tanks are filled, take the pumps back on the quay and start ballasting the tanks in the aft.
3. Submerge the aft of the barge until the wanted trim angle is reached.
4. Start ballasting the fine tuning tanks and sink the barge until the water level reaches the fore extremity.
5. Bring the barge on trim 0 and continue submerging it until it is grounded in the aft.
6. Put tension in the winch in the fore and keep the launching platform on trim 0 while the floater reaches the needed draft and starts floating.
7. The tugboats pull the floater to the side and the de-ballasting of the tanks in the fore begins.
8. Reach the previously determined trim then start de-ballasting all of the fine tuning tanks.
9. When the fore extremity is above the water level, stop de-ballasting the tanks in the fore and bring the barge on trim 0.
10. Once the launching platform is on trim 0 and has freeboard, the de-ballasting of the tanks in the fore and aft begins again until the 6.32 m draft is reached.

6. COSTS ESTIMATION

For a proper estimation of the project's costs, the CapEx and the OpEx were approximated as accurately as possible.

CapEx, or Capital Expenditure, represents the sum of money that the organization uses to purchase, maintain and upgrade fixed assets. Usually by fixed assets it is understood as buildings, vehicles, equipment or land. If the asset is newly purchased, in the present case the newly built barge, it is considered as a capital expenditure. (Fernando, 2022)

OpEx, or Operational Expenditure, represents the day-to-day cost of the operational activities. By operational activities it is understood as running a system or a product. (Kenton, 2022)

6.1 CapEx

In the Capital Expenses, for this project, are included the costs for building the barge and for acquiring the pumps and the pipes.

For the building process, normally a meeting with the shipyard is set up. After looking at the project and making some rough estimations, the people from the shipyard come up with an offer. Most of the time, for not very complex structures, the price is of 4-6 euros/kg. In this price, it is included the labor, the paint and the steel.

The prices of the pumps, the air vents and the pipes are also included in the CapEx as they aren't consumables. Because the approximation is done only for the WindMoor case, the steel supports are also classified as Capital Expenditures and are included in the steel cost.

Table 40. Capital Expenditures

Cost	Quantity	Price per unity [€]	Price [€]
Steel	2335000 [kg]	4	9340000
Pump	8 [-]	10000	80000
Extra equipment	2000 [kg]	10	20000
Total Price			9440000

6.2 OpEx

The barge won't operate 24/7 for the entire year. Therefore, it is not needed to buy some of the systems that will be used, just to rent them. For this part, most of the costs were approximated based on the experience of the CoreMarine company from their previous projects.

3 tugboats are rented: 2 to pull the floater when it starts floating and another to help with the submerging and de-ballasting of the barge. Each tugboat has a pilot. The period for the renting is assumed 16 hours, out of conservative reasons.

The portable pumps are used just between the end of the load-out and the beginning of the launching operation. Considering the amount of water needed to be pumped into the tanks and to be conservative, a period of 3 hours is assumed for the renting time.

The air system is not used during the operational periods so the flexible pipes are not connected to the barge and the valve is closed. Before the launching operation begins, the pipes are connected during the Mean Sea Level, when the barge has a draft of 6,32 m. Therefore, the pipes are rented for the launching operation period plus 3 more hours, just to be conservative.

Table 41. Operational Expenses

Cost	Quantity	Time [h]	Price $\left[\frac{€}{qty \cdot h}\right]$	Price [€]
SPMT	10	2	250	5000
Tugboat	3	16	600	28800
Pilot	3	16	200	9600
Mobile Pump	5	3	50	750
Flexible Pipe	20 [m^2]	8	50	8000
Total Price				52150

This represents the cost per one day of operations. It is forecasted that throughout the year, approximately 20 operations shall take place.

6.3 Port dues

For the cost of the port dues, the prices of the Cadiz Port couldn't be found so the ones for the Bilbao Port are considered. (Bilbao Port, n.d.)According to the authorities, the prices should be in the same range and therefore, very close to one another. Considering that this one is just a rough approximation, it is considered a correct estimation.

The rent tax is calculated with respect to the Gross Tonnage of the barge, a correction coefficient and a corresponding coefficient.

$$GT = V \cdot K_1 = V \cdot (0{,}2 + 0{,}02 \cdot log_{10}V) = 16728{,}986 \quad (25)$$

$$Tax = \frac{GT}{100} \cdot Time \cdot B \cdot Correction\ Coefficient \cdot Corresponding\ \ Coefficient \quad (26)$$

Where:

- V is the interior volume of the barge
- K_1 is a coefficient dependent on the volume
- B is a basic rate, established by the port
- The correction coefficient is 1,05

For the barge presented in this paper, the corresponding coefficient is set to the case of prolonged time spent and prolonged use of berthing facilities.

This rental cost is set for vessels which have more slender hulls and therefore cover a significantly reduced area. By using the same formula, the price obtained for the barge is too high. For the launching platform presented in this paper, a discussion with the port authorities should take place and a discount must be set. Usually, the price can be reduced to $\frac{1}{4} - \frac{1}{5}$ of the price for normal vessels.

Table 42. Rental Cost for a year

	Price Per Day [€]	Nr. of Days	Total Cost [€]
Normal Cost	703.8	365	256887
Reduced cost	140.8	365	51377.4

7. CONCLUSIONS

In the present paper the basic design of an innovative semisubmersible launching platform for load-out of floating wind turbines and the operations planning have been presented.

An overview of the different types of existing ports has been presented and the launching methods have been shown in the Chapter 2. The floaters considered in the design concept have been presented in Chapter 3.

An analysis of the vessel types used in the Floating Wind Turbines has been done and the chosen type has been decided: non-self-propelled barge. The dimensions have been set with respect to other similar barges and to the dimensions of the studied floaters. The dimensions obtained in the end are 73.27 m length, 80.56 m width and 10.58 m height. This part took 3 iterations.

The plans of the hull have been presented, depicting properly the shape. A comparative analysis between the concrete and the steel supports has been done with respect to the number and the pressure. The final decision is to use the steel supports as the loads on the deck are highly reduced and it offers a better resistance. After setting the positions of the supports on the barge, SPMTs from 3 different providers have been analyzed. The PPU Z390 + Z180 has been chosen and the number has been decided. This part took 3 iterations.

The general arrangement has also been finished after several iterations and it has been presented. The barge houses 34 tanks, out of which one is the Pump Room. The details regarding the openings in the deck and the tank access ways, as well as drawings have been provided. Setting the proper tank positioning and deciding the size took 4-5 iterations.

It has been established among the tanks which would be the gross ballast tanks and which would be the fine-tunning ones. The calculations regarding the pump capacity needed have been done with respect to the estimated operational period. The result obtained is 6000 m^3/h and considering the requirements of DNV, it has been shown that 8 pumps are needed. The most optimal solution found at the moment for the air system has been decided and shown in 2 views. Based on the number of needed pumps and the best positioning found at the moment, the piping lay-out for the ballasting and de-ballasting has been set. This part took 3 iterations.

The DNV rules have been checked and the class notation for the barge has been set. Next, the pressure and the loads that act on the launching platform have been calculated by using the Classification Society’s formulas. The maximum allowable bending moment and shear force, along with the corresponding stresses have been set. Maxsurf has been used to check the maximum BM and SF obtained by using different floaters and supports. Once the maximum values have been obtained in the allowable range, the analysis went on to the next step. This part took 3 iterations.

For the scantling part, the DNV rules don't have clear set requirements regarding semi-submersible barges. To be conservative, the rules for the "Semi-submersible heavy transport vessels" have been considered and respected. The minimum thicknesses for different components have been calculated with respect to the previously determined loads. The material has been chosen in such a way that provides the hull enough resistance to the maximum bending moment and shear force obtained.

The number and profile of the supporting elements have been set and the section modulus of the barge has been calculated. It has been checked to respect the range required by the rules. This part took 5-6 iterations. The 3D model has been done accurately with respect to the thicknesses obtained through the calculations.

Different lightweight cases have been analyzed, more precisely the lightweight and the required filling levels of the tanks. An analysis of how the different level of tanks filling affects the trim and the transversal metacentric height has been done.

As per the rules, the intact stability has been analyzed with respect to the IMO rules. All of the results are in the required range and have been satisfying.

The port has been decided, Cadiz, and the tide range has been checked. It was decided to do the operations in the water depths corresponding to the Mean Sea Level and the Minimum High Tide. This proved that the operations can be done all around the year. This part took 3 iterations.

The Load-out Operation's steps have been decided and simulations of the operations have been done. The timeline has been finalized and the final time period obtained for the Load-out is 1 hour and 16 minutes. The stability has also been analyzed. Considering the significant transfer of loads during the operations, the BM and SF have been checked. This part took 5 iterations.

The Launching Operation has been simulated and the results have been presented. The timeline has been set and the period obtained is of 4 hours and 50 minutes. This part took 3-4 iterations.

The sub-operations of the two operations have been presented step by step.

The cost estimation is prepared and a CapEx and an OpEx analysis has been presented, based on the forecasted costs.

7.1 Recommendations for future work

1. As in the current study the chosen port for launching is Cadiz, the Olav Olsen and the Principle Power floaters couldn't be completely included in the analysis. For the completion of the study and so the barge can deserve its full purpose, it is suggested to choose a port with a higher water depth. This factor will lead to different changes needed throughout the project.
2. The Limit States requirements should be checked then the structure should be fully analyzed for the corresponding Limit States.
3. The detail design phase can be started and the outfitting done properly.
4. The reduction of the rent cost is to be discussed with the port authorities and a new price set.
5. A more complex economic analysis regarding both the CapEx and the OpEx can help in assessing the viability of the project, with respect to a forecast of the Incomes.
6. In the industry, it has been noticed the interest for a launching platform like the one designed in the present study. A modification of the project to better fit the industry requirements can be done.

8. ACKNOWLEDGEMENTS

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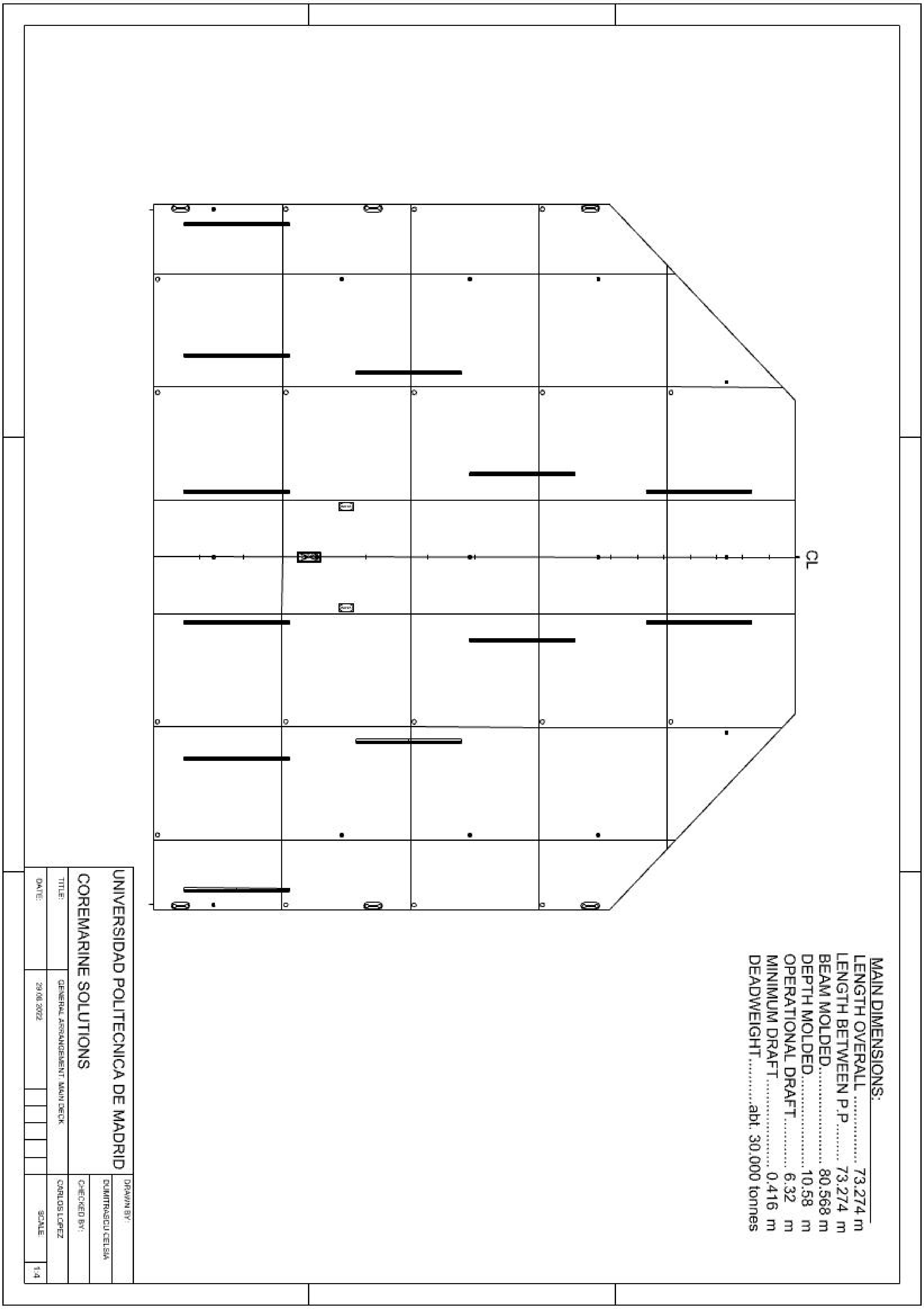
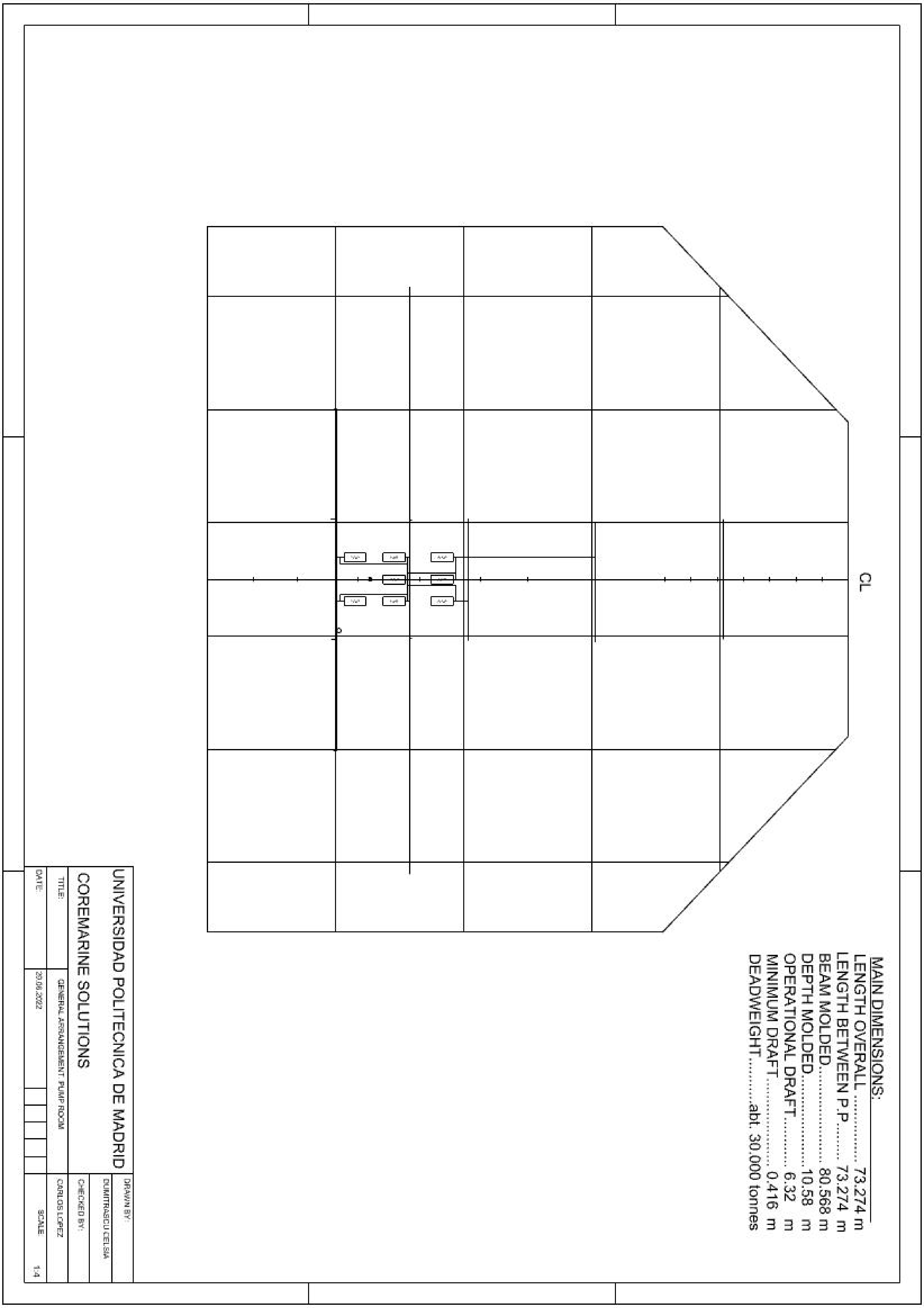
10. ANNEXES

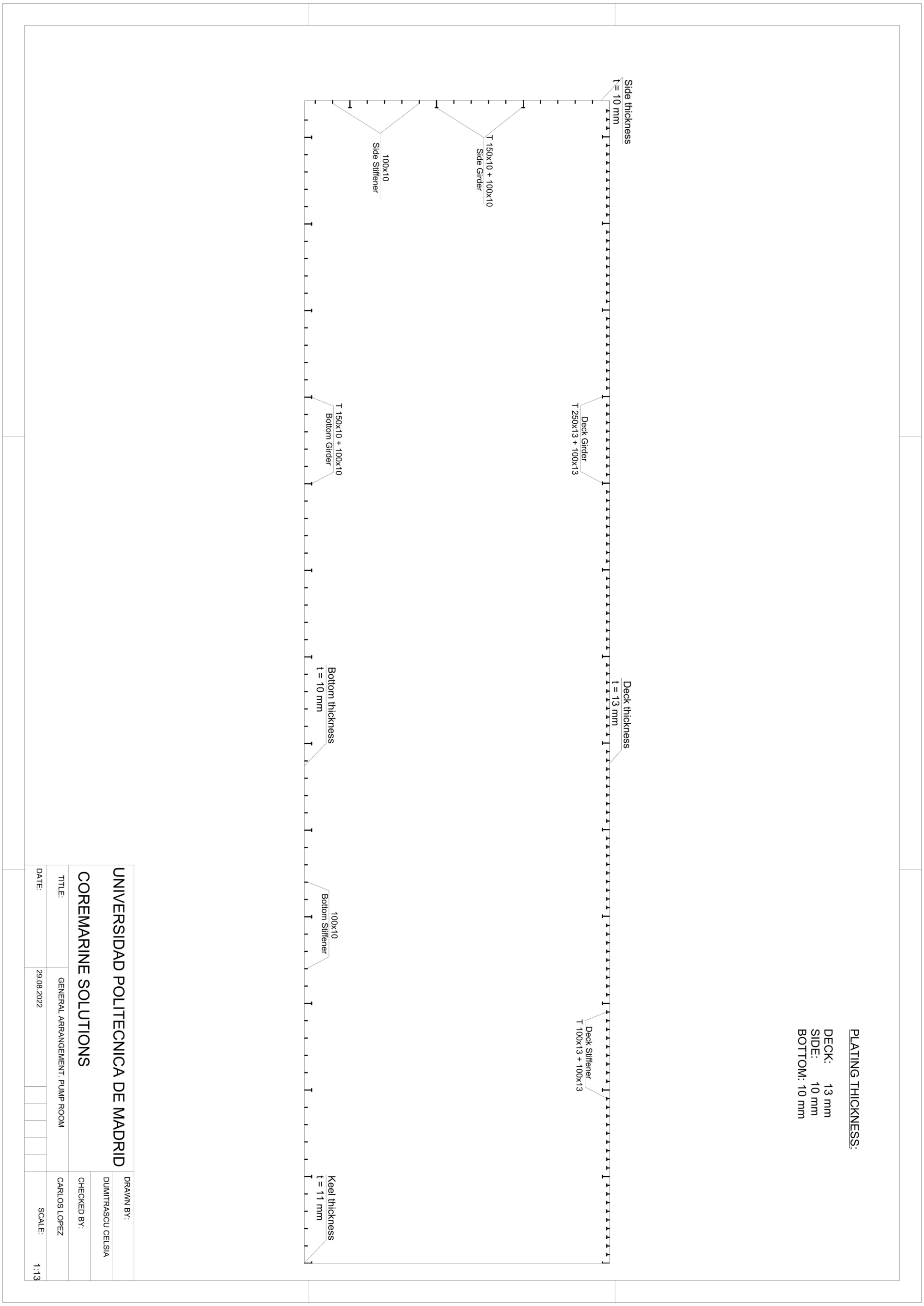
10.1 Annex 1. General Arrangement of Main deck

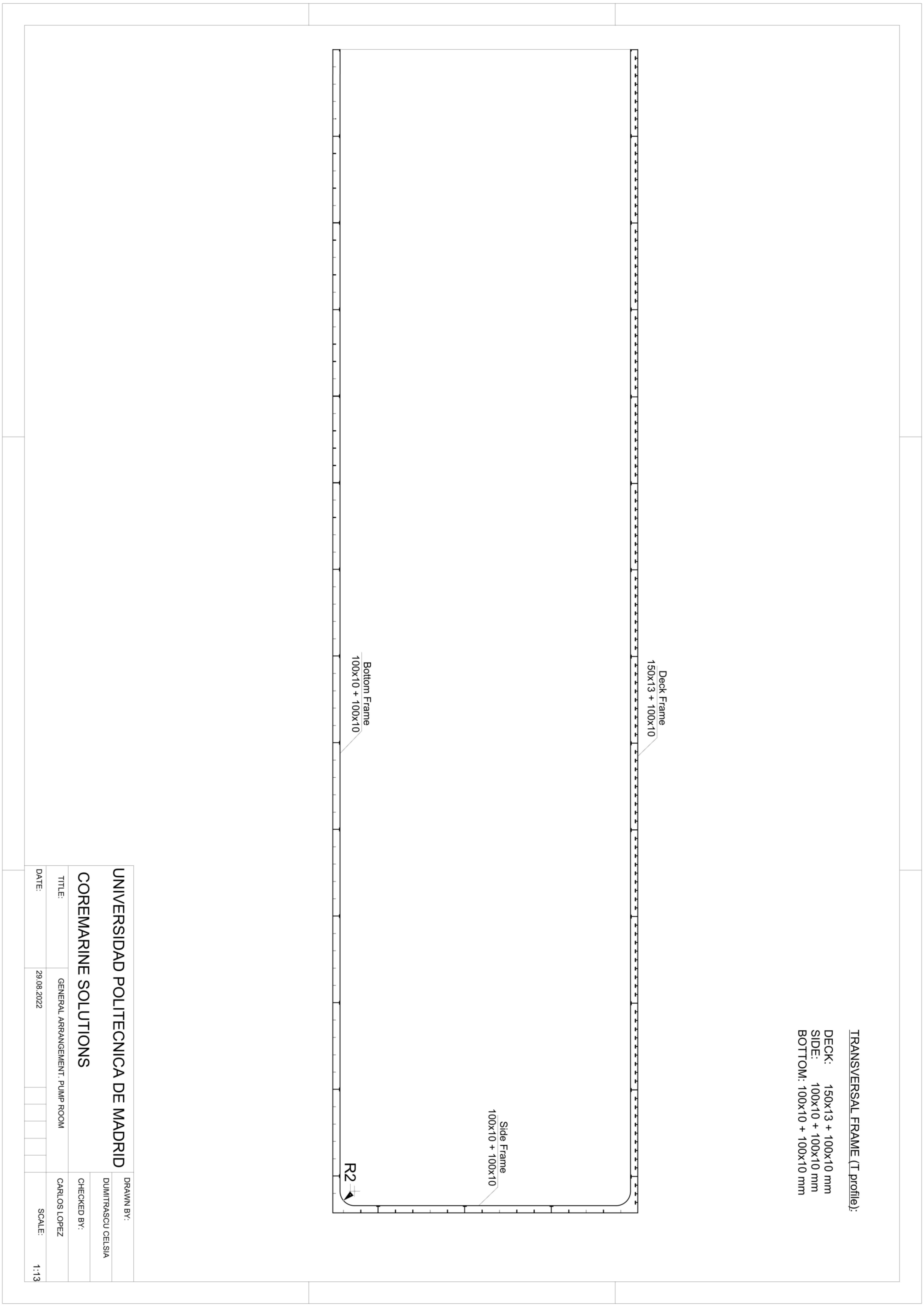


10.2 Annex 2. General Arrangement of Pump Room

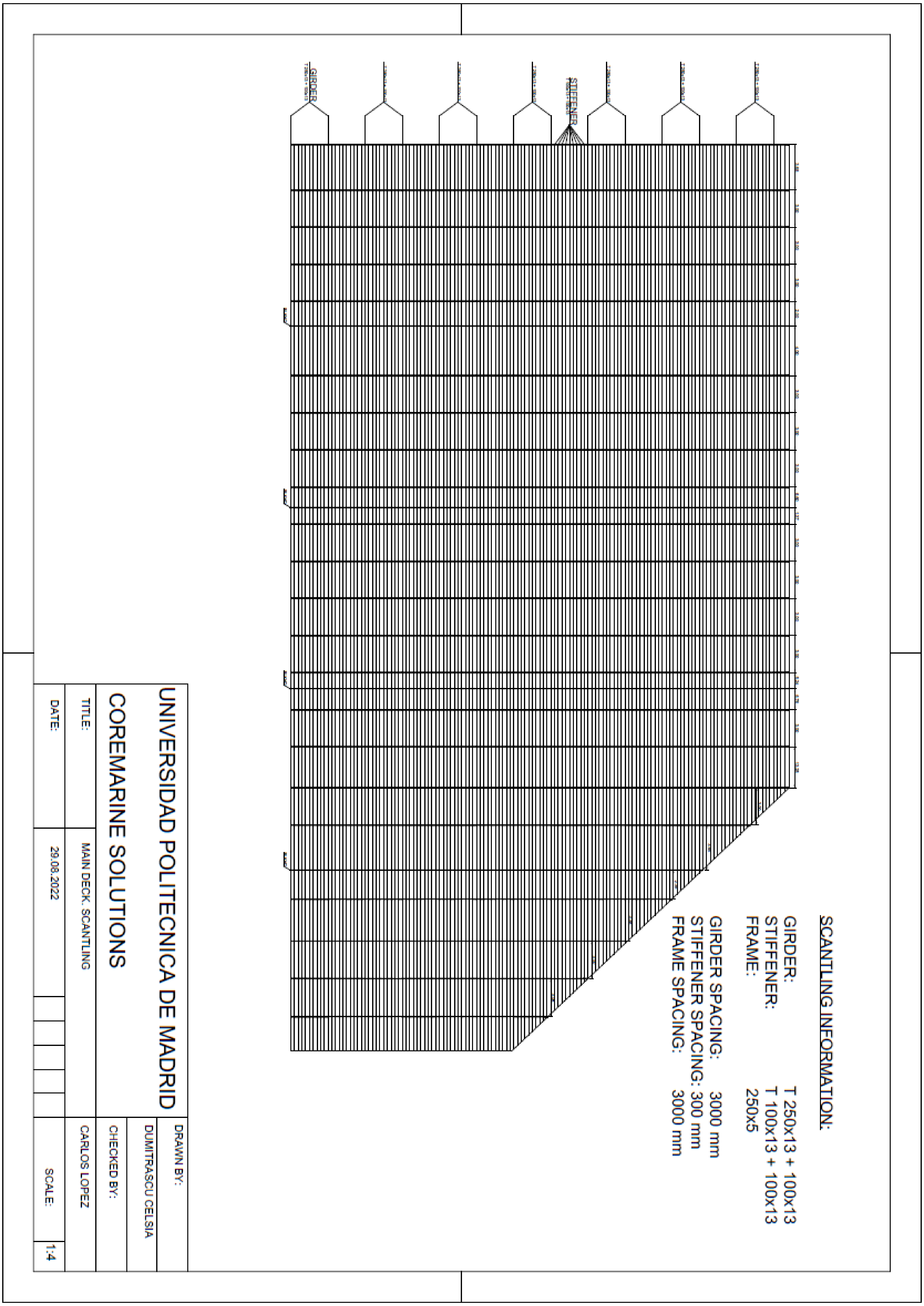


10.3 Annex 3. Midship Section. Scantling

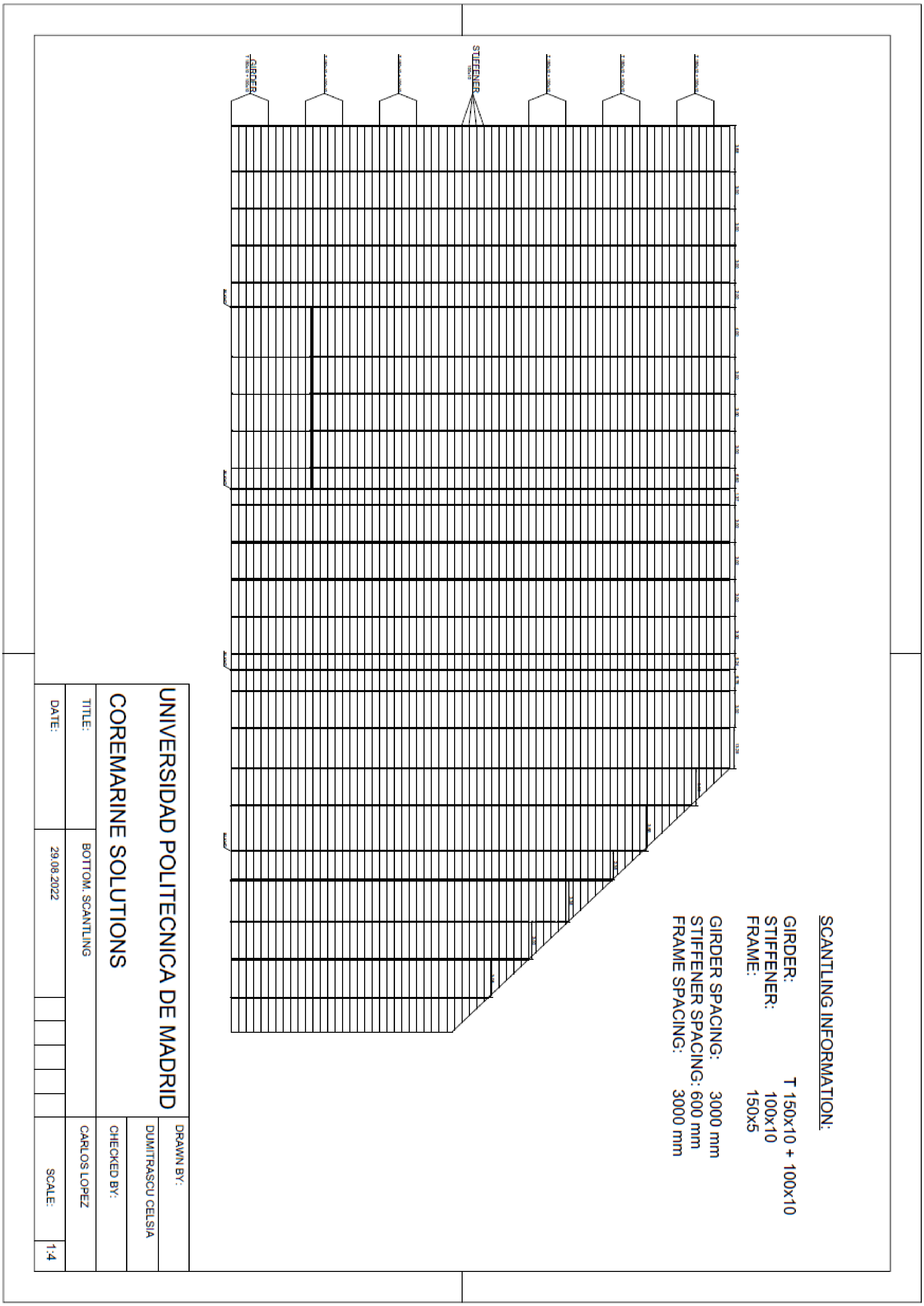



TRANSVERSAL FRAME (T profile):
DECK: 150x13 + 100x10 mm
SIDE: 100x10 + 100x10 mm
BOTTOM: 100x10 + 100x10 mm
Deck Frame
150x13 + 100x10
Bottom Frame
100x10 + 100x10
Side Frame
100x10 + 100x10
R2
UNIVERSIDAD POLITECNICA DE MADRID
COREMARINE SOLUTIONS
DRAWN BY:
DUMITRASCU CELSIA
CHECKED BY:
CARLOS LOPEZ
TITLE:
GENERAL ARRANGEMENT. PUMP ROOM
DATE:
29.08.2022
SCALE:
1:13

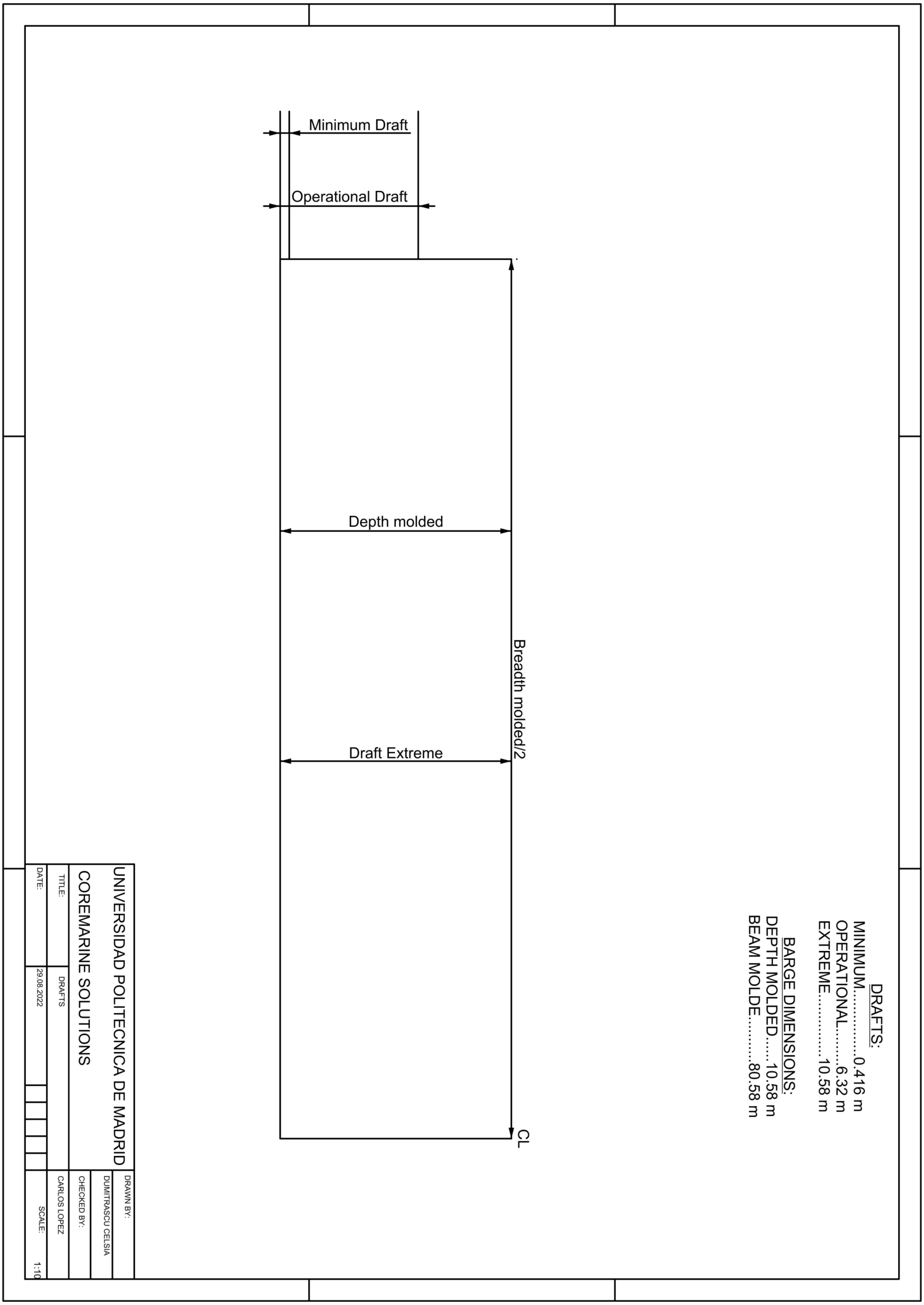
10.4 Annex 4. Main Deck. Scantling



10.5 Annex 5. Bottom. Scantling



10.6 Drafts


Minimum Draft
Operational Draft
Depth molded
Draft Extreme
Breadth molded/2
CL
DRAFTS:
MINIMUM............0.416 m
OPERATIONAL.......6.32 m
EXTREME............10.58 m
BARGE DIMENSIONS:
DEPTH MOLDED.....10.58 m
BEAM MOLDE.........80.58 m
UNIVERSIDAD POLITECNICA DE MADRID
COREMARINE SOLUTIONS
TITLE:
DRAFTS
DATE:
29.08.2022
DRAWN BY:
DUMITRASCU CELSIA
CHECKED BY:
CARLOS LOPEZ
SCALE:
1:10