



Research article

Preliminary Design of a 10,000-Ton Floating Dry Dock with a SIL-Based Dynamic Ballast Control System

Diseño preliminar de un dique seco flotante de 10 000 toneladas de capacidad de levante con un sistema de control dinámico de lastre basado en SIL

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Abstract: This work presents the preliminary design of a floating dry dock with a rated lifting capacity of 10,000 t, intended to operate in the Bay of Cartagena, Colombia. The design follows the ABS rules "Steel Floating Dry Docks" (January 2022) and checks the requirements for stability, structural strength, and minimum freeboard. The main dimensions were obtained from regressions built on similar vessels and floating docks, giving a maximum immersion draft of 14.91 m; together with the local bathymetry, this made Bajos de Pasacaballo (up to 18.5 m deep) the most suitable site. MAXSURF Modeler was used for the hull model and MAXSURF Stability to analyze five load cases. The structural weight was first estimated at 6,700 t, then adjusted to 7,073.02 t with the Harvald & Juncher method, and finally refined to 5,075.76 t after a more detailed take-off; the stability analyses used the lightweight based on the initial estimate (7,004.84 t), whereas the cost estimate used the refined take-off. The midship section was checked with MARS 2000, and the ballast dynamics were modeled as a damped motion under wave action and simulated in LabVIEW with local data. The estimated direct construction cost is about COP 123.74 billion. Within the scope of this preliminary design and the load cases analyzed, the dock meets the ABS stability, strength, and freeboard requirements that were checked, and Software-in-the-Loop (SIL) simulation provides a first approach to the study of its ballast control.

Keywords: Floating dry dock; Preliminary design; Software-in-the-Loop (SIL); Dynamic control; Ballast; Stability; Buoyancy

Resumen: Este trabajo presenta el diseño preliminar de un dique seco flotante con una capacidad de levante nominal de 10 000 t, previsto para operar en la bahía de Cartagena, Colombia. El diseño sigue las reglas ABS "Steel Floating Dry Docks" (enero de 2022) y verifica los requisitos de estabilidad, resistencia estructural y francobordo mínimo. Las dimensiones principales se obtuvieron mediante regresiones a partir de embarcaciones y diques flotantes semejantes, con un calado máximo de inmersión de 14,91 m; junto con la batimetría local, esto hizo de Bajos de Pasacaballo (hasta 18,5 m de profundidad) el sitio más adecuado. Se empleó MAXSURF Modeler para el modelo del casco y MAXSURF Stability para analizar cinco condiciones de carga. El peso estructural se estimó inicialmente en 6 700 t, se ajustó a 7 073,02 t con



el método de Harvald y Juncher y finalmente se refinó a 5 075,76 t mediante un cómputo más detallado; los análisis de estabilidad emplearon el peso en rosca basado en la estimación inicial (7 004,84 t), mientras que la estimación de costos empleó el valor refinado. La sección media se verificó con MARS 2000 y la dinámica del lastre se modeló como un movimiento amortiguado bajo oleaje, simulado en LabVIEW con datos locales. El costo directo de construcción estimado es de unos COP 123,74 mil millones. Dentro del alcance de este diseño preliminar y de las condiciones de carga analizadas, el dique cumple los requisitos de estabilidad, resistencia y francobordo de ABS verificados, y la simulación Software-in-the-Loop (SIL) constituye una primera aproximación al estudio del control de su lastre.

Palabras clave: Dique seco flotante; Diseño preliminar; Software-in-the-Loop (SIL); Control dinámico; Lastre; Estabilidad; Flotabilidad

1. Introduction

Colombia's shipbuilding industry faces a clear limitation: it lacks the infrastructure to build, repair, and maintain vessels of up to 10,000 t. This gap keeps the country from competing in the global market and slows its technological development in the maritime sector.

Floating dry docks are one of several solutions for lifting vessels out of the water, and their global market has been analyzed by type [5]. Other documented solutions include small floating docks, such as the 1,000 LT "Diver" dock in the Bahamas [1], slipway cradles able to haul out 1,800 t ships [3], and Syncrolift shiplift installations [4]. The design of floating dry docks is governed by classification-society rules, such as those of the American Bureau of Shipping [7], and has been addressed in terms of analysis and design [8], naval-architecture considerations [23], and the structural design and stability of a 6,000-ton dock under DNV-GL rules [12]. Other studies have developed deflection and inclination measuring systems for floating docks [14;25], have discussed wireless and optoelectronic systems for monitoring large structures [15;22], and have analyzed the dynamics of de-ballasting operations of a floating dock with a malfunctioning pump [26]. Regarding the testing of control systems, hardware-in-the-loop testing has been applied to marine control systems [20], and Software-in-the-Loop (SIL) simulation has been used to implement an autopilot for fixed-wing aircraft [18]. Locally, previous naval-design studies at Universidad Tecnológica de Bolívar (Cartagena) include the hull dimensioning of an interoceanic tug and its propulsion system [9] and the design and construction management plan of a crane-barge hull [10].

These studies differ from the case addressed here in capacity or classification rules (e.g., the 6,000-ton dock designed under DNV-GL rules by Gangadharan et al. [12]), in focus (structural monitoring, or the de-ballasting response under a specific pump malfunction [14;25;26]), or in application domain (SIL and hardware-in-the-loop testing applied to aircraft autopilots or to marine control systems in general [18;20]). None of the works cited addresses the preliminary design of a 10,000-ton floating dock for a Colombian site together with a SIL model of its ballast control, and the country still lacks this type of infrastructure.

To help close this gap, this work presents the preliminary design of a floating dry dock with a rated lifting capacity of 10,000 t. The dock uses an optimized box-shaped hull to maximize usable space and operating performance. Although floating docks are attractive because they can be moved between locations, the Bay of Cartagena was selected as the operating site, given the region's high volume of naval and commercial activity. Because reliable, efficient operation depends on the ballast system, the design integrates a SIL control scheme for the pumping system, intended to keep ballasting smooth and continuous. The contribution of the study is threefold: (i) the main dimensions, weights, drafts, freeboards, intact stability, and midship scantlings of the dock, checked against the ABS rules; (ii) a SIL model of ballast-tank filling with a proportional controller, implemented in LabVIEW as a first step toward dynamic ballast control; and (iii) an estimate of the direct construction cost. Beyond improving the operational capacity of Colombia's naval industry, this approach is intended to help strengthen the country's maritime capabilities and respond to the sector's growing demand. Section 2 describes the methodology, Section 3 presents and discusses the results, and Section 4 summarizes the conclusions.

2. Materials and Methods

The methodology starts by defining the dock's capacity, functional, and buoyancy requirements; researching the operating site and the vessels it will dock; validating the design against classification-society rules; checking buoyancy; and selecting the materials and components of the pumping system. Lines plans and 3D models were then produced for a box-type arrangement. The hull was modeled in MAXSURF Modeler, the load cases were analyzed in MAXSURF Stability, the midship section was checked with MARS 2000, and renders and drawings were produced in Rhinoceros.

In the next stage, the system is described with predictive mathematical models. The components of the SIL simulation are defined, and the control algorithm is integrated, in LabVIEW, with the models of the hydraulic system and of the dock motion, so that the control parameters can be tested and tuned (Section 3.13).

Finally, a market study and a cost estimate are carried out to size the project budget and assess its application. Figure 1 summarizes the full workflow.

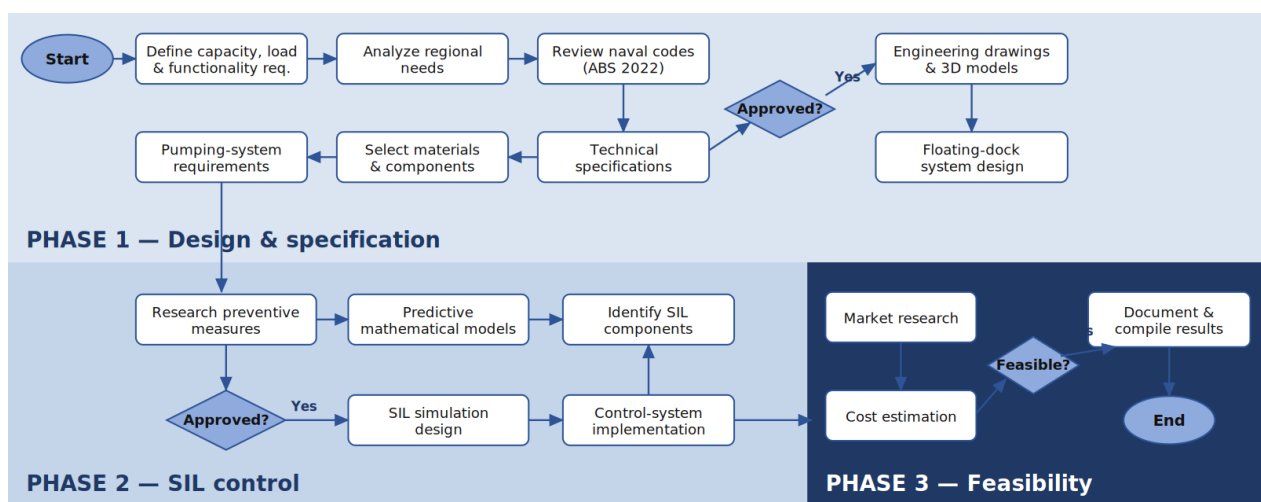


Figure 1. Proposed methodology.

Source: The authors.

3. Results and Discussion

This section presents and analyzes the results obtained by applying the methodology described above. It considers the variables and assumptions defined earlier—including the selected models and techniques—to keep the methodological approach and the results consistent. The impact of each factor is discussed, along with the main limitations and a critical view of the validity and applicability of the results.

3.1. Preliminary design of the floating dry dock

The preliminary design was structured around the requirements of the operating site, the functional requirements of the vessels to be docked, and the safety and stability criteria set by the ABS rules [7]. Considering the maximum immersion draft (14.91 m; Table 8) and the local bathymetry, Bajos de Pasacaballo, in the Bay of Cartagena (up to 18.5 m deep), was selected as the most suitable site; the sedimentological and morphological characterization of the bay is reported by Villanueva García et al. [24].

3.2. Regression of similar vessels and docks

We first collected data on vessels with a displacement close to the rated lifting capacity, taking into account their draft relative to the depth of the protected waters of the Bay of Cartagena (Table 1). The goal was to find the characteristic dimensions of the vessels to be lifted: the average displacement sets the maximum

lifting capacity, the length sets the maximum keel-block length, the mean beam is the basis for the working area and the clear distance between wing walls, and the average draft sets the maximum immersion draft and the dock height.

Table 1. Characteristics of similar vessels.

Source: The authors.

Name	L_{bp} (m)	B_s (m)	d_s (m)	DWT (t)	LWT (t)	Δ (t)	Type
Yerupaja	140.0	23.00	5.51	11,863	1,772.6	13,635.6	Container
Asian Trader	148.0	23.00	6.03	13,732	2,051.9	15,783.9	Container
Arabella	107.5	18.00	7.10	7,703	3,127.0	10,830.0	Tanker
Belisaire	124.3	20.00	6.75	12,680	1,083.0	13,763.0	Tanker
Lachin	137.1	16.90	4.54	7,875	2,536.0	10,414.0	Tanker
Golfo dei Coralli	179.2	25.00	4.33	7,100	8,825.0	15,925.0	Ro-Pax ferry
Navis-1	116.8	16.50	7.75	6,328	2,266.0	8,594.0	Dry cargo
Knight	128.6	21.00	7.48	8,837	7,737.0	16,574.0	Deepwater cable layer
Mega Express	159.7	24.80	4.46	3,500	11,000.0	14,500.0	Ferry
Azervayan	148.0	17.50	4.91	5,757	4,681.0	10,438.0	Rail & car ferry
Aranui 5	117.0	22.20	5.25	4,021	6,467.0	10,488.0	Cargo cruise ship
Marem Mols	125.3	24.00	6.00	4,030	5,537.0	9,567.0	Ro-Pax ferry
OHS Achiever	117.7	22.00	6.75	7,486	5,574.0	13,060.0	Multipurpose support
Bergen Star	81.5	16.50	6.20	4,400	2,100.0	6,500.0	Tanker
Mega Express II	159.7	24.80	6.55	3,500	11,000.0	14,500.0	Ferry
Blue Ivy	131.2	15.87	7.68	10,297	3,220.0	13,517.0	General cargo
Ocean Trader	103.0	18.20	8.22	9,705	6,668.0	16,373.0	General cargo
Sea Explorer	96.6	16.24	6.70	5,528	3,801.0	9,329.0	General cargo
Breb Cuxhaven	103.9	18.47	7.01	7,815	3,169.0	10,984.0	General cargo
Mistral	143.8	20.60	7.00	7,478	5,258.0	12,736.0	Ro-Ro cargo

Averaging these values gives the main dimensions used for the maximum lifting capacity and the keel-block length (Table 2).

Table 2. Average dimensions of the similar vessels.

Source: The authors.

Average dimension	Value
Length, L (m)	128.45
Beam, B (m)	20.23
Draft, d_s (m)	6.31
Displacement, Δ (t)	12,375.6

We then compiled data on similar floating docks whose lifting capacity (LC) is around 10,000 t (Table 3).

3.3. Main dimensions

Combining the analyses above yields the consolidated main dimensions of the floating dry dock (Table 4).

3.4. Lifting capacity, permanent water, and compensating ballast

Following the ABS rules “Steel Floating Dry Docks” (January 2022), a rated (nominal) lifting capacity must be defined—here, 10,000 t. A maximum lifting capacity is also required; based on the mean displacement of the similar vessels (Table 2), it was set at 12,375.6 t. The dock must lift and hold these weights safely while keeping a minimum pontoon freeboard at both capacities (Table 9).

Table 3. Main particulars of similar floating docks.

Source: The authors.

Name	L_p (m)	B (m)	H_t (m)	LC (t)
Dubai Drydocks	205.50	43.00	13.10	15,000
Bai Yun Shan, Shanghai	190.00	26.90	13.00	11,500
Hai Hua	192.00	40.50	14.40	12,000
SOCIBER, Valparaíso, Chile	167.10	26.10	5.60	10,000
IPP Eng. / TLG, Hamburg	164.00	33.40	15.63	6,000
Floating dock, Port Blair, India	188.70	40.00	15.50	11,500
SINE 212CD dock	190.00	42.00	13.00	10,000
Gorodets shipyard, Russia	158.00	36.85	13.35	8,000
Metalships & Docks	162.00	30.80	14.80	8,000
Shipyard Yantar JSC	150.00	29.00	17.70	12,000

Table 4. Main dimensions of the proposed dock.

Source: The authors.

Main dimensions	Value
Overall length, L_m (m)	140
Keel-block length, L_{kb} (m)	128.45
Overall beam, B (m)	38
Internal beam, B_I (m)	31
Wing-wall width, b (m)	3.50
Working beam, B_s (m)	20.23
Block coefficient factor, C	5.3855
Total height, H_t (m)	16
Pontoon height, H (m)	5
Wing-wall height above pontoon, H_p (m)	11
Pontoon-deck camber (m)	0.0155
Keel-block height (m)	1.8
Safety draft margin, H_s (m)	7.870

Permanent water—the trapped water that cannot be pumped out of the ballast tanks—is estimated at 3,000 t, corresponding to a 0.5 m level in the tanks.

The critical distances for the compensating ballast were defined from the smallest vessel whose displacement is close to the rated lifting capacity; among the selected vessels, Arabella meets these criteria (10,830 t, 107.5 m length, 18 m beam). With $x_L = 13.435$ m and $x_T = 5.584$ m, the compensating ballast is $CW_L = 1,177.92$ t (longitudinal) and $CW_T = 4,007.78$ t (transverse). The larger, transverse ballast is used for the load-case study.

3.5. Lightweight and deadweight estimation

Based on data from similar floating docks, the dock structure (structural weight) is estimated at 6,700 t; adding the fixed auxiliary equipment gives a total lightweight of 7,004.84 t (Table 5).

As a cross-check, the structural weight was also computed with the Harvald & Juncher method, an empirical method developed for ships, giving 7,073.02 t (Table 6); empirical lightship-mass calculation methods for merchant ships are discussed by Slapničar et al. [21].

A final, more detailed take-off gives a structural weight of 5,075.76 t, considered the most realistic figure, although it is about 24% lower than the initial estimate of 6,700 t. This last value already includes additional structural elements such as piles and brackets, so the total could be somewhat higher.

The weights adopted in each analysis are as follows. The drafts in Table 8, the stability analyses (Section 3.9), and the SIL simulations (Section 3.13) use the lightweight of Table 5 (7,004.84 t), which is based on the initial structural estimate of 6,700 t. The refined take-off (5,075.76 t) is used as the installed weight in

Table 5. Lightweight estimate.

Source: The authors.

Category	Weight (t)	Description
Dock structure	6,700.00	Main structure of the dock
Generators (2)	10.00	Two 255 kW generators
Bilge pumps (4)	6.40	Electric pumps, 1,600 m ³ /h each
Bilge / GS / FiFi pumps (4)	8.00	Electric pumps VM-EP 50/20
Cooling-water pumps (3)	2.40	VM-EP 50/20, 22 m ³ /h
Anchor	2.14	2,140 kg anchor
Capstans (4)	40.00	10 t each
Mooring winches (2)	40.00	20 t each
Cranes (2)	20.00	10 t each
CO ₂ system	1.50	For the generator room and switchboards
Outfitting	174.40	Piping
Total lightweight	7,004.84	

Table 6. Structural weight—Harvald & Juncher method.

Source: The authors.

Parameter	Value
Dock structure (t)	7,073.02
C _s	0.08
U	2.42
Sup (m ³)	5,327.68

the construction cost estimate (Section 3.14). The effect of the refined structural weight on drafts and stability was not evaluated at this preliminary stage.

The operational deadweight groups all the variable weights: transverse compensating ballast, wastewater, crew, and other variable items. The crew is set at 45 people with an average weight of 75 kg, distributed across both wing walls. Other variable weights include provisions, temporary materials, mobile equipment, loose tools and gear, welding cables, gas-cutting hoses, gas cylinders, staging for the docked ship, a cherry picker, a forklift, waste and scrap containers, paint buckets, and miscellaneous items. Only the transverse compensating ballast is considered for stability. Table 7 summarizes the estimated weights.

Table 7. Operational deadweight estimate.

Source: The authors.

Item	Weight (t)	
Longitudinal compensating ballast, CW _L *	1,177.92	
Transverse compensating ballast, CW _T	4,007.78	
Oils	9.45	
Fresh water	1.00	
Sewage	1.20	* Longitudinal ballast is excluded
Sludge	5.50	
Bilge water	8.20	
Persons on board (45 × 75 kg)	3.38	
Other variable weights	75.00	
Total operational deadweight**	4,111.50	

from the total, which is based on the transverse ballast used for stability. ** Sum of transverse ballast and variable weights.

3.6. Drafts and freeboards

Table 8 lists the drafts for the five load cases (a–e) of the preliminary design, together with the operational draft at the rated lifting capacity (e'). The lightship draft (a) corresponds to the lightweight (7,004.84 t; Table 5) plus the permanent water (3,000 t); the operational drafts (e and e') additionally include the operational deadweight (4,111.50 t; Table 7) and the maximum (12,375.6 t) or rated (10,000 t) lifting capacity, respectively. The minimum freeboards required by ABS were also computed and are compared with the defined values in Table 9.

Table 8. Drafts for the load cases.

Source: The authors.

Load case	Draft	Value (m)
a	Lightship draft (with permanent water), T_{lwt}	1.83
b	Maximum immersion draft, T_s	14.91
c	Keel-block top draft, T_{kb}	6.80
d	Pontoon-deck draft, T_p	5.00
e	Operational draft (max. LC), T_w	4.86
e'	Operational draft (rated LC), T'_w	4.42

Table 9. Defined vs. ABS-required freeboards.

Source: The authors.

Freeboard	Defined (m)	ABS min. (m)
Total, F_t	1.14	1.00
Pontoon at rated LC, F_p	0.58	0.30
Pontoon at max. LC, F_p	0.14	0.075

3.7. Keel blocks

Using data from similar docks, the keel-block characteristics were estimated as shown in Table 10.

Table 10. Keel-block characteristics.

Source: The authors.

Characteristic	Value
Height (m)	1.80
Width (m)	1.219
Length (m)	0.914
Total weight (t)	476.75

3.8. Ballast-tank arrangement

The floating dock has 28 ballast tanks—14 of them J-type and the rest conventional. The arrangement was designed in MAXSURF, as shown in Figure 2.

3.9. Stability: hydrostatics and load cases

Hydrostatic curves were generated in MAXSURF over the full range of operating drafts, from the lightship draft to the maximum immersion draft, to check compliance with the intact-stability criteria (2008 Intact Stability Code) and the ABS requirements. The first MAXSURF load case considers only the dock's lightweight (7,004.84 t; Table 5), without permanent water. In this condition the draft is 1.288 m and the initial metacentric height (GM) is 79.069 m, which satisfies the ABS criterion ($GM > 1$ m); the righting-arm



Figure 2. Ballast-tank arrangement (MAXSURF): plan view of the 28 ballast tanks (top) and transverse section (bottom). Source: The authors.

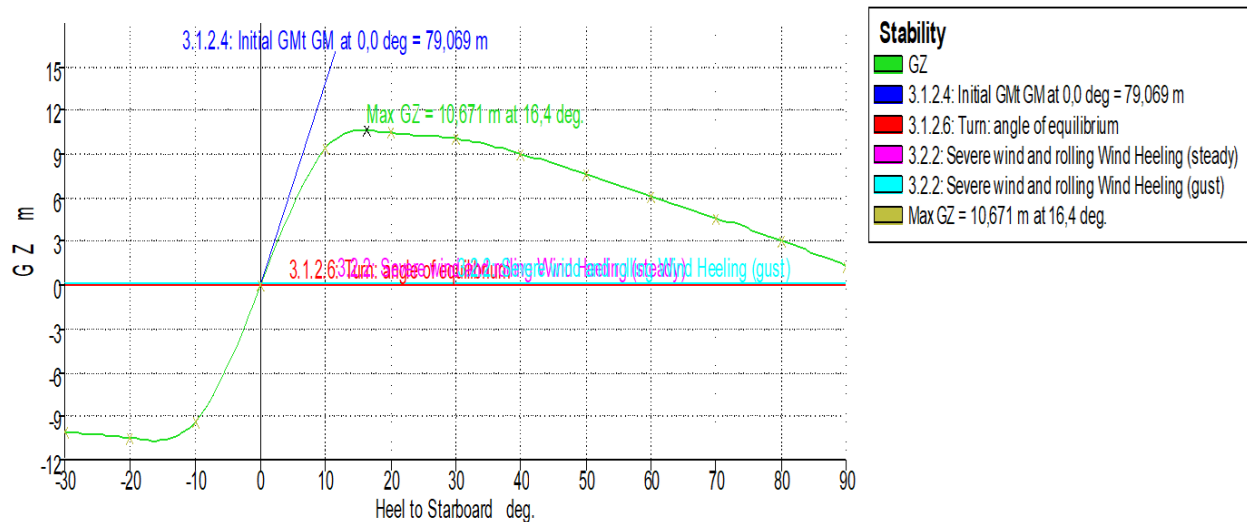


Figure 3. Intact-stability (GZ) curve for the lightweight-only case without permanent water (MAXSURF): draft 1.288 m, initial GM 79.069 m, maximum GZ 10.671 m at 16.4°.

Source: The authors.

curve reaches its maximum GZ of 10.671 m at 16.4°, and all the intact-stability criteria evaluated are satisfied (Figure 3).

The stability curves for the five load cases are plotted together in Figure 4 to show how stability changes across cases and to guide ship loading.

The metacentric heights for each case were also estimated in spreadsheets as $GM = KB + BM - KG$ [19], and all comply with the rules: 62.9 m for the lightship condition with permanent water (a), 8.43 m for maximum immersion (b), 5.00 m for holding the dock at the top of the keel blocks (c), 17.97 m for the pontoon-deck level (d), and 18.12 m for the operational condition at maximum lifting capacity (e). Each case therefore has a positive initial stability that meets the rule and is in line with typical values for 10,000-ton floating docks [23]. Table 11 lists the KG and BM used for each case.

The lightweight-only MAXSURF case (Figure 3) and load case a do not represent the same condition. Load case a is the lightship condition with the 3,000 t of permanent water retained in the tanks (Section 3.4),

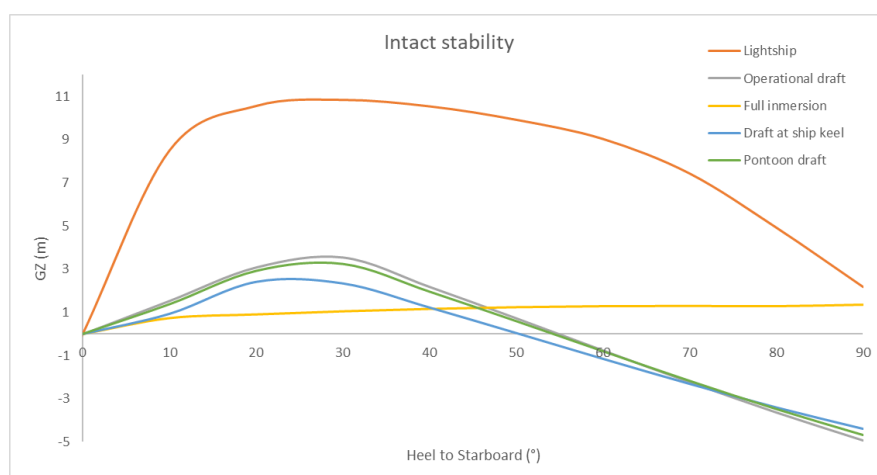


Figure 4. Intact-stability (GZ) curves for the five load cases. Legend labels: Lightship (a), Full immersion (b, maximum immersion), Draft at ship keel (c, keel-block top), Pontoon draft (d, pontoon deck), and Operational draft (e).

Source: The authors.

which is also the final stage of the deballasting sequence (Figure 5, “Lightship + permanent ballast”); its draft is 1.83 m (Table 8) and its spreadsheet GM is 62.9 m. The MAXSURF case considers the lightweight alone (7,004.84 t), which gives the lower draft of 1.288 m. For the wall-sided box pontoon, the ratio between both drafts ($1.83/1.288 \approx 1.42$) agrees with the ratio between the corresponding displacements ($((7,004.84 + 3,000)/7,004.84 \approx 1.43)$), and the BM of case a in Table 11 (65.69 m) agrees with the value $B^2/(12T)$ for a box section with $B = 38$ m and $T = 1.83$ m (65.76 m). The initial GM obtained in MAXSURF for the lightweight-only case (79.069 m) therefore corresponds to a different loading condition from that of case a (62.9 m) and was obtained with a different tool; the two values are not directly comparable, and both satisfy the ABS criterion ($GM > 1$ m).

Table 11. KG and BM per load case (spreadsheet calculation).

Source: The authors.

Load case	KG (m)	BM (m)
a – Lightship (with permanent water)	3.61	65.69
b – Maximum immersion	4.12	8.16
c – Keel-block top	7.97	10.33
d – Pontoon deck	8.60	24.07
e – Operational (max. LC)	9.08	24.77

3.10. Suggested deballasting sequence

Ballasting and deballasting change the weight distribution and can produce excessive shear forces or bending moments that put the dock at risk. Figure 5 shows the suggested deballasting sequence, from full immersion (b) to the lightship condition with permanent water (a). From the shear-force and bending-moment analysis of this sequence, the maximum bending moment is 65,000 t·m—a key input for the section modulus required by the rules.

3.11. Structural analysis: scantlings and section modulus

Following the ABS rules [7], for a maximum bending moment of 65,000 t·m the minimum midship section modulus is 2.24 m³. Plate thicknesses for the dock hull and the stiffener profiles were then defined following ABS Section 3-2-3; the stiffeners improve buckling resistance and overall structural integrity under the various load cases. HEA profiles were used for the bottom and decks, and equal-leg L angles for the walls; the span (the effective width between supporting members) was set according to the designer’s criterion.

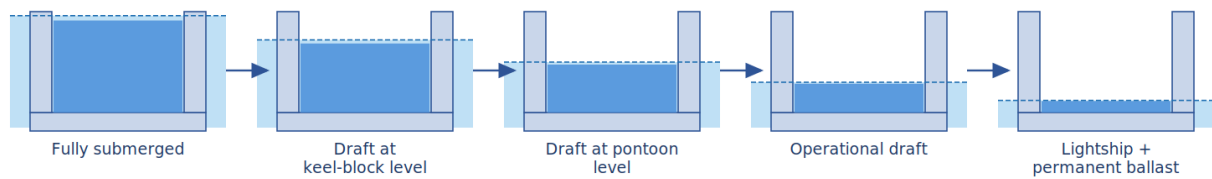


Figure 5. Suggested deballasting sequence, from full immersion (b) to the lightship condition (a); “permanent ballast” denotes the permanent water defined in Section 3.4.

Source: The authors.

With MARS 2000, the midship scantlings—with longitudinal stiffeners only—give a section modulus of 10.089 m^3 (Figure 6), about 4.5 times the minimum required.

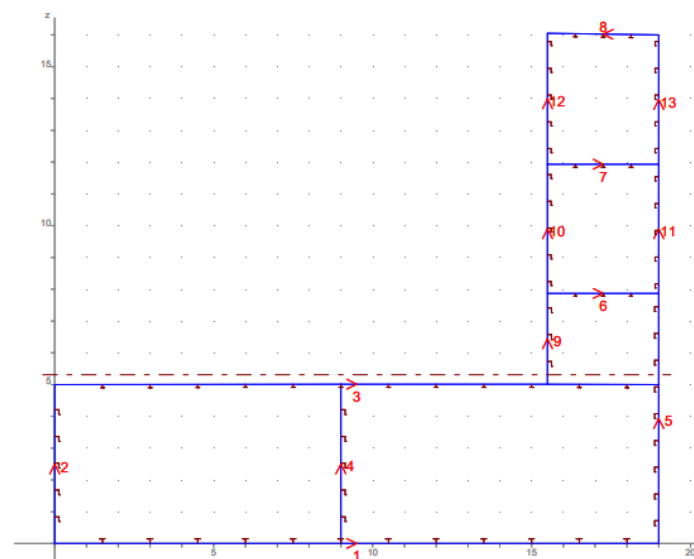


Figure 6. Midship-section scantlings (half-section) of the 10,000-ton dock (MARS 2000).

Source: The authors.

3.12. 3D render

At this preliminary stage, Rhinoceros was used to obtain renders and drawings of the floating dock (Figure 7).

3.13. SIL results: dynamic ballast control

Following the SIL methodology (Figure 1, Phase 2), the equations of the hydraulic (tank-filling) system and of the dock motion were solved to estimate the dock's inclination for a given tank fill level. The ballast dynamics were modeled as a damped motion under wave action and simulated in LabVIEW with local data. A block diagram of a proportional (P) controller for tank filling was built in LabVIEW (Figure 8) as a first approximation to the general arrangement of 16 water tanks. For each load case, the corresponding KG and BM values were used (Table 11). As shown on the front panels in Figure 9, the model inputs are the KG and BM of the load case, the openings of the inlet valve and of the outlet valve (“Outlet Valve 2”), and the time step dt ; the outputs are the tank water level, the signal labeled h_{n+1} , and the pitch frequency ω , which are plotted on a waveform chart, while the tank indicator shows the current water level.

For simplicity, a single box-type ballast tank 5 m high (the pontoon depth, up to the pontoon deck) is considered, and only the pitch degree of freedom is analyzed. Figure 9 shows the front panel for each load case: (a) lightship, (b) maximum immersion, (c) keel-block top, and (d, e) pontoon deck and operational,

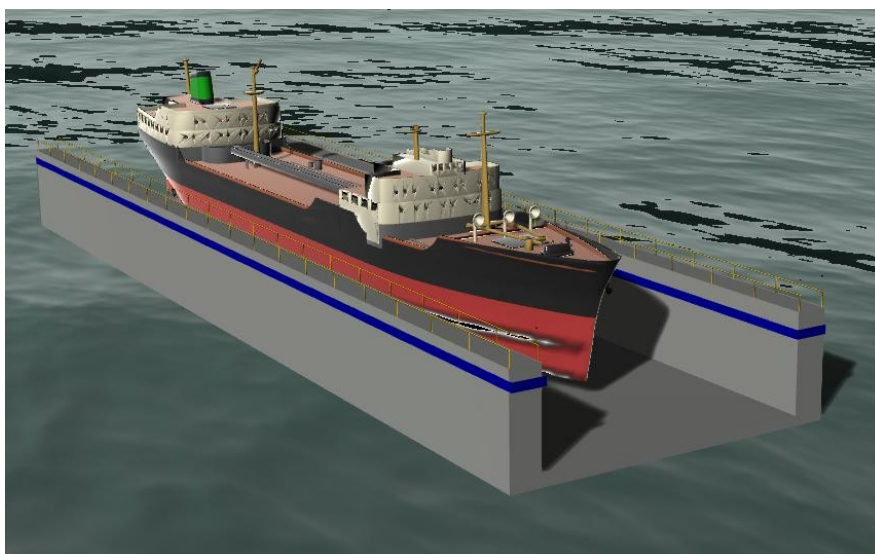


Figure 7. 3D render of the floating dry dock (Rhinceros).

Source: The authors.

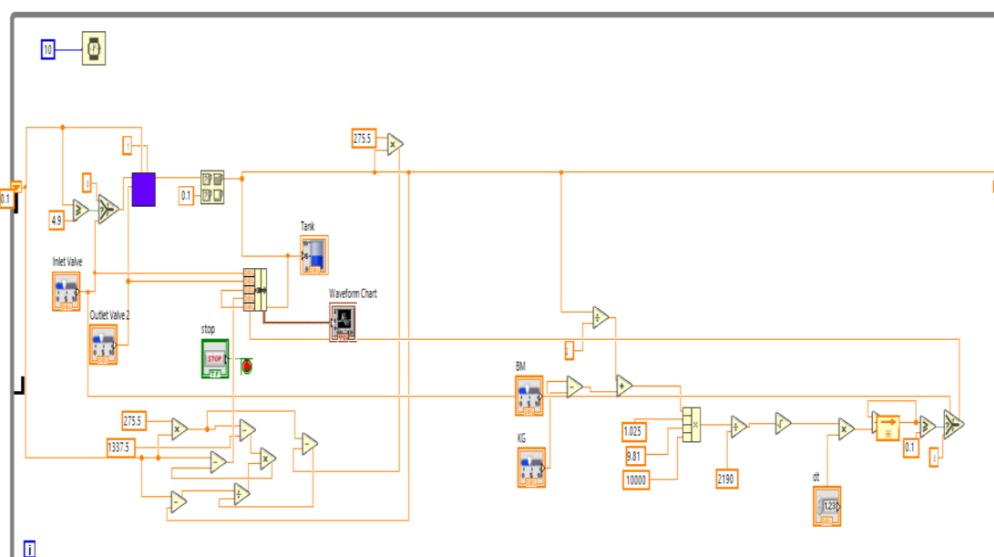


Figure 8. Block diagram of the P controller for tank filling (LabVIEW).

Source: The authors.

which share one panel. In all cases, with $dt = 6$, the water level (green curve) rises monotonically, without overshoot or oscillation, and levels off below the 5 m tank height; the tank indicators show levels of 4.629 m (a), 4.626 m (b), 4.627 m (c), and 4.623 m (d, e) when the simulation was stopped. Over the plotted interval (about 100 time units in each panel), the pitch frequency ω (magenta line) remains practically constant. The filling response is therefore nearly identical for all load cases, and the differences in KG and BM between cases (Table 11) produce no visible change in the level curve within the simulated interval. Cases d and e are shown together because their drafts (5.00 m and 4.86 m; Table 8) and their KG and BM values (Table 11) are very close. These results show that, under the simplifying assumptions adopted, the P controller fills the tank smoothly and stably; they do not yet describe the dynamic response of the complete ballast system.

Compared with previous work, the SIL model presented here is a simplified first approximation. Zhang et al. [26] analyzed the dynamics of de-ballasting operations of a floating dock with a malfunctioning pump, whereas the present model considers a single ballast tank, a P controller, and the pitch degree of freedom only,

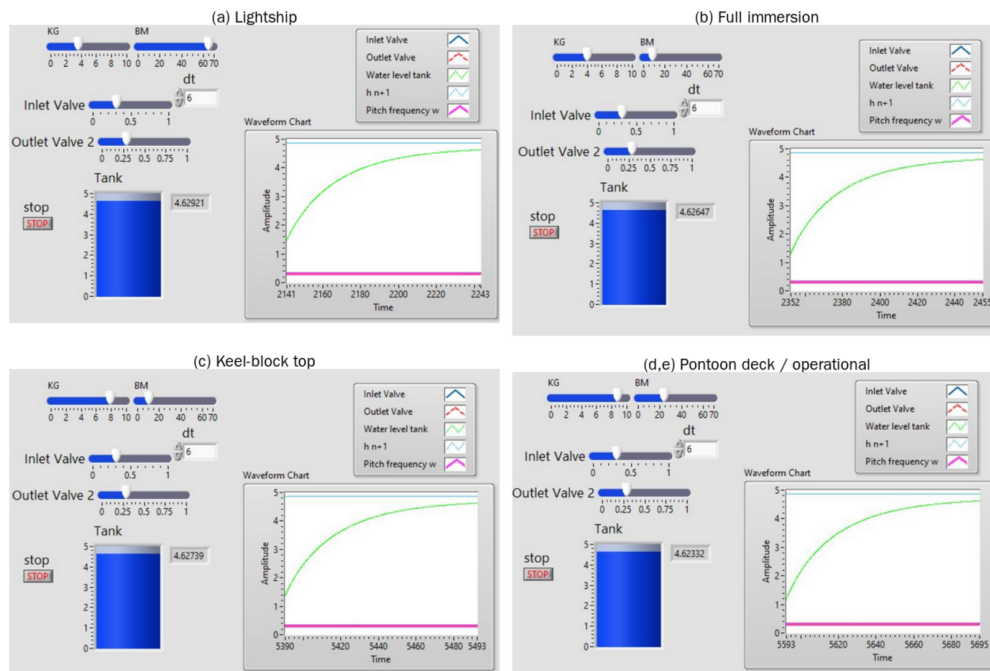


Figure 9. LabVIEW front panels of the SIL simulation of single-tank filling for load cases a–e: (a) lightship; (b) maximum immersion (labeled “Full immersion”); (c) keel-block top; (d, e) pontoon deck and operational. Green: tank water level; magenta: pitch frequency ω ; KG and BM from Table 11.

Source: The authors.

and does not analyze failure scenarios. Likewise, SIL simulation has been used to implement an autopilot for fixed-wing aircraft [18], and hardware-in-the-loop testing has been applied to marine control systems [20]; the present study applies the SIL approach to the ballast control of a floating dock at a preliminary level. Extending the model to all ballast tanks, to three degrees of freedom, and to failure scenarios such as the one analyzed by Zhang et al. [26] would allow a quantitative comparison with those studies.

3.14. Construction cost estimate

Material costs cover plates, structural profiles, and piping; they total about COP 28.31 billion (Table 12). Fixed-equipment costs—based on the unit price and quantity of each item—total about COP 2.76 billion (Table 13). Other resources (labor, cleaning and painting, support equipment, welding, oxygen, gas, general services, quality control, and technical management) are estimated from a price per installed kilogram applied to the total installed weight, which corresponds to the refined structural weight (5,075,765 kg, i.e., the plates and structural profiles in Table 12), and total about COP 92.67 billion (Table 14). The total direct construction cost is therefore about COP 123.74 billion (Table 15).

Table 12. Material cost estimate (COP).

Source: The authors.

Material	Weight / length	Unit price	Total
Plates, A131	2,053,910.6 kg	5,221.40 /kg	10,724,186,671.34
Structural profiles, A36	3,021,854.5 kg	5,659.99 /kg	17,103,665,564.87
Piping	1,500 m	322,997.25 /m	484,495,875.00
Total			28,312,348,111.21

Table 13. Fixed-equipment cost estimate (COP).

Source: The authors.

Fixed equipment	Qty	Total price
Generators	2	37,037,018.00
Bilge pumps	7	753,660,250.00
Bilge pumps (VM-EP)	4	17,217,906.74
Anchors	2	8,613,260.00
Capstans	4	86,123,986.74
Winches	2	179,402,226.88
Cranes	2	1,678,654,951.12
Total		2,760,709,599.48

Table 14. Other-resources cost estimate (COP). Installed weight = 5,075,765 kg for every item.

Source: The authors.

Other resources	Price /kg	Total
Labor	6,052.11	30,719,079,073.10
Cleaning and painting	6,052.11	30,719,079,073.10
Support equipment	2,017.37	10,239,693,024.37
Welding	706.08	3,583,892,558.53
Oxygen	806.95	4,095,877,209.75
Gas	201.74	1,023,969,302.44
General services	1,008.68	5,119,846,512.18
Quality control	605.21	3,071,907,907.31
Technical management	806.95	4,095,877,209.75
Total		92,669,221,870.51

Table 15. Total direct construction cost (COP).

Source: The authors.

Item	Total (COP)
Total materials	28,312,348,111.21
Total fixed equipment	2,760,709,599.48
Total other resources	92,669,221,870.51
Total direct cost	123,742,279,581.20

4. Conclusions

By compiling data on similar vessels, we obtained a mean displacement of 12,375.6 t, which was adopted as the maximum lifting capacity of the dock (rated lifting capacity: 10,000 t) and used in the stability calculations for the five load cases. The structural weight was first assumed from data on other floating docks (6,700 t), then estimated with the Harvald & Juncher method (7,073.02 t)—a method focused on ships—and finally refined to 5,075.76 t after a more detailed take-off. The spread among these three estimates shows the uncertainty involved at this preliminary stage; the last value already includes extra structural elements such as piles and brackets, so the real weight could be higher. The drafts, stability analyses, and SIL simulations were performed with the lightweight based on the initial estimate (7,004.84 t), whereas the cost estimate uses the refined take-off.

In terms of structural strength, the midship section modulus obtained with MARS 2000 (10.089 m³) exceeds the ABS minimum of 2.24 m³ for the maximum bending moment of the suggested deballasting sequence (65,000 t·m). In terms of stability, the initial metacentric height is positive and meets the rule requirement in the five load cases analyzed, and the intact-stability criteria evaluated in MAXSURF are

satisfied for the lightweight-only case (Figure 3). These results apply to the load cases, weights, and deballasting sequence considered in this preliminary design; compliance of all load cases with the 2008 Intact Stability Code should be confirmed in the detailed design stage.

The SIL model built in LabVIEW, with a P controller acting on a single 5 m box-type ballast tank and considering only the pitch degree of freedom, produced a smooth, monotonic filling response for all load cases. This result supports the use of SIL simulation as a first tool for studying the ballast control of the dock, but it does not yet demonstrate efficient and safe control of the complete ballast system during operation. The analysis should therefore be extended to all tanks and to the global response in three degrees of freedom (pitch, roll, and heave).

The direct construction cost is estimated at about COP 123.74 billion, based on the refined structural weight. This figure is a first approximation of the direct investment required and does not by itself establish the economic feasibility of the dock; assessing feasibility would require a more detailed study that includes indirect costs—permits, environmental studies, and long-term operation and maintenance.

Finally, a self-docking arrangement could be considered as an alternative to the box type proposed here. Because the structure is exposed to the corrosive environment of the Bay of Cartagena, such an arrangement could ease maintenance and allow more effective preventive management of structural corrosion; however, since this study did not compare both arrangements, this option should be evaluated in future work.

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