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Simulation to adjust the draft of RO-RO pontoon

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Abstract. Floating pontoon berthing facilities are used by RO-RO ships and ferries to provide temporary or semi-permanent docking and loading/unloading capabilities. In order to accommodate ships having various freeboards, especially during operating heavy weights, it may be necessary to adjust the draft of the pontoon. In this article, the authors propose a software for calculating the draft of a RO-RO pontoon that retrieve, process and transmit data for the operations of adjusting the draft using of a programmable logic controller. The RO-RO pontoon we are referring to has actually a manual operation of the ballast installation. The software is implemented and simulated using the Codesys application. By introducing the command system, the work performed by the human operator is automatically facilitated, reducing the number of workers, decreasing the risks following the wrong maneuvers performed by the operator. This study establishes the foundations for future experimental procedures.

Introduction

Despite being under staff supervision, floating pontoons serve as public access points and maintain the connection between the land and the sea [1].

The pontoon types covered in this workpaper are RO-RO pontoons (Fig. 1). For RO-RO ships, they are utilized for vehicle loading and unloading. The stability of floating structures can be affected by various factors, including the object's weight, draft (It is represented by the vertical distance between the lower face of the bottom plates, without considering the keel or other fixed points and the plane of the water level), shape, and the high of the submerged portion. This contrasts with ships, which can only be operated efficiently at small heel angles [2,3].

The regulation of the pontoon's draught is done by a seawater ballasting/de-ballasting installation in/from the dedicated tanks in its construction. The ballast installation present on board the pontoon is a manually operated installation that consists of two electric pumps, a piping system for each tank and a system of electrically operated valves controlled from the control panel dedicated to this system. This actuation system is outdated compared to maritime vessels, including RO-RO ships that have an automated ballast/de-ballast system integrated on board. Additionally, the actuation of the ballast systems on board these vessels can also be managed through software that calculates cargo loads, which adds even greater value to the ballast system onboard the ships.

Despite the additional costs in the case of the automated system, but the reduction of human and crew errors, this paper will illustrate both types of installations applied in the case of the pontoon for mooring RO-RO ships. Draft stabilization and regulation installations that have an automation system consist of a PLC (Programmable Logic Controller) and a set of sensors: level sensors, pressure sensors, flow sensors, etc.

Fig. 1 Current pontoon structure in use for ro-ro ship mooring operations

Draft stabilization and regulation systems that have an automation system consist of a PLC (Programmable Logic Controller) and a set of sensors: pressure sensors, flow sensors, level sensors, etc. [4].

Manual operation of the RO-RO pontoon draft adjustment system

The draught control system, also known as the ballast system, with manual operation consists of one or more pumps that are operated locally or remotely and a set of manually operated valves. By combining closed and open valves, ballast tanks can be filled or emptied.

Fig. 2 Onboard ballast manually operated control valve system

Instead of the manual valves shown above (Fig. 2) electrically operated, electro-pneumatic, electro-hydraulic valves, etc. can be used. Although they are valves that bring a contribution to their ease of operation, the closing or opening operation falls into the category of manual actuation, since a human operator is needed to carry out these commands [5].

Ballast installation present on board the RO-RO pontoon

The ballast installation installed on board the RO-RO pontoon consists of two ballast pumps, remotely operated electric valves and the piping related to the installation.

The power supply and start/stop control are done by means of a soft starter, the electric motors related to the pumps being connected in a delta connection. The MSB [Main switchboard] is presented in Fig. 3.

Fig. 3 Main electrical switchboard of the pontoon: open and closed states

Automatic operation of the RO-RO pontoon draft adjustment system

The ballast plant can be automated by introducing a PLC (Programmable Logic Controller) that can take data, process data and transmit data. The role of the PLC is to facilitate the work of the personnel, to display more information than that provided by the manual system and to perform more precise maneuvers than that of the human operator, eliminating human error. However, it must be taken into account that errors may occur within the system including hardware malfunctions, which would require the intervention of authorized personnel.

For the writing of the automatic ballasting software, the Codesys [6] program was used. The software is written in two programming languages:

1. Ladder Logic (LD): This programming language is primarily used for developing software for programmable logic controllers (PLCs). It employs graphical representation similar to hardware logic circuit diagrams, resembling a ladder with vertical rails and horizontal rungs [7].
2. Structured Text (ST): A high-level programming language with syntactical similarities to Pascal, ST is part of the IEC 61131-3 standard aimed at standardizing PLC programming languages. Its flexibility and intuitive design make it suitable for control algorithms and complex mathematical tasks, offering efficiency comparable to Ladder Logic [8].

For the PLC to be able to calculate the draft, it needs more input data: the capacity of the ballast storage tanks, input data from the pontoon stability calculation, information from sensors etc.

To enable the software to function in absence of physical level sensors, a sensor simulator was incorporated within the system. Given that multiple types of sensors can be utilized, the next section will introduce the ToughSonic 30 Level & Distance Sensor as a representative example. (Fig. 4)

ToughSonic 30 Level & Distance Sensor employs ultrasonic sound waves for measuring distances in the air. This innovative technology offers various benefits over optical, mechanical, and radar systems. A significant advantage is that ultrasonic waves remain unaffected by conditions such as ambient lighting, target hue, transparency, or reflectivity. Additionally, the sensor features a detection area that is considerably wider than that of optical sensors, facilitating the effective identification of both small and large objects [9]. The major disadvantage of using this type of sensor is that its optimal operating range is between 25.4 cm and 6.1 m, which requires additional care in its positioning. Additionally, it is essential to consider the proximity of the signal cables to power lines, as the electromagnetic field generated by these cables can cause inaccurate sensor readings. Proper shielding and cable routing are critical to avoid such errors.

Fig. 4 ToughSonic 30 Sensor: Profile view and illustrative diagram of operation [10]

Following the presentation of the sensor example, the authors specify that it can be implemented in software but also other sensors that send information in current, voltage or on a communication protocol.

The code structure and diagram in the LD for each tank is identical, with differences in the name of the variables (Fig. 5).

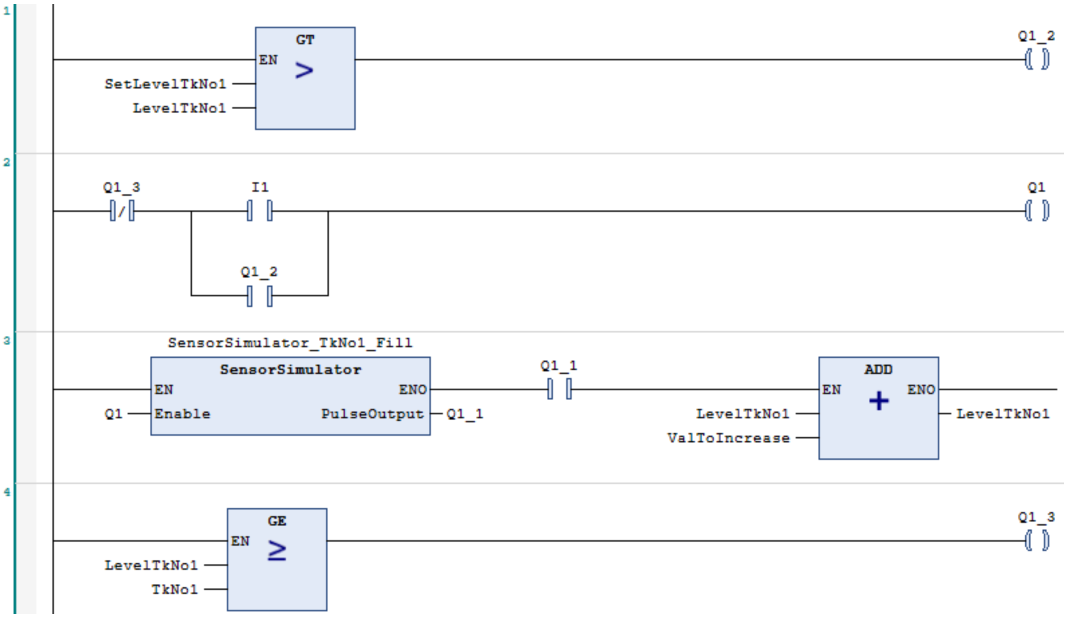


Fig. 5 Ladder logic diagram for tank level sensor simulation no.1 (Tank filling)

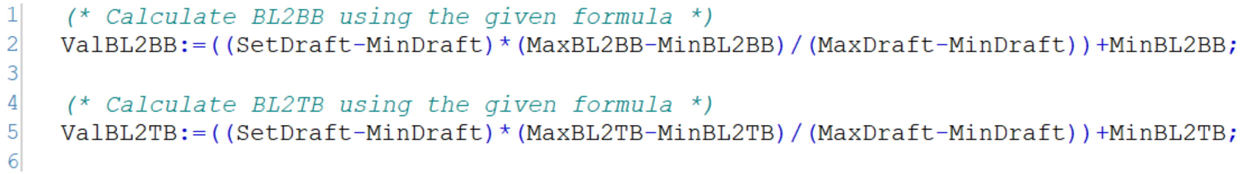
Filling ballast tanks according to the desired draft

The calculation of the filling of the tanks according to the draft set in the software is made based on the "SetMidDraft”. This block calculates the filling of each tank separately by means of the code written in the Structured Text (Fig. 6). The calculations present in this block were made following several stability simulations with the Napa Software. This software has the possibility to simulate the filling of each tank, the calculation of intact stability and stability in case of failure. The output data from the simulations show us that the minimum draft of the pontoon is 0.719 [m], the maximum draft is 1.419 [m]. At these drafts the pontoon can bear an additional weight when unloading ships of 162.4 [t]. This unloading weight is divided as follows [11]:

- 50 [t] — Ramp of the RO-RO type vessel (divided into 25 [t] on the port side and 25 [t] on the starboard side);

- 48 [t] – Goods towing vehicle;
- 64.4 [t] – Trailer of the towing vehicle.

Loading the pontoon with the specified weights will change the minimum draft which will be 1.2 [m] and the maximum draft to the value of 1.7 [m].



```
(* Calculate BL2BB using the given formula *)
ValBL2BB:=((SetDraft-MinDraft)*(MaxBL2BB-MinBL2BB)/(MaxDraft-MinDraft))+MinBL2BB;

(* Calculate BL2TB using the given formula *)
ValBL2TB:=((SetDraft-MinDraft)*(MaxBL2TB-MinBL2TB)/(MaxDraft-MinDraft))+MinBL2TB;
```

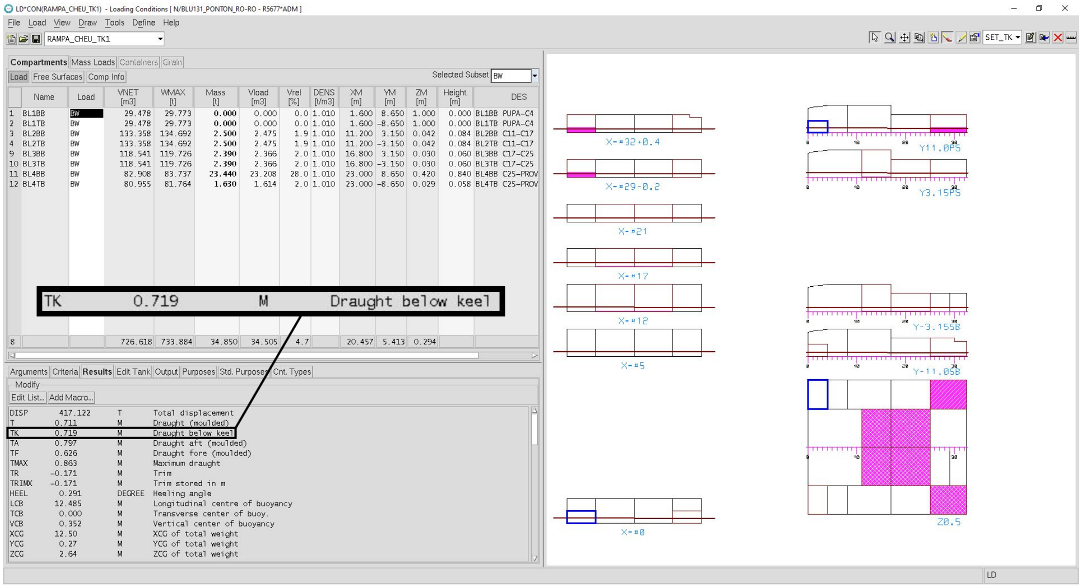
Fig. 6 Code sequence in Structured Text of block "SetMidDraft"

For the safety of tank filling calculations, using extrapolation, it was found that the draught level and the ballast levels in the tanks are directly proportional, and the values increase linearly. The values are presented in Table 1.

Table 1 Calculation of ballast tank load at interval of 0.05 [m]

Pontoon draft with moored vessel and cargo [m]	Pontoon draught without moored vessel and without load [m]	BL2BB [t]	BL2TB [t]	BL3BB [t]	BL3TB [t]	BL4BB [t]	BL4TB [t]
1.000	0.719	2.500	2.500	2.390	2.390	23.440	1.630
1.050	0.769	6.997	6.228	10.771	10.771	25.115	3.856
1.100	0.819	11.494	9.955	19.152	19.152	26.790	6.081
1.150	0.869	15.991	13.683	27.533	27.533	28.466	8.307
1.200	0.919	20.489	17.410	35.915	35.915	30.141	10.532
1.250	0.969	24.986	21.138	44.296	44.296	31.816	12.758
1.300	1.019	29.483	24.865	52.677	52.677	33.491	14.983
1.350	1.069	33.980	28.593	61.058	61.058	35.167	17.209
1.400	1.119	38.477	32.320	69.439	69.439	36.842	19.434
1.450	1.169	42.974	36.048	77.820	77.820	38.517	21.660
1.500	1.219	47.471	39.775	86.201	86.201	40.192	23.885
1.550	1.269	51.969	43.503	94.583	94.583	41.867	26.111
1.600	1.319	56.466	47.230	102.964	102.964	43.543	28.336
1.650	1.369	60.963	50.958	111.345	111.345	45.218	30.562
1.700	1.419	65.460	54.685	119.726	119.726	46.893	32.787

According to data from Table 1, it is noted that the tanks with the number one on the port board and the starboard board are not used for adjusting the draft. This is verified with the help of NAPA software. According to Fig. 7 and Fig. 8 of the simulations carried out in the case of the pontoon without the ship moored and without cargo, the list of tanks and their loads can be seen in the upper left, the draft of the pontoon in the lower left and implicitly the graphic illustration of the tank loads on the right side. In the graphic illustration, the tank loads hatched or filled with magenta are seen (depending on the amount of liquid in the tanks), together with views from both sides, aft and top view. In the side views, the medium loading line of the pontoon, the purple line, is also present.

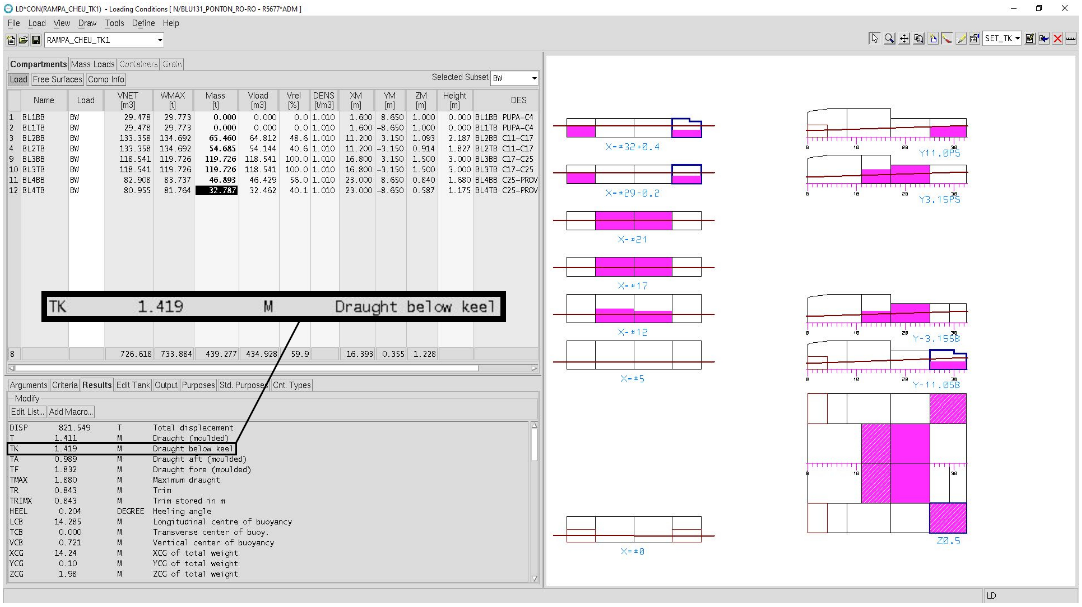


	Name	Load	VNET [m3]	WMAX [t]	Mass [t]	Vload [m3]	Vrel [%]	DENS [t/m3]	XM [m]	YM [m]	ZM [m]	Height [m]	DES
1	BL1BB	BW	29.478	29.773	**0.000**	0.000	0.0	1.010	1.600	8.650	1.000	0.000	BL1BB PUPA-C4
2	BL1TB	BW	29.478	29.773	**0.000**	0.000	0.0	1.010	1.600	-8.650	1.000	0.000	BL1TB PUPA-C4
3	BL2BB	BW	133.358	134.692	**2.500**	2.475	1.9	1.010	11.200	3.150	0.042	0.084	BL2BB C11-C17
4	BL2TB	BW	133.358	134.692	**2.500**	2.475	1.9	1.010	11.200	-3.150	0.042	0.084	BL2TB C11-C17
9	BL3BB	BW	118.541	119.726	**2.390**	2.366	2.0	1.010	16.800	3.150	0.030	0.060	BL3BB C17-C25
10	BL3TB	BW	118.541	119.726	**2.390**	2.366	2.0	1.010	16.800	-3.150	0.030	0.060	BL3TB C17-C25
11	BL4BB	BW	82.908	83.737	**23.440**	23.208	28.0	1.010	23.000	8.650	0.420	0.840	BL4BB C25-PROV
12	BL4TB	BW	80.955	81.764	**1.630**	1.614	2.0	1.010	23.000	-8.650	0.029	0.058	BL4TB C25-PROV
8			726.618	733.884	34.850	34.505	4.7		20.457	5.413	0.294		

```
TK          0.719          M          Draught below keel
```

```
DISP      417.122     T       Total displacement
T         0.711       M       Draught (moulded)
TK        0.719       M       Draught below keel
TA        0.797       M       Draught aft (moulded)
TF        0.626       M       Draught fore (moulded)
TMAX      0.863       M       Maximum draught
TR       -0.171       M       Trim
TRIMX    -0.171       M       Trim stored in m
HEEL       0.291      DEGREE  Heeling angle
LCB       12.485      M       Longitudinal centre of buoyancy
TCB        0.000      M       Transverse center of buoy.
VCB        0.352      M       Vertical center of buoyancy
XCG       12.50       M       XCG of total weight
YCG        0.27       M       YCG of total weight
ZCG        2.64       M       ZCG of total weight
```

Fig. 7 Simulation of tank loads at draft 0.719 [m] using NAPA software



	Name	Load	VNET [m3]	WMAX [t]	Mass [t]	Vload [m3]	Vrel [%]	DENS [t/m3]	XM [m]	YM [m]	ZM [m]	Height [m]	DES
1	BL1BB	BW	29.478	29.773	**0.000**	0.000	0.0	1.010	1.600	8.650	1.000	0.000	BL1BB PUPA-C4
2	BL1TB	BW	29.478	29.773	**0.000**	0.000	0.0	1.010	1.600	-8.650	1.000	0.000	BL1TB PUPA-C4
3	BL2BB	BW	133.358	134.692	**65.460**	64.812	48.6	1.010	11.200	3.150	1.093	2.187	BL2BB C11-C17
4	BL2TB	BW	133.358	134.692	**54.685**	54.144	40.6	1.010	11.200	-3.150	0.914	1.827	BL2TB C11-C17
9	BL3BB	BW	118.541	119.726	**119.726**	118.541	100.0	1.010	16.800	3.150	1.500	3.000	BL3BB C17-C25
10	BL3TB	BW	118.541	119.726	**119.726**	118.541	100.0	1.010	16.800	-3.150	1.500	3.000	BL3TB C17-C25
11	BL4BB	BW	82.908	83.737	**46.893**	46.429	56.0	1.010	23.000	8.650	0.840	1.680	BL4BB C25-PROV
12	BL4TB	BW	80.955	81.764	32.787	32.462	40.1	1.010	23.000	-8.650	0.587	1.175	BL4TB C25-PROV
8			726.618	733.884	439.277	434.928	59.9		16.393	0.355	1.228		

```
TK          1.419          M          Draught below keel
```

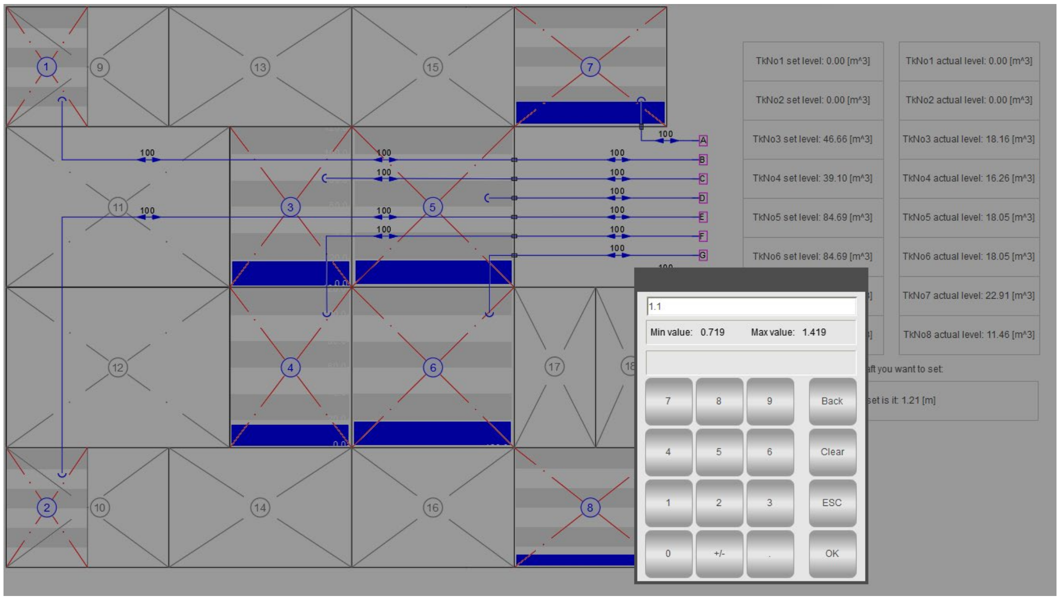
```
DISP      821.549     T       Total displacement
T         1.411       M       Draught (moulded)
TK        1.419       M       Draught below keel
TA        0.989       M       Draught aft (moulded)
TF        1.832       M       Draught fore (moulded)
TMAX      1.880       M       Maximum draught
TR        0.843       M       Trim
TRIMX     0.843       M       Trim stored in m
HEEL       0.204      DEGREE  Heeling angle
LCB       14.285      M       Longitudinal centre of buoyancy
TCB        0.000      M       Transverse center of buoy.
VCB        0.721      M       Vertical center of buoyancy
XCG       14.24       M       XCG of total weight
YCG        0.10       M       YCG of total weight
ZCG        1.98       M       ZCG of total weight
```

Fig. 8 Simulation of tank loads at draught 1,419 [m] using NAPA software

Graphical interface of the pontoon software

The graphical interface on the HMI (Human Machine Interface) (Fig. 9) is composed of the following elements:

- The diagram is seen from above of the pontoon with the efferent piping. The diagram highlights the ballast tanks and as the load level increases, a mime (Digital images of the assets and processes that have been created in the HMI/SCADA system) of alabaster color is observed that expresses the approximate load in percentages [12];
- The current filling level of each tank expressed in m^3;
- The set level resulting from the calculations performed in the block "SetMidDraft" expressed in m^3;
- The draught set by the operator expressed in m.



TkNo1 set level: 0.00 [m^3]
TkNo2 set level: 0.00 [m^3]
TkNo3 set level: 46.66 [m^3]
TkNo4 set level: 39.10 [m^3]
TkNo5 set level: 84.69 [m^3]
TkNo6 set level: 84.69 [m^3]
TkNo1 actual level: 0.00 [m^3]
TkNo2 actual level: 0.00 [m^3]
TkNo3 actual level: 18.16 [m^3]
TkNo4 actual level: 16.26 [m^3]
TkNo5 actual level: 18.05 [m^3]
TkNo6 actual level: 18.05 [m^3]
TkNo7 actual level: 22.91 [m^3]
TkNo8 actual level: 11.46 [m^3]
aft you want to set:
set is it: 1.21 [m]
1.1
Min value: 0.719 Max value: 1.419

Fig. 9 HMI interface for pontoon control: top view and draft adjustment control

Conclusions

The automation of the pontoon ballast installation offers significant operational benefits, but also presents certain challenges that should be considered. The key advantages include increased efficiency in ballast operations, simplified control through the replacement of manual systems with an automated interface, and a reduction in human error. Additionally, the need for separate draft monitoring systems is eliminated, as the automation system integrates real-time data collection and processing. These improvements contribute to safer and more streamlined operations, ultimately enhancing the overall performance and reliability of RO-RO pontoon berthing facilities.

However, the implementation of such an automated system incurs considerable costs. These include expenses related to the acquisition and installation of sensors, communication cabling, and modifications to the main switchboard to accommodate the programmable logic controller (PLC). Additional costs stem from labor required for installation, as well as the integration of a touchscreen interface, which may necessitate modifications to the existing infrastructure.

While the benefits of automation are clear, the associated costs and potential technical challenges, such as system failures or limitations in the sensors' measuring range, must be carefully assessed. Detailed experimental validation of the proposed automated system is necessary to confirm its effectiveness and reliability in real-world scenarios. This validation should encompass a range of operational conditions to comprehensively evaluate the system's performance and identify any potential limitations. Future research should focus on developing a scale model of the pontoon, equipped with the necessary automation components (PLC, valves, pumps), to conduct performance testing under various operational conditions.

Moreover, comparative studies with existing manual systems and other automated solutions could provide valuable insights into the advantages of the proposed approach. Understanding the practical implications of system failures and the limitations of the sensors' measuring range will be vital for developing robust contingency plans. Overall, the establishment of a detailed framework for experimental validation and performance assessment will not only support the proposed automation system's implementation but also foster ongoing improvements in the design and operational protocols of pontoon ballast system. This comprehensive approach will ultimately ensure a smoother transition to automated systems while maintaining high safety and operational standards.

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