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Comparison of the Calculated Wind Loads to the Power Generated by the Main Propulsion and Thrusters of the Ship with the Results of Simulation Tests

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ABSTRACT: One of the main factors affecting the safe port maneuvers by ships is wind, which directly affects the ship's movement. The article presents a comparison of calculated wind loads to the power generated by thrusters and the main propulsion of the ship with the results of simulation tests in order to determine the safe wind force limits allowing safe port maneuvers with a particular ship model.

1 INTRODUCTION

The research was carried out for two theoretical locations of the ramp at the ferry terminal in the port of Gdynia [7]:

- in the first variant, for the ramp located in the area where the wharfs meet: Polish and Finnish, mooring the ship along the Polish Quay, stern to the ramp (bow pointing towards the interior of the pool), as shown in Fig. 1.
- in the second variant, for the ramp located at the Polish Quay, in the area of the western part of the present warehouse No. 2, mooring the ship along the Polish Quay, stern to the ramp (bow pointing towards the port exit) - Fig. 2.

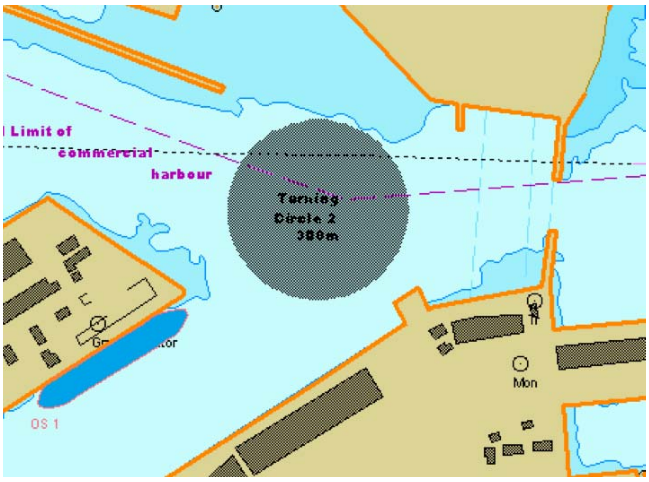

Figure 1. Ramp located in the area where the wharfs meet: Polish and Finnish.

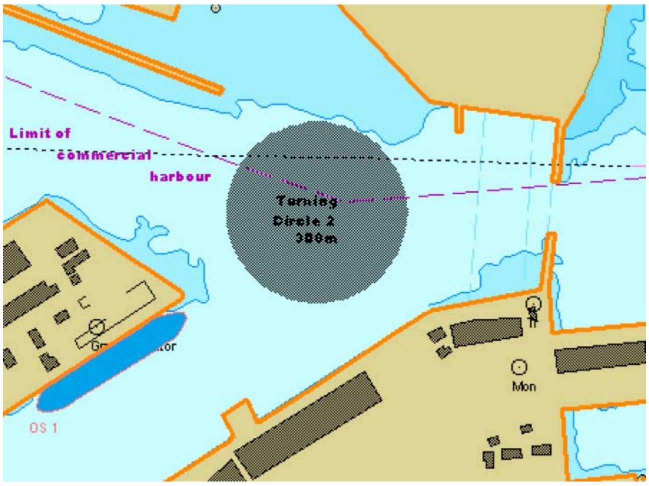

Figure 2. Ramp located at the Polish Quay..

The performed research was analyzed for a safe approach and departure by a simulation model for both variants. The simulation model was prepared based on the data of characteristic ferries calling at passenger terminals [8].

The test results will also allow to indicate a better location of the ramp from the point of efficiency and safety of navigation during approach and departure maneuvers. Safety of navigation in case of maneuvers of such large vessels is the subject of many research [6] and highlights its importance in the case of selecting the location of the planned wharf. The implementation of the full range of tests for the selected location of the ramp will allow to determine the operational and hydro meteorological conditions for the ship.

2 NAVIGATIONAL SIMULATOR

The Navi Trainer 5000 Professional navigational simulator [5], certified by the classification company DNV (Det Norske Veritas), and the electronic map simulator and ECDIS Navi-Sailor 4000 systems as well as the Model Wizard application (v. 5,0), were used in the research. The simulator is located in the laboratory of the Navigation Department of the Maritime University of Gdynia. The Transas simulator was used in numerous scientific studies, research work and expertise [1, 2].

For the simulation studies, a model of a geographical simulation area was built based on geographical coordinates, reflecting the port basin in Gdynia along with the theoretical location of ramps after performing the possible reconstruction of the port (Figure 1-2). In the preparation of the geographical area of the simulation, maps and navigational aids were included. A visualization of the port basin in Gdynia along with quays and newly planned ramps was also carried out (Figure 3-4). In the simulation area, it is possible to create any hydro meteorological conditions (wind, wave, current) affecting the model maneuvering in this area.

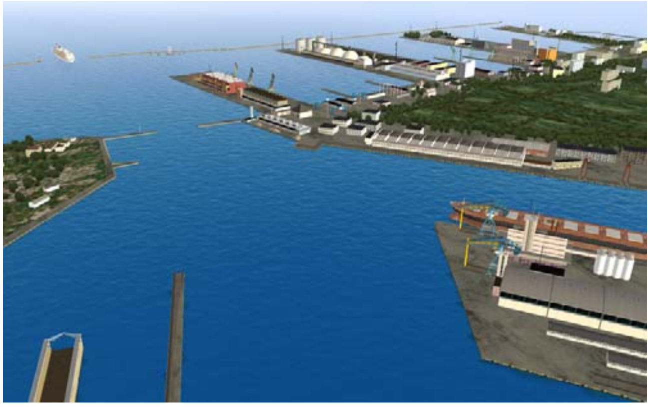

Figure 3. Visualization of the new simulation area - Port of Gdynia (Variant I).

Figure 4. Visualization of the new simulation area - Port of Gdynia (Variant II).

3 SHIP MODELS

In order to select the model for research, the data of characteristic ferries calling at passenger terminals in the port of Gdynia were used [7, 8]. The contours of the ferries, along with a short characteristic (Figure 5-7) are listed below.

Ferry	Length overall [m]	Draft [m]	Fn - Surface area of the above-water body [m2]	Fp - Surface area of the underwater part [m2]	k= F_p/ F_n
Stena	240,5	6,40	6773,59	1373,26	0,2027

Figure 5. Stena ferry - contour and characteristics of the surface of the longitudinal section above and underwater part of the hull.

Ferry	Length overall [m]	Draft [m]	Fn - Surface area of the above-water body [m2]	Fp - Surface area of the underwater part [m2]	$k = F_p / F_n$
Scandinavia	243,3	6,30	6293,49	1447,25	0,2299

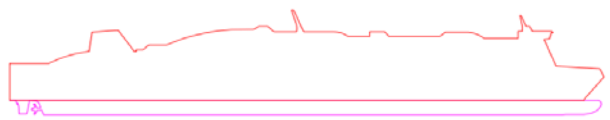

Figure 6. Scandinavia ferry - contour and characteristics of the surface of the longitudinal section above and underwater part of the hull.

Ferry	Length overall [m]	Draft [m]	Fn - Surface area of the above-water body [m2]	Fp - Surface area of the underwater part [m2]	$k = F_p / F_n$
Germanica	240,1	6,15	5814,48	1328,50	0,2285

Figure 7. Germanica ferry - contour and characteristics of the surface of the longitudinal section above and underwater part of the hull.

In order to carry out the analysis of safe approach and departure of ships in both variants of the location of the ramp at the ferry terminal in the port of Gdynia, the simulation model PCS1 (Fig. 8) was selected. The characteristics and contours of the simulation model are shown in Figure 8.

Ferry	Length overall [m]	Draft [m]	Fn - Surface area of the above-water body [m2]	Fp - Surface area of the underwater part [m2]
PCS1	290,00	8,00	6172,00	1417

Figure 8. Simulation model PCS1 - contour and characteristics of the surface of the longitudinal section above and underwater part of the hull.

4 WIND LOADS

The main component of the resistance when maneuvering the ferry at low speeds is the force of air pressure on the above-water part of the ship's hull (wave resistance and friction can be neglected). It can be calculated by the formula [3, 4]:

Rpow. = 0,5*Cpow.*ϱpow. *V2 pow.*Fn

where:
Rpow. - air resistance (kG)
Cpow. - coefficient of air resistance (for the hull 1.0, for simple superstructures 1.0 to 1.2)
ϱpow. - air density 1,226 kg/m3 at temperature 20C and normal atmospheric pressure 1013hPa;
V pow. - relative air velocity (m/s);
Fn - surface of the longitudinal ship's section (m2)

After entering the averaged values Cpow. = 1,1, and ϱpow. = 1,226 kg/m3, the above can be simplified to the form [3, 4]:

R pow. = 0,069 * V2 pow.*Fn [kG]

This formula was used to calculate wind pressure forces on the surface of the longitudinal ship's section. In case of mooring and unmooring maneuvers without the assistance of tugs, in the most unfavorable directions and wind force, the power generated by the thrusters and main engines must be greater than the calculated wind pressure forces of the characteristic vessels and the simulation model considered. A summary of the calculated wind pressure forces is shown in Table 1.

Table 1. List of wind pressure forces

Ferry	Wind Force [°B]	Wind speed [m/s]	Wind pressure force [KG]
Scandinavia	4°	5,5-7,9	27101,6
	5°	8,0-10,7	49717,4
	6°	10,8-13,8	82698,7
	7°	13,9 -15,0	97766,4
Stena	4°	5,5-7,9	29169,0
	5°	8,0-10,7	53510,1
	6°	10,8-13,8	89007,4
	7°	13,9 -15,0	105160,0
Germanica	4°	5,5-7,9	25038,5
	5°	8,0-10,7	45933,3
	6°	10,8-13,8	76404,4
	7°	13,9 -15,0	90269,8
Model PCS1	4°	7,9	26578,4
	5°	10,7	48757,6
	6°	13,8	81102,3
	7°	15,0	95820,3

Comparison of the longitudinal sectional area of the underwater part of the Fp hull to the longitudinal section of the above water section of the Fn determine (k = Fp / Fn) that the adopted simulation model differs in a non-significant way from models with the characteristic parameters presented in Table 1 (only in the case of the Stena ferry, about 12%). The results for the model adopted for simulation and maneuvers reliably correspond to a ferry with the characteristic parameters presented in Table 1.

The selected model corresponds to the characteristic ferries (similar dimensions, the ratio of the surface area of the water body to the surface area of the underwater part and characteristics of maneuvering devices). The shortage of power of the bow thruster on the bow in the selected model in relation to the set of characteristic ferries is compensated by the application in which the simulator is equipped. Similarly, the power shortage on the bolts has been supplemented. The simulation model used is an extensive mathematical model of the real unit. Both the simulation area and the models used for simulation are highly realistic.

5 SIMULATION TEST

The research has been divided into two parts. In the first part, the approach and departure maneuver was performed with the PCS1 simulation model for both theoretical variants of the ramp position. Part II is a continuation and supplement to the research in Part I. The results of the tests from the second part allowed to determine the operational and hydro meteorological conditions for the particular ship.

The wind strength and direction have a significant impact on the execution of the safe port maneuvers, especially for units with a large wind area section. The scheme bellow is based on key directions that can be important at critical moments during the entire maneuver, ie: set in or under the wind line during entry and exit to and from basin IV (directions: 045 ° and 237 ° - Fig. 9), and wind acting perpendicular to the ship's side (290 ° and 135 ° - Fig. 10) at the moment of approach and departure to and from the Polish berth.

Figure 9. Wind from 045° and 237°

Figure 10. Wind from directions 290° and 135°

For the considered ramp location (variants I and II) at the Polish Quay, two series of simulation tests (mooring and unmooring maneuvers) of the PCS1 simulation model have been planned. In the first stage of the tests, simulations were carried out at a wind speed of 10 m / s. Such a study will allow to assess the difficulty, duration, needed water area and safety of maneuvers for both variants of the proposed ramp locations.

Table 2 shows the duration of simulation of mooring maneuvers and unmooring the PCS1 simulation model in both variants of the location.

Table 2. Duration of maneuvers

Wind [direction/ speed]	Duration of maneuvers [hh:mm:ss] Berthing Location I	Location II	Unberthing Location I	Location II
290° 10m/s	00:12:53	00:12:17	00:18:15	00:06:47
045° 10m/s	00:20:24	00:14:14	00:10:07	00:06:44
135° 10m/s	00:27:40	00:18:43	00:18:46	00:05:56
237° 10m/s	00:11:56	00:10:12	00:11:05	00:11:07
Average duration of maneuvers	00:18:13	00:13:51	00:14:33	00:07:38

The comparison shows that both the duration of mooring maneuvers as and unmooring is longer for the first variant.

Example of a trajectory of the ship's movement during the test is shown in Fig. 11.

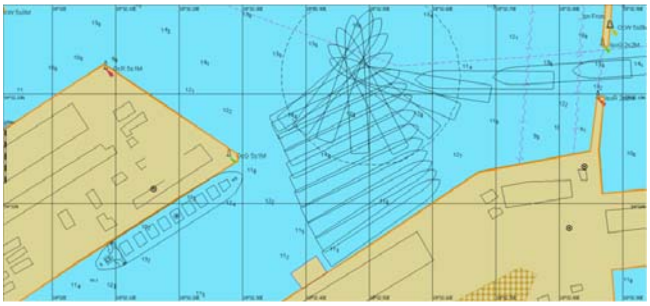

Figure 11. Mooring maneuver of the PCS1 simulation model. Variant II. Wind: 045 ° - 10 m/s.

In order to determine the permissible wind force, a comparison of theoretical calculations (the ratio of the wind pressure force at given speeds to the power generated by the bow thrusters and the ship's main propulsion that can reduce the wind pressure force) was compared with the results of simulation tests. As theoretical calculations showed that the permissible wind force for both the characteristic and simulation ferries is within the wind speed range of 13.3 m/s - 14.1 m/s, four series of simulation tests were performed (mooring and unmooring maneuvers for wind speed 13 m/s and 14 m/s).

During mooring and unmooring maneuvers of the PCS1 simulation model with wind blowing at the speed of 13 m/s throughout the maneuvers, the control of the ship's movement was maintained. Using the thrusters and rudder maneuvers and main propulsion, the ship safely moored and unmoor at the selected location.

After increasing the wind speed to 14 m/s, at the least favorable wind directions (blowing perpendicularly to the ship's side at the time of parallel approach / departure to the wharf) power generated by the main drive and steer maneuvers and jet thrusters were not enough to counterbalance the wind pressure, which resulted in the loss of control over the ship's movement.

6 SUMMARY

The reliability of the obtained test results from the compliance of the results of tests performed on the simulator, theoretical calculations and confirming the opinion of masters with knowledge and experience in the studied area.

The research shows that the duration of mooring and unmooring maneuvers, the width of the navigation channel needed to perform them, the complexity of the maneuvers themselves and the maneuverability of a twin-screw ship are more advantageous for mooring to the ramp located at the Polish Quay in the western part of the current warehouse No. 2, mooring the ship along the Polish Quay, stern to the ramp (bow towards the sea) (option II).

It is also important that this variant ensures greater safety of the ferry during its stoppage and during exit maneuvers due to less difficulty in their performance. In this case, the ferry rotates on the turntable and approaches the ramp with the stern. The place of maneuvers (the supply of navigable water needed to perform the maneuver) is virtually unlimited. This also applies to unmooring and departure maneuvers, when the ferry may follow the exit immediately after unmooring.

The research does not exclude the location of the ramp located in the area where the wharfs meet: Polish and Finnish. However, they show that maneuvers related to mooring and unmooring will be more difficult and more complicated, their duration will be longer, and thus they will be less safe, especially in the winds from the directions of W and NW - prevailing in the port of Gdynia. The time of both berthing and unberthing maneuvers will be significantly longer (as confirmed by simulation tests - Table 2).

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