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New Mielno Port design – results by real time simulation study

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Abstract

Construction of new ports requires applying the entire range of methods and the close cooperation between designers and specialists of different field including safety of navigation or oceanography. At present there is no possible to conduct of such investments without carrying out simulation examinations. These studies most often take place as multistage where the next stage is the result of the previous one. The paper presents complex method of water areas optimization with consideration of navigational safety. In the present study was implemented real-time simulation method. Methods of the simulation of the real time leaning against manoeuvre simulators have been applied. Two distinct from each other alternatives have been explored and the best in terms of safety of navigation has been selected as final. The results were used as a guideline for the development project of a small Polish seaport in Mielno.

Introduction

Marine Traffic Engineering (MTE) research team of Maritime University of Szczecin (MUS) since 70-ties is engaged in research works concerned with evaluation of navigation safety for port design and optimization of water areas [1, 2]. The researches described in this paper are focused on new Mielno Port establishment which is one of the most important research studies of MTE team deled with complex sea port planning and design [3]. The main aim of researches was concerned with [4]:

1. Determination of optimal parameters of:
   - new sea port in Mielno area with respect to shape, width and depth;
   - outer and inner port breakwaters with respect to its shape taking into consideration wave height in port;
   - turning places with respect to its shape and optimal depth;
   - the berthing places in inner port in respect to its shape, length, depth, maximal energy of ships contact, maximal speed of ships propeller and bowthruster streams on the bottom.
2. Determination of safety conditions of port operation in respect to:
   - admissible meteorological conditions for given kind of ships and manoeuvres;
   - other navigational conditions and limitations like presence of other ships on berths, use of position fixing systems on approach, navigational markings, vessel traffic service.
3. Determination of manoeuvring procedures during berthing and unberthing for different kind of ships and propulsion systems.
4. Determination of underkeel clearance by Monte Carlo method.
5. Determination of usage of main engine during entrance.
6. Determination of researches ships distances to the most dangerous objects.
7. Carrying out most typical emergency runs (typical failures on entrance) and describe necessary emergency action for the captains.

The Port of Mielno is a small fishing place (beach port) without breakwaters localized at west Polish coast between the Baltic Sea and sea lake Jamno (Fig. 1).

As a characteristic ship (m/f “Design”) for new Mielno Port design in presented study according to investors economic analysis and their needs the typical Baltic Sea small passenger ship of length

L = 60 m (Fig. 2) has been chosen. The essential parameters of design ship are presented in the table 1.

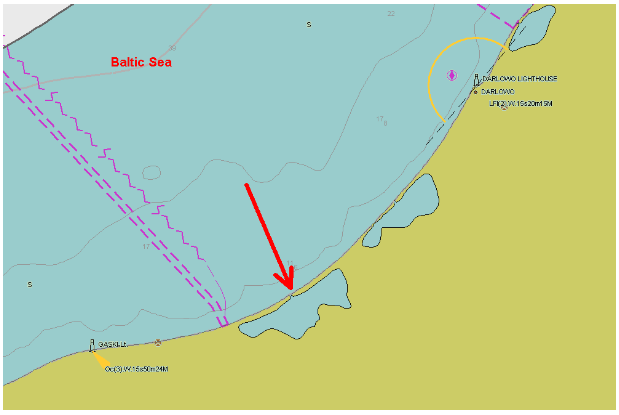

Fig. 1. Planned Mielno port localization [S-57 navigational chart]

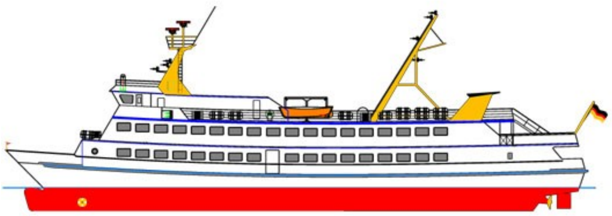

Fig. 2. General arrangement of m/f "Design" (based on plans of m/f "Adler Dania") [www.adler-schiffe.de]

Table 1. Main parameters of design passenger ship (*L* = 60 m) operated on the Baltic Sea area [3]

Parameter	m/f "Design"
Length – LOA	60 m
Breadth	12 m
Draft	2.5 m
Machinery	total 2 × 1.200 kW at 900 rpm.
Propeller	1 variable pitch propeller
Propeller	diameter = 1.83 m at rpm 360
Speed	approx. 18 kn. (at 90%)
Rudder	1 × 35 deg./area = 2.7 m^2 /conventional
Bowthruster	150 kW
Lateral wind area	approx. 500 m^2

Design of the Port of Mielno

The most important aim design of the Port of Mielno is to provide access to the port by passenger ships up to 60 m length and enable future port development in respect to cargo and fishing activities [3]. The main design restrictions are as follows (Fig. 3):

1. to design sea port with two breakwaters with inner and outer port (for better wave dumping) well sheltered from extreme weather conditions;
2. design at least one turning place inside the new port;

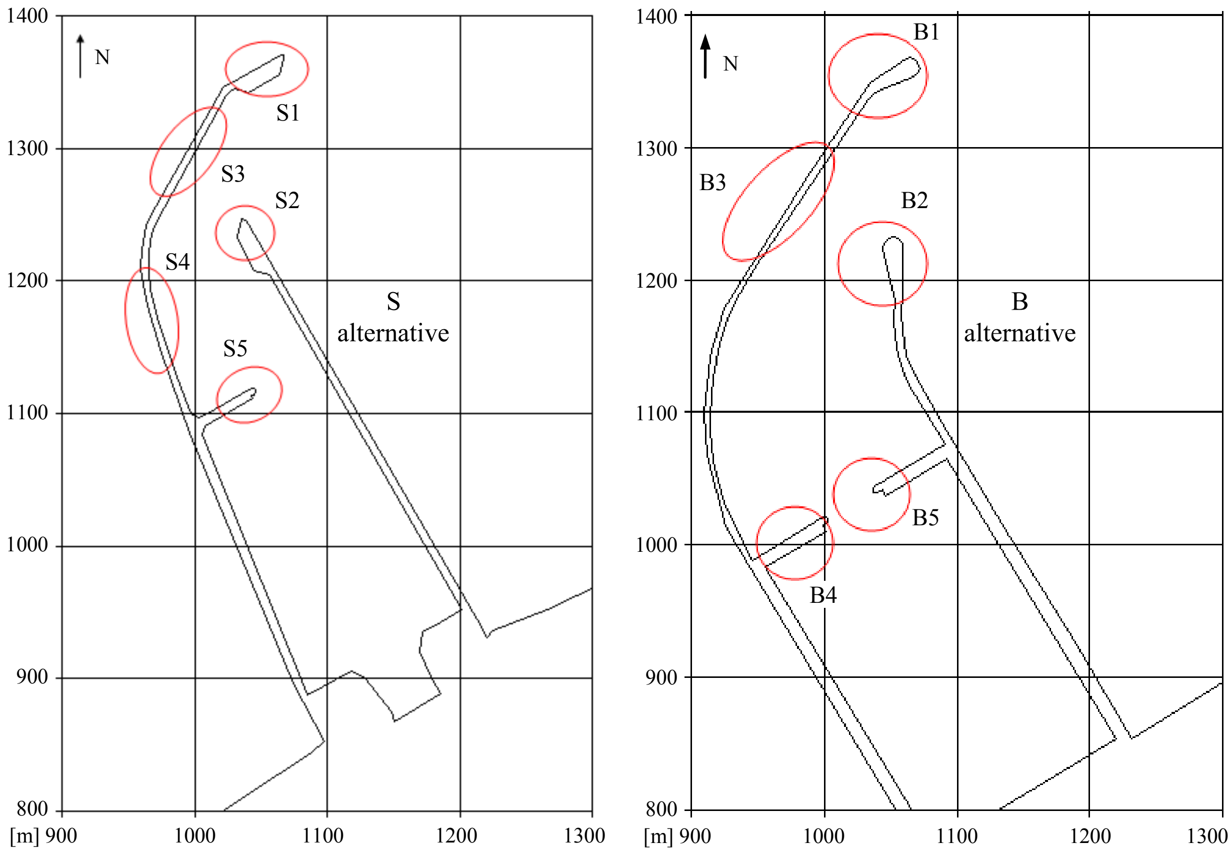

Fig. 3. Two design alternatives at Mielno Port (S design – left and B design – right) with critical points [3]

3. create at least 4 berthing places for design ships;
4. to test and validate at least TWO alternative designs ports made by two independent teams of project (S and B team).

Methods applied

The real time simulation interactive method with captains and pilots engaged in ships manoeuvring trials was applied. This method is assumed as most reliable and suitable in this kind of research studies [5]. MTE research team possess several kinds of manoeuvring simulators: form limited task with 2D display to modern full mission simulator with 3D and real control systems.

Real time simulation method – limited task simulator

Two classes of hydrodynamic models in MTE team own limited tasks simulators are utilized. First class of models are used when only limited parameters are known (usually when non existing ships or general class of ships are modelled) the second class models are used when detailed and exact characteristics of hulls, propellers and steering devices are known. Additionally real manoeuvring characteristics are used for validation of models. The model of m/f "Design" used in researches is based on modular methodology where all influences like hull hydrodynamic forces, propeller drag and steering equipment forces and given external influences are modelled as separate forces and at the end summed as perpendicular, parallel and rotational ones.

The model is operating in the loop where the input variables are calculated instantly (settings and disturbances) as the forces and moments acting on the hull and momentary accelerations are evaluated and speeds of movement surge, sway and yaw. The most important forces acting on the model are:

1) thrust of propellers;
2) side force of propellers;
3) sway and resistant force of propellers;
4) bow and stern thrusters forces;
5) current;
6) wind;
7) ice effects (neglected);
8) moment and force of bank effect (neglected);
9) shallow water forces;
10) mooring and anchor forces (neglected);
11) reaction of the fenders and friction between fender and ships hull;
12) tugs forces (neglected);
13) other depending of special characteristics of power and steering ships equipment.

The functional idea of the ship manoeuvring simulation model is presented in figure 4.

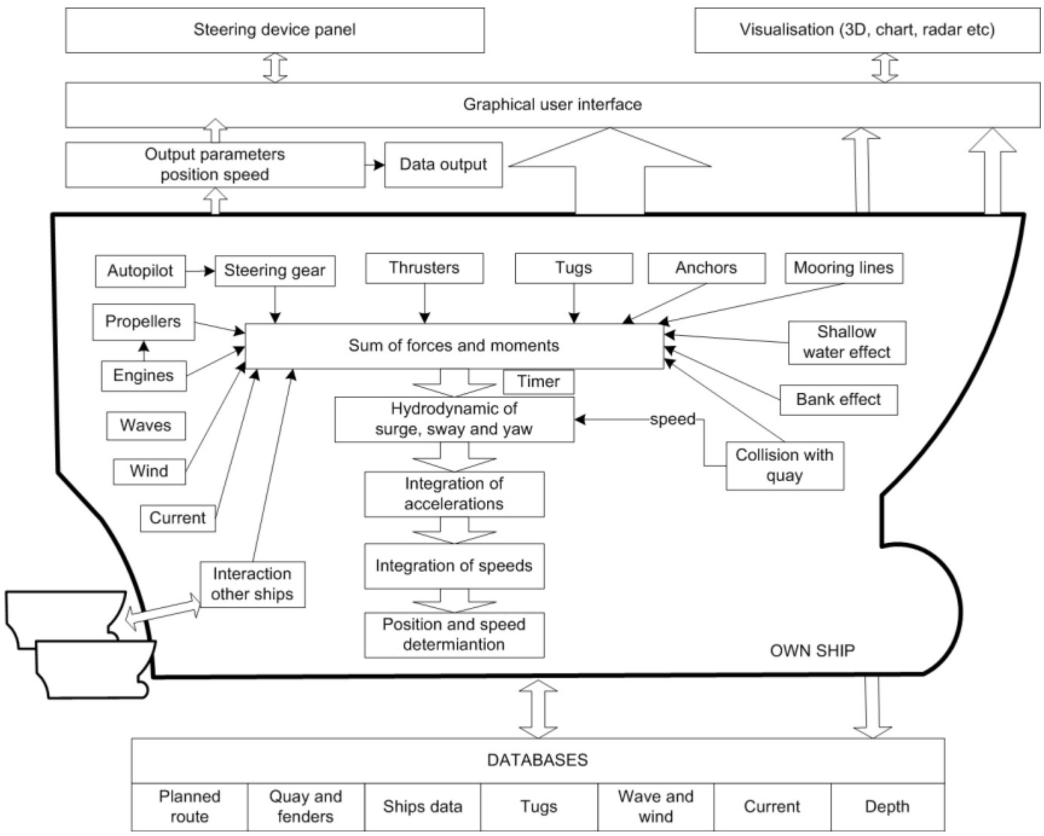

Fig. 4. The main functional diagram of simulation model

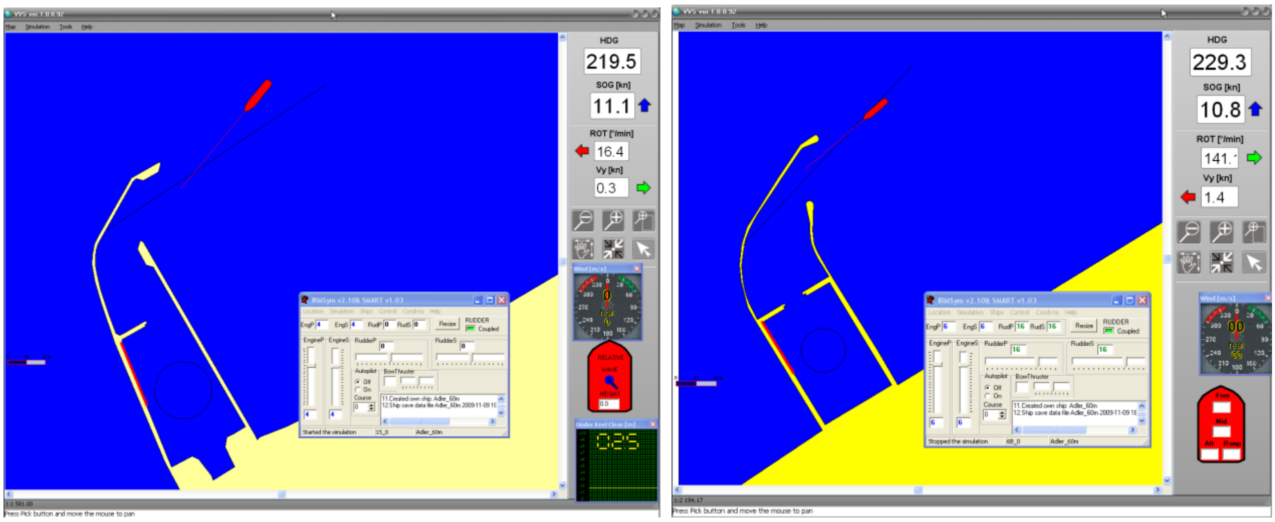

Fig. 5. Interface of simulation model m/f "Design" turning at outer turning place of S (left) and B (right) Mielno port (limited task simulator)

Interface of model is typical 2D nautical chart – like interface (Fig. 5). The interface covers information of ships state (position, course speed, yaw etc), quay and shore line location, navigational markings, soundings, external conditions, tug and line control and control elements of the model. The model is implemented in Object Pascal with use of Delphi™ environment and Visual C™ with use of C++ language.

Limiting to the usual 3DOFs (the horizontal planar motion), the ship movement over the ground (thus the so-called dynamic effect of the water current is introduced) is given by [6]:

$$\begin{cases} (m+m_{11})\dfrac{\mathrm{d}\,v_x^g}{\mathrm{d}\,t} = \\ \quad = (m+c_m m_{22})\,v_y^g\omega_z + (m_{11}-c_m m_{22})\,v_y^c\omega_z + F_x \\ (m+m_{22})\dfrac{\mathrm{d}\,v_y^g}{\mathrm{d}\,t} = \\ \quad = -(m+m_{11})\,v_x^g\omega_z + (m_{11}-m_{22})\,v_x^c\omega_z + F_y \\ (J_z+m_{66})\dfrac{\mathrm{d}\,\omega_z}{\mathrm{d}\,t} = \\ \quad = -(m_{22}-m_{11})\left(v_x^g-v_x^c\right)\left(v_y^g-v_y^c\right) + M_z \end{cases} \tag{1}$$

$$\frac{\mathrm{d}\,x_0}{\mathrm{d}\,t} = v_{NS}^g, \quad \frac{\mathrm{d}\,y_0}{\mathrm{d}\,t} = v_{EW}^g, \quad \frac{\mathrm{d}\psi}{\mathrm{d}\,t} = \omega_z \tag{2}$$

$$\begin{bmatrix} v_{NS}^g \\ v_{EW}^g \end{bmatrix} = \begin{bmatrix} \cos\psi & -\sin\psi \\ \sin\psi & \cos\psi \end{bmatrix} \cdot \begin{bmatrix} v_x^g \\ v_y^g \end{bmatrix} \tag{3}$$

where:

v_x^g, v_y^g, ω_z – ship surge, sway and yaw velocity over the ground;

x_0, y_0, ψ – position Cartesian coordinates and heading;

m – ship mass;

m_{11}, m_{22}, m_{66} – added masses;

c_m – empirical factor;

F_x, F_y, M_z – external excitations (resultant / total surge, sway force and yaw moment), generally consisting of the following items (denoted by additional subscripts) and being generally the functions of ship speed through the water (v_w):

$$\begin{cases} F_x = F_x\left(v_x^w, v_y^w, \omega_z\right) \\ F_y = F_y\left(v_x^w, v_y^w, \omega_z\right) \\ M_z = M_z\left(v_x^w, v_y^w, \omega_z\right) \end{cases} \tag{4}$$

$$v_x^w = v_x^g - v_x^c, \quad v_y^w = v_y^g - v_y^c \tag{5}$$

$$\begin{bmatrix} v_x^c \\ v_y^c \end{bmatrix} = \begin{bmatrix} \cos\psi & \sin\psi \\ -\sin\psi & \cos\psi \end{bmatrix} \cdot \begin{bmatrix} \left|\vec{v}^{\,c}\right| \cos\gamma_c \\ \left|\vec{v}^{\,c}\right| \sin\gamma_c \end{bmatrix} \tag{6}$$

where: $\left|\vec{v}^{\,c}\right|$ and γ_c represent the velocity and geographical direction of the water current (a uniform current by default).

Statistical methods of data processing

Ship simulators are very widely used today. The hydrodynamic models are becoming more and more reliable. Without efficient statistical data processing it is not possible however to draw conclusions from the conducted experiments. Usually different kind of data processing analysis is applied in case when horizontal and vertical ships movement is considered.

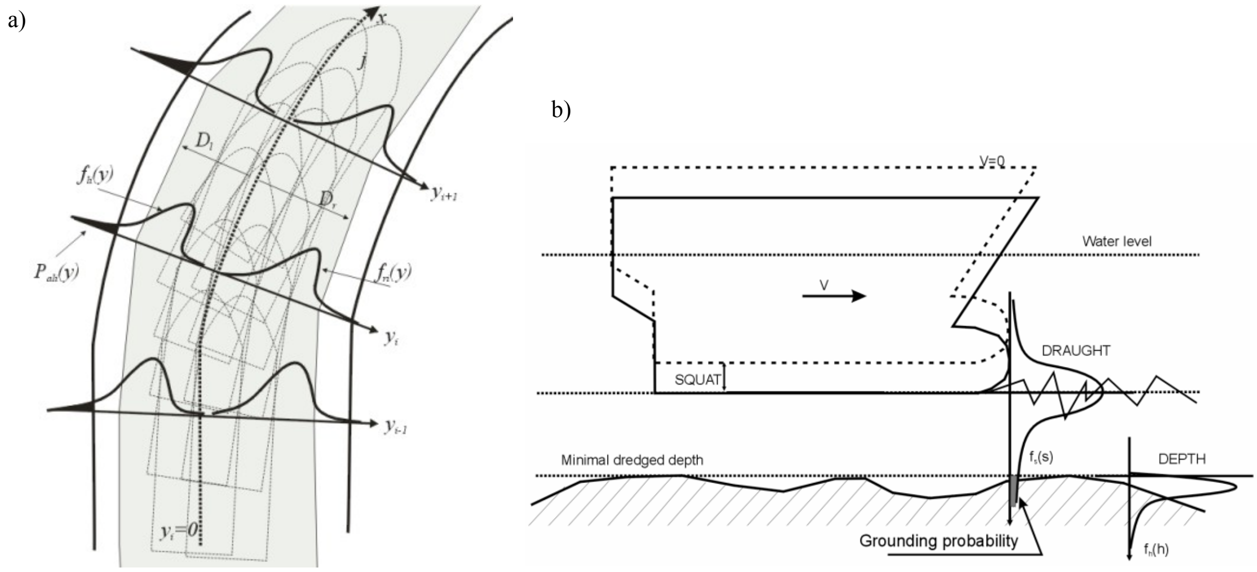

Fig. 6. Probabilistic concept of safe manoeuvring area determination on the waterway (a) and underkeel clearance of ships determination (b)

Safe manoeuvring areas – method of simulation result data processing

The most important factor is safety horizontal area needed for navigators for performing manoeuvres [2, 5, 7]. The assumption of such model is that the ship moves along predefined route x (Fig. 6a) with following probability of accident:

$$P_{AW} = P_{SA/A} P(Y \geq y_{MAX}) = P_{SA/A} \int_{y_{MAX}}^{+\infty} f(y) \mathrm{d}y$$

where:

$P_{SA/A}$ – conditional probability of serious accident;
$f(y)$ – the distribution of ships position;
y_{MAX} – distance from to the centre of the waterway (route) to the waterway border.

Probability of serious accident $P_{SA/A}$ could be defined by the Heinrich ratio or more detailed consequence analysis. One of the most important stages of accident probability evaluation is statistical analysis of the results. The probabilistic concept of safety manoeuvring area is presented in figure 6a. The distributions are strongly dependant of waterway area arrangement and could be evaluated in simulations and validated in real experimentations.

The research plan

The following conditions for manoeuvring have been considered:

– zero conditions – for validation and comparing of manoeuvring areas;
– wind 11 m/s (lower limit of 6°B);
– wind 17 m/s (lower limit of 8°B).

Two directions of wind have been considered:

– NW as hardest to port entrance;
– NNE as problematic wind form stern directions that could course the problems with enter due to moment of inertia on ships in stern area.

Height of significant wave is according to wind and typical wind-wave conditions on the Baltic are presented in table 2.

A series of simulation

There have been conducted 10 simulation series each for 13 to 14 ship passages (entrances only). Detailed plan of simulation passages is presented in table 2. The technique of manoeuvres is presented in figure 7.

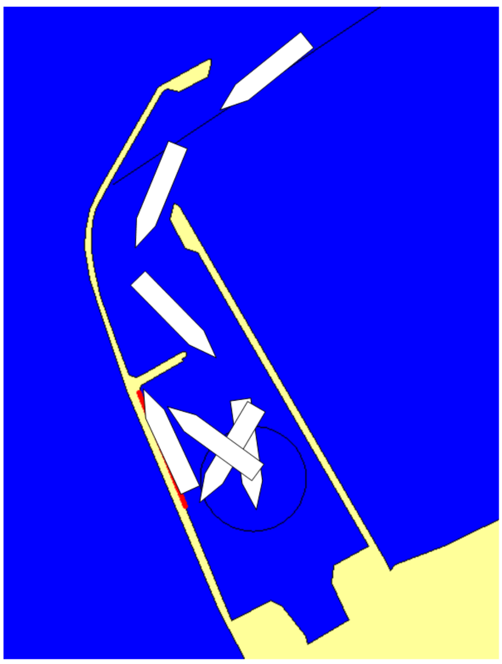

Fig. 7. Technique of ship manoeuvre the same for S and B design alternative (entrance, immediate turning and mooring)

Table. 2. The detailed plan of simulations

No.	Port design alternative	Manoeuvre	Wind [m/s (B)]	Wave [m]	No. of simulation passages
1	S	Entrance and port turn	0	0	14
2			NW 11 (6)	0.9	14
3			NW 17 (8)	1.8	14
4			NNE 11	0.9	13
5			NNE 17	1.8	13
6	B		0	0	14
7			NW 11	0.9	14
8			NW 17	1.8	13
9			NNE 11	0.9	13
10			NNE 17	1.8	13

Research results

All the simulation trials have been conducted by skilled captains and pilots having experience in this kind of ships and manoeuvres. The simulation data have been recorded and analyzed. Analysis of simulation results was made in basis of following criterions:

1. ship manoeuvring lanes widths (horizontal safe manoeuvring area dimension);
2. under keel clearance (Monte Carlo method);
3. energy induced in contact point with berth structures;
4. velocities of propeller bottom stream;
5. engine and rudder settings;
6. probabilities of collision with given points;
7. time of manoeuvre;
8. emergency manoeuvres.

In this paper only the results according to the first criterion have been presented. The safe manoeuvring areas on 95% level of confidence are widely used in analysis. The results from one series with eastern wind of 20 m/s are presented in figure 8. Additionally, maximum area as the area of all ferry passages in given simulation series is presented.

The wave analysis have been made for B alternative only. The results for significant height of wave of 2 m from direction NNE are shown in figure 9. It shows well damping factor of waves by breakwater structure and outer port.

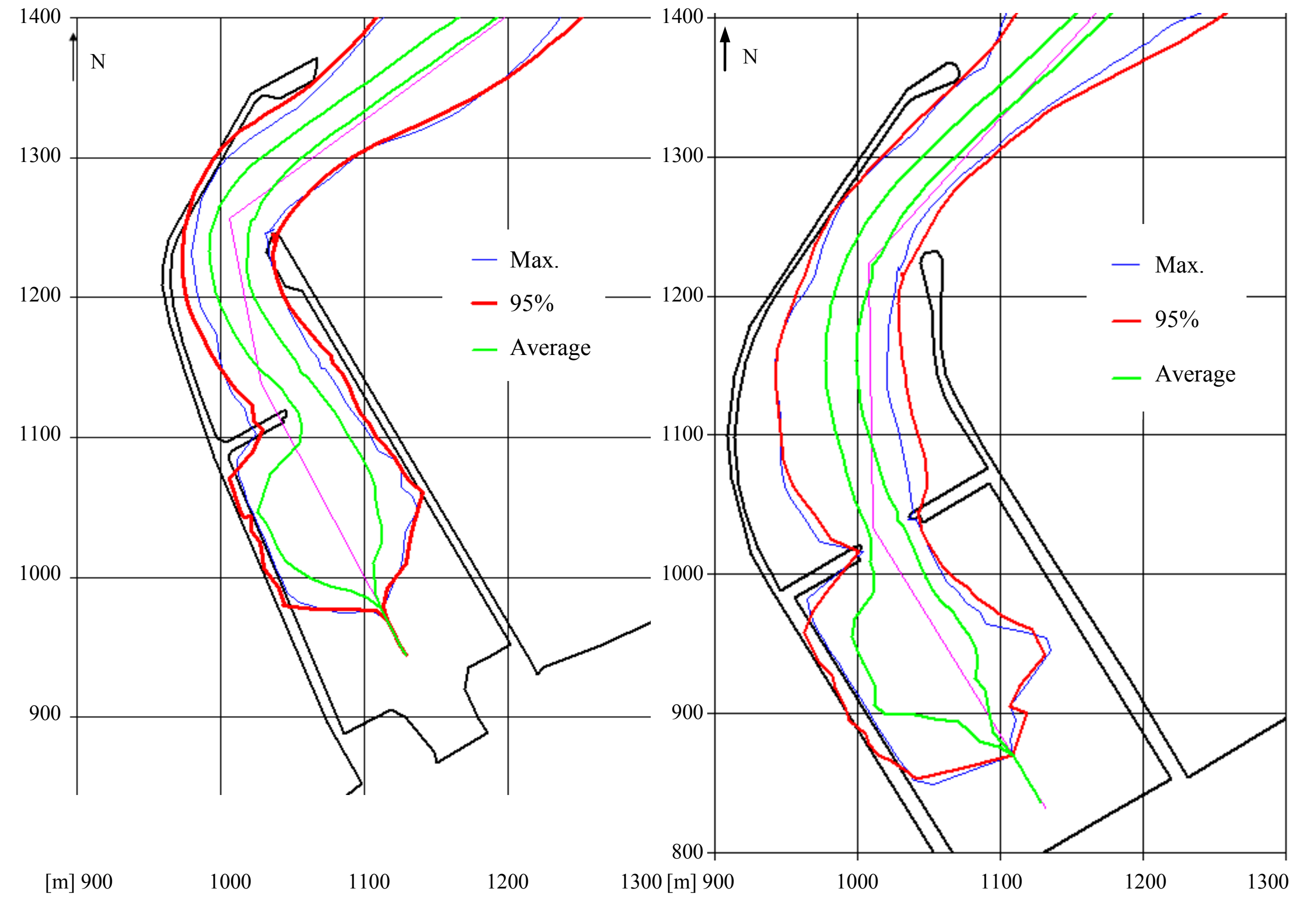

Fig. 8. Manoeuvring areas of m/f “Design” ferry during entrance with NNE 17 m/s wind – comparing simulation series 5 and 10. The 95% confidence level presented in red (mean and maximal area are presented blue and green) for S (left) and B (right) alternative

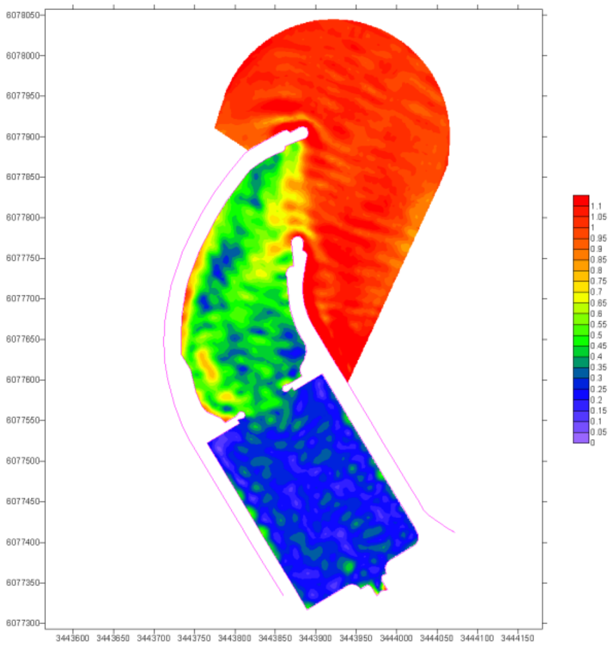

Fig. 9. The numerical wave analysis for B alternative (waves system in port significant wave height outside the breakwaters NNE 2 m and period of 7 s) [8]

Conclusions

Presented complex study could be used for guidelines for port design, operational weather limits and for risk assessment of new port and breakwaters designs. Conclusions related to conditions of safe manoeuvring passenger ship m/f "Design" in the Port of Mielno might be stated as follows:

1. The alternative S is not acceptable in compare to alternative B, so the alternative B is taken into consideration for further development (Table 3 shows differences between alternatives and necessary changes in given critical parts of breakwaters in critical places, see Fig. 3),
2. Some minor corrections (up to 5 m shape changes of breakwater) are necessary to provide in alternative B (Table 3).
3. The alternative B could used as the final stage of port design the Port of Mielno in scope of navigational safety with taking into account height of wave inside the inner port.
4. The acceptable conditions of wind for safe entrance of $L = 60$ m length ferry is NNE 17 m/s wind with wave height equals 1.8 m outside the port.

Table 3. Comparison of necessary changes in breakwaters in S and B alternative design

Simulation series	Alternative	Additional width in critical points (see Fig. 3) [m]				
		S1	S2	S3	S4	S5
1	S	0	5	0	0	10
2	S	0	10	10	5	25
3	S	0	5	0	10	40
4	S	0	5	10	0	35
5	S	5	0	0	0	40
Mean		1	5	4	3	30
Max.		**5**	**10**	**10**	**10**	**40**
S alternative – additional width of min. 5 m needed in turning place area						
Simulation series	Alternative	Additional width in critical points (see Fig. 3) [m]				
		B1	B2	B3	B4	B5
6	B	0	0	0	2	0
7	B	0	5	0	2	0
8	B	0	2	0	0	0
9	B	0	0	0	5	5
10	B	0	0	5	5	5
Mean		0	1.4	1	2.8	2
Max.		**0**	**5**	**5**	**5**	**5**

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