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Optimization of the parameters of the Świnoujście outer container port

Stanisław Gucma, Rafał Gralak, Marcin Przywarty, Bartosz Muczyński

Maritime University of Szczecin
1–2 Wały Chrobrego St., 70-500 Szczecin, Poland
e-mail: {s.gucma; r.gralak; m.przywarty; b.muczynski}@am.szczecin.pl
corresponding author

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Abstract

The article presents an original two-stage simulation method for the optimization of seaport parameters. Presentation of the method is based on example of parameter optimization of the outer container port in Świnoujście. Presented method uses two limitations of the objective function related to safety of manoeuvring and mooring of ships. It consist of two stages, first one is carried out for the parameters defined in the preliminary stage of design. On the basis of results from this stage, layout and other parameters of port waterways can be adjusted to satisfy assumed safety criteria. The second stage uses the parameters established in the first stage. It allows for small adjustments which will not change the safety of manoeuvring. The result of second stage is optimal parameters of the examined port waterways.

Introduction

A seaport is a complex system consisting of a set of various types of waterways. Optimization of the parameters of a typical port is usually performed in two stages:

- optimization of the approach fairway parameters,
- optimization of the parameters of the port entrance, the turning basin and the port basin with quays.

The common feature of these optimization tasks are the same conditions for the safe operation of ships maneuvering there.

Simulation methods are used to optimize the various types of waterways (Gucma, Gucma & Zalewski, 2008; PIANC, 2014). They are relatively well recognized for the optimization of different types of waterways that are carried out separately (Gucma, 2015).

For the port systems that consist of a set of different types of waterway, the optimization methods are poorly recognized (Gucma et al, 2015). This especially applies to the systems of port waterways, with restrictions resulting not only from basic conditions of navigation safety, but also from the safety conditions of moored ships.

The paper has presented an original, two-stage simulation method for the optimization of seaport parameters, where the objective function is limited by conditions resulting from both the safety of navigation and the safety of moored ships. The presented method was used to optimize the parameters of the new outer container port in Świnoujście, which has been designed to handle container carriers of up to 400 meters length. The capacity of the planned port is 1.5 million TEU (Twenty-Foot Equivalent Unit) with the possibility of this being doubled if necessary.

Optimization of the parameters of the seaport's waterways

From the marine traffic engineering viewpoint, a seaport is a set of waterways that begins from the roadstead, where an anchorage is located, and ends at a port basin quay.

A typical seaport is composed of the following set of waterways:

- anchorage (roadstead of the port);
- fairway (approach channel);
- entrance to the port;
- turning basin;
- port basin with quays.

The parameters of the port, considered as a system consisting of various types of waterway, are a function of the assumed conditions for the safe operation of vessels (Gucma et al., 2015):

$$\begin{bmatrix} \boldsymbol{A}_i \\ \boldsymbol{N}_i \end{bmatrix} = F(\boldsymbol{W}_i) \qquad (1)$$

where:

$\boldsymbol{A}_i$ – subsystem of the area (i-th section of the port's waterway);
$\boldsymbol{N}_i$ – navigational subsystem (i-th section of the port's waterway);
$\boldsymbol{W}_i$ – conditions for safe ship operation in the i-th section of the port's waterway.

Conditions for safe operation of ships in the port waterway system divide the port into three differently defined groups, whereby the port entrance is assigned to the second or third group, depending on whether the ship enters by itself or with tug assistance. These are:

- anchorage;
- fairway and port entrance (no tug assistance);
- turning basin, port basin and port entrance (with tug assistance).

The set of conditions for safe port entrance operations with tug assistance, turning and berthing of 'maximum ships' can be represented as follows:

$$\boldsymbol{W}^{\boldsymbol{p}} = \left[t_{\text{type}}, \text{LOA}, B, T, H, F, P, P_{bt}, n_t, P_t, \boldsymbol{H}^{\boldsymbol{p}}\right] \qquad (2)$$

where:

t_{type} – type of 'maximum ship';
LOA – length overall of 'maximum ship';
B – breadth of 'maximum ship';
T – draft of 'maximum ship';
H – airdraft of 'maximum ship';
F – lateral windage area of 'maximum ship';
P – main propulsion power of 'maximum ship';
P_{bt} – power of bow thrusters;
n_t – number of tugs engaged in berthing of 'maximum ship';
P_t – total bollard pull of tugs engaged in berthing;
$\boldsymbol{H}^{\boldsymbol{p}}$ – set of acceptable hydrometeorological conditions in the port for safe manoeuvring of 'maximum ship' to a given berth.

The set of allowable hydrometeorological conditions for turning and berthing:

$$\boldsymbol{H}^{\boldsymbol{p}} = \left[d/n, \Delta h^p, V_w, V_c\right] \qquad (3)$$

where:

d/n – time of day;
Δh^p – allowable drop of water level on the fairway for 'maximum ship';
V_w – allowable wind speed for 'maximum ship' entering the port;
V_c – allowable current speed for 'maximum ship' entering the port.

When determining the safe operating conditions for ships in a typical port it should be noted that in the port waterway system the parameters of the 'maximum ship' are identical for all its sections (groups). The allowable speeds of the wind V_w and the current V_c are identical for manoeuvres such as channel passage, turning and berthing and differ from anchoring manoeuvres, where these values are much higher.

The optimization of the parameters of the sea waterways system is carried out when such a system is built or rebuilt (water area subsystem and navigational subsystem). As there are some differences in defining and solving the optimization problems (objective function) for different types of waterways, three optimization methods have been specified for:

- berthing and turning basins;
- one-way fairways and entrances;
- two-way fairways,

and for the port as a system consisting of various waterways.

The objective function in problems of the optimization of marine waterway parameters is to minimize the costs of construction/reconstruction and subsequent operation/maintenance of waterway subsystems. Adopting these assumptions, the objective function of the optimization of waterway parameters can be defined as follows (Gucma, 2013; Gucma & Ślączka, 2015):

$$Z = (A_1 + A_2 + N_1 + N_2 + S) \rightarrow \min \qquad (4)$$

with the constraint implied by the basic conditions of navigational safety (Gucma, Gucma & Zalewski, 2008):

$$\begin{gathered} \boldsymbol{d}_{\boldsymbol{ikz}(1-\alpha)} \subset \boldsymbol{D}_{\boldsymbol{i}}(t) \\ \bigwedge_{p(x,y)\in \boldsymbol{D}(t)} h_{xy}(t) \geq T_{xy}(t) + \Delta_{xy(1-\alpha)} \end{gathered} \qquad (5)$$

and limitations of the height of waves entering the port (Thoresen, 2014):

$$h_w \leq h_w^{\text{safe}} \qquad (6)$$

where:

Z – cost of the construction and operation of the waterway system;

A_1 – cost of the construction/reconstruction of the waterway;

A_2 – cost of the waterway operation;

N_1 – construction cost of the ship position determination subsystem (navigation systems);

N_2 – operating cost of the navigation systems;

S – ship's operating costs associated with the passage through the waterway (waiting for passage, pilotage, tug assistance, etc.);

$\boldsymbol{d}_{ikz\,(1-\alpha)}$ – safe manoeuvring area of the k-th ship performing a manoeuvre in the i-th section of the waterway in the z-th navigational conditions determined at the confidence level of $(1-\alpha)$;

$\boldsymbol{D}_i(t)$ – navigable area in the i-th section of the waterway (the condition of safe depth at instant t is satisfied);

$h_{xy}(t)$ – water depth at point (x, y) at instant t;

$T_{xy}(t)$ – ship's draft at point (x, y) at instant t;

$\Delta_{xy\,(1-\alpha)}$ – underkeel clearance at point (x, y) determined at the confidence level of $(1-\alpha)$;

h_w – maximum wave height at the quay;

h_w^{safe} – acceptable wave height that is safe for the mooring vessel.

The costs of construction and operation of the waterway system and the corresponding costs of the navigation system depend on the size of the navigable area and its depth:

$$Z = F\left(\boldsymbol{D}_i, \boldsymbol{h}_{xy}\right) \to \min \tag{7}$$

For sea waterways with a constant depth (h_{xy} = const), the objective function can be written as:

$$Z = F\left(\boldsymbol{D}_i\right) \to \min \tag{8}$$

with the constraint:

$$\boldsymbol{d}_{i(1-\alpha)} \subset \boldsymbol{D}_i(t) \tag{9}$$

Simulation method for the optimization of the parameters of the Świnoujście outer container port

The parameters of the port waterways (entrance, turning basin, approach channel and quay) have been optimized in a two-stage simulation method.

Stage 1. Determination of the most cost-effective parameters of the port waterways by computer simulation of vessel movement. The parameters of the port waterways in the simulation experiment were defined at the preliminary stage of design. For the solution that was thus obtained the wave action analysis was carried out, and its results created grounds for correcting the layout and the other parameters of port waterways to satisfy the criterion of wave height at a given berth.

Stage 2. Determination of the optimal parameters of the examined port waterways by computer simulation of vessel movement. At this stage of the simulation experiment, the preliminary parameters of the port waterways were those defined in stage 1. The wave analysis was also carried out for the obtained solution. Small adjustments to the parameters were possible as they will not affect the safety of manoeuvring.

The conditions for the safe operation of a 'maximum' container ship in the outer container port in Świnoujście were determined by empirical methods (Gucma, Kotowska & Ślączka, 2016).

These conditions can be represented in the form of the following set:

- 'maximum' ship type – t_{type}, a container ship;
- 'maximum' ship's length overall – LOA = 400 m;
- breadth of 'maximum' ship – B = 60 m;
- 'maximum' ship draft – T = 13.0 m;
- allowable speed of 'maximum' ship – V = 4.0 knots;
- number of assisting tugs – n_t = 4, azimuth or cycloidal propulsion;
- total bollard pull of the assisting tugs – P_t = 250 tonnes;
- allowable time of day – *d/n* – no restrictions;
- allowable drop in water level – Δh = 0.4–0.6 m (depends on the port area and the manoeuvre performed);
- allowable wind speed – V_w = 12.5 m/s;
- wind direction restrictions – DIR_w – no restrictions;
- allowable current speed – V_c = 1 knot;
- current direction restrictions – DIR_c – no restrictions;
- allowable wave height – h_w^{safe} = 1.0 m.

The use of the simulation methods resulted in a detailed specification of the safe manoeuvring areas of ships operated or intended for operation, i.e. identification of the widths of safe manoeuvring areas for 'maximum' ships expected to be operated in each section of the port waterway allowable for the operating conditions of those vessels at a specified confidence level $\boldsymbol{d}_{ijk(1-\alpha)}$.

Using the basic conditions for safe navigation, the navigable waterway area $\boldsymbol{D}_i(t)$ can be determined as a set of maximum available widths in each (i) waterway section.

The simulation testing procedure in marine traffic engineering is as follows (Gutenbaum, 2003; Gucma, Gucma & Zalewski, 2008):

- formulation of the problem, including the indication of the design objective, simulation methods and types of simulators to be used;
- construction of the test area model;
- construction or choice of vessel movement models in the selected simulator and their verification;
- design of the experimental system and performance of the experiment;
- processing and statistical analysis of the test results.

The formulation of the research problem of a simulation experiment in the process of waterway design consists of these steps:

- determination of the research objective;
- determination of the level of confidence or acceptable risk for the safe manoeuvring area;
- choice of a simulation method;
- choice of a manoeuvring simulator.

Simulation tests make use of the results of the preliminary waterway design (empirical methods), a basis for defining the:

- preliminary parameters of the outer container port in Świnoujście – building version A;
- changes in the aids to navigation: buoys 15 and 16 to be moved 4 cables north, a new buoy to be established on the western side of the fairway – in the position of the existing buoy 15;
- vector of the safe operating conditions for the 'maximum ship' that was used at the preliminary stage to define the parameters of waterway elements:

$$\boldsymbol{W}_{\max} = \left\lfloor t_{\text{type}}, \text{LOA}, B, T, H, V, n_t, P_t, \boldsymbol{H}_i \right\rfloor \quad (10)$$

The simulation tests were aimed at determining the safe manoeuvring areas of a 'maximum' container ship during its entry, turning, berthing and mooring in the outer container port in Świnoujście. Once the safe manoeuvring areas are known, the available navigable areas in each part of Świnoujście's outer container port can be determined. The widths of these areas have been defined at the confidence level $(1-\alpha) = 0.95$.

The tests made use of real time simulation (RTS) and non-autonomous models of ships, in which ship movement is controlled by a human (pilot, captain). Simulation tests were performed on a multi-bridge ship handling a Polaris simulator with a 3D projection, from Kongsberg Maritime AS. This full mission bridge simulator is installed at the Marine Traffic Engineering Centre, Szczecin Maritime University.

A geometric three-dimensional model of the test area was developed in the simulator using the UTM projection in the reference WGS 1984 system. It consists of the following geometric models:

- terrain topography;
- environment features;
- radar database;
- area depths.

A simulation model of a 'maximum' container ship was built on the assumption that maximum ocean-going container ships, that can enter the Baltic Sea through the Danish Straits, have a maximum length of 400 m and a breadth of 60 m. The maximum draft of these container ships is around $T = 16.0$ m. Due to the specific cargo such as containers (bulky items) and the nature of the Baltic container shipping (feeder ports), the draft of the container ships that usually enter the Baltic is not bigger than 13 meters. It has been assumed for the above reasons that a 'maximum' container ship operating in the outer container port in Świnoujście in the future will have such parameters.

The MSC JADE, launched on 1 May 2015, is a typical ship of that group. Its main particulars are as follows:

• deadweight	– 200,148 tons;
• length overall	– 398.4 m;
• breadth	– 59.1 m;
• maximum draft	– 16.0 m.

The ship, loaded to $T = 13.0$ m, was modelled in a simulation experiment. The three-dimensional geometric model of a container ship (Figure 1) was built in the CAD environment, based on the technical documentation of the vessel. The model was characterized by a possibly faithful representation of the real ship's dimensions, scale, navigational and manoeuvring parameters and texture mapping, taking into account the limited computing power of the visual computers and modelling techniques used. To implement the models in the simulation

Figure 1. A geometric model of the 'maximum' container ship, MSC JADE

environment, the low poly technique was used for their construction.

The movement of the container ship MSC JADE was modelled using the hydrodynamic modelling tool (HDMT) installed in the Polaris simulator. The ship movement model was verified using the shipyard manoeuvring trial data of the MSC JADE (Artyszuk, 2013).

Simulation tests – stage 1 of the optimization

The simulation experiment was designed for the outer container port in Świnoujście, whose parameters had been determined at the preliminary design stage by empirical methods – building version A (Figures 2 and 3). The buoys 15 and 16 were moved 4 cables to 2.1 km of the fairway. In place of buoy 15 an additional buoy was moored to mark the western limit of the navigable area. A safe depth contour of 14.5 m runs 100 m from the existing and planned breakwater.

For a 'maximum' container ship LOA = 400 m, the entry manoeuvre into Świnoujscie's outer container port is more difficult than the departure manoeuvre.

The ship's entry consists of the following specific manoeuvres:

- entry into the port;
- turning around starboard side (approximately 90°);
- stern-to entry into the basin and berthing;
- mooring alongside starboard side.

The ship's departure consists of the following specific manoeuvres:

- unberthing;
- leaving the port basin (bow first);
- turning to port side (approximately 90°);
- departure from the port.

The maximum allowable wind speed assumed for the manoeuvring of the container ship was $V_w = 12.5$ m/s. It should be noted that in accordance with existing manoeuvring practice for large ships in the port of Świnoujście (including Q-Flex gas tankers) the safe wind speed for ingoing vessels is $V_w = 10$ m/s, with a possible unpredicted increase of wind speed to 12.5 m/s during the passage through the approach channel. The least favourable conditions during the port entry manoeuvring occur when winds blow from the stern. The same applies to the direction of the current.

Taking the above assumptions into account, the following assumptions and conditions for stage 1 of the simulation experiment could be formulated:

1. Container ship MSC JADE: 200,000 DWT, LOA = 398.4 m, $B = 59.0$ m, $T = 13.0$ m (16.0 m).

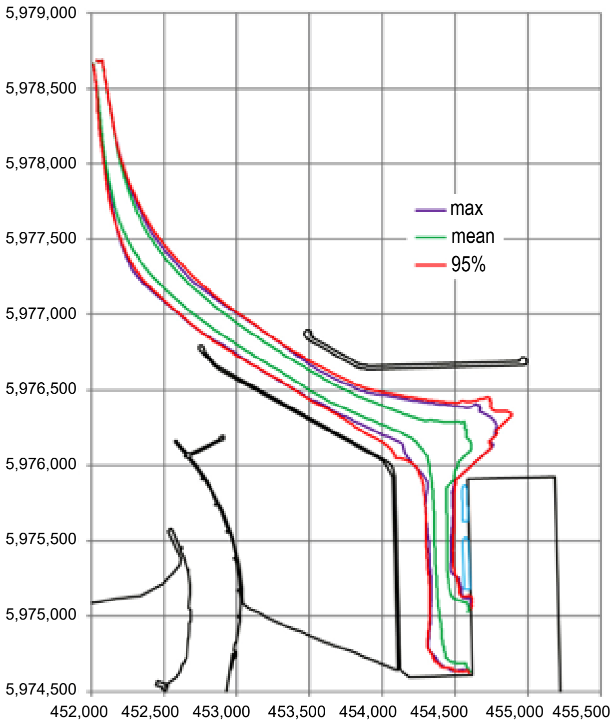

Figure 2. Safe maneuvering areas of the container ship with $L_c = 400$ m, wind N 12.5 m/s, ingoing current 1.3 knots (mean maximum) – building version A

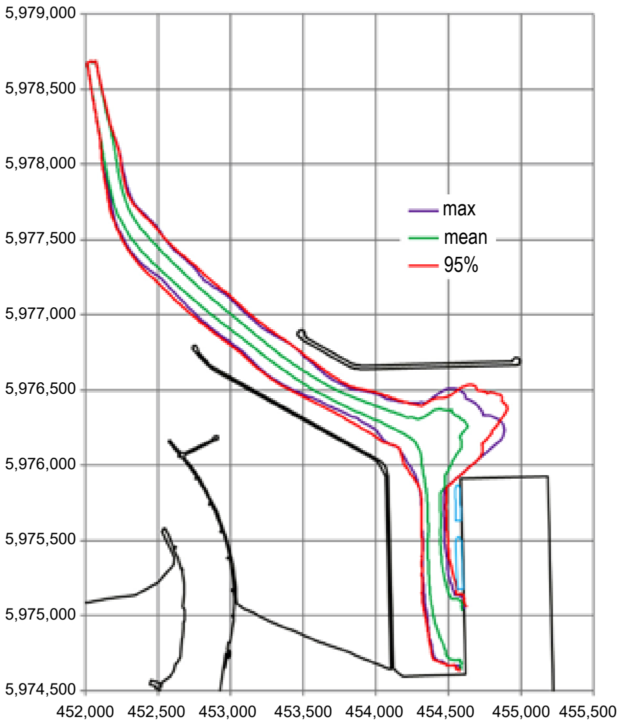

Figure 3. Safe manoeuvring areas of the container ship with $L_c = 400$ m, wind W 12.5 m/s, outgoing current 1.0 knot (mean maximum) – building version A

2. The experiment addresses these manoeuvres: entry, turning and starboard side berthing to berth No. 1 (internal berth).
3. The No. 2 berth (middle) accommodates an ocean-going container ship (LOA = 400 m, B = 60 m) and No. 3 berth (external) accepts a feeder ship (LOA = 250 m; B = 32 m).
4. The entry always begins with the 'new pair of buoys' abeam, established 0.4 km from the existing buoys 15 and 16.
5. The position of the container ship: fairway centre ± 30 m.
6. The container ship is on the course 170° ± 2°, proceeding at 4 knots ± 0.5 knot.
7. Bow and stern towing lines are passed to tugs with azimuth drive, each having a bollard pull of 70 t, while two tugs (70 t and 40 t) assist by pushing. The total bollard pull of four tugs is Σ = 250 tonnes.
8. The length of the free berth No. 1 is 540 m.
9. The pilots on board perform one or two passages each in one series, starting from series No. 1.

Two series were performed, each consisting of 12 port entries.

- Wind N – 12.5 m/s, current 1.3 knots, ingoing (mean maximum).
- Wind N – 12.5 m/s, current 1.0 knot, outgoing (mean maximum).

The vertical and horizontal current speed distributions were adopted in accordance with the model defined by the Institute of Hydroengineering, Polish Academy of Sciences (Robakiewicz, 1993). The adopted wind speed was the average speed.

Simulated entries were conducted by pilots from the Szczecin-Świnoujście Pilot Station, and captains with experience in manoeuvring large container ships. Each of the pilots/captains was able to make one or two passages in one series.

Statistical processing of the results of the simulation tests came down to calculating the safety criteria of the performed manoeuvre, which were then used for comparison of the results from each variant of the simulation series (Gucma, 2001).

Several criteria of navigational safety (performed manoeuvre) were used in this study, which were:

- safe manoeuvring area defined on the basis of these parameters: swept path width, navigational reliability, probability of accidents;
- distribution of the first ship-berth contact kinetic energy;
- duration of entry, turning and berthing manoeuvres.

The safe manoeuvring area was determined by a random variable representing the maximum distances of the ship's extreme points on the left and right-hand sides of the hypothetical axis of the examined area.

The width of the safe manoeuvring area for a specific series of simulated passages was calculated at the confidence level:

- 50% average;
- the maximum, as a maximum envelope of a specific series;
- 95%.

The safe manoeuvring area width at $(1-\alpha)$ confidence level was determined using the following relationship:

$$h_{j(1-\alpha)} = d_{lj} + c\delta_{lj} + d_{rj} + c\delta_{rj} \tag{11}$$

where:

$h_{j(1-\alpha)}$ – width of the ship's safe manoeuvring area in the j-th swept path;

d_{lj} – average of the maximum distances of the ship's extreme points to the left of the axis in the j-th swept path;

d_{rj} – average of the maximum distances from the ship's extreme points to the right of the axis of the j-th swept path;

δ_{lj}, δ_{rj} – standard deviations of the passage series for the maximum distances of the extreme points to the left and right of the axis in the j-th swept path;

c – coefficient defining the confidence level (we assumed c = 1 for the confidence level of 50% and c = 2 for the confidence level of 95%.

The results of the simulated entries to the outer container port, turning, berthing and mooring of the container ship with LOA = 400 m, presented as safe manoeuvring areas specified at confidence levels of 50%, 95% and maximum (maximum envelope from a series), have been shown in Figures 2 and 3.

Analyses of the safe manoeuvring areas and wave conditions for the building version A (Analiza, 2017) allowed for the identification of the available manoeuvring area and the determination of a new building version, Figure 4 (version B). The available manoeuvring area was bounded by a safe depth contour, adopted as 14.5 m. The minimum safe distance of the depth contour to the breakwaters was assumed to be equal to 100 m.

The stage 1 optimization resulted a change in the geometry and length of the front breakwater (Figure 4 – building version B), which was extended from the west by about 50 m and deflected at an 8° angle; from the east it was extended by 355 m and deflected by 35°. These changes optimized the shape of the port entrance, i.e. a minimum safe entry width and a minimum length of the front breakwater, assuring the safety of ships along the berth (the safety criterion is a wave height at the berth of $h_w \leq 1.0$ m). A minimum safe entry width (at the bottom, at a depth of 14.5 m) was established on the basis of the simulation experiment carried out in the least favourable navigational conditions for the entry manoeuvre (Wind from the N and W).

Optimal parameters of the outer container port in Świnoujście – optimization stage 2

The aim of stage 2 of the optimization was to determine the eastern border of the turning basin, the width and shape of the port basin and a minimum safe bollard pull of the tugs. This required planning and conducting a simulation experiment of the 'maximum' container ship's entry to the designed port: one series of 12 entries, with E wind of 12.5 m/s, and outgoing current of 1.0 knot (mean maximum). The other operating conditions were the same as in stage 1.

The results of simulated entries to the outer container port, turning, berthing (berth No. 3) and mooring of a container ship with LOA = 400 m, presented in the form of safe manoeuvring areas for confidence levels of 50%, 95% and the maximum (maximum envelope from the series) have been shown in Figure 4.

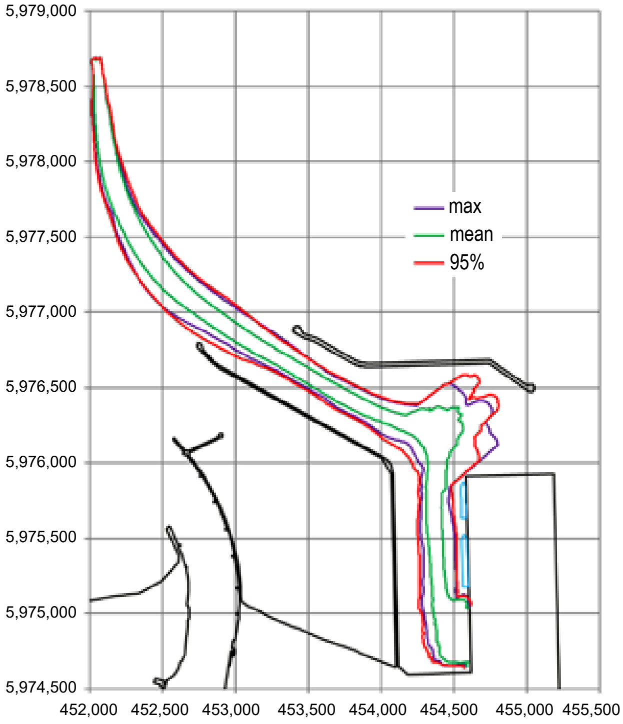

Figure 4. The safe manoeuvring area of the container ship with $L_c = 400$ m. Wind E 12.5 m/s; current 1.0 knot, outgoing – building version B

The analyses of the safe manoeuvring areas obtained in stages 1 and 2 and of the wave conditions in the outer container port, building version B, allowed for the determination of the ultimate

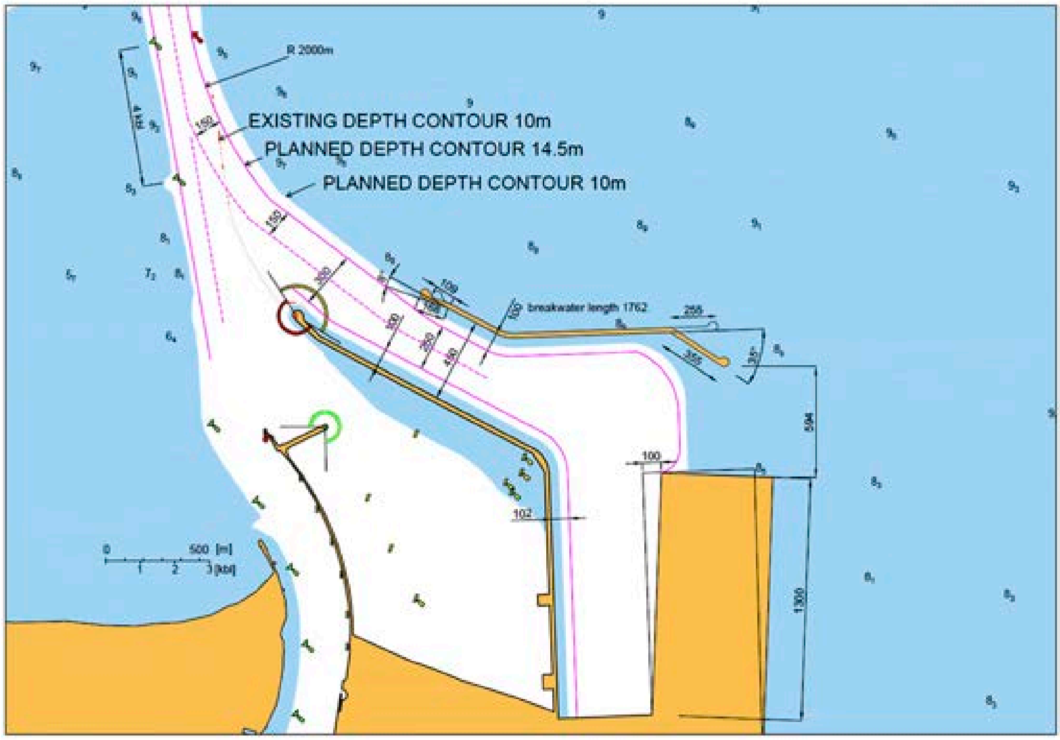

Figure 5. Optimal design solution of the outer container port in Świnoujście (parameterization after stage 2 of the simulation optimization method) – building version C

optimal outline of the port – building version C. Version C differed from version B as it features the container jetty front shifted towards the east (moved by 100 m). This variant created safer manoeuvring conditions for ships turning and did not increase wave impact. The optimal shape and parameters of the outer container port (building version C) have been shown in Figure 5. An analysis of wave conditions in building version C verified that ships would be able to safely moor along the jetty (Analiza, 2017).

The kinetic energy of the first contact of a 'maximum' container ship with the berth during berthing manoeuvres depends on wind direction:

- N 12.5 m/s – E (0.95)= 1422 kNm;
- W 12.5 m/s – E (0.95) = 1111 kNm;
- E 12.5 m/s – E (0.95) = 485 kNm.

The lowest energy of the first contact occurs when the wind was pushing the ship away.

The mean manoeuvring times were independent of wind direction and were as follows:

– total time of entry (from buoys 15/16 being abeam to the jetty):

$$t_{\mathrm{man}} \approx 75 \text{ min}$$

– time to reach the entrance heads (from buoys 15/16 being abeam to the front breakwater heads abeam):

$$t_{\mathrm{man}} \approx 18 \text{ min.}$$

Conclusions

The original simulation method for the optimization of seaport parameters presented here was divided into two stages. The objective function in this optimization method was to minimize port construction and operational costs by minimizing the available navigable area bounded by safe depth contours and minimizing the length of the sheltering breakwater. The objective function constraints were:

The basic condition for navigational safety:

$$\boldsymbol{D} \subset \boldsymbol{d}\,(1-\alpha) \tag{12}$$

in which the safe manoeuvring area d $(1-\alpha)$ was determined by simulation of the vessel's passage, the simulation experiment was carried out in carefully planned conditions of the ship's safe operation.

The wave height at the berth during the least favourable stormy conditions:

$$h_w \leq h_w^{\mathrm{safe}} \tag{13}$$

in which the allowable wave height at the berth h_w^{safe} determines the safety of moored vessels.

The simulation method for seaport optimization was used to determine the key parameters of the outer container port in Świnoujście (Figure 5). The new port is expected to handle the largest ocean-going ships entering the Baltic Sea with a cargo capacity of 20,000 TEU and length of up to 400 m. The expected annual throughput of the port is estimated at 1.5 million TEU.

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References

1. Analiza (2017) Szczegółowe określenie parametrów i warunków bezpiecznej eksploatacji Zewnętrznego Portu Kontenerowego w Świnoujściu (analiza nawigacyjna). Praca naukowo-badawcza. Akademia Morska w Szczecinie.
2. Artyszuk, J. (2013) *Modelowanie i symulacja ruchu jednostek pływających w zagadnieniach bezpieczeństwa i efektywności manewrowania*. Szczecin: Wydawnictwo Naukowe Akademii Morskiej w Szczecinie.
3. Gucma, S. (2001) *Inżynieria Ruchu Morskiego.* Gdańsk: Wydawnictwo Okrętownictwo i Żegluga.
4. Gucma, S. (2013) *Optymalizacja parametrów systemu morskich dróg wodnych w ujęciu inżynierii ruchu morskiego.* Materiały na Międzynarodową Konferencję Naukową Transport XXI wieku. Ryn, 16–19.09.2013.
5. Gucma, S. (2015) Studying sea waterway system with the aid of computer simulation methods. *Polish Maritime Research* 1(85).
6. Gucma, S. et al. (2015) *Morskie drogi wodne. Projektowanie i eksploatacja w ujęciu inżynierii ruchu*. Gdańsk: Fundacja Promocji Przemysłu Okrętowego i Gospodarki Morskiej.
7. Gucma, S., Gucma, L. & Zalewski, P. (2008) *Symulacyjne metody badań w inżynierii ruchu morskiego*. Szczecin: Wydawnictwo Naukowe Akademii Morskiej w Szczecinie.
8. Gucma, S., Kotowska, I. & Ślączka, W. (2016) Wybór lokalizacji terminalu kontenerowego w Świnoujściu. *Inżynieria morska i geotechnika* 6.
9. Gucma, S. & Ślączka, W. (2015) Methods for optimization of sea waterway systems and their application. *Polish Maritime Research* 3(87).
10. Gutenbaum, J. (2003) *Modelowanie matematyczne systemów*. Warszawa: Polska Akademia Nauk.
11. PIANC (2014) *Harbour Approach Channels – Design Guidelines*. PIANC Report No. 121 – 2014. PIANC Secrétariat Général. Bruxelles.
12. Robakiewicz, W. (1993) *Warunki hydrograficzne Zalewu Szczecińskiego i cieśnin łączących Zalew z Zatoką Pomorską*. Gdańsk: IBW PAN.
13. Thoresen, C.A. (2014) *Port Designer's Handbook*. London: ICE Publishing.