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YSTAD PORT MODERNISATION STUDY ON THE BASIS OF REAL TIME MANOEUVRING SIMULATION METHOD

Summary. The paper presents complex method of water areas optimisation with consideration of navigational safety. The real time simulation method was implemented in presented study. The results were used as design guidelines for Ystad port development.

OPRACOWANIE STUDIUM MODERNIZACJI PORTU YSTAD NA PODSTAWIE SYMULACYJNYCH BADAŃ CZASU RZECZYWISTEGO

Streszczenie. W artykule przedstawiono kompleksową metodę projektowania i optymalizacji dróg wodnych z uwzględnieniem bezpieczeństwa nawigacji. Jako metodę badawczą zastosowano symulację czasu rzeczywistego. Rezultaty badań zostaną wdrożone jako wytyczne do modernizacji portu Ystad w Szwecji.

1. INTRODUCTION

Marine Traffic Engineering (MTE) research team of Maritime University of Szczecin since the 70-ties is engaged in research works concerned with evaluation of navigation safety for port design and optimization of water areas. The researches described in this paper are focused on Ystad port modernisation which is one of the latest research studies of MTE team. The main aim of researches was concerned with [Computer simulation 2008]:

1. Determination of optimal parameters of:
   - approach channels to reconstructed port of Ystad with respect to shape, width and depth,
   - inner and outer port breakwaters with respect to its shape with respect to waving in port,
   - turning places with respect to its shape and optimal depth,
   - two new 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 such as 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 ferry distances to the most dangerous objects;

7. Carrying out most typical emergency runs and describe necessary emergency action for the captains.

Two characteristic Ro-Pax ship was chosen as typical for the development of Ystad port. M/f *Wolin* is a midi size ferry originally built as train ferry. The second ship m/f *Piast* is a newly designed ferry build for Unity Line by Stocznia Szczecinska Shipyard. Most important parameters of ferries are presented in the Table 1.

Tab. 1

Main parameters of *Wolin* and *Piast* as typical ferries operated on the Baltic Sea area

Parameter	PIAST	WOLIN
Operator (route)	Unity Line (Swinoujscie-Trellborg)	Unity Line
Building year	1986 / 2002 rebuild	expected 2009
Length - LOA	207 m	188.9 m
Breadth	27 m	23.7 m
Draft	6.3 m	5.9 m
DWT	8000 t	5143 t
Machinery	total 21.600kW at 500rpm.	total 13.200kW at 600 rpm.
Propeller	2 variable pitch propellers turning inside at 145 rpm	2 variable pitch propellers turning inside at 150 rpm
Speed	approx. 21 kn.	18 kn.
Rudder	2x70 deg. active	2x70 deg. active
Bowthrusters	2x2.300kW	2x1100 kW
Sternthruster	1x1.200kW	1x736 kW
Lateral wind area	approx. 3000m2	approx. 2700m2
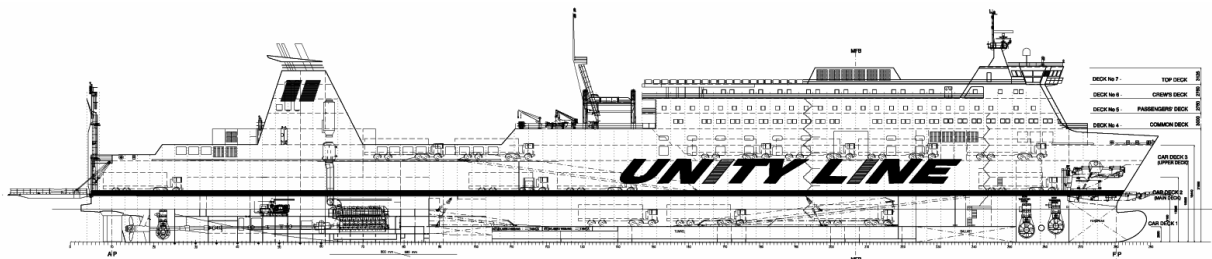
Fig. 1. General arrangement of m/f *Piast*
Rys. 1. Plan promu Piast

Fig. 2. *Wolin* ferry
Rys. 2. Prom Wolin

2. MODERNISATION OF YSTAD PORT

The most important aim of Ystad port modernisation is to provide access to the port by ferries up to 210m length and enable future port development in the future to serve ships of 240m length [Computer simulation 2008]. Three most important changes are planned (Fig. 3):
1. building two instead of three ferry quays in inner port,
2. design of new turning place in outside port,
3. shortening of inner western breakwater,
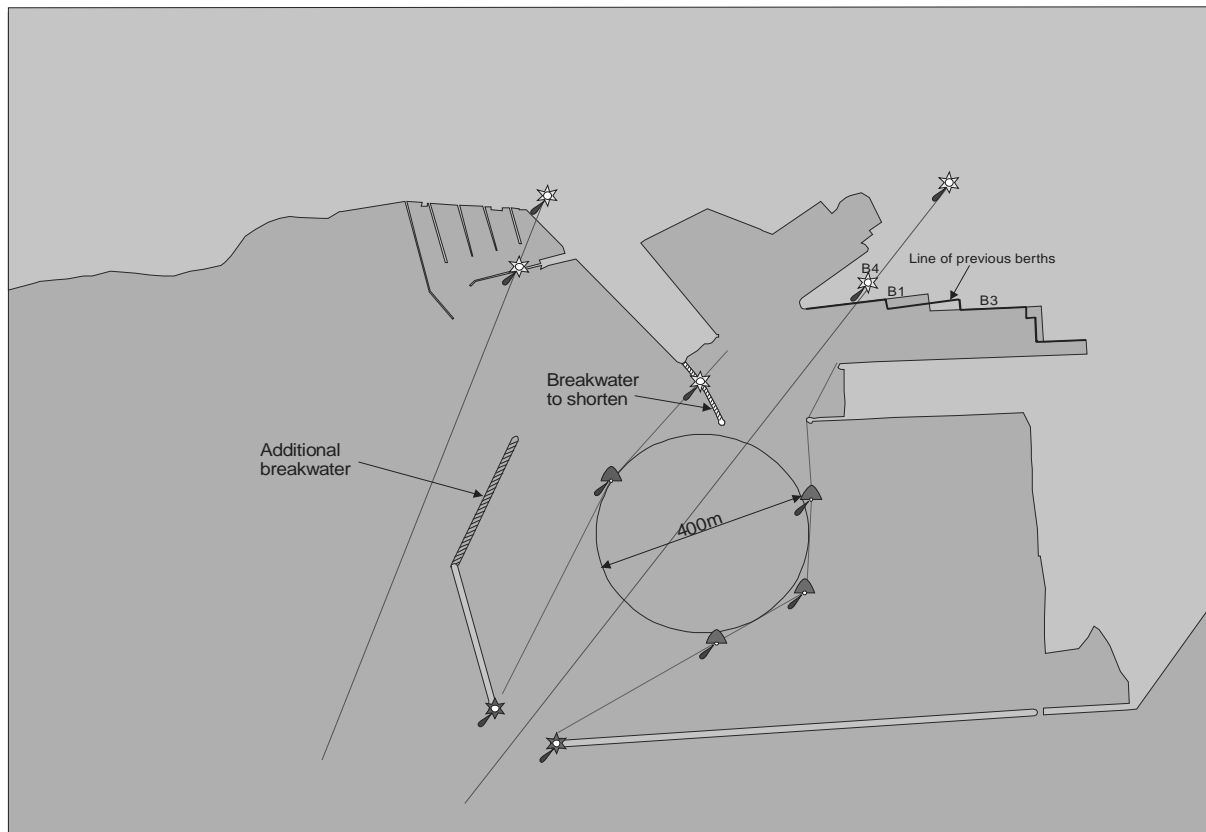4. lengthening of outer breakwater to provide shelter in western winds of turning place.

Fig. 3. Proposed changes in berths, turning place and breakwaters arrangements in Port of Ystad
Rys. 3. Proponowane zmiany w układzie nabrzeży, obrotnicy i falochronów w Porcie Ystad

3. 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 [Gucma 2005]. 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.

3.1. 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. In present researches the second model was used (m/f *Wolin* exists and sea trials are available *Piast* trial parameters was extrapolated).

The model 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,
8. moment and force of bank effect,
9. shallow water forces,
10. mooring and anchor forces,
11. reaction of the fenders and friction between fender and ships hull,
12. tugs forces,
13. other depending of special characteristics of power and steering ships equipment.

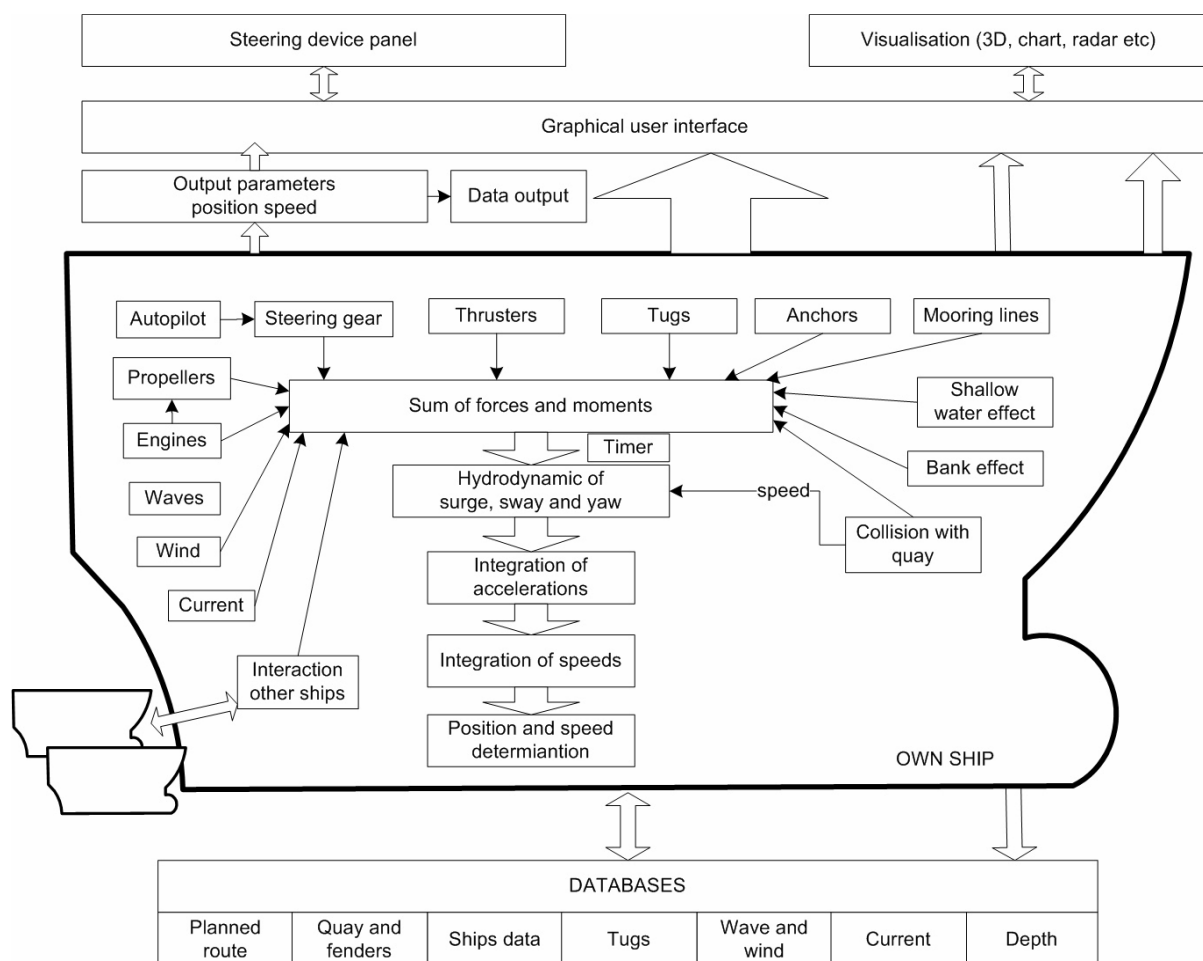The functional idea of the ship manoeuvring simulation model is presented in Fig. 4.

Fig. 4. The main diagram of simulation model
Rys. 4. Schemat funkcjonalny modelu symulacyjnego

Interface of model is typical 2D chart 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.
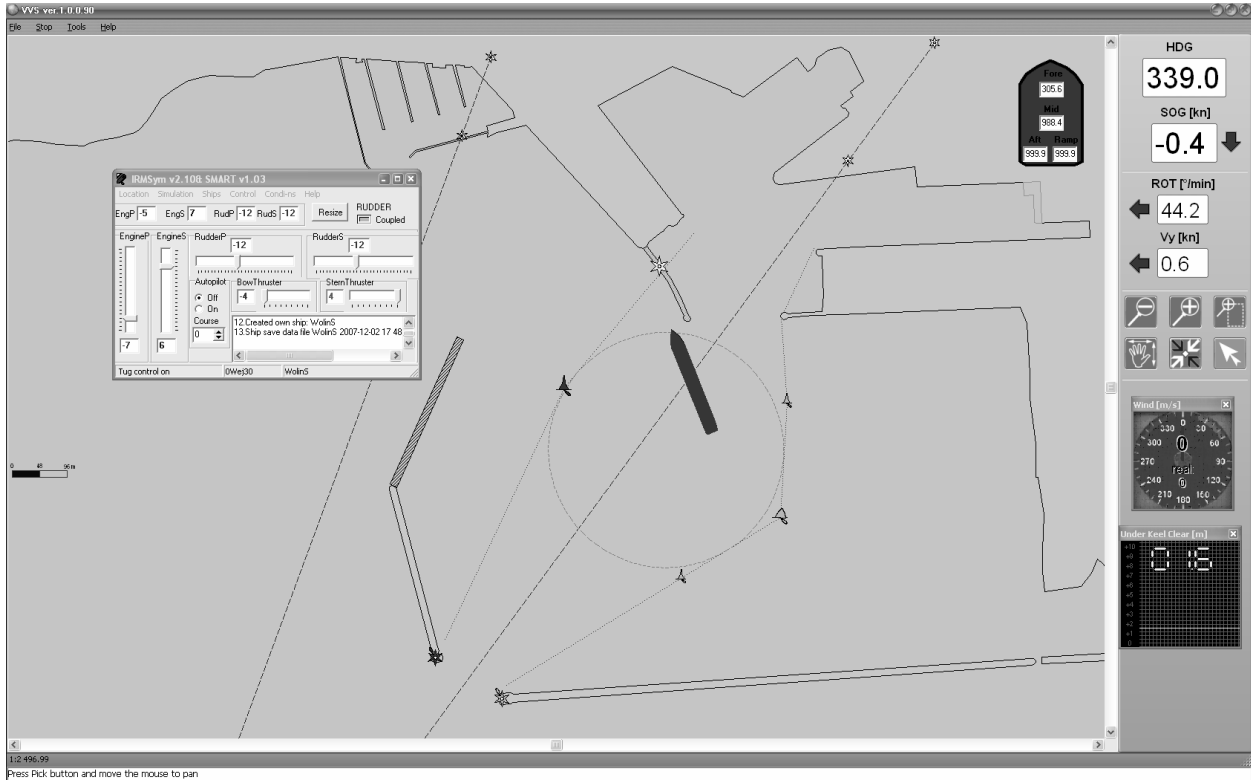

Fig. 5. Interface of simulation model ferry *Wolin* turning at outer turning place of Ystad Port (limited task simulator)
Rys. 5. Interfejs komputerowy modelu symulacyjnego. Prom Wolin obraca się na zewnętrznej obrotnicy w Porcie Ystad

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 [Artyszuk 2005]:

$$
\begin{cases}
(m+m_{11})\dfrac{dv_x^g}{dt} = (m+c_m m_{22})v_y^g\omega_z + (m_{11}-c_m m_{22})v_y^c\omega_z + F_x \\[2mm]
(m+m_{22})\dfrac{dv_y^g}{dt} = -(m+m_{11})v_x^g\omega_z + (m_{11}-m_{22})v_x^c\omega_z + F_y \\[2mm]
(J_z+m_{66})\dfrac{d\omega_z}{dt} = -(m_{22}-m_{11})(v_x^g-v_x^c)(v_y^g-v_y^c) + M_z
\end{cases}
$$

(1)

$$
\frac{dx_0}{dt} = v_{NS}^g \quad , \quad \frac{dy_0}{dt} = v_{EW}^g \quad , \quad \frac{d\psi}{dt} = \omega_z
$$

(2)

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

(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'):

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

(4)

$$v_x^w = v_x^g - v_x^c \,, \; v_y^w = v_y^g - v_y^c$$

(5)

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

(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).

3.2. Real time simulation method – full mission simulator

Kongsberg Polaris™ simulator located at Marine Traffic Engineering Centre (MTEC) premises in Maritime University of Szczecin comprises (Fig. 6):
- one full mission navigation bridge simulator with 270° visual projection and live marine ship equipment (DNV class A),
- two part task navigation bridges with 120° visual projection and mix of real and screen-simulated ship-like equipment including one Voith-Schneider tug console (DNV class B),
- two desktop PC simulators with one monitor visual projection and one monitor screen-simulated ship-like equipment.

Fig. 6. Bridge A at MTEC (with 270° visual projection) and captain "at work"
Rys. 6. Mostek A w CIRM (kąt projekcji równy 270°) i kapitan przy pracy

All hardware and software forming the Polaris ship manoeuvring simulator was granted DNV certificate for compliance or exceeding the training regulations set forward in STCW'95 (section A-I/12, section B-I/12, table A-II/1, table A-II/2 and table A-II/3).

In order to create own ship models a hydrodynamic ship-modelling tool is available. This tool enables creating almost any ship type (controls for at least two engines with propellers' controls for fixed propeller, adjustable pitch propeller and azimuth; rudder controls adequate for various types of

conventional rudders, active rudders, Z-drive/azimuth and thrusters) with very high fidelity hydrodynamics in 6 DOF (surge, sway, heave, yaw, roll, pitch). The hydrodynamics comprise all known to state of the art external effects like squat, bank and channel effects.

4. STATISTICAL METHODS OF DATA PROCESSING

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.

4.1. Safe manoeuvring areas

The most important factor is safety horizontal area needed for navigators for performing manoeuvres [Gucma 2005, Irribaren 1999]. The assumption of such model is that the ship moves along predefined route x (Figure 7.a) with following probability of accident:

$$P_{AW} = P_{SA/A}P(Y \geq y_{MAX}) = P_{SA/A} \int\limits_{y_{MAX}}^{+\infty} f(y)dy$$

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 7.a. The distributions are strongly dependant of waterway area arrangement and could be evaluated in simulations and validated in real experimentations.

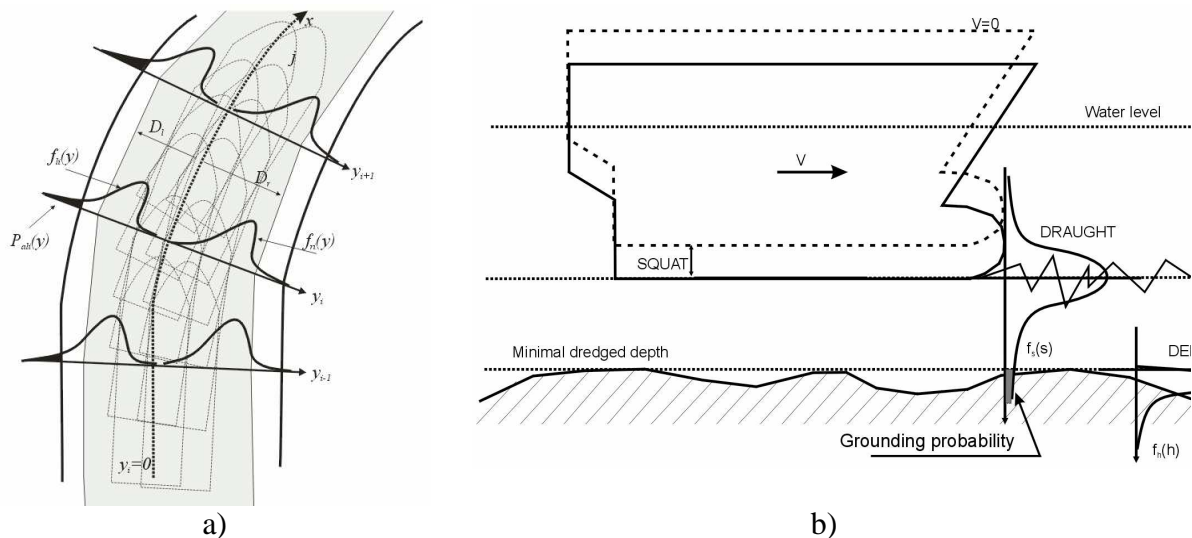a)   b)

Fig. 7. Probabilistic concept of safe manoeuvring area determination on the waterway (a) and underkeel clearance of ships determination (b)
Rys. 7. Probabilistyczna koncepcje określania bezpiecznego poziomego (a) i pionowego (b) obszaru manewrowego

4.2. Model of underkeel clearance

The stochastic model of under keel clearance evaluation was presented in [Gucma and Schoeneich 2007]. It is based on Monte Carlo methodology where overall ships underkeel clearance is described by following mathematical model (Fig.7.b):

$$UKC = (H_0 + \sum \delta_{Hoi}) - (T + \sum \delta_{Ti}) + (\Delta_{Swa} + \sum \delta_{Swi}) + \delta_N$$

where: δ_{Hoi}–the uncertainties concerned with depth and its determination, δ_{Ti}–the uncertainties concerned with draught and its determination, δ_{Swi}–the uncertainties concerned with water level and its determination, δ_N –navigational and manoeuvring clearance.

The most important factor is squat. The special model of squat was used in the model of UKC. It was validated by means of real experiments with use of RTK system mounted in ferries [Gucma et al 2006].

4.3. Propeller stream on the bottom

The model used for determination of propeller stream on the bottom was presented in [Gucma and Jankowski 2001]. The model assumes stream deflection according to the rudder's position and presence of fixed structures (Fig. 8). The influence of propellers is calculated on the base of recorded simulation trails. Additionally the streams from side thrusters were calculated.
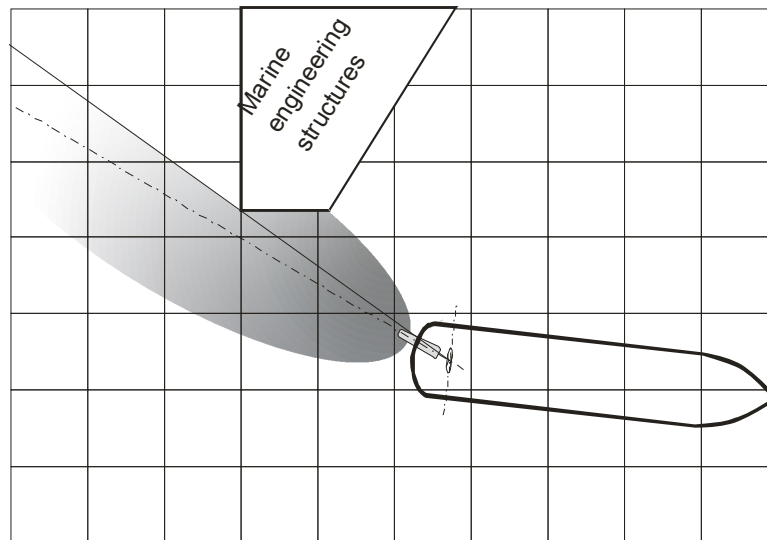

Fig. 8. The distribution of the bottom's streams when main propeller working ahead
Rys. 8. Rozkład prędkości strumienia zaśrubowych przy dnie

4.4. Ships berthing energy

Ships berthing energy is calculated by Vasco Costa method [Vasco Costa 1969] which enables to consider of yaw movement of ship during first contact, ships movement during contact with fender and ships reflection speed.

5. RESEARCH PLAN

In researches maximum wind speed assumed as 20m/s (9°B). Experience from m/f *Wolin* ferry operated in Swinoujscie and Trelleborg showed that it could be maximum allowable side wind speed, that ferry can operate safely (i.e. enter and leave the port).

In researches two worst wind and current conditions were taken into consideration for entering the port: Easterly wind of 20m/s, and westerly wind with 20m/s.

Total number of series was as follows: *Wolin* ferry: 12 series and *Piast* ferry: 6 series (6 on limited task and 6 on full mission). Minimum 15 runs were performed in each series (it gives a total of 270 on limited task simulator and 90 runs on full mission). Turning was performed in inside the port (2 series only) and new turning place (rest of series). All manoeuvres were performed without tugs assistance. Each captain was engaged in 2-3 runs of given series. In researches 8 captains performed the simulations.

6. RESULTS OF RESEARCHES

Analysis of simulation results was made in basis of following criterions:
- traffic lane widths (horizontal safe manoeuvring area),
- under keel clearance (Monte Carlo method),
- energy induced in contact point with berth structures,
- velocities of propeller bottom stream,
- engine and rudder settings,
- probabilities of collision with given points,
- time of manoeuvre,
- emergency manoeuvres.

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 Fig. 9. Additionally maximum area as the area of all ferry passages in given simulation series is presented.
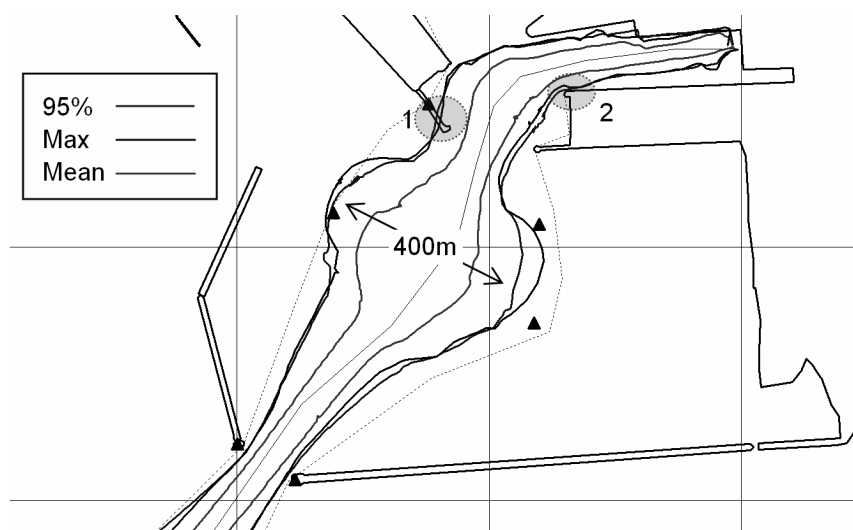

Fig. 9. Manoeuvring areas of *Piast* ferry during entrance with east 20m/s wind to berth no 3 on 95% confidence level (mean and maximal area are presented)
Rys. 9. Obszary manewrowe na poziomie ufności 95% promu Piast przy wejściu do portu, wiatr 20m/s nabrzeże numer 3 (zaznaczono również średnie i maksymalne obszary)

The most important places are marked as red shaded circles (number 1 and 2 in Fig.9). Those are western inner breakwater (1) and inner corner of cargo quay (2). The researches conclusion is to shorten the western breakwater of 90m minimum and to cut the corner of cargo quay at least of 15 meters. These results are used also for design of turning place.

The energies during berthing could be used for design of fender system. The histogram of berthing energies in 3 different series is presented in Fig. 10.a. Maximal energies are not exceeding 400kNm and mean are around 100kNm. The typical distribution used here is gamma distribution. The points of first impact of ferries (Fig. 10.b) could be used for guidelines of fender positioning.

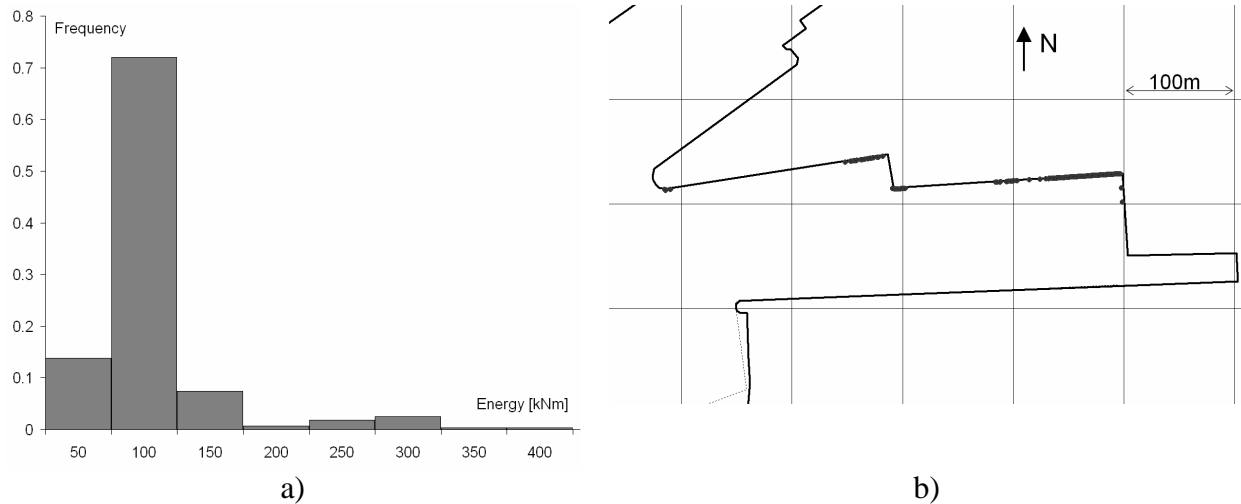a)   b)

Fig. 10. Histogram of induced energies (a) and distribution of contact points during mooring of m/f *Wolin* ferry to berth no.1 and 3.
Rys. 10. Histogram energii pierwszego kontaktu (a) i rozkład punktów zderzeń z nabrzeżem promu Wolin przy nabrzeżu 1 i 3.

The maximum propeller streams locations are important as the guidelines for bottom protection (Fig. 11). The stream speed calculated on the bottom by presented model is not exceeding 6m/s in given trial.
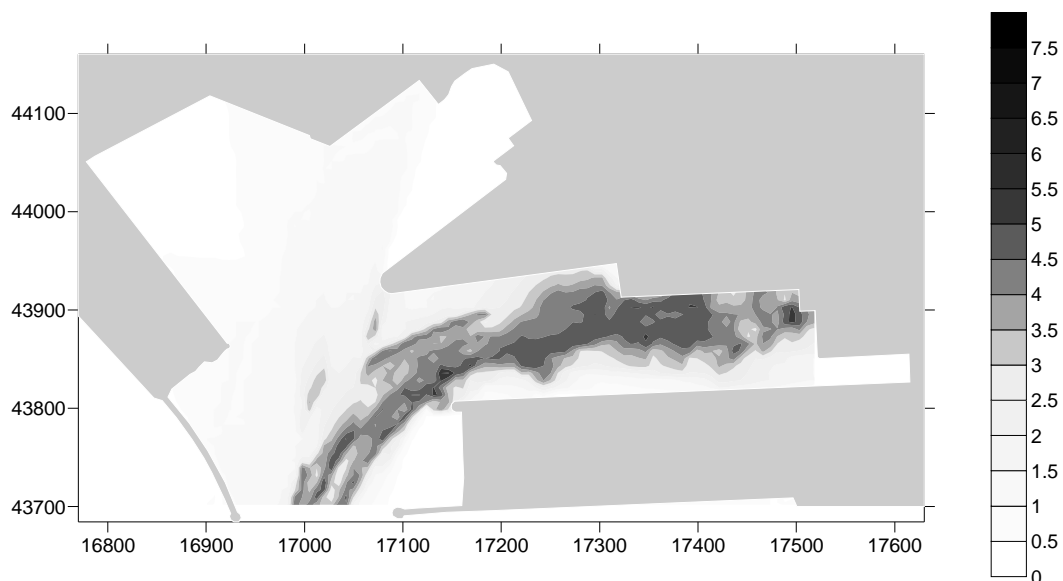
Fig. 11. Propeller streams of m/f *Wolin* during entrance to no. 3 berth. Wind S20m/s
Rys. 11. Strumienie zaśrubowe przy dnie promu Wolin przy podejściu do nabrzeża nr.3

The Monte Carlo method of UKC calculation is widely used today. The results in function of distance to outer breakwater entrance are presented in Fig. 12.b. The histogram of simulated UKC in the entrance calculated by means of presented method is presented in Fig 12.a. The confidence intervals could be used for uncertainty determination in risk analysis of hitting the bottom.
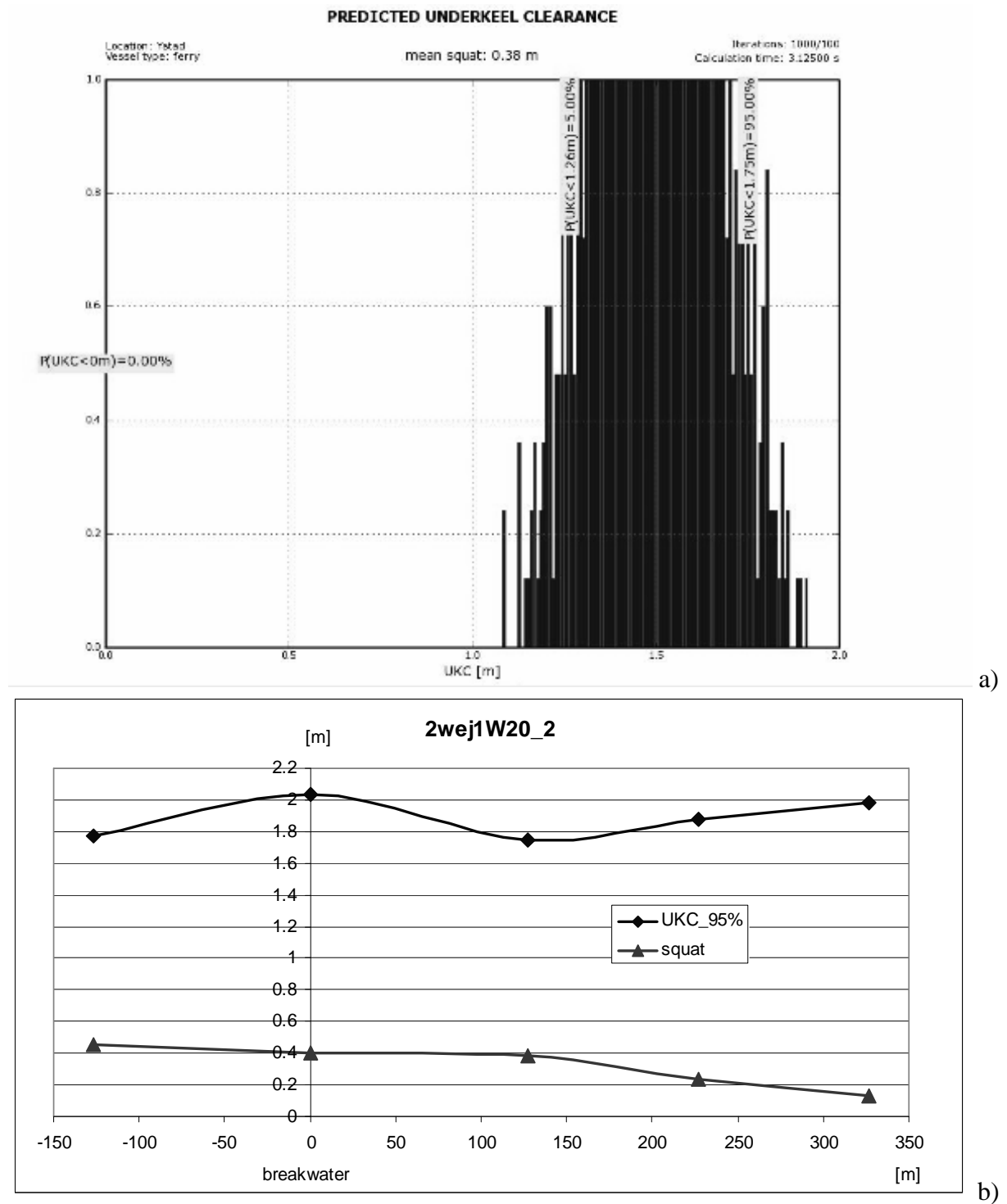

a)

b)

Fig. 12. Histogram UKC and squat value at 130m behind heads (sea wave =0m). UKC of ferry in meters on approach with West 20m/s wind (x=0 at outer breakwater)

Rys. 12. Przykładowy histogram symulowanych zapasów pod stępką 130m przed główkami (wys. fali =0m) oraz Zapas wody pod stępka na poziomie 95% w funkcji odległości do główek przy wietrze zachodnim 20m/s (główki zewnętrzne przyjęto jako x=0)

7. CONCLUSIONS

Presented complex study could be used for guidelines for port modernisation, operational limitations and for risk assessment of selected water areas.

Conclusions related to conditions of safe manoeuvring ferry m/f *Wolin* and *Piast* in Ystad port might be stated as follows:

1. Entrance to port of Ystad is safe up to following extreme conditions:
   a. wind from sector NE-SE, wind speed up to 18m/s, current 270°/0.3 kn,
   b. wind from sector NW-SW, wind speed up to 18m/s, current 90°/0.4 kn,
   c. other sectors and current combinations wind speed up to 20 m/s.
2. Turning of ferry in avanport at designed turning area might be performed as well as port and starboard side depending on wind direction and is safe to wind speed up to 20m/s regardless of its direction.
3. Entering to inner port (aft or bow first) depending on manoeuvre is safe under condition:
   a. shortening of western head of wavebreaker of minimum 90 m,
   b. shortening of corner of cargo quay of 15m,
   c. wind speed up to 20 m/s.
4. Mooring of ferry to new layout of berths 1, 3 and 4 (*Wolin* only) is safe under conditions:
   a. berths equipping in fender of admissible energy E = 400 kNm,
   b. wind speed up to 20m/s.
5. Unmooring and leaving of examined ferries from Ystad port is safe with wind speed up to 22m/s.
6. Turning in inside turning place is possible with southern wind up to force 20m/s.

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