Scientific Journals
of the Maritime University of Szczecin

Zeszyty Naukowe
Akademii Morskiej w Szczecinie

2018, 54 (126), 103–109
ISSN 1733-8670 (Printed)
ISSN 2392-0378 (Online)
DOI: 10.17402/291

Received: *16.04.2018*
Accepted: *28.05.2018*
Published: *15.06.2018*

Applying simulation studies to define further development of the approach channel to Ystad

Lucjan Gucma, Rafał Gralak, Jarosław Artyszuk, Renata Boć

Maritime University of Szczecin, Institute of Marine Traffic Engineering
1-2 Waly Chrobrego St., 70-500 Szczecin, Poland
e-mail: {l.gucma; r.gralak; j.artyszuk; r.boc}@am.szczecin.pl
corresponding author

Key words: model of manoeuvring a ship, navigation safety, designing seaports, applying simulation, approach channel, PIANC method

Abstract

The increasing sizes of ships determine the interest in modifying the already existing solutions. Simulation models allow us to analyse the possible modernisation options. The article presents analysis results for the width of the fairway to Ystad, marked with buoys with respect to navigation safety. After a thorough analysis, taking into account the safety of navigation, further possibilities of development have been determined. Study results are aimed at designing new solutions in case of modernization of the approach channel to Ystad.

Introduction

The port of Ystad is a medium-sized harbour with good facilities for handling passenger, roro, bulk and general cargo. Tugs are not compulsory but, when used, they meet vessels at the entrance buoy. Ship lines are used. An approach to the port of Ystad (Figure 1) is from the SW, close to the Ystads Redd Light-buoy (safe water 55º23.6' N 013º47.2' E), which marks the seaward end of the fairway.

Figure 1. The navigational marking of approach to port of Ystad (South Baltic Four Corners, 2017)

Modernisation of Ystad Port was planned as long ago as 2010. The need for such modernisation comes from the narrow inner port, with a lack of ferry berths, and growing competition from Trelleborg Port, where such modernization is currently ongoing. Existing infrastructure provides berths for ferries of only $L = 200$ m fulfilling safe navigation conditions. The most important aim of Ystad port modernisation is to provide access to the port by ferries up to 210 m length and enable future port development to serve ships of 240 m length. (Gucma, 2008)

The mathematical modelling of analysed ferry

The Marine Traffic Engineering Centre, Maritime University of Szczecin, used the Polaris simulator to design and implement mathematical models of the movement of the RoPax ferry for the Ystad

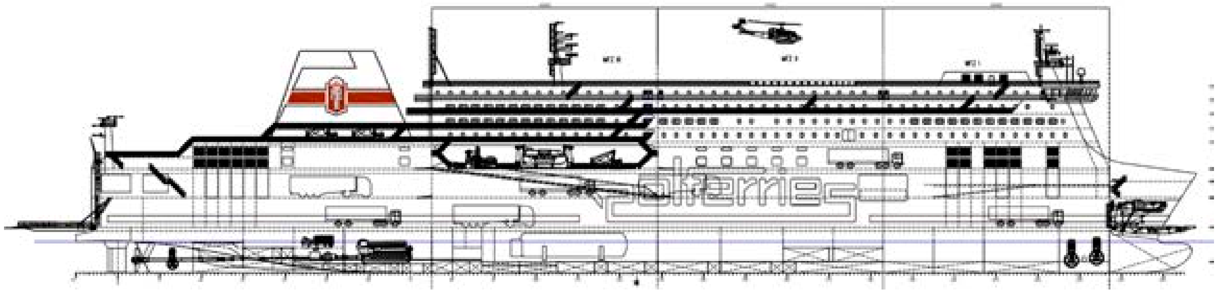
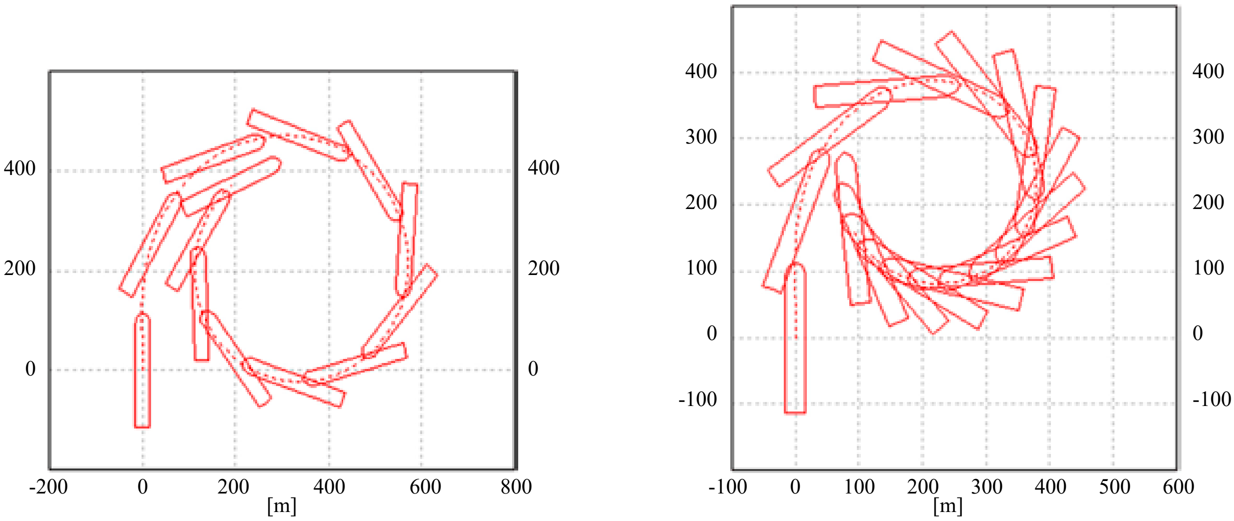


Figure 2. General arrangement of Batory predesign as the base for Ystad230 model



17 kn/20°, time 360 s, ship contour 30 s,
speed/drift angle: 8 kn/15°

12 kn/35°, time 480 s, ship contour 30 s,
speed/drift angle: 3 kn/20°

Figure 3. Turning circle tests of Batory predesign as the base for Ystad230 model

Port research and development study. The model of ship motion dynamics used in the Polaris simulator is one of the most innovative solutions in the field in terms of mathematics and programming.

Ystad230 represents a future ferry for the Baltic Sea with an optimal design for the outer Ystad Port.

The model of this ferry was created on the basis of Polferries' *Batory* preliminary design. The general arrangement is presented in Figure 2 and Table 1. The ferry is characterised by a large windage area (almost 6.5 thousand m^2) and relatively small engine and tunnel thruster power. Turning circle tests are presented in Figure 3.

Table 1. Ferry main parameters used in simulations

Parameter	Ystad230
Length overall [m]	L_c = 230 m
Breadth [m]	B = 31.8 m
Draft [m]	T = 6.3 m
Lateral windage area [m^2]	F_{ny} = 6,400 m^2
Total engine power [kW]	P = 2 × 9.000 kW
Propellers	2 × CPP inward
Bow thruster power [kW]	P_{ttb} = 2×2,300 kW
Stern thruster power [kW]	P_{tta} = 1,500 kW
Rudder	Becker 45 deg.
Max. transverse wind for static surge [m/s]	v_k = 15 m/s

The method of navigational safety assessment by means of statistical models

Simulations are usually performed in different meteorological conditions. In each set of conditions, an adequate number of trials are executed by navigators. After simulations, each trial is processed statistically in order to obtain the probability density function of the ship's maximum distances from the centre of the waterway and calculate the probability of an accident in the given conditions. Later, the safe water area can be obtained and plotted on the area map, with attention to the previously established admissible risk level.

The vessel can safely navigate only in an area where each point satisfies the depth requirement. This area is referred to as the safe navigable area. The vessel carrying out a manoeuvre in a navigable area sweeps a certain area determined by the successive positions of the vessel. The parameters of that area have a random character and depend on a number of various factors. The area calculated at a certain level of confidence is called a safe manoeuvring area SMA (Gucma, 2004).

In a single series of simulation trials, several ship paths (two-dimensional area occupied by the ship in a single passage) can be obtained, which depends on the number of experiments performed. Statistical processing of the simulation results allows determination of the statistical parameters necessary to define the safe manoeuvring area (SMA).

The characteristic values for the examined waterway are areas occupied by ships, determined at the level of (Figure 5):

- maximum,
- average,
- as given confidence level (assumed as SMA).

The most important factor is a safe horizontal area necessary for manoeuvres for navigators (Irribaren, 1999; Gucma, 2002). Analysis of simulation results leads to determination of horizontal safe manoeuvring area parameters. In simulation tests, these parameters are determined based on the width of the ship's traffic lane, which is the area occupied by a single ship while performing a specific manoeuvre. A traffic lane (referred to as PATH) is defined for a specific ship and manoeuvre, whereas the "safe manoeuvring area" (SMA) is a term given to different ships and manoeuvres. Figure 4 shows that the safe manoeuvring area exceeds the available water area (AWA), which indicates the necessity of introducing some changes (such as dredging works) to avoid accidents.

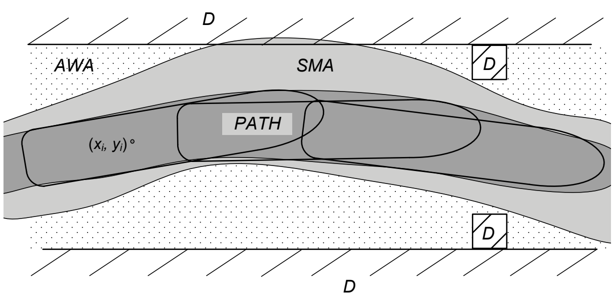


Figure 4. Definition of the ideas connected with horizontal areas taken by ships (marking: PATH – 2D lane of single ship, AWA – available water area, SMA – safe manoeuvre area on the required confidence level)

The safe manoeuvring area is the area in which the probability of collision of the ship with the edge and/or the bottom, is on the assumed low level (usually below 5%). The condition of safe navigation must fulfil dependency:

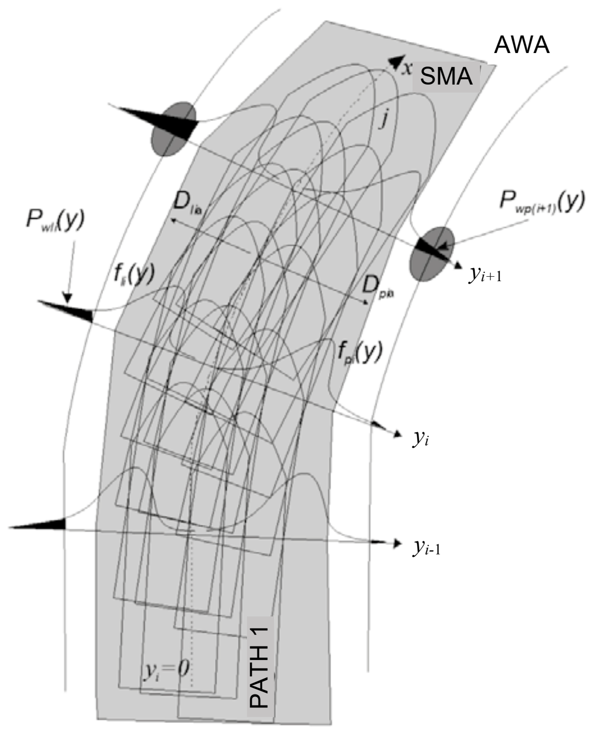


Figure 5. Method of defining the safe manoeuvre area SMA and the probability of collision with obstacles located on the edge of the waterway

$$d_{i\alpha} \le D_i \tag{1}$$

where:

D_i – depth of i-th point of the waterway at the bottom for safe depth;

$d_{i\alpha}$ – width of safe manoeuvring area on defined confidence level $(1 - \alpha)$ (Gucma, 2002).

It should be noted that general populations with infinite number are all simulation trials of a particular ship in the water area at the same hydrometeorological conditions, whereas the sample will be the series of simulation trials conducted in the same conditions. The width of the safe manoeuvring area of the ship is the range that contains specified as a percentage part (fraction) of the general population. It can be defined accordingly to dependency that takes advantage with range of confidence term:

$$d_{i\alpha} = m_{di} + k_\alpha \sigma_{pi} + k_\alpha \sigma_{li} \tag{2}$$

where:

$$m_{di} = m_{pi} - m_{li} \tag{3}$$

or according to equivalent dependence in the form of:

$$d_{i\alpha} = d_{ip\alpha} - d_{il\alpha} \tag{4}$$

for:

$$d_{ip\alpha} = m_{pi} + k_\alpha \sigma_{pi} \quad \text{and} \quad d_{il\alpha} = m_{li} - k_\alpha \sigma_{li} \tag{5}$$

where:

$d_{i\alpha}$ – width of the safe manoeuvring area at i-th point of the waterway defined on the confidence level $(1 - \alpha)$;

m_{di} – mean of the safe manoeuvring area width;

k_α – factor dependent on fraction of general population p, which should be taken into estimation (like: assumed as $k = 1.96$ for $p = 1 - \alpha = 0.95$);

m_{li}, m_{pi} – mean from maximum distance of ship's points to the right from i-th point of the waterway;

σ_{li}, σ_{pi} – standard deviations of maximum distance of ship's points to the right from i-th point of the waterway;

$d_{il\alpha}$, $d_{ip\alpha}$ – width of the right and the left safe manoeuvre area at i-th point of the waterway at defined confidence level $(1 - \alpha)$.

General simulation research assumptions

Simulation research is based on a series of manoeuvring trials (inbound/outbound) for detailed variants. These scenarios determine a given problem. Comparison of results for each variant is done with attention to navigational safety criteria. Scenarios for research were determined with the following conditions:

- operational conditions of given berth;
- previous research results (m/f *Polonia*, *Piast*, *Wolin* and *Scania* in Ystad port);
- assumptions of analysis;
- investigated area;
- given vessel types;
- navigation conditions;
- manoeuvring tactics.

General simulation research assumptions:

- In these research simulations, the maximum wind speed was assumed as 15 m/s and 17 m/s (7°B covers 13.9 m/s to 17.2 m/s) for Ystad230 respectively. The wind was determined in several preliminary manoeuvres by experts, using the simulator.
- In the research simulations, the worst wind conditions were taken into consideration for turning, mooring and departures:
  - wind: E as most frequent wind unfavourable for approach to the port;
  - wind: W as most frequent wind unfavourable for approach to the port.
- All manoeuvres were performed without tug service. 10 simulation runs were performed in each series (some were excluded during statistical processing).
- Each captain performed a maximum of 3 runs in each series. In the simulations, 7 regular and 5 additional (during simulator commissioning) captains performed simulations.

Analysis of simulation results of approach channel to Ystad

Analysis of simulation results is usually made on the basis of several navigational safety criteria, such as:

- Manoeuvring area widths (horizontal safe manoeuvring area);
- Underkeel clearance (vertical safe area);
- Energy induced in contact point with berth structures;
- Velocities of propeller bottom stream;
- Speed of ferry on entrance and inside;

The width of the approach channel to Ystad is presented in Figure 6.

The starting point of the ferry was more than 5L from the breakwater. It is clear that the ship needs time to stabilise its trajectory and such stabilisation is observed around 2L before the entrance (standard deviation and width of 95% manoeuvring area decreases and stabilises). As shown in Figure 7, the width of the approach channel should be a minimum of 115 m. However, some additional factors should be considered for human error and wind gusts. Also, factors related to the stone breakwater embankments and possible accidental collision are important and additional width is beneficial here (MU, 2017).

The assumed 95% level of confidence is usually applied for normal ship operations, however in some cases 99% level is used especially for extreme port operations, or when the risk of accident is high.

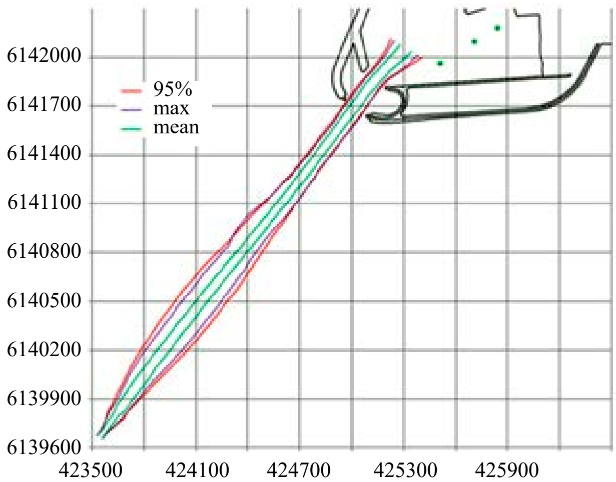


Figure 6. Safe manoeuvring areas for joint scenario No. 1 and 2. Ystad230. Approach channel shaping

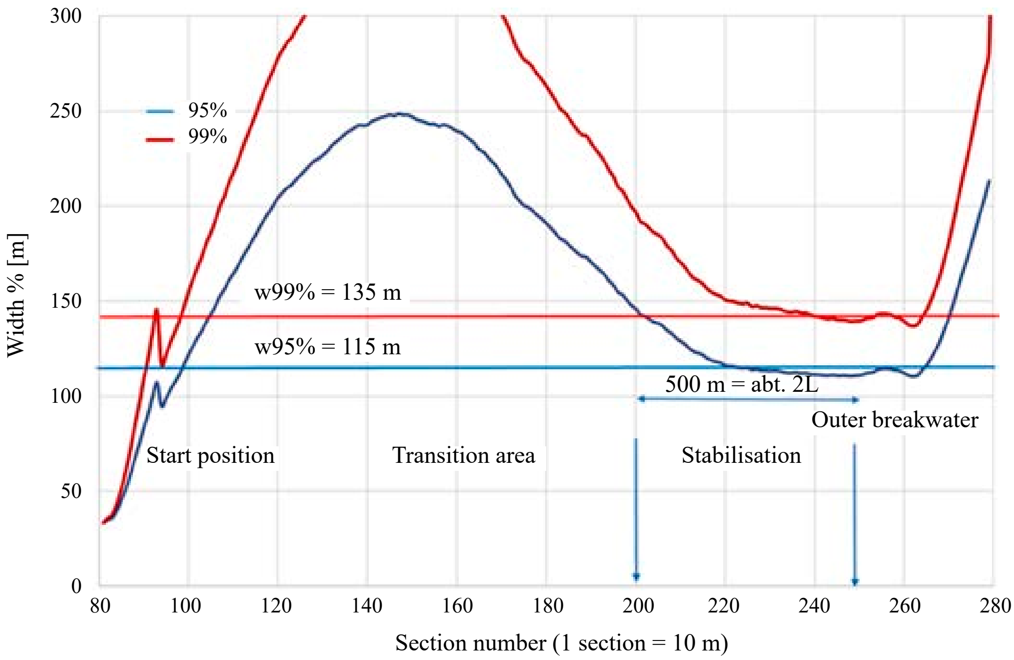


Figure 7. Width of approach channel from simulation series 1 and 2 at confidence level 95% and 99%

In such cases, the width of the waterway on 99% confidence level should be 135 m.

The drift angle at the outer breakwater is presented in Table 2 The results show inconsistency and lack of symmetry, which could be disputed. The new direction of approach is 030°. The drift in scenario 1 and 2 should be similar or the same but opposite (negative and positive). The achieved results (almost zero drift in scenario 1 on entrance) could be the intentional captain's decision to start the manoeuvre earlier, when the ship was just inside the outer breakwater. Normally the ferry should safely pass the breakwater before this manoeuvre begins.

Table 2 Drift angle inside the outer breakwater

Scenario	Mean drift angle	Standard deviation of drift angle
1 (W 15 m/s)	1.28	2.25
2 (E 15 m/s)	11.71	2.56

PIANC method approach channel width validation

The PIANC method was used for validation of achieved results (PIANC, 1985).

The width of the channel was calculated according to PIANC recommendations (PIANC, 2014). The overall bottom width of a channel W is given for a one-way channel by:

$$W = W_{BM} + \sum W_i + W_{BR} + W_{BG} \tag{6}$$

and for a two-way channel by:

$$W = 2W_{BM} + 2\sum W_i + W_{BR} + W_{BG} + \sum W_p \tag{7}$$

where:

W_{BM} – width of basic manoeuvring lane;

W_i – additional widths for the effects of wind, current etc.;

W_{BR}, W_{BG} – bank clearance on the 'red' and 'green' sides of the channel;

W_p – passing distance, comprising the sum of a separation distance between both manoeuvring lanes and an additional distance for traffic density.

For the evaluation of the width of the approach channel to Ystad port, it was assumed that:

- ferry length (LOA) is 230 m, beam is 31.8 m, draught is 6.3 m;
- ferry has good manoeuvrability;
- channel is one-way and outer (open water);
- ferry speed is moderate 8 kts ≤ V_s < 12 kts;
- prevailing cross wind is strong 33 kts – 48 kts (Beaufort 7 – Beaufort 9);
- prevailing cross-current is low < 0.2 – 0.5 kts;
- prevailing longitudinal current is low < 1.5 kts;
- beam and stern quartering wave height is between 1 m and 3 m;
- AtoN availability level is good;
- depth of waterway is less than 1.5 and greater than 1.25 times the draught of the ship;
- the bottom is smooth and soft;
- underwater channel slope is gentle.

Table 3. PIANC method for approach channel design

Symbol	Name	Assumed in simulation conditions	Highly unfavourable conditions
W_{BM}	width of basic manoeuvring lane	1.3	1.3
W_a	additional width for vessel speed	0.0	0.0
W_b	additional width for cross wind	0.7	0.7
W_c	additional width for cross-current	0.25	1.2
W_d	additional width for longitudinal current	0.0	0.0
W_e	additional width for beam and stern quartering wave	0.5	0.5
W_f	additional width for AtoN	0.2	0.2
W_g	additional width for bottom surface	0.1	0.1
W_h	additional width for depth of waterway	0.1	0.1
W_i	additional width for high cargo hazards	0.0	0.0
W_{BR}	additional width for bank clearance – red side	0.1	0.1
W_{BG}	additional width for bank clearance – green side	0.1	0.1
	Total	3.35	4.3

The values of channel width components are presented in Table 3

Calculated width of the channel is 3.35 times beam of the ferry which gives width of approach channel. Considering the table LOA vs B the maximum RoPax breadth is B = 32 m and width of approach channel shall be equal to: $w = 3.35 \cdot 32$ m = **107 m** which gives high correlation with simulation runs.

Taking into account highly unfavourable conditions on approach i.e. cross current 1.5–2.0 kns (highly unusual conditions) the width of approach channel should be $w = 4.3 \cdot 32$ = **138 m**.

Concluding the above results, it is proposed to shape the entrance channel to the Port of Ystad as presented in Figure 8, in such way as to keep the width of the entrance equal to **150 m** at a distance of 500 m before the entrance (abt. 2L of ferry) and reduce it to **130 m** within the transition area (also 500 m). However, keeping the 150 m channel on all its length is more favourable from a navigational safety point of view and a decision could be made after Cost Benefit Analysis.

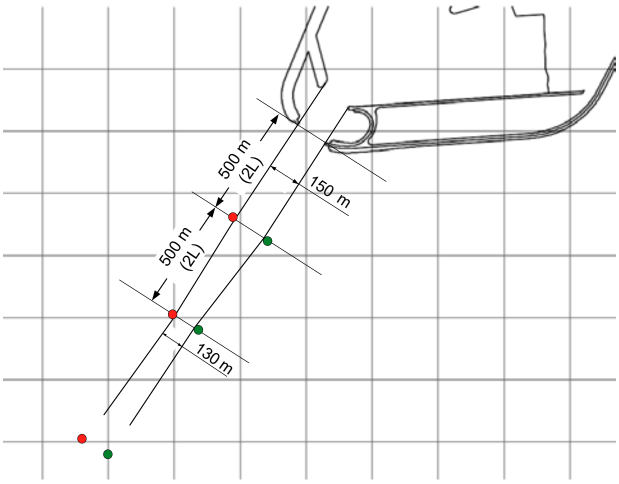


Figure 8 Approach channel shape proposition with its navigational marking

Conclusions

The results presented in the paper are aimed at designing new solutions in case of the modernization of the approach channel to Ystad. The manoeuvrability of ships is restricted and they are subject to large lateral forces by wind and currents. The PIANC method was used for validation of the achieved results. After modernization, the ferry could operate safely under the following conditions:

- Wind from any sectors of force up to 15 m/s;
- Approach channel of width 130 m increasing up to 150 m in entrance is considered safe for even extreme port operations,
- Extensive manoeuvres should be avoided when the ferry is passing the outer breakwater.

Acknowledgment

This research outcome has been achieved under grant No. 3/MN/IIRM/17 financed by a subsidy of the Ministry of Science and Higher Education for statutory activities.

References

1. Gucma, L. (2002) *Navigation risk assessment for vessels manoeuvring in various conditions*. Risk Analysis III. Southampton, WIT Press

2. Gucma, L. (2008) *Ystad Port modernisation study on the basis of real time manoeuvring simulation method*. Gliwice, International Scientific Journal
3. Gucma, S. (2004) *Determination of maximal ship safe conditions for entrance to the ports*. Risk Analysis IV. Southampton, WIT Press
4. Iribarren, J.R. (1999) *Determining the horizontal dimensions of ship maneuvering areas*. PIANC Bulletin No. 100, Bruxelles.
5. MU (2017) *Determination of optimal shape of new berths parameters and navigational safety conditions for L = 230 m and L = 200 m ropax ferries in modernised Ystad port by real time simulation methods according to Ystad vision 2030 project*. Maritime University of Szczecin.
6. PIANC (1985) *Underkeel Clearance for Large Ships in Maritime Fairways with Hard Bottom*. Report of a working group of the Permanent Technical Committee II, Supplement to Bulletin No. 51.
7. PIANC (2014) *Report No. 121. Harbour Approach Channels Design Guidelines*. Bruxelles.
8. South Baltic Four Corners (2017) [Online] Available from: www.sailing-guide.eu [Accessed: 20.10.2017]