TRANSPORT
ISSN 1648-4142 print / ISSN 1648-3480 online
2013 Volume 28(2): 166–174
doi:10.3846/16484142.2013.802746

EVALUATING THE WIDTH OF NAVIGATIONAL CHANNELS

Vytautas Paulauskas, Donatas Paulauskas
Department of Shipping, Klaipėda University, H. Manto g. 84, LT-92294 Klaipėda, Lithuania

Submitted 9 January 2012; accepted 13 June 2012

Abstract. The width of a navigational channel is a very important issue for navigational safety, and therefore is calculated on the basis of ship parameters and surroundings. Research on the passes of navigating ships under different conditions is crucial for navigational safety in ports etc. The evaluation of the width of navigational channels under certain circumstances is the main objective of investigation discussed by the authors of this article. The evaluation of the width of navigational channels for big ships coming into Klaipėda port (Lithuania) has been taken as a case study. Also, the received results could be used in other ports and navigational channels.

Keywords: navigational channels; channel width; navigational risk assessment; shipping lane; ship steering.

Reference to this paper should be made as follows: Paulauskas, V.; Paulauskas, D. 2013. Evaluating the width of navigational channels, *Transport* 28(2): 166–174. http://dx.doi.org/10.3846/16484142.2013.802746

Introduction

The width of navigational channels is very important for navigational safety and is calculated considering ship parameters and environmental conditions (Alderton 2011; Boffey *et al*. 1979; BS 6349-1:2000; BS 6349-4:2000; Cho, Perakis 1996; Hsu, Hsieh 2007; Paulauskas 2011; Paulauskas, V., Paulauskas, D. 2009, 2013; Recommendations of the Committee… 2010). To calculate and evaluate the width of navigational channels, certain standards and recommendations such as BS – British Standard: BS 6349-1:2000; BS 6349-4:2000, PIANC – Permanent International Association of Navigational Conferences: PIANC 1997, etc. are used. Under ideal conditions, the width of navigational channels is constructed on the basis of experimental results received from calculations and simulations of real ships.

New navigational equipment and technologies assist in evaluating the navigational channels and depend on ship parameters and new navigational systems, like Real Time Kinematic (RTK) etc. (Gucma, Montewka 2005; Zalewski, Montewka 2007).

At the same time, some places encounter difficulties in designing the width of navigational channels due to complicated natural or other conditions, like the islands having historical buildings located near navigational channels, breakwaters and other obstacles that are impossible to be removed from the existing locations.

Ship parameters increase constantly in many ports, and therefore push the authorities to decrease the permitted width of navigational channels thus highly increasing navigational risk (Paulauskas 2011).

Research on the passes of navigating ships under different conditions and request for the width of navigational channels under certain situations is the main objective of the analysis discussed in this article. This paper suggests the forecast for calculating the probability of navigational risk and looks at special measures for minimising navigational risk on the basis of limited hydro-meteorological conditions, additional aids of navigation and tug assistance in narrow navigational channels using special navigational equipment to decrease navigational risk.

1. Typical situations in ports and navigational channels

During the last decades, a number of ports have dramatically increased the permitted parameters of the ships with minimum improvement in ports and navigational channels (Kutz 2003). New terminals have been developed in many ports, especially in oil, gas, bulk cargo and container terminals. Simultaneously, ship parameters have substantially grown. For example, for the last 10 years, container vessels have increased from 6000÷8000 TEU up to 15,000÷18,000 TEU. Plenty of ports try to attract bigger ships, because from an economical point of view, such ships are more effective for cargo owners and stevedoring companies that very often dictate transportation conditions, particularly transportation directions (Ortúzar, Willumsen 2011). The abovementioned situations could be faced in old ports located in fiords,

Corresponding author: Vytautas Paulauskas
E-mail: donatasp@takas.lt

Taylor & Francis
Taylor & Francis Group

lakes, rivers and have many historical and other obstacles imposing limitations on an increase in the width of navigational channels. Many ports on the seaside have breakwaters, and therefore extending the width of navigational channels between them is a complicated task (Figs 1 and 2).

Investigation into basic theoretical calculations (Paulauskas, V., Paulauskas, D. 2013; Paulauskas 2011; Tomczak 2008), simulations and real ship sailing when approaching ports and other channels are very important for detecting the probability of real navigational risk to take precaution measures.

Due to limited width, the port gate is always a high risk area to vessels. Navigational risks to large vessels at the port entrance are the results of the following:

– high current speeds;
– crosswinds;
– stormy sea, heavy waves;
– strong lateral currents along the seacoast; and
– heavy ice conditions.

In individual cases, the convergence of the above introduced factors may have a synchronic impact. In some ports, the current's velocities at the port gate may reach up to 4.0÷4.5 knots, which is the current's speed that may occur due to tidal conditions during spring thaw or be subject to lasting strong winds (storms) when lagoons are flooded with sea water. As an example, Table 1 presents the rate of the current's speed at Klaipėda port's gate (Port of Klaipėda 2011) depending on the debit flow (volume of water outlet from the lagoon).

Minimum flow velocity is usually expected during summer time, cold winters and within the period of changes in the current's direction. In most cases, actually over 70% of the time, the flow rate is from 1500 to 2500 m^3/s. During spring thaw and after lasting storms, due to heavy sea water ingress in the lagoon, the flow rate may reach about 3000÷4000 m^3/s. In exceptional cases, the debit flow goes up to 5000÷6000 m^3/s.

Port gate navigation is dangerous to ships at the time of strong cross-directional winds, because the wind's velocity reaches above 15 m/s and forms a lateral flow (along the coast) and the drift speed of a large vessel can reach up to 3÷4 knots, i.e. while heading at about 10 knots, the drift angle goes up to 8÷10°, which is a dangerous rate for ships.

A heavy swell at the port entrance gate under wave height in exceptional cases goes up to 4.5÷5.5 m and may cause risks at the port entry due to complicated ship steering. While leaving the port due to suddenly increased resistance, the crosswinds may cause a possible larger drift.

Ice conditions at the port gate area in Klaipėda last up to a maximum of 7÷10 days per year; in some cases, when the ice comes from the sea during west winds, the ice run time may be longer.

2. Theoretical basis for the width of navigational channels and calculation of risk assessment

Channel width has been analysed in two ways:

– Referring to the classical theory about the determination of channel width using ship kinematic parameters obtained under natural conditions, calculation methods and simulator support (BS 6349-1:2000; BS 6349-4:2000; Demirci 2003; Hayuth *et al*. 1994; Hensen 1999; Paulauskas 2011; Recommendations of the Committee... 2010; Thiers, Janssens 1998; Zalewski, Montewka 2007);
– Considering PIANC or other recommendations for similar conditions (PIANC 1997; Recommendations of the Committee... 2010).

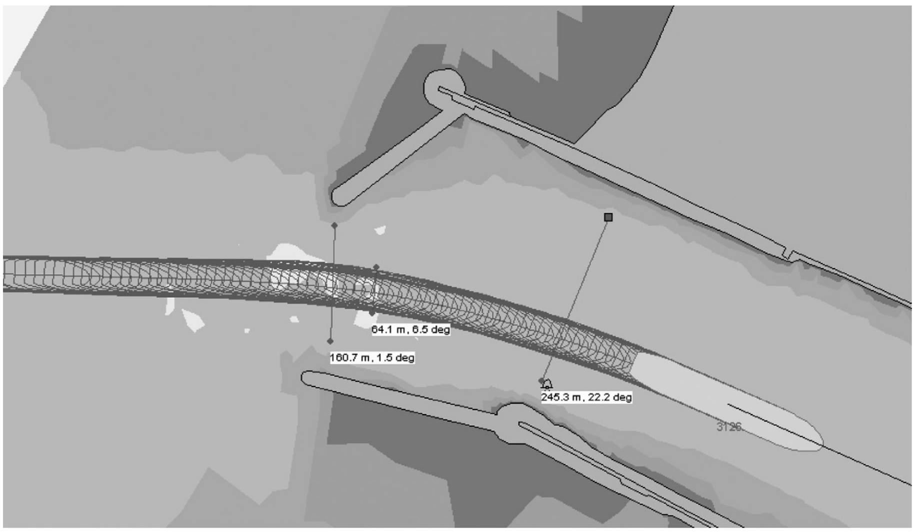

Fig. 1. The inner navigation of a big ship through the port entrance channel; channel width at the port gate; the outline of ship and lane width at the N wind of 14 m/s (port entry)

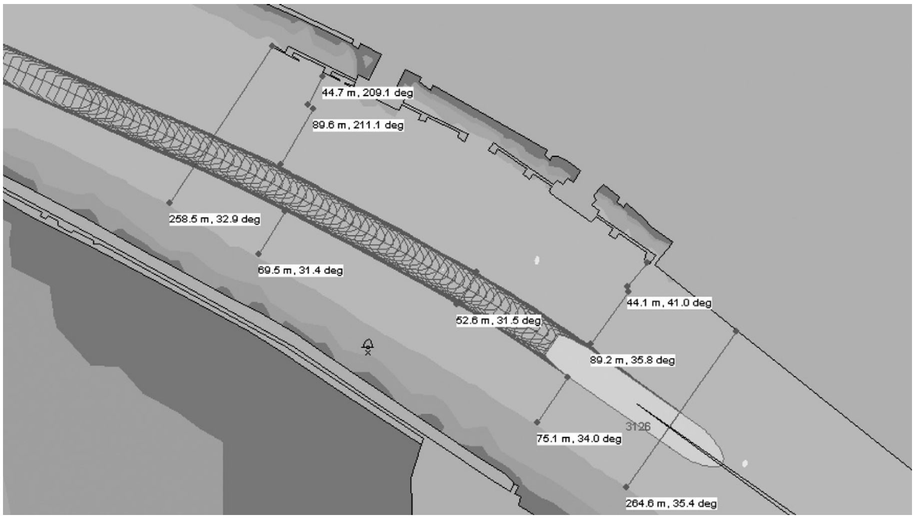

Fig. 2. The inner navigation of a big ship through the channel at berths; channel and lane parameters; distance from the channel sides and berths; shipping lane at the N wind of 14 m/s (port entry)

Using the classical theory, the channel's width in case of one-way traffic B_k is calculated applying the below formula (Paulauskas 2011):

$$B_k = L \cdot \sin\beta + B \cdot \cos\beta + L \cdot \sin\Delta K + P' \cdot \sigma_y + b_{nav}, \quad (1)$$

where: L – ship length (maximum overall); B – ship width; β – the drift angle of a ship while proceeding to the channel; ΔK – the sway angle of the vessel along the course while heading through the channel; b_{nav} – navigational margin depending on the aids of a navigation system, channel slope accuracy, etc.; P' – probabilistic maintenance factor in case the probability is 95% as accepted in navigation, thus P' for channels is about 2; σ_y – ship positioning accuracy in a way of the channel axis, e.g. leading line sensitivity etc.

The drift angle of the ship while proceeding to the channel can be assessed employing the formula:

$$\beta = arctg\beta = \frac{v_d + v_c \cdot \sin q_c}{v}, \quad (2)$$

where: v – ship speed in the channel (many ports accept six or more knots); v_c – current speed; q_c – current course angle; v_d – the drift speed of the ship and the evaluation of wind effect can be calculated using the formula:

$$v_d = v_a \sqrt{\frac{C_a \cdot \rho_1 \cdot S_x \cdot \sin q_a}{C_y \cdot \rho \cdot F_d}} \quad (3)$$

Table 1. The rate of current speed at Klaipėda port gate depending on the debit flow

Debit, m^3/s	1000	2000	3000	4000	5000	6000
v, m/s	0.35	0.71	1.07	1.43	1.79	2.14
v, kn	0.68	1.38	2.08	2.78	3.47	4.16

where: v_a – wind velocity; C_a – the aerodynamic coefficient of 1.07 can be adopted; ρ_1 – air density, calculations use 1.25 kg/m^3; S_x – the space of projection onto a diametrical plane (DP) of the wind surface area of the vessel; C_y – hydrodynamic coefficient, calculations accept 1.5÷1.8; ρ – water density; F_d – the space of projection onto a DP of the underwater area of the vessel; q_a – the course angle of the wind.

The necessary probabilistic safety assessment of port channels and turning basins was performed using the so-called maximum dispersion method (Ventsel 1999) that can be used in case of at least five measurements of a specific parameter (if less, measurement reliability is low); more than 12 measurements would have no effect on the final outcome. Using the abovementioned method, the following relationship applies for:

$$B_k' = B + P' \cdot k_n \cdot R, \quad (4)$$

where: B_k' – the expected (required) shipping lane (channel width); P' – a probabilistic maintenance factor in case of ± 1 means the probability of 68.3%, in case of ± 2 – the probability of 95.3% and in case of ± 3 – the probability of 99.7% (Ventsel 1999); k_n – a factor depending on the number of measurements n, i.e. if the number of measurements n is 3 – $k_n = 0.55$; 4 – $k_n = 0.47$; 5 – $k_n = 0.43$; 6 – $k_n = 0.395$; 7 – $k_n = 0.37$; 8 – $k_n = 0.351$; 9 – $k_n = 0.337$; 10 – $k_n = 0.329$; 11 – $k_n = 0.325$; 12 – $k_n = 0.322$; R – result dispersion, i.e. the difference between the maximum and minimum values of the measured parameters. According to the Three Sigma Rule (Pukelsheim 1994), probability in the case of $P' = 3$ could be less than 99%.

Based on the above measurements of the real vessel or simulator (SimFlex Navigator 2011), a probabilistic shipping lane can be calculated in any specified port area. On the basis of the received results,

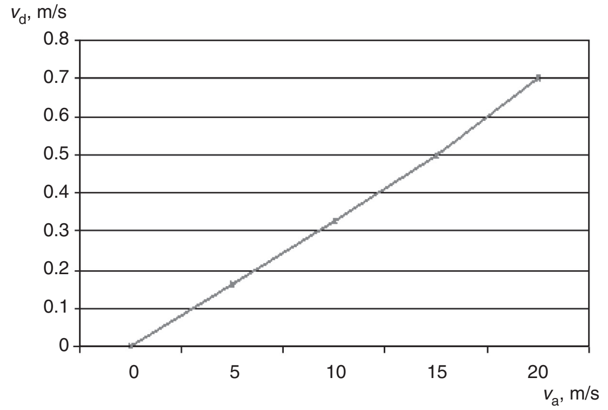

Fig. 3. The dependence of the drift speed (m/s) of the ship ($L = 290$ m) on perpendicular wind velocity

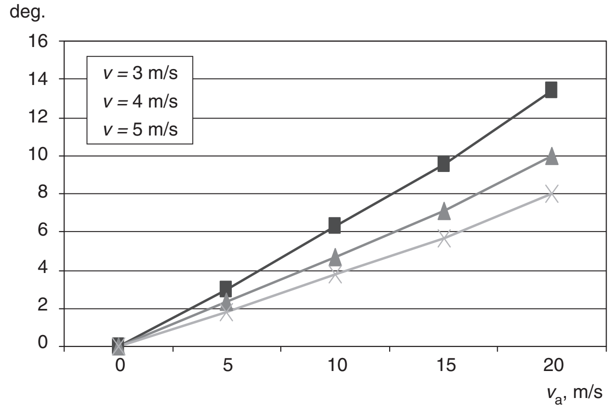

Fig. 4. The dependence of the drift angle (degrees) of the ship ($L = 290$ m) on perpendicular wind velocity

additional precaution measures to decrease the probability of navigational risk to ships could be planed.

3. Practical width of a navigational channel and investigations into risk assessment

For the case study and calculation purposes, large ships having the length of 290 m, width of 48 m and draft of 12.5 m at 100% of laden capacity and the draft of 8.5 m in ballast were taken; the space of projection on a DP of the wind surface area of the vessel is 6000 m^2 at 100% of laden capacity and 7200 m^2 in ballast; the space of projection on a DP of the underwater area of the vessel is 3750 m^2 at 100% of laden capacity and 2260 m^2 in ballast.

The drift speed of the ship and the drift angle depend on wind velocity. Calculation results are given in Figs 3 and 4.

The above rates and conditions show that the estimated drift angle goes up to $4.0 \div 6.0°$. The assessment of navigation through the straight passages approaching internal channels shows that the realistic drift angle goes up to $3 \div 5°$ at the ship's speed of $6 \div 7$ knots.

For the estimated vessels, the wind velocity goes up to 12 m/s (mostly longitudinal currents along the channel) and the vessel sway along the course (ΔK) goes up to $1.0 \div 1.5°$.

A navigational margin that implies the position of the channel slope and possible changes in sloping at ports has been accepted to be 0.25 B on each side of the channel, which totally makes 0.5 B (width of the vessel).

Ship positioning accuracy in a way of the channel axis using the leading line system, buoyage and modern RTK system reaches $3 \div 5$ m.

In addition, a $10 \div 25\%$ margin can be applicable to big and dangerous ships transporting goods.

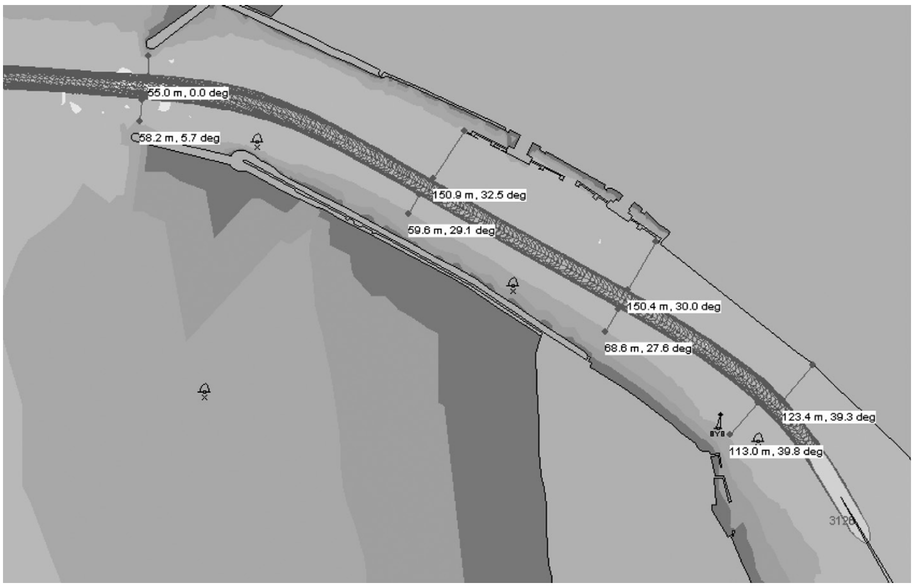

Fig. 5. The inner navigation of a big ship ($L = 290$ m) through the channel and lane parameters; the distance to the sides and berths of the channel; shipping lane at the E wind of 14 m/s (port entry)

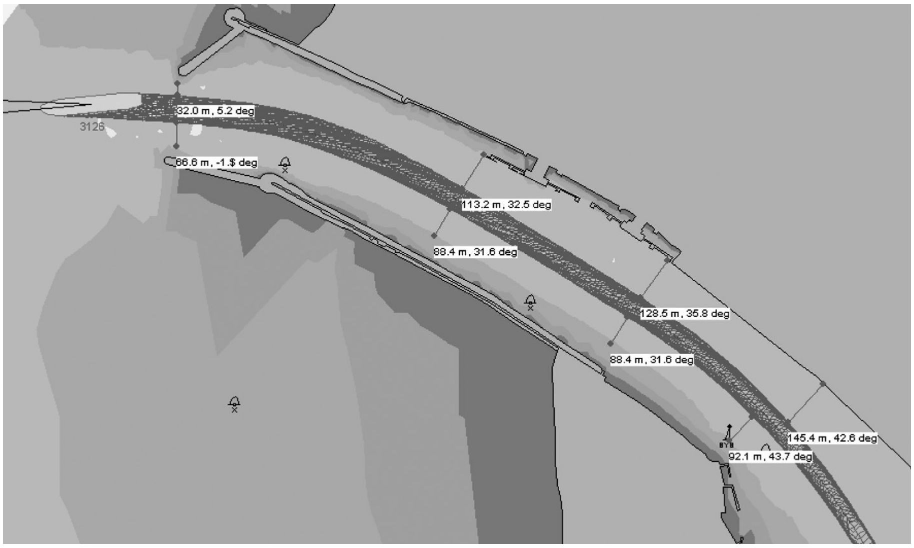

Fig. 6. The outward pilotage of a big ship ($L = 290$ m) proceeding to the channel and outside port gate; channel and lane parameters; the distance to the sides and berths of the channel; shipping lane at the SW wind of 14 m/s (departing the port)

Thus, the minimum width of the channel on the straight sections of the referred ships of big tonnages should be at least 142 m, whereas in bends (channel width should be increased by approximately 15% when approaching turning angles exceeding 20°) the width of the minimum channel for the specified vessel ($L = 290$ m) must be maintained at 163 m.

In accordance with the new PIANC recommendations, a channel's width recommended for vessels carrying dangerous cargoes, including LNGC, crude oil or light oil product tankers should be around $3.0 \div 3.5\ B$; thus, for the referred vessel, it makes about $144 \div 169$ m (in straight sections and bends).

Visual navigation simulator, *SimFlex Navigator* (2011), was used for analysing the navigation of big ships approaching the channel through the port entrance gate and further through inner port channels. Research was based on the wind speed of 14 m/s in all directions, i.e. N, NE, E, SE, S, SW, W, N, under active currents and the swell based on the information on hydro-meteorological investigation.

To conduct investigation, eight simulated ship entries to and the same number of departures from the harbour through the port entrance channel using inner port channels were analysed up to 17 m isobaths offshore.

Probabilistic computations of a shipping lane were made at fixed points (berths, piers or pier ends) making additional measurements to provide other general information.

The simulated examples of inward pilotage (entering the port and navigation inside the channel up to the turning basin at the N wind of 14 m/s up to the NW wind of 14 m/s) and the input of some other data are shown from Figs 5 to 10.

Simulation-based research (calibrated visual simulator *SimFlex Navigator* was applied) on the expected maximum big ship ($L = 290$ m, $B = 48$ m) has analysed a shipping lane and is a case study on Klaipėda port located at different places. Simulations were performed by one of the authors (deed sea captain) and port pilots having practical experience of work on similar-sized ships. Additionally, shipping lanes were checked referring to the real ships of a similar size (PANAMAX container vessels and POST-PANAMAX tankers) by the pilots and authors of the article using high accuracy port navigational RTK system E-Sea Fix implemented in Klaipėda port.

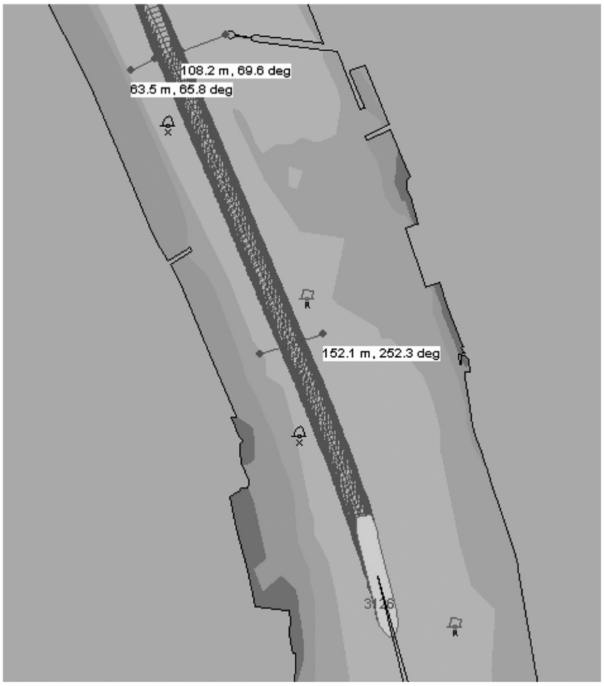

Fig. 7. The inner navigation of a big ship ($L = 290$ m) through the channel; channel parameters at the SW wind of 14 m/s; corresponding current conditions (entering the port)

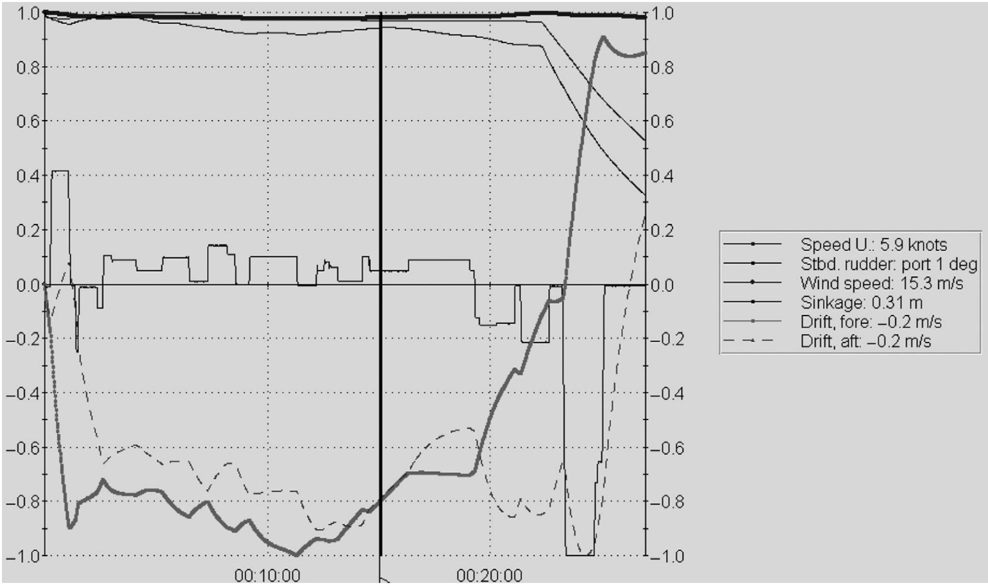

Fig. 8. Vessel passage inside the channel and external parameters at the SW wind of 14 m/s (entering the port)

Navigation conditions for one-way traffic are as follows:

- Port entrance gate – the leading line used for port entry;
- Port entrance gate – navigational marking (buoyage etc.) used for departures;
- Berth 1 – used navigational marking (buoyage etc.);
- Berth 2 – used navigational marking (buoyage etc.);

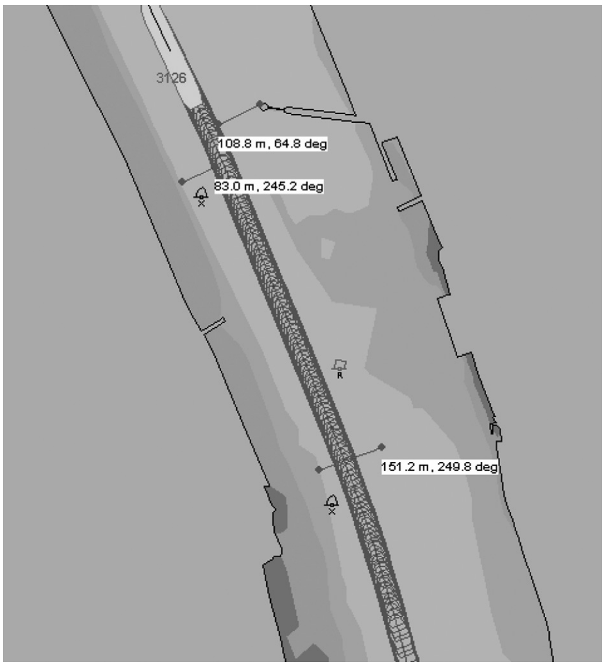

Fig. 9. The outer navigation of a big ship ($L = 290$ m) through the channel; channel parameters at the NW wind of 14 m/s; corresponding current conditions (departing the port)

- Berth 6 – used navigational marking (buoyage etc.);
- Berth 66A – the leading line used for port entry;
- Berths 71 and 72 – used navigational marking (buoyage etc.);
- Berth 81A – used navigational marking (buoyage etc.).

The number of simulated inner/outer navigational analyses conducted in the specified port locations as well as real data on experiments with ships are as follows:

- Port entrance channel and port gate (port entry) – 8;
- Port entrance channel and port gate (departure) – 8;
- Berth 1 – 19;
- Berth 2 – 16;
- Berth 6 – 16;
- Berth 66A – 5;
- Berths 71–72 – 19;
- Berth 81A – 5.

On the basis of the information received on simulated and real ships of a big size ($L = 290$ m) and considering the width of shipping lanes situated in different parts of the port, the expected general data on the width of the channel (shipping lanes) have been obtained (see Tables 2 and 3).

In addition, the measurements of the drift angle of the ship inside the channel (calculated and checked by a simulator on the real ships of a similar size) for a big ship ($L = 290$ m) proceeding to and from the harbour were taken. The obtained results are shown in Figs 11 and 12.

All simulated manoeuvres of inward and outward pilotage and navigation at the wind velocity of 14 m/s in various directions show that the referred big

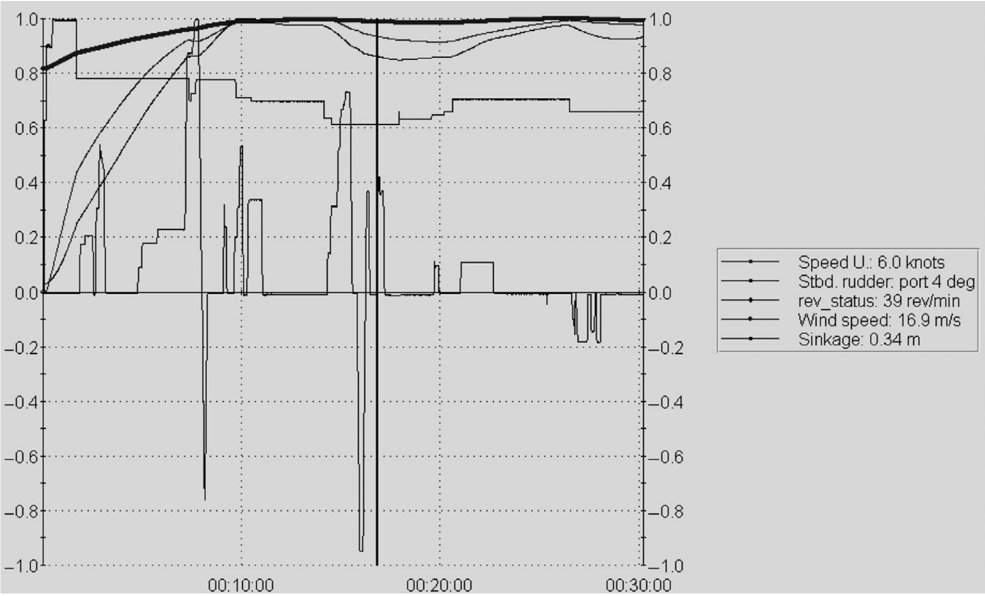

Fig. 10. Vessel passage inside the channel and external parameters at the NW wind of 14 m/s (departing the port)

Table 2. The expected channel width and a shipping lane of a big ship ($L = 290$ m) at the probability of 68.3÷99.7%; inward direction at the wind speed of 14 m/s from different directions and the corresponding current and wave conditions

Port channel section	Channel width resulting from the upgrade of the intended project, m	Shipping lane at the probability of 68.3%, m	Shipping lane at the probability of 95.3%, m	Shipping lane at the probability of 99.7%, m	Notes
Port entrance channel and the port gate	150	68	89	110	Satisfactory
From the entrance gate to Berth 9	250	108	168	228	Satisfactory
From Berth 10 to Berth 65	150	74	100	126	Satisfactory
At Berth 66A	215	74	100	126	Satisfactory
At Berths 71 and 72	215	80	112	144	Satisfactory

ship ($L = 290$ m) can safely navigate inside the channel proceeding to and from the harbour. The adoption of a safety margin for weather conditions is close to 2, especially concerning the inward pilotage of a maximum-sized big ship ($L = 290$ m), which is appropriate to reducing the allowable wind speed from 10 to 11 m/s and increases the safety coefficient up to 2 ($10^2 = 100$; $14^2 = 196$). An additional safety factor can be improved using the tugs with double-increased towing capacity comparing that with minimum necessary power. In case of reducing the allowable wind

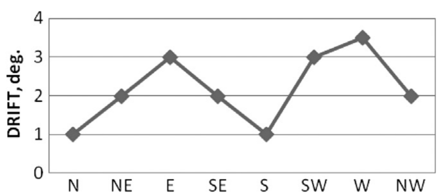

Fig. 11. The drift angle of a maximum big ship ($L = 290$ m) proceeding inside the channel to the harbour at the wind speed of 14 m/s from different directions and the current corresponding to the relevant current field

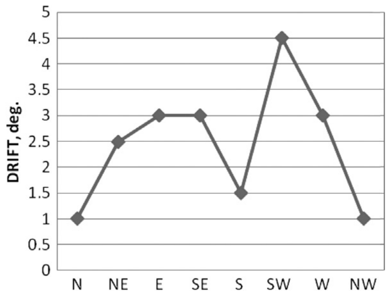

Fig. 12. The drift angle of a maximum big ship ($L = 290$ m) proceeding inside the channel from the harbour at the wind speed of 14 m/s from different directions and the current corresponding to the relevant current field

Table 3. The expected channel width and a shipping lane of a big vessel ($L = 290$ m) at the probability of 68.3÷99.7%; outward direction at the wind speed of 14 m/s from different directions and the corresponding current and wave conditions

Port channel section	Channel width resulting from the upgrade of the intended project, m	Shipping lane at the probability of 68.3%, m	Shipping lane at the probability of 95.3%, m	Shipping lane at the probability of 99.7%, m	Notes
Port entrance channel and the port gate	150	88	129	170	To maintain up to 97% probability, advisable to reduce the allowable wind speeds up to 12 m/s
From the entrance gate to Berth 9	250	108	168	228	Satisfactory
From Berth 10 to Berth 65	150	80	112	144	Satisfactory
At Berth 66A	215	80	112	144	Satisfactory
At Berths 71 and 72	215	80	112	144	Satisfactory
At Berth 81A	200	88	129	169	Satisfactory
At Berths 82 to 89	300	105	162	219	Satisfactory

velocity from 14 m/s to 10 m/s and increasing the tug pulling force twice, the navigation safety factor can rise up to 4, which is important for the ships carrying dangerous goods, such as natural liquid gas, oil production, chemicals, etc.

A comparison of the received results of the calculated channel width and data on the experiments of simulated and real ships with PIANC recommendations (PIANC 1997) has shown that the channel width received using PIANC recommendations, in case of an exact evaluation of all components and conditions, is very close to that discussed in this article.

Conclusions

All inward/outward manoeuvres calculated using classical methods, simulated by SimFlex Navigator and compared with the experimental results of real similar ships at the wind velocity of 14 m/s in all directions show that the estimated big ship ($L = 290$ m) can safely enter and leave the port through the port's gateway and navigate inside the port's channels to and from the harbour.

The width of the port's entrance channel from the port and the channels inside the harbour terminals must maintain at least 150 m straight passages using leading lines and buoyage in the specified port channel sections (leading lines produce higher accuracy), whereas in other places of the channel, the minimum width of 220÷250 m and the use of a proper buoyage system for water area markings are mandatory.

As for big ships ($L = 290$ m), the minimum width of the channel in straight sections should be at least 144 m (recommended not less than 150 m), whereas in bends (with a turning angle exceeding 20°, channel width is increased by about 15%), the channel's width for specified big ships must maintain at least 163 m (99.7% probability).

An adequate vessel traffic system at the port should allow for minimal restrictions to port terminal operations and navigation.

References

Alderton, P. M. 2011. *Reeds Sea Transport: Operation and Economics*. Reeds. 336 p.

Boffey, T. B.; Edmond, E. D.; Hinxman, A. I.; Pursglove, C. J. 1979. Two approaches to scheduling container ships with an application to the North Atlantic route, *The Journal of the Operational Research Society* 30(5): 413–425. http://dx.doi.org/10.2307/3009708

BS 6349-1:2000. *Maritime structures: Code of practice for general criteria*. British Standard.

BS 6349-4:2000. *Maritime structures: Code of practice for design of fendering and mooring systems*. British Standard.

Cho, S.-C.; Perakis, A. N. 1996. Optimal liner fleet routeing strategies, *Maritime Policy and Management* 23(3): 249–259. http://dx.doi.org/10.1080/03088839600000087

Demirci, E. 2003. Simulation modelling and analysis of a port investment, *Simulation* 79(2): 94–105. http://dx.doi.org/10.1177/0037549703254523

Gucma, L.; Montewka, J. 2005. Landborne laser rangefinder measurements for navigation safety assessment, *European Journal of Navigation* 3(4): 1–6.

Hayuth, Y.; Pollatschek, M. A.; Roll, Y. 1994. Building a port simulator, *Simulation* 63(31): 179–189. http://dx.doi.org/10.1177/003754979406300307

Hensen, H. 1999. *Ship Bridge Simulators: a project Handbook*. The Nautical Institute. 168 p.

Hsu, C.-I.; Hsieh, Y.-P. 2007. Routing, ship size, and sailing frequency decision-making for a maritime hub-and-spoke container network, *Mathematical and Computer Modelling* 45(7–8): 899–916. http://dx.doi.org/10.1016/j.mcm.2006.08.012

Kutz, M. 2003. *Handbook of Transportation Engineering*. McGraw-Hill Professional. 1000 p.

Ortúzar, J. D.; Willumsen, L. G. 2011. *Modelling Transport*. Wiley. 606 p.

Paulauskas, V. 2011. *Optimalus uostas: Monografija* Klaipėda: Klaipėdos universiteto leidykla. 320 p. (in Lithuanian).

Paulauskas, V.; Paulauskas, D. 2009. *Laivo valdymas uoste* Klaipėda: Klaipėdos universiteto leidykla. 256 p. (in Lithuanian).

Paulauskas, V.; Paulauskas, D. 2013. Ships entry into floating docks with tugs assistance, *Marine Engineering Frontiers* 1(1): 13–18.

PIANC. 1997. *Approach Channels: a Guide to Design*. Joint PIANC–IAPH report. 108 p.

Port of Klaipėda. 2011. Available from Internet: http://www.portofklaipeda.lt/en

Pukelsheim, F. 1994. The three sigma rule, *The American Statistician* 48(2): 88–91. http://dx.doi.org/10.2307/2684253

Recommendations of the Committee for Waterfront Structures Harbours and Waterways EAU. 2004: Digitized and updated version 2009 (Digital) 2010. Wiley-VCH Verlag GmbH. 250 p.

SimFlex Navigator. 2011. Ship Simulator System.

Thiers, G. F.; Janssens, G. K. 1998. A port simulation model as a permanent decision instrument, *Simulation* 71(2): 117–125. http://dx.doi.org/10.1177/003754979807100206

Tomczak, A. 2008. Safety evaluation of ship's maneuvers carried out on the basis of integrated navigation systems (INS) indications, *Journal of Konbin* 4(1): 247–266. http://dx.doi.org/10.2478/v10040-008-0021-y

Ventsel, E. S. 1999. *Teoriya veroyatnostey*. Moskva: Vysshaya Shkola. 576 s. (in Russian).

Zalewski, P; Montewka, J. 2007. Navigation safety assessment in an entrance channel, based on real experiments, *In Proceedings of the 12th International Congress of the International Maritime Association of the Mediterranean (IMAM 2007)*, 2–6 September 2007, Varna, Bulgaria, 1113–1120.