TransNav
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 11
Number 3
September 2017
DOI: 10.12716/1001.11.03.22

Applying Simulation Studies to Define Further Development of the Przemyslowy Canal in Szczecin

L. Gucma, R. Boć & A. Bąk
Maritime University of Szczecin, Szczecin, Poland

ABSTRACT: The increasing sizes of ships and lack of functionality of the existing solutions determine the interest in rebuilding the already existing solutions. Simulation models allow to analyse the possible modernisation variants taking into account the variability of elementary parameters. The article presents analysis results for the Przemyslowy Canal in Szczecin with respect to navigation safety and regulating traffic regulations in the Przemyslowy Canal taking into consideration the interests of all subjects involved. The paper applies real-time simulation methods based on manoeuvring simulators. After a thorough analysis that took 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 Przemyslowy Canal in Szczecin.

1 INTRODUCTION

The development and modernisation of the already existing port solutions is aimed at regulating traffic norms and satisfying the needs of all interested parties in the Przemyslowy Canal of the Szczecin port. Changes in the port infrastructure greatly influence the land economy in its vicinity, thus it seems plausible to analyse future solutions and variants in the form of, for example, necessary dredging works. These works will make it possible to extend the scope of the port's operations. In 2014, the Przemyslowy [8]. Wharf was put into use where the maximum ship is a general/bulk cargo vessel of the parameters L=120m, B=16.5m, T=6.5m (Figure 1). In earlier analyses, the need to stop the trans-shipment of vessels that trans-ship in the SWFiL (Baltchem) Wharf while the vessel moves to the Przemyslowy Canal was pointed to, and the width of the waterway in the Przemyslowy Canal was defined as D=50m for the depth of 7m. Practice has shown that the proposed way of the coexistence of the SWFiL (Baltchem) and Przemyslowy Wharfs caused problems linked to technical difficulties in stopping the trans-shipment in SWFiL (Baltchem), which as a result hinders the organization of optimum handling of the Przemyslowy Wharf. The analysis provides an answer to the question about possible enlargement of vessels approaching the SWFiL (Baltchem) Wharfs and the Przemyslowy Wharf to the parameters L=130m, B=22m and T=6.5m[PIANC 2014]:.

At the stage of preliminary analyses, the main objectives were formulated:
- Determining the possibility of exploiting a tank vessel (product tanker) of the length L=130m, breadth B=22m and draught T=6.5m at the SWFiL (Baltchem) Wharf in the Przemyslowy Canal using simulation methods;
- Determining the safety of the movement of a vessel L=120m, B=16.5m and T=6.5m and a vessel L=130m, B=22m and T=6.5m to the north sector of the Przemyslowy Canal (Przemyslowy Wharf – Cronimet) with vessels moored at the SWFiL

(Baltchem) Wharf of diverse (variant) breadth of between 16.5m and 22m using simulation methods;
- Determining the acceptable conditions for manoeuvring (wind, tugboats and other) for maximum vessels in the area of the Przemyslowy Canal;
- Determining the conditions for the movement of vessels in the area of the Przemyslowy Canal.

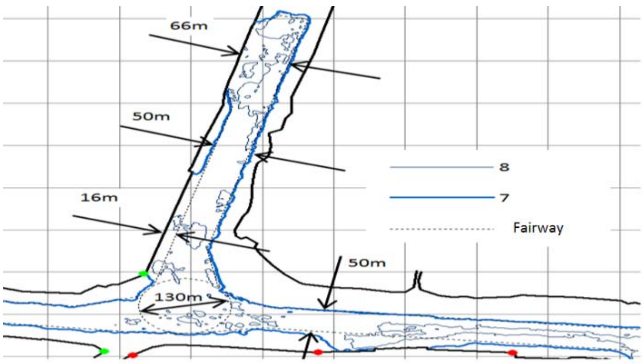


Figure 1. Current parameters of the waterway in the vicinity of the SWFiL (Baltchem) and Przemyslowy Wharfs, and the Parnica turning place after completing and accepting the investment in this region.

2 DEFINING SELECTED PARAMETERS OF WATERWAYS IN THE AREA OF STUDIES USING SIMULATION METHODS

At the Maritime University in Szczecin, a whole family of analytical and experimental models of ship movements were designed [Gucma S. 1990]. In this paper, the SMART model was used as a more precise one.

2.1 *A mathematical model of ship movement*

The model used for studying ship motions belongs to force models of modular structure, i.e. one where hydrodynamic forces of the hull, forces from propelling and steering units, external forces and other are separated as independent elements of the model and summed up accordingly in the final phase as longitudinal, lateral and rotational forces [Gucma S. et al. 2007].
- Propeller pressure,
- Propeller lateral operation,
- Carrying and steer resistance,
- Bow thrusters operation,
- Current, wind and ice,
- Sucking and rotational torque of the bank effect,
- Braking of shallow water,
- Hawser and anchor operation,
- Wharf reaction and friction between the wharf and the ship hull,
- Tugs,
- And other resulting from the characteristics of each propelling and steering device.

The scheme of how the model works is presented in Figure 2 [Artyszuk J., 2004].

2.2 *Detailed description of the SMART math model*

In the analysis, the following labelling most frequent in the hydrodynamics of vessel manoeuvring was adopted:
- ***$Ox_0y_0z_0$* (immobile) linked to the ground** to position the vessel, both in terms of its location (*x-y* position) on the surface of the earth as well the orientation
- ***Mxyz* (mobile) linked to the vessel** to record the dynamics of the movement (change in the speed of the movement due to external forces).

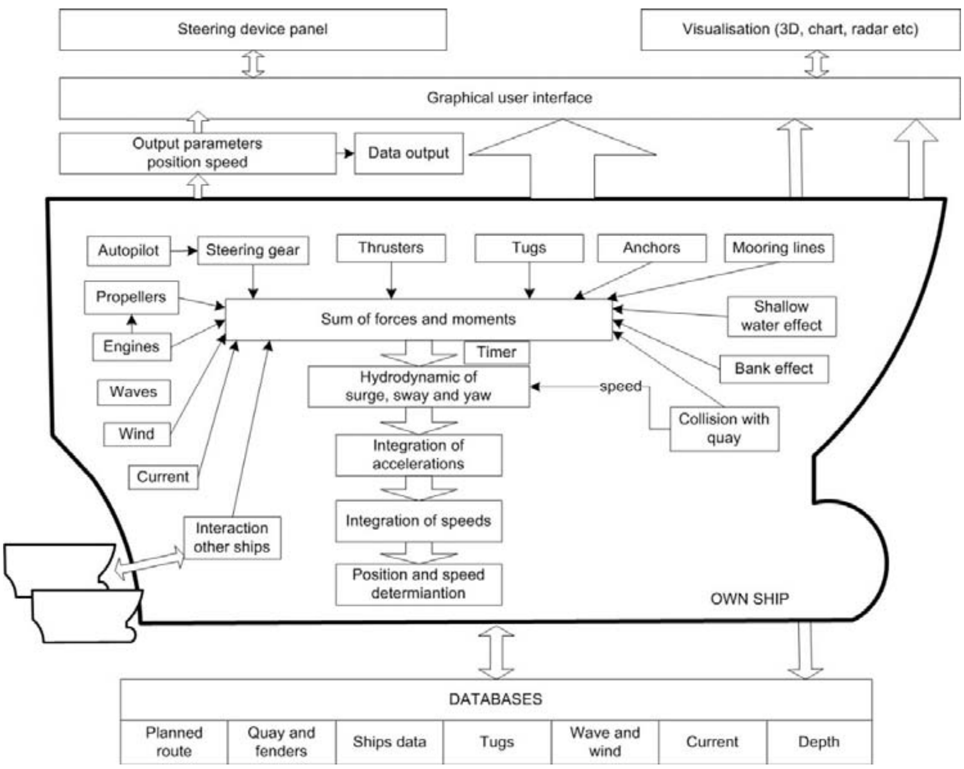


Figure 2. The main functional diagram of simulation model

Omitting the effects that are less important in manoeuvring, the model can be presented as a set of infinitesimal equations whose results show the change in the speed of the ship with respect to the bottom of the basin ('v^g') for three levels of freedom. The basis for the math model of manoeuvring movements of a vessel applied (infinitesimal equations of movement and the structure of functional dependences of each external interaction) was presented in detail among others in [Artyszuk, 2005] and are in line with the current state of knowledge in this field.

$$\begin{cases} (m+m_{11})\dfrac{dv_x^g}{dt} = (m+c_m m_{22})v_y^g\omega_z + (m_{11}-c_m m_{22})v_y^c\omega_z + F_x \\ (m+m_{22})\dfrac{dv_y^g}{dt} = -(m+m_{11})v_x^g\omega_z + (m_{11}-m_{22})v_x^c\omega_z + F_y \\ (J_z+m_{66})\dfrac{d\omega_z}{dt} = -(m_{22}-m_{11})(v_x^g-v_x^c)(v_y^g-v_y^c) + M_z \end{cases} \tag{1}$$

$$\frac{dx_0}{dt} = v_{NS}^g \quad , \quad \frac{dy_0}{dt} = v_{EW}^g \quad , \quad \frac{d\psi}{dt} = \omega_z \tag{2}$$

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

where:

v_x^g, v_y^g, ω_z – Longitudinal, cross and tangential velocity

x_0, y_0, ψ – Position coordinates and vessel's course

M – Vessel's displacement (weight)

M_{11}, m_{22}, m_{66} – Added weights (resulting from movement in ideal liquid)

c_m – Empirical coefficient taking into account viscosity effects

F_x, F_y, M_z – External interferences (total longitudinal and cross forces, and the tangential moment) which can be spread into the following for the modelled two-propeller ship (with two conventional rudders) with a double stern thruster:

$$\begin{cases} F_x = F_{xH} + \sum_{i=1}^{2} F_{xPi} + \sum_{i=1}^{2} F_{xRi} + F_{xA} + F_{xWV2} \\ F_y = F_{yH} + \sum_{i=1}^{2} F_{yPi} + \sum_{i=1}^{2} F_{yRi} + F_{yA} + F_{yWV2} + \sum_{i=1}^{2} F_{yLTi} \\ M_z = M_{zH} + \sum_{i=1}^{2} M_{zPi} + \sum_{i=1}^{2} M_{zRi} + M_{zA} + M_{zWV2} + \sum_{i=1}^{2} M_{zLTi} \end{cases} \tag{4}$$

The indexes stand for:

H – Hull,

P – Propeller,

R – Stern rudder,

A – Wind,

WV2– Irregular wave (2nd class forces, so-called drift forces),

LT – Thruster.

All the above components of the generalized external forces are basically a function of the ship's speed with respect to the water ('v^w'):

$$\begin{cases} F_x = F_x\left(v_x^w, v_y^w, \omega_z\right) \\ F_y = F_y\left(v_x^w, v_y^w, \omega_z\right) \\ M_z = M_z\left(v_x^w, v_y^w, \omega_z\right) \end{cases} \tag{5}$$

$$v_x^w = v_x^g - v_x^c \ , \ v_y^w = v_y^g - v_y^c \tag{6}$$

$$\begin{bmatrix} v_x^c \\ v_y^c \end{bmatrix} = \begin{bmatrix} \cos\psi & \sin\psi \\ -\sin\psi & \cos\psi \end{bmatrix} \cdot \begin{bmatrix} |\vec{v}^c|\cos\gamma_c \\ |\vec{v}^c|\sin\gamma_c \end{bmatrix} \tag{7}$$

where:

$|\vec{v}^c|$ and γ_c are the speed and geographical direction of the sea current

2.3 *Verification of data used for simulations in the SMART program*

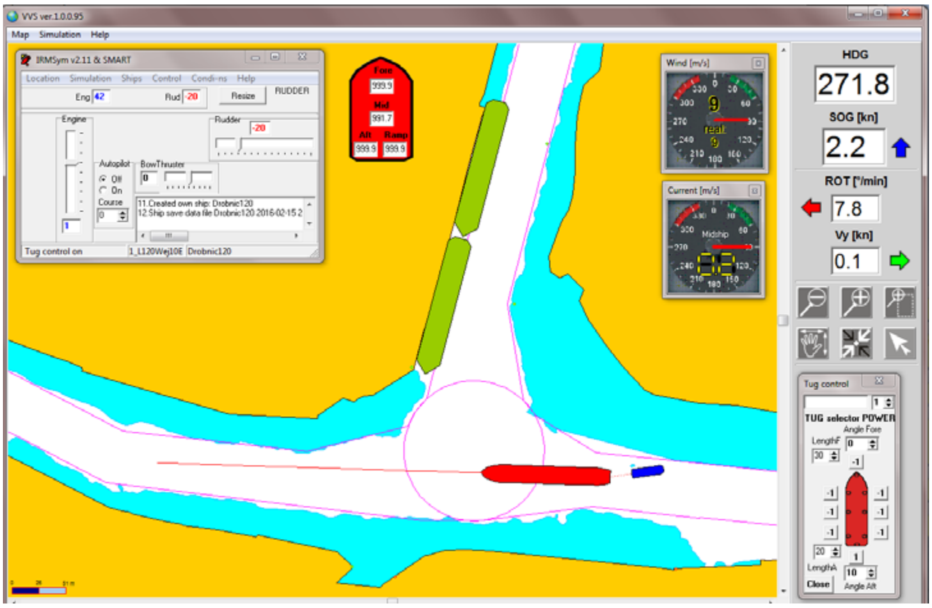
To optimise the model, original software based on the MS Excel 2000 spreadsheet and the mode of accelerated time of the above-mentioned SMART program were used, with the visualization of the convergence of predictions to the actual data playing an important role in it. The correct functioning of the prediction code of the model applied was confirmed by several years of research during classes in ship manoeuvring for students at the Maritime University in Szczecin and research studies of an academic team of sea traffic engineers, among others [Gucma L, 2005].

The hydrodynamic coefficients of each force and moment were also initially determined according to literature data published after hull (surface and underwater parts) model research. In case of gross disproportion, the appropriate extrapolation of research results to technical and operation conditions of the model vessel was used.

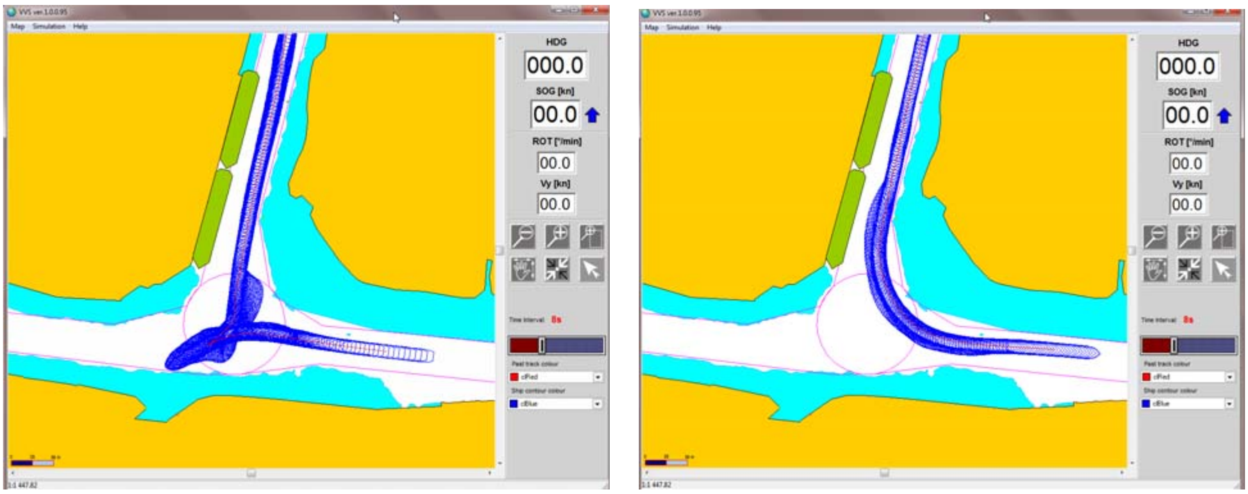
The results of the verification of the ship model studied were conducted based on the manoeuvring characteristics commonly adopted for verification: speed, braking and acceleration, circulation and standard test confirmed that the model of the optimisation program created was correct. Trials were conducted under zero conditions and on deep waters, and additionally circulation tests were conducted on shallow waters.

2.4 *Model interface*

The interface of the model is presented in Figure 3. It is the so-called "single task" model (aimed for designing waterways) with a perspective 2D visualization (bird's eye view) of the electronic map type. It contains information on the location of the post, bathymetry of the basin, information on the state of the ship, hydrometeorological conditions and control elements for steering. The model is implemented in the Delphi™ environment using the Object Pascal language and in the Visual C™ environment using the C++ language.



Figrue 3. Graphic interface of the simulation model of ship movement (a 120m vessel with a tugboat enters the turning place).



4a) 4b)

Figure 4. Graphic comparison of a single entrance 4a) series 1 of a tank vessel / general cargo ship Lc=120m, with the stern towards the Przemyslowy Canal in the presence of moored vessels of B=22m and 4b) series 2 of a tank vessel / general cargo ship Lc=120m exiting the Przemyslowy Canal with the bow away from it in the presence of moored vessels of B=22m.

3 CHARACTERISTIC VESSELS AND ASSUMPTIONS FOR SIMULATION STUDIES

The aim of the research is to determine the conditions from passing to the northern part of the Przemyslowy Canal and the necessary breadth of the possible waterway widening, and defining safety on the Parnica Turning place and its possible modernisation. Two types of characteristic vessels loaded for the Przemyslowy Canal were selected for the study:

– The current on for the southern part of the Przemyslowy Canal and the SWFiL Wharf (Baltchem),
– The future one for the SWFiL (Baltchem) and Przemyslowy Wharf (Tabel 1).

Table 1. Vessels selected for the analysis and their parameters.

	Type	L [m]	B [m]	T [m]	V [w]	Manoeuvrability
Current	Tank vessel	120	16.5	6.5	3	good
Future	Tank vessel / general cargo ship	130	22.0	6.5	3	good

The hydrometeorological conditions adopted are the eastern wind of 9m/s (5°B), which is the most unbeneficial direction due to the vessel's drifting in the SWFiL Wharf. No wind veil was assumed. In reality, there is a small tree-covered area on the east side of the canal, so such wind will be equivalent to the maximum wind of 5°B. No waves and good visibility were assumed. In the analyzed waters it was not current research. The experience and expert opinion indicate that flow in the Przemyslowy Canal are small and come up to several cm / s.

Four simulation series were planned, each representing typical manoeuvres under different conditions, selected in a way that would allow them to cause biggest hindrance. Table 5.2 shows the plan of the study. Each simulation series represents the most difficult manoeuvring situations linked to the exploitation of ships in this region, respectively:

- Series1 – entrance of the stern of a general cargo ship Lc=120m in the Przemyslowy Canal in the presence of 2 vessels of the breadth of B=22m moored in SWFiL (Figure 4)
- Series2 – exit of the bow of a general cargo ship Lc=120m out of the Przemyslowy Canal in the presence of 2 vessels of the breadth of B=22m moored in SWFiL (Figure 4)
- Series3 – entrance of the stern of a tank vessel / general cargo ship Lc=130m in the Przemyslowy Canal in the presence of 2 vessels of the breadth B=16m in SWFiL
- Series4 – exit of the bow of a tank vessel / general cargo ship Lc=130m out of the Przemyslowy Canal in the presence of 2 vessels of the breadth B=16m in SWFiL

4 STUDY RESULTS

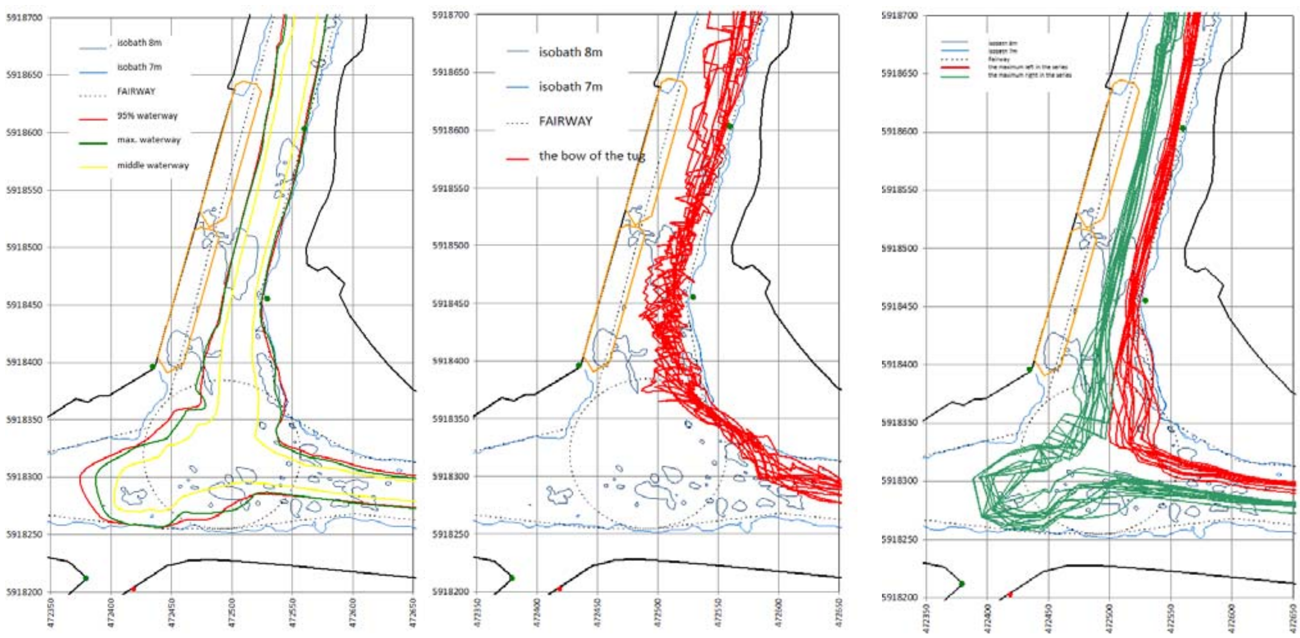
Simulation studies were conducted by qualified captains and pilots experienced in this type of ships and manoeuvres. The simulation data was registered and analysed. The minimum number of correct passages is >15 in similar studies. After going through the passages carried out by captains, the following numbers of simulation passages in series were qualified for further processing:

- Series 1 – 15 passages.
- Series 2 – 22 passages.
- Series 3 – 17 passages.
- Series 4 – 21 passages.

The stretch analysed was divided into sections of 5m of width, and the average waterway and standard deviation were calculated for each of them. The safe manoeuvre area of 95% (95% waterway) was created as a result of adding a 1.95 multiple of the standard deviation to the middle waterway. The maximum waterway is a maximum envelope of the ship from all the attempts in a series. The statistical processing of the simulation studies results boils down to calculating the safety criteria of the manoeuvre carried out that are used to compare the study results of each variant (series of simulation passages) [Gucma S, 2001]

The results of the Series 1 studies for a general cargo ship Lc=120m analysed are presented in Figure 5 (results of the middle, maximum and 95% waterways are presented in Figure 5a), the results of the location of the bow extreme point of the stern tugboat are presented in Figure 5b), the results of the extreme location (maximum distance in each section of the waterway) of manoeuvring vessels in each of the passages analysed are presented in Figure 5c)).

The analyses of series 1, 2, 3 and 4 show that there is no risk related to the insufficient size of the manoeuvring space. The 95% waterway for the vessel Lc=120m and Lc=130m coincides with the safe isoline (7m), i.e. in the region of the Elektownia (area marked) and on the eastern shore of the Przemyslowy Canal (Figure 6). The area covered by the extreme bow point of the tugboats shows considerable narrowing in the north-eastern region of the turning place due to limited space for its manoeuvring.



a) b) c)
Figure 5. Results of the analysed studies in Series 1 for a general cargo ship of Lc=120m.

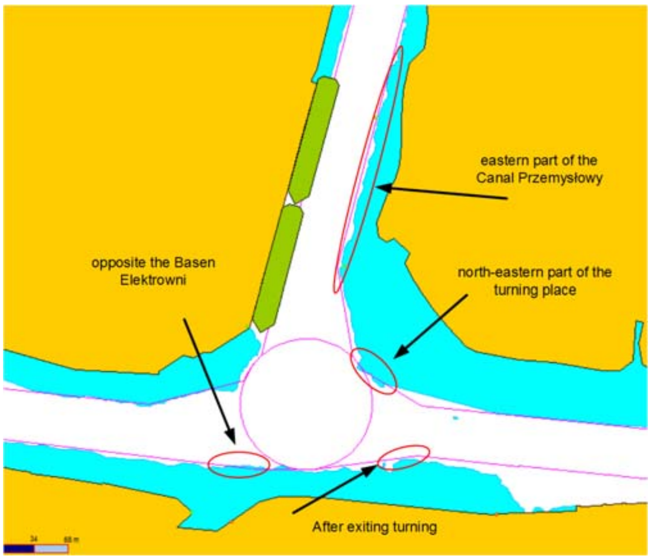


Figure 6. The location of particularly sensitive spots in the area of the entrance to the Przemyslowy Canal.

5 CONCLUSIONS

The simulation study results presented can be used to determine further development of the Przemyslowy Canal as far as the dimensions of manoeuvre areas for vessels larger than L=130m are concerned, which is considered realistic. It can be completed through the following actions:

- Developing the turning place towards the north-eastern direction and the Elektownia basin (south-western) by giving it the shape of an ellipsis which is perfect for the half-turn vessel manoeuvre in this region.
- Widening the Przemyslowy Canal and the approach way towards it from the turning place .
- Minor correction of the waterways so that they fit the new turning place .
- Attempting at marking the region of the turning place near the entrance to the Elektownia basin (south-western part of the turning place), which will be difficult due to the fact that the waterways are utilised by other users of a smaller draught.

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