Dimensioning the approach to the Liquefied Natural Gas terminal in Świnoujście using analytical and simulation methods

Anna Anczykowska[✉], Wojciech Ślączka

Maritime University of Szczecin
1–2 Wały Chrobrego St., 70-500 Szczecin, Poland
e-mails: {a.anczykowska; w.slaczka}@am.szczecin.pl, [✉] corresponding author

Abstract

This article presents a comparison between the use of analytical methods and simulations for dimensioning the approach to the liquefied natural gas (LNG) terminal in Świnoujście. Parameters of rectilinear sections of the fairway were obtained by analytical methods, widely used in traffic engineering. These methods are: the method of the Three Components, the Panama Canal method, the Canadian method, the method of the INM and the PIANC method. Dimensioning the approaching fairway to the LNG terminal in Świnoujście was conducted for two types of LNG tankers: Q-flex and Q-max. Results for simulation methods were obtained using a navigational bridge simulator. Results obtained using analytical and simulation methods allowed the comparison of parameters of the approach to the LND terminal in Świnoujście, and an indication of the optimal dimensioning methods of a fairway's straight sections.

Introduction

Increased demand for natural gas in Poland and the need to diversify sources of supply has resulted in a decision by the Government of the Republic of Poland concerning the construction of the liquefied natural gas (LNG) Terminal in Świnoujście. A consequence of this was the need to adjust the waterways and port regulations. Building new, or remodeling existing fairways, requires an appropriate dimensioning of the port approach (Gucma, 2013). Existing infrastructure allows admission of LNG tankers with maximum length of up to 320 m (Gucma, 2011). Analysis carried out includes *Q*-flex that meets this condition and *Q*-max, whose dimensions slightly exceed the established values. It was assumed in the study to increase the capacity factor of the port to support ships.

Calculating the optimal dimensions of the approach for a given vessel uses a number of methods from marine traffic engineering: The Three Components, Panama Canal, PIANC, the Canadian Method and the method of INM. The aim of the analysis was to identify the analytical method giving acceptable results in comparison with the reference method of simulation. Aims are identified which indicate the analytical method that can be used at the early stage of the design of waterways.

Description of the research area

An external port in Świnoujście leads a waterway passing through the Pomeranian Bay. The waterway leading to Świnoujście can be divided into the following parts:
- Western approaching way, Figure 1, for buoy N-1 by SWIN-N passing through the German territorial sea, to the East of Rügen Island. The natural minimum depth of the area through which the Western approaching way passes is 15.1 m (Gucma et. al., 2012).
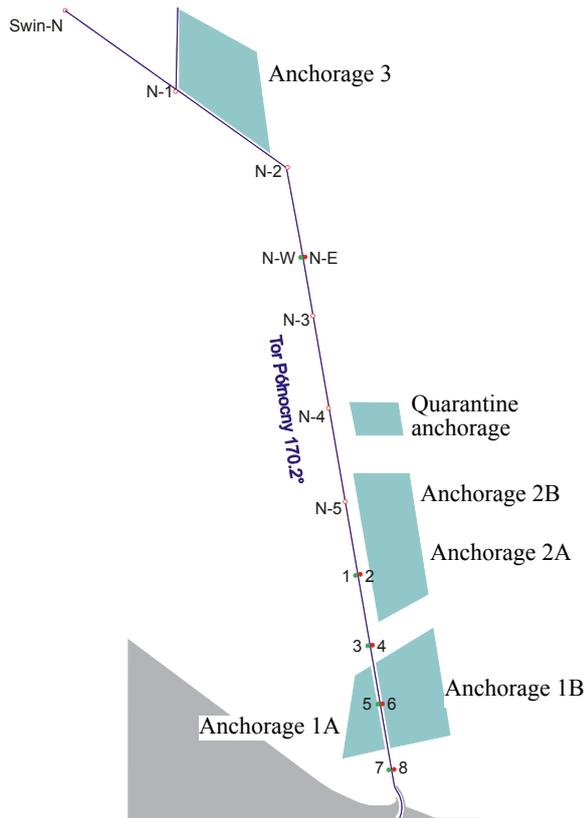
Figure 1. The fairway to Świnoujście with anchorages (Gucma et al., 2012)

- The Northern part of the approaching way, Figure 1, leads from buoy N-1 for 43.175 km to buoy N-2, and a further track of 15.0 km. The minimum depth of 14.4 m, with a width of 200–220 m, shall ensure to a large extent that the natural depth of area, with the extension of the section of length 27.8–31.4 km located to the North of buoy N-3, is an improved track.
- The Southern part of the approaching way passing Pomeranian Bay, from the 15.0 km track to

the East of the head of port Świnoujście (0.0 km). It is a dredged fairway with the minimum depth of 14.3 m and a width of 180 m.

The parameters of the fairways from the "REDA" buoy to the port of Świnoujście, and further to the port of Szczecin, are defined in regulation by the Minister of Transport and Construction: "amending regulation on the determination of objects, devices and installations within the infrastructure, providing access to the port of primary importance for the national economy" dated 27.01.2006 (Dz. U. of 10.02.2006, No. 22, item 167). Also defined in regulation by the Minister of Infrastructure, dated 16.01.2009 under the same title (Dz. U. of 02.02.2009, No. 17, item 89).

In accordance with these legal acts, the technical depth of the Northern approaching fairway in the Pomeranian Bay, on the 35.6 km length from the heads of the breakwater to buoy N-2, is 14.3 m. The widths at the bottom are as follows, and are shown in Figure 2:
- 180 m from 0.0 km to 16.3 km;
- 200 m from 16.3 km to 26.8 km;
- 220 m from 26.8 km to 35.6 km.

In regard to the foregoing limitations, the purpose of the study was to adapt the approaching fairway to the capacities of gas tankers, with a length of at least 300 m and a draught of 13.5 m, and larger, if it is justified in terms of the adjustment of the waterway.

Analytical methods of dimensioning the approaching fairway

Dimensioning the approaching fairway to the LNG Terminal in Świnoujście has been carried out using the following analytical methods:
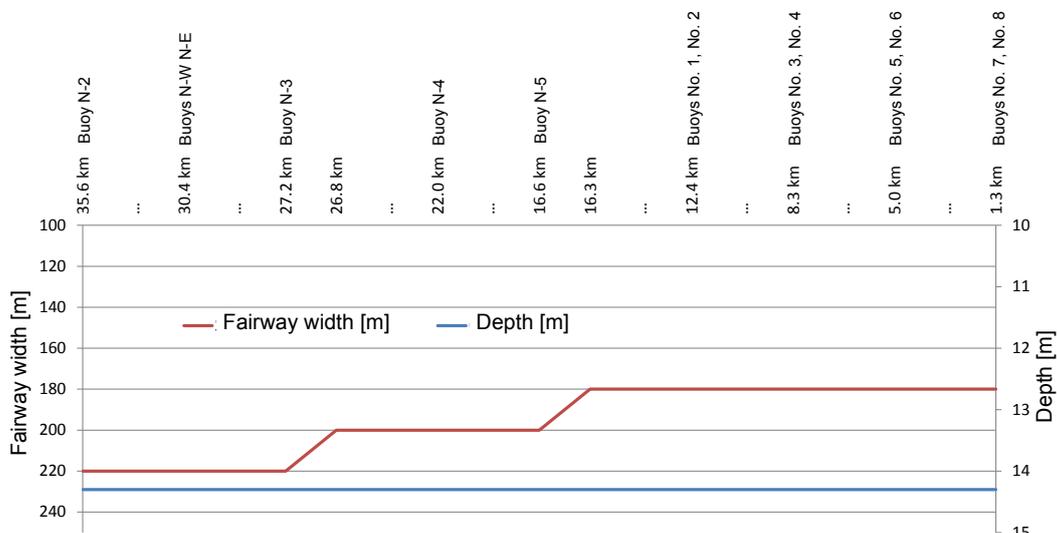
Figure 2. The parameters of the Northern approaching fairway to the port of Świnoujście (Gucma et al., 2012)

a method of Three Components, the Panama Canal, PIANC, Canadian Method and method of the Maritime Navigation Institute (INM). The greatest influence on the width of the fairway is a molded breadth for the maximum sized vessel, adopted for a given area. In this analysis we took into account the Q-flex and Q-max vessels. The specific analytical methods adopted the basic parameters according to Table 1.

Table 1. The basic parameters of the Q-flex and Q-max (Samsung, 2015)

Type of ship	LOA [m]	Breadth [m]	Draught [m]	Capacity [thousands of m^3]
Q-flex	315	50.0	12.0	210–216
Q-max	345	53.8	12.0	266

The Three Components Method

The Three Components method is determining the components of the lane width: navigational, maneuvering and lane width associated with shore-channel effect. For a one-way fairway, lane width can be calculated using the following formula (1) (Gucma, 2001; 2004):

$$d = 2\,(d_n + d_m + d_r)\ [\text{m}] \qquad (1)$$

where:
d_n – navigational component of the lane width [m];
d_m – maneuvering component of the lane width [m];
d_r – lane width reserve [m].

The navigational component of the lane width was calculated on the basis of the circular error of position (p); the value is 10 m, which is due to the accuracy of the positioning system. The position of the vessel is determined in a continuous manner. Changing the ship's velocity does not affect the value of the navigational component. For both ships this value is constant and it is 18.6 m.

The maneuvering component of the lane width is the sum of two variables d_{m1} and d_{m2}. The values adopted for the analysis are as follows:

- variable d_{m1}, which takes into account the velocity of unit AT approaching waterway, with a medium square error of the ship course over ground, and the sum of the response times of the master or the pilot, steersman, rudder stock and course inertia of ship. The maximum speed on the approaching fairway follows from the port regulations and is: 10 kn from buoy N-1 to a pair of buoys 9–10, 8 kn from buoys 9–10 to a pair of buoy 15–16, 4 kn from the pair of buoys 15–16 and external port area (UMS, 2013). The values of the d_{m1} are in Table 2;

- variable d_{m2}, which takes into account the total length and breadth of the vessel, drift angle and the average square error of ship course over ground. The values of d_{m2} are presented in Table 2 (Gucma, 2001; 2004).

Table 2. Component values of lane widths with maximum velocities for Q-flex and Q-max vessels

Type of ship	Q-flex			Q-max		
Velocity [kn]	10.0	8.0	4.0	10.0	8.0	4.0
d_n [m]		18.60			18.60	
d_{m1} [m]	4.45	3.56	1.78	4.45	3.56	1.78
d_{m2} [m]		40.11			43.46	
d_r [m]		30.00			32.28	
D [m]	180.99	184.55	186.32	185.55	189.11	190.88

On the basis of the port regulations, for further analysis ware taken into account the lane width calculated for the maximum speed of the 4.0 kn. These values are: 186.32 m for Q-flex and 190.88 m for Q-max.

Panama Canal Method

The lane width, determined using the Panama Canal method, is a function of the vessel's breadth in Formula 2 (Gucma, 2001; 2004):

$$d = k\,B + 2\,d_r\ [\text{m}] \qquad (2)$$

where:
k – coefficient determined experimentally [m];
B – molded breadth of the ship [m];
d_r – lane width reserve [m].

The coefficient k depends on the ship's maneuverability during transition of the waterway. The k factor, in practical terms, depends on the value of the mean square error of maintaining the vessel on a given course m_k.

The coefficient k takes the following values (Gucma, 2001; 2004):
$k = 1.2$ – good maneuverability, $m_k \leq 1°$;
$k = 1.6$ – average maneuverability, $1° < m_k \leq 2°$;
$k = 1.8$ – compromised maneuverability,
$\qquad 2° < m_k \leq 3°$

In the analysis of the lane widths, three values of the k factor are specified for both types of ships. The obtained results are presented in Table 3.

Table 3. The lane widths for Q-flex and Q-max depending on the k factor

	Q-flex			Q-max		
k	1.2	1.6	1.8	1.2	1.6	1.8
D [m]	120.00	140.00	150.00	129.12	150.64	161.40

In accordance with port regulations of such tankers, LNG tankers are required to support the towage assistance of 1 Nm on the North from a pair of buoys 1–2. Tug assistance allows improvement to the maneuverability of the ships. In this regard, factor $k = 1.2$ was adopted for further analysis and that gives a lane width for Q-flex of 120.00 m, and 129.12 m for Q-max.

PIANC Method

This method was developed by the Permanent International Association of Navigation Congresses. This is the association of uniting experts from the fields of maritime infrastructure and transport. The value of the lane width consists of: basic maneuvering width, extra amendments to take account the hydro-meteorological conditions and the specificity of the area, and lane width reserve to the left and right sides.

The method is based on the following Formula 3 (PIANC – IAPH, 1997):

$$d = d_m + \sum_{i=1}^{9} d_i + d_{rz} + d_{rc} \qquad (3)$$

The analysis assumes the following parameters:

d_m – due to the ship's good maneuverability, with tug assistance, the value of maneuvering lane width is 1.3 of the ship's breadth;

d_1 – speed when the ship approach to be analyzed will fall in the range of 8–12 kn and 5–8 kn, therefore the correction is 0;

d_2 – transverse wind speed for the analysis was adopted to be 20 kn and the correction for this value at the velocity of the ship in the range 5–8 kn is 0.5 B;

d_3 – cross current speed is assumed to be analyzed to be 1 kn and the correction for this value at the ship's velocity in the range 5–8 kn is 1 B;

d_4 – transverse current speed for the analysis was adopted to be 2 kn and the amendment for this value at the vessel's speed in the range 5–8 kn is 0.2 B;

d_5 – on the basis of an analysis of the hydro-meteorological conditions of the area, it follows that the wave height is greater than 1 m but less than 3 m, and its length is equal to the analyzed ships LOA. The correction for these values at the ship's speed in the range 5–8 kn is 0.5 B;

d_6 – on the marked coast the area is covered by operation of the VTS Świnoujście. As vessel traffic should be governed by port regulations, the value of the correction is 0 (UMS, 2013);

d_7 – type of seabed in analysis area was accepted as medium, i.e. sand and gravel, so the value of the correction is 0.2 of ship's breadth;

d_8 – in accordance with port regulations, the maximum permissible draught is 12.5 m for freshwater. The depth of the fairway is an average 14.3 m, and the ratio of depth-to-draught is 1.14, so the correction should be 0.2 of the vessel's breadth (UMS, 2013);

d_9 – ship is a LNG tanker, so the value of correction is 1 B, due to the load being carried (PIANC – IAPH, 1997).

The lane widths for analyzed vessels computed for the above values are presented in Table 4.

Table 4. Lane widths calculated using PIANC method for Q-flex and Q-max

	Q-flex	Q-max
One direction fairway D [m]	240.00	258.24
Two directions fairway D [m]	330.00	355.08

Canadian Method

The Canadian method is a modification of PIANC method, developed on behalf of Canadian Waterways Development. Lane width on the rectilinear fairway section consists of the design width and additional corrections (Canadian Coast Guard, 1999).

$$d = \sum_{i=1}^{6} d_{di} + \sum_{j=1}^{5} d_{aj} \quad [m] \qquad (4)$$

For the analysis the following values were adopted:

d_{d1} – due to the ship's good maneuverability, with tug assistance, the value of maneuvering lane width is 1.3 of the ship's breadth;

d_{d2} – due to the fact that traffic can be carried in two directions, there is a hydrodynamic interaction between passing vessels, so the correction should be 0.2 of the ship's molded breadth;

d_{d3} – transverse wind speed for the analysis was adopted to be 20 kn and the correction for this value for the ship velocity in the range 5–8 kn is 0.5 B;

d_{d4} – cross current speed is assumed to be analyzed to 1 kn and the correction for this value at the ship's velocity in the range 5–8 kn is 1 B;

d_{d5} – the width reserve due to the shore-channel effect was specified for good maneuverability. Due to the assistance of tugs and wind-weather conditions, the value is 1 of the vessel breadth;

d_{d6} – on the marked coast the area is covered by operation of the VTS Świnoujście. As vessel

traffic should be governed by port regulations, the value of the correction is 0 (UMS, 2013);

d_{a1} – ship is a LNG tanker, so the value of correction is 1 B due to the load being carried;

d_{a2} – in accordance with port regulations, the maximum permissible draught is 12.5 m for freshwater. The depth of the fairway is an average 14.3 m, and the depth-to-draught ratio is 1.14, so the correction should be 0.2 of the vessel's breadth (UMS, 2013);

d_{a3} – type of seabed in analysis area was accepted as a medium, i.e. sand and gravel, so the value of the correction is 0.2 of ship's breadth;

d_{a4} – the analysis assumes that the entry of the vessel will be with tug assistance, so in conditions of good daytime visibility the value of the correction is 0;

d_{a5} – the correction should be adopted for high speeds of more than 12 kn, but the velocities of the ship's entry to be analyzed are less than 12 kn (Canadian Coast Guard, 1999), which should be governed by the port regulations (UMS, 2013).

The widths of the lanes has been calculated for these values and are presented in Table 5.

Table 5. Lane widths calculated using Canadian method for Q-flex and Q-max

	Q-flex	Q-max
One direction fairway D [m]	265.00	280.58
Two directions fairway D [m]	275.00	290.58

INM Method

This method is based on the Panama Canal method and was established at the Maritime Navigation Institute Maritime University of Szczecin. The lane width of a rectilinear section of the fairway can be calculated for any positioning system of the vessel. For the purpose of the analysis, the following have been adopted:

- $2d_n$ – navigational component lane width has been continuously determined on the basis of knowledge of the circular error of position for GPS system;
- $k*B$ – factor depends on the maneuverability of the ship, known on the basis of knowledge of the mean square error of maintaining the vessel on a given course (m_k). For a vessel with good maneuverability ($m_k \leq 1°$) this factor is 1.2 of the ship's breadth;
- $2d_r$ – lane width reserve which is 0.6 of the ship's breadth.

The widths of the lane based on the above assumptions are presented in Table 6.

A summary of the results obtained for Q-flex and Q-max is presented in Table 7.

Table 6. Lane widths calculated with the INM method for Q-flex and Q-max

	Q-flex	Q-max
D [m]	156.00	165.12

Table 7. Dimensioned widths of approaching fairways to the port of Świnoujście for Q-flex and Q-max

Method	D [m]	
	Q-flex	Q-max
Three Components	186.32	190.88
Panama Canal	120.00	129.12
PIANC	240.00	258.24
Canadian	265.00	280.58
INM	156.00	165.12

The greatest value for the width of the lane, for the same essential approaching fairway, was obtained by the PIANC and Canadian methods. This is due to the fact that these methods take into account many variables affecting ship movement. The minimum value was calculated using the Panama Canal method. This is due to the fact that the tug assistance required by port regulations significantly improves the ship's maneuverability. Intermediate lane width values were obtained by the INM and Three Components methods. In the INM method, due to assumption that the positioning system determines the position continuously, the vessel's speed is not affected. For the values obtained by the Three Components, the biggest impact was given by the d_{m2} correction, which takes into account the drift angle and the average square error of the course over ground.

Simulation method of dimensioning the approaching fairway

Measuring the width of the ship's lane, and at the same time the width of approaching fairway based on the simulation method, consists in the appointment of its boundaries in relation to the adopted reference axis, which is the axis of the fairway. The dimensions of the approaching fairway borders are the maximum distance to the left and right of the contractual fairway axis or line, which is the point of reference.

It should be calculated using the value of the inverse of the normal cumulative distribution RNO:

$$X = \mathrm{RNO}(P_n; \bar{x}; \sigma) \qquad (5)$$

Arguments of this function are: reliability of navigation P_n, and the average $\bar{x}$ and standard deviation σ, derived from statistical analysis of one series of simulation trials. X values must be calculated for each section of the maneuvering area and then converted to geographic coordinates on a map of the area.

The reliability of navigation is the probability that a given type of vessel under certain navigational and meteorological conditions, navigated by qualified navigator in a certain period of time and place. It will be shown on the lanes for the intended direction, taking into account the minimum safe depth under keel, and the distance from an obstacle. Hence the lane is an area designated by a maneuvering ship in the area.

The reliability of navigation can be written using the normal distribution (Ślączka, 2002):

$$P_n = P(X_j \leq d_j) \qquad (6)$$

where:

X_j − random variable that represents the maximum distance of the vessel's extreme point on the left and right of the fairway axis in j-th stretch of the area;

d_j − the shortest distance to danger from the axis of the fairway, for example the breakwater, in a j-th stretch of the area.

In order to determine the reliability of navigation, every simulation trial is subjected to statistical treatment as a result of the maximum value, the average and standard deviation of a random variable X,

which is the position of the vessel's waterline in j-th section of the area. As a result of standardization of the formula for reliability of navigation, it is given in the form of a standardized notation of the normal distribution (Ślączka, 2002):

$$P_n = P\left(\frac{X_j - \bar{x}_j}{\sigma_j} \leq \frac{d_j - \bar{x}_j}{\sigma_j} \right) \qquad (7)$$

where:

$\bar{x}_j$ − the average maximum distance left or right of the axis of the fairway for the j-th lane [m];

σ_j − the standard deviation of a random variable X_j being the maximum distance of the vessel's extreme points on the left and right of the fairway axis for j-th stretch of lane [m].

Parameters $\bar{x}_j$ and σ_j are calculated on the basis of the results of simulation studies, registered in the determination of the lane width to be used for a given maneuver.

As can be seen from the analysis in Figure 3, the maximum width of the fairway for Q-max is 196.5 m and a prediction width for the established interval confidence 0.05, calculated at the level of $p = 0.95$, is 201.2 m.

Comparative analysis of analytical and simulation methods

Benchmarking will be performed on the results for larger gas takers − Q-max. The calculated values of the lane widths of Q-max using analytical methods and simulation, allowed us to obtain
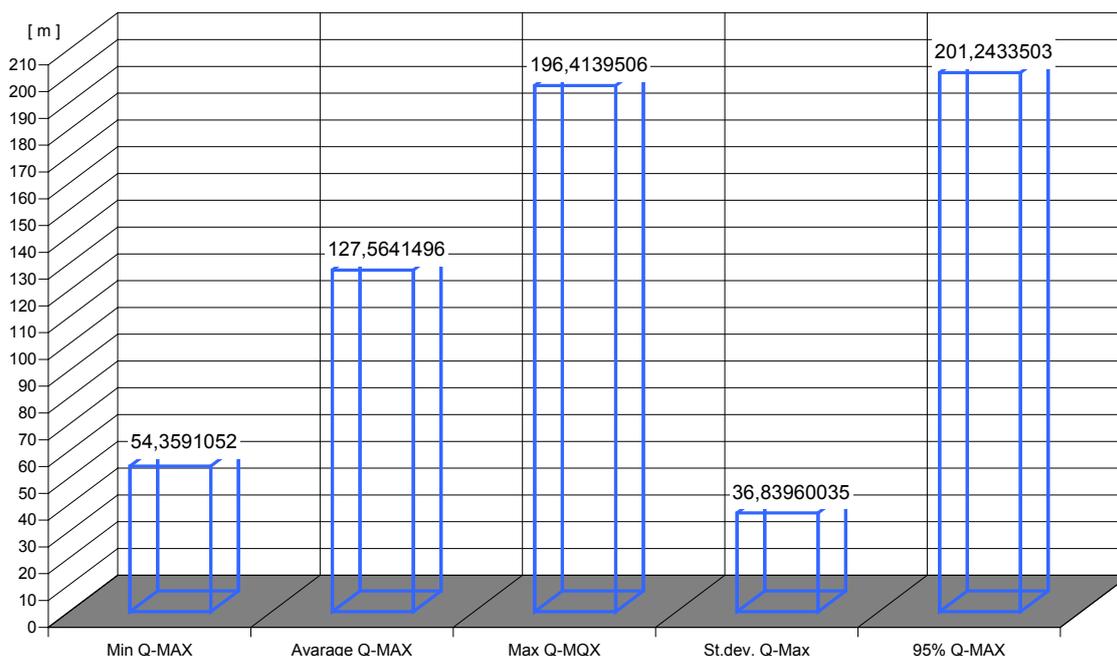
Figure 3. Dimensioned widths of the fairway for *Q*-max at the entrance to the port of Świnoujście (Gucma et al., 2012)

a)

b)

c)
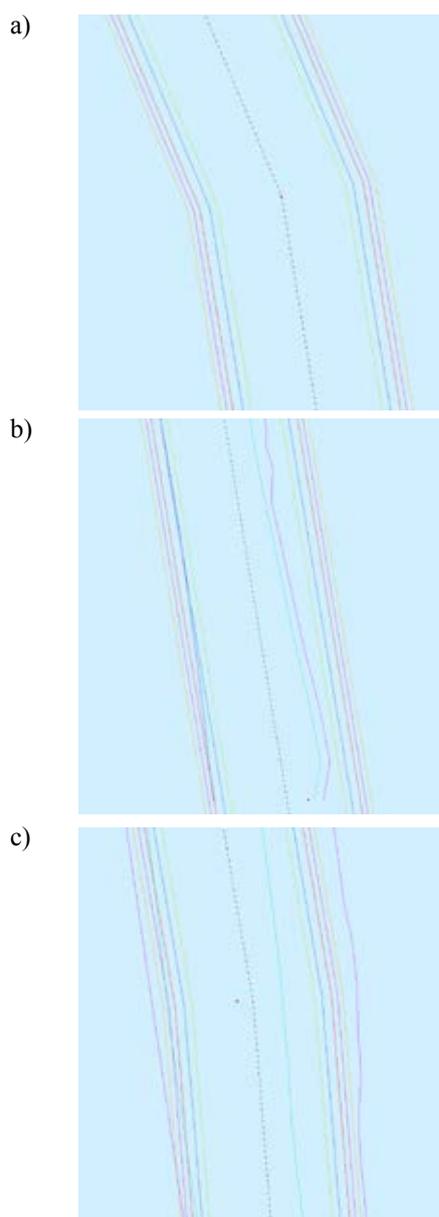
Figure 4. The lane widths for *Q*-max obtained using analytical methods (a) and analytical and simulation methods (b, c) for a selected section of the approaching fairway (own work using ArcGIS)

the coordinates of the points relative to the fairway axis. This allowed us to delineate lane width borders on a map. The obtained results are presented in Figure 4.

Graphic and numerical analysis of the results showed:
- the narrowest fairway width using analytical methods was obtained with the Panama Canal method giving a value of 129.12 m;
- of the analytical methods the greatest width of the fairway was obtained using the Canadian method giving a value of 280.58 m;
- using simulation methods to calculate the width of the dimensioned fairway gave 201.2 m.

Differences in the location of the boundaries of dimensional waterways using various methods on the figures are shown.

Conclusions

An important part of the design of waterways and, in particular, of approaching fairways, is that it is possible to estimate a range of changes. In terms of waterways, the financial effort to adapt to the pursued objectives influences the future. More often than not, at the outset there are commitments to errors resulting from incorrect assumptions that lead to too much investment. To define the correct research results that the next phase of the simulation test, is very expensive to do in an optimal manner.

One way to do this is to initially establish, using analytical methods, the width of the fairway necessary for safely maneuvering the ship. In the dimensioning process using analytical methods, the most important thing is to find the one which is as close as possible to the results of the simulation method.

Studies show that the most adequate method for application to rectilinear fairway section dimensioning is the Three Components method. The results obtained here for the established impacts of external forces are the most similar to the analogous research based on simulation method.

References

1. Canadian Coast Guard (1999) *Canadian waterways national manoeuvring guidelines: channel design parameters*. Waterways Development, Marine Navigation Services.
2. GUCMA, S. (2001) *Inżynieria ruchu morskiego*. Gdańsk: Okrętownictwo i Żegluga.
3. GUCMA, S. (2004) *Nawigacja pilotażowa*. Gdańsk: Fundacja Promocji Przemysłu Okrętowego i Gospodarki Morskiej.
4. GUCMA, S. (2011) Minimalne wymagane parametry podejściowych torów wodnych do Portu Świnoujście. *Inżynieria Morska i Geotechnika* 32 (2). p. 143.
5. GUCMA, S. (2013) Warunki bezpiecznej eksploatacji statków w systemach morskich dróg wodnych. *Materiały na XV Międzynarodową Konferencję Naukową „Inżynieria Ruchu Morskiego"*. October 16–18, 2013, Świnoujście.
6. GUCMA, S. et al. (2012) *Projekt systemów zapewniających bezpieczną nawigację i obsługę statków LNG na podejściu i w porcie zewnętrznym w Świnoujściu.*
7. PIANC – IAPH (1997) *Approach Channels – A Guide for Design.*
8. Samsung (2015) *Samsung Heavy Industries builds the world's largest LNG Carrier*. [Online] Available from: http://www.shi.samsung.co.kr [Access: 26 August 2015].
9. ŚLĄCZKA, W. (2002) *Wymiarowanie obszaru manewrowania statku na podstawie analizy ryzyka awarii*. Rozprawa doktorska. Szczecin: Wyższa Szkoła Morska w Szczecinie.
10. UMS (2013) *Regulation No. 3 of the Director of Maritime Office in Szczecin of 26th July 2013*. Port regulations.