ARCHIVES OF TRANSPORT
Volume 50, Issue 2, 2019

ISSN (print): *0866-9546*
e-ISSN (online): *2300-8830*
DOI: *10.5604/01.3001.0013.5696*

OPTIMIZATION OF LNG TERMINAL PARAMETERS FOR A WIDE RANGE OF GAS TANKER SIZES: THE CASE OF THE PORT OF ŚWINOUJŚCIE

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Abstract:

LNG terminals are built to handle tankers of specific size, with cargo capacities within a narrow scope. This is related to the differences in cargo, fender and mooring systems used for LNG tanker handling of various sizes. The research problem solved in the article is the development of the method for optimal design of a universal LNG cargo handling facility that enables safe operations of LNG tankers in a wide range of cargo capacity that covers almost entire spectrum of global fleet tanker sizes. The article presents a methodology of optimizing the parameters of LNG cargo terminals to accommodate both small bunker ships with cargo capacity of 500 m3 (50 metres in length) to Q-flex type tankers capable of carrying up to 220 000 m3 (320 m in length). The authors have determined conditions for the safe operation of these tankers in sea LNG terminals and described differences in the construction of cargo, fendering and mooring systems. The optimization of both location and terminal parameters for a wide range of gas tanker sizes as well as approach channels leading to the LNG berths was performed using a specially designed two-stage simulation method of optimization. In the first stage the best location of a universal LNG terminal and its berths in the existing port basin is determined. The second stage defines optimal parameters of approach waterways to the berths of a universal LNG terminal. The optimization criterion at both stages was the minimization of the costs to build and to operate a universal LNG terminal. The developed optimization methodology was actually used in the design of the universal LNG terminal in the outer port of Świnoujście. The tests made use of real time simulation (RTS) and non-autonomous models of ships, in which ship movement is controlled by a human (pilot, captain). Simulation tests were performed on a multi-bridge ship handling Polaris simulator with a 3D projection, from Kongsberg Maritime AS. This full-mission bridge simulator (FMBS) is located at the Marine Traffic Engineering Centre, Maritime University of Szczecin. Two simulation ship movement models were built and verified for testing the manoeuvres of port entry and berthing. These are: Q-flex type tanker (length: 320 m) and an LNG bunker ship, 6,000 m3 capacity, 104 m in length. The test results were used in the design of the universal LNG terminal in the outer port of Świnoujście and approach waterways leading to the berths (now this investment project is in progress).

Keywords: *LNG terminal, optimization of port waterways, navigational safety in restricted areas.*

To cite this article:

Gucma, S., Gucma, M., 2019. Optimization of LNG terminal parameters for a wide range of gas tanker sizes: the case of the port of Świnoujście. Archives of Transport, 50(2), 91-100. DOI: https://doi.org/10.5604/01.3001.0013.5696

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1. Introduction

The construction of universal dolphin-structure LNG terminals that can accommodate a wide range of tanker sizes in existing ports requires developing a new design methodology that will optimize their location and dimensioning.

The seaport is a system consisting of a set of various waterways (port basins), such as anchorages, fairways, port entrances, turning basins and berthing/mooring areas (Mazurkiewicz, 2009). The parameters of each waterway belonging to the port determine the conditions of safe operation of ships manoeuvring within this area (Gucma S. et al., 2017; PIANC, 2014).

In a typical seaport, conditions for the safe operation of ships are defined by basic parameters of a 'maximum ship' that can safely manoeuvre in a given waterway in hydrometeorological conditions allowable for this manoeuvre. A universal terminal capable of handling large LNG tankers, feeders and bunker ships, which represent a large spectrum of cargo capacities from a 500 m^3 (bunker ship) to 220.000 m^3 (Q-flex type tanker) calls for redefining safe operation conditions and different methods of berth parameter optimization.

The conditions of safe operation of universal LNG terminals must address the largest and smallest gas carriers that will be berthing along the terminal, and the optimization of navigable area parameters refers to all users of port basins regardless of ship size.

The article defines and presents:
- the conditions for the safe operation of LNG tankers coming along a universal LNG terminal;
- method of selecting the location of universal LNG terminals;
- simulation methods of optimizing the parameters of universal terminals and approach channels.
- methodology of universal LNG cargo terminal design.

These relationships and methods enable the optimisation of parameters of universal LNG terminals and related approach channels.

The developed methodology was used in the design of the universal LNG terminal built in the Świnoujście outer port (MUS, 2017; MUS, 2018). The developed methodology has been applied in the design of the universal LNG terminal built in the Świnoujście outer port (MUS, 2017; MUS, 2018). Detailed structural and operational issues in LNG terminal design has been discussed and presented in (Yong & Jin, 2016). Application measures of risk assessment in the LNG terminal design using the FSA method was discussed in (Perkovic et al., 2012). While partial assumption of the proposed methodology in the crude terminal has been presented in (Vidmar & Perkovic, 2018). It shall be noted that simple models like the one presented in PIANC (PIANC, 2014) can be utilized only with certain level of confidence and shall always be verified with simulations.

2. Conditions for the safe operation of LNG terminals handling a wide range of LNG carrier sizes

The port basin including a designated turning area and a universal LNG terminal, which may consist of a few berths, is a waterway system defined by three subsystems: area, navigational, berths, which are the function of the conditions for safe operation of LNG tanker manoeuvring (Gucma S. et al., 2017).

$$\mathbf{W} = f\begin{bmatrix}\mathbf{A}\\ \mathbf{N}\\ \mathbf{K}\end{bmatrix} \tag{1}$$

The subsystem of the port basin area with the LNG terminal that may include a few berths is defined by a set of parameters:

$$\mathbf{A}=\begin{bmatrix}\mathbf{D}_i\\ h_i\end{bmatrix} \tag{2}$$

where:

$\mathbf{D}_i$ – available navigable area for i-th berth (meeting the minimum depth condition);

h_i – minimum depth of the approach to i-th berth.

The navigational subsystem of the port basin with a universal (multi-berth) LNG terminal is described by this set of parameters:

$$\mathbf{N}=\begin{bmatrix}p_{ij}\\ m_{ij}\\ n_{ij}\\ w_{ij}\end{bmatrix} \tag{3}$$

where:

p_{ij} – accuracy of j-th navigational system - directional error perpendicular to i-th berth line;

m_{ij} – availability of j-th navigational system at the approach to i-th berth ;
n_{ij} – reliability of j-th navigational system at i-th berth approach;
w_{ij} – integrity of j-th navigational system at i-th berth approach;

The berth subsystem of LNG terminal is described by these parameters:

$$\mathbf{K} = \begin{bmatrix} T_i \\ k_i \\ a_i \\ E_i \\ b_i \\ P_i \end{bmatrix} \quad (4)$$

where:
T_i – type of i-th berth structure (dolphins or solid);
k_i – length of the line of mooring of ith berth;
a_i – spacing of i-th berth fenders;
E_i – allowable kinetic energy absorbed by fenders at i-th berth;
b_i – spacing of the mooring devices;
P_i – allowable loads of mooring hooks;

The conditions for the safe operation of ships manoeuvring in the port basin and berthing along the LNG terminal berths may be written as a set of these parameters:

$$\mathbf{W} = \left[r_i, L_c^{max}, L_c^{min}, B_i, T_i, F_i, M_i, M_{sti}, n_{hi}, U_{hi}, \mathbf{H}_i \right] \quad (5)$$

where:
r_i – type of maneuvers of 'maximum ship' coming to i-th berth;
L_c^{max} – length overall of 'maximum ship' coming to i-th berth;
L_c^{min} – length overall of 'minimum ship' coming to i-th berth;
B_i – maximum breadth of the ship coming to i-th berth;
T_i maximum draft of the ship coming to i-th berth;
F_i – the 'maximum lateral windage of 'maximum ship' coming to i-th berth;
M_i – main propulsion power of 'maximum ship' coming to i-th berth;
M_{sti} – power of bow thrusters of 'maximum ship' coming to i-th berth;
n_{hi} – the number of tugs assisting in the berthing of 'maximum ship' coming to i-th berth;
U_{hi} – total bollard pull of the tugs assisting in the berthing of the 'maximum ship' berth' coming to i-th berth;
$\mathbf{H}_i$ – set of hydrometeorological conditions allowable for the berthing manoeuvres of 'maximum ship' coming to i-th berth.

$$\mathbf{H}_i = \left[d/n, s, \Delta h_i, V_{wi}, V_{pi}, h_{fi} \right] \quad (6)$$

where:
d/n – allowable time of day (daylight or no restrictions);
S – allowable visibility;
Δh_i – allowable drop of water level at i-th berth;
h_{fi} – allowable wave height at i-th berth;
V_{wi} – allowable wind speed at i-th berth;
V_{pi} – allowable current speed at i-th berth;

The determination of the conditions for the safe operation of LNG tankers coming to an LNG berth involves various types of berthing manoeuvres:
- single-propeller ships with bow thrusters - berthing without assistance;
- ships with bow thrusters - berthing with assistance of one tug,
- ships berthing with assistance of more than one tug.

Depending on the type of berthing manoeuvres, the vector of their safe operation conditions may be differently written (different set of parameters) (Gucma S. et al., 2017).

3. Parameters of LNG cargo terminals capable of accepting a wide range of gas tanker sizes

LNG terminals for a wide range of LNG tanker sizes are usually designed as two-berth terminals. One dolphin-based berth is intended for handling large LNG carriers and feeder ships, the other – pier berth – for handling LNG bunker ships. Where large volumes of LNG to be loaded onto bunker ships are projected, another configuration can be considered: one berth for large gas tankers and feeders, two berths for LNG bunker ships. In case of determined constrains of size or amount of LNG transfers single stations jetties can be designed, equipped with the differentiated loading and mooring system.

The breakdown of LNG ships by size handled at each berth of a universal cargo terminal results from differences of the structure and parameters of the systems (Gucma L. et al., 2013):

– cargo;
– fendering;
– mooring.

The cargo system of LNG tankers and feeders consists of a few (2-5) loading arms, while LNG bunker ships are loaded via flexible cryogenic hoses and hose-handling davits. The size of the loading arms determines their working range between:

– the level of cargo manifold of a minimum ship at low water,
– the level of a maximum ship under ballast at high water.

This is related to the height of the technological platform above the water surface. The height of the technological platform should also be taken into account in the cargo systems of bunker ships using flexible hoses.

The **fendering system** of the berth is characterized by two parameters: fender spacing (a_i) and allowable kinetic energy absorbed by the fenders (E_i). The kinetic energy absorbed by fenders is determined using the results of the simulation experiment of 'maximum ship' berthing. The fender spacing depends on the type of berth structure (dolphins and pier).

In the case of piers intended for loading LNG bunker ships, the spacing of fenders is chosen similarly to berths for handling conventional cargo ships (Mazurkiewicz, 2009). In the case of dolphin berths, fenders are mounted on dolphin islands equipped with mooring and fender or only fender devices.

The fender system of a dolphin berth must meet the following requirements:

– the smallest LNG tankers to be handled (loaded and under ballast) must contact a minimum of two fenders with their flat part of the side;
– maximum LNG tankers (L_{oa}>270 m) intended for operation should rest their flat side part on at least four fenders.
– medium size LNG tankers (180 m< L_{oa} < 270 m) should rest their flat part of the side on at least three fenders.

The length of the flat parallel body of LNG tankers (l_p) relative to their length overall (L_c) depends on the loading condition and ranges:

$$l_p = 0.45L_{oa} \div 0.55L_{oa} \quad (7)$$

The flat surface of LNG tanker side is shifted aft relative to the manifold by approximately 0.25 l_p.

The **mooring system** of the berth is characterized by the number and location of mooring hooks (b_i) and their allowable working load (P_i). The parameters of the mooring system depend on the type of berth structure and the sizes of 'maximum gas tankers' handled there.

In the case of dolphin berths handling LNG tankers and feeder ships, the system consists of the following devices:

– quick release double mooring hooks with increased swivel angle;
– capstan mounted at each mooring hook for heaving up mooring lined passed from the ship;
– remote hook release system with a local release option;
– system of determining mooring loads and onboard monitoring function.

The location of mooring hooks and their allowable working load is determined by the graphic-analytic method based on the following assumptions (OCIMF, 2013):

– working load of mooring hooks is determined for the 'maximum gas tanker';
– calculations are made for the highest wind speed blowing in the area under consideration perpendicularly to the line of berthing (pushing) and along that line;
– the distance between the extreme mooring devices should not exceed 1.5 lengths of the maximum ship (1.5 L_c);
– minimum number of mooring lines: 4 - forward, 4 - aft, (double lines for a gas tanker $L_c > 180$ m) and 3 - forward, 3 - aft (double lines for $L_c \leq 180$ m);
– line of mooring dolphins (head and breast lines) is shifted away from the berth line by a minimum of half breadth of the ‘maximum gas tanker’ (1/2 B).

The location of spring line hooks is planned so that the spring lines in all examined cases run at a minimum angle with the line of mooring. The positions of mooring hooks are planned so that the angle between the mooring lines and the line of mooring is not less than 45°.

The verification of the location of mooring hooks and the arrangement of mooring lines of 'maximum gas tankers' is done by using dedicated software recommended by SIGGTO/OCIMF (OCIMF, 2013).

In the case of piers or partial pier structures handling LNG bunker ships, the mooring system can be reduced to single mooring hooks and a remote system of hook release, or bollards placed on the pier and dolphin islands.

4. The simulation method for optimization of the parameters of LNG berths for a wide range of tanker size

The location and the parameters of approach channels leading to LNG terminal berths universal in terms of tanker size were optimized using a specially developed two-stage simulation method of optimization. The objective function of this type of problem can be written thus:

$$Z = \sum_{i=1}^{n} (A_i + N_i + G + S_i) \rightarrow \min \tag{8}$$

with these constraints:

1) manoeuvring safety of a tanker coming to i-th berth of LNG terminal

−the condition of navigational safety:

$$\forall p(x,y) \subset \mathbf{D_i}(t) \quad \left.\begin{array}{l} \mathbf{d}_{ikz(1-a)} \subset \mathbf{D_i}(t) \\ h_{xyi} \geq T_{ik} + \Delta_{ik(1-\alpha)} \end{array}\right\} \tag{9}$$

2) safety of ships manoeuvring in a port basin.

−condition of navigational safety of the manoeuvres of all ships entering a port basin and mooring along j-th berth of this basin:

$$Z = \sum_{i=1}^{n} (A_i + N_i + G + S_i) \rightarrow \min \tag{10}$$

3) safety of ships mooring in a port basin.

− the safety condition resulting from the risks associated with LNG transhipment operations for other port basin users:

$$\mathbf{B}_j \not\subset \mathbf{F}_j \tag{11}$$

where:

- Z − cost of the construction and operation of a universal LNG terminal
- A_i − cost of the construction of approach waterways to i-th berth
- N_i − cost of the construction of the subsystems for the determination of ship position and speed of approach to i-th berth (navigational systems)
- G − cost of the construction of LNG pipelines to a transhipment berth
- S_i − costs of ship operation related to the approach to i-th berth
- $\mathbf{d}_{ikz(1-\alpha)}$ − safe manoeuvring area of k-th 'maximum gas tanker' coming to i-th berth of universal transhipment facility in z-th navigational conditions determined at the confidence level (1-α)
- $\mathbf{D}_i\mathbf{(t)}$ − available navigable area leading to i-th berth (the condition of safe depth at instant t is satisfied)
- h_{xyi} − area depth at point (x,y) in approach channel to i-th berth
- T_{ik} − draft of k-th ‘maximum gas tanker’ coming to i-th berth
- $\Delta_{ik(1-\alpha)}$ − underkeel clearance of k-th ‘maximum gas tanker’ coming to i-th berth, determined at the level of confidence (1-α)
- $\mathbf{d}_{jz(1-\alpha)}$ − safe manoeuvring area of the ‘maximum ship’ coming to j-th berth in z-th navigational conditions
- $\mathbf{F}_j$ − area occupied by the hull of the ‘maximum ship’ lying at j-th port basin berth
- $\mathbf{B}_j$ − hazard zone related to LNG transhipment operations for a ship lying at j-th berth.

The simulation method for the optimisation of multi-berth LNG facilities with a broad range of tanker size handled consists of two stages (MUS, 2018; Gucma S. & Gucma M., 2018):

- stage 1 (preliminary) makes use of empirical methods of marine traffic engineering;
- stage 2 (detailed) is carried out using the methods of computer simulation of ship movement.

The parameters of the examined waterway system determined in the first stage will be used as preliminary parameters for the stage of simulation tests (stage 2).

In stage 1, the objective function is limited to the minimisation of the costs of the construction of approach waterways and LNG transport pipelines. These costs depend on the size of the navigable area **(D_i),** safe depths of these areas (h_i) and length of LNG pipelines (g):

$$Z = \sum_{i=2}^{n} F(Di,\ _{hi,}\ g) \rightarrow \min \tag{12}$$

and with predefined safe depths of the available navigable area, the objective function can be written as:

$$Z = \sum_{i=2}^{n} F(\mathbf{D}i, g) \rightarrow \min \qquad (13)$$

with constraints 2 and 3.

The best location of LNG terminal in a port basin is determined by the graphic method, using:
- terminal parameters;
- safe manoeuvring areas of tankers coming to LNG berth and other ships manoeuvring in the basin **($\mathbf{d}_{jz}$)** determined by empirical methods used in marine traffic engineering (MUS, 2008; MUS, 2017; Gucma S., 2007; Gucma S. et al., 2017);
- the radius of the hazard zone related to LNG transhipment operations adopting a permissible density of thermal radiation 5 kW/m^2, which at sea is approximately 550 m (SANDIA, 2004; Gucma S.et al., 2017).

In stage 2, the objective function is written in this form:

$$Z = \sum_{i=1}^{n} F(Di) \rightarrow \min \qquad (14)$$

with these constraints:
- the manoeuvring safety of LNG tanker (the condition of navigational safety)

$$\mathbf{d}_{ikz(1-\alpha)} \subset \mathbf{D}_i \qquad (15)$$

- the safety of manoeuvring of tankers coming to LNG berth in the port basin (relative to other ships lying in the port basin)

$$\mathbf{D}_i \not\subset \mathbf{F}_j \qquad (16)$$

In stage 2, safe manoeuvring areas of the ‘maximum gas tankers’ coming to LNG berth ($\mathbf{d}_{ikz(1-\alpha}$) are determined from the results of simulation tests carried out on full mission bridge simulators (FMBS).
The simulation tests procedure applied in designing marine waterways runs in the following sequence (Gutenbaum, 2003):
- problem formulation, including the indication of design objective, simulation methods and types of simulators to be used;
- construction or choice of vessel movement models on the selected simulator and their verification;
- design of the experimental system and performance of the experiment;
- processing and statistical analysis of test results.

5. The application of the developed methodology for optimization of parameters of the designed universal LNG terminal in the port of Świnoujście

The expansion of the LNG terminal in Świnoujście consists of the construction of a universal berth for handling LNG tankers, feeder ships and LNG bunker ships in wide range of capacity (from 500 m^3 to 220.000 m^3). It shall be stated that traffic analysis shows no constrains in flow for the approach and entrance (MUS, 2008; MUS 2017).
Such assumptions and limitations concerning the loading system of these vessels led to the definition of the concept of the universal LNG mooring facility in the outer port of Świnoujście, consisting of two berths (Gucma S. & Gucma M., 2018):
No 1 – transshipment berth of LNG tankers and feeders with L_{oa} = 110 m ÷ 320 m, draft up to T = 12,5 m (ships with cargo capacity from about 7.500 m^3 do 220.000 m^3).
No 2 – loading berth for LNG bunker ships with length L_{oa} = 50 m ÷ 110 m and draft T up to 6,0 m (ships with cargo capacity from 500 m^3 to approx. 7.500 m^3).
The conditions for safe operation of LNG facility and its berths and design principles for cargo, fender and mooring systems allowed determining the parameters of two-berth LNG transshipment facility in the port of Świnoujście. The schematic diagram of the two-berth transhipment facility with a maximum and minimum size LNG tankers are shown in Fig. 1.
The outcome of the first stage of optimization was the location of universal LNG terminal in the outer port of Świnoujście (Fig.2) (MUS, 2018).
The simulation tests of the second stage were intended to determine optimal location of the universal LNG facility and optimal parameters of navigable areas for maximum vessels coming to berth No 1 and No 2 of that facility.
The simulation tests resulted in the determination of safe manoeuvring areas of 'maximum tankers' coming to berths Nos 1 and 2 under least favourable navigational conditions ($\mathbf{d}_{ikz(1-\alpha)}$) that were used for determining the navigable area of a given berth ($\mathbf{D}_i$).

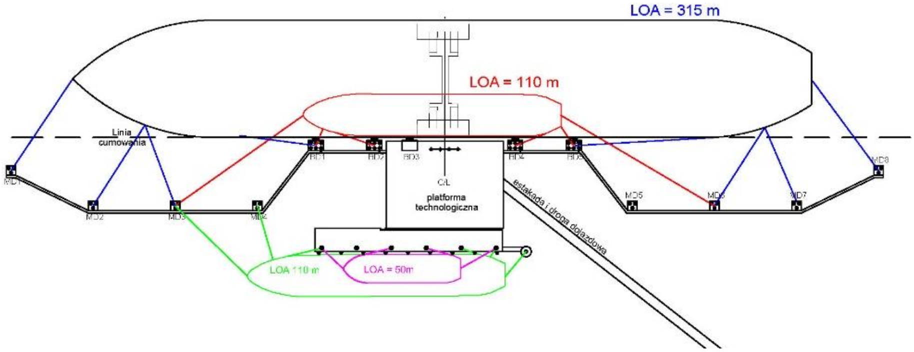

Fig. 1. The mooring diagram of LNG tankers with L_{oa} = 315 m and L_{oa} = 110 m at berth No 1 and for LNG bunker ships with length L_{oa} = 110 m and L_{oa} = 50 m at berth No 2 of the universal LNG terminal in Świnoujście

Fig. 2. Preliminary location of the universal LNG transshipment facility and the existing LNG discharge berth

The tests made use of real time simulation (RTS) and non-autonomous models of ships, in which ship movement is controlled by a human (pilot, captain). Simulation tests were performed on a multi-bridge ship handling Polaris simulator from Konsberg Maritime AS with a 3D projection. This full-mission bridge simulator (FMBS) is located at the Marine Traffic Engineering Centre, Maritime University of Szczecin.

Two simulation ship movement models were built and verified for testing the manoeuvres of port entry and berthing. These include a Q-Flex gas tanker

(L_{oa} = 320 m) and LNG bunker ship 6.000 m^3 L_{oa} = 104 m. The simulated passages were performed by sea pilots. One series for a specific wind direction was composed of 12 simulated manoeuvres.
Experimental simulations of entry, turning and berthing to berth No 1 by a Q-flex tanker were conducted under least favourable wind directions N and W for these manoeuvres and a speed V_w = 12.5 m/s. The simulated passages were performed by ship pilots. One series for a specific wind direction was composed of 12 simulated manoeuvres. Four tugs assisting in the manoeuvres had azimuth propellers and bollard pull of 2x55 tons and 2x45 tons.

The simulation experiment of entry, turning and berthing to the berth No 2 by an LNG bunker ship of 6.000 m^3 capacity was carried out under least favourable wind directions N and E and speed V_w = 12.5 m/s. The manoeuvring ship was assisted by one pushing tug with a bollard pull of 15 tons.
The optimal navigable area (depth contour 14.5 m) has been determined using safe manoeuvring areas of Q-Flex gas tankers approaching the designed universal LNG terminal (berth No 1) and the existing LNG discharge berth with the least favourable wind direction of V_w = 12.5 m/s (Fig. 3) (MUS, 2018).

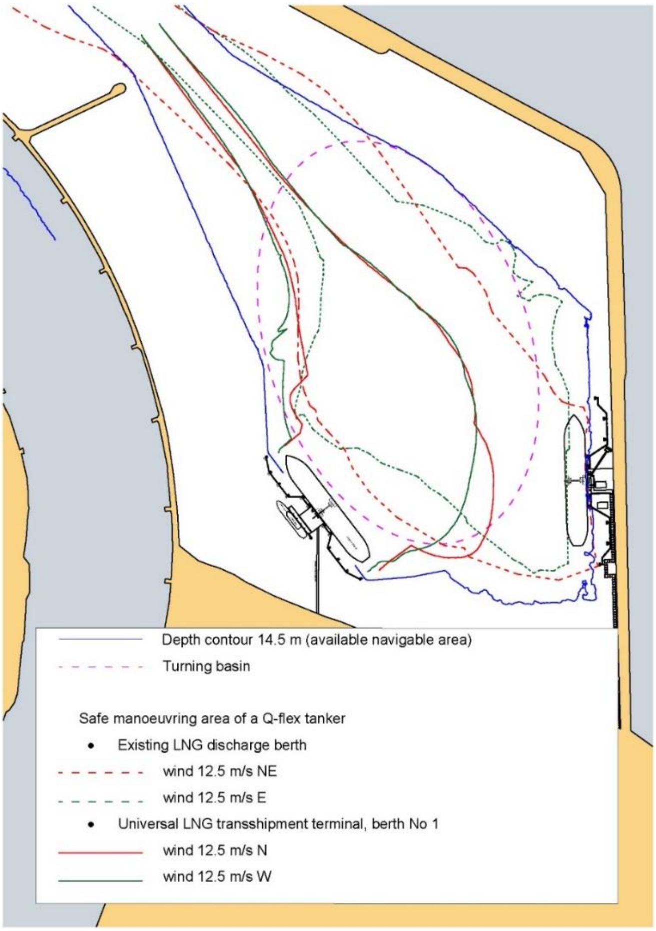

Fig. 3. The navigable area (depth contour 14.5 m) and safe manoeuvring areas of Q-Flex gas tankers approaching the existing LNG discharge berth and the berth No 1 of a designed universal terminal at a level of confidence (1-α) = 0.95

The optimal available navigable area (depth contour of 7.3 m) has been determined using safe manoeuvring areas of LNG bunker ship 6.000 m^3 approaching berth No 2 of the universal terminal with least favourable wind direction V_w = 12.5 m/s (Fig. 4) (MUS, 2018).
The kinetic energy of first contact with the berth absorbed by fenders determined at confidence level (1-α) = 0,95, is respectively:
– Q-flex LNG tanker E = 1.100 kNm
– LNG bunker 6.000 m^3 E = 100 kNm
and average manoeuvring times:
– Q-flex LNG tanker, from the central breakwater groyne abeam to first contact with berth t=45 min,
– LNG bunker 6.000 m^3 from the turning basin centre to the moment of first contact with the berth t = 17 min.

6. Summary

The article presents problems related to the location and optimization of LNG terminal for a large range of handled ship sizes, from a bunker ship 50 m long to a Q-flex tanker 320 m in length. Conditions for safe operation of LNG tankers berthing along such universal cargo-handling facilities have been determined. The authors also present the principles for classifying gas tankers into certain size groups handled by each berth of the facility resulting from

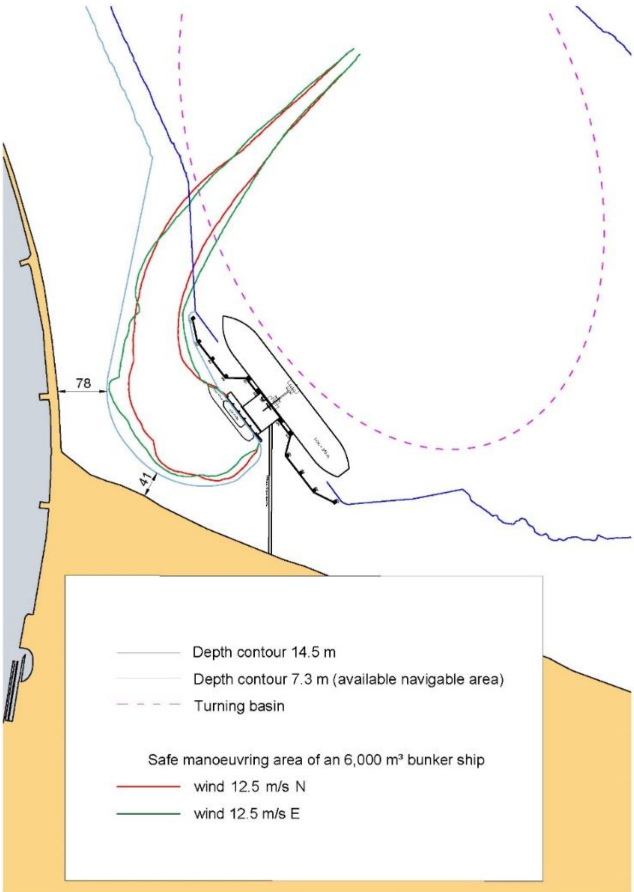

Fig. 4. The available navigable area (depth contour 7.3 m) and safe manoeuvring area of an LNG bunker ship of 6,000 m^3 coming to berth No 2 of the designed universal LNG terminal determined at a confidence level (1-α) = 0.95

the differences in berth construction and the specific parameters of the cargo, fender and mooring systems.

The parameters of LNG berths altogether capable of handling a wide range of vessel sizes were optimized by means of the newly-developed two-stage method. In the first stage of this method, the best location is determined for a universal LNG facility in the existing port basin, while the optimal parameters of the approaches to that facility are defined in the second stage.

The research was based on the method of ship movement simulation in real time using non-autonomous models, controlled by the human (captain, pilot). Additional simulation experiments were performed, where berth No 1 was approached by a Q-flex type gas tanker (cargo capacity 220.000 m^3) and berth No 2 was approached by a small gas tanker (cargo capacity 6000 m^3). The simulation experiments were carried out under least favourable hydrometeorological conditions (acceptable conditions of safe operation).

The basic criterion of optimization is the minimisation of the construction and operation costs of the universal LNG terminal and the construction costs of approach waterways and related navigational systems. The objective function constraints are:

- manoeuvring safety of gas tankers approaching the berths of the universal LNG terminal,
- manoeuvring safety of ships approaching other berths of the port basin,
- safety of mooring and cargo handling operations of ships at all berths of the port basin.

The developed optimization methodology was actually used in the design of the universal LNG terminal in the port of Świnoujście. The facility is intended for the handling of LNG tankers in the range of cargo capacity from 500 m^3 to 220.000 m^3.

The herein described two-stage simulation method of optimization can be used for designs of universal LNG terminals, and is applicable to both existing LNG terminals and those under construction.

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