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Areas of emergency maneuvers and the navigational risk of accidents in fairways due to ship technical failures determined by the ship movement simulation method

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Abstract

The identification of navigational risks of accidents in fairways is a basic principle for the construction or modernization of waterways in restricted waters and when the conditions of safe operation change. The estimation of navigational risk requires the evaluation of the consequences of accidents occurring in fairways: grounding, impact against a vertical shore, port/offshore structure or moored ship. When determining the consequences of these accidents, it is necessary to know the emergency maneuvering area and the speed of the ship at the time of the accident. The method of ship movement simulation in real time was used to determine the parameters of emergency maneuvering areas and the speed of vessels during the maneuvers. The results of the simulation experiment include full form vessels (bulk carriers, tankers) with a capacity ranging from 5,000 DWT to 100,000 DWT. The presented results of simulation tests enabled the evaluation of probability and consequences of ships' accidents in fairways resulting from technical failures of ships' steering equipment, allowing to assess the navigational risk for ships sailing through different types of fairways (approach channels, port entrances and inner port fairways).

Introduction

The situation where a ship sails beyond the available navigable area due to a technical failure of shipboard machinery such as steering gear, main engine or generator sets may lead to an accident: grounding or impact against the vertical shore, breakwater, quay or moored ship. The evaluation and analysis of the navigational risk of such accidents should be carried out during the design (construction or modernization) of sea waterway systems in restricted waters (PIANC, 2014) and when the conditions of safe operation change (e.g. with the increase of operating ships' parameters) (Gucma & Zalewski, 2020). This is particularly true for port waterways such as approach channels, port entrances and inner port fairways.

The sea waterway system – fairway or port entrance – is defined by the parameters of its elements (subsystems). Two elements of this system are the function of safe-operation conditions for ships maneuvering therein:

$$\begin{bmatrix} \boldsymbol{A}_i \\ \boldsymbol{N}_i \end{bmatrix} = F(\boldsymbol{W}_i) \tag{1}$$

where:

$\boldsymbol{W}_i$ – conditions for safe operation of vessels in the fairway (i-th section);
$\boldsymbol{A}_i$ – area subsystem (of the fairway);
$\boldsymbol{N}_i$ – navigational subsystem of the fairway.

The conditions for safe ship operation on a waterway are described by a set of safe-operation conditions for a 'maximum ship' on the i-th section of the examined waterway, written as follows:

$$\boldsymbol{W}_i = [\boldsymbol{Q}_i, \boldsymbol{h}_i, \boldsymbol{H}_i] \quad (2)$$

where:
$\boldsymbol{W}_i$ – conditions for safe-operation of vessels on i-th waterway;
$\boldsymbol{Q}_i$ – conditions relating to 'maximum ships' on i-th waterway;
$\boldsymbol{h}_i$ – conditions relating to the required tug assistance to 'maximum ships' on i-th waterway;
$\boldsymbol{H}_i$ – hydrometeorological conditions allowed for 'maximum ship' maneuvers on i-th waterway.

Note that:

$$\boldsymbol{Q} = [L_{ck}, B_k, T_k, V_{ik}] \quad (3)$$

$$\boldsymbol{h} = [n_{hik}, U_{hik}, u_{hik}] \quad (4)$$

$$\boldsymbol{H} = [z, V_w, V_{pi}, \Delta_{hi}] \quad (5)$$

where:
L_{ck}; B_k; T_k – length overall, breadth and draft of the 'maximum ship' of k-th type (group of types), respectively;
V_{ik} – permissible speed of the 'maximum ship' of k-th type on i-th waterway;
n_{hik} – number of tugs assisting in maneuvers of k-th ship type on i-th waterway;
U_{hik} – minimum safe bollard pull of all the tugs assisting in maneuvers of k-th ship type on i-th waterway;
u_{hik} – minimum safe bollard pull of each of the tugs assisting in maneuvers of k-th ship type on i-th port waterway;
z – permissible visibility for maneuvers in the waterway system;
V_w – permissible wind speed for maneuvers in the waterway system;
V_{pi} – permissible current speed on i-th port waterway;
Δ_{hi} – permissible drop of water level on i-th waterway.

The navigational risk of the passage by a specific type and size of a ship through a waterway system at a given annual frequency is defined as the probable annual losses, i.e. consequences of accidents due to failures of their machinery or tugs (Gucma & Ślączka, 2019; Gucma et al., 2019). This definition of navigation risk allows us to state that it is the function of both the area subsystem (fairway parameters) and the safe ship operation conditions. Therefore:

$$R_i = f(\boldsymbol{A}_i, \boldsymbol{W}_i) \quad (6)$$

where: R_i – navigation risk of passing i-th waterway section by the ship under certain safe-operation conditions.

The navigational risk of ship's passage through a waterway is determined as the product of the probability of the accident and its consequences. These consequences are the function of ship's speed at the time of an accident, i.e. grounding or hitting the shore, port structure or moored ship.

The consequences of accidents on fairways resulting from technical failures onboard ships can be estimated if we know the trajectory and speed of the ship during emergency maneuvers. This, particularly, refers to rudder jamming, because trajectories of ships during blackout (generator set failure) are well known as trajectories of free stopping determined in sea trials of the ship. Failures of the main engine, in turn, have minimal consequences, rarely leading to accidents.

This article aims at determining the speed and orientation of the ship relative to the fairway centerline during emergency maneuvers following rudder jamming. These parameters were determined by using the method of real time simulation of the ship movement. The results obtained allow for a more precise evaluation of the consequences of accidents caused by machinery failure and more accurate estimation of navigational risk.

Navigational risk of accidents in fairways caused by failure of ship equipment

Analysis of hazards within fairways covered by a vessel traffic service (VTS) for each maneuver performed by a ship allows us to identify a group of characteristic accidents (Gucma et al., 2017):

1. For a passage along a one-way straight fairway:
   - grounding (on the channel slope),
   - hitting a port facility (vertical shore),
   - hitting a moored ship (lying by the fairway).
2. For a two-way straight fairway:
   - grounding (on the channel slope),
   - hitting a port facility (vertical shore),
   - hitting a moored ship (lying by the fairway),
   - collision with a ship on the opposite course.
3. For turning in the fairway bend:
   - grounding (on the channel slope),
   - hitting a port facility (vertical shore).

Analysis of navigational risk in restricted waters (waterways) has shown (Gucma & Ślączka, 2019) that:

- those accidents do not cause human losses (no fatalities or injured persons);

- environmental safety risks should be limited only to the transport of hazardous materials;
- economic consequences, due to low speeds of ships, should be limited to the loss of one small ship (L_C < 100 m – one hold) with cargo (~ 25 million USD). This applies only to fairways located along the port facilities with moored ships.

Given the above conditions, the consequences of accidents during passage of a specific ship through a given waterway system have been limited to economic consequences. Therefore, navigational risk of passages by a given ship type through a waterway system with a specific annual frequency can be defined as likely annual losses – consequences of such accidents (Gucma, 2009).

The estimated navigational risk of passing a waterway system by ships of a specific type is the sum of risks caused by technical failures of ship machinery during the transition through all sections of the fairway.

$$R = I \sum_{i=1}^{m} \sum_{q=1}^{p} P_{iq} S_{iq} \tag{7}$$

where:

R – navigational risk of passing a waterway system by a specific ship resulting from technical failures [USD/year];

I – annual frequency of passing through a waterway system by ships of specific type and size [year^{-1}];

P_{iq} – probability of q-th type of accident on i-th section of the waterway (fairway);

S_{iq} – the consequences of q-th type of accident on i-th section of the waterway (fairway).

An accident in fairways and port entrances is identified as moving outside the available navigable area by a ship due to technical failure of its major machinery (rudder, main engine, generator sets). A ship affected by any of those failures performs emergency maneuvers to avoid an accident or minimize its consequences. These maneuvers vary depending on which component has failed, and in the case of steering gear, they also depend on the deflection angle of the jammed rudder. The primary objective of emergency maneuvers is to stop and anchor the ship in the available navigable area. Notably, full form ships (bulk carriers, tankers of capacity over 30,000 DWT) may start anchoring maneuvers at a maximum speed of 3 knots while ships of capacity less than 10,000 DWT may start anchoring at a maximum speed of 5 knots.

Conditions for safe performance of emergency maneuver can be written as follows:

$$\left.\begin{aligned} \boldsymbol{d}_{aik(1-\alpha)} \subset \boldsymbol{D}_i(t) \\ \bigwedge_{p(x,y)\in \boldsymbol{D}} h_i(t) \geq T_k + \Delta_i \end{aligned}\right\} \tag{8}$$

where:

$\boldsymbol{D}_i(t)$ – available navigable area of i-th fairway section (condition of safe depth at instant t is fulfilled);

$\boldsymbol{d}_{aik\,(1-\alpha)}$ – safe emergency maneuver area of k-th ship on i-th waterway under permitted navigational conditions at confidence level $(1 - \alpha)$;

$h_i(t)$ – minimum depth of i-th waterway at instant t;

T_k – maximum draft of k-th ship;

Δ_i – underkeel clearance on i-th waterway.

The probability of an accident due to technical failure of ship machinery depends on its reliability. Technical reliability is identified with accident-free performance of a specific maneuver. It depends on reliable work of the main engine, generator sets, or steering gear. Each of the above machines has a certain probability of reliable work during maneuver performance.

For the calculation of the probability of reliable work of the above machines, the failure rate function $\lambda(t)$ in time t is used, which is the failure density function, provided that a failure has not occurred till that instant. By considering only the stable phase of operation of the machinery concerned (surveyed by classification societies) (Anantharaman et al., 2018), it was established that the risk function $\lambda(t)$ is not time-dependent and constant (Gucma et al., 2015).

The consequences of accidents are defined as costs of:

- salvage operation after an accident,
- shipping losses related to vessel traffic reduction on the waterway,
- post-accident repairs of ships,
- repairs of port infrastructure.

An analysis of accidents that may occur during ship's maneuvering on waterways and their consequences shows general types of accidents, whose consequences (indicators of consequences) are determined differently (Gucma et al., 2017):

- blocking of the fairway by a ship anchored in an emergency condition,
- grounding,
- hitting a port structure,
- hitting a moored ship by a maneuvering ship,
- collision with a ship in motion.

To estimate the navigational risk of accidents on fairways caused by technical failures of shipboard machinery, the following has to be known:

1. The safe area of emergency maneuver, i.e. the distance from the fairway center line to the point where the ship will anchor when a failure of the specific ship machine occurs.
2. The speed of the ship at the instant of possible grounding or hitting a port facility or a moored ship.

It should be noted that in the former case, the consequences of a failure come down to towage costs and shipping losses related to traffic reduction on the fairway, which depend on the location of the accident. In the latter case the consequences of the grounding, hitting a port facility or a moored ship should be increased by salvage operation costs and post-accident repairs of the ships and port infrastructure. They are the function of the consequences indicator *S*.

The indicators of consequences for accidents such as grounding, hitting a port structure or moored ship are given below:

The consequences of grounding depend on factors such as the maximum kinetic energy of the ship at the time of contact with the bottom and the permissible energy of safe contact with the bottom at which the ship will be capable of refloating. The indicator of consequences can be presented in this form:

$$S_m = \frac{E(t)}{E^m_{\text{dop}}} \tag{9}$$

where:

$E(t)$ – kinetic energy of the ship at the instant of hull-bottom contact;

E^m_{dop} – the permissible energy of safe ship-bottom contact, at which the ship will be able to refloat on its own.

The kinetic energy of the ship at the instant of ship's contact with the bottom taking account of the accompanying added mass is determined from this relationship (Ślączka, 1999):

$$E(t) = \frac{1}{2} M \left(1 + \frac{2T}{B}\right) V^2 \ \text{[Nm]} \tag{10}$$

The speed of the ship at the instant of grounding (V) depends on the ship's speed during maneuvering on the waterway, its type, length, loading condition, and on the parameters of the available navigable area (e.g. the fairway width). This speed will be determined further in this article.

The permissible kinetic energy at which the ship can refloat without assistance can be determined by the simplified relationships (Gucma et al., 2015):

$$E^m_{\text{dop}} = \frac{3U^2}{L_{pp} \cdot B \cdot \gamma \cdot \mu \cdot \tan\theta'} \ \text{[Nm]} \tag{11}$$

where:

M – the mass of the ship [kNs^2/m];

U – the pull force when refloating [N];

γ – specific gravity of the water [N/m^2];

μ – hull-bottom friction coefficient;

θ' – angle of the slope in relation to grounding ship's centerline.

The consequences of a ship's unintended impact against a port structure or moored ship depend on factors such as maximum impact energy and the permissible impact energy at which the ship's hull plating will not be damaged. The indicator of consequences can be presented in this form:

$$s_u = \frac{E(t)}{E^u_{\text{dop}}} \tag{12}$$

where:

s_u – the indicator of the consequences of ship's impact against a port structure, shore or moored ship;

$E(t)$ – maximum kinetic energy of the ship at the instant of impact against a port structure or moored ship;

E^u_{dop} – the permissible ship's energy of impact against a port structure at which the ship's hull plating will not be damaged.

The maximum kinetic energy of the ship at the instant of unintended impact against a port structure or moored ship is determined using an approximate relationship (Gucma et al., 2015):

$$E(t) = \frac{M \cdot u^2}{4} \ \text{[kNm]} \tag{13}$$

where:

M – ship's mass and added mass [kNs^2/m];

u – the ship's speed at the instant of impact (normal to port structure line or moored ship side [m/s].

The speed of the ship at the instant of impact (u) depends on the ship's speed during maneuvering on the waterway, its type, length, loading condition, and on the parameters of the available navigable area (e.g. available fairway width). This speed will be determined further in this article.

The permissible kinetic energy of ship's impact against a port structure or moored ship can be determined using fender factors. The fender factor is defined as the ratio of the maximum reaction force to kinetic energy of ship's impact against the quay or fender. In the case of mooring facility not protected by fenders, the factor can be assumed as equal to $k = 150$ kN/kNm (PIANC, 2002).

Knowing the permissible load of ship' hull (q) and the approximate surface of ship's side contact with the quay (f) we can determine the permissible energy of ship's impact against a port structure.

$$E^{u}_{\mathrm{dop}} = q \cdot f / k \quad [\mathrm{kNm}] \tag{14}$$

where:

q − maximum hull load, depending on ship size and type [kN/m^2] (PIANC, 2002)

f − the approximate area of ship's side contact with the quay [m^2];

k − fender factor [kN/kNm].

Areas of emergency maneuvers in fairways and ship's speed after failure identified/determined by simulation methods

After each of the three failures of ship equipment in fairways, different maneuvers are performed, which consequently determine/define various emergency maneuvering areas and ship's speed after the failure. An analysis of particular emergency maneuvers leads to the following conclusions:

- the failure of generators causing blackout usually generates the most serious consequences because of impossibility of steering the ship until the anchors are dropped;
- the failure of the main engine generates relatively the minimal consequences, because the ship can be steered until it reaches its steerageway and an anchor can be dropped within the navigable area of the fairway;
- rudder failure may generate relatively adverse consequences. The area of emergency maneuvers after rudder jamming is poorly identified, so this article addresses this problem.

The **failure of generator sets** resulting in blackout stops the running of the main engine and jams the rudder at its position. The ship then moves along the trajectory of free stoppage, and when it reaches a speed of three knots the anchors can be dropped. Dropping anchors at a higher speed in order to dredge them may result in breaking anchor chains. The distance and speed during free stopping depend on the ship's type and size, its loading condition and the maintained fairway speed. These parameters can be read from the distance/speed curve for stopping maneuvers performed in sea trials of every ship (Nowicki, 1999). With these data, we can determine the ship's speed in fairway bends at any instant after the failure of the generator sets.

After the **failure of the main engine**, the ship can still be maneuvered till it reaches steerageway. This speed depends on the ship's type, its loading condition and hydrometeorological conditions. Steeragway usually ranges from three to five knots (Nowicki, 1999). At three knots the anchors can be dropped in the fairway navigable area without risk of breaking the anchor chain.

Rudder failure generates relatively adverse consequences, since the rudder jammed at a specific deflection angle often leads to a situation where the emergency maneuver area exceeds/moves outside the navigable area. This maneuver consists of changing the engine setting to emergency full astern (crash-stop) till the speed is reduced to three knots and an anchor is dropped. The anchoring speed of three knots is assumed for full form ships, with a capacity of more than 30,000 DWT. The consequences of such accidents can be determined by knowing the speed distribution as a function of the ship's bow distance from the fairway centerline during emergency maneuvers.

The speed distribution as a function at the bow distance to the fairway centerline during the emergency rudder failure manoeuvre has been determined by the method of simulation of ship movement in the real time; performing a simulation experiment for three full form ships (tankers) with the following parameters:

1. $L_C = 103.6$ m; $B = 16.6$ m; $T = 7.1$ m; capacity ~ 5,000 DWT.
2. $L_C = 176.8$ m; $B = 31,3$ m; $T = 11.88$ m; capacity ~ 30,000 DWT.
3. $L_C = 249.9$ m; $B = 43.8$ m; $T = 13.46$ m; capacity ~ 100,000 DWT.

The simulation experiment was conducted in the straight fairway section and a bend with a radius of $r = 2000$ m and a turn angle 90° to port.

Conditions of the simulation experiment in the straight section of the fairway:

- the ship's speed at the instant of rudder jamming $V = 8$ knots;
- jamming at rudder position 5° to starboard. In straight sections, this is the maximum rudder angle;
- wind 0 and wind 10 m/s from port side (least favorable direction).

Conditions of the simulation experiment at the fairway bend:

- the ship's speed at the instant of rudder jamming $V = 7$–8 knots, rate of turn 10°/min to port,
- jamming at rudder position 5° to starboard. According to experts (maritime pilots), this is the

least favorable rudder jamming during the reduction of ship's rate of turn,
- wind 0 and wind 10 m/s from the stern (least favorable direction).

In both cases the emergency maneuver consisted of the following maneuvers using the engine:
- stop – 5 seconds after rudder jamming,
- emergency full astern – 10 seconds after rudder jamming.

The appropriate rudder angle of jamming and least favorable wind directions as well as emergency maneuvers were determined based on expert tests carried out by experienced sea pilots and shipmasters.

The simulation experiment was conducted in real time on a Polaris simulator from Kongsberg at the Maritime University of Szczecin. The simulated maneuvers were performed by navigators. The number of simulation trials – emergency maneuvers in four series (for two different wind speeds in the straight section and in the bend) was five. The statistical analysis was conducted to determining the arithmetic mean and the standard deviation of the distance from the fairway centerline to the ship's bow for each speed and the arithmetic mean and standard deviation of the heading angle relative to the fairway centerline for each speed.

The simulation experiment resulted in determining (refer Figure 1):

1. Distance from the fairway centerline to the ship's bow as the function of its linear speed during the emergency maneuver,

$$d_{ejk} = f_1\,(V_{jk}) \tag{15}$$

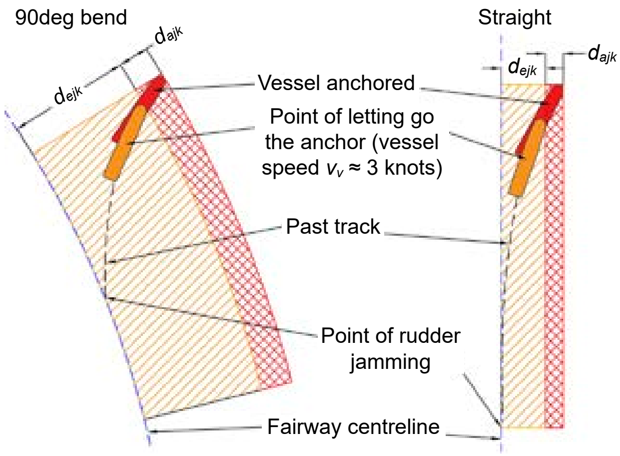

Figure 1. Areas of emergency maneuvers when the rudder jamming occurs in the straight section and fairway bend

where:

d_{ejk} – distance from the j-th type fairway centerline to the bow of k-th ship;

V_{jk} – the linear speed of the ship from three knots to the fairway speed of the k-th ship in j-th type fairway.

2. Distance from the fairway centerline to the ship's bow at the instant of its stopping at anchor, provided that the ship stops after sailing 0.5 L_C once the anchor is dropped.

$$d_{ajk} = f_2\left(V_{jk}^a\right) \tag{16}$$

where:

d_{ajk} – distance from the fairway centerline to the ship's bow at the instant of ship's stopping at anchor;

V_{jk}^a – the linear speed of the ship when the anchor is dropped.

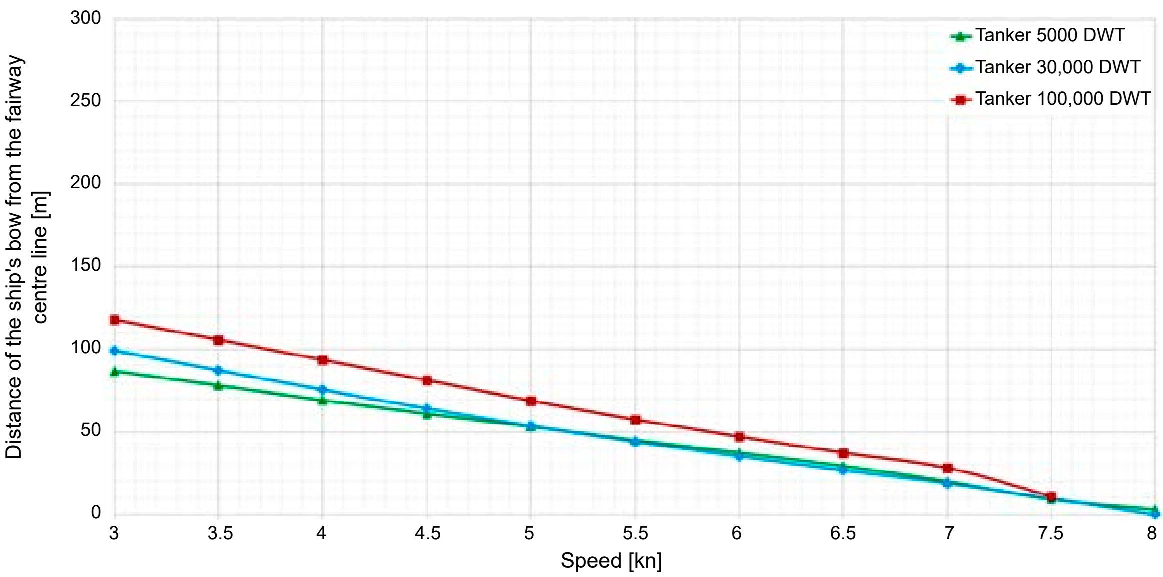

Figure 2. Distance of the ship's bow from the fairway centerline as the function of speed. Straight fairway section, wind 270° 10 m/s

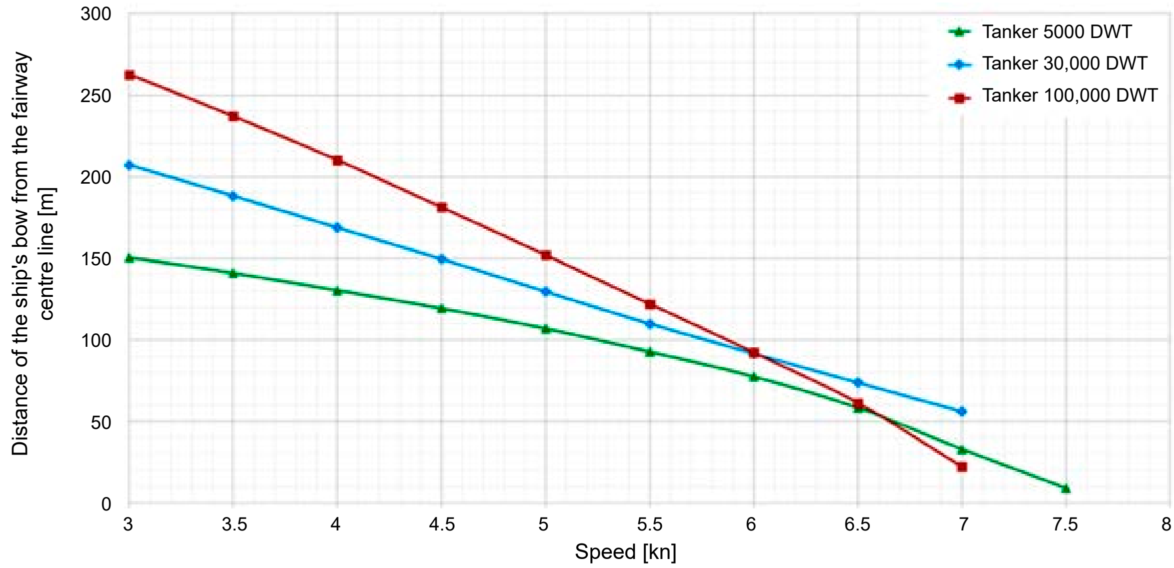

Figure 3. Distance of the ship's bow from the fairway centerline as the function of speed. Bend, wind 180° 10 m/s

The ship was assumed to stop after passing half its length (0.5 L_C) from the moment its anchors were dropped, at speed three knots for large ships (DWT > 30,000) to 5 knots for small ships (DWT < 10,000).

The distance of the three tested ships from the straight fairway centerline as the function of their speed during the emergency maneuver after 5° rudder jamming to starboard is shown in Figure 2. These diagrams illustrate the emergency maneuvers at the speed of 10 m/s from the port side. This is the least favorable wind direction: the width of the emergency maneuver area is the greatest.

Figure 3 presents the distances of the three tested ships' bows from the fairway bend centerline (the bend radius r = 2,000 m) as the function of their speed during the emergency maneuver after 5° rudder jamming to starboard. The diagrams illustrate the emergency maneuvers performed at the wind speed of 10 m/s from the stern. This is the least favorable wind direction at which the width of the emergency maneuver area is the greatest. It should be noted that the rudder jamming to the starboard side (when reducing the rate of turn) is the least favorable for turning to port, as it generates the largest emergency maneuver areas. The reverse situation occurs at the bend turn to starboard.

Using the graphs in Figures 2 and 3 when determining the navigational risk caused by rudder

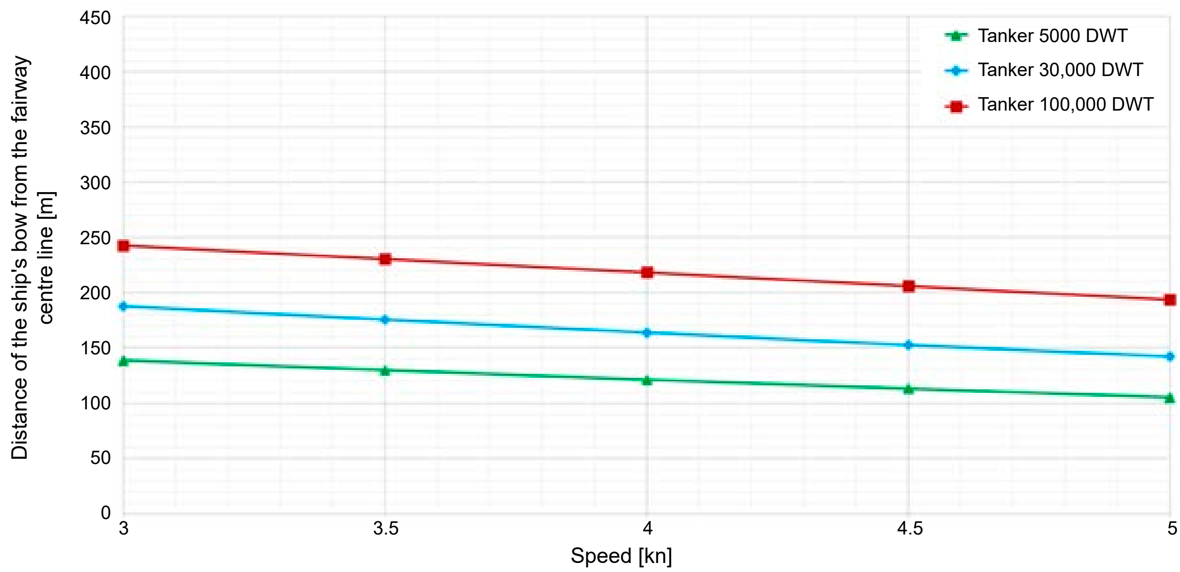

Figure 4. Distance from the fairway centerline to the ship's bow at the instant of stopping at anchor as the function of anchoring speed. Straight fairway section, wind 270° 10 m/s

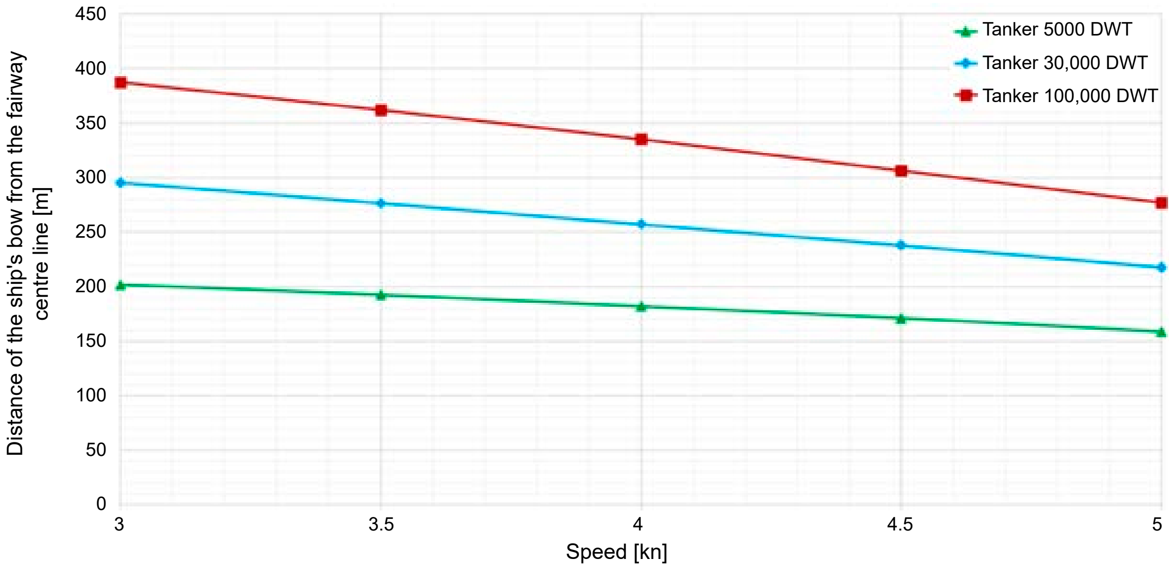

Figure 5. Distance from the fairway centerline to the ship's bow when stopping at anchor as the function of anchoring speed. Bend, wind 180° 10 m/s

jamming, we can determine the ship's speed at the instant of the accident, *i.e.* when the ship moves outside the available navigable area, that should be adopted/assumed as equal to the distance from the bow to the fairway centerline d_{ejk}. This speed can be determined by interpolating the charts/diagrams, the size of the test loaded ship (tanker or bulk carrier) with the block coefficient CB = 0.72÷0.82 and capacity ranging from 5,000 DWT to 100,000 DWT. Knowing the ship's speed after crossing the available navigable area, we can estimate the consequences that depend on the type of accident (grounding, hitting a port structure or moored ship).

Another problem is to determine the minimum width of the available navigable area at which the accident will not occur, as the ship will anchor (stop) at its border. This width can be determined using graphs in Figure 4 (straight fairway section) and Figure 5 (fairway bend) by appropriately interpolating the ship size. The ship's speed at the instant of dropping anchors should be based on the following assumptions:

- $V_{ajk} \approx 3$ knots – ship capacity > 30,000 DWT,
- $V_{ajk} \approx 5$ knots – ship capacity < 10,000 DWT.

Higher speeds can cause anchor chains to break.

It should be noted that the relationships presented in the above graphs (Figures 2–5), may differ slightly from reality, due to certain lags in the time of reversing the main engine and differences in the technical parameters of the ships such as the engine power output or the ship windage areas. The presented relationships do not consider the sea current impact, which should be taken into account separately.

Conclusions

The estimation of the navigational risk of accidents on fairways caused by technical failures of ship equipment requires the evaluation of:

- safe area of emergency maneuver, i.e. the distance from the fairway centerline to the point where the ship will anchor when a failure of the specific ship machine component occurs;
- speed of the ship at the instant of grounding or hitting a port facility or a moored ship.

The article presents the results of simulation tests determining the ship's speed and position during emergency maneuvers. Emergency areas were determined by the method of computer simulation of ship movement in real time after rudder failure. The simulation experiment was conducted for three loaded ships with capacity of 5,000 DWT; 30,000 DWT, and 100,000 DWT in straight sections of the fairway and bends at least favorable wind direction and speed of 10 m/s, which is the maximum allowable wind speed on inner port fairways.

The results of the obtained simulation tests can be used when estimating navigational risk in fairways caused by technical failure of ship steering equipment. They allow determining the probability and consequences of accidents such as grounding, hitting the port facility, vertical shore or moored ship. The article presents methods for calculating the consequences of the above mentioned accidents.

The results of the simulation experiment presented in the article allow determining the navigational risk of full form ships in the examined vessel size range.

References

1. Anantharaman, M., Khan, F., Garaniya, V. & Lewarn, B. (2018) Reliability Assessment of Main Engine Subsystems Considering Turbocharger Failure as a Case Study. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation* 12, 2, pp. 271–276.
2. Gucma, L. (2009) *Wytyczne do zarządzania Ryzykiem Morskim*. Maritime University of Szczecin Press (in Polish).
3. Gucma, S. et al. (2015) *Sea waterways – designing and exploitation in terms of maritime traffic engineering*. Foundation of shipyard and marine promotion. Gdańsk (in Polish).
4. Gucma, S. et al. (2017) *Inżynieria ruchu morskiego – wytyczne do projektowania morskich dróg wodnych i portów oraz warunków ich bezpiecznej eksploatacji*. Fundacja Przemysłu Okrętowego i Gospodarki Morskiej, Gdańsk (in Polish).
5. Gucma, S., Gucma, M., Gralak, R., Bilewski, M. & Muczyński, B. (2019) A simulation method for the detrmining the minimum pull of tugs assisting in port manoeuvres. *Scientific Journals of the Maritime University of Szczecin, Zeszyty Naukowe Akademii Morskiej w Szczecinie* 57 (129), pp. 49–55.
6. Gucma, S. & Ślączka, W. (2019) *Navigational risk as a criterion for the assessment of the safe ship operation conditions in seaports*. International Scientific Conference "Transport XXI wieku", Ryn, 9–11.06.2019.
7. Gucma, S. & Zalewski, P. (2020) Optimization of fairway design parameters: Systematic approach to manoeuvring safety. *International Journal of Naval Architecture and Ocean Engineering* 12, pp. 129–145.
8. Nowicki, A. (1999) *Knowledge about Sea Ships Manoeuvring*. Trademar, Gdynia (in Polish).
9. PIANC (2002) *Guidelines for the Design of Fenders System: 2002*. Report of Working Group 33. PIANC. General Secretariat. Brussels.
10. PIANC (2014) *Harbour Approach Channels Design Guidelines*. Report 121-2014. PIANC. General Secretariat. Brussels.
11. Ślączka, W. (1999) *Determination of ship's damage arising during going aground – physical aspect*. Materials for the National Safety and Reliability Conference KONBiN'99. Zakopane – Kościelisko.