Article

Maximum Safe Parameters of Outbound Loaded Vessels for Wind Turbine Installation

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Featured Application: The proposed method can be applied to determine the maximum allowable length of wind turbine blades loaded across jack-up vessels navigating through the waterway.

Abstract: A paper presents problems related to the safe operation of wind turbine installation vessels in port waterways. It presents a developed method for determining maximum safe lengths of blades of wind turbines loaded transversely on a jack-up vessel leaving a given port. In this method, the safety criterion for navigation is the acceptable risk of accidents, whose scenarios are determined by the identification of hazards in the studied waterway. Based on this safety criterion, the confidence level of the width of the safe maneuvering area of the loaded jack-up vessel and the maximum safe lengths of the transversely loaded wind turbine blades, respectively, are determined.

Keywords: maritime traffic engineering; safe maneuvering area; wind turbine installation vessel

1. Introduction

The observed increase in the capacity of offshore wind turbines (OWT) designed and installed worldwide determines the construction of vessels for their installation. The following types of vessels are used for the construction of wind turbines:
• Foundation transport and installation vessels (FTIV);
• Wind turbine transport vessels (WTTV) to transport offshore wind turbine components;
• Wind turbine installation vessels (WTIV).

This paper will present problems related to the safe operation of WTIV jack-up vessels in port waterways. Taking into account the criterion of the jack-up vessel navigation safety, the attachment and transport of the cargo transverse to the ship axis should be taken into account, where one of the most important parameters determining the length of the wind turbine wing panel (half of the rotor diameter minus half of the hub diameter) is the surface width of the available navigation area. If a vessel passes through a waterway with a deck load extending beyond the outline of the vessel’s sides, there is a possibility of the vessel (deck load) striking a hydrotechnical structure or moored vessel. The length of the transversely loaded wind turbine blades on jack-up vessels determines the safety of the departure of these vessels from the ports.

Designing terminals to handle WTIV vessels with wind turbine blades loaded across them involves the need to ensure safe passage of these vessels through the waterway system leading to these terminals.

The paper will present an elaborated method for determining maximum safe lengths of wing blades of wind turbines loaded transversely on a jack-up vessel leaving a given port. In this method, the safety criterion for navigation is the risk of acceptable accidents, whose scenarios are determined by the identification of hazards in the studied waterway. Based on this safety criterion, the confidence level of the width of the safe maneuvering area of the loaded jack-up vessel and the maximum safe lengths of the transversely loaded wind turbine blades, respectively, are determined.
2. Offshore Wind Turbines and Vessels for Their Installation—Current Status and Development Trends

No offshore wind turbine with a unit capacity greater than 10 MW has yet been installed in the world (as of December 2021). Currently, the largest OWT installed onshore is a Siemens Gamesa Renewable Energy (SGRE) prototype named SG 14-222 DD, whose generated power in boost mode can reach 15 MW. It was installed for testing in Østerild in November 2021 [1]. Offshore installation of such a turbine is planned in 2025 at the Sofia farm [2]. SGRE has thus overtaken the previous, leader General Electric (GE), whose prototype offshore wind turbine named Haliade-X with a capacity of 12 MW was installed for testing in the port of Rotterdam in 2019. According to GE’s statement, the first installation of this type of OWT is scheduled at the Dogger Bank Teesside A and B farm in early 2022, followed by the installation of a modified version with a capacity increased to 13 MW at the Sofia farm in 2023 [3]. The largest model of the Haliade-X turbine, with a capacity of 14 MW, is expected to be used at the Dogger Bank Teesside C farm in 2025 [4]. By November 2021, the largest offshore wind turbine whose prototype has been submitted for testing is the V236-15 MW from Vestas capable of generating a nominal 15 MW. It will be installed at Østerild in the first half of 2022 [5].

An analysis of global trends in the size of installed OWTs (resulting from an increase in the power they generate) clearly indicates that wind turbines with a capacity of more than 10 MW, referred to as 4th-generation turbines, will be used to build offshore wind farms. A predictive analysis of the increase in the number of installed OWTs in the coming years shows that compared to the global market, the European offshore wind market will use the newest and largest 4th-generation wind turbines for the construction of offshore wind farms (Figure 1).

Figure 1. Predicted trend of wind turbine capacity growth [6].

As of the end of 2021, a concept for a future offshore wind turbine larger than 16 MW has not yet been published, but literature analysis indicates that we can expect such a solution in the next decade. This is indicated by annual reports and analyses of the wind power market [7–10] and by the start of planning and construction by ship owners to install 20 MW+ OWT vessels with wingspan lengths up to 130 m.

The drive to reduce average energy costs has resulted in a significant increase in wind turbine size, but larger rotors face significant technical and logistical challenges. The largest published design for a 25 MW offshore wind turbine rotor has a diameter of 260 m [11]. However, an analysis of the publications indicates that from a materials engineering point of view, a 50 MW turbine with a wing panel length of more than 250 m and a weight of about 502 tons is feasible [12].
Additionally, it should be taken into account that offshore wind farms being built in the Baltic Sea in the Polish economic zone will have a total generated capacity of 6 GW by 2030 [13]. In order to obtain such power, the construction of about 430 offshore wind turbines with a unit capacity of 14 MW or more is planned.

In recent years, the momentum of the 4th-generation OWT design and construction process has significantly outpaced the pace of technological development of vessels capable of offshore installation. The offshore wind industry is just beginning to respond to the lack of WTIV impacts capable of installing the latest generation of offshore wind turbines, but there is still uncertainty about the capacity of the global fleet to support planned offshore investments [14,15]. Determined in 2020, the estimated number of WTIV vessels in the global fleet capable of installing OWT categorized by generated capacity is shown in Figure 2. In late 2021, the actual number of vessels capable of installing 14 MW turbines slightly exceeds the estimates.

![Figure 2. Estimated number of WTIV vessels in the world fleet categorized in terms of OWT generated power [6].](image-url)

An analysis of the characteristics of WTIV vessels in service as of 2021/22 shows that only 12 of them are currently capable of installing turbines above 10 MW [16].

To meet the market needs, shipowners are currently building several new WTIV. For example, Jan De Nul is currently building the largest jack-up vessel, called Voltaire [17]. Voltaire has a specially designed positioning system that makes the vessel capable of operating in sea depths of up to 80 m. The lifting capacity of the main crane is over 3000 tons. Voltaire is expected to be completed in 2022 and has already been contracted to install the GE Haliade-X turbine in the Dogger Bank project in 2020.

Although only a handful of new WTIVs are being built in 2021, a number of offshore wind industry shipowners have signed contracts to build new vessels. Triumph Subsea Services signed a letter of intent to build two WTIV vessels, designated GustoMSC NG-2000X, with planned entry into service in 2023 [18]. Knud E. Hansen of Norway has published a new design for his jack-up vessel, named ATLAS Class C, for installation of wind turbines of 20 MW or more [16]. With an overall length of 170 m, a width of 60.2 m, and a draft of 6.7 m, the ATLAS vessels, equipped with a 3000-ton crane, will have the capacity to transport at least five complete 20 MW turbine assemblies [19].
3. Navigational Risks of Maneuvering in Port Waterways of a Loaded Wind Turbine Installation Vessel (WTIV)

If a vessel passes through a waterway with deck cargo extending beyond the contours of the vessel’s sides, there is a possibility of the vessel (deck cargo) striking a hydrotechnical structure or moored vessel even with basic navigation safety condition fulfilled [20,21]:

\[ D_i \geq d_i(1 - \alpha) \]  

where:
- \( D_i \) - Width of the available navigable water body bounded by the safe isobaths of the \( i \)-th section of the waterway;
- \( d_i(1 - \alpha) \) - Width of the safe maneuvering area of the “maximum ship” for the \( i \)-th section of the waterway determined at the confidence level \((1 - \alpha)\).

To identify such a hazard, an additional condition for navigation safety was introduced:

\[ D_{i,\text{nad}} \geq d_{i,\text{nad}}(1 - \alpha) \]

where:
- \( D_{i,\text{nad}} \) - Surface width of the available navigable water body limited by the above-water hydro-technical infrastructure and parameters of ships mooring at the passing quays;
- \( d_{i,\text{nad}}(1 - \alpha) \) - Surface width of the safe maneuvering area of the “maximum ship” for the \( i \)-th section of the waterway determined at the confidence level \((1 - \alpha)\).

The above-water width of the safe maneuvering area at the specified confidence level \( d_{i,\text{nad}}(1 - \alpha) \) is, respectively:

\[ d_{i,\text{nad}}(1 - \alpha) = d(1 - \alpha) + L_{\text{blades}} - B \]  

where:
- \( L_{\text{blades}} \) - Length of wind turbine blades loaded across the vessel;
- \( B \) - Vessel breadth.

The probability of an accident per year caused by the maximum vessel in the \( i \)-th section of a port waterway crossing an available navigable body of water is determined by the following relationship:

\[ P_{wi} = P_{ai} I_r / G_r \]

whereby the probability of crossing the available navigable waterway through the safe maneuvering area of the tested vessel in the \( i \)-th waterway in the \( j \)-th direction from the fairway axis is:

\[ P_{aij} = 1 - P_{nij} \]

and the maximum probability of crossing an available navigable body of water from the set of hazardous directions is selected for the accident probability calculation:

\[ P_{ai} = \max_{j} P_{aij} \]  

where:
- \( P_{wi} \) - Probability of an accident caused by a surveyed vessel crossing an available navigable body of water on the \( i \)-th waterway (1/year);
- \( P_{ai} \) - Maximum probability that the safe maneuvering area of the test vessel will cross an available navigable body of water;
- \( I_r \) - Average annual number of passing maneuvers of the tested vessel through the \( i \)-th section of the track (1/year);
- \( G_r \) - Number of days in a year (365);
- \( P_{nij} \) - The probability of not crossing an available navigable body of water from the safe maneuvering area of the tested vessel in the \( i \)-th waterway in the \( j \)-th direction from the fairway centerline.
Safety of navigation can be assessed using navigational risk (maneuvering risk). Navigational risk is equated with the risk of ship accident while maneuvering in a restricted area. Maneuvering risk for all types of waterways (maneuvers performed on them) can be represented as a function [20,21]:

\[ R_i = f(A_i, Q_i, N_i, H_i, M_i, I_i, Z_i) \]  \hspace{1cm} (7)

where:

- \( R_i \) - Navigational risk at the \( i \)-th section of the waterway;
- \( A_i \) - Parameters of water area;
- \( Q_i \) - Vessel parameters;
- \( N_i \) - Parameters of position-determination systems;
- \( H_i \) - Hydro-meteorological conditions;
- \( M_i \) - Parameters of the executed maneuver;
- \( I_i \) - Movement intensity parameters;
- \( Z_i \) - Motion-control system parameters.

Navigational safety function (Navigational risk) \( R_i \) is the dependent variable determined by the independent variables \( A_i, Q_i, N_i, H_i, M_i, I_i, \) and \( Z_i \), which consist of a number of factors describing the system: ship, basin, positioning system, prevailing hydro-meteorological conditions, traffic intensity, traffic regulation system, maneuvering tactics.

In the case under consideration, it is assumed that:

- The parameters of the motion-control system ensure collision-free passage of the test vessel regardless of traffic intensity,
- Hydro-meteorological conditions are within an acceptable range,
- Vessel parameters will be expanded to include the length of the transversely loaded (symmetrical or asymmetrical) blades being carried.

Navigational risk is often equated with the annual probability of a given type of accident occurring for specific consequences (consequence determinant) [20,22]:

\[ R_{iqk} = P_{iqk} \]  \hspace{1cm} (8)

Based on this method of determining navigational risk, criteria were developed for estimating the safety of navigation in restricted waters using the acceptable risk, which is [20,22]:

\[ R_{akc} = 1 \times 10^{-3} \text{ [1/year]} \]  \hspace{1cm} (9)

The basic prerequisite for the safety of navigation of a given vessel in the studied waterway section is the fulfillment of the relationship [20,22]:

\[ R_{iqk} \leq R_{akc} \]  \hspace{1cm} (10)

where:

- \( P_{iqk} \) - Annual probability of occurrence of the \( q \)-th accident on the \( i \)-th waterway for the \( k \)-th vessel;
- \( R_{iqk} \) - Navigational risk of occurrence of \( q \)-th accident on \( i \)-th waterway during the year with specified consequences for \( k \)-th ship [1/year].

In port waterways, accidents involving potential fatalities only include a passing ship striking a moored ferry or other passenger vessel on the fairway. Where any of the accident scenarios involve loss of life, they should be considered separately before analyzing the risk of a ship passing through the waterway system under study. The risk of an accident in which human life is endangered with human fatalities is determined according to the following relationship:

\[ R_s = P_A P_{sp} \]  \hspace{1cm} (11)

where:
Risk of an accident resulting in the death of a person; 
Likelihood of an accident in which human life is at risk; 
Probability of a person dying as a result of an accident.

As a condition of accepting a fatal accident, the relationship must be met:
\[ R_s \leq R_{s\, akc} \] (12)

where:
\[ R_{s\, akc} \] - Acceptable risk of fatal accident.

The acceptable risk of a fatal accident in shipping is assumed to be [22]:
- For a crew member: \( 1 \times 10^{-4} \) (1/year);
- For a passenger or a group of crew members: \( 1 \times 10^{-5} \) (1/year);
- For a group of passengers: \( 1 \times 10^{-6} \) (1/year).

It should be noted that the economic impact risk analysis can proceed when the human death risk condition is met.

Figure 3 presents the basic flowchart for calculation of the permissible safe length of wind turbine blades.

4. A Method for Determining Maximum Safe Blade Lengths of Wind Turbines Loaded across a Jack-Up Vessel in Port Waterways

Contingency scenarios (accident types) are specified for maneuvers performed by ships of a given type and size based on hazard analysis and accident statistics in specific bodies of water. The emergency scenarios do not take into account navigational mistakes made by humans, which are classified as gross errors. Instead, they take into account accidental and systematic errors of all types of navigational measurements and assessments and maneuvering inaccuracies committed by a navigator with specific qualifications while maneuvering the vessel [23].

Assuming that wind turbine blades can be loaded across a jack-up vessel symmetrically or asymmetrically to either starboard or port side depending on the turbine installations being performed, contingency scenarios need to be determined depending on the infrastructure and operating conditions of the waterway section.

Contingency scenarios resulting from a loaded jack-up vessel crossing an available shipping area include the following accidents:
- Striking a moored vessel or hydro-engineering structure with the blade tip;
- Striking a moored vessel or hydro-engineering structure with the side of a jack-up vessel;
- Grounding of the jack-up vessel.

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Figure 3. Flowchart for calculation of the permissible safe length of wind turbine blades.
To determine the acceptable length of wind turbine blades, an original method based on the value of acceptable risk was developed. This risk depends on the possible consequences of an accident involving a jack-up vessel, and its value can be assumed on the basis of typical values available in the literature. Using the assumed acceptable risk, the permissible probability of the safe maneuvering area crossing the available shipping area is determined. The value of this probability is calculated using the author’s original relation taking into account the value of acceptable risk and traffic intensity. In the next step, assuming that the calculated probability is equal to the required level of significance, the width of the safe maneuvering area is determined. For the calculations, the CIRM method, which has been previously developed and well-tested in practice, is used. The calculated width of the maneuvering area together with the width of available maneuvering area and ship parameters enable to determine the acceptable length of the wind turbine blades. The novelty of the developed method results from the original dependencies that allow calculating the acceptable probability of exceeding the available navigable area by the safe maneuvering area and the acceptable length of the wind turbine blades.

The above-water width of the navigable water body of the section $D_{nad}^i$ should be taken as the minimum distance between:

- The sides of “maximum” ships standing at quays or hydrotechnical constructions on both sides of the fairway;
- The side of the “maximum” vessel or hydrotechnical structure on one side of the waterway and a safe isobath on the other side.

The navigational risk of accidents resulting from a loaded jack-up vessel crossing the waterway width of the available shipping area is determined by the following relationship:

$$R = p_{nad}^i \times I_i / G_r \left[ \text{year}^{-1} \right]$$

(13)

where:

- $p_{nad}^i$ - The probability of the safe maneuvering area of the loaded jack-up vessel $d_{nad}^i$ crossing the above-water available navigation area $D_{nad}^i$ on the $i$-th section of the waterway.

Assuming that navigational risk equals acceptable risk:

$$R = R_{akc}$$

(14)

the permissible probability of the above-water safe maneuvering area of a jack-up vessel loaded transversely with wind turbine blades was obtained:

$$p_{nad}^i = R_{akc} \times G_r / I_r$$

(15)

The above-water width of the safe maneuvering area of a jack-up vessel loaded transversely with wind turbine blades determined at the confidence level $(1-\alpha)$ is:

$$d_{iad}^i (1-\alpha) = d_i (1-\alpha) + L_{blades} - B$$

(16)

where:

- $d_i (1-\alpha)$ - Width of the safe maneuvering area of a jack-up vessel passing through the $i$-th waterway section determined at the confidence level $(1-\alpha)$;
- $L_{blades}$ - Length of loaded across ship wind turbine blades;
- $B$ - Width of jack-up vessel

The width of the safe maneuvering area of the jack-up vessel determined by the CIRM method at the confidence level $(1-\alpha)$ for the $i$-th track section is [24]:

$$d_i (1-\alpha) = d_m + 2d_m (1-\alpha) + d_r^p + d_r$$

(17)

where:
\[ d_m \quad - \quad \text{Maneuvering component of the lane width;} \]
\[ d_{n(1-\alpha)} \quad - \quad \text{Navigation component of the lane width determined at the confidence level } (1-\alpha); \]
\[ d_p, d_{lr} \quad - \quad \text{Provision for the bank and channel effect of the right and left sides of the waterway, respectively.} \]

Assuming that the significance level is equal to the permissible probability of crossing the above-water navigation area \( (D_{nad}^i) \) by the above-water safe manoeuvring area \( (d_{nad}^i) \):

\[ \alpha = p_{nad}^i \] (18)

determining the acceptable safe length of wind turbine blades loaded across the jack-up vessel at the level of accepted navigational risk,

\[ L_{akc}^i = D_{nad}^i + B - d_m - 2d_{n(1-\alpha)} - d_p - d_{lr} \]
\[ \alpha = p_{nad}^i \] (19)

where:

\[ p_{nad}^i = R_{akc} \times \frac{G_r}{I_r} \] (20)

The developed method is recommended to be used with the average annual number of jack-up loaded vessel exits in the range:

\[ I_r = 7-100 \text{ [year}^{-1}] \] (21)

Within these limits, the significance level \( (\alpha) \) corresponding to the acceptable probability of a ship’s above-water safe maneuvering area exceeding the above-water accessible navigable area determined for an acceptable risk of \( R_{akc} = 1 \times 10^{-3} \) is, respectively:

\[ \alpha = 0.05 \div 0.003 \] (22)

that is, it ranges from the standard confidence level assumed in navigation, \((1-\alpha) = 0.95\), to the confidence level \((1-\alpha) = 0.997\), corresponding to three standard deviations.

If the average number of maneuvers per year is less than seven, the navigational risk criterion for a specific accident per year should not be applied, but the navigational risk criterion for a specific accident per (single) maneuver should be used assuming, respectively:

- Acceptable risk of accident: \( R_{akc} = 5 \times 10^{-2} \);
- Acceptable risk of a fatal accident:
  - For a crew member: \( R_{sakc} = 1 \times 10^{-3} \);
  - For passenger: \( R_{sakc} = 1 \times 10^{-4} \).

5. Application of the Developed Method to Determine the Acceptable Length of Wind Turbine Blades in the Port of Świnoujście

A terminal for offshore wind farms is planned to be built in the port of Świnoujście on the Świna river. The terminal will be used for the construction of offshore wind turbines on the Baltic Sea in the Polish economic zone [25].

The terminal will consist of service and installation berths. WTTV vessels will be handled at the service berths and WTIV jack-up vessels at the installation berths.

Jack-up vessels at installation berths load themselves by standing on the legs of the jack-up system. The deck cargo of these vessels includes, among other things, wind turbine blades loaded symmetrically or asymmetrically across the vessel.

The method was applied to determine the permissible blade lengths of wind turbines loaded across the jack-up vessel to allow safe passage on the Świnoujście–Szczecin fairway between the Mielińska Obrotica and the pair of buoys “15”–“16”. The exit of the loaded jack-up vessel (with the permissible blade length) should be safe for the “maximum vessels”
moored at the Ferry Terminal facilities in Świnoujście (Figure 4) and Chemików Quay (Figure 5).

Figure 4. Available navigation area, stand no. 2 of the ferry terminal in Świnoujście.

It was assumed that the “maximum ship” of the jack-up type operated in Świnoujście port will be the “Voltaire” currently under construction with the following parameters:

- LOA = 170 m;
- B = 60 m;
- T = 7.5 m.

On the Świnoujście–Szczecin fairway from the Mielińska Obrotnica to the pair of buoys “15”–“16”, there are two sections with the smallest above-water widths limiting the navigational risk and thus the maximum (allowable) length of transversely loaded blades on an outbound jack-up vessel.

These are:

- Passage along the designed ferry stand no. 2 during moored ferry LOA = 230 m (4.3 km of track), D = 210 m, $D_{\text{nad}}$ = 231 m (Figure 3);
• Passage along the Chemików Quay during berthing of a bulk carrier with width $B = 50$ m (1.3 km of track), $D = 198$ m, $D_{nad} = 266$ m (Figure 4).

Figure 5. Available navigation area, Chemików Quay.

The accident contingency scenarios for the two track sections generating the greatest navigational risk can be characterized as follows:

**Scenario 1:** Impact of the outgoing jack-up vessel with turbine blades loaded asymmetrically on the starboard side on the moored ferry LOA = 230 m at the modernized ferry stand no. 2. The kinetic energy of impact of this vessel on the ferry is relatively high ($V = 4 \div 6$ knots), which may cause damage to gangways and ramps. The result of such an accident may be the death of a group of passengers.

The acceptable risk of such an accident should be taken as equal:

- $R_{a1c1} = 1 \times 10^{-6}$ (1/year).

**Scenario 2:** Impact of an outbound jack-up vessel with its blades asymmetrically loaded on the starboard side on a moored bulk carrier with a width of $B = 50$ m at the Chemików Quay. The kinetic energy of the impact of this ship against the bulk carrier (at a speed of $4 \div 6$ knots) may cause damage to the wind turbine blades, the jack-up vessel, and the bulk carrier.

The acceptable risk of such an accident should be taken as equal:
• $R_{akc2} = 1 \times 10^{-3}$ (year$^{-1}$)

Assuming the predicted average annual number of jack-up vessel maneuvers from Świnoujście port as equal to $I_r = 20$, the calculation significance levels for both scenarios were determined:
• $a_1 = 1.852 \times 10^{-5}$,
• $a_1 = 1.852 \times 10^{-2}$,

and the corresponding navigational components—the widths of the safe maneuvering area [26]:
• $d_{n(1-a_1)} \approx 10$ m,
• $d_{n(1-a_2)} \approx$ m.

The permissible safe lengths of wind turbine blades loaded across the jack-up vessel leaving the port of Świnoujście are, respectively:
$L_{akc1} \approx 170$ m (at $R_{akc1} = 1 \times 10^{-6}$);
$L_{akc2} \approx 140$ m (at $R_{akc2} = 1 \times 10^{-3}$).

When calculating the safe blade lengths, the basic maneuvering component $d_m = 1.3B$ (very good ship steering) and $d_r = 0.1B$ (ship speed $4 \div 6$ knots) were assumed. Detailed results for determining the acceptable safe lengths of wind turbine blades loaded across the jack-up vessel leaving the port of Świnoujście are presented in Table 1.

Table 1. Detailed results for determining the acceptable safe lengths of wind turbine blades loaded across the jack-up vessel leaving the port of Świnoujście.

| Scenario 1 | Scenario 2 |
|------------|------------|
| Surface width of the available navigable area | $D_{nav}^{side}$ | 231 | 198 | (m) |
| Acceptable risk | $R_{akc}$ | $1 \times 10^{-6}$ | $1 \times 10^{-3}$ | (1/year) |
| Significance level | $a$ | $1.852 \times 10^{-5}$ | $1.852 \times 10^{-2}$ | (–) |
| Width of the safe maneuvering area | $d_{(1-a)}$ | 125 | 122 | (m) |
| Permissible safe lengths of wind turbine blades loaded across the jack-up vessel | $L_{akc}$ | $\approx 170$ | $\approx 140$ | (m) |

6. Discussion and Conclusions

Based on the above results of calculations, it should be assumed that jack-up vessels loaded crosswise with wind turbine blades of maximum length $L = 140$ m will be able to safely exit from the designed offshore wind farm terminal in Świnoujście.

This paper presents a method for determining the maximum safe blade lengths of wind turbines loaded across jack-up vessels maneuvering in port waterways. In this method, after identifying the hazards in the waterway under study, the acceptable risk of each accident scenario was determined.

The navigational safety criterion used is the impassibility of acceptable risk. Based on this criterion, a confidence level was determined, based on which the above-water width of the safe maneuvering area of jack-up vessels with wind turbine blades loaded crosswise was determined. Considering the above-water available width of the study shipping area, the maximum safe length of the wind turbine blades for a specific accident scenario was also determined.

It has been established that the developed method is recommended to be used within the range of $7 \div 100$ departure maneuvers of a loaded jack-up vessel from the port per year.

The developed method was applied to determine the allowable length of wind turbine blades loaded across jack-up vessels exiting the proposed offshore wind farm terminal in Świnoujście. This length is $L_{akc} = 140$ m.
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