SHIPS SAFETY IN OPEN PORTS

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Open ports or terminals, which are not protected from wind at all, are problematic for ships, which have high boards and big influence by aerodynamic forces is arising. Mooring systems in such cases must take into account static and dynamic (harmonic) forces. Evaluation methods in case of open sea ports are presented in this article. Possibilities to evaluate aerodynamic forces for mooring ships and possibilities to prepare right ships mooring schemes in concrete conditions can positively increase ships safety in ports preventing navigational and environmental accidents. In this paper are presented analysis of situations, theoretical basis for study and practical calculations.

Keywords: aerodynamic forces, ships mooring, open sea port, mooring ropes

1. Introduction

Some ports are built in open sea parts, which are named as avant-ports. Such ports as Ventspils (oil and gas terminals), Zeebrugge, Gdansk Polnotzny port, planned Klaipeda deep sea port, usually are protected from short and long wave’s penetration, minimizing currents acting, but can not be protected by wind action at all. Open port places without any resistance against the wind some time make difficulties for moored ships with big wind surface (area), such as Ro-Ro vessels, Container ships, bulk ships and tankers in ballast.

In some ports, like Europort (Rotterdam) have been constructed wind protection walls, but it is necessary to have more deep studies for the wind protection or decreasing possibilities with minimum investments.

2. Open Sea Ports Analysis

Open sea ports built in sea part and safe land, which is very expensive in countries, which has short sea shore, like Belgium, Lithuania and others, decrease dredging works, especially in hard soil and some time decrease investments for the port infrastructure [Baublys, A. 2003; Paulauskas, V., 2004]. In such cases there are built breakwater systems, which protect quay walls from short and long waves penetration (Fig. 1) and minimize currents influence in case if a port is constructed on river’s delta (Fig. 2, Fig. 3).

Wind acting in open sea port, without any or minimum wind resistance, exists in big number of such type ports and terminals [Baublys, A., 2007], because there are open sea areas for the wind. In some ports, which are built on a very flat sea shore, has very low resistance for the wind, like Europort, which has the same problems as open sea ports (Fig. 4).

In open sea ports wind creates very high aerodynamic forces on moored ships, which have big influence on ships mooring systems and quay walls fenders and mooring bollards and finally on quay walls [EAU, 2004, 2006].

3. Aerodynamic Forces Which Create Wind Acting on the Ships

In the open sea ports wind acting on the ships is the same as in open sea, that means wind velocity change from 0 near ground (water) up to average or maximum on level above water level 5–7 m. Aerodynamic forces, which are acting on ship, spread on constant and periodical (harmonic) wind force components [Vensel, 1969]. Constant wind velocity component creates forces, which can be calculated as follows [Paulauskas, V., 1998]:

\[ F_c = C_a \frac{D}{2} (S_x \cdot \cos q_a + S_y \cdot \sin q_a)v_{ac}^2, \]  

(1)
where: $C_a$ – aerodynamic coefficient, can be taken from concrete ship data, which model has been tested in aerodynamic tube; $\rho$ – air density, for the calculations can be taken as 1.25 kg/m³; $S_x$ – wind surface area on ship’s diametric direction; $S_y$ – wind surface area on ship’s middle direction; $q_a$ – wind course angle; $v_{ac}$ – average wind velocity.
Periodical forces can be calculated via acceleration as follows:

\[ F_p^* = \frac{4\pi^2 t}{\tau^2} a \cdot \sin \frac{2\pi}{\tau}, \]  

and finally periodical force can be expressed as:

\[ F_p = F_p^* \cdot m, \]  

where: \( m \) – ship’s mass; \( \tau \) – period of wind guess; \( a \) – integration constant, which can be found as:

\[ a = C_a \rho \frac{\Delta v^2}{4} (S_x \cdot \cos q_a + S_s \cdot \sin q_a). \]  

Maximum forces, which can create periodical component of the wind, will be in case \( \sin \frac{2\pi}{\tau} = 1 \), and maximum periodical forces in such case will be:

\[ F_{p_{\text{max}}} = \frac{4\pi^2 t}{\tau^2} a \cdot m. \]  

Finally, maximum aerodynamic forces, which could act on the ship, will be as follows:

\[ F_a = F_c + F_{p_{\text{max}}}. \]  

In the same time it is necessary to take in account these directions, which are dangerous for the ships and quay walls mooring systems and is possible to take one-criterion method [Catmale, T. et al., 2007]. In case wind direction to quay wall, ship will be pressed to quay wall and just fenders must absorb ships energy, which is created by wind acting. In case of wind direction from quay wall, mooring ropes mainly must compensate forces and energies, which are created by wind acting on ship. In the same time periodical wind forces component has not big influence, because ship has not big movements and does not create big forces, which can be calculated by formula (5). More dangerous situation for the ship and quay wall mooring systems could be in case when wind is acting with some angle to quay wall, when constant and periodical wind forces will be maximum, that means the ship is pushed from quay wall by constant aerodynamic force and moved along quay wall by harmonic wind force and creates big inertia forces (Fig. 5) [Paulauskas, V., 2006].

**Figure 5. Dangerous wind direction on the ship and quay wall mooring system**

In case of course angle of the wind to moored ship, total aerodynamic force can be calculated as follows:

\[ F_{aa} = F_c \cdot \sin q_a + F_{p_{\text{max}}} \cdot \cos q_a, \]  

where: \( q_a \) – wind angle to the quay wall. Presented mathematical model can be used in concrete conditions for the aerodynamic forces calculations in case if no big resistance against the wind before moored ship.
4. Wind Protection Walls in Open Ports and Its Theoretical Basis

In some places in the open ports’ parts for the decreasing wind acting on moored to quay walls ships, there are constructed special wind protection walls (Fig. 6).

![Wind protection wall in Europort](image)

**Figure 6. Wind protection wall in Europort**

Wind protection wall’s effectiveness is very important, because constructions are very big and cost a lot and can be evaluated as wind velocity or wind forces decreasing on the ship. Theoretical and experimental studies of the wind protection walls effectiveness have been made on model shown on Fig. 7,

![Wind velocity distribution after clause wall](image)

**Figure 7. Wind velocity distribution after clause wall (between protection wall and ship)**

and on basis of tests results, have been received mathematical dependence as follows:

\[ y = \exp(-ax)^2 \]

where \( y \) – the altitude on which wind has initial velocity \( (v_a) \); \( a \) – the coefficient; \( x \) – the distance from protection wall.

In case of non close wind protection wall, it very much depends on the wall configuration and distances between wall elements. In general distance between elements should be short, that energy which absorbs protection wall elements would be bigger then energy, which goes between protection wall elements.
Wind energy, which is absorbed (protect) by protection wall elements, can be calculated as follows:

\[ E_w = \frac{m_a \cdot v_a^2}{2}, \]

(9)

where: \( m_a \) – air mass, which is acting on protection wall element, can be calculated as add mass:

\[ m_a = k_a \cdot V'_a \cdot \rho, \]

(10)

where \( V'_a \) – volume (circumference) of the protection wall element, \( k_a \) – air add mass coefficient, could be taken as 1,7–1,8. Horizontal distribution is the same as in close wall, which is shown on Fig. 7. Experiments, which have been provided near close and non close walls, results are the same and presented on Fig. 8.

\[ h / H_w = 0,0149 \left( \frac{S}{H_w} \right)^2 - 0,1836 \frac{S}{H_w} + 1. \]

(11)

Results, which have been received during testing and study, can be used for the practical tasks in open sea ports or other places.

5. Practical Wind Protection Wall Influence on Moored Ship Evaluation

For the practical evaluation one North Sea port with tidal altitude 5,5 m and in case of moored Ro-Ro ship is taken, which has high board about 25 m above the water level. Evaluation scheme is presented on Fig 9.
Logistics

Wind velocity distribution calculation is made by methodology, presented in section 4 of this article. Wind protection walls can be constructed by containers with different positioning, that means constructing containers in vertical position or using horizontal position walls. In bough cases final result that means reduction of the wind velocity will be the same (for the same height of the wall and distances between wind protection wall elements).

Aerodynamic coefficient of such type of the walls will be also independent of the containers positioning. According to testing in aerodynamic tubes, aerodynamic coefficient will be close to 2.

Maximum wind velocity distribution line for the protection constructions or ships in case distance between wind protection wall and protected construction is about 80 m, will be above water level in low water level case on altitude 1/3 of total protection wall (breakwater and protection wall) height. It means, wind velocity in case of initial wind velocity 30 m/s in low water level and in case tidal amplitude is about 7,5 m and total wind protection wall height is 25 m (breakwater and protection wall), will be about 21,8 m/s (decreasing about 27%) and in high water level mean wind velocity will be about 22,8 m/s (decreasing about 24%).

Received calculation results for the presented case in this article have good correlation with results, received in Europort. Differences between Europort experimental results and calculation results for the study case in this article mainly are linked with difference in aerodynamics coefficients of the wind protection wall construction elements.

Possibilities of reducing forces on vessels mooring ropes in open sea ports can be done in few ways, but the best solution – combination of the options:
- decrease ship’s inertia forces;
- reduction of the real acting wind on vessel;
- preparing new mooring schemes, which take in account maximum tensions on mooring ropes and decrease changing length and angles of mooring ropes.

Decreasing of ship’s inertia forces are linked with mooring schemes, that means mooring schemes must prevent ship movement along quay wall in case acting of periodical forces. As mentioned above, ship’s inertia forces could be very high in case of short mooring ropes.

Decrease of the ship’s inertia forces could be made by harder mooring to quay wall. In such case is very important to use longer mooring ropes and uses combination long mooring ropes in different places of the ship. The main task for decreasing ship’s inertia forces as result of the ship moving along quay wall to minimize ships free steps and in the same time to avoid very short mooring ropes that would be possible to increase period $\tau$ (formula (5)). Increased period $\tau$ decreases acceleration and in the same time ship’s inertia forces.

Reduction of the real acting wind velocity on constructions or vessels could be made by wind protection wall and as were shown before, such decreasing can be up to 20–30%, but in the same time in case of very strong storm, when wind whiffs reach up to 50 m/s, just wind protection wall can not fully improve situation and combination of the wind velocity reduction and ship’s inertia forces decreasing is necessary.

Ship’s inertia forces decreasing can be resulted on basis preparation of good mooring scheme in case to avoid very short mooring ropes and increasing long mooring ropes and springs. In this case as an example for the Ro-Ro ship mooring scheme for the storm conditions can be as an example shown on Fig. 10.

![Figure 10](image)

Figure 10. Ro-Ro ship mooring scheme in strong storm conditions: 1 – fore long mooring ropes (from 4 up to 6); 2 – fore springs (at least 2); 3 – astern springs (at least 2); 4 – astern long mooring ropes (from 4 up to 6)
On Fig. 10 in the mooring scheme no short mooring ropes are used and in case of ship’s moving along the quay wall period $\tau$ increases up to the shortest mooring rope working period, which can be calculated on the basis of moving distance and ship moving speed, that means:

$$\tau = \frac{\Delta S}{v'},$$

(11)

where: $\Delta S$ – movement distance, equal to the shortest mooring rope extension in horizontal direction, m; $v'$ – average ship movement speed near the quay wall, m/s.

Mooring ropes position very much influences on the forces, which are created in the mooring system for the protection of outer forces, such as wind loads, ship’s inertia forces and other.

Ro-Ro, bulk vessels and tankers in ballast, usually has high hull and mooring ropes have big vertical and horizontal angles as stated by Paulauskas V. et al., 2008. For such type of ships mooring rope tension, which against wind loads perpendicular to ship (quay wall) direction $W$, can be calculated as follows:

$$F_w = F \cdot \cos \alpha \cdot \sin \beta,$$

(12)

where: $F$ – real mooring rope tension; $\alpha$ – mooring ropes vertical angles; $\beta$ – mooring ropes horizontal angles.

As an example, the mooring rope with real tension $F = 50$ T, vertical angle $\alpha = 60^\circ$, and horizontal angle $\beta = 30^\circ$ is taken. In this case force by mooring rope against wind loads will be: $F_w = 50 \times 0.5 \times 0.5 = 12.5$ T.

It shows, that in case of maximum mooring rope tension (50 T), just 12.5 T is against wind loads.

As mentioned before, ship’s inertia forces try moving ship along the quay wall and inertia forces must be compensated by mooring ropes and fenders. Investigations in many terminals have shown that about 50% of inertia forces are compensated by mooring ropes and about 50% are compensated by fenders (Fig. 11).

As an example, the mooring rope with real tension $F = 50$ T, vertical angle $\alpha = 60^\circ$, and horizontal angle $\beta = 30^\circ$ is taken, in this case force by mooring rope against ship’s inertia force will be: $F_i = 50 \times 0.5 \times 0.866 = 21.7$ T.

Finally, mooring ropes take ship’s inertia forces, which can be calculated as follows:

$$F_i = F \cdot \cos \alpha \cdot \cos \beta.$$

(15)

As an example, the mooring rope with real tension $F = 50$ T, vertical angle $\alpha = 60^\circ$, and horizontal angle $\beta = 30^\circ$ is taken, in this case force by mooring rope against ship’s inertia force will be: $F_i = 50 \times 0.5 \times 0.866 = 21.7$ T.
The presented example shows clearly, that mooring scheme with proper positioning of mooring ropes, plays very important role and can prevent the breaking of mooring ropes during storm conditions, that means compensation wind loads and ship’s inertia forces.

Conclusions

1. During the storm conditions ship is influenced by wind loads and inertia forces, which must be compensated by mooring ropes and fenders.
2. Wind loads can be decreased partly by wind protection wall and partly by mooring ropes.
3. Wind protection wall for big ships such as Ro-Ro vessels can not be very complicated, that means high, and it creates limit of the wind protection walls capability.
4. Wind protection wall, constructed by containers (vertical or horizontal positioning) with height up to 13–15 m can decrease wind velocity for the Ro-Ro vessels up to 25% and wind loads up to 30%.
5. Correct or proper mooring schemes are very important part for the Ro-Ro ship safety guaranty and together with wind protection wall, can be very useful in open sea port conditions.
6. Before wind protection wall implementation, simulation in aerodynamic tube is recommended for the wind protection wall in concrete conditions’ optimisation.

References


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