TRANSPORT
2009
24(2): 113–120

SHIP SAFETY IN OPEN PORTS

Vytautas Paulauskas[1], **Donatas Paulauskas**[2], **Joep Wijffels**[3]

[1, 2]Klaipėda University, H. Manto g. 84, 92294 Klaipėda, Lithuania
[3]Lievense N.V., Bijenstraat 26, B-9051, Gent, Belgium
E-mails: [1]donatasp@takas.lt; [2]d.paulauskas@arijus.lt; [3]jwijffels@lievense.be

Received 1 November 2008; accepted 10 April 2009

Abstract. Ports and terminals open to prevailing winds can cause problems to moored ships with a high freeboard. Such ships, i.e. ship and berth mooring systems, have to deal with significant aerodynamic loads.This paper addresses the theoretical approach of the influence of aerodynamic loads on a mooring system for ship and investigates whether windscreens can reduce aerodynamic loads on ships in ports.

Keywords: aerodynamic loads, ship mooring schemes, open seaport, mooring ropes, bollards, windscreen.

1. Introduction

Some ports (called 'avant-ports') have been built in the open sea area as an extension to the coast and include Zeebrugge in Belgium, Rotterdam in the Netherlands, Gdansk Polnotzny in Poland, planned Klaipėda deep seaport in Lithuania, Ventspils oil and gas terminals in Latvia, etc.

These ports have breakwaters that protect the port from long and short-wave penetration and minimize the influence of currents. Breakwaters will, however, hardly shelter from winds.

In cases of no shelter from winds, high wind loads and an unfavourable wind direction, ships with a high freeboard such as ro-ro and container ships, car carriers and bulk- and oil carriers in ballast will have problems of stable and safe mooring (Paulauskas 2009; Paulauskas *et al.* 2008; Česnauskis 2007).

This paper analyses and evaluates the theoretical basis and practical design of:

- aerodynamic loads on ships;
- accompanying mooring schemes;
- the introduction to sheltering windscreens.

2. Open Seaports

Reasons for open seaports are as follows:

- the unavailability of large inland zones to build or extend ports (Jaržemskis and Vasilis Vasiliauskas 2007);
- deep draught requirements + direct access to the seaways (Çakmak and Ersöz 2007);
- quick access to terminals, the avoidance of inland sailing time and the passage of locks;
- the creation of safe distance between environmental risky terminals and populated areas;
- reducing the investment costs of the port infrastructure (Baublys 2003; Paulauskas 2004);
- reducing maintenance costs such as dredging.

To create a safe navigation environment and to maintain the required draught, open seaports are built between breakwaters the layout of which prevents from and reduces the impact of short and long-waves and currents from the open sea.

The examples of open seaports at the North Sea are presented in the Figs 1–5.

Fig. 1. The Port of Zeebrugge (Belgium)

ISSN 1648-4142 print / ISSN 1648-3480 online
www.transport.vgtu.lt
DOI: 10.3846/1648-4142.2009.24.113-120

Fig. 2. The Port of Rotterdam (The Netherlands)

Fig. 3. The Port of Gdansk Polnotzny (Poland)

Fig. 4. The Port of Ventspils (Latvia)

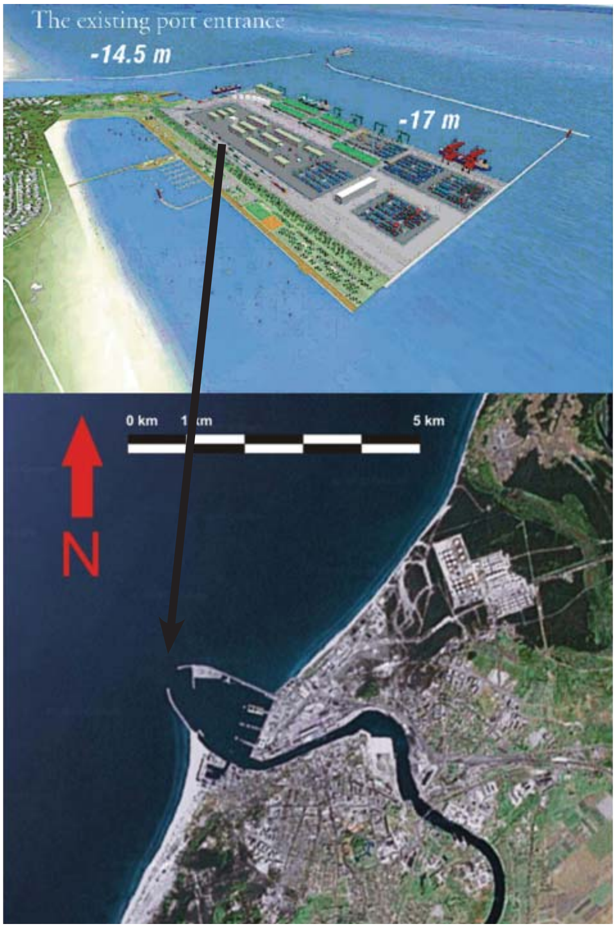

Fig. 5. The Port of Klaipėda + planned extension (Lithuania)

A disadvantage of an open seaport is the absence of natural wind protection such as buildings, trees etc. Strong winds will have a negative impact on the manoeuvrability and mooring stability of ships with a limited draught and a high freeboard (Criteria for Movements … 1995).

The design and layout of navigation channels and berths within the seaport should consider the impact of the wind. However, other environmental aspects will not always make this possible. Specific measurements are required to facilitate navigation and mooring (Guidelines for the Design … 2002; BS 6349-1: 2000; BS 6349-4: 2000; Recommendations of the Committee … 1996 and 2004).

The Port of Rotterdam recognised the impact of the wind on ship manoeuvrability and has constructed a windscreen to reduce wind loads to facilitate the passage of the vessels of the Caland-bridge and the access to Brittanniëdock, see Figs. 6 and 7.

3. Aerodynamic Loads on Ships – Classical Determination

Aerodynamic (wind) loads on ships in open seaports are similar to those on ships offshore.

In such cases, the wind speed varies from 0 m/sec at ground/water level up to the average or maximum values from 5 to 7 m above ground/water level.

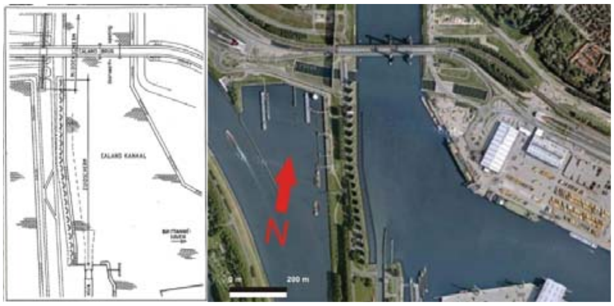

Fig. 6. Windscreen Calandkanaal – The Port of Rotterdam (The Netherlands)

Fig. 7. Windscreen Calandkanaal – The Port of Rotterdam (The Netherlands)

Aerodynamic loads on ships, see Fig. 8, consist of:

- constant aerodynamic load components (F_C);
- periodical (harmonic) aerodynamic load components (F_P) (Paulauskas *et al.* 2008; Вентцель 1969);
- the direction of aerodynamic loads.

3.1. Constant Aerodynamic Load Components

Following Paulauskas (1998), constant aerodynamic loads are as follows:

$$F_C = C_a \frac{\rho_1}{2}(S_x \cdot \cos q_a + S_y \cdot \sin q_a) v_{aC}^2, \qquad (1)$$

F_C = constant aerodynamic load;
C_a = aerodynamic coefficient, can be derived from ship data the model of which was tested in an aerodynamic tube;
P_1 = air density (kg/m^3), varies from 1.3096 kg/m^3 at 0° C to 1.1703 kg/m^3 at 30° C, – average value makes 1.25 kg/m^3;
S_x = the longitudinal projected area of the vessel above the waterline (m^2);
S_y = the transverse projected area of the vessel above the waterline (m^2);
q_a = angle wind direction to the vessel's axes;
v_{aC} = design wind speed at a height of 10 m above water level (m/sec).

3.2. Periodical (Harmonic) Aerodynamic Load Components

Periodical (harmonic) aerodynamic loads can be determined by acceleration (Paulauskas 1998 and 2006):

$$F_P'' = \frac{4\pi^2 t}{\tau^2} a \cdot \sin\frac{2\pi t}{\tau}, \qquad (2)$$

$$F_P = F_P'' \cdot m, \qquad (3)$$

F_P = periodical (harmonic) aerodynamic load;
τ = a period of the gust of wind (sec);
m = ship's mass (ton);
a = integration constant:

$$a = C_a \frac{\rho_1}{4} \Delta v_a^2 (S_x \cdot \cos q_a + S_y \cdot \sin q_a). \qquad (4)$$

The maximum periodical (harmonic) aerodynamic load (F_{Pmax}) will occur at $\sin\frac{2\pi t}{\tau} = 1$:

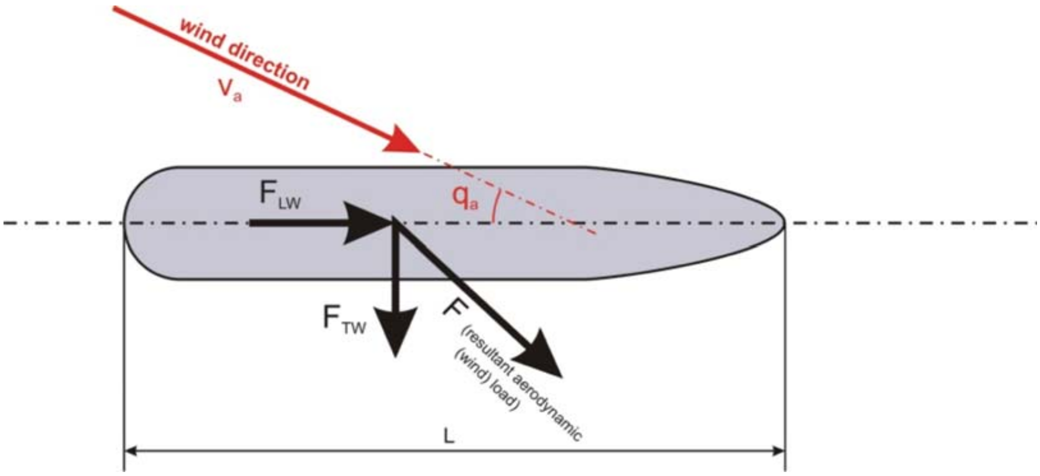

Fig. 8. Aerodynamic loads on ships

$$F_{P\max} = \frac{4\pi^2 t}{\tau^2} a \cdot m. \tag{5}$$

Maximum aerodynamic loads on a ship will be:

$$F_a = F_C + F_{P\max}. \tag{6}$$

3.3. Direction of Aerodynamic Loads

The location and direction of the ship and the direction of aerodynamic loads will have a determining effect on the fender and mooring systems of berths and ships:

1. In case they are directed to the berth, the ship will be pushed to the berth, see Fig. 9:
   - the fender-system will absorb aerodynamic loads;
   - periodical aerodynamic loads will not have a considerable influence due to the restricted movements of the ship;
2. In case they are directed from the berth, the ship will be pushed from the berth, see Fig. 10:
   - the mooring-system will take aerodynamic loads;
   - the ship is pushed from the berth by constant aerodynamic loads;
   - the ship will move along the berth by periodical aerodynamic loads creating significant inertia loads.

4. Aerodynamic Loads on Ships – EAU 2004 (EAU 2004)

In accordance with the Recommendations of the Committee … (2004), determinations see below.

Wind load components:

$$W_t = (1 + 3{,}1 \cdot \sin\alpha) \cdot k_t \cdot H_u \cdot L \cdot v^2, \tag{7}$$

$$W_1 = (1 + 3{,}1 \cdot \sin\alpha) \cdot k_1 \cdot H \cdot L_u \cdot v^2. \tag{8}$$

Equivalent wind loads for

$$W_t = W_{tb} + W_{th}, \tag{9}$$

$$W_{tb} = W_t \cdot (0{,}5 + k_e), \tag{10}$$

$$W_{th} = W_t \cdot (0{,}5 - k_e). \tag{11}$$

A load diagram (schematic) see in Fig. 11 where:

H = the greatest freeboard height of the vessel (ballasted or unloaded) and an additional height of load above freeboard (m).
L_u = overall length (m).
V = relevant wind speed (m/sec).
W_i= wind load components (kN).
K_t and k_1 = wind load coefficients.
K_e = the coefficient of eccentricity.
α = angle wind direction to the vessel's axes (degr.).

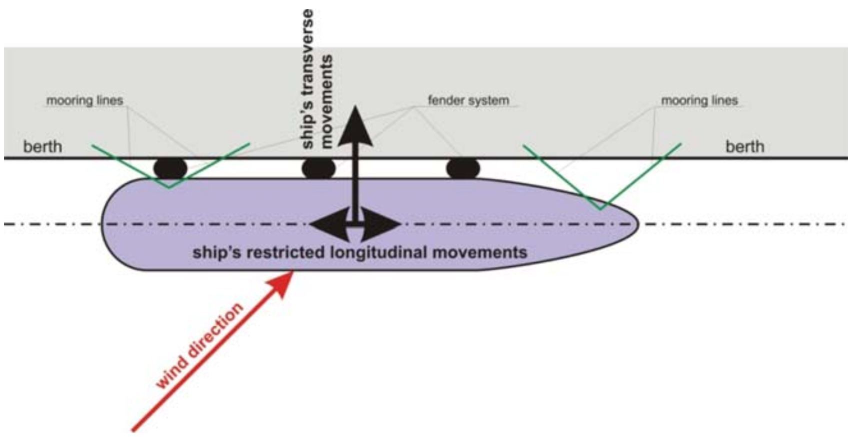

Fig. 9. Aerodynamic loads directed to the berth

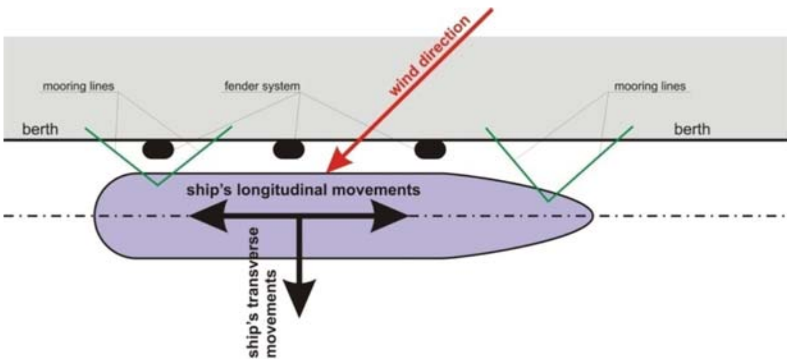

Fig. 10. Aerodynamic loads directed from the berth

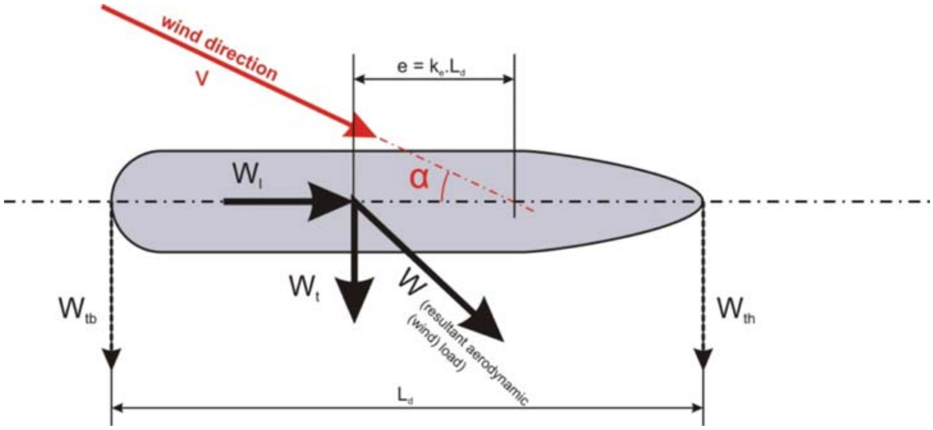

Fig. 11. Aerodynamic loads on ships (Recommendations of the Committee … 2004)

Relevant wind velocity:

In relation to the mass inertia of vessels, it is not the short-term peak of gusts (*order of magnitude = second*) relevant for determining mooring rope loads but rather the average wind over a period of time (T). The value of T should be taken as 30 sec for vessels op to 50,000 dwt and 60 sec for larger vessels. The wind intensity of the maximum wind averaged over one minute is generally 75% of that of the value over one second. A 50-year return wind is recommended for design purposes (Final Report of the … 1984; Recommendations of the Committee … 2000).

Aerodynamic Loads on Ships – BS 6349-I (BS 6349-1: 2000, BS 6349-4: 2000)

Determination in accordance with the British Standard (BS 6349-1: 2000), see below.

Wind load components:

$$F_{TW} = C_{TW} \cdot \rho_a \cdot A_L \cdot v_a^2 \cdot 10^{-4}, \quad (12)$$

$$F_{LW} = C_{TW} \cdot \rho_a \cdot A_L \cdot v_a^2 \cdot 10^{-4}. \quad (13)$$

A load diagram (schematic) see in Fig. 12 where:

F_{TW} = the transverse wind load, forward or aft (kN);

F_{LW} = the longitudinal wind load (kN);

C_{TW} = the transverse wind force coefficient, forward or aft, see 4 for values related to the type of a ship;

C_{LW} = the longitudinal wind force coefficient, see 4 for values related to the type of a ship;

ρ_A = air density (kg/m^3) varies from 1.3096 kg/m^3 at 0° C to 1.1703 kg/m^3 at 30° C;

A_L = the longitudinal projected area of the vessel above the waterline (m^2);

V_W = design wind speed at a height of 10 m above water level (m/sec);

α = angle wind direction to the vessel's axes (degr.).

BS6349-1:2000 wind loads on moored vessels are accepted as follows:

- in accordance with BS 6349-1: 2000, 1 min mean wind speed is used for the design of moorings which is related to time needed for full line loads to develop taking into account the inertia of the vessel;
- the value of 1 min wind speed can be estimated in the following way: 1 min mean speed (V_w) = 0.85×3 s gust. V_w = 0.85×45 = 38.25 m/s, for a 3 sec wind gust of 45 m/s;
- the determination in accordance with the BS 6349-1: 2000 takes into account inertia effects by applying correct wind force coefficients (C_{TW} and C_{LW}).

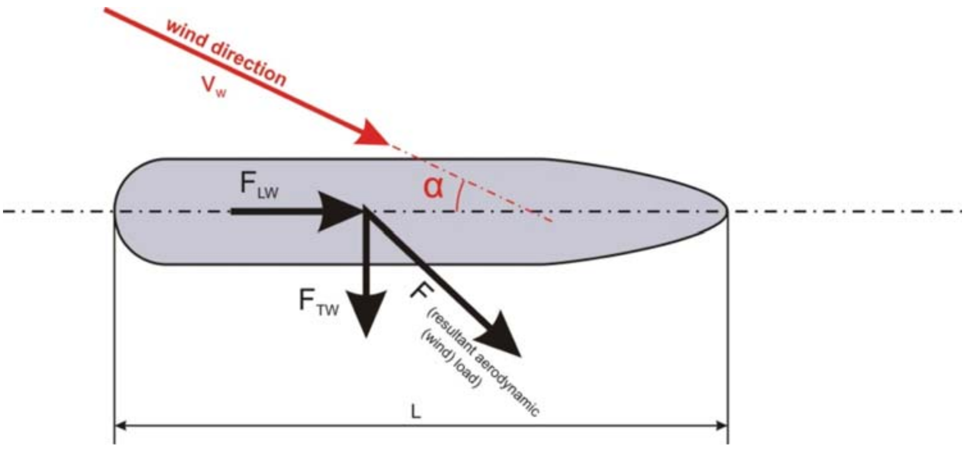

Fig. 12. Aerodynamic loads on ships (BS 6349-4: 2000)

6. Windscreens for Reducing Aerodynamic Loads on Ships in Open Seaports

To facilitate the berthing and mooring of ships in open seaports, the installation of wind reducing screens can be considered (Baublys 2007, 2008 and 2009; Bagdonienė 2008). The theoretical and experimental studies of wind reducing screens show the relation between the influence of the windscreen and the sheltered/lee side of the windscreen; see Fig. 13. At the sheltered/lee side of the windscreen, the level of equal wind speed values drops and rises again.

Note to Fig. 13:

v_a = design wind speed (equal wind speed values) (m/sec);

h = the level of design wind speed (m);

H_w = the height of the windscreen (m);

S = distance from the windscreen at the sheltered side of the windscreen (m).

$$h/H_w = 0,0149(\frac{S}{H_w})^2 - 0,1836\frac{S}{H_w} + 1. \quad (14)$$

To achieve the aerodynamic load reducing the effect of the wind on berthing and mooring ships, the location of the berth at the lee side of the windscreen should be at position *A* or position *B*, see Fig. 14.

The influence of a windscreen also depends on a type of a screen which can be:

– a closed wall;

– a wall with gaps, see Fig. 16 (in that case, only a part of aerodynamic loads will be reduced).

The wind energy to be taken by the screen can be determined by:

$$E_a = \frac{m_a \cdot v_a^2}{2}, \quad (15)$$

v_a = design wind speed (equal wind speed values) (m/sec).

m_a = air mass (kg) acting on the windscreen:

$$m_a = k_a \cdot V_a' \cdot \rho_a. \quad (16)$$

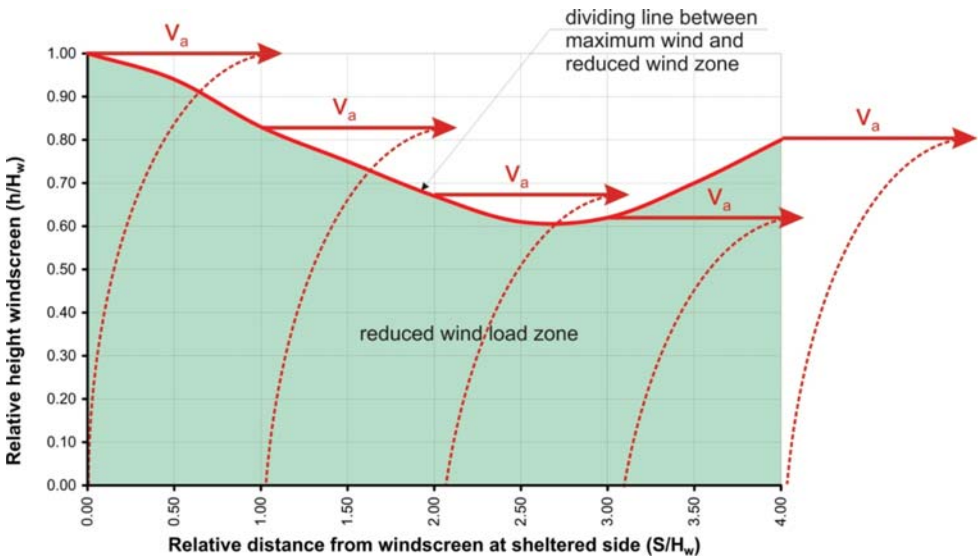

Fig. 13. Windscreen influence on the sheltered/lee side of the windscreen

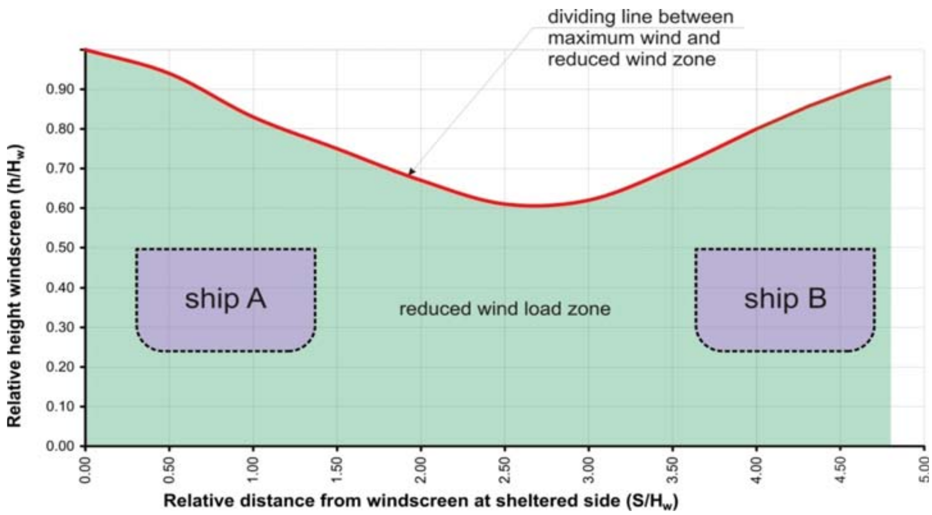

Fig. 14. Locations of berths at the sheltered/lee side of the windscreen

P_1 = air density (kg/m^3), varies from 1.3096 kg/m^3 at 0° C to 1.1703 kg/m^3 at 30° C, average value makes 1.25 kg/m^3;
V_a = the volume (circumference) of the windscreen (m^3);
k_a = the air add mass coefficient (= 1.7 or 1.8).

7. Example

Fig. 15 shows a typical example of a moored ship and a windscreen at an open seaport. In this case, the prevailing wind will push the ship from the berth. The windscreen will reduce the mooring loads and number of mooring lines and will allow the operator to continue loading and unloading operations under high wind speed conditions.

Note to Fig. 16:

- mooring line 1: fore long mooring lines – the number of lines vary from 4 to 6.
- mooring line 2: fore spring mooring lines – the number of lines starts from 2.
- mooring line 3: astern spring mooring lines – the number of lines starts from 2.
- mooring line 4: astern long mooring lines – the number of lines vary from 4 to 6.

Fig. 16 shows a possible mooring scheme under storm conditions. The applied mooring will depend on the following factors (Paulauskas *et al.* 2008):

- allowable mooring line load;
- allowable bollard load;
- the configuration of winches and hawseholes on the ship;
- the variation of the lengths of mooring lines.

As a consequence of wind gusts, angled wind impact etc. (the inertia loads) the ship will surge, sway, heave, pitch, roll and yaw. Restrictions on mooring lines and the fender system will load both mooring lines and the fender system.

Investigations carried out at several terminals show that inertia loads are distributed in about 50 % to mooring lines and 50 % to the fender system.

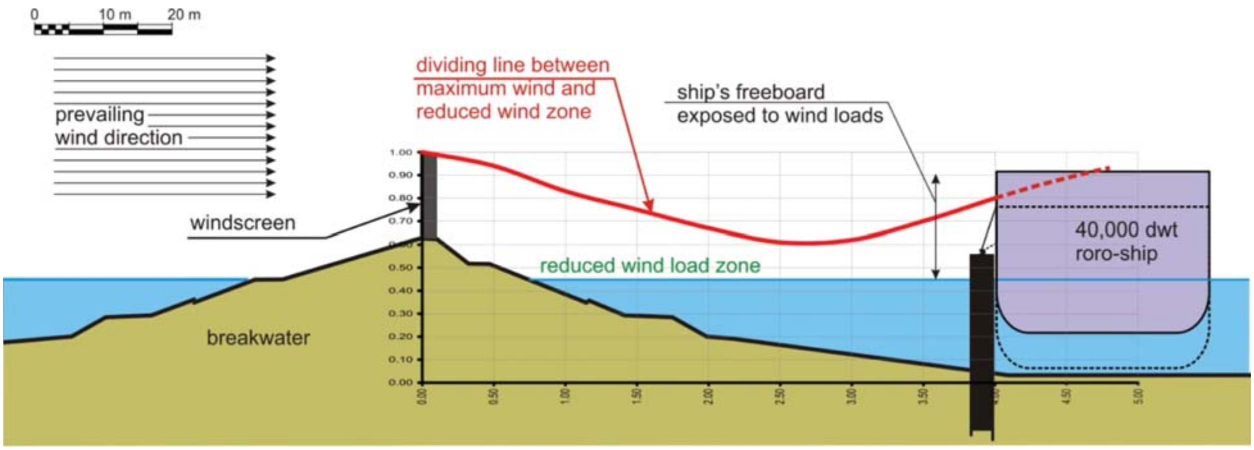

Fig. 15. A typical example: breakwater + windscreen + berth roro-ship

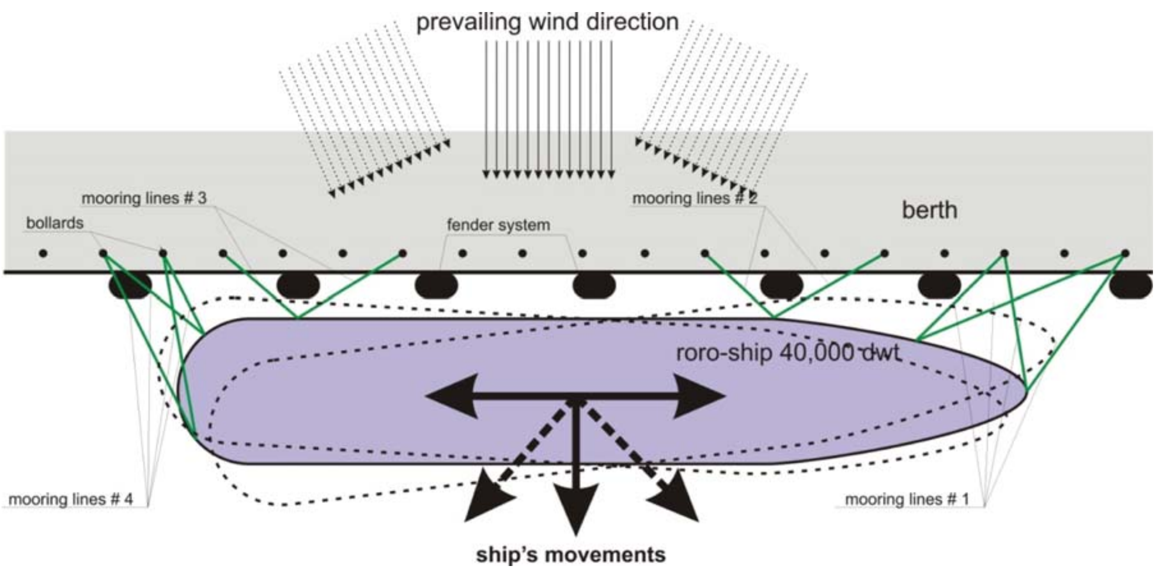

Fig. 16. A typical mooring scheme of a roro-ship

Conclusions

1. Under storm conditions, inertia loads are an important factor. The mooring and fender system of both ships and berths should be designed to accept inertia loads.
2. Wind loads at open seaports can only partly be reduced by windscreens depending on the wind direction and the location of the screen and berths.
3. If possible, berths at open seaports should be located in such a way that moored ships will be pushed to the berth under storm conditions.
4. For a quick theoretical assessment, to determine aerodynamic loads on a ship, the British Standard BS 6349-1: 2000 method 2 is a suitable tool.
5. The most effective location of a screen to reduce aerodynamic loads on ships will be near berths.

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