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Quay walls mooring capacity increasing

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1. Introduction

Quay walls construction and mooring equipment such as bollards, hocks and other elements are calculated on the basis of wind, waves, current, ice possible forces [1 - 6]. At the same time new loading and unloading equipment in terminals has high intensively, sometimes up to 1500 – 2000 tons per hour in bulk terminals and up to 6000 – 10000 tons in liquid cargo terminals. Ships during loading operations change draft very fast [7 - 9]. Traditional ship's mooring equipment in case of delay slash mooring ropes of the ship creating big additional floating forces, which have an influence on quay walls construction via quay wall mooring equipment and ship's and quay wall mooring equipment as well [10, 11].

This article analyses and evaluates the theoretical basis and practical experience and design results of:

- aerodynamic and hydrodynamic loads on ships;
- ships floating forces and loads on the ship and quay wall mooring equipment;
- the accompanying mooring schemes;
- the use of mooring programs.

These components and specific ship and berth data will be a part of the analysis to minimise the probability of accidents and damage to the berth, berth furniture, ship, etc. [12, 13].

Mooring software will assist in the composition of the mooring schemes for a specific berth and ship and / or the maximum safe mooring wind and other conditions.

Ship's floating forces during its handling operations are very important and sometimes can create hundreds or thousands kN additional loads on quay walls and ship's mooring equipment.

2. Reasons and theoretical aspects of quay walls strength decreasing

Quay walls strength decreasing is mainly linked with long exploitation time of the quay wall (50 – 70 years), accidents with ships during mooring, loading, unmooring operations or substandard situations, such as hydrodynamic influence of a moving ship depends or wind pulsation or waves acting on the ship and big additional inertia forces of the ship.

The aerodynamic (wind) loads on ships in seaports are similar to aerodynamic loads on ship's offshore (Fig. 1). In those cases the wind speed varies from 0 m/sec at ground/water level up to the average or maximum values at 5 till 7 m above the ground/water level [11, 13]. Aerodynamic loads on the ship consist of:

- constant aerodynamic load components (F_c);
- periodical (harmonic) aerodynamic load components (F_p);
- direction of the wind or waves.

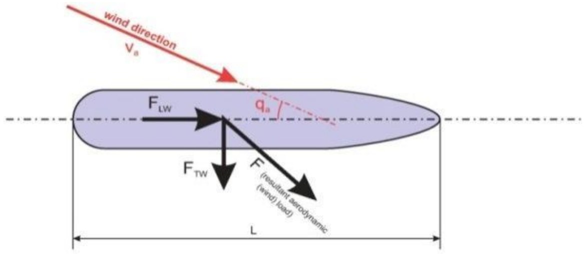

Fig. 1 Aerodynamic loads on a ship and ship's movements created by them

The constant aerodynamic loads can be determined as [14, 15]

$$F_C = C_a \frac{\rho_1}{2}\left(S_x \sin q_a + S_y \cos q_a\right) v_{ac}^2 \quad (1)$$

where F_C is constant aerodynamic load; C_a is aerodynamic coefficient can be derived from ship's data, of which the model was tested in an aerodynamic tube; ρ_1 is density of air, kg/m^3; varies from: 1.3096 kg/m^3 at 0°C to 1.1703 kg/m^3 at 30°C, average value: 1.25 kg/m^3; S_x is longitudinal projected area of the ship above the waterline, m^2; S_y is transverse projected area of the ship above the waterline, m^2; q_a is angle of wind direction to the ship's axes; v_{ac} is design speed of the wind at a height of 10 m above water level, m/sec.

Periodical (harmonic) aerodynamic loads can be determined by the acceleration

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

$$F_P = F_P'' m \quad (3)$$

where F_p is periodical (harmonic) aerodynamic load; τ is period of gust of wind, sec; m is ship's mass, ton; t is running time, s.; a is integration constant

$$a = C_a \frac{\rho_1}{4} \Delta v_a^2 \left(S_x \sin q_a + S_y \cos q_a\right) \quad (4)$$

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

$$F_{P\,max} = \frac{4\pi^2 t}{\tau^2} a\, m \quad (5)$$

The maximum aerodynamic loads on a ship will be

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

The location and direction of the ship and the direction of the aerodynamic and hydrodynamic loads will have a determining effect for the fender and mooring systems of the berths and ships: In case they are directed to the berth the ship will be pushed to the berth (Fig. 2):

- the fender-system will absorb a part of the aerodynamic and hydrodynamic loads;
- the periodical aerodynamic and hydrodynamic loads will not have a considerable influence, due to the restricted movements of the ship.

In case they are directed from the berth the ship will be pushed from the berth (Fig. 3):

- the mooring-system will take the aerodynamic and hydrodynamic loads;
- the ship is pushed from the berth by constant aerodynamic and hydrodynamic loads;
- the ship will have movements along the berth due to periodical aerodynamic and hydrodynamic loads, which will create significant inertia loads.

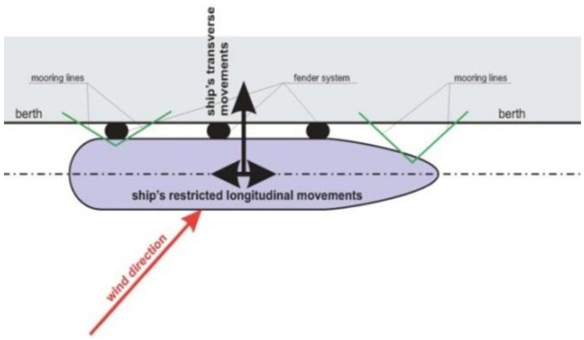

Fig. 2 Aerodynamic loads directed to the berth

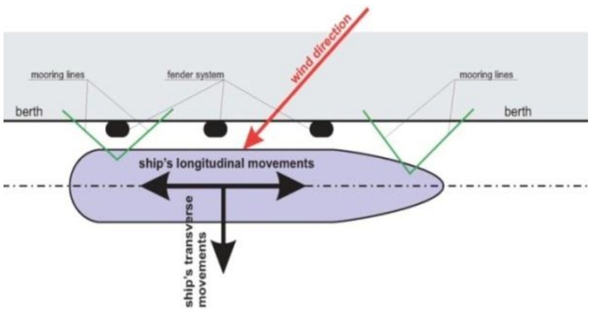

Fig. 3 Aerodynamic loads directed from the berth

Ship's floating loads can be calculated as follows [11]

$$F_F = q \Delta Q \tag{7}$$

where q are number tons per 1 cm draft; ΔQ is quantity of the cargo unloaded from ship.

Aerodynamic and hydrodynamic loads of the wind, current and waves can be calculated by EAU 2004 methodic, BS 6349 standard methodology or could be used Optimoor simulator system [3, 16, 17]. Ship's floating loads could be added to the aerodynamic and hydrodynamic loads. Fig. 4 shows a ship's typical mooring scheme. The mooring line numbers are clarified in Table 1 [1, 10].

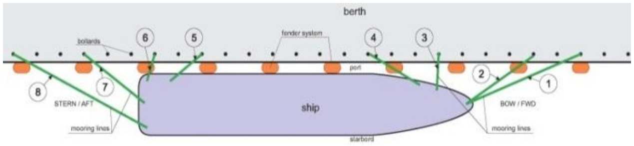

Fig. 4 Typical mooring scheme

Table 1

Mooring ropes number, names and purposes

Mooring line (hawse) number	Mooring line name	Purpose
1	Bow (FWD) long line	Prevent backwards movement
2	Bow (FWD) line	Prevent backwards movement
3	Forward Breast line	Keep close to berth
4	After Bow Spring line	Prevent from advancing
5	Forward Quarter Spring line	Prevent from moving back
6	Quarter Breast line	Keep close to berth
7	Stern (AFT) line	Prevent forwards movement
8	Stern (AFT) long line	Prevent forwards movement

The mooring capacity is defined by:

- allowable mooring line load;
- capacity of the mooring line winch;
- allowable bollard load;
- configuration of the mooring line winches and hawseholes (fairleads) on the ship;
- variation of the mooring lines' lengths.

As a consequence of wind gusts, angled wind impact, etc. (inertia, current, waves loads) the ship will surge, sway, heave, pitch, roll and yaw (Fig. 5). The restrictions of the mooring lines, bollards and fender system will create the addition to the constant loads: the periodical aerodynamic, hydrodynamic and inertia loads.

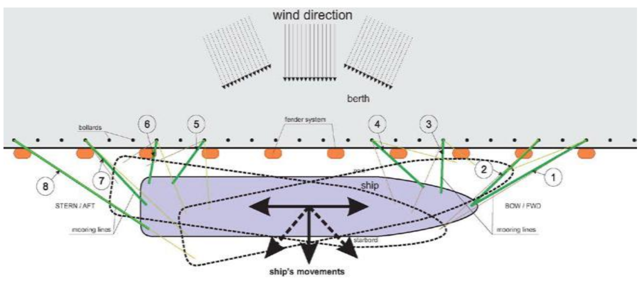

Fig. 5 Ship's movements under wind loads

The location of the fairleads on the ships in relation to the positions of the bollards on the berth can lead to wide mooring line angles in the vertical plane (α), see Fig. 6. In some cases α can be up to 70° - 80°. Another reducing factor will be mooring line angles in the horizontal plane (β) [13], see Fig. 7.

This wide mooring line angle will reduce the horizontal mooring capacity and allow movement of the

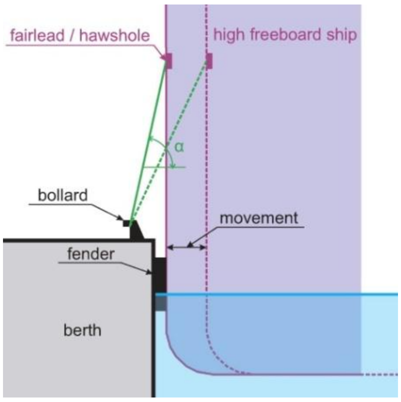

Fig. 6 Mooring ropes vertical angle

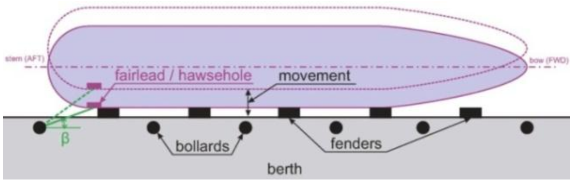

Fig. 7 Mooring ropes horizontal angle

moored ship. Mooring lines from the bow and the opposite side of the berth side of the ship at the stern will reduce the wide mooring line angle and could have a positive effect on the mooring capacity. A higher pretensioned load on the breast lines necessity to force the ship close to the berth is limited with regards to the balance of the ship. As a consequence of the reduced effectiveness of the forward and quarter breast lines, the bow, spring and stern mooring lines, with a sharper mooring line angle, will take a part of the breast mooring line loads. To avoid movements from the berth in case of unfavourable high aerodynamic and hydrodynamic loads one is inclined to increase the pretension of the mooring lines and / or increase the number of mooring lines. This could lead to utilize the quay wall construction, mooring lines, bollards, etc. to the limit. At a gust the limit capacity of the quay wall construction, mooring lines, bollards, etc. could be exceeded, creating dangerous situations, such as:

- uncontrollable movement of the ship from the berth, causing the collapse of the ship's catwalk to the berth;
- breaking of the mooring lines;
- breaking off of the bollards;
- collision of the ship with other berths and / or other ships;
- uncontrollable movement of the ship to the berth.

Presented in this section theoretical aspects of the quay wall strength decreasing reasons and possible practical situations would be important and used for the case study.

3. Case study for the emergency quay wall

Emergency quay walls mainly link with accidents and technical parameters are changed without real improvement of the quay walls. Technical parameters of the quay walls after accidents decrease that means decrease quay walls payloads, mooring bollards capacity, possibilities of the quay wall anchor system and other technical parameters.

As an example (case study) is taken the emergency quay wall shown on Fig. 8. Mistakes of the detail project and construction works s and low quality of the construction make quay wall much weaker as were designed in technical project. As a result of the ship's aerodynamic, hydrodynamic and ship's floating forces acting and weakness of the real quay wall technical parameters quay wall movement to water side stimulated. During accident quay wall head about 40 m in length moves from 0.4 up to 1.0 m to the water direction. After excavation of the quay anchor wall it was fount were find that fixed points between quay wall anchors and quay anchor wall are very weak. Additionally during excavation of the quay wall it was found that the soil under quay wall head was not enough compressed during construction works and empty place is about 0.2 m in high.

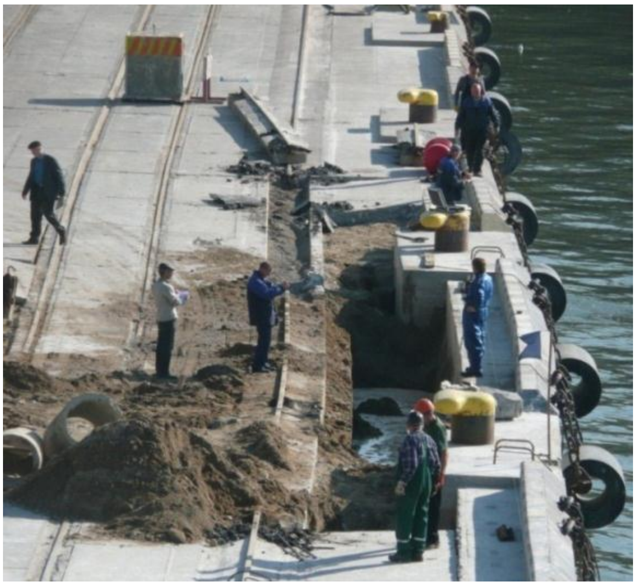

Fig. 8 Quay wall after movement to water side (general view)

According detail project (layouts) under crane rails VHP (very high pressure) columns were designed for the support crane rails, which should be create in filled sand. It is very complicated VHP columns to create in filled sand conditions, and in fact in the mentioned quay wall such columns were not found at all, just some separate concrete pieces were found during excavations (Fig. 9).

Fig. 9 Real situation of quay wall with anchors and VHP columns (after excavation)

The mentioned quay wall was operated very intensively and until quay wall renovation works it is necessary to make exact calculations, preparing useful operation conditions (payloads, capacity of the quay wall mooring bollards, ships mooring schemes etc.) to avoid additional damage of the quay wall during operation on emergency and losses of the cargo flows (Figs. 10 and 11). One of the main problems, which was necessary to solve – minimize tension forces of quay wall anchor system.

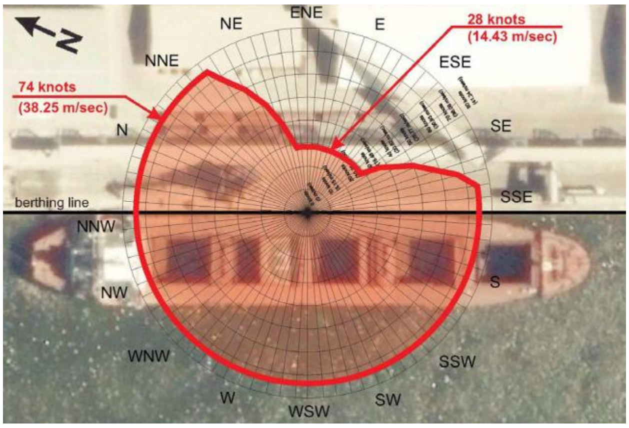

Fig. 10 Maximum wind speeds at berth (wind rose)

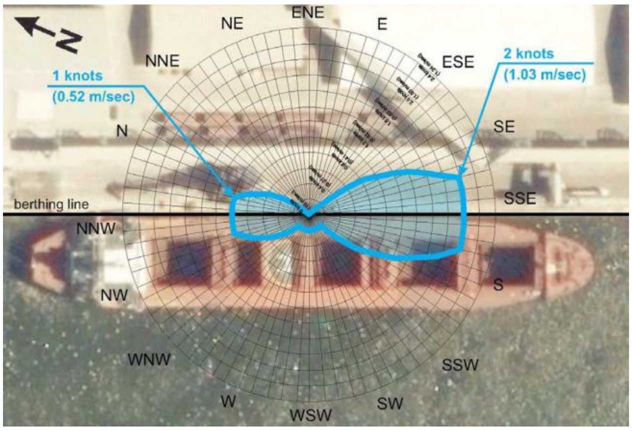

Fig. 11 Maximum current speeds at (current rose)

For the study were taken bulk ships with the main parameters: L = 200 m, B = 27.0 m, T = 8.0 m (in ballast), S_x = 2800 m² (in ballast).

For the calculations were used Classical modified (including inertia forces) determination method, EAU 2004 and BS6349 methodologies and Optimoor simulation model.

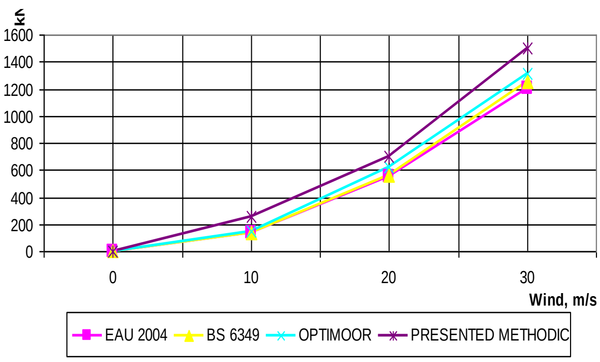

Fig. 12 Wind loads received for the Bulk ship 200 m long by different methods

Bulk ships mooring limitations to the quay wall have shown, that it is necessary find technical solutions for the increasing ships mooring possibilities by additional mooring bollards, which are not directly linked with quay wall construction.

Future calculations and simulations of the new quay wall situation with using storm bollards are shown on Figs. 12 and 13.

Fig. 13 Possible additional storm bollards on quay the wall for increasing its mooring possibilities

For the more easy and flexible using of quay wall territory in case of normal external conditions (when it is not necessary to use storm bollards), it is recommended install special clause inside the quay wall (in a sunken pit) bollards, as shown on Fig. 14.

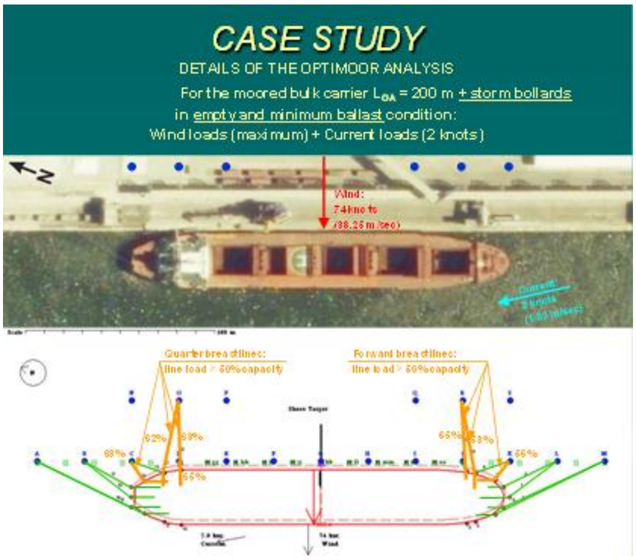

Fig. 14 Optimoor simulation results of the quay wall for the bulk ship 200 m long in case using storm mooring bollards

Received aerodynamic, hydrodynamic, inertia and floating forces must be spread on the quay wall mooring bollards including special storm bollards. The mention of calculated forces are the basis for the ship's mooring schemes preparation and finally concrete limitations of wind, current direction and velocity, as well inertia and floating (Figs. 15 and 16.).

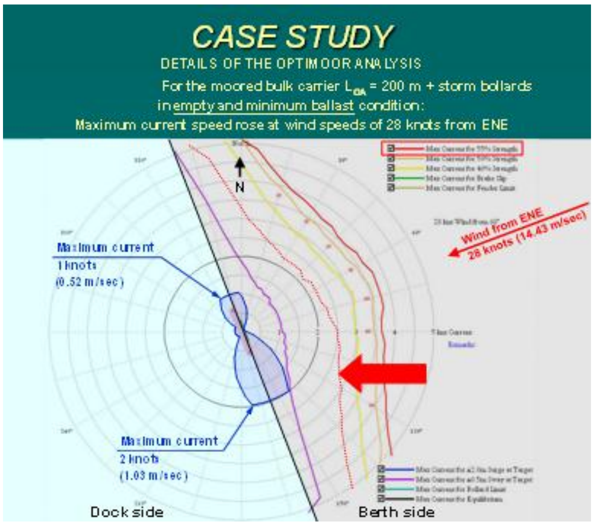

Fig. 15 Quay wall increasing limitations for the bulk ship 200 m long in case of using storm bollards depend on external forces

Fig. 16 Installation of clause inside quay wall (in a sunken pit) bollards

4. Conclusions

In evaluation of emergency quay walls is very important to find the possibilities to continue quay walls exploitation.

The main horizontal forces on the quay walls anchor system should be studded and later evaluated.

The presented in the article methodic evaluation and calculation of the forces acting on emergency quay wall including inertia and floating forces can be used for the practical tasks.

At severe aerodynamic and hydrodynamic conditions it will not always be possible to prevent movements of a moored ship.

In advance the study for each type of ship, should be made.

The article addresses the expected behaviour at severe aerodynamic, hydrodynamic, inertia and floating conditions of the moored ship at the destined berth.

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KRANTINIŲ ŠVARTAVIMO GEBOS DIDINIMAS

R e z i u m ė

Silpnos krantinių konstrukcijos bei krantinių avarijos apsunkina terminalų eksploataciją, o atskiros krantinės turi būti nuolat intensyviai eksploatuojamos. Straipsnyje pateiktos krantinių, ypač avarinių, skirtingų apkrovų ir jėgų skaičiavimo ir vertinimo metodų ir modelių lyginamasis tyrimas, leidžia priimti teisingus sprendimus, kaip apriboti krantinių laikomąją gebą bei sutvirtinti avarines ir techniškai nepatikimas krantines, kad jas laikinai būtų galima saugiai eksploatuoti.

Straipsnyje pateikti įvairių krantinių skaičiavimo, tyrimų ir vertinimo metodų palyginamieji rezultatai bei avarinių krantinių vertinimo metodikos. Pateikta avarinių ir silpnų krantinių ribinių sąlygų skaičiavimo ir vertinimo metodika kaip padidinti krantinių laikymo gebą bei laivų švartavimo galimybes.

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QUAY WALLS MOORING CAPACITY INCREASING

S u m m a r y

Weak quay walls constructions and accidents with the quay walls rice problems for the terminals and on busy quay walls, which very often are necessary, to continue operations. Different methods and models of the quay walls loads and forces calculation and evaluation, especially of the emergency quay walls, allow to correct actions for the quay walls limitations and strengthening emergency or weak quay walls in ports for the safe continue quay wall exploitation.

In these paper different methods of the calculation, simulation and evaluation of the quay walls and case study of the emergency quay wall and evaluation methodology are presented. Presented methodology could be used for the weak and emergency quay walls evaluation, limitations calculations and possible quay walls capacity increasing solutions.

Keywords: emergency quay walls, ship's mooring.

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