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Passing ship's influence on quay wall via moored to quay wall ships

Vytautas Paulauskas, Donatas Paulauskas

***Abstract*— Quay walls construction and mooring equipment are calculated on the basis of wind, waves, current, ice possible forces. In case of the located quay walls clause to the navigational channels, big additional dynamic forces are created on moored to quay wall ships by passing clause to moored ships. In this Article are studded possible forces, which has influence on quay wall, such as passing ship's created forces on moored to quay wall ship, additional inertia forces by moored ship. Calculation, simulation and experimental results are presented in Article.**

***Index Terms*—quay wall, passing ship's forces, moored ship's inertia forces, port schemes.**

I. INTRODUCTION

Quay walls construction and quay walls mooring equipment such as bollards, hocks, fenders and other elements are calculated on the basis of mooring ship energies, wind, waves, current, ice possible forces [1 - 6]. Quay walls, which are located clause to the navigational channels, big additional dynamic forces are created on moored to quay wall by ships passing clause to moored ships. Traditional ship's mooring equipment in case of delay slash mooring ropes of the ship creating big additional dynamic forces, which have an influence on quay walls construction via quay wall mooring equipment and on 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:

- Dynamic loads on moored ships by passing clause to moored ship other ships;
- The accompanying mooring schemes.

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

II. PORTS LOCATIONS AND QUAY WALLS SCHEMES

A lot of Sea ports located clause to sea shore or in the rivers and other similar places. Typical such ports scheme: clause to the port entrance located terminals, which request big depths, like oil, bulk ant other terminals, and clause to the quay walls located navigational channel for the ships, which pass to the other terminals. Klaipeda port (Lithuania) is one of such example: clause to the port entrance located oil and bulk terminals, navigational channel located clause to the oil terminal quay walls, in the other places of the port (Central and South part of the port), located big bulk and Container terminals.

Fig. 1. Oil terminal in the port of Klaipeda (Lithuania).

In ports, which have navigational channels clause to the quay walls with moored ships, passing ships make big influence on moored ships and via moored ships influence on quay walls structures, bollards and fenders. Dynamic forces, which create by passing ships, depends of the passing ships mass, distances between moored and passing ships (horizontal clearance) and passing ships speed. In many ports and other similar places where are moored ships clause to navigational channel are speed limitations for the passing ships, but in same time passing ship's speed should be enough for the good ship's steering.

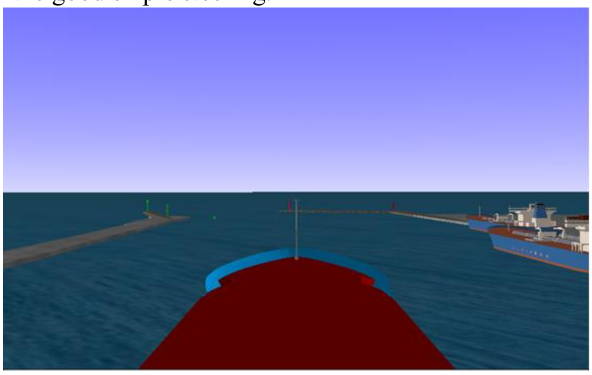

Fig. 2. Ship passing near quay walls with moored ships (visual picture).

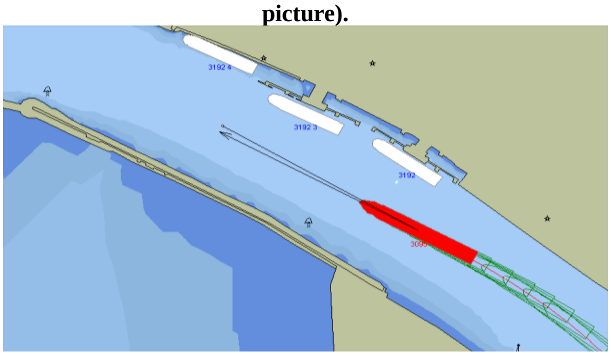

Fig. 3. Passing and moored ships to quay wall on digital map.

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Mentioned conditions are very important for the ports quay walls and ships, moored to the quay walls safety and should be studded on basis theoretical and experimental methods and include in quay walls design and ships mooring schemes preparation for the taken precaution measures for the passing near quay walls ships and moored to quay walls ships.

III. ASSING SHIP'S DYNAMIC INFLUENCE ON OTHER SHIP THEORETICAL BASIS

Passing ship near quay walls with moored ships create hydrodynamic forces, which influence on moored to quay walls ships as result of pressures and washing big quantities of the water (water add mass), which influence on the moored ship similar as current. Created forces on moored to the quay wall ship depend of passing ship's mass (*V*), speed (v) and distance between passing and moored hips (*S*), that means:

$$F = f(V, v, S) \tag{1}$$

Investigation of the mentioned dependences by theoretical and experimental methods in the real conditions in few ports, using RTK (real time kinematic) navigational and laser systems, which has accuracy of the moored ship's position up to +/- 3 – 5 mm (Dockmaster – 3 system, which is installed in Klaipeda port on oil terminal quay walls) confirmed dependences, received by theoretical methods which are presented in this article.

As main force dependency of the created by passing ship on moored to quay wall ship, received by theoretical way could be expressed as:

$$F = (A \cdot \exp(-\frac{S}{S^{'}}) + F^{'}) \cdot k(V) \cdot k(v) + F_{in} \tag{2}$$

Where: *A* – coefficient; *S* – actual distance between ships (horizontal clearance); *S'* – distance on which no real influence between passing and moored ships; *F'* – force on distance *S'*; *k(V)* – passing ship's mass dependence; *k(v)* – passing ship's speed dependence; F_{in} - inertia force.

Coefficient *A* could be receiving on the basis experimental investigations for the concrete type of the ships. *S'* distance in many cases could be taken about 3*B* (*B* – width of the passing ship) of the passing ship, because as received by theoretical studies and experimental testing results in Klaipeda and other ports for the different type of the ships, on distances more than 3*B* no real influence, that means *F'* – force on distance *S'* should be clause to 0, but in reality could be some additional constant influence by current, wind, waves, which should be detected and included in calculations.

Passing ship's mass dependence (*k(V)*) received for big ship shown that it could be calculate as follows:

$$k(V) = D\left(\frac{V}{V_1}\right)^2 \tag{3}$$

Where: *D* – coefficient, could be calculated on basis experimental data; *V* – passing ship's displacement; V_1 - moored ship's displacement.

Passing ship's speed influence on moored to quay wall ship influence $k(v)$ could be calculated as follows:

$$k(v) = Cv^2 \tag{4}$$

C – coefficient, could be calculated on basis experimental data; *v* – passing ship's speed.

Finally, force, which is created by passing ship on moored to quay wall ship could be calculate as follows:

$$F = ((F^{'} + A \cdot \exp\left(\frac{S}{3B}\right)) \cdot D\left(\frac{V}{V_1}\right)^2 \cdot Cv^2) + F_{in}$$

(5)

Created by passing ship on moored ship force *F* spread on fenders and ship's mooring ropes. In many cases force distribution could be about 50 % on fenders and about 50 % on ship's mooring ropes. Ship's mooring ropes, depend of the type of mooring ropes, can extend in length - Δl from 3 % (steel ropes) up to 30 % (synthetic ropes).

Force, which is created by passing ship on moored ship start move moored ship along quay wall. Inertia force, which creates moored ship's movement, could be calculated as follows:

$$F_{in} = m \cdot a \tag{6}$$

Where: m - mass of the ship, together with water added mass; a - acceleration

Acceleration of the moored ship can be expressed as follows:

$$a = \frac{dv}{dt} = \frac{8\Delta l}{T^2} \tag{7}$$

Where: Δl - shortest long line or spring mooring line; *T* – ships movement period, which was investigated by theoretical and experimental methods and could be calculated as follows:

$$T = L/3 \tag{8}$$

Where: *L* – moored to quay wall ship's length.

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On basis presented theory it is possible calculate forces, which create passing ship clause to mooring to quay wall ship.

IV. PRACTICAL EVALUATION OF THE PASSING SHIP INFLUENCE

For the case study and calculation purposes of the evaluation of the passing ship influence on moored to quay wall ship and quay wall, where taken passing large ships having a length of 290 m, a width of 48 m and a draft of 12,5 m at 100 % laden capacity , which has displacement of 120000 t, and the draft of 8,5 m in ballast (displacement of 88000 t) were taken; the space of projection onto a diametrical plane (DP) of the wind surface area of the vessel is 6000 m² at 100 % laden capacity and 7,200 m² in ballast; the space of projection onto a diametrical plane (DP) of the underwater area of the vessel is 3750 m² at 100% laden capacity and 2260 m² in ballast. Moored ship was taken loaded PANAMAX type tanker, which has length 220 m, width 32,4 m, draft 12,5 m, displacement 85000 t.

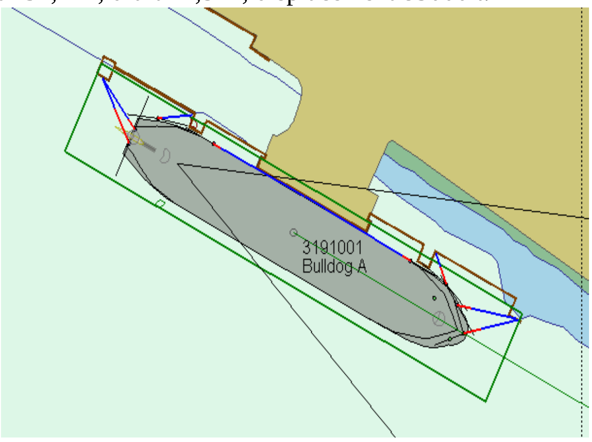

Fig. 4. Mooring arrangements PANAMAX type tanker. The centers of the ships are set approximately align to the manifold ashore.

Evaluation of the passing ship influence on the moored to quay wall ship was investigated by visual simulator SIMFLEX Navagator (Denmark) after calibration on the basis testing results on the real similar dimensions ships. For the calibration were used E-Sea Fix RTK system and laser mooring system (DOCKMASTER 3). Simulation results are presented on Fig. 5 and Fig. 6.

Fig. 5. Big passing ship sail on distance 90 m from moored to quay wall ship (visual view)

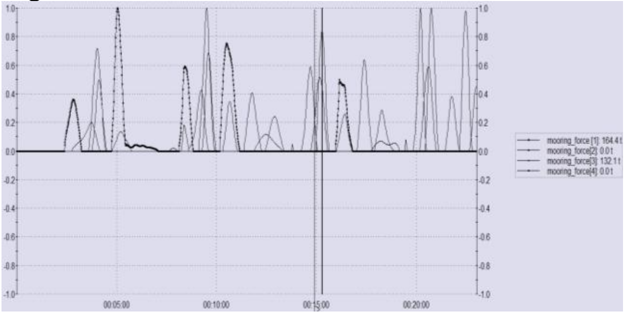

Fig. 6. Morred ships forces on the mooring lines in case of the sailing passing big ship on distance 90 m from moored to quay wall ship.

Passing and moored ships testing by calibrated simulator were made on different passing ship's speed from 6 knots up to 9 kn and distances between moored ship and passing ship from 20 m up to 160 m increasing mentioned distance every 20 m. During testing were used average wind from South West 14 m/s and current, according current map in mentioned wind conditions. Evaluation results (testing and calculations) are presented on fig. 7 and fig. 8.

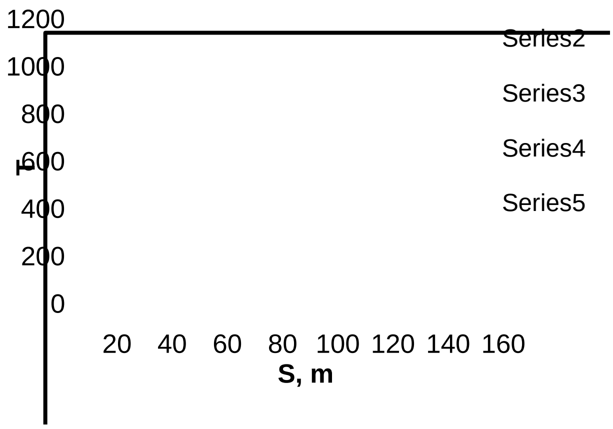

Fig. 7. Moored PANAMAX tankers fore long lines and aft springs forces depend of distance between passing and moored ships and passing ship's speed: series 2 – passing ship's speed 6 knots; series 3 – passing ship's speed 7 kn; series 4 – passing ship's speed – 8 kn; series 5 – passing ship's speed 9 kn.

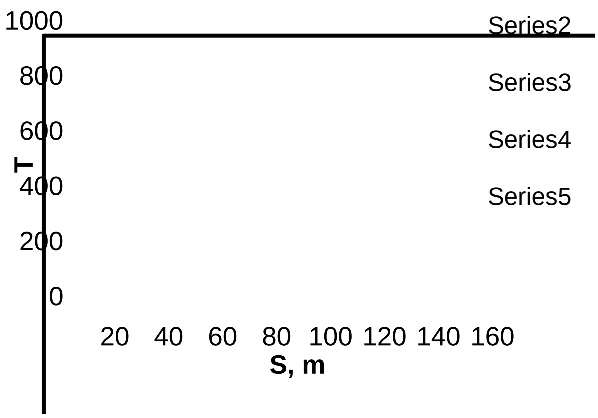

Fig. 8. Moored PANAMAX tankers aft long lines and fore springs forces depend of distance between passing and moored ships and passing ship's speed: series 2 – passing ship's speed 6 knots; series 3 – passing ship's speed 7 kn; series 4 – passing ship's speed – 8 kn; series 5 – passing ship's speed 9 kn.

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Received results were used for the Klaipeda and other East Baltic ports ships mooring schemes preparation. Mentioned mooring schemes were tested few years and shown good comparable with real ships results.

V. CONCLUSION

Ports located close to the sea shore or in the open sea regions where ships passing and waves penetrate in port areas must take in account not only a direct impact of waves but also possible forces and energies created by moored ships and waves. The combination of several possible methods (theoretical calculations, simulator testing and, for example PIANC recommendations) is very important for receiving reliable guaranty for trustful results. Forces produced by passing ships near moored to quay wall ships, as well wind, current and waves and energy via ship mooring affect quay walls, can be very powerful and have a real influence on the safety and stability of the quay wall. Ship mooring and safe stay near the quay wall is very important for all ports under varying conditions. The presented calculation and evaluation methods were tested in a number of ports and can be implemented in port areas, particularly in those open for passing ships, waves, current and wind actions.

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AUTHOR BIOGRAPHY

Vytautas Paulauskas, Kaliningrad maritime academy in 1974 (Master Marine), St.-Petersburg Maritime academy in 1979 (PhD Navigation), Vilnius Gedimino technical university in 1993 (Habilitate dr.), since 1981 – deep sea captain. Now professor in Klaipeda University (Lithuania). Published 26 monographs and study books, more than 220 scientific Articles. Project manager in and partner in EU, Lithuania and other projects in navigational safety, transport technology etc.

Donatas Paulauskas, Klaipeda university in 2004 (Master of the Port Development) author and co-author more than 20 scientific Articles, monograph and study book. Research direction – port development and optimization. Now Director of Container Shipping lines in Company “Arijus” (Lithuania).