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DETERMINATION OF THE WIND SPEED LIMITS CAUSING THE BREAK AWAY OF THE VESSEL FROM JETTY P IN NAFTOPORT – SIMULATION STUDY

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Abstract

The safety of the tanker during the loading operations carried out in the oil terminal is influenced by many factors. Based on the observations of port personnel and weather analyses in that area it was found that for Naftoport one of the most important factors affecting the security of the tanker is the wind, and more precisely – its direction and speed. Less important are accompanying waves and generated by it variable and periodic wind current. In this selected area of the Baltic Sea the direction and speed of wind change very dynamically depending on the activity of pressure patterns, which are very closely related to the occurrence of seasons. For the purpose of the article simulations were carried out of variable wind speeds, from directions causing the breakaway of the ship from the jetty, with an application of the model of the tanker in the least favourable load condition. The results obtained – the load in the mooring ropes from simulation tests were compared with the requirements of the OCIMF (Oil Companies International Marine Forum), determining the methodology of performing calculations of these forces for the selected type of tanker.

Keywords: *mooring, tankers, simulation, oil terminal, Naftoport*

1. Introduction

Due to the characteristics of the handled cargo and its impact on the state energy security [7] the Liquid Fuels Terminal (Naftoport Oil Terminal, BPPP) is an important element of the national fuel supply chain. Because of its strategic importance, the BPPP is still being developed and modernized. Currently tankers arriving at Naftoport can use five modern operational berths, whose annual handling capacity is estimated at 40 million tons [6]. Only in the first half of 2015 Naftoport served about 200 tankers, of which about 25% with the tonnage of over 80 thousand tonnes [11]. During loading and unloading of oil, oils and all petroleum products are used in automated systems, which greatly increase the level of safety. Due to the extreme flammability and toxic character of the transported cargo with respect to the environment, marinas were equipped with anti-spill protection barriers and advanced fire protection equipment, and the call of each tanker is previously analysed for its safe berthing and manoeuvres in the harbour basin. Determination of the wind speed limits causing the breakaway of the vessel from jetty it is a part of that analysis.

2. Characteristics of the research area

2.1. Port infrastructure characteristics

The port infrastructure, the length of quays and the available depth of the water allow introducing ships with a total length not exceeding 350 m, including the VLCCs (Very Large Crude Carriers) with a maximum capacity of 300 thousand tonnes. The maximum permitted draught of vessels operating along the BPPP quays amount to 10.00 m (position O); 12.70 m (position T1) and 15.00 m (positions P, R, T) [10].

Operational positions are divided among the three Fuel Basins and depending on their performance parameters; they are equipped with different loading facilities. The smallest of the available berth, (O), is able to receive and handle vessels with an overall length not exceeding 155 m and a draught of 10 m [10]. The capacity of the port installations allows for pumping 1000 m^3 of fuel oil per hour [11]. Sizes of P and R jetties allow for berthing in Naftoport the tankers with a maximum length of 300 m and a draught of 15 m [10]. In both berths there are a total of 12 loading arms, including 7 for transporting oil (4x16" – P, and 3x16" – R), with a capacity of 10,000 m^3/h [11]. Apart from oil, is also possible to trans-ship gasoline, diesel oil and fuel oil, as well as jet fuel.

2.2. Hydro-meteorological conditions

One of the key elements affecting the proper implementation of port manoeuvring is hydro-meteorological conditions prevailing in the basin. Because of the port infrastructure protecting the vessels from surges, the main impact on the safety of the ship during mooring at the wharf are the wind and the current impacting the hull. The effects of each of these weather factors are closely related to the loading status of the ship. Fully loaded vessels with deep draught are more susceptible to the sea current, whereas vessels in ballast, with a considerable windage react adversely to the wind present.

Based on many-year measurements [2], in the area of Port Gdansk there are distinguished three dominant wind directions with the total prevalence at the level of 45% [1]. The most commonly annually reported wind directions are west (17%), southwestern (14%) and south (14%) [1]. Due to the fact that the processed data relate to the whole Port Gdansk without splitting into smaller sub-areas, an analysis of messages SYNOP (FM-12) from years 2007-2012 was conducted, for the data recorded directly by the WMO 12140 station (Gdansk – Northern Port) – the measurements of that station are the most applicable to meteorological conditions observed in Naftoport. The results showed a higher incidence of the wind from the south (25%) [12] and the smaller of the NE direction, in comparison to the values obtained from the many-year measurements. Fig. 1 shows the average annual prevalence of the wind directions in the area of Port Gdansk and the measuring station Gdansk – Northern Port.

The infrastructure of the Northern Port, in particular the system of breakwaters makes wind directions with the highest incidence (S-SW-W), cause less difficulty while operating cargo handling and port manoeuvring than a strong wind of the 045-090° angular sector. This is due to the geographical position of the Northern Port, namely smaller covering of the oil terminal and the manoeuvring basin by the port hydro-technical structures. In order to carry out a detailed analysis, the wind directions that most affect the safety of ships moored in Naftoport were divided into smaller sectors of different angular span. Fig. 2 shows the incidence of the wind directions as divided into consecutive months for the measuring station Gdansk – Northern Port.

2.3. Model (Oil Tanker Disp. 30645)

Selected model, which was used in the research, was carried out after statistical processing and analysis of data on ships calling at BPPP. This information took the form of real notices of arrival

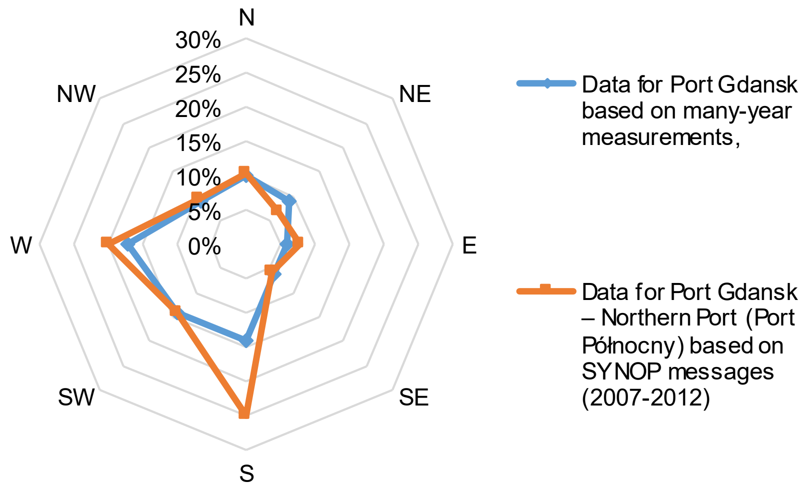


Fig. 1. Frequency of wind directions for Port Gdansk and Northern Port annually [1], based on [2, 12]

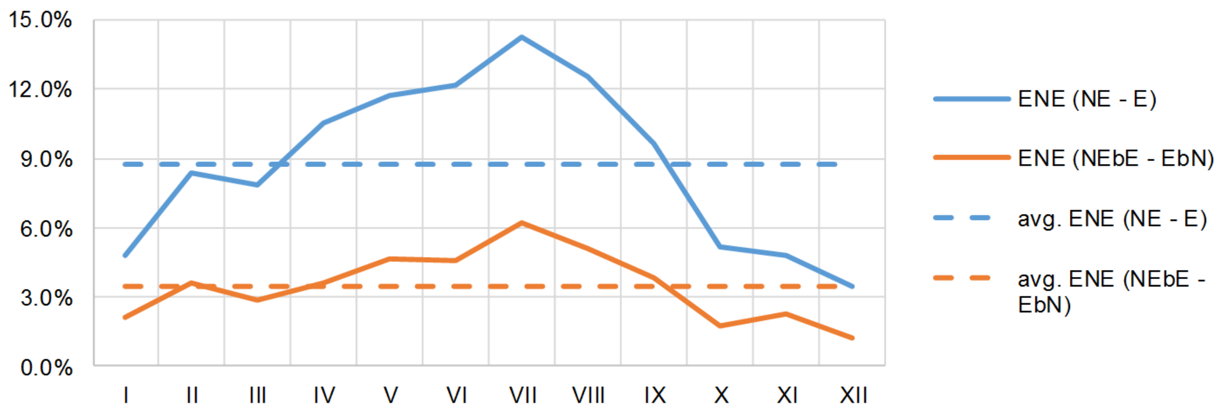


Fig. 2. Frequency of ENE wind annually for different angular sectors along with average values [1]. Based on [12]

of the ships to the Base Liquid Fuels Handling the North Port of Gdansk in the period 17.04-12.10.2015.

The ships that arrived at the BPPP at that time were divided into three main groups depending on their type and characteristics. For the purpose of the article, a model of Oil Tanker (LOA 242.80 m) has been selected, as a model representing the vessels of a total length of 228.60 – 275.70 m (32.4% of the analysed ships).

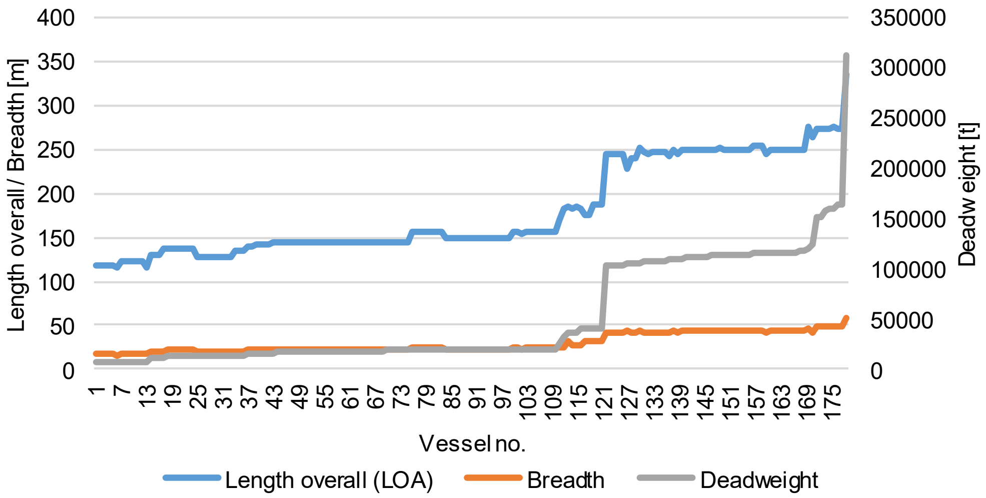
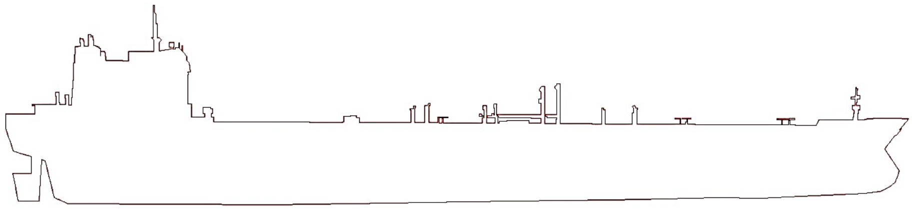


Fig. 3. Comparative analysis of the main technical parameters of ships calling at BPPP [1]

Tab. 1. Characteristic and the basic operating parameters of the model Oil Tanker. Based on [8]



Model	Length overall [m]	Breadth [m]	Draft forward/aft [m]	Displacement [t]	Type of Engine	Propeller
Oil Tanker	143.97	21.82	9.15/9.15	21515.0	Medium Speed Diesel 6300 kW	CPP

3. Requirements

3.1. OCIMF Requirements

The guidelines and requirements for oil tankers carrying oil supplies are regulated by the OCIMF (Oil Companies International Marine Forum). It offers industry standards established by a group of experts – respecting those standards is recognized as complying with best practice and may be required by an organizational unit supervising the ship.

One of the main weather factors affecting the change of the ship position at the berth is the wind. For this reason, OCIMF has developed formulas allowing calculating and taking into account the forces impacting the vessel, which are caused by the presence of horizontal movements of air masses. In order to perform the correct calculation, you must bring the speed of the wind acting on the ship (v_W) to a common reference level [5]. This is due to changes in wind speed, respectively with the height above sea level. If the measurement was taken at a height other than 10 m, it is necessary to use formula (1) to obtain a corrected value which will be used in further calculations [4].

$$V_W = v_W \left(\frac{10}{h}\right)^{\frac{1}{7}}, \tag{1}$$

where:
V_W – wind speed at the height of 10.0 m [m/s],
v_W – wind speed measured at the height h [m/s],
h – measurement level above the sea [m].

The result of the occurrence of the wind on the waters on which the tanker is moored are the emerging external forces acting on longitudinal and transverse directions, as well as torques. Their values are due to the impact of the wind on the vessel can be determined on the basis of the following formulas [4]:

– The power of impact of wind on the longitudinal direction [4]:

$$F_{XW} = \frac{1}{2} C_{XW}\, \rho_P\, V_W^2\, A_T\ , \tag{2}$$

$$F_{XW} = 0.000624\, C_{XW}\, V_W^2\, A_T \ \ [\mathrm{kN}]\,, \tag{3}$$

where:
C_{XW} – coefficient for the longitudinal force of wind impact from Fig. A2 [4],
ρ_P – air density [t/m^3],
V_W – designated wind speed [m/s],
A_T – transverse surface of the vessel exposed to the wind [m^2].

– The power of impact of wind on the transverse direction [4]:

$$F_{YW} = \frac{1}{2} C_{YW}\, \rho_P\, V_W^2\, A_L\,, \tag{4}$$

$$F_{YW} = 0.000624\, C_{YW}\, V_W^2\, A_L \ \ [\mathrm{kN}], \tag{5}$$

where:
C_{YW} – coefficient for the transverse force of wind impact from Fig. A3 [4],
ρ_P – air density [t/m^3],
V_W – designated wind speed [m/s],
A_L – longitudinal surface of the vessel exposed to the wind [m^2].
– The torque applied by the action of wind [4]:

$$M_{XYW} = \frac{1}{2} C_{XYW}\, \rho_P\, V_W^2\, A_L\, L_{BP}\,, \tag{6}$$

$$M_{XYW} = 0.000624\, C_{XYW}\, V_W^2\, A_L\, L_{BP} \ \ [\mathrm{kNm}], \tag{7}$$

where:
CX_{YW} – coefficient for the wind torque from Fig. A4 [4],
ρ_P – air density [t/m^3],
V_W – designated wind speed [m/s],
A_L – longitudinal surface of the vessel exposed to the wind [m^2],
L_{BP} – ship length between postal sections [m].

In accordance with the requirements of the *Mooring Equipment Guidelines*, a typical arrangement of mooring lines (Fig. 4) for the tanker includes the use of 4 mooring lines (two at the bow and two at the stern of the ship), 8 breasts (two per each mooring dolphin – a total of 4 in the bow and 4 in the stern part of the vessel), and 4 spring lines (2 bow and 2 stern ones) fixed to the loading platform [4].

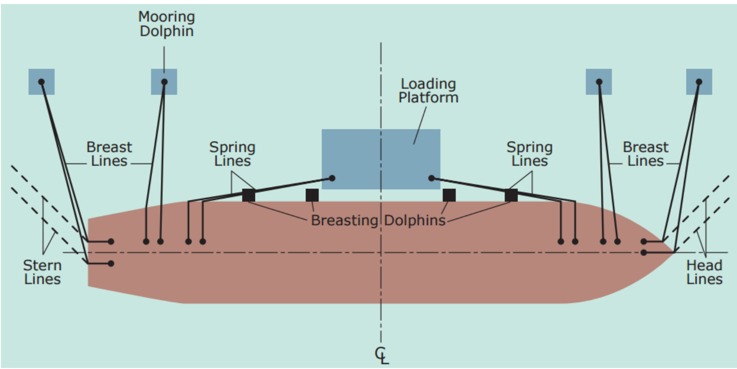


Fig. 4. Typical Mooring Pattern recommended by OCIMF [4]

During calculations taking into account external factors such as the wind and the current there should be considered the least favourable scenarios, assuming the occurrence of summary vectors of wind and current speed from given direction. Due to the large area of inflow, the wind impacting the hull from transverse directions generates up to five times more power than the wind at the same speed but from longitudinal directions [4]. The maximum values of the transverse forces generated by the action of weather factors occur in the direction of the wind from about 080° to 110° relative to the bow, and the greatest generated axial forces appear during the impact of the wind from the bow or the stern parts of the ship. In order to increase the torque, the current direction should differ slightly from the axis of symmetry of the ship and impact the bow or stern at an angle of about 5° [4].

OCIMF required that tanker's mooring arrangement and fittings should be resist for forces generating by wind, current and waves. Whether condition and wind speed always limited all cargo operations in oil terminal and with wind speed:

– 25 knots (12.5 m/s) terminal suspended cargo operations,
– 30 knots (15.0 m/s) terminal disconnected cargo arms,
– 35 knots (18.0 m/s) terminal required tug assistance for tanker and vessel should be ready any time to unberthing.

Additional OCIMF required that all tankers should be resist to acting forces caused by wind speed up to 60 knots (31 m/s), but strength in single rope should be not greater than 55% of the MBL lines. Limit for strength in mooring lines depends also on the type of material used, and MEG specify following limits:

– not more than 55% MBL for steel wires with tails,
– not more than 50% MBL for synthetic lines,
– not more than 45% MBL for polypropylene lines.

3.2. Local requirements

Apart from the recommendations of the OCIMF, the units manoeuvring or mooring in port areas are required to meet the requirements of the administration of the coastal state. In the case of Naftoport and Fuel Basins, regulations governing the conditions for port manoeuvres carried out by tankers are determined by the Maritime Office in Gdynia. Those regulations include both general guidelines, for Port Gdansk and detailed ones for Northern Port. Ordinance No. 5 of the Director of Maritime Office in Gdynia, dated 20 February 2013 – *Port Regulations* – sets specific requirements and safety requirements for ships in the study area. Additional information governing the rules of conduct of tankers operating in Naftoport when entering and leaving the port, as well as a stop at the wharf were included in the *Atlas of Permitted Draughts*.

The guidelines contained in Port Regulations define the basic requirements for tankers operating in Gdansk – Northern Port; they include, among others, the permissible length of vessels mooring at quays, the minimum number of tugs used in manoeuvres, linesmen or the required number of pilots taken on board before entering the port. The most important requirements provided for tankers manoeuvring in Fuel Basins located in the area of Naftoport are [9, 10]:

– the permissible length of the vessel entering Northern Port excluding the DCT (*Deepwater Container Terminal*) and the waterfront T is a maximum of 300 m. The permissible draft of 15.0 m with an average water level of 500,
– oil tankers with a total length of more than 200 m and a draft of more than 13.0 m are required to use the services of 2 pilots,
– the number of tugs required to maintain assistance involving tankers operating in Northern Port depends on their total length. For vessels exceeding 220 m the required maximum number of tug boats is 4, as prescribed by regulations,
– tankers operating in the internal waters of Northern Port are additionally required to make effective use of not less than one tug boat tied to a towing rope,
– for VLCC type vessels (*Very Large Crude Carrier*) during manoeuvres in Naftoport there are envisaged weather limit conditions under which it is possible to perform a safe entry to and exit from the port. When entering the ship, the permissible wind speed is 10.7 m/s in the daytime and 5.4 m/s at night. In the case of manoeuvring while leaving the port those values are 13.8 m/s and 7.9 m/s, respectively,
– in the case of VLCC vessels, the Harbour Master may order the removal of the ship, if the weather forecast foresees winds of more than 11°B,
– the wind speed at which – according to the *Atlas of Permitted Draughts* – it is recommended to disconnect the loading arms is 24.4 m/s.

Requirements for Port Gdansk and Naftoport are mainly the same as mentioned above with

OCIMF recommendation for oil terminals. However, there are some additional factors, which should be taken in to account, when the vessel is moored in Naftoport. Especially current within Fuel Basin no. 1 affected safe mooring and cargo operations.

4. Research studies

To carry out the research studies Transas Navigational Manoeuvring Simulator NaviTrainer 5000 Professional [8], a simulator of electronic charts (ECDIS) NaviSailor 4000 and a Model Wizard application have been used. Devices selected to analyse apply complex mathematical models. As a result, it is possible to perform the detailed mapping of reaction and behaviour of the ship and its surroundings according to the phenomena observed in real conditions.

The TRANSAS simulator was repeatedly used in numerous scientific studies, design work and expertise. Besides the objectives of researches, the devices are used at regularly conducted specialized courses and didactic classes for future watch-keeping officers, senior merchant navy officers and Deep-Sea captains. The simulator is accredited by the classification society DNV (*Det Norske Veritas*) and has certificates confirming its ability to perform certified specialist courses in accordance with the requirements of the International Maritime Organization – IMO.

4.1. Theoretical calculations

The scope of calculations and simulations was conducted based on the following scenarios:

- The direction of wind and current running parallel to the quay, causing longitudinal movement of tanker at berth P;
- The direction of wind and current running along the quay, causing parallel movement (moving away) of tanker at berth P.

All calculations were carried out appropriate to the simulation scenarios. Results obtained for the direction of wind and current running parallel to the quay, causing longitudinal movement of tanker at berth P – fore.

- maximum frontal wind and current force: 603 kN,
- total load in mooring ropes: 967 kN.

Results obtained for the direction of wind and current running parallel to the quay, causing longitudinal movement of tanker at berth P – aft

- maximum frontal wind and current force: 428 kN,
- total load in mooring ropes: 665 kN.

The direction of wind and current running along the quay, causing parallel movement (moving away) of tanker at berth P.

- maximum lateral wind and current force: 2096 kN,
- total load in mooring ropes: 2197 kN.

On the base theoretical calculations recommended by Naftoport mooring pattern, fulfil OCIMF requirements.

4.2. Simulation studies

The second part of the analysis of the conditions of ships berth at the quay included the execution of simulation tests, in order to compare them with previously obtained results of theoretical calculations. The measurements were carried out for Oil Tanker ship's model (Tab. 1) at selected wind and current directions and speeds, in accordance with the recommendations contained in the Mooring Equipment Guidelines [3]. In order to obtain the dynamic changes in the load of the mooring lines during vertical movements of the ship, they also included the presence of waves in Fuel Basins.

In the simulations and calculations, they retained the configuration and placement of the mooring lines in accordance with the Mooring Arrangement [3]. Based on the data on the strength of mooring devices with which quays are fitted, they set the maximum strength of mooring ropes for the selected tanker. Due to the lack of data, the nominal strength of the mooring lines – (minimum breaking load, MBL) – for the tested model was determined based on the guidelines contained in the publication Guidance on shipboard towing and mooring equipment IMO MSC/Circ.1175 [5]. The calculation and simulation tests used the smallest value from a designated range of the strength of the mooring lines.

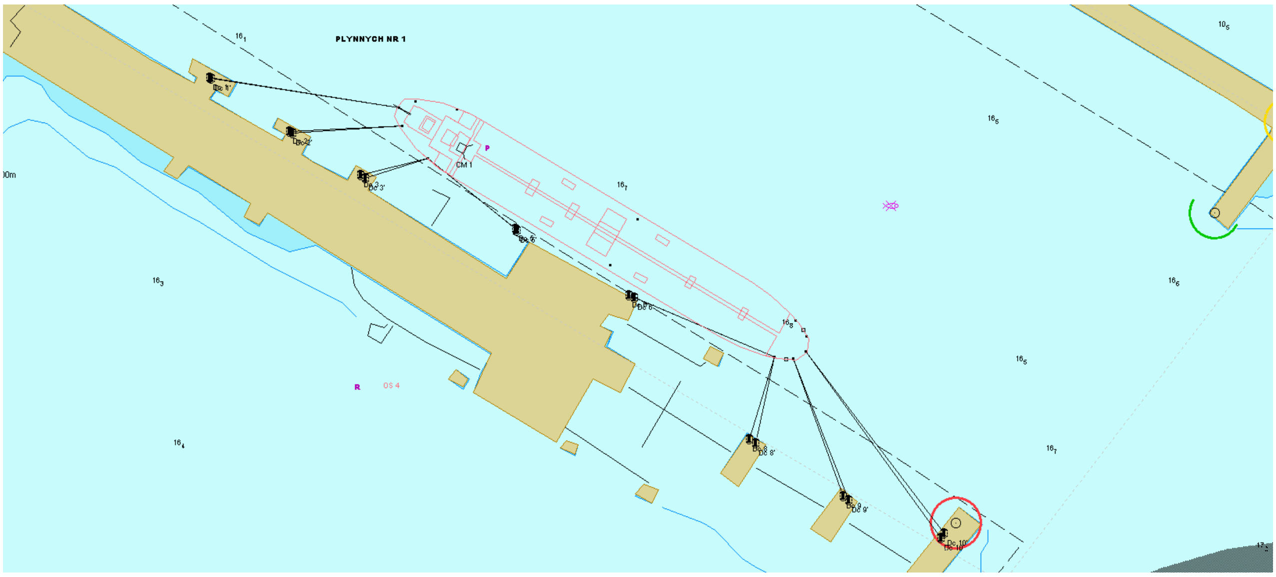


Fig. 5. Mooring arrangement for Oil Tanker model on Transas NaviTrainer 5000 Professional [8]

For the selected berth and the ship model, the recommended configuration and strength of mooring lines carries only a certain value of the forces associated with the impact of wind and current. In unfavourable conditions, they may result in the tanker's moving away from the quay. In such situation, it may be necessary to mount additional mooring lines that will most effectively transfer the increasing load from external forces. Also, the load limit values should be accounted for each of the mooring lines so that they are not exceeded.

Tab. 2. Partial results for selected lines at different time of simulation in each scenario

Simulation scenario	Simulation time [hh:mm:ss]	Mooring line to Bollards Forces [t]									Total force from all the mooring lines		
		Dc 9 – 2nd forward breast line		Dc 8 – 4th forward breast line		Dc 5 – 2nd aft spring line		Dc 3 – 2nd aft breast line		True wind speed [knt]	Lat. [t]	Long. [t]	Yawing moment [t*m]
		Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.				
001	00:40:00	6.58	–9.35	8.42	–7.14	1.69	–11.86	8.85	3.16	39.42	77.54	–32.37	233.35
	00:50:00	6.85	–9.75	8.65	–7.36	1.83	–12.81	8.53	3.04	48.87	78.92	–40.81	43.97
	01:00:00	7.49	–10.71	9.14	–7.82	2.07	–14.60	7.78	2.75	58.30	77.28	–54.92	–469.41
002	00:40:00	4.78	–6.49	6.32	–4.89	1.10	–7.55	9.78	3.90	39.42	75.66	21.31	1337.07
	00:50:00	4.50	–6.08	6.22	–4.79	0.97	–6.63	10.46	4.18	48.87	77.40	32.22	1642.23
	01:00:00	3.87	–5.22	5.28	–4.05	0.81	–5.53	10.16	4.09	58.30	73.94	45.12	1875.46
003	00:40:00	10.32	–14.26	21.63	–17.89	0.80	–5.48	16.86	5.97	39.42	137.12	0.01	–541.28
	00:50:00	14.58	–19.70	36.87	–29.58	0.54	–3.58	26.16	9.36	48.87	201.34	0.50	–1307.20
	01:00:00	19.93	–26.32	57.31	–44.63	0.33	–2.09	39.96	14.43	58.30	289.53	–0.38	–1854.30

During the simulation research specified the maximum wind speeds at the uploaded directions, for MBL limit values of used ropes and the brake of mooring winches.

According to the mooring pattern, the Oil Tanker model in ballast condition affected by the wind from the stern, is able to maintain its position at a quay with the wind speed up to 60 knots and the current speed equal to 2 knots. The simulation tests have confirmed that the vessel can maintain its position at a quay during wind with a constant speed according to OCIMF requirements.

The maximum load values for a single mooring line equal to about 35-40% of the MBL appeared in simulation tests on a bow spring line and at a wind speed of 60 knots and a current speed of 2 knots (maximum requirements).

In simulation 003 limit of 50% MBL is exceeded, therefore, at the wind directions 210° at speeds greater than 60 knots, providing additional spring lines or unberthing operation should be considered.

Finally recommended, by oil terminal mooring pattern on jetty P for such size of tanker fully satisfy OCIMF requirements.

5. Summary

Theoretical values obtain on base the OCIMF recommendation do not contain dynamic changes of forces due to wind gusts and ship reaction from waves which increased strength in the mooring lines. Normally maximum values of forces obtain from simulation, which caused break away from jetty are less than these obtain from mathematical formulas. It means that values of forces from calculations always will indicate, that vessel can be resist for greater wind speed than in real situation. The calculations of forces should be used as the base to be aware and find the value of wind caused break away from jetty, but also should be taken into account that vessel can move and lines can be broken by the wind's speed less than this expected form the calculations.

Simulation research give more realistic results and allow the terminal staff to find proper means to protect berth and vessel during port stay.

Simulations give also answer which line is weakest link in recommended by terminal mooring pattern, and where the crew should put greater attention to protect the lines and in case deterioration of the weather find proper solution or give additional lines.

Simulations give additional information regarding force distribution between all mooring lines, and allow monitoring which line is strengthen more than others. Values of force in single line more than 55% MBL is one of limits for safe berthing.

Some terminals delivered booklet, where on the base of simulation research obtain the limits of wind speed on different directions. Such presentation of limits allows monitoring weather condition and in proper time introducing, the relevant means to protect vessel and jetty.

Oil terminals used mooring hooks, which are monitored by operator, not only in emergency release but also to control the value of the strength in the ropes. When strength value cross the limits relevant procedures should be applied and vessel staff informed accordingly.

Results obtain from simulation research should be used as the base to prepare the relevant emergency procedures and information for tankers berthing in Naftoport.

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