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LNG Ship Mooring Analysis in Gazenica Port

Abstract

The safe mooring of LNG ships at Gazenica port is part of safe cargo handling operations and for reducing the risks of accidents. This paper analyzes the elements of the mooring system, including the type of mooring equipment, the impact of external forces (such as the wind, waves, and tidal movements), and optimal mooring angles. A particular focus of the research is the analysis of the existing infrastructure at Gazenica port, including the bollards and the implementation of advanced technologies, such as sensors for monitoring the forces acting on the mooring lines and the ship during mooring operations. The paper also takes into account the compliance with international safety standards and regulatory requirements, including IMO (International Maritime Organization) and OCIMF (Oil Companies International Marine Forum) standards, and analyzes specific requirements arising from LNG terminal regulations. Based on the conducted analysis, the paper provides recommendations for improving the mooring system at Gazenica port, improving safety, efficiency, and environmental protection. The conducted analysis contributes to a better understanding of the challenges associated with the mooring of LNG ships and suggests infrastructure improvement. Furthermore, the paper points out the importance of integrating new technologies into the mooring process, enabling better monitoring and optimization of operations and increasing safety during the ship's stay at berth.

Keywords: LNG, mooring, safe, berth

1. Introduction

The arrangement of a ship's mooring system and its implementation are key factors in maintaining safety at berth. By correctly configuring the mooring system, a ship experiences reduced movement at berth, which improves the safety of operations. Therefore, during mooring system planning, many factors must be considered, such as the breaking load and elasticity of the lines, the angles at which mooring lines act, external forces and permissible ship movements, while also taking into account the berth location and cargo handling technology. The mooring system must also comply with various requirements set by the relevant authorities [1]. Although shipboard equipment is commonly used during ship mooring, modern terminals may employ advanced shore-based mooring equipment. During a ship's stay at berth, continuous monitoring of mooring lines is essential. Significant assistance may be provided by sensors installed on key system components, enabling the monitoring of acting forces [2]. Since mooring a ship is one of the riskier operations, it is important to ensure crew safety, both during mooring and throughout the ship's stay at berth [3]. Given the challenges posed by the size of LNG ships and the high forces generated by external forces such as wind, waves, tides, and sea currents, mooring must be carried out with thorough planning [4]. Ship safety at berth depends on the mooring system, as poor mooring configuration can lead to damage to the ship, mooring equipment, fender systems, or terminal infrastructure [5]. Accidents during mooring operations may include collisions and grounding, while during the ship's stay at berth dangerous ship movements or an improper distribution of external forces acting on the ship, which can cause equipment damage or environmental incidents. For this reason, it is necessary to understand the importance of an effective mooring system [6]. Furthermore, a safe mooring system for LNG carriers plays an important role in optimizing terminal operational efficiency. This includes reducing the time required to safely moor the ship and enabling faster and safer cargo operations [7]. A safe mooring system also reduces maintenance costs, as proper mooring decreases loads on equipment and infrastructure, thereby reducing the need for maintenance [8]. Continuous analysis and optimization of mooring systems enhance safety, efficiency, and the sustainability of all processes. The integration of new technologies, such as sensors for monitoring external forces acting on mooring lines, enables control and adjustment of mooring arrangements [9]. These technologies also improve risk management and reduce the human error [10].

The port of Gazenica is currently used as oil products port and in the future there is a possibility that it may accommodate LNG ships. In order to accept LNG ships, it is essential to analyze the current mooring arrangement using appropriate tools and ensure that it complies with the previously mentioned requirements. This paper analyzes the physical aspect of mooring arrangement, together with the applicable requirements, using Optimoor software. The recommendations aim to improve the safety of mooring operations at the berth and enable safe cargo handling operations, while ensuring that the proposed solutions are practical and cost-effective.

2. Structure of Optimoor software

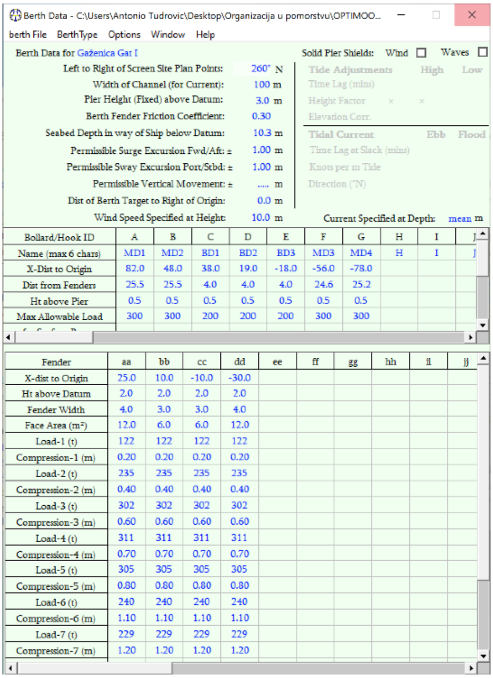
OPTIMOOR software is a tool used for the analysis of ship mooring systems. The user inputs the data related to the ship and the berth, after which the software calculates the forces acting on the mooring lines resulting from external factors such as wind, waves, and currents. Calculations are performed instantly, allowing for quick analysis of various mooring scenarios, environmental conditions and drafts. The user defines the mooring configuration by specifying the types of mooring lines used on the ship and bollard locations. Line tensions can be adjusted by simulating the heaving in or paying out of mooring lines. OPTIMOOR can also be used as a planning and simulation tool to verify the safety of mooring a ship at a berth under varying conditions. It allows users to pre-plan mooring arrangements and assists in operational mooring management. In addition, the software can be used as a training tool to familiarize crews and terminal personnel with the advantages and limitations of different mooring methods and conditions [11].

2.1. Input data for analysis

Before calculations, it is necessary to collect input data to enable realistic modelling of operational conditions. The minimum data set includes:

- terminal/berth data
- fender data
- ship data
- environment conditions, and
- ship windage area.

Terminal or berth data are important for determining mooring lines arrangement. It is necessary to properly determine the position and height of bollards and fenders. Berth data also includes external factors, which includes determining berth orientation, navigating channel width and depth and height of the berth (Figure 1).



Berth Data for Gaženica Gat I

Solid Pier Shields: Wind ☐ Waves ☐

Left to Right of Screen Site Plan Points: 260° N
Width of Channel (for Current): 100 m
Pier Height (Fixed) above Datum: 3.0 m
Berth Fender Friction Coefficient: 0.30
Seabed Depth in way of Ship below Datum: 10.3 m
Permissible Surge Excursion Fwd/Aft: ± 1.00 m
Permissible Sway Excursion Port/Stbd: ± 1.00 m
Permissible Vertical Movement: ± ..... m
Dist of Berth Target to Right of Origin: 0.0 m
Wind Speed Specified at Height: 10.0 m
Current Specified at Depth: mean m

Bollard/Hook ID	A	B	C	D	E	F	G	H	I	J
Name (max 6 chars)	MD1	MD2	BD1	BD2	BD3	MD3	MD4	H	I	J
X-Dist to Origin	82.0	48.0	38.0	19.0	-18.0	-56.0	-78.0			
Dist from Fenders	25.5	25.5	4.0	4.0	4.0	24.6	25.2			
Ht above Pier	0.5	0.5	0.5	0.5	0.5	0.5	0.5			
Max Allowable Load	300	300	200	200	200	300	300			

Fender	aa	bb	cc	dd	ee	ff	gg	hh	ii	jj
X-dist to Origin	25.0	10.0	-10.0	-30.0						
Ht above Datum	2.0	2.0	2.0	2.0						
Fender Width	4.0	3.0	3.0	4.0						
Face Area (m²)	12.0	6.0	6.0	12.0						
Load-1 (t)	122	122	122	122						
Compression-1 (m)	0.20	0.20	0.20	0.20						
Load-2 (t)	235	235	235	235						
Compression-2 (m)	0.40	0.40	0.40	0.40						
Load-3 (t)	302	302	302	302						
Compression-3 (m)	0.60	0.60	0.60	0.60						
Load-4 (t)	311	311	311	311						
Compression-4 (m)	0.70	0.70	0.70	0.70						
Load-5 (t)	305	305	305	305						
Compression-5 (m)	0.80	0.80	0.80	0.80						
Load-6 (t)	240	240	240	240						
Compression-6 (m)	1.10	1.10	1.10	1.10						
Load-7 (t)	229	229	229	229						
Compression-7 (m)	1.20	1.20	1.20	1.20						

Figure 1. Example of berth information in Optimoor software [11].

Fenders are an essential component of a berth; therefore, it is necessary to define their key characteristics. These include the front plate area, the height of the contact point, the energy absorption capacity, the type of material, the type of fender, the deformation curve, the location of the contact point (centered or off-centered), and the operating temperature range.

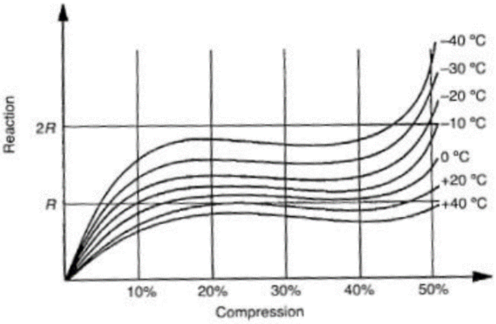


Figure 2. Example of fender deformation in different temperatures [12].

The influence of temperature on the fender force–deformation curve is shown in Figure 2, where it can be observed that the reaction force increases as the temperature decreases. The fenders are tested at 23 °C in accordance with PIANC (The World Association for Waterborne Transport Infrastructure) procedures [13]. In OPTIMOOR, it is necessary to define up to ten points along the force–deformation curve. The initial zero point does is not required, and the first point should correspond to the end of the "linear" portion of the curve, for example, 200 tons (Figure 3).

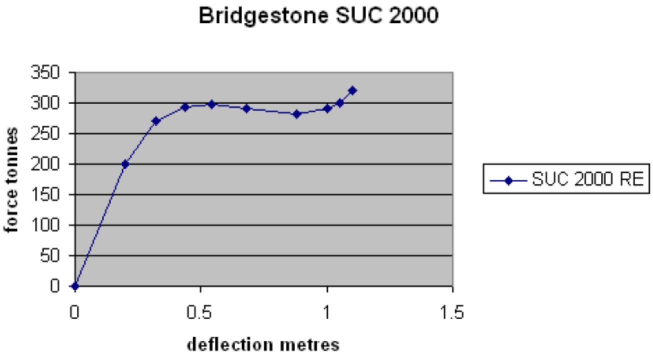


Figure 3. Example of fender force–deformation curve [12].

Off-center ship fender contact causes asymmetric fender deformation, which results in a reduction of force for the same level of deformation compared to symmetric deformation. The term "low contact", shown in Figure 4, refers to asymmetric fender deformation, producing a lower curve compared to symmetric or "central contact" deformation.

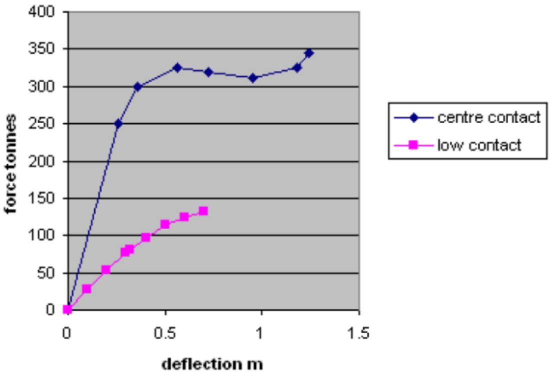


Figure 4. Comparison of centered and off-centered ship fender contact point [12].

For reliable analysis of ship maneuvering, mooring operations, and overall safety management, it is necessary to collect a set of technical and operational data of the ship. The data enable modelling of the ship's behavior in interaction with external forces and port infrastructure. The required parameters are the ship's length between perpendiculars, beam, draft, lateral and frontal areas above the main deck exposed to wind, as well as the length and height of the parallel midship section, bow, and stern (always referenced to the ship's centerline and main deck), considering either prismatic or spherical geometry.

Besides ship data, it is necessary to determine the environmental conditions at berth. It is necessary to know local conditions, as localized variations can significantly influence safety. On-site specific parameters are wind speed and direction relative to the berth or true geographic orientation, current speed and direction relative to the berth or true geographic orientation, significant wave height and other forces that can affect the ship, such as tug assistance or passing traffic.

In OPTIMOOR, the wind-exposed surface area of a ship has two components: the freeboard section and the areas above the main deck. The freeboard area is calculated automatically by OPTIMOOR, as the user provides the ship's draft, hull height, length between perpendiculars, and the beam. The surface area above the main deck varies among different types of LNG carriers, and therefore, the user must manually determine and enter this value. Figure 5 shows an example of how to measure the lateral wind-exposed surface using a surface measurement tool. The area of the aft superstructure is subtracted from the total above-deck area, and a nominal allowance is included for all railings, pipelines, and masts. For a specific draft, this area can be derived from shipbuilding plans; however, such plans may contain errors. It is generally preferable to measure directly from the ship's drawings. Precision may vary, as the wind resistance coefficients in OCIMF MEG4 [1] already include approximately 10% conservatism.

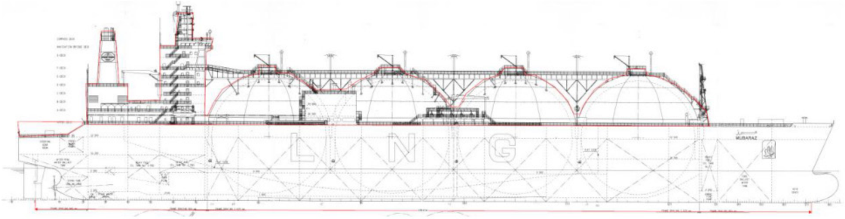
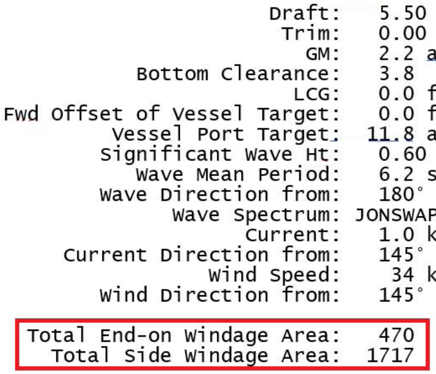


Figure 5. Example of calculation of ship wind-exposed surface [12].

Figure 6 shows an example from OPTIMOOR, showing the total wind-exposed surface area (freeboard plus above-deck area). Changing the ship draft automatically adjusts the calculated surface area for that specific draft.



```
                    Draft:   5.50 (initialised at 7.00)
                     Trim:   0.00 (initialised at this trim)
                       GM:   2.2 and  3.3 (Guest)
        Bottom Clearance:   3.8
                      LCG:   0.0 from midship (+ve forward)
 Fwd Offset of Vessel Target:   0.0 from Berth Target
      Vessel Port Target:  11.8 above Pier
     Significant Wave Ht:   0.60
        Wave Mean Period:   6.2 sec
     Wave Direction from:   180° True  -80° Screen Right
           Wave Spectrum: JONSWAP
                 Current:   1.0 knots
  Current Direction from:   145° True -115° Screen Right
              Wind Speed:    34 knots (NPD Spectrum)
     Wind Direction from:   145° True  245° Screen Right

Total End-on Windage Area:    470
  Total Side Windage Area:   1717
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Figure 6. OPTIMOOR software ship windage area result [11].

Table 1 shows an extract of data on lateral and frontal wind-exposed surface areas for different classes of ships, specifically for LNG carriers. Those areas represent an important factor in the calculation of mooring line loads, as they directly influence the total wind resistance acting on the ship.

Table 1. An extract of data on lateral and frontal wind-exposed surface areas for different classes of LNG carriers [12].

Type of LNG ship	Draft (m)	Longitudinal windage area (m^2)	Total longitudinal windage area (m^2)	Transverse windage area (m^2)	Total transverse windage area (m^2)
Spherical LNG ship with 5 tanks	9.50	3793	8273	1047	1780
	11.70		7657		1679
Spherical LNG ship with 4 tanks	9.50	3744	8557	1061	1903
	11.50		8007		1807
Spherical LNG ship with protected tanks	9.80	4810	9850	1248	2090
	11.50		9350		2010
Prismatic LNG ship with capacity of 153000 m^3	9.35	2248	6843	666	1410
	11.37		6286		1320

Prismatic LNG ship with capacity of 174000 m^3	9.30	2985	7947	870	1668
	11.50		7313		1566
Prismatic LNG ship with capacity of 210000 m^3 (QFlex)	9.40	3060	8393	800	1680
	12.00		7605		1550
Prismatic LNG ship with capacity of 260000 m^3 (QMax)	9.50	3489	9317	1101	2064
	12.00		8484		1926
Prismatic LNG ship with capacity of 12000m^3	5.50	906	1717	301	470
	7.00		1559		437

3. Meteorological and oceanographic characteristics of the analysis area

The Port of Gazenica is located in the central part of the Adriatic Sea, in the vicinity of the city of Zadar. In this analysis, data from the Zadar meteorological station is used, along with sources describing the atmospheric and oceanographic conditions characteristic of the central Adriatic. Due to the configuration and the orientation of the coastline, the most frequent and most significant winds in the area of the Port of Gazenica originate from the southeast (SE), northwest (NW), and east (E). This indicates a dominant influence of the sirocco and the maestral, while exposure to the bora (NE) is considerably lower as a result of orographic barriers in the hinterland, particularly the Ravni Kotari region. Owing to shelter from the open sea and the surrounding terrain configuration, strong and storm-force winds occur much less frequently in this area than in the northern and southern Adriatic [14]. During the period from 1997 to 2006, the highest recorded wind speed was 20.8 m/s (10-minute mean), associated with an ESE wind. According to data from the Zadar meteorological station, the strongest winds throughout the year predominantly originate from the SE and ESE directions, while winds from the NE and NW sectors are also among the more intense. Winds from the N and NE directions generally have a lower impact, as the bora loses strength while passing over the Ravni Kotari region. Particular attention should be given to south-easterly winds (sirocco), which represent the most frequent winds from the southern sector and can reach speeds of up to 23 m/s, with gusts exceeding 25 m/s. Prolonged sirocco events can significantly affect navigation safety and mooring conditions. The second most frequent wind is the maestral (NW), which typically does not exceed speeds of 17 m/s. The third most common wind is the levant (E), which may reach speeds of up to 20 m/s and can also influence ship maneuvering and safety at berth [14, 15]. Long-term measurements (1961–1990) indicate that Zadar experiences an average of approximately 25 days per year with moderately strong or stronger winds (≥ 5 Beaufort). Storm-force winds (≥ 8 Beaufort) occur on average only 1.5 days per year. Data from a shorter observation period (1981–2001) confirm that SE and NW winds are the most frequent. During this period, 12 days with winds exceeding 6 Beaufort were recorded, while no days with winds of 8 Beaufort or higher were observed. Summer months are characterized predominantly by weak winds, with very rare episodes of strong or storm-force gusts. Calm conditions (wind speeds below 0.3 m/s) occur on average on 29% of days per year and are most frequent during summer. This period also coincides with an increased number of arrivals of smaller ships at the Port of Gazenica, providing favorable conditions for safe navigation and maneuvering. For most of the year, winds in the Port of Gazenica area do not have a significantly adverse impact on navigation, maneuvering, or ship's stay at berth. However, under strong and stormy wind conditions, particularly during berthing operations involving ships of various sizes, maneuvers may become difficult or impossible, with smaller ships being especially vulnerable to adverse weather conditions [16].

Due to the very short fetch lengths, resulting from the distribution of islands within the surrounding maritime area, the region of Zadar is classified among areas with highly variable conditions for wave generation and development. Owing to the limited fetch lengths, wave heights in this area are generally relatively small. However, "swell" waves originating from more distant sources may occasionally reach significantly greater heights. The wave characteristics of the Zadar Channel, specifically in the area in front of the Port of Gazenica, were determined based on assessment and are presented in Table 2.

Table 2. Wave characteristics in front of the Port of Gazenica [14, 15].

Direction	**SE**	**SSE**	**S**	**SW**	**W**	**NNW**
Fetch (km)	3.2	10.4	6.8	4.6	5.6	10.8
Speed (m/s)	20.7	20.7	17.1	17.1	17.1	17.1
Wave height H1/3 (m)	1.05	1.8	1.2	1.05	1.1	1.5
Period (s)	2.8	3.6	3	2.8	2.9	3.4
U (1/s)	0.36	0.28	0.33	0.36	0.34	0.29
Length (m)	12.2	20.2	14.3	12.2	13.1	18
v (m/s)	4.39	5.66	4.72	4.39	4.45	5.22
v (kn)	8.53	11	9.17	8.53	8.65	10.17

Table 2 shows that the Port of Gazenica is most exposed to waves from the southeast (SE) to north-northwest (NNW) direction. Due to very short fetch lengths, waves from the northern and eastern directions have a low impact and can be disregarded in the analysis of waves. It was estimated that wave heights under slightly wavy conditions reach up to 0.5 m, under moderate wavy conditions up to 1.5 m, while under rough conditions they exceed 1.5 m. Limited fetch lengths cause disproportion between wave heights and wind strength. Consequently, waves are not expected to pose a threat to the safety of larger and medium-sized ships [15].

In the observed area of the Zadar and Pasman Channel, current speeds generally do not exceed 0.5 knots. During strong winds, the surface layer of the sea may reach speeds of 3 to 4 knots, but at shallower depths, speeds decrease to approximately 1.5 knots. Within the port waters of Gazenica, these values are even lower, however during very strong winds, the surface current may reach up to 1 knot, while at shallower depths it does not exceed 0.7 knots. Considering the enclosed nature of the port basin and the generally weak currents in the area in front of the port, it can be concluded that currents do not have a significant impact on the safety of navigation [17].

The tidal characteristics in the Port of Gazenica are similar to those in the open Adriatic Sea. However, under conditions of strong and prolonged southerly winds (sirocco), the sea level may be slightly higher than in the open sea, whereas during bora events, a slightly more pronounced decrease in sea level relative to the open Adriatic occurs. Tidal fluctuations in sea level are important for the safety of ships at berth [18].

4. Analysis of the mooring system for the Port of Gazenica

The safety of ships at berth, especially LNG ships, is critical for the safety of cargo operations at terminals. A dynamic analysis of mooring lines was performed using the *Dynamic Mooring Window* interface in OPTIMOOR [11]. The simulation provided data in mooring line loads and fender reactions, while detecting ship movements in longitudinal, lateral, and yaw directions. The simulation was performed over a 12-hour period, with a time step of 6 seconds. To ensure that a ship is properly and safely moored, compliance with international guidelines is essential. These guidelines assume that a ship may be exposed to strong winds or sea currents from any direction. Basic recommendations for mooring arrangements are presented in Figure 7. Mooring lines should be arranged as symmetrically as possible relative to the ship's centerline, as such layout provides an even distribution of loads. Breast lines should be as perpendicular as possible to the centerline of the ship and positioned as close as possible to the bow and stern. Spring lines should be oriented as parallel as possible to the ship's centerline. Bow and stern mooring lines should be directed at no more than 15 degrees relative to the bow or stern [1].

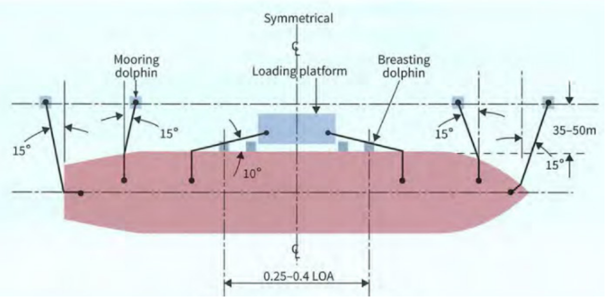

Figure 7. Suggested distribution of ship mooring ropes regarding horizontal angles [1].

The vertical angle of the mooring lines should be minimized to ensure efficiency and safety of a ship at berth, and in any case should not exceed 25 degrees, as shown in Figure 8 [1].

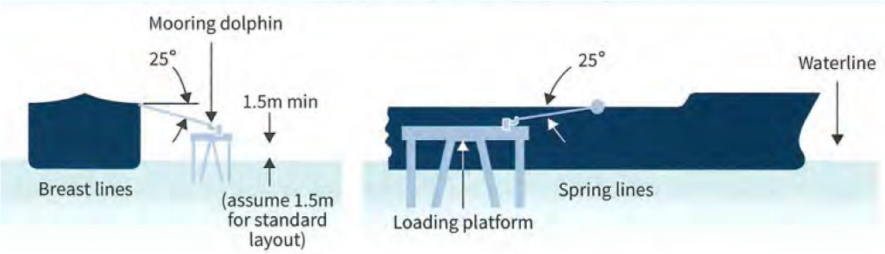

Figure 8. Maximum permissible vertical angle of mooring ropes [1].

According to MEG4, the steel wire has an allowable working load of 55 % of the ship’s design ultimate strength, while all other (synthetic) ropes have an allowable working load of 50 % of the ship’s design ultimate strength [1].

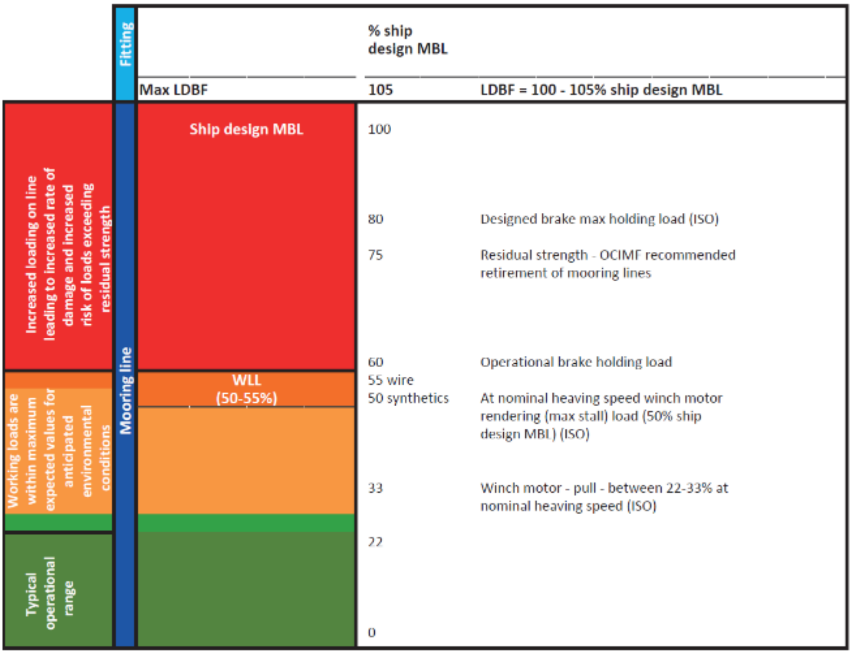

Figure 9. Maximum allowed loads of mooring lines [1].

4.1. Calculation of current condition

At Berth 1 in Gazenica port it is possible to moor an LNG ship of 12000 m^3 of capacity (LBP=105 m, B=22 m, H=13.2 m). This calculation uses the data and parameters currently available for mooring a ship at berth 1. The data of the berth include the geometric characteristics of the berth, the arrangement and breaking strength of the bollards, the positions and characteristics of fenders according to current information and the condition of the bollards, as well as the basic environmental conditions such as water depth, quay height, allowable ship movements, and the effects of wind and sea currents. The height of the quay above the reference level (datum) is 3.0 m, while the water depth in the ship zone is 10.3 m. The coefficient of friction between the ship and the fenders is specified as 0.40. The allowable ship movement in longitudinal and lateral directions is ±1.00 m. For the calculation of environmental loads, the wind speed at a height of 10 m and the mean value of sea currents at mid-depth of the ship were taken into account.

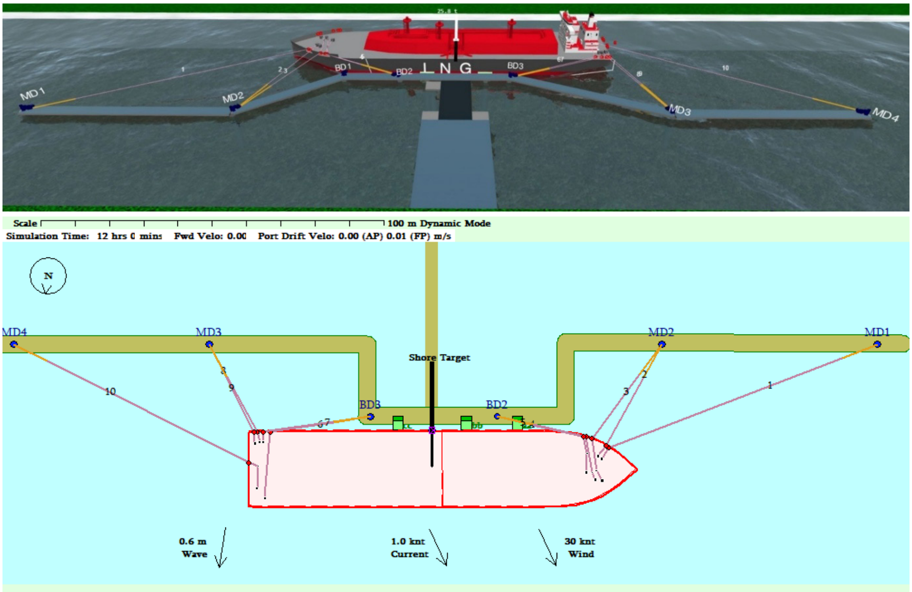

Figure 10. Visualization of ship mooring at Gazenica port [11].

This calculation is based on the current configuration of the mooring lines and moderate environmental conditions (wind up to 30 knots). This variant uses standard mooring components and serves as a reference baseline for comparison.

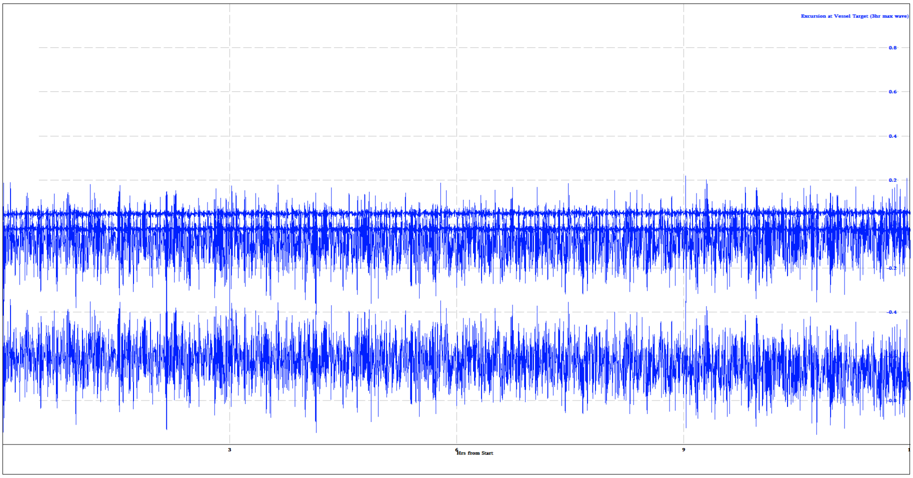

Figure 11. Longitudinal and transversal ship movement in 12 h dynamic simulation in current conditions [11].

4.1. Calculation of upgraded conditions

This calculation uses the upgraded data and parameters for performing mooring assessments for ships at Berth 1 in the Port of Gazenica, Zadar. It includes the geometric characteristics of the berth, the arrangement and breaking load of the mooring bollards, the positions and characteristics of fenders optimized according to OCIMF MEG 4 guidelines [1], as well as the basic environmental conditions such as water depth, quay height, allowable ship movements, and the effects of wind and sea currents.

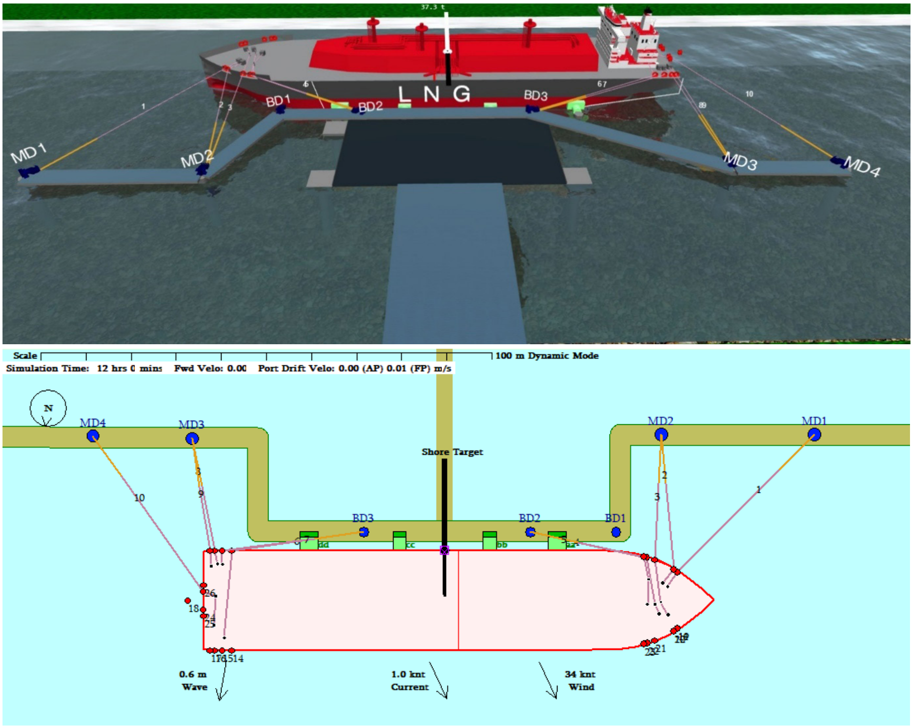

Figure 12. Visualization of upgraded ship mooring at Gazenica port [11].

Calculation with upgraded conditions includes more adverse environmental conditions, with lateral wind (up to 34 knots), and a technically optimized mooring arrangement. The optimization involves strengthening the breaking load of the mooring bollards, adding an additional fender, and using materials with an improved coefficient of friction, thereby simulating a modernized and more robust system configuration.

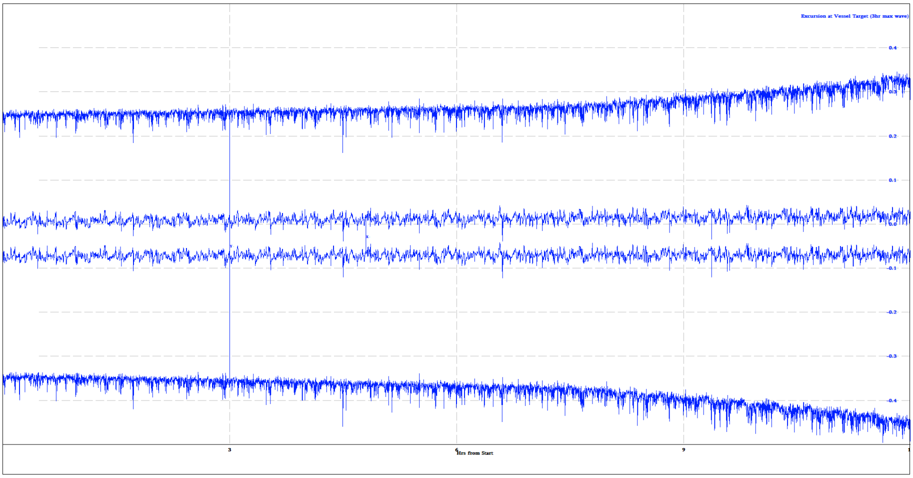

Figure 13. Longitudinal and transversal ship movement in 12 h dynamic simulation in upgraded condition [11].

5. Analysis of results

The goal of the analysis was to determine the influence of external forces, different technical characteristics and configurations of berth equipment, including the number and arrangement of fenders, the availability of mooring bollards, and their load-bearing capacities on safety of ships at berth. The analysis used a mooring modelling software tool and was based on the comparison of key parameters such as dynamic ship movement, fender responses, the distribution of forces in the mooring lines, and safety margins relative to the design load limits. Attention was given to evaluating how optimization of the mooring system and mooring arrangement can affect mooring safety and resilience under extreme weather conditions. The comparison of results allowed recommendations for further optimization of the mooring system at the Port of Gazenica.

Table 3. Differences between current and upgraded calculation [11].

Parameter	**Current condition**	**Upgraded condition**
Wind speed	30 knots	34 knots
Fender friction coefficient	0.40	0.40
Bollards breaking load (MD1–MD4)	180 t (3x60t)	300 t (3x100t)
Auxiliary bollards breaking load (BD1–BD3)	120 t (2x60t)	200 t (82x100t)
Number and type of fenders	3 (aa, bb, cc)	4 (aa, bb, cc, dd)

In upgraded condition calculation, infrastructural improvements were made to enable safe mooring arrangement under adverse weather conditions. The addition of a fourth fender and the increased breaking load of the mooring equipment provide greater strength, and improved materials of the mooring ropes reduce friction and assist in reducing the ship–fender contact forces. An increase in wind speed by 4 knots in calculation simulates adverse meteorological conditions, which affects the lateral forces acting on the ship hull. This scenario tests the efficiency of the optimized mooring arrangement under increased forces. Despite the adverse conditions, upgraded conditions have all parameters within allowable limits. The analysis of forces in individual mooring lines was conducted for both calculations, with the results presented in Table 4.

Table 4. Mooring lines load analysis in current and upgraded conditions [11].

Line	**Current condition Force (t)**	**% MBL**	**Upgraded condition Force (t)**	**% MBL**
Line 1 (MD1)	10.7	20.2%	19.9	37.5%
Line 2 (MD2)	24.9	47%	23.6	44.5%
Line 3 (MD2)	21.2	40%	22.4	42.3%
Line 4 (BD2)	9	17%	12.4	23.4%
Line 5 (BD2)	9.2	17.4%	12.5	23.6%
Line 6 (BD3)	7.3	13.8%	11.6	21.9%
Line 7 (BD3)	7.5	14.2%	11.9	22.4%
Line 8 (MD3)	25.3	47.7%	26.2	49.4%
Line 9 (MD3)	25.8	48.7%	26.5	50%
Line 10 (MD4)	12	22.6%	22.3	42.1%

In upgraded conditions, an increase in mooring lines loads is visible. Five out of ten lines exceed 40 % of their minimum breaking load (MBL). Although all forces remain within operationally acceptable limits, the increased load level requires heightened operational vigilance. The introduction of additional mooring lines or the rearranging of existing ones may help achieve a more even force distribution.

Table 5. Dynamics hip movement in calculated conditions [11].

Criteria	Current condition	Upgraded condition
Transverse movement F/A (sway) ±1.0 m	0.09 m / -0.06 m	0.04 m / -0.12 m
Longitudinal movement P/S (surge) ±1.0 m	0.28 m / -0.95 m	0.35 m / -0.50 m
Fender forces (max)	147.9 t (aa)	156.5 t (aa)
Bollard forces (MD3)	50.6 t (MD3)	51.9 t (MD3)

The increased lateral wind in current condition analysis results in higher loads on the ship's mooring lines in the transverse direction. This increased force activates the fenders, leading to a higher overall load on the mooring arrangement. Despite the adverse lateral forces, the ship in current conditions remains within the allowable position and is temporarily without direct contact with the fenders. In contrast, in upgraded conditions, active fender contact is constant, with a measured maximum force of up to 142 t. In that optimized scenario, the lateral movement of the ship is reduced, and the ship maintains contact with the fenders. The loads on the mooring lines in the optimized configuration (upgraded conditions) are higher compared to current conditions, which is a result of the improved mooring line arrangement. That layout enables more efficient load distribution, even under increased wind force conditions. Regarding longitudinal ship movements, upgraded conditions show lower values compared to current conditions. This indicates a more appropriate and efficient mooring line arrangement, which provides improved longitudinal stability of the ship. The maximum fender force in both calculations remains within permissible limits. However, in upgraded conditions, it is 5.8 % higher than in current conditions, indicating more interaction between the ship and the fenders. This is due to lower lateral ship movement and continuous fender contact, which limits hull motion. The comparison of the two calculations demonstrates that all parameters of the ship's dynamic response remain within prescribed criteria. Current conditions show greater longitudinal movement and lower fender forces, whereas upgraded conditions provide a more stable ship response, with higher total mooring system loads but enhanced safety due to the optimized mooring line arrangement.

6. Conclusion

The analysis of the mooring system for liquefied natural gas (LNG) ships at the Port of Gazenica was conducted in accordance with international guidelines provided by the Oil Companies International Marine Forum (OCIMF) and the MEG 4 (Mooring Equipment Guidelines). OPTIMOOR software, which is specialized for simulating ship behavior under various external forces, was used in the analysis. The analysis provided detailed insights into ship motion dynamics, force distribution across mooring lines, and the influence of different mooring configurations and variable environmental conditions on ship safety at berth. The results indicate that proper mooring configuration, the appropriate selection and arrangement of mooring equipment, and consideration of external forces are critical to ensuring the safety of berthed ships. Under significant environmental loads, inadequate mooring arrangement may lead to severe consequences, including equipment damage, ship drift from the berth, or even interruption of LNG handling operations. Accordingly, this paper provides recommendations for optimizing the mooring system at the Port of Gazenica to enhance the safety and reliability of port operations. The comparison of the two calculations demonstrates that all analyzed parameters remain within the prescribed criteria. Current conditions showed greater negative longitudinal movement and lower fender forces, whereas upgraded conditions showed better longitudinal response, with higher overall mooring system loads. Operationally, both scenarios are acceptable; however, upgraded conditions may be preferable in terms of limiting longitudinal ship movement at berth. The comparison showed that upgraded conditions represent an improved and more robust mooring arrangement due to:

- design for safer ship reception under adverse weather conditions,
- enhancements including bollards increased breaking load,
- the addition of an extra fender, and
- additional bollards.

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