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A Study on the Arrangement of Mooring system at the Quay-type LNG terminal in Ulsan Port

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울산항 안벽식 LNG 터미널의 계류시스템 배치에 관한 연구

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Abstract : *Recently, the interest in eco-friendly energy sources, including liquefied natural gas (LNG), has considerably increased both domestically and internationally, and the development of LNG-handling facilities and berths is actively underway. Ulsan Port has been selected as a Northeast Asian oil and energy hub and is actively developing LNG and oil storage facilities and berths. The LNG terminal currently under construction in the North Port district of Ulsan New Port is a quay-type terminal rather than a dolphin-type terminal, which is the existing main-pier type. However, no domestic or international design standards for the mooring-system arrangement of quay-type LNG terminals exist. Therefore, in this study, to establish design standards for mooring systems for quay-type LNG terminals, we developed a pier that reflected the dolphin-type mooring system arrangement in the Harbour and Fishery Design Criteria and analyzed the sensitivity of mooring-evaluation parameter for actual target berthing vessels. The results showed that, compared to the mooring system arrangement of the existing quay-type pier, the tension of the mooring line, load of the QRH, reaction force of the fender, and ship motion of 6-DOF were generally reduced under the same environmental conditions, which are beneficial for improving ship and pier safety. The results of this study offer a foundation for developing design standards for quay-type LNG terminals.*

Key Words : *LNG Terminal, Quay-type pier, Ulsan Port, Mooring safety evaluation, Mooring system*

요 약 : 최근 국내외적으로 LNG를 포함한 친환경 에너지에 대한 관심이 급증하여 LNG 취급시설 및 선석 개발이 활발히 진행되고 있다. 울산항은 동북아 오일 및 에너지 허브 항만으로 선정되어 LNG 및 오일 저장시설과 선석을 개발 중이다. 현재 울산신항 북항지구에 건설 중인 LNG 터미널은 기존의 주요 부두 형태인 돌핀식이 아닌 안벽식 터미널로 건설 중이나 국내외적으로 안벽식 LNG 터미널의 계류시스템 배치에 대한 설계 기준이 없는 실정이다. 그러므로 본 연구에서는 안벽식 LNG 터미널의 계류시스템 설계 기준을 마련하기 위해 항만 및 어항 설계기준에서 돌핀 형태의 계류시스템 배치를 반영한 부두를 개발하여 실제 접안대상 선박에 대한 계류 평가 요소의 민감도를 분석하였다. 분석 결과, 기존 안벽식 부두의 계류시스템 배치와 비교하여 동일한 환경조건에서 계류삭 장력, 계선주 하중, 계류라인 수직각도, 방충재 반력, 선체 6자유도 운동값이 대체로 감소하여 선박 및 부두의 안전성 향상에 유리한 것으로 분석되었다. 본 연구 결과는 안벽식 LNG 터미널의 설계 기준 개발을 위한 기초자료로 활용될 수 있을 것이다.

핵심용어 : LNG 터미널, 안벽식 부두, 울산항, 계류 안전성 평가, 계류시스템

1. Introduction

1.1 Analysis of LNG Industry Trends

Interest in eco-friendly energy such as LNG has increased recently in response to carbon neutrality and changes in the energy paradigm both domestically and internationally, and there is a large movement to create an energy hub by building LNG handling facilities (Maeilnews, 2021). Accordingly, a plan to build a Northeast Asian oil and energy hub began in 2008 at Ulsan Port in Korea, and from 2020, as the first stage of the oil and gas hub project in the North Port district of Ulsan New Port, in addition to LNG and oil storage facilities, a berth where quay-type LNG

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carriers can dock will be built. It is currently in operation and commercial operation will begin in July 2024. This is a project to create an oil and gas hub with a capacity of 24.3 million barrels in three stages by investing 2.7 trillion won in the Ulsan New Port area by 2030, making Ulsan one of the world's four largest oil hubs (ksilbo, 2023).

This is expected to contribute to the creation of eco-friendly energy logistics at Ulsan Port and revitalization of the local economy by supplying competitive fuel to power plants and industrial facilities in Ulsan through the handling of liquefied gas such as onshore LNG (Ulsan Port Authority, 2024).

Additionally, as the IMO strengthened eco-friendly regulations, it was agreed to reduce carbon emissions from the shipping industry to zero by 2050. The shipping industry accounts for about 2.7% of global greenhouse gas emissions currently. In accordance with IMO's zero-emission agreement, demand for LNG bunkering is expected to exceed 20% of the entire ship fuel market in the mid to long-term, making it an essential industry to increase shipping and port competitiveness (IMO, 2024). Accordingly, in the 4th Port Basic Plan, it was planned to build LNG bunkering infrastructure facilities at major domestic ports in order to enter the LNG bunkering market in Korea. In particular, for the first time in Korea, a 10,000 DWT class LNG bunkering pier is being built at Ulsan Port (Ministry of Oceans and Fisheries, 2020).

The Ministry of Oceans and Fisheries designated the hinterland complex of Ulsan New Port as an eco-friendly energy specialized area in December 2023 in order to foster a leading eco-friendly energy base port following the adoption of IMO's 2050 carbon neutral goal and the acceleration of the conversion to eco-friendly ships. With the designation of a specialized area, some areas within the hinterland complex of Ulsan New Port are linked to the energy hub phase 1 port terminal project, expanding the basis for attracting large-scale investment in eco-friendly energy, and economic effects such as investment and jobs are expected at Ulsan Port (Ministry of Oceans and Fisheries, 2023).

The LNG terminal currently under construction in the North Port district of Ulsan New Port is a quay-type terminal rather than a dolphin-type terminal, which is the existing main pier type. The quay-type LNG terminal is located in the Ulsan Petroleum and Chemical Complex and has the advantage of being easy to connect pipes, and the outer breakwater ensures a calmness and makes it easy for large ships to berth.

However, since the quay-type LNG terminal capable of berthing very large LNG carriers is being built for the first time in Korea, there is no design standard for the mooring system layout of the quay-type LNG terminal in domestic and foreign port design standards.

1.2 Analysis of design criteria

Terminals where domestic LNG carriers can dock for unloading are typically located in Incheon, Pyeongtaek, Dangjin, Boryeong, Gwangyang, Tongyeong, and Samcheok. Among them, all domestic LNG terminals that can dock very large LNG carriers are operated as dolphin-type mooring facilities. This is a form of mooring in the open sea in the form of a dolphin and carrying out unloading work, and the design standards are based on OCIMF's Mooring Equipment Guidelines and domestic Harbour and Fishery Design Criteria.

Dolphin-type mooring facilities are usually easy to access in the open sea, and have the advantage of being safe from damage on land in the event of an emergency accident such as an LNG leak. However, it has the disadvantage of being difficult to build a pier and taking a lot of time to build because the pipes must be buried in the deep sea. In addition, the standards for moored ships are greatly influenced by external environmental forces such as waves and currents, so mooring safety may be reduced (Ministry of Oceans and Fisheries, 2017b).

Fig. 1 is the ideal layout of the dolphin-type mooring provided by OCIMF. The angles of the head line, stern line, and breast line must be 15° in the direction perpendicular to the longitudinal axis of the ship, and the spring line must be within 10° in the direction parallel to the longitudinal axis of the ship (OCIMF, 2018).

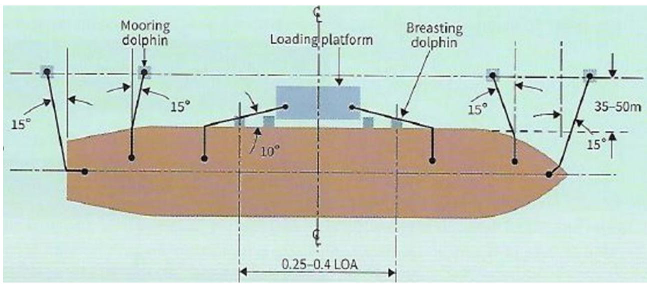

Fig. 1. Design criteria of dolphin in OCIMF.

The layout of the dolphin-type mooring system according to Harbour and Fishery Design Criteria is shown in Fig. 2. The breast line should be planned at right angles to the longitudinal axis of the ship and should not deviate more than 15°. It is desirable that the head and stern line be within 30~45° of the berthing line. The spring line should be planned in a direction parallel to the longitudinal axis of the ship, but within 10°. It is desirable to plan the vertical angle of the mooring line to be within 25° as shown in Fig. 3, and should not exceed 30° (Ministry of Oceans and Fisheries, 2017b).

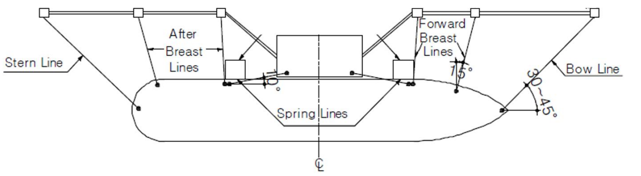

Fig. 2. Design criteria of dolphin for gas carrier.

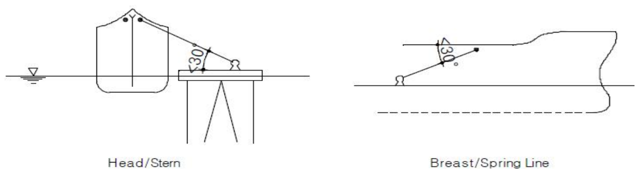

Fig. 3. Design criteria in vertical angle of mooring line.

Therefore, since there are no standards for mooring facilities when constructing a quay-type LNG terminal at Ulsan New Port, it is necessary to arrange mooring facilities for a quay LNG terminal in consideration of the design standards of dolphin-type piers to improve mooring safety and ensure safe unloading operations.

1.3 Prior research and research overview

As a result of research related to LNG carriers, Wang and Noh (2022) verified the similarity by comparing the mooring force calculated from a spectrum according to the OCIMF mooring facility guidelines in response to environmental loads when an LNG ship docks at a terminal, and the results of OPTIMOOR, a mooring safety evaluation software. Lee and Chang (2017) proposed the design of a pile guide mooring system for an offshore LNG bunkering terminal and performed the design for the Port of Singapore. In this way, research on the mooring system of LNG carriers has been conducted in ports and sea areas, but no research has been conducted on the arrangement of the mooring system when constructing a quay-type LNG terminal in a specific port.

As a result of research on mooring safety of ships, Kim (2020b) reviewed the safety and limitations of the mooring system through mooring safety evaluation when a training vessel was moored at a pier that exceeded its berthing capacity, and proposed a risk matrix based on simulation data. Kim et al. (2022) conducted a mooring safety evaluation on a car ferry moored in Jeju Port that exceeded its berthing capacity, analyzed the mooring safety of the ship according to the environmental conditions, and derived a plan to improve the mooring safety. Kim (2023) selected Mokpo Port and analyzed the sensitivity of mooring evaluation factors for actual berthing vessels according to sea level rise scenarios in order to derive measures to improve the mooring safety of ships moored at the pier when sea levels rise. In this way, various studies are being conducted to improve the safety of ships moored at piers. However, in order to establish mooring system design standards for quay-type LNG terminals, comparison studies of the mooring safety evaluation results based on the mooring system layout of the existing quay pier and the mooring safety evaluation results reflecting the dolphin-type mooring system layout have rarely been conducted.

Therefore, in order to establish mooring system design standards for quay-type LNG terminals, this study developed a pier that reflects the dolphin-type mooring system layout of Harbour and Fishery Design Criteria. A mooring safety simulation evaluation according to the scenario was performed using a mooring safety evaluation program targeting actual berthing target vessels. Accordingly, by comparing the safety results according to the mooring system arrangement of the existing quay pier, design standards for a mooring system suitable for a quay LNG terminal that can improve mooring safety were derived.

2. Selection of target port and pier

2.1 Selection of target port

For this study, Ulsan Port was selected, where Korea's first quay-type LNG terminal dock was built and is scheduled to be operated. Table 1 shows the volume of gas cargo handled by Korean ports, such as LPG and LNG, by year (PORT-MIS, 2024).

Incheon Port and Pyeongtaek·Dangjin Port are responsible for the gas consumption in Korea's metropolitan area, and Ulsan ranks 7th in gas handling volume in Korea, following Masan Port, Boryeong Port, Gwangyang Port, and Hosan Port, which have developed industrial complexes. In addition, since port development is planned by promoting an oil and gas hub project at Ulsan Port by 2030, the volume of gas cargo at Ulsan Port is expected to increase every year (Ulsan Port Authority, 2024).

Table 1. Gas cargo processing performance by port

Port \ year	2021	2022	2023
Incheon	28,599	29,491	26,396
Pyeongtaek·Dangjin	27,280	26,832	25,569
Masan	17,476	18,115	16,306
Boryeong	9,579	9,559	10,920
Gwangyang	10,377	9,022	9,463
Hosan	7,336	8,448	8,182
Ulsan	6,729	5,976	5,049
Daesan	3,546	3,755	2,827
Jeju	130	168	156
Etc.	826	1,035	1,191
Total	111,878	112,401	106,059

2.2 Selection of target pier

There are six berths under construction in the first phase of the oil and energy hub in the North Port district of Ulsan New Port, including one LNG terminal, four oil tanker terminals, and one LNG bunkering terminal.

For this study, Pier 2, an LNG terminal, was selected among the first phase oil and gas hub terminals in the Ulsan New Port North Port District under development. Pier 2 is scheduled to accommodate vessels with the largest berthing capacity among the quay-type piers currently under development, and the target vessel is a 180,000 CBM LNG carrier. In addition, it is close to the end of the breakwater geographically, so it is a location where the impact of external environmental forces on moored ships is expected to be the greatest. Fig 4 is the location of the target dock selected for this study.

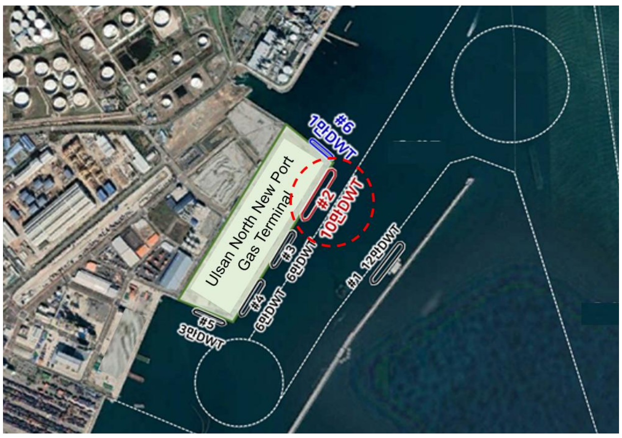

Fig. 4. Port overall plan in Ulsan North New port Gas Terminal.

Accordingly, when a 180,000 CBM LNG carrier, the largest ship with berthing capacity, berthed at the quay-type LNG terminal in the North Port district of Ulsan New Port, a simulation of the mooring safety of the berthing vessel according to external environmental forces was performed. Mooring element sensitivity was analyzed through simulation results and a plan to improve mooring safety was derived.

3. Mooring safety simulation evaluation

A mooring safety simulation was conducted to analyze the sensitivity of mooring factors according to environmental external forces and mooring facilities when a 180,000 CBM LNG carrier berthed at Pier 2 of the oil and gas hub first phase terminal in Ulsan New Port's North Port district.

This simulation was performed using OPTI-MOOR SW (Ver. 6.8.2) from TTI (Tension Technology International). OPTI-MOOR is an analysis program that is representatively used for mooring safety evaluation simulation at home and abroad because it can apply accurate modeling through linear analysis and has high utilization (Kim et al., 2016).

3.1 Selection of target ship

To select the target ship for simulation, a 180,000 CBM LNG carrier, which is the largest ship among the ships actually berthing at the target pier, was selected, and the main specifications of the target ship are shown in Table 2. These were set considering the specifications of ships with actual port entry history, and the mooring direction was set to port side berthing, which is the actual berthing type. The cargo loading condition was set to a ballast condition, which is considered the worst condition for securing mooring safety because the wind pressure area is larger than the full load condition (Kim, 2020a).

Table 2. Specifications of target ship

Category		180,000 CBM LNG Carrier
LOA (m)		298.9
LBP (m)		293.6
Breadth (m)		48.0
Depth (m)		26.4
draft (m)	fore	8.6
	aft	10.0
Projected Windage Areas (m^2)	Transverse	1,778
	Lateral	7,987

3.2 Modeling of mooring conditions

Table 3 shows the detailed specifications of the pier length, water depth, and crown height of the target pier modeled for this numerical simulation evaluation of mooring safety, and the arrangement and specifications of the mooring system such as mooring lines, bollards, and fenders. This is data that matches the specifications of the currently constructed pier.

Table 3. Specifications of mooring condition

Category		Target pier
Length of pier (m)		360.0
Depth of water (m)		15.0
Crown height (m)		2.5
Mooring Line	Type / Dia.(mm)	Steel Wire / 44
	M.B.L (ton)	138
	S.W.L (ton)	75.9
Tail Line	Type / Dia.(mm)	Nylon Rope / 110
	M.B.L (ton)	169
Bollard	Type	QRH 3Hooks
	Max. Load (ton)	450 (150 × 3Hooks)
Fender	Type	Cone Type 1,400H
	Interval (m)	18
	Max. Load (ton)	242

The specification of the target ship's mooring line was Steel Wire Rope, diameter 44mm, which is the type actually used on ships of the same size. The M.B.L. (Minimum Breaking Load) of the mooring line is 138 tons and the S.W.L. (Safety Working Load) was at 75.9 tons, which is 55% of the M.B.L., according to Table 4 (OCIMF, 2018).

Table 4. Safety working load of mooring rope

Material	S.W.L	SF (M.B.L/S.W.L)	× M.B.L
Wire	Highest load calculated for adopted standard environmental criteria	1.82	0.55
Polyamide		2.22	0.45
Other Synthetic		2.00	0.50

Mooring system modeling was set as shown in Fig. 5 for the mooring arrangement of the existing quay-type pier (original), and Fig. 6 was set for the mooring arrangement of dolphin-type (new). When comparing this, the coordinates of Q1 and Q4 for the aft line and Q5 and Q8 for the fore line are the same, and the positions of Q2, Q3, Q6, and Q7 are different depending on the type of pier (original, new).

In Fig. 5, the positions of Q2, Q3, Q6, and Q7 are the mooring arrangement of the existing quay-type pier, so the horizontal distance from the end of the pier to the inside is the same, and the distance between each QRH is set at 20.0 m. In Fig. 6, the positions of Q2, Q3, Q6, and Q7 are located approximately 16.0 m inward from the end of the pier to maintain the vertical angle of the mooring line at 30°, considering the mooring arrangement of the actual dolphin-type LNG terminal, and the spacing is the mooring points of the dolphin-type LNG terminal were considered. Detailed QRH intervals were set considering the locations of major facilities, including unloading facilities, within the pier.

The detailed mooring arrangement of mooring lines, QRHs, and fenders in Fig. 5 and Fig. 6 is shown in Table 5.

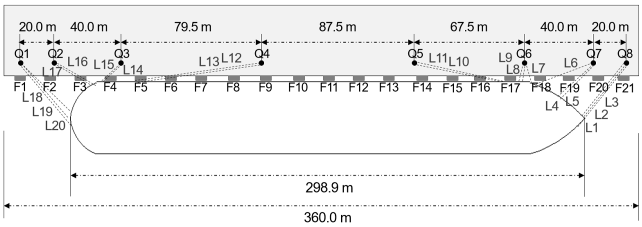

Fig. 5. Mooring arrangement of target ship (original).

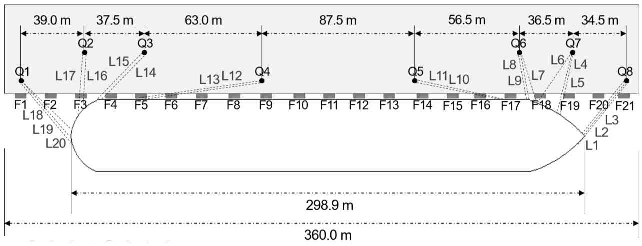

Fig. 6. Mooring arrangement of target ship (new).

Table 5. Mooring arrangement

Category			Arrangement
Line	Fore	Head	L1, L2, L3
		Breast	L4, L5, L6, L7, L8, L9
		Spring	L10, L11
	Aft	Spring	L12, L13
		Breast	L14, L15, L16, L17
		Stern	L18, L19, L20
Bollard	Fore	Head	Q8
		Breast	Q6, Q7
		Spring	Q5
	Aft	Spring	Q4
		Breast	Q2, Q3
		Stern	Q1
Fender	Fore		F12~F21
	Aft		F1~F11

3.3 Modeling of environmental external forces

The environmental external forces for the simulation reflected the characteristics of the target pier. The current in the North Port district of Ulsan New Port is weak due to the influence of the topography of the port, and flows northeast during flood tide and southwest during ebb tide. Accordingly, the direction and speed of the current at the target pier were calculated by setting the strongest current at 045 degrees and 0.3 knots.

The wave height was set to 1.2 m, the 50-year frequency wave height by reflecting the results of numerical model experiments among the 0.7 to 1.5m wave height, which is the limit wave height for very large ships according to the port design standards (Ministry of Oceans and Fisheries, 2017a). The wave direction was set at 060 degrees in the east-northeast direction, which is the main wave direction, reflecting the characteristics of harbor. The wave period was set to 5.0 seconds measured as the main incident wave period of the target pier.

The wind direction was set to the whole bearing which is typical for mooring safety evaluation, and the wind speed was evaluated at 48 knots and 56 knots, which are mooring limit levels, depending on the mooring arrangement of the target pier.

3.4 Evaluation factors of simulation

Ship motion occurs when external forces such as wind, waves, and currents act on the vibration system consisting of the hull and mooring system. The evaluation factors of the general mooring safety simulation are the tension acting on the mooring line, the load acting on the bollard, and the reaction force acting on the fender. And it is an unloading safety evaluation that evaluates whether the ship's normal unloading work is within the possible range when the hull is moving by an external force (Cho, 2017).

The evaluation factors of this simulation were the maximum tension acting on the mooring line, the maximum load acting on the QRH, the maximum reaction force acting on the fender, the vertical angle of the mooring line, and the momentum due to the movement of the ship’s 6-DOF (Kim, 2018).

4. Results of Evaluation

4.1 Tension of mooring line

The maximum tension of the mooring line according to the mooring system arrangement of pier was analyzed. In the mooring system arrangement of the existing quay-type pier (original), the limit wind speed of mooring was derived as 48 knots, and in the mooring system arrangement of the new dolphin-type pier (new), the limit wind speed of mooring was derived as 56 knots. The results of the sensitivity analysis of mooring line tension according to mooring system arrangement and wind speed are shown in Fig. 7.

In the mooring system arrangement of the existing quay-type pier, when the wind speed was 48 knots, the maximum tension of the mooring line was 74.4 tons at fore breast line No. 8, which was 98.0% of the S.W.L. of 75.9 tons, and was analyzed to reach the mooring allowable limit. When the wind speed was 56 knots, the maximum tension of the mooring line was 87.0 tons at fore breast line No. 8, which exceeded S.W.L, making it difficult to secure mooring safety.

In the mooring system arrangement of the new dolphin-type pier, when the wind speed was 48 knots, the maximum tension of the mooring line was 62.3 tons at the stern line No. 18, which was 82.0% of the S.W.L of 75.9 tons. When the wind speed was 56 knots, the maximum tension of mooring line was analyzed to be 74.9 tons at stern line No. 18, reaching the mooring allowable limit at 98.7% of S.W.L.

At the same wind speed of 48 knots, the maximum tension of the mooring line according to the mooring system arrangement of pier was 74.4 tons for the existing quay-type arrangement and 62.3 tons for the dolphin-type arrangement, which was analyzed to be a 16.3% decrease in the maximum tension of the mooring line compared to the existing arrangement. It was analyzed that the maximum tension of the mooring line at a wind speed of 56 knots decreased by 13.9% when deploying a dolphin-type mooring system.

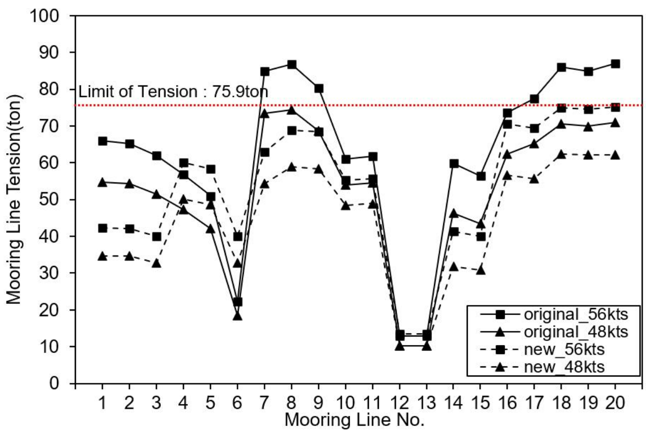

Fig. 7. Evaluation of mooring line tension by mooring arrangement.

4.2 Load of QRHs

The maximum load of QRH according to the mooring system arrangement of pier was analyzed. It was analyzed that it was within the allowable level of 450 tons for mooring in all scenario conditions, and the sensitivity analysis results of maximum load of QRH according to mooring system arrangement and wind speed are shown in Fig. 8.

In the mooring system arrangement of the existing quay-type pier, when the wind speed was 48 knots, the maximum load of QRH was 215.0 tons at QRH No. 6 used in the fore breast line, which was 47.8% of the maximum allowable load of 450 tons. When the wind speed was 56 knots, the maximum load of QRH was 257.8 tons for QRH No. 1 used in the stern line, which was 57.3% of the maximum allowable load of 450 tons.

In the mooring system arrangement of the new dolphin-type pier, when the wind speed was 48 knots, the maximum load of QRH was 186.5 tons for QRH No. 1 used in the stern line, which was 41.4% of the maximum allowable load of 450 tons. When the wind speed was 56 knots, the maximum load of QRH was 224.3 tons for QRH No. 1 used in the stern line, which was 49.8% of the maximum allowable load of 450 tons.

At the same wind speed of 48 knots, the maximum load of QRH according to the mooring system arrangement of pier was 215.0 tons for the existing quay-type arrangement and 186.5 tons for the dolphin-type arrangement, which was analyzed to be a 13.3% decrease in the maximum load of QRH compared to the existing arrangement. It was analyzed that the maximum load of QRH at a wind speed of 56 knots decreased by 13.0% when deploying a dolphin-type mooring system.

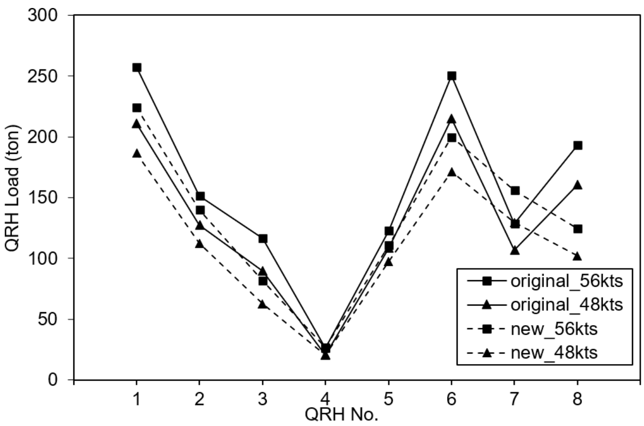

Fig. 8. Evaluation of QRH load by mooring arrangement.

4.3 Vertical angle of mooring line

The vertical angle of the mooring line according to the mooring system arrangement of pier was analyzed. The vertical angle of the mooring line also changes depending on the mooring system arrangement.

As the vertical angle of the mooring line increases, the efficiency of horizontal tension of the mooring line decreases, so it is important to maintain an appropriate vertical angle. For example, when the vertical angle is 25°, the tension efficiency against wind power is measured to be 91%, and when the vertical angle is 45°, the tension efficiency against wind power is measured to be 71% (OCIMF, 2008). Harbour and Fishery Design Criteria and OCIMF recommend a vertical angle of less than 30°.

The results of the vertical angle sensitivity analysis of the entire mooring line according to the mooring system arrangement of pier are shown in Fig. 9. In the mooring system arrangement of the existing quay-type pier, the vertical angle of the mooring line was derived from the fore breast line to 50~51°, which exceeded the vertical angle limit of 30° by about 20°, which reduced the efficiency of the mooring line. In the mooring system arrangement of the new dolphin-type pier, the vertical angle of the mooring line was derived from the fore breast line to 26~28°, and it was analyzed that the vertical angle of all mooring lines did not exceed the limit of 30°.

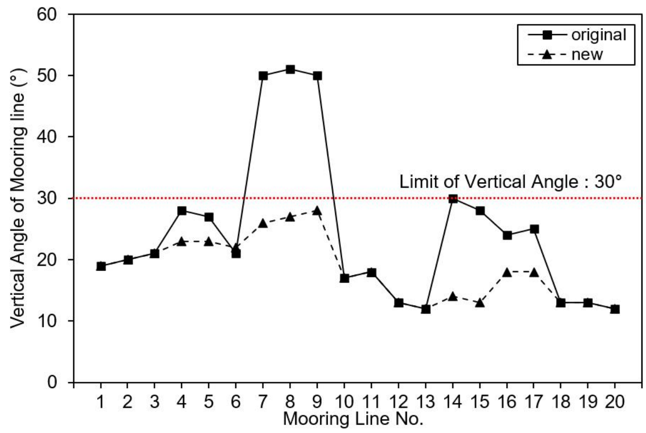

Fig. 9. Vertical angle of mooring line by mooring arrangement.

4.4 Reaction force of fender

The maximum reaction force of the fender according to the mooring system arrangement was analyzed. It was analyzed that the reaction force of the fender was within the allowable level of 242 tons in all scenario conditions, and the sensitivity analysis results of the maximum reaction force of the fender according to the mooring system arrangement and wind speed are shown in Fig. 10.

In the mooring system arrangement of the existing quay-type pier, when the wind speed was 48 knots, the maximum reaction force of the fender was 185 tons at Fender No. 7 used on the stern side, which is 76.4% of the maximum allowable load of 242 tons. When the wind speed was 56 knots, the maximum reaction force of the fender was 207 tons at Fender No. 7 on the stern side, which is 85.5% of the maximum allowable load of 242 tons.

In the mooring system arrangement of the new dolphin-type pier, when the wind speed was 48 knots, the maximum reaction force of the fender was 158 tons at Fender No. 7 used on the stern side, which is 65.3% of the maximum allowable load of 242 tons. When the wind speed was 56 knots, the maximum reaction force of the fender was 177 tons at the stern side Fender No. 7, which is 73.1% of the maximum allowable load of 242 tons.

At the same wind speed of 48 knots, the maximum reaction force of the fender according to the mooring system arrangement of pier was 185.0 tons for the existing quay-type arrangement and 158.0 tons for the dolphin-type arrangement, which was analyzed to be a 14.6% decrease in the maximum reaction force of the fender compared to the existing arrangement. It was analyzed that the maximum reaction force of the fender at a wind speed of 56 knots decreased by 14.5% when deploying a dolphin-type mooring system.

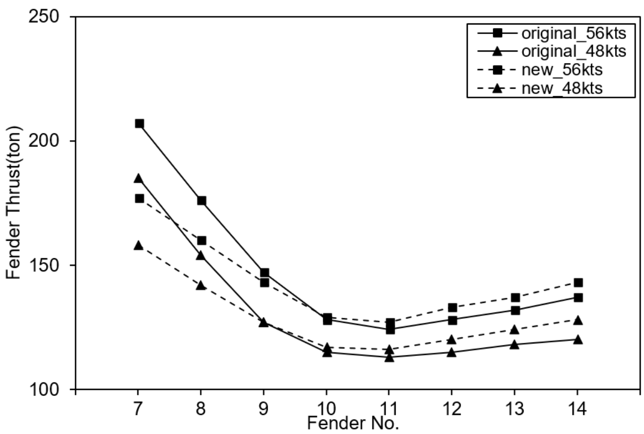

Fig. 10. Evaluation of fender reaction force by mooring arrangement.

4.5 Ship motion in 6-DOF

The amount of ship's motion according to the mooring system arrangement was analyzed. Table 6 shows the 6-DOF morion values of ship according to wind direction conditions and mooring system arrangement of pier. The movements with the largest change values depending on wind speed are surge and sway, and the change values of surge and sway depending on wind speed are shown in Fig. 11.

In the mooring system arrangement of the existing quay-type pier, the unloading limit wind speed at which the surge and sway motion values exceed 1.0 m was derived as 45 knots, and in the mooring system arrangement of the new dolphin-type pier, the unloading limit wind speed was derived as 53 knots.

In the mooring system arrangement of the existing quay-type pier, the ship's momentum was derived as surge 0.92m and sway 1.0m when the wind speed was 45 knots. When the wind speed was 53 knots, the ship's momentum was derived as surge 1.07m and sway 1.28m, making it difficult to secure unloading safety.

In the mooring system arrangement of the new dolphin-type pier, when the wind speed was 45 knots, the ship's momentum was derived as surge 0.85m and sway 0.64m. It was analyzed that when the wind speed was 53 knots, the ship's momentum reached the limit value of unloading safety with surge 1.0m and sway 0.85m.

At the same wind speed of 45 knots, the sway motion according to the mooring system arrangement of pier was 1.0 m for the existing quay-type arrangement and 0.64 m for the dolphin-type arrangement, which was analyzed to be a 36% decrease in sway motion compared to the existing arrangement. It was analyzed that at a wind speed of 53 knots, the sway motion decreased by 33.6% when deploying a dolphin-type mooring system.

Table 6. Motion for 6-DOF by environmental forces

Mooring Arrange-ment	Wind Speed(kts)	Surge (m)	Sway (m)	Heave (m)	Roll (°)	Pitch (°)	Yaw (°)
original	40	0.84	0.83	0.13	0.2	0.0	0.0
	45	0.92	1.00	0.13	0.2	0.0	0.0
	48	0.97	1.10	0.13	0.2	0.0	0.0
	53	1.07	1.28	0.13	0.2	0.0	0.0
	56	1.13	1.40	0.13	0.2	0.0	0.0
new	40	0.77	0.52	0.13	0.1	0.0	0.0
	45	0.85	0.64	0.13	0.1	0.0	0.0
	48	0.90	0.72	0.13	0.1	0.0	0.0
	53	1.00	0.85	0.13	0.1	0.0	0.0
	56	1.06	0.94	0.13	0.1	0.0	0.0

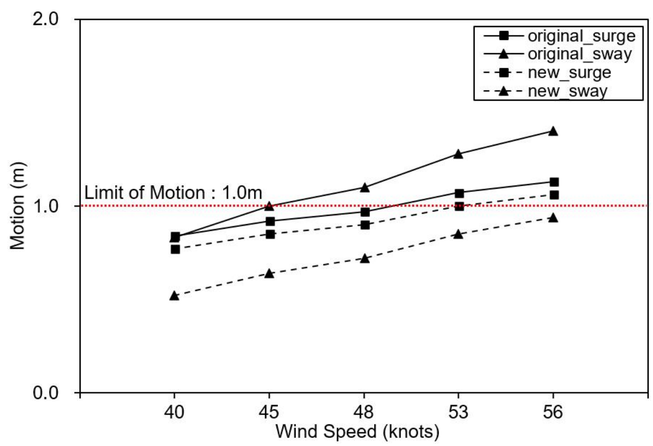

Fig. 11. Evaluation of surge, sway motion by mooring arrangement.

5. Conclusion

Recently, interest in eco-friendly energy, including LNG, has rapidly increased both domestically and internationally, and the development of LNG handling facilities and berths is actively underway. Korea's Ulsan Port has been selected as a Northeast Asian oil and energy hub port and is developing LNG and oil storage facilities and berths. The LNG terminal currently under construction in the North Port district of Ulsan New Port is being built as a quay-type terminal rather than the existing main dock type, Dolphin. However, there are no design standards for the mooring system arrangement of quay-type LNG terminals.

Therefore, in this study, in order to establish design standards for the mooring system arrangement of a quay-type LNG terminal, a pier was developed that reflects the layout of a dolphin-type mooring system in the design standards of Harbour and Fishery Design Criteria. In addition, a sensitivity analysis of mooring elements was performed by conducting a mooring safety simulation evaluation at a pier developed as an actual berthing target vessel. Based on the analysis results, the following conclusions were drawn.

(1) As a result of analyzing mooring elements according to the mooring system arrangement of pier, the limit wind speed of mooring at which all mooring elements are within the limit value was derived to be 48 knots in the mooring system arrangement of the existing quay-type pier and 56 knots in the mooring system arrangement of the new dolphin-type pier. It was analyzed that when the mooring system was deployed considering the dolphin-type mooring arrangement, the limit wind speed of mooring increased by 8 knots.

(2) As a result of the mooring safety simulation according to the scenario, when deploying the mooring system arrangement of the new dolphin-type pier under the same wind speed of 48 knots, the maximum tension of mooring line decreased by 16.3%, the maximum load of QRH decreased by 13.3%, the maximum reaction force of the fender decreased by 16.3%, and the sway motion decreased by 34.5% compared to the existing quay-type pier.

(3) As a result of analyzing the vertical angle of the mooring line, it was found that in the mooring system arrangement of the existing quay-type pier, the vertical angle of the mooring line was derived from 50 to 51° from the fore breast line, which reduced the efficiency of the mooring line. In mooring system arrangement of the new dolphin-type pier, the vertical angle of the mooring line was analyzed to not exceed the limit of 30° for all mooring lines.

(4) Therefore, when constructing a quay LNG terminal, it was evaluated that placing the QRH for the fore and aft breast lines within 15 to 20 m from the end of the pier, considering the dolphin-type mooring system arrangement, would improve mooring safety. In addition, detailed QRH intervals and placement must be set to ensure smooth unloading operations, taking into account the details of the target vessel and the locations of major facilities, including unloading facilities such as loading arms, within the pier.

The results of this study can be used as basic data for the deployment of mooring systems such as QRH when constructing a quay-type LNG terminal. It can also be used to establish design standards for quay-type LNG terminals at home and abroad. In future research, we plan to conduct research on the optimal arrangement of mooring systems in quay-type LNG terminals according to the size of berthing vessels in various ports and propose design standards for mooring systems in quay-type LNG terminals.

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