A Study on Improvement of Criteria for Mooring Safety Assessment in Single Point Mooring

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Abstract: The recent increase in crude oil trading has led to an increase in the workings of SPM for crude oil carriers. VLCCs generally encounter difficulty entering port due to limitations in terms of sea depth and maneuverability. The SPM is a system that allows mooring to the buoy located in the outer sea for such vessels. However, the buoy is more affected by relatively external forces because of their offshore location. Therefore, the safety assessment of SPM is particularly important as it can lead to large oil pollution disasters in the event of SPM accidents. Despite this, in the implementation of the Marine Traffic Safety Audit Scheme in Korea, there exists no guidance for SPM. In this study, a SPM mooring safety assessment is performed using OPTIMOOR, a numerical analysis program, so as to understand the mooring characteristics of SPM. As a result, it is confirmed that the tension of mooring lines and hull movement in the SPM are greatly affected by the encounter angles with external forces. In addition, it is found that the maximum tension of the mooring line is elevated as the water depth becomes shallower through sensitivity analysis. According to SPM characteristics, which has a large influence on the encounter angle, this study has proposed an amendment to setting criteria in the implementation of the Maritime Traffic Safety Audit Scheme which could improve the reliability and accuracy of mooring safety assessments.

Key Words: SPM, VLCC, OPTIMOOR, Mooring Safety Assessment, Maritime Traffic Safety Audit Scheme, Encounter angle, Sensitivity analysis

1. Introduction

The Maritime Traffic Safety Audit Scheme in Korea was introduced on 27th May, 2009 and has been in full implementation since 28th November, 2009, following a six-month grace period. The system plays a role in the process of deriving harms from the maritime works, and in establishing safety measures against them (Cho, 2011).

Nevertheless, there is no separate mooring safety assessment guideline in the case of SPM (Single Point Mooring), so the assessment results may change according to the subjective judgment of the assessor, which is contrary to the Maritime Traffic Safety Audit Scheme for the purposes of safety accident prevention. Kim (2015) has studied the operational status and problems inherent to the Maritime Traffic Safety Audit Scheme, suggesting that this system should be developed through the revision of laws and regulations, followed by continual revision.

Kim (2016) has conducted a study on the necessity of the post-management system for the Maritime Traffic Safety Audit Scheme. Through this, the accuracy of the audit was verified, and it was expected that this would eliminate any potential risk factors, as well as improve maritime safety.

Cho and Cho (2013) proposed the application of the meta-evaluation model as a method for enhancing the Maritime Traffic Safety Audit Scheme. In this way, the urgency of the system improvement is quantified, and a systematic improvement of the audit system through the priority is suggested.

Meanwhile, recently the demand for the SPM method for VLCC (Very Large Crude-oil Carrier) has been increasing as the volume of crude oil carriers has increased. SPM is exposed to strong natural external force as compared to general mooring, which is sheltered at port and shore structure. SPM however is moored to an offshore oil buoy unlike the general port mooring method. In the case of the quay mooring method, the mooring line of the ship, the fender and the bollard of the wharf are assessed for mooring safety, but in the case of SPM only the mooring lines connecting the buoy and the ship are assessed for mooring safety.

Because of these differences, it is necessary to analyze the SPM mooring safety assessment compared to other standards and implementation guidelines. However, there are no separate guidelines for the implementation of the Maritime Traffic Safety Audit Scheme.

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In this study, the SPM mooring safety assessment was performed by modeling Ulsan port in Korea. Based on the assessment results, the characteristics of the SPM which differ from other mooring cases have been sorted out. Therefore, the objective of this study is to present new amendments which reflect these characteristics to the current Maritime Traffic Safety Audit Scheme.

2. Related studies and theoretical review

2.1 Maritime Traffic Safety Audit Scheme

Since the Maritime Traffic Safety Audit Scheme was introduced in 2009 and the audit began in 2010, research on technical improvement methods for the audit has been carried out steadily. However, there are no research papers pertaining the improvement and revision of the Marine Traffic Safety Audit Scheme in terms of mooring safety assessments.

Table 1 shows the implementation guidelines for the mooring safety assessment of the Maritime Traffic Safety Audit Scheme. The direction of the external force is to be set in the main direction of the target sea area, or in the direction determined to adversely affect the moored ship.

Cho (2017), Kim et al. (2016), Kang and Park (2016) studied the mooring safety of the vessel at a general quay. The heading of the ship cannot be changed when it is moored at the quay. Therefore, according to the implementation guidelines, the wave direction and current is set to the most frequent direction in the target area, and the wind is set to all directions.

However, in the case of SPM, the vessel’s heading can be freely changed due to the characteristics of the ship when moored to the oil buoy. Therefore, in establishing the direction of external forces such as wind, wave, and current, it is necessary to assess using alternative setting criteria.

2.2 Single Point Mooring

SPM is an abbreviation for Single Point Mooring, also known as SBM (Single Buoy Mooring). It is the kind of oil terminal designed to allow VLCCs, which are difficult to navigate in the harbour area or to be moored at port due to limitations of water depth and control capability, thus opting for berthing on an oil buoy located in the offshore area.

This system consists of four main components: buoy body, mooring and anchoring elements, product transfer system, and ancillary components. The typical form of SPM is shown in Fig. 1 (Jiang et al., 1995).

![Fig. 1. SPM configuration.](Source: Jiang et al., 1995)

<table>
<thead>
<tr>
<th>Category</th>
<th>Setting criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>External force setting criteria</td>
<td>Wind 1. Speed: Maximum wind speed at the area or maximum wind speed at which the vessel can be moored. 2. Direction: Main direction of the target area or the direction which is adverse to the moored vessel.</td>
</tr>
<tr>
<td></td>
<td>Current 1. Apply the maximum flood current or maximum ebb current at the target sea area. 2. Consider the tidal fluctuation of the target sea area (spring tide), but MSL (mean sea level) is applicable. 3. For the newly built wharf, use the distribution of tidal current considering the completion of the wharf.</td>
</tr>
<tr>
<td></td>
<td>Wave 1. Height: Maximum wave height at which vessel can load &amp; unload cargo. 2. Direction: Main direction of the target area or the direction which is adverse to the moored vessel. 3. Period: the wave period which was setup at 1. 4. For the newly built wharf, use the wave distribution of wave considering the completion of the wharf.</td>
</tr>
<tr>
<td>Overall assessment</td>
<td>1. Presentment of vessel's displacement and mooring analysis outcome. 2. Evaluation of mooring safety and presentments for improvement of safety with various external forces.</td>
</tr>
</tbody>
</table>
The main types of SPM are Catenary Anchor Leg Mooring (CALM) and Single Anchor Leg Mooring (SALM). Typical CALM and SALM shapes are shown in Fig. 2 (OCIMF, 2015).

(a) CALM (Catenary Anchor Leg Mooring)
(b) SALM (Single Anchor Leg Mooring)

Fig. 2. Typical CALM and SALM system.
(Source: OCIMF, 2015)

The CALM method is a type where a buoy is fixed by an anchor chain extending to an anchor point at a specified distance from the buoy. SALM is similar to CALM except in that it is fixed via a single anchor leg. Since the CALM method has advantages including ease of maintenance as compared to the SALM method, it is known that 82% of SPM buoys installed since the mid-1990s have adopted the CALM method around the world (Kim et al., 2005).

As for previous studies related to SPM, Lee et al. (2003) have studied the behavior of vessels moored in SPM with irregular waves. The effects of irregular wave and nonlinear waves applying force to the slew motion, which can occur during mooring, were studied.

Lee and Kang (2003) studied the control methods of ship motions through the use of a control simulation by the bow-thruster engine and a method utilizing a bridle when a slewing motion affeted SPM vessels.

Yun and Park (2013) analyzed cases of domestic and overseas SBM installation operations and conducted research on the optimal positioning of SPM oil buoys.

3. SPM mooring safety assessment

3.1 Summary of mooring safety assessment

In general, the mooring safety assessment of a ship analyzes the load received by a mooring system, including loads applied to mooring lines, fenders, and bollard under natural external force conditions of the target sea area. Through this load analysis, the assessment is aimed at examining safety aspects such as mooring limits and the loading limit of the ship.

The mooring safety assessment in this study is performed using the latest version of OPTI-MOOR SW (Ver.6.2.6) of TTI (Tension Technology International). The software is a numerical analysis program employing linear analysis. It is simple to use but accurate modeling is possible compared to other mooring safety analysis programs. Therefore, it is widely used in the implementation of mooring safety assessments of the Maritime Traffic Safety Audit Scheme in Korea (Kim et al., 2016; Cho, 2017).

(1) Target sea area

In this study, Ulsan port in Korea has been selected as the target sea area for numerical simulation of the SPM mooring safety assessment. Many SPM facilities, such as S-Oil No. 1 SPM and No. 2 SPM as well as KNOC (Korea National Oil Corporation) have SPM installed and operated at Ulsan Port, which is a target port of this study.

The harbor chart of the area is shown in Fig. 3.

Fig. 3. Location of the target sea area (Ulsan SPM terminal).

(2) Target vessel

The target ship for the SPM mooring safety assessment is selected as the 325,000 DWT (Deadweight) class VLCC which is
moored primarily via SPM. Table 2 shows the main specifications of the ship.

The mooring lines connecting between the oil buoy and the ship are modeled with a 144 mm nylon double braid mooring line as shown in Table 3, which is frequently used in SPM for VLCC.

Table 2. Main specifications of the 325,000 DWT class VLCC

<table>
<thead>
<tr>
<th>Classification</th>
<th>Full load condition</th>
<th>Ballast condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length over all (LOA), m</td>
<td>333.0</td>
<td></td>
</tr>
<tr>
<td>Length Between Perpendicular (LBP), m</td>
<td>320.0</td>
<td></td>
</tr>
<tr>
<td>Breadth, m</td>
<td>60.0 (L/B = 5.55)</td>
<td></td>
</tr>
<tr>
<td>Depth, m</td>
<td>30.4</td>
<td></td>
</tr>
<tr>
<td>Distance from buoy, m</td>
<td>55.0</td>
<td></td>
</tr>
<tr>
<td>Mooring direction</td>
<td>Fore</td>
<td></td>
</tr>
<tr>
<td>Fore draft, m</td>
<td>22.5</td>
<td>8.1</td>
</tr>
<tr>
<td>Aft draft, m</td>
<td>22.5</td>
<td>10.1</td>
</tr>
<tr>
<td>Windage area of end-on, m²</td>
<td>1187.3</td>
<td>1859.3</td>
</tr>
<tr>
<td>Windage area of side-on, m²</td>
<td>3625.2</td>
<td>7224.8</td>
</tr>
</tbody>
</table>

Table 3. Mooring ropes of target ship

<table>
<thead>
<tr>
<th>Item</th>
<th>Target ship</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of rope</td>
<td>Nylon double braid</td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
<td>144.0mm</td>
<td></td>
</tr>
<tr>
<td>Minimum Breaking Load (MBL)</td>
<td>346.0ton</td>
<td></td>
</tr>
<tr>
<td>Safety Working Load (SWL)</td>
<td>190.3ton</td>
<td>SWL = MBL × 55 % (OCIMF, 2018)</td>
</tr>
</tbody>
</table>

The analysis of the vessel is divided into two conditions; full load and ballast, owing to that there are significant differences in the draft and windage area between the two conditions, as shown in Table 2.

Results of SPM modeling in OPTIMOOR using this data are shown in Fig. 4.

(3) Natural external condition

The external conditions in this study are applied to the cargo stop conditions of the SPM operation guideline in Ulsan port, as shown in Table 4.

Table 4. SPM operation guide in Ulsan port

<table>
<thead>
<tr>
<th>Condition</th>
<th>Possible berth</th>
<th>Cargo stoppage</th>
<th>Emergency unberthing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. wind speed</td>
<td>Under 13m/s</td>
<td>Over 14m/s</td>
<td>Over 15m/s</td>
</tr>
<tr>
<td>Max. Wave Height</td>
<td>Under 2.0m</td>
<td>Over 2.5m</td>
<td>Over 3.0m</td>
</tr>
<tr>
<td>Current</td>
<td>Under 2.0kts</td>
<td>Over 2.0kts</td>
<td>Over 2.5kts</td>
</tr>
</tbody>
</table>

Wind is input via Davenport spectrum, which is used chiefly for mooring safety assessments. The Davenport spectrum of Eq. (1) can be expressed as follows (Davenport, 1961).

\[ S_{1}(f) = \frac{4fC_{D}[V_{1}(10)]^{2}}{f^{2}(2+f)^{4}} \]

where:

- \( S_{1}(f) \) : Spectral density function corresponding to the speed fluctuation wind power (\( m^{2}/s \))
- \( f \) : Frequency (Hz)
- \( C_{D} \) : Surface drag coefficient
- \( V_{1}(10) \) : Average wind velocity at the height of 10m (m/s)

The wind drag force of the ship is proportional to the windage area and the square of the wind speed. The wind drag force can be estimated using Eq. (2) (Redondo et al., 2016).

\[ F_{WIND} = \frac{1}{2} \rho_{air} V_{WIND}^{2} A C_{S} \]

where:

- \( F_{WIND} \) : Wind drag force
- \( \rho_{air} \) : Density of air
- \( V_{WIND} \) : Velocity of wind
- \( A \) : Projected area of the structure exposed to wind
- \( C_{S} \) : Wind force coefficient

The wind drag force for surge, sway, yaw is shown in Eq. (3).

\[ \begin{bmatrix} F_{x} \\ F_{y} \end{bmatrix} = \frac{1}{2} \rho_{air} V_{WIND}^{2} A \begin{bmatrix} C_{x} \\ C_{y} \end{bmatrix} \]

\[ M_{y} = \frac{1}{2} \rho_{air} V_{WIND}^{2} A L_{hy} C_{y} \]
where:
\[ F_x : \text{Longitudinal force due to wind (Surge)} \]
\[ F_v : \text{Lateral force due to wind (Sway)} \]
\[ M_y : \text{Yawing moment due to wind} \]
\[ L_{pp} : \text{Length between perpendiculars} \]
\[ C_{x}, C_{y}, C_{N} : \text{Wind force coefficient (Surge, sway, yaw)} \]

As for wave, an irregular wave is applied via the PM (Pierson-Moskowitz) spectrum (Pierson and Moskowitz, 1964).

The PM spectrum is adopted as a standard spectrum which represents a sufficiently large open sea area because Ulsan port can be effective expressed through PM’s use. The PM spectral equation is shown in Eq. (4).

\[
S_{PM} (f) = -0.3125 H_s^2 f^p f^{-5} \exp \left[ -1.25 \left( \frac{f}{f_p} \right)^{4} \right] 
\]

where:
\[ H_s : \text{Significant wave height (m)} \]
\[ T_s : \text{Peak period (sec)} \]
\[ f_p : \text{Peak frequency (1/Tp, Hz)} \]
\[ f : \text{Frequency (Hz)} \]

The current drag force is proportional to the square of the velocity of current and draft of the vessel. Eqs. (5) to (7) for each of the current drag forces for surge, sway, and yaw are as follows (Ractliffe et al., 1981).

\[
F_{xC} = \frac{1}{2} C_{xC} \rho_o V_c^2 L_{pp} T
\]

\[
F_{vC} = \frac{1}{2} C_{vC} \rho_o V_c^2 L_{pp} T
\]

\[
M_{yC} = \frac{1}{2} C_{yC} \rho_o V_c^2 L_{pp}^2 T
\]

where:
\[ F_{xC} : \text{Longitudinal force due to current (Surge)} \]
\[ F_{vC} : \text{Lateral force due to current (Sway)} \]
\[ M_{yC} : \text{Yawing moment due to current} \]
\[ C_{xC}, C_{vC}, C_{yC} : \text{Current force coefficient} \]
\[ \rho_o : \text{Density of sea water} \]
\[ V_c : \text{Velocity of current} \]
\[ L_{pp} T : \text{Length between perpendiculars, draft of vessel} \]

### 3.2 Mooring safety assessment results

#### (1) Tension on mooring lines

In general, a mooring safety assessment at a quay is conducted by analyzing the maximum tension sustainable by the mooring lines, the maximum reaction force of fenders, the maximum tractive force of the bollards, and hull motions. However, in this study only the maximum tension of the mooring lines is analyzed because there are no fenders or bollards included in the structural features of SPM.

A typical rope load-extension curve is shown in Fig. 5. In this study, the mooring line connecting the hull and moored part in the oil buoy is a nylon double braid type. The breaking curve of the mooring line is generally proportional to the extension of the mooring line. As shown in Fig. 5, the wire rope shows almost no extension. However, in the case of nylon rope, the extension is relatively large compared to that of a wire rope (John et al., 1998).

![Fig. 5. Typical load-extension stiffness characteristics of rope. (Source: John et al., 1998)](image-url)

The Minimum Breaking Load (MBL) of the mooring lines in this study is specified as 346 tons. However, according to OCIMF regulations, it is considered to be dangerous in excess of 190.3 tons, equivalent to 55% of the MBL (OCIMF, 2018). The results of analyzing the tension on the mooring lines in time series under the cargo stoppage condition in Table 4 are shown in Fig. 6.

As shown in Fig. 6, when the encounter angle between the ship’s heading and the external forces is 000 degree (the bow direction), it can be observed that the maximum tension does not change much according to the loading conditions. Also, it can be seen that the maximum tension is relatively elevated as the encounter angle closes to the transverse direction. Table 5 shows the maximum tension of the mooring lines obtained by time series analysis.
As shown in Table 5, the maximum tension of the mooring lines is found to be within safety parameters because the Safety Working Load (SWL) was not exceeded in all cases. However, it can be observed that the maximum tension difference according to the encounter angle is significant. In particular, the maximum tension at the encounter angle of 060 degree is about 166.3 tons, which is about 3 times that of 58.1 tons at the 000 degree. It can be seen that the encounter angle bears great influence on the line tension. However, in the case of 090 degree, it shows a decreasing tendency, and further analysis is needed.

In this way, ship motions are analyzed so as to confirm the cause of the line tension changes depending upon the loading conditions and the encounter angle.

(2) Analysis of ship motions

In the case of the analysis of ship motions, only the motion on the horizontal plane of the ship (Surge, sway, yaw) is analyzed among the 6-Degrees Of Freedom (DOF) of the ship.

The coordinate system is as shown in Fig. 7.

![Ship’s coordinates system](image)

**Table 5. Maximum tension of mooring line**

<table>
<thead>
<tr>
<th>Encounter angle</th>
<th>Vessel condition</th>
<th>Max tension</th>
<th>Line no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>000 degree</td>
<td>Ballast</td>
<td>58.1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Full load</td>
<td>59.1</td>
<td>2</td>
</tr>
<tr>
<td>030 degree</td>
<td>Ballast</td>
<td>94.2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Full load</td>
<td>66.8</td>
<td>2</td>
</tr>
<tr>
<td>060 degree</td>
<td>Ballast</td>
<td>166.3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Full load</td>
<td>107.2</td>
<td>2</td>
</tr>
<tr>
<td>090 degree</td>
<td>Ballast</td>
<td>124.1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Full load</td>
<td>155.9</td>
<td>2</td>
</tr>
</tbody>
</table>
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Fig. 8. Time series analysis for ship motion under fully loaded condition (Surge, sway, yaw).

Fig. 9. Time series analysis for ship motion under ballast condition (Surge, sway, yaw).
The analysis of the time series of surge, sway, yaw according to the encounter angle indicates that the ship motions under fully loaded conditions are displayed in Fig. 8, while the ship motions under ballast conditions are shown in Fig. 9.

As shown in Fig. 8, under fully loaded conditions, the motion values of surge, sway, and yaw gradually increase as the contact angle increases from 000 degree to 090 degree. In addition, the ratio of sway motion to surge motion is confirmed as similar, and at the contact angle of 060 degree or more, the maximum value of motion in surge and sway differs little.

In the case of yaw, there is very little movement at 000 degree of the contact angle. However, as the encounter angle increases, the yaw motion can be confirmed to be about 1/3 of the encounter angle. For example, when the encounter angle is 030 degree, the yaw value is about 010 degree, and the yaw is about 020 degree at a contact angle 060 degree. Also, there is about 030 degree of yaw movement at the encounter angle of 090 degree.

As shown in Fig. 9, under ballast conditions, the motion values of surge, sway, and yaw gradually increase as the contact angle increases from 000 degree to 090 degree similar to the fully loaded conditions. However, unlike fully loaded condition, it is confirmed that the ship motions sharply increased as the encounter angle increased particularly in terms of sway motion. For example, at an encounter angle of 030 degree, only a sway of about 20m is observed under fully loaded condition, whereas under ballast conditions a motion of about 90m is observed.

In the case of yaw motion, about 2/3s of the encounter angle under ballast conditions is exhibited, unlike under fully loaded conditions the same is approximately 1/3.

The difference of the hull motions according to the loading condition is analyzed because the structure of the VLCC, which is the subject ship, shows that there is a large difference with respect to wind pressure area under the influence of the wind at the upper part of the water surface.

In addition, to confirm the direction of the hull movement depending on the encounter angle, hull motion is confirmed using surge input and sway motions as X and Y axes, respectively, as shown in Fig. 10.

As shown in Fig. 10, the closer the vessel is to ballast conditions in all encounter angles, the larger the ship's motions are.

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Fig. 10. Ship motion analysis depending on encounter angle.
Also, as the encounter angle increases, ship motions also tend to increase. It can be observed that the sway motion is greater than the surge motion in all cases.

### 3.3 Sensitivity analysis according to sea depth change

In this study, changes in mooring line tension during SPM is analyzed as depth changes. Since the target area was analyzed at the SPM quay of Ulsan port with a depth of 38.0m, it is checked in order to verify what changes are made to the maximum tension of the mooring lines when water depth is altered to 25.0m.

The results of sensitivity analysis according to depth are shown in Figs. 11 to 12 depending upon the loading conditions.

![Fig. 11. Sensitivity analysis by sea depth (Full load).](image)

As shown in Fig. 11, the numerical values of the mooring line tension did not show the significant difference with the sea depth change. However, it can be seen that the maximum tension of mooring line increases as the sea depth becomes shallower (means the under keel clearance becomes smaller) in all conditions.

![Fig. 12. Sensitivity analysis by sea depth (Ballast).](image)

### 4. Proposal for amendments to the implementation guidelines

#### 4.1 Difference between general mooring and SPM

Table 6 shows the studies about mooring safety assessment.

<table>
<thead>
<tr>
<th>Research</th>
<th>External force direction criteria</th>
<th>Port and Ship type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jun et al., 2008</td>
<td>Wind: 0, 90, 180, 270°</td>
<td>Ulsan, Tanker</td>
</tr>
<tr>
<td></td>
<td>Wave: Fixed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Current: Fixed</td>
<td></td>
</tr>
<tr>
<td>Kang and Park, 2016</td>
<td>Wind: All (Interval 5°)</td>
<td>Ulsan, Tanker</td>
</tr>
<tr>
<td></td>
<td>Wave: Fixed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Current: Fixed</td>
<td></td>
</tr>
<tr>
<td>Kim et al., 2016</td>
<td>Wind: All (Interval 5°)</td>
<td>Ulsan, Tanker</td>
</tr>
<tr>
<td></td>
<td>Wave: Fixed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Current: Fixed</td>
<td></td>
</tr>
<tr>
<td>Cho, 2017</td>
<td>Wind: All (Interval 5°)</td>
<td>Busan, Training ship</td>
</tr>
<tr>
<td></td>
<td>Wave: Fixed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Current: Fixed</td>
<td></td>
</tr>
</tbody>
</table>

As shown in the research papers on the mooring safety assessment in Table 6, most of the papers are fixed in wave directions and current by the main direction, or the direction that adversely affects the moored ship. Also, in the case of wind, it is set in all 360 degrees while covering the interval.

This can be interpreted as the result of settings similar to the target sea area because there is a direction in which the vessel’s heading is fixed to the pier while the wave and current are blocked by port structures and facilities.

However, for SPM moored to the buoy located offshore, since there are no structures, external forces such as wind, wave, and current can approach from any direction. Therefore, it is necessary to set the external force direction to another standard.

For this reason, the direction of the current is set to the bow direction (000 degree), because the heading of the ship which is not moored (drifting or anchoring) is generally directed to the current direction in this study. Wave and wind have been set in the direction leading from vessel’s heading ± 90°, not the primary direction, because these forces can come from all directions in the open sea, and them approaching from the same direction will adversely affect the moored ship.

#### 4.2 Proposal for amendments

The present implementation guidelines in Maritime Traffic Safety Audit Scheme do not have specific guidelines for SPM, so
differing results can be derived depending on the subjective judgment of the assessor. This not only violates aspects of ensuring safety for maritime traffic, which is the original purpose of the audit scheme, but can also lead to side effects that increase the probability of a safety accident.

This study proposes several amendments, detailed in Table 7, reflecting these differences.

Table 7. Proposal for amendments

<table>
<thead>
<tr>
<th>External force</th>
<th>Setting criteria</th>
<th>Proposal for amendment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>Main direction of the target sea area or the direction which is adverse to the moored vessel</td>
<td>360 degrees in all directions or ship heading standard ±90°</td>
</tr>
<tr>
<td>Wave</td>
<td>Maximum flood current or maximum ebb current</td>
<td>Ship heading direction</td>
</tr>
</tbody>
</table>

In the mooring safety assessment according to the guidelines of the existing Maritime Traffic Safety Audit Scheme, the direction of the current is set as the maximum flood or ebb current. Wind and wave have been set in the main direction of the target sea area, or in the direction which is determined to be disadvantageous to the moored ship.

However, in the case of SPM, it is necessary to set a new standard that meets SPM characteristics, not the existing setting standard. Therefore, for the SPM mooring safety assessment, a new guideline has been proposed, in which the current is set in the bow direction of the ship, and the wind and wave are set in the omnidirectional direction or in the direction coming from the heading standard, ± 90°.

5. Conclusion

Recently, SPM facilities have been actively installed for handling VLCCs in order to deal with growth in crude oil transportation. Despite these trends, there has been little research done on SPM mooring safety assessments. In the case of SPM mooring accidents, this could lead to significant oil pollution. Therefore, it is more important now than ever to examine safety protocols through accurate initial mooring safety assessments prior to operation.

In this study, a 350,000 DWT class VLCC moored at the Ulsan SPM terminal in Korea is modeled and the mooring safety assessment is performed under the external force condition of the target sea area. Through the mooring safety assessment, this study attempted to analyze the changes to mooring line tension and hull motion changes in the SPM. After analyzing the SPM characteristics, we aimed to propose an amendment to the implementation guidelines of Maritime Traffic Safety Audit Scheme based on the results. The results are summarized below.

(1) As a result of analyzing the mooring line tension changes in time series, it is confirmed that tension changes are different according to the encounter angle and the loading conditions of the ship. In particular, when the encounter angle is greater than 060 degree, it is confirmed that the mooring line tension increased sharply. If the mooring safety assessment is made according to existing guidelines, it may not lead to a proper result because it is possible to make an assessment without consideration of the encounter angle according to the subject of the assessor. Therefore, it is necessary to specify the implementation guidelines in detail.

(2) It is difficult to grasp the SPM characteristics merely through mooring line tension analysis. Therefore, the hull motion of surge, sway, and yaw is analyzed. As a result of analysis, it is confirmed that the hull motions are larger when the ship operates under ballast conditions compared to fully loaded. It is determined that the difference in the windage area of the upper part of the water surface between light and fully loaded conditions is significant. In particular, the sway motion shows that the vessel under fully loaded condition moves about 60m while the ballast condition ship moves about 200m when the encounter angle is 090 degree.

(3) Sensitivity analysis is carried out according to the sea depth during SPM. As a result of the comparison of mooring line tension between a depth of 38m in the target sea region and a shallow depth of 25m, the difference is not large. However, it is confirmed that the tension of the mooring line increases as depth becomes shallower. That is, as the UKC decreases.

(4) In the case of SPM, which is different from general mooring characteristics, it is confirmed that a new standard is necessary rather than following the guidelines specified by the Maritime Traffic Safety Audit Scheme. Setting the external force in a direction that has a high frequency of occurrence, or that adversely affects the mooring vessel does not fit the SPM case. According to the results of this study, the current is set to the ship ‘s bow direction and the wind and wave are set to have the encounter angle with the vessel to match SPM characteristics. It can be expected that such a method will lead to more accurate results.

In this study, it is meaningful to present a new amendment to the implementation guideline of the Maritime Traffic Safety Audit Scheme through SPM mooring safety assessments. However, this study is based on the result of mooring safety assessment while
utilizing simple numerical analysis. Therefore, further study will be carried out via CFD (computational fluid dynamics) analysis or the water tank model experiment. Furthermore, a sensitivity analysis involving more factors is left for further study to identify SPM characteristics.

References


