Mooring Tension Analysis of the Effect of Mooring Configuration Variations when LNG Carrier Moored to a Jetty

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Abstract. Oil and gas exploration is mainly carried out offshore, which results in the need for an efficient means of structure for further onshore oil and gas processing. LNG Carrier is an effective and efficient means of transportation, therefore to maintain and restrain the movement of LNG Carrier during offloading to remain in a stable condition, it is necessary to build a mooring system facility. One of the critical things regarding the mooring system is the configuration of the number of moorings installed. It will affect the determination of operating limits and also the effectiveness of the installation. In this study, configurations will analyze the configuration of mooring vessel to jetty with variations in configurations 2-3-1, 3-3-2, and 4-4-3 and variations in vessel load case using operating environmental conditions and extreme conditions with swell effects. This research focuses on tension analysis in each mooring to find out the proper and effective configuration as well as obtain the operating limits that have been set.

Keywords. LNG Carrier, Mooring System, Jetty, Tension

1. Introduction

In recent times, natural gas was only a byproduct of oil production. The interest in oil and gas exploration for energy sources continues to grow (Clauss, 2014). Oil and gas exploration is mainly carried out offshore so, it makes the need for efficient transportation for processing and fixed it. According to Clauss (2014), LNG (Liquefied Natural Gas) vessels are a more economical alternative than using pipelines whose efficiency is considered less significant. Floating Liquefied Natural Gas (FLNG) is a floating structure that functions as a terminal or temporary storage area for Liquefied Natural Gas (LNG) which will be distributed to other vessels such as the LNG Carrier. There are several advantages to choosing LNG; there is no need for a vast space to store natural gas in the form of vapour. Natural gas has been compressed into a liquid, namely LNG, so in this case, the costs incurred are very economical (Ramadhan, 2020). In transferring LNG from one vessel to another or from vessel to land, the required is mooring. Mooring is defined as processing the ship's motion in such a way as to anchor the vessel to the dock so that the ship's movement is limited. This type of mooring rope usually has a large diameter depending on the load present during the mooring operation. (Port skills and Safety UK, 2010).

Some factors can influence the movement in the vessel mooring system, and there are external and internal factors. External factors include, for example, the condition of the sea, which is influenced by
weather, including rain, wind, waves, and currents. The water's state is very much considered because if the seawater recedes, there will be a decrease in water in the middle and an increase in laden backs. The external factors referred to are factors that come from the ship itself like the model of the vessel, the type and type of engine power, the number, place, and type of propeller, vessel draft, vessel cargo, vessel stability, and of course configuration selection. One of the things that are pretty influencing is the choice of configuration in ship mooring. Using the case study as a problem in this study, an LNG storage port terminal in area X. LNG Carrier will be anchored to a jetty where the vessel is light or the lowest load. The LNG Carrier is offloading using MLA (Marine Loading Arms). Marine Loading Arms is a pipe system used to transfer liquids or gases to and from one to another or from vessel to land (Sastry, 2016). Ding the offloading process, it is necessary to develop a mooring arrangement that is appropriate and safe to operate in the specified environmental conditions. In this study, an analysis of the LNG Carrier's mooring to the jetty will be carried out with many states; there are 1-year, 50-years, and 100-years.

The purpose of this research is to determine the hydrodynamics of LNG Carrier during free-floating conditions, to determine the mooring tension generated from each variation of the mooring configuration by considering several safety factor conditions indicated by OCIMF. From the results of this study, we will be able to find information about safe and accurate operating limits for each mooring configuration in the environmental conditions determined and by the safety factor hinted at by OCIMF. The Operating limit is beneficial for choosing decisions in making mooring arrangements. Hopefully, in the future, it can be used as a reference for technicians who will design a mooring system in similar conditions. Some of the limitations of the problem in this study include the LNG Carrier analysis carried out at the lowest water load. The hydrodynamic analysis of the ship using the MOSES software in free-floating conditions and some variations there are 3-3-2, 4-4-3, and 2-3-1, the type of mooring used is polypropylene. Tension mooring analysis using OrcaFlex software, wind, wave, and current work in the same direction. The analysis in this study does not consider fenders and bollards, marine arm offloading is also not analyzed, the standard of safety factor considered by OCIMF, and the wave spectra used is Ochi-Hubble.

2. Basic Theory

a. Literature

Significant reserves of gas are found in remote offshore areas where pipeline transportation is not feasible or not economically viable. It makes the floating production platform development increase because it is considered quite efficient. After all, the gas reserves taken have been liquefied in LNG, which is undoubtedly more profitable and economical (Arronson, 2012).

Mooring arrangement is one of the most important things that need more knowledge in LNG Carrier processing, especially during offloading conditions. The purpose of this study is to look for the operating limits in each mooring configuration start with the calculation of the mooring tension and value of the mooring system will be entered into each predetermined environmental condition and can be used as a reference in making a mooring system design with similar conditions. This study research is reviewed from previous studies which state that the mooring configuration is significantly affected for continuity of the offloading of the floating facilities. One of the studies regarding mooring is discussed by Nopian (2016). It explains if the mooring system used for FSO mooring must withstand environmental loads, wildly wave loads, which proves a reasonably close relationship between the mooring system and the surrounding environmental conditions.

In his research, Sholihin (2016) states that the mooring stress analysis is carried out to obtain the value of the maximum stress or tensile stress. To determine the mooring rope safety during operation necessary to find the ratio of the MBL (Minimum Breaking Load) of the rope to the value of the maximum operating tension. This study research includes certain limitations in the analysis, one of which is the analysis used at the lowest water-laden water-laden. Research by Ramadhan (2020), which discusses the effect of the depth of mooring water when offloading with side-by-side conditions, states that the maximum tension value of the mooring rope occurs in the condition of a ballast ship. The less the ship's load, the more unstable the vessel will be so that the tug of the mooring line will be more significant, which causes the tension of the mooring rope to be even greater. Problems related to mooring tension are also discussed by Rosari (2016). It explains that in a single moored and operating condition subject to operating environmental loads,
the floating structure experiences the most significant motion response at 75% load conditions in the 0° loading direction for surge and pitch motion, 45° loading direction for heave and yaw motion, as well as the loading direction of 90° for sway and roll motion. The tension that occurs in the mooring line is in the 2000 to 7000 kN value range. The safety factor value ranges from 2 to 3. In this research, the safety factor used refers to OCIMF. Later it will be seen what operating limits are appropriate and safe as indicated by OCIMF.

b. LNG Carrier
LNG Carrier ships to be distributed to the market (Ramadhani, 2016). LNG carriers are specialized ships designed to transport Liquefied Natural Gas (LNG). They are fitted with insulated double-hulled tanks, designed to contain the cargo slightly above atmospheric pressure at a cryogenic temperature of approximately -160°C. An average LNG carrier presents a tank capacity of about 160,000 m³, and typically, the storage tanks operate at 0.3 bar with a design pressure of 0.7 bar. LNG presents a density between 430 and 470 kg/m³ typically, depending on its composition and state (Mokhatab et al., 2014).

c. Offloading
Offloading is the process when the mooring ropes and fenders are working optimally and ensuring that the loading arm is in the operating envelope. Dianiswara (2016) states that the offloading cycle can be divided into 2 phases, and each phase consists of several operations as below:

1. Approach/berthing
   The initial approach is the initial procedure when the LNG Carrier position approaches the FSRU for a long distance. This operation ends when the LNG Carrier is in a position parallel to the FSRU in a radius of 100 - 150 meters. The hold station is a position that explains that the LNG-C is parallel to the FSRU with a distance of 100 - 150 meters and remains in that position only with the help of a tug boat. Parallel berthing is the position when the LNG Carrier moves slowly towards the FSRU with the help of a tug boat. Fender kissing is the first time a fender collides; mooring is the time of binding and pre-tensioning the mooring line. Loading arm connection is an activity to connect the loading arm on the FSRU to the manifold on the LNG Carrier.

2. Depart/Sail away
   Disconnection is an operation when the loading arm is removed from the manifold. Unmooring is an activity when the mooring rope is released.

d. Mooring System
The vessel must remain in a stable condition on the wharf to facilitate loading and unloading operations. Therefore, the vessel must be tied with ropes to the structure of its backrest. This arrangement of the rope is called mooring. The essential elements for the movement of vessels moored are mooring lines, and fenders, which are considered more flexible elements in mooring arrangements (Kudale, 2016).

   The mooring system in a floating building structure facility, in principle, functions to maintain its position to remain in its place or reach a distance. In general, the mooring system can be categorized into two kinds, weathering and non-weathering. It is said that weathering if the response of the floating building structure is free to rotate 360° depending on the direction of environmental loads that hit it, for example, the tower mooring system. Whereas non-weathering, the direction of the structure response is limited, and the environmental loads that hit it are held back by the floating building structure, for example, dolphin mooring (Ramadhan, 2017).

3. Result and Discussion

a. LNG Carrier Modelling and Validation
The initial modelling and analysis of LNG Carrier, solved in this study using Maxsurf software to obtain hydrostatic data. Structural modelling is adjusted to the size of General Arrangement and several approach formulas for unknown data. In addition, modelling in the Maxsurf software to find the coordinate points of the model will be used for further modelling and analysis in the MOSES software. The modelling of LNG Carrier with Maxsurf can be seen in figure 2.
After modelling it with Maxsurf, validation is qualified from the initial data obtained with the data obtained from Maxsurf. For unknown initial data, calculations using the approximate formula. The hydrostatic data obtained from Maxsurf and the original vessel data can be validated in table 1.

### Table 1. Validation of Vessel Model

| Parameter                  | Different Criteria Limits | Original Data | Software Data (By Maxsurf) | Percentage of Different | Status |
|----------------------------|---------------------------|---------------|-----------------------------|-------------------------|--------|
| Displacement               | 1%                        | 10667.44 ton  | 10667 ton                   | 0.0%                    | OK!    |
| Length of Waterline (LWL)  | 2%                        | 108 m         | 107.40 m                    | 0.6%                    | OK!    |
| LCB                        | 2%                        | 53.18 m       | 53.45 m                     | 0.5%                    | OK!    |
| VCB                        | 2%                        | 3.96 m        | 3.92 m                      | 1.0%                    | OK!    |
| KG                         | 2%                        | 6.08 m        | 6.04 m                      | 0.7%                    | OK!    |
| Coeffisien Midship (CM)    | 2%                        | 0.98          | 0.98                        | 0.7%                    | OK!    |
| Coeffisien Prismatic (CP)  | 2%                        | 0.69          | 0.69                        | 0.7%                    | OK!    |
| Coeffisien Block (CB)      | 2%                        | 0.68          | 0.68                        | 0.6%                    | OK!    |

### Analysis of Structural Motion Characteristic

Hydrodynamic analysis of LNG Carrier was performed using MOSES Editor software. Some of the variables generated at this stage include additional mass, attenuation, and structural response, which will be input to extract the value of mooring stress. Below is a table of the maximum value of each structural response in all scenarios of vessel load conditions. 4 load variations are analyzed, full load with ballast condition, full load without ballast condition, light load with ballast condition, light load without ballast condition. This study will be analyzing some critical conditions. The first is complete load condition with ballast (there is ballast water in the vessel), and the other is the vessel with a full load but without ballast, which means there is no water ballast in the vessel, but still with complete load condition. The next is light condition. Same with the previous, there are two cases for light conditions. The first is light load with ballast, which means there is ballast water with a light load, and the second is light load without ballast, which means there is no ballast water but still in light load. The study analyzes it, how the response of each vessel condition with variations in mooring configuration. The following is the table of maximum RAO in each load case.
Table 2. Maximum RAO Value of Full Load with Ballast Condition

| Motion Mode | Unit   | Maximum RAO Value of Full Load with Ballast Vessel Condition |
|-------------|--------|-------------------------------------------------------------|
|             |        | 0°  | 45° | 90° | 135° | 180° |
| Surge       | m/m    | 0.95 | 0.67 | 0.00 | 0.67 | 0.95 |
| Sway        | m/m    | 0.00 | 0.70 | 0.99 | 0.70 | 0.00 |
| Heave       | m/m    | 1.00 | 1.00 | 1.60 | 1.00 | 1.00 |
| Roll        | deg/m  | 0.02 | 6.52 | 8.76 | 6.59 | 0.02 |
| Pitch       | deg/m  | 1.73 | 1.90 | 0.23 | 1.90 | 1.75 |
| Yaw         | deg/m  | 0.00 | 0.85 | 0.07 | 0.92 | 0.00 |

Amplitude Operator (RAO) surge response is the largest at 0° and 180° angles, 0.95 m/m. The angles of 0° and 180° are parallel to the surging movement so that the movement will be maximal at that angle. The largest sway Amplitude Operator (RAO) response occurs at an angle of 90°, 0.99 m/m. The angle of 90° is an angle that is parallel to the swaying movement so that the movement will be maximized at that angle. The Amplitude Operator (RAO) heave response at 0°, 45°, 135°, and 180° angles is 1 m/m, and 1.60 m/m at 90° because the angle of 90° is an angle parallel to the motion of the heave hitting the side of the largest area of the ship so that movement will be maximal at that angle.

The most significant Response Amplitude Operator (RAO) roll occurs at an angle of 90°, 8.76 rad/m. The angle of 90° is an angle that is perpendicular to the roll movement that the most significant area side of the ship so that the movement will be maximized at that angle. The largest pitch Amplitude Operator (RAO) response occurs at angles of 45° and 135°, 1.90 rad/m because that angle has a more significant moment measured from the centre of gravity (Center of Gravity). The largest yaw Amplitude Operator (RAO) response occurs at an angle of 135°, 0.92 rad/m, while the angle of 45° is not much different, at 0.85 deg/m. Why does the biggest yaw occur at an angle of 135° and 45° instead of a 90° angle? The angle of 135° and is an angle that has a more significant moment measured from the centre of gravity (Center of Gravity) of the ship than at an angle of 90°, and angles 135° and 45° have a hit area wide enough for the ship's hull.

Table 3. Maximum RAO Value of Full Load without Ballast Condition

| Motion Mode | Unit   | Maximum RAO Value of Full Load with Ballast Vessel Condition |
|-------------|--------|-------------------------------------------------------------|
|             |        | 0°  | 45° | 90° | 135° | 180° |
| Surge       | m/m    | 0.95 | 0.67 | 0.00 | 0.67 | 0.95 |
| Sway        | m/m    | 0.00 | 0.70 | 0.99 | 0.70 | 0.00 |
| Heave       | m/m    | 1.00 | 1.00 | 1.51 | 1.00 | 1.00 |
| Roll        | deg/m  | 0.00 | 5.32 | 6.64 | 5.30 | 0.00 |
| Pitch       | deg/m  | 2.70 | 3.12 | 0.11 | 3.21 | 2.77 |
| Yaw         | deg/m  | 0.00 | 0.66 | 0.05 | 0.66 | 0.00 |

Amplitude Operator (RAO) surge response is the largest at 0° and 180° angles, 0.950 m/m. It is because the angles 0° and 180° are parallel to the surging movement so that the movement will be maximal at that angle. The largest sway Amplitude Operator (RAO) response occurs at an angle of 90°, 0.990 m/m. The 90° angle is an angle that is parallel to the swaying movement so that the movement will be maximized at that angle. The Amplitude Operator (RAO) heave response at 0°, 45°, 135°, and 180° angles is 1 m/m, and 1.510 m/m at 90° angle because the 90° angle is an angle parallel to the motion of the heave hitting the side of the largest area of the ship so that movement will be maximal at that angle.
The most significant response Amplitude Operator (RAO) roll occurs at an angle of 90°, 6.640 rad/m. The 90° angle is an angle that is perpendicular to the roll movement. It hits the most significant area side of the ship to maximize the movement at that angle. The largest Amplitude Operator (RAO) pitch response occurs at an angle of 135°, which is 3.210 rad/m. The most incredible yaw value occurs at an angle of 135° and 45° instead of a 90° angle because the angle of 135° and is an angle that has a more significant moment measured from the ship's centre of gravity (Center of Gravity) than at an angle of 90° and 135° and 45° angles have a reasonably wide hit area. To the hull, the yaw movement response will tend to be greater at an angle of 135° and 45°.

### Table 4 Maximum RAO Value of Light Load with Ballast Condition

| Motion Mode | Unit | 0° | 45° | 90° | 135° | 180° |
|-------------|------|----|-----|-----|------|------|
| Surge       | m/m  | 0.97 | 0.69 | 0.00 | 0.69 | 0.98 |
| Sway        | m/m  | 0.00 | 0.70 | 0.99 | 0.70 | 0.00 |
| Heave       | m/m  | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Roll        | deg/m | 0.00 | 5.41 | 10.31 | 5.43 | 0.00 |
| Pitch       | deg/m | 1.66 | 1.57 | 0.13 | 1.68 | 1.77 |
| Yaw         | deg/m | 0.03 | 3.02 | 0.05 | 3.03 | 0.00 |

Amplitude Operator (RAO) surge response is the largest at 0° and 180°, 0.976 m/m. The angles of 0° and 180° are parallel to the surging movement so that the movement will be maximal at that angle. The largest sway Amplitude Operator (RAO) response occurs at an angle of 90°, 0.993 m/m. The 90° angle is an angle that is parallel to the swaying movement so that the movement will be maximized at that angle. The response Amplitude Operator (RAO) heave at all angles is 1 m/m including height, due to the shallow draft so that the heave of ships moving on the Z-axis experiences a reasonably large response.

The most significant response Amplitude Operator (RAO) roll occurs at an angle of 90°, 9.993 rad/m. It is because the angle of 90° is an angle that is perpendicular to the roll movement that hits the side of the largest area of the ship so that the movement will be maximized at that angle. The largest pitch Amplitude Operator (RAO) response occurs at an angle of 135°, 2.276 rad/m because that angle has a more significant moment measured from the centre of gravity (Center of Gravity). Supposedly the direction of the angle that causes the most incredible pitch is 0° and 180°; we can see that the value of the two angles is not much different from the pitch value in the direction of 135°. The largest yaw Amplitude Operator (RAO) response occurred at an angle of 135°, which was 0.655 rad/m, while at an angle of 45°, it was not much different at 0.648. Why does the greatest yaw occur at 135° and 45° angles instead of 90° (the most perpendicular to the yaw)? The angle is 135° and is an angle that has a more significant moment measured from the ship's centre of gravity (Center of Gravity) than the 90° angle, and the 135° and 45° angles have a reasonably wide impact area to the ship's hull, so the yaw movement response will tend to be larger at an angle of 135° and 45°.

### Table 5 Maximum RAO Value of Light Load Without Ballast Condition

| Motion Mode | Unit | 0° | 45° | 90° | 135° | 180° |
|-------------|------|----|-----|-----|------|------|
| Surge       | m/m  | 0.97 | 0.69 | 0.00 | 0.69 | 0.98 |
| Sway        | m/m  | 0.00 | 0.70 | 0.99 | 0.70 | 0.00 |
| Heave       | m/m  | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Roll        | deg/m | 0.00 | 5.41 | 10.31 | 5.43 | 0.00 |
| Pitch       | deg/m | 1.66 | 1.57 | 0.13 | 1.68 | 1.77 |
| Yaw         | deg/m | 0.03 | 3.02 | 0.05 | 3.03 | 0.00 |

The largest Surge Amplitude Operator (RAO) response occurred at an angle of 0° and 180°, which was 0.976 m/m. It is because the angles 0° and 180° are parallel to the surging movement so that the movement will be maximal at that angle. The most significant sway response occurs at an angle of 90°, which is 0.993
m/m. It is because the angle of 90° is an angle that is parallel to the swaying movement so that the movement will be maximized at that angle. The response Amplitude Operator (RAO) heave at all angles is 1 m/m including height, due to the shallow draft so that the heave of ships moving on the Z-axis experiences a reasonably large response.

The most significant response Amplitude Operator (RAO) roll occurs at an angle of 90° equal to 10,306 rad/m. It is because the 90° angle is an angle that is perpendicular to the roll movement that hits the side of the largest area of the ship so that the movement will be maximized at that angle. The largest pitch Amplitude Operator (RAO) response occurs at an angle of 180°, 1,765 rad/m. Because the angle of 180° is the most perpendicular to the pitch, 180° and 0° are the most perpendicular angles to the pitch. It can be seen that the RAO values in both angles are equally significant and not much different, namely 1.765 rad/m and 1.663 rad/m.

Meanwhile, the 45° and 135° directions also experienced high responses because those with a more significant moment were measured from gravity (Center of Gravity). The largest yaw Amplitude Operator (RAO) response occurs at an angle of 135°, 3,015 rad/m. It is because the angle of 135° is an angle that has a more significant moment measured from the ship's centre of gravity (Center of Gravity) than at 0° and 180° angles. Yaw movement response will tend to be greater at an angle of 135°. If we look at the overall response value of an empty load structure without ballast is higher than the response of an empty load structure with ballast, this shows that the lower the draft, the higher or unstable the structure's response.

c. Analysis of Mooring Configuration on Operating Limit Mooring Tension

After obtaining the hydrodynamic parameters of each load case, modelling and analyzing the LNG Carrier and mooring system using the OrcaFlex software. The LNG Carrier, jetty, and fender modelling can be seen in figure 2.

![Figure 2. The Model of LNG Carrier, Jetty, and Fender with OrcaFlex](image)

After modelling, the next step is to calculate and analyze a mooring tension with OrcaFlex software. Tension analysis is modelled in several conditions, and there are full load with ballast, full load without ballast, light load with ballast, and light load without ballast. The configurations made are 2-3-1, 3-3-2, and 4-4-3. The configuration 2-3-1 means two lines for the headline part, three lines for the breast line part, and four lines for the spring line part. The configuration 3-3-2 means three lines for the headline part, three lines for the breast line part, and two lines for the spring line part. The configuration 4-4-3 means four lines for the headline part, four lines for the breast line part, and three lines for the spring line part.

The results of validation with the OCIMF Mooring Equipment Guidelines (1997) show that all individual maximum mooring lines in the MT. Adria model meets the safety factor criteria with no value less than 2. The environmental conditions used are 1-year, 50-years, and 1-year using the swell effect. In terms of the location of maximum tension, the maximum overall tension lies at the spring line and breast line. The mooring rope, which has the smallest or most dived angle, is on the spring line and breast line. The more dive the corner, the greater the tension generated. The following is a graph of the maximum mooring tension obtained:
The existing tables and graphs show that the loading direction of 90° has the highest stress result. It is influenced by the high heave when it is in the direction of 90°. In addition, the graph shows that the 4-4-3 configuration tends to have relatively small stress on each line, compared to the 3-3-2 and 2-3-1 configurations, because the loading of the vessel and the environment is supported by more mooring, 11 moorings at the bow, and 11 moorings at the stern. All stress results in each configuration meet the safety factor standards required by OCIMF, but the highest safety factor or lowest tension value is in the 4-4-3 configuration because, with the same load, the load received by each line is lighter compared to individual loads. The configuration of 3-3-2, and 2-3-1, where the number of lines is less accepted by considering the standard of OCIMF safety factor, and the consideration of a more effective mooring installation, it can be seen that the mooring configuration has operational limits that meet and is effective for use in each load condition and existing environmental conditions is a configuration of 2-3-1.

d. Analysis of Mooring Configuration on Operating Limit Mooring Tension
The analysis will be given the loading directions, 225°, 270°, and 315° to simulate the reflection waves.
The loading direction is modelled for three configurations, 2-3-1, 3-3-2, and 4-4-3 configurations, on ships with load conditions with the highest structure response, namely light mutants without ballasts. The loading direction and load condition are entered into the same wave conditions as analyzed using the previous incident wave.

Overall, all loading scenarios result in a safe safety factor above two according to OCIMF. Below will be shown the comparison between the maximum individual mooring tension generated by the incident wave and the maximum individual mooring tension produced by the reflection wave, with the same load conditions, namely the light load without ballast using the same mooring configurations, namely 2-3-1, 3-3-2, and 4-4-3. The mooring tension graphic tension of each wave condition can be seen in figure 6, figure 7, and figure 8.

![Figure 6. Graphic of Mooring Tension in Wave Condition 1-Year (0°-315°)](image)

![Figure 7. Graphic of Mooring Tension in Wave Condition 100-Years (0°-315°)](image)

![Figure 8. Graphic of Mooring Tension in Wave Condition 1-Year with Swell Effect (0°-315°)](image)

Based on the graph above, when compared with the value of mooring tension at the same load condition, namely the light load without ballast using incident wave data, the value of tension using incident waves is much higher than the tension generated when using reflection waves. The average maximum tension remains in the loading direction 90° or is subject to incident waves. It shows that the reflected waves do not influence the mooring system design considerations, such as the mooring jetty configuration when the vessel is moored. It should be noted that the wave data used for the simulation here only considers the effect of reflection and does not consider any other wave deformation parameters.

By calculation, the resulting reflection wave reaches about 40% of the incident wave, with the wave
condition reaching 40% of the incident wave only, the value of mooring tension obtained is very small or insignificant, mainly if the simulation also uses wave data that takes deformation parameters into account. For other waves such as diffraction, refraction, breaking waves, and other things, of course, the value of the resulting mooring tension will be much lower because the waves obtained will be tiny. It implies that the reflection wave does not need to be considered in the design of the mooring system. The incident wave is enough to be a parameter and consideration used because the value of the incident wave is much greater and has a significant effect on the operating limits of the mooring system, in this case regarding the mooring jetty on the moored vessel.

4. Conclusion

1. Vessel Motion Response

From the results of the analysis that has been carried out, the ship's load or load condition will affect the ship's motion. The lighter the ship, the higher the resulting response. In this study, simulations were carried out on four critical conditions of vessel loads, including light loads without ballasts, light loads with ballasts, full loads without ballasts, and full loads with ballasts, and the condition of the ship that has the highest response is light cargo without ballasts. Apart from the ship's cargo, the direction of loading also dramatically affects the ship's motion response results.

2. The Effect of Configuration on Mooring Rope Tension

a. The mooring rope tension analysis carried out by the time domain method using three mooring configurations makes different mooring rope tension. However, all results of mooring tension in each configuration, load condition, and environmental conditions are accepted by OCIMF rule, which is the safety factor, more than 2. By entering the calculation of the maximum stress divided by the minimum breaking strength, the results show that the average lowest safety factor is 6, so the overall load cases are safe.

b. The results of the mooring rope tension analysis carried out by the time-domain method show that the highest individual maximum tension value occurs at full load without ballast with the environmental load direction of 90°. It is because the condition of the vessel and the direction of the environmental loads will experience a more significant movement than the others.

c. The mooring tension analysis carried out by the time-domain method shows that the individual maximum tension values occur in the spring line and breast line. It is because the more you dive the corner, the greater the resulting stress.

d. From the results of the mooring rope tension analysis carried out by the time-domain method, it can be concluded that the most appropriate configuration in terms of operating limits, in the sense of having the highest safety factor, where the minimum is 2 (according to OCIMF) is a 4-4-3 configuration. However, the 2-3-1 configuration is the effective operating limit and the fastest installation estimate in the field.

3. The Effect of Reflection Waves on the Tension of the Mooring Cords

Based on the analysis of tension mooring using reflection waves, when compared with the value of mooring tension at the same load condition, namely light loads without ballasts using incident wave data, the value of tension using incident waves is much higher than the tension generated when using reflection waves. Average maximum tension remains in the loading direction of 90° or is subject to incident waves. It shows that the reflection waves have no influence on design considerations and the determination of the operating limits of the mooring system, in this case, the mooring jetty configuration when the ship is moored.

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