Station-keeping analysis of an FPSO to prevent collision with SPM using AHTS

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Abstract. An FPSO that attached to an SPM with several mooring lines has a collision risk due to the environmental loads. This paper presents analysis of station-keeping FPSO and SPM to prevent collision using an AHTS. The principal dimension of the FPSO is 180m in length, 33m in breadth, 18m height and 12m draft, while the environmental loads is 6m wave height, wind speed around 30knots, current 1 m/s. The analysis shows that the FPSO requires 122 ton bollard pull AHTS for full load and 147 ton for ballast load. The bollard pull can be divided into two vessels in order to make a safe operation which means 74 ton for each AHTS which can be divided into two vessels in order to make a safe operation.

1. Introduction

Station-keeping method is crucial for successful marine operations such as FPSO that connected to an SPM. A configuration of SPM-FPSO requires a vessel who keeps the position in its place which usually using tug boat or anchor handling and tug service (AHTS) [1]. The problem is how to keep the position of the FPSO and SPM in safe distance to prevent the collision between FPSO and SPM [2]. This paper presents the study of station-keeping of SPM-FPSO system in a rough weather. The basic concept is using the resistance of the FPSO in rough weather. One of the concept is how many horse power is required to maintain the position of the FPSO in zero speed [3]. The principal particular of the FPSO can be shown in Table 1.

Table 1. Principal Particular of the FPSO

| Particular | FPSO |
|------------|------|
| LBP        | 180m |
| Breadth    | 31m  |
| Depth      | 18m  |
| Draft      | 12m  |
| DWT        | 44,000 ton |
The calculation of the bollard pull must involve the environmental condition which include wind, current and wave [2] [4]. The environmental data obtained based on the measurement and 100 years return period were accounted [5]. Based on the prediction of 100 years return period from the most extreme several possible directions [6], the environmental data can be summarized as follows:

| Particular     |           |
|---------------|-----------|
| Current max   | 1,0 m/s   |
| Hs            | 4.6 m     |
| Wind Speed    | 21 m/s    |
| Water depth   | 100 m     |

Table 2. Environment data

To conduct the calculation the mooring layout and direction of extreme condition must be considered based on the Metocean data [7] [8] [9]. It is important to define the required bollard pull and make perimeter the safe condition of the mooring system [6].

2. Method of Analysis

The analysis is conducted using numerical method, the required power to maintain position calculated using the extreme condition of weather [10]. The mooring layout of the field can be shown in Figure 1. The assumption is that the north direction is 90°, west is 0°, south is 270°, East is 180°, and back to north. The procedure of analysis must consider the accidental load [11] [12], so the analysis of motion response conducted from 0°, 45°, 90°, 135° and 180°. Since the dangerous environmental loads for this type of configuration are coming from stern-seas (East 180), Quarter 30 stern-seas, Quarter 60 stern-seas, Beam-seas (North 90), the bollard pull analysis conducted from those directions.

2.1. Procedure and Motion Response

The procedure of station-keeping in this paper can be shown in Figure 2.

![Figure 1](image-url)
In order to conduct the analysis, the first step is to design the numerical model of the FPSO. Based on the numerical model, the motion response or Response Amplitude Operator (RAO) of the FPSO can be obtained. The evaluation of motion responses is using numerical software MOSES. The illustration of the motion seen in Figure 2. Surge is can be defined as moving forwards and backwards along the longitudinal horizontal x-axis, Sway is moving left and right along the lateral horizontal y-axis, heave is moving up and down along the vertical z-axis. While the rotational motion which include roll, pitch, and yaw can be defined as follows. Roll is rotation of a vessel about its longitudinal x-axis, pitch is rotation of a vessel about its transverse y-axis, yaw is rotation of a vessel about its vertical z-axis [13].

To obtain the RAOs, we should analyze the dynamic behavior of the platform due to an incoming harmonic wave. To represent the case, the hydromechanics of a single mass-spring system are illustrated in Figure 4 [14].

For a simple mass spring system, the following equations are applied based on newton 2\textsuperscript{nd} Law.

\[ F = m\ddot{x}(t) \]  \hspace{1cm} (1)

\( F \) is external force in N, \( \ddot{x} \) is acceleration in m/s\(^2\), \( t \) is time in s. By considering c as hydrostatic stability of platform, \( m \) is mass, \( x \) is position, \( \ddot{x} \) is acceleration, \( t \) is time in s, the equation can be modified as follows:

\[ F = m\ddot{x}(t) + cx(t) \]  \hspace{1cm} (2)

\[ x(t) = X_0 \cos(\omega t + \varepsilon_x) \]  \hspace{1cm} (3)
\[ X_a = \sqrt{x(0)^2 + \left(\frac{x(0)}{\omega_n}\right)^2} \]  

(4)

\[ \varepsilon_x = \arctan \left( \frac{x(0)}{x(0) \cdot \omega_n} \right) \text{ and } \omega_n = \sqrt{\frac{c}{m}} \]

Where \( X_a \) is the motion amplitude, \( \omega \) is frequency in rad/s, \( \varepsilon_x \) is phase of the motion, \( \omega_n \) is natural frequency in rad/s, and \( \dot{x} \) is velocity of the motion.

To represent the floating platform, the mass term must consider the hydrodynamic added mass, \( a(\omega) \) and the mass can be rewritten as \( m = m + a(\omega) \). The detailed equation of the added mass and hydrostatic damping can be written as follows:

\[ F(t) = (m + a(\omega)\dot{x}(t) + b(\omega)x(t) + Cx(t) \]

(5)

Where \( b \) is damping coefficient, \( C \) is stiffness of the system.

While the harmonic wave forces has the following formula:

\[ F(t) = F_a \cos(\omega t) \text{ or } F(t) = Re\{F_a e^{i(\omega t)}\} \]

(7)

\[ x(t) = R\{X_a e^{i(\omega t)}\} \]

(8)

\[ X_a = \frac{F_a}{-(m+a(\omega))\omega^2+iab(\omega)+c} \]

(9)

Based on the above mass-spring system, the motion RAOs for the 6 degrees of freedom are achieved by solving the \( X \).

\[ \{-\omega^2 \cdot (M + A(\omega)) + i\omega \cdot B(\omega) + C\} \cdot X(\omega, dir) = F(\omega, dir) \]

(10)

Where \( C \) is the vessel stiffness, \( B(\omega) \) is the hydrodynamic damping, \( M \) is the mass of the vessel, \( A(\omega) \) is the hydrodynamic added mass, \( F(\omega, dir) \) is the hydrodynamic force vector and \( X(\omega, dir) \) is in 6 DOF matrix of vessel motions for the wave frequency ‘\( \omega \)’ and the wave direction ‘\( dir \)’. The hydrodynamic wave forces are calculated for a unit wave with amplitude \( \zeta \).

The final RAO equation as follows:

\[ RAO(\omega, dir) = \{-\omega^2 \cdot (M + A(\omega)) + i\omega \cdot B(\omega) + C\}^{-1} \cdot F(\omega, dir) \]

(11)

Based on the equation, the RAO can be defined as motion amplitude per unit wave amplitude.

\[ RAO_a(\omega, dir) = \left(\frac{X(\omega, dir)}{\zeta}\right) \]

(12)

To calculate the RAO, this paper uses Moses software.
2.2. Numerical Modeling and Analysis

The numerical model of the FPSO was created in Moses software and the results of the numerical model can be shown in Figure 5.

![Figure 5. Body Plan of FPSO](image)

Based on the calculation the particular of the FPSO can be presented in Table 3. This numerical model will be used in further analysis which involve the FPSO, SPM and the environmental data [11].

| Particular             | Value         |
|------------------------|---------------|
| Wetted Surface Area    | 8516 m²       |
| Windage Area Above Deck| 405 m²        |
| Hull Roughness Coeff   | 0.0004        |
| Displacement           | 5500 ton      |

3. Results and Discussion

3.1. Results

3.1.1. Motion response Ballast Load.

The motion response analysis were conducted in several direction in order to obtain the extreme condition that could occurred.

![Motion Response Heading 0 Degree](image)
Figure 6. RAO 0° Environmental Heading (from bow)

Figure 7. RAO 45° Environmental Heading (from bow)
Figure 8. RAO 90° Environmental Heading (quarter sea)

Figure 9. RAO 135° Environmental Heading (from bow)
3.1.2. Resistance Coefficient.

The numerical analysis involve the resistance of the FPSO and the resistance coefficient can be shown in Figure 11, while the residual resistance coefficient can be shown in Figure 12.

![Figure 10. RAO 180° Environmental Heading (from bow)](image)

![Figure 11. Resistance coefficient](image)

![Figure 12. Resistance coefficient](image)
Where the x axis represents \( \frac{v}{\sqrt{gL}} \), Y axis \( L/B \) and Z axis is \( Cr \).

3.1.3. Bollard Pull for station-keeping

The calculation of the bollard pull capacity for station-keeping conducted in two conditions, the ballast load and full load. The results of the calculation of ballast load can be shown in Table 4 while the results of the Full Load can be shown in Table 5. Based on the calculation conducted using numerical model, the required bollard pull in full load is 122 ton while in ballast load is 147.28 ton.

| Table 4. Bollard pull for station-keeping (Full Load) |
|-----------------------------------------------|
| Environment 100 yr period                   |
| Wave Height                                  | 4.6 m |
| Peak Period                                  | 11.7 s |
| Wind speed                                   | 21 m/s |
| Current speed                                | 1 m/s |
| Required Bollard Pull                        |
| Stern-seas (East 180)                        | 121.13 ton |
| Quarter 30 stern- seas                       | 113.99 ton |
| Quarter 60 stern- seas                       | 71.19 ton |
| Beam-seas (North 90)                         | -0.05 ton |

| Table 5. Bollard pull for station-keeping (ballast Load) |
|-----------------------------------------------|
| Environment 100 yr period                   |
| Wave Height                                  | 4.6 m |
| Peak Period                                  | 11.7 s |
| Wind speed                                   | 21 m/s |
| Current speed                                | 1 m/s |
| Required Bollard Pull                        |
| Stern-seas (East 180)                        | 147.28 ton |
| Quarter 30 stern- seas                       | 122.05 ton |
| Quarter 60 stern- seas                       | 70.67 ton |
| Beam-seas (North 90)                         | -0.05 ton |

3.2. Discussion

For the operation safety, the station-keeping procedure must consider the situation in the field, one of the method is using visual check if there is no force sensor attached in the hawser that connect FPSO and SBM. The first condition is where the hawser is in moderate tension as shown in Figure 13. During this condition, the AHTS no need to act to pull the FPSO.

![Figure 13. Safe condition (moderate hawser tension)](image-url)
The second condition is where the hawser tension is high as shown in Figure 14. The AHTS no need to pull the FPSO but must be in cautious condition since the tension is high.

![Figure 14. Alert Condition (High hawser tension)](image)

The third condition is where the hawser tension is very low or the hawser is loose as shown in Figure 15. The AHTS need to pull the FPSO to keep the safe distance from the SBM also to prevent the collision between FPSO and SBM. This condition usually occurred due to stern environmental load as proved by the previous calculation.

![Figure 15. Danger Condition (Loose hawser tension)](image)

Since the required bollard pull is high and it is not easy to find AHTS with 147 ton capacity, this paper would like to recommend configuration of two AHTS for the station-keeping. The configuration can be shown in Figure 16.

![Figure 16. Configuration of two AHTS](image)

To fulfil the required AHTS bollard pull, each of the AHTS must be at least 74 ton of Bollard pull.

4. Conclusion
The design tow resistance of the FPSO is determined considering the hydrodynamic and aerodynamic resistance. From the total tow resistance (R), the minimum required bollard pull (BP) for the tow FPSO is computed, by considering a tug efficiency factor of 0.75. Based upon the result of load cases, the maximum bollard pull for fully loaded draft is 121.13 MT occurred during 100-years return period environment coming from FPSO stern. The maximum bollard pull for ballast draft is 147.28 MT occurred during 100-years return period environment coming from stern of FPSO.
5. References

[1] International Society of Offshore and Polar Engineers et al., “ISOPE-2012 Rhodes conference proceedings; the proceedings of the Twenty-Second (2012) International Offshore and Polar Engineering Conference; Rhodes, Greece, June 17-22, 2012; [including 7 specialty symposia.” International Society of Offshore and Polar Engineers (ISOPE), 2012.

[2] M. Muslim and M. S. Kamil, “FPSO Mooring Configuration Based On Malaysia’s Environmental Criteria,” 2017.

[3] K.-T. Ma, *Mooring system engineering for offshore structures*. 2019.

[4] DNV GL Rules, “Assessment of station keeping capability of dynamic positioning vessels.” DNV GL, Jul. 2016, Accessed: Mar. 13, 2020. [Online]. Available: https://rules.dnvgl.com/docs/pdf/DNVGL/ST/2016-07/DNVGL-ST-0111.pdf.

[5] K.-T. Ma, Y. Luo, T. Kwan, and Y. Wu, “Environmental loads and vessel motions,” in *Mooring System Engineering for Offshore Structures*, Elsevier, 2019, pp. 41–62.

[6] D. T. Brown, “Mooring Systems,” in *Handbook of Offshore Engineering*, Elsevier, 2005, pp. 663–708.

[7] M. J. Petersen, “Dynamics of ship collisions,” *Ocean Eng.*, vol. 9, no. 4, pp. 295–329, 1982.

[8] H. Fang and M. Duan, “Safety System Engineering for Offshore Oil,” in *Offshore Operation Facilities*, Elsevier, 2014, pp. e183–e347.

[9] Z. Górski and M. Giernalczyk, “STATISTIC DETERMINATION OF MAIN PROPULSION POWER AND TOTAL POWER OF ONBOARD ELECTRIC POWER STATION ON ANCHOR HANDLING TUG SUPPLY VESSELS AHTS SERVICING OIL RIGS,” p. 6.

[10] G. J. Blight and P. Y. T. Dai, “Resistance of offshore barges and required tug horsepower,” in *Offshore Technology Conference*, 1978.

[11] M. Storheim, J. Amdahl, and I. Martens, “On the accuracy of fracture estimation in collision analysis of ship and offshore structures,” *Mar. Struct.*, vol. 44, pp. 254–287, 2015.

[12] D. N. Veritas, “Design against accidental loads,” *Recomm. Pract. DNV-RP-C204*, 2010.

[13] R. de Winter, B. van Stein, M. Dijkman, and T. Bäck, “Designing Ships Using Constrained Multi-objective Efficient Global Optimization,” in *Machine Learning, Optimization, and Data Science*, vol. 11331, G. Nicosia, P. Pardalos, G. Giuffrida, R. Umeton, and V. Sciacca, Eds. Cham: Springer International Publishing, 2019, pp. 191–203.

[14] D. Skandali, “Identification of response amplitude operators for ships based on full scale measurements,” T.U Delft, 2015.

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