ABSTRACT

The stability and dynamic positioning of any floating structure is essential during offshore activities. It is therefore necessary to carry out offshore mooring system analysis in order for it to withstand extreme environmental forces of wind, wave, and current that will act on the structures. This project is focused on designing a fit-for-purpose catenary mooring system to achieve the stability and dynamic positioning of a 5000 tonnes Offshore Work barge with an Helicopter landing Platform and a crane carrier. The mooring design is based on engineering and scientific principle (numerical method), in which elastic catenary equation are derived and applied to determine the dynamic response; the degree of environmental force in the floating structure and the minimum line required for mooring. Classification society of Det Norske Veritas DNV regulations were adopted.

Keywords: Mooring system, offshore Structure, environmental force, fit-for-purpose mooring system.

1. INTRODUCTION

The consistent demands for offshore resources have seen the maritime industry to an era of increasing application of deep water technology and concept for better engineering productivity. The sustained drive to improve the harvest from offshore oil exploration, production and distribution and storage has led to the design of various structures such as, floating production systems, fuel barges and work barges. They are designed to meet the specific need of the industry under peculiar circumstances.

Therefore, it is important to note that; floating structures, (fuel or work barges, ships, FPSO) etc like any other, require stability to be operational, especially, under extreme environmental conditions of loadings such as wave, wind and current. Mooring systems are required to provide such stability against vessel dynamics, while ensuring allowable excursion.

With so much dependence of the floating structures on the mooring system, it is worthwhile to understand to a high degree of accuracy the performance of each of the system components and the global response of the mooring system.

The performance of any mooring system is typically a function of the type and size of the vessel in use such as the operational water depth, environmental forces, seabed condition; and the competence of the mooring lines and the anchor weight. These various factors must be closely complementary for a mooring system to harness its full potential against environmental loads.

The challenge of understanding the behaviour of a floating structure under environmental loads is quite enormous and producing designs of mooring system with high integrity requires the ability to isolate the various behaviors of the system as induced by different loads. This paper will focus more on catenary mooring system with the following objectives:

- To study the dynamic response of Catenary Mooring lines under the influence of external forces
- To determine the minimum length of mooring lines required for a catenary system
- To analyze the environmental factors acting on the mooring lines (catenary mooring system).

Component of Mooring System

The principal components of a mooring system consist of:

- Chain (wire or rope)
- Connector
- Anchor (self-weight anchor or suction anchor)

The design procedure for mooring design includes design and verification phase.
In 1970’s and 80’s the earliest spread moored production platform was installed in relative shallow water (under 500m) in the north sea of Brazil. These were mostly all chain catenary systems, which provided the compliance required to resist wave dynamics in such a depth. As platforms progressed into depths beyond 500m and up to 1000m in the 90’s, catenary mooring evolved into wire-chain system.

In 2010 a comprehensive study in mooring system and its ability to retain floating system in fixed position was done. The research established the loading and offloading configurations and the influence of hydrodynamic interaction during the offloading process. (RATNA NITA PERWITASARI). A software analysis tool WADAM was used for the analysis. Also in 2011 “development design tool for statically equivalent deepwater mooring system” a detail study was carried out using both numerical simulation and model testing (Hybrid method).

The study analyzes the importance of design of mooring system to ensure that static properties of prototype floater are limited by those of the model in the wave-based design prior to testing. A fit-for-purpose numerical tool called STAMOORSYS was developed.

2. MATERIALS AND METHODS

To overcome the issue of underperforming mooring system and for the future development of offshore mooring system a robust engineering approach is proposed, in brief, proposed engineering methodology consist of:

a) Understanding the environmental condition at the area of investigation
b) Design and analysis of the mooring system using numerical models.

The mooring system design is assessed in terms of three limit state based on the following criteria.
• Ultimate Limit State (ULS). Ensuring that individual mooring lines have suitable strength when subjected to forces caused by extreme environment loads (wave).
• Accidental limit state: ensuring that, the mooring system has suitable reserve capacity when lines or thruster has failed.
• Fatigue limit state: Ensuring that each mooring lines has suitable reserve capacity when subjected to cyclic loading

Nevertheless, in catenary mooring design concept, load characteristics for a single line and a spread mooring are established. Ignoring fluid forces on the lines

**Loading Mechanism**

\[ F_{\text{environmental}} = F_{\text{wave}} + F_{\text{wind}} + F_{\text{current}} \]
Fig. 3: Environmental forces acting on a moored vessel in head sea conditions and transverse motion of catenary mooring lines.

Fig. 4: Mooring Lines of the Work Barge.
CATENARY LINE EQUATIONS

Suspended line length

\[ L_s = a \sinh \left( \frac{x}{a} \right) \]  

(1)

Vertical dimension (depth)

\[ h = a \left\{ \cosh \left( \frac{x}{a} \right) - 1 \right\} \]  

(2)

Combining Equation (1) and (2)

\[ L_s^2 = h^2 + 2ha \]  

(3)

Where parameter

\[ a = \frac{T_H}{w} \]  

(4)

Using line Tension at the platform

Tension at the top is

\[ T = W \left( \frac{L_s^2 + h^2}{2h} \right) = \sqrt{T_H^2 + T_Z^2} \]  

(5)

\[ T_H = T \cos (\theta_w) \]  

(6)

Maximum tension

\[ T_{max} = T_H + wh \]  

(7)

Combining equations (3), (4) and (7)

We have the minimum limit length

\[ L_{min} = \frac{a}{2} \sqrt{\frac{T_{max}^2}{wh} - 1} \]  

(8)

Requirement

\[ T_{max} \leq T_{br} \]  

(9)

(breaking strength/tension in mooring line).

Considering the horizontal distance \( x \) between the anchor point “A” and the point where the lines are connected to the vessel. 

\[ X = L - L_s + x \]  

(10)

\[ X = L - h \sqrt{\left(1 + \frac{2T_H}{h} \right) + \frac{T_H}{w} \cosh^{-1} \left(1 + \frac{wh}{T_H} \right)} \]  

(11)

\[ X = \cosh^{-1} \left(1 + \frac{h}{a} \right) \]  

(12)

Definition of parameters

<table>
<thead>
<tr>
<th>Ls</th>
<th>suspended line length</th>
</tr>
</thead>
<tbody>
<tr>
<td>h</td>
<td>vertical dimension (depth)</td>
</tr>
<tr>
<td>T_H</td>
<td>Horizontal restoring force applied by the mooring lines</td>
</tr>
<tr>
<td>T</td>
<td>Tension at the top</td>
</tr>
<tr>
<td>T_Z</td>
<td>Vertical component of tension</td>
</tr>
<tr>
<td>T_{max}</td>
<td>Maximum tension</td>
</tr>
</tbody>
</table>

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W = Weight per unit length of chain/cable in water
L_{min} = Minimum line length
a = Horizontal dimension
Sinh and Cosh are parabolic function

**DYNAMIC ANALYSIS OF MOORING LINE SYSTEM**

In carrying out the dynamic analysis of mooring system it is important to understand the floating structure (FPSO, Fuel barges, ship), the medium upon which the floating structure exist, the environmental loads conditions (wind, wave and currents) and also the cable lines holding the structure in position.

It is true that the stiffness of the cable represents the principal parameter affecting the mooring lines dynamics response, and therefore the deduction would improve the dynamic performance of the mooring lines.

### 3. ANALYSIS AND DISCUSSION OF RESULTS

The calculations are made in accordance with the classification society, Det Norske Veritas

**Design Parameter and environmental wave data**

- Length of Anchors Chain (L) = 600m
- Number of Anchors used = 4 Anchors
- Horizontal pretension T_H = 300KN
- Weight of Anchor in water (W) = 1000 N/M
- Height of Water depth (h) = 250m
- Length of Work Barge L_p = 80m
- Breadth of Work Barge B_p = 30m
- Height of Work Barge H_p = 4.5m

These mooring lines are designed to stabilize the pontoon for the storage of fuel offshore with design SPECIFICATION of Net Norske Veritas.

- Distance between anchor A and B
  - From the geometry of the figure, the distance is \( (2x + L_p) \) m.
  - Using the expression,
    \[
    X - x = L - L_s \\
    X = L - L_s + x
    \]
  - Where \( L_s^2 = h^2 + 2ha \)
  - Where \( a = \frac{T_H}{W} \)
    \[
    a = \frac{300}{1.0} \text{ KN/N} = 300m
    \]
  - Hence \( L_s^2 = 250^2 + 2 	imes 250 	imes 300 \)

  Therefore, \( X = 364.2m \) into equation (1)
  \[
  X = 600 - 460.98 + 364.2 = 503.22m
  \]

- Line Tension at the platform

  Tension at the Top
  \[
  T = W \left( \frac{L_s^2 + h^2}{2h} \right)
  \]

  and maximum tension
  \[
  T_{max} = T_H + W_h
  \]

  Where
  \[
  T_H = \text{ Horizontal component of Tension} \\
  T_z = \text{ Vertical component of Tension} \\
  T_H = 300KN \text{ and} \\
  T_z = W \times L_s = 1 \times 460.98 = 460.98KN
  \]

  \[
  T = \sqrt{300^2 + 460.98^2}
  \]

  Tension at the Top \( T = 550KN \)

  Therefore Maximum Tension \( T_{max} \)
\begin{align*}
= T_H + Wh \\
T_{\text{max}} = 300 + 1 \times 250 = 550\text{KN}
\end{align*}

From the geometry of the figure below, \(X_a\) representing increase in \(X_A\) due to movement as a result of environmental RHS force.

\(X_b\): Decrease in \(X_B\) due to movement of platform in response to RHS environmental force to pull anchor A. The environmental force on the platform to move anchor A is a right hand side pulling force \(F_{\text{R}}\) (RHS); movement of the platform stretches the touchdown point until the length of the anchor line is fully extended at anchor A.

As the touchdown length approximates to the full length of the anchor line, the work barge is equally displaced forward by an amount \(X_a\) which is equal to a reduction \(X_b\) towards anchor B, ie. \(x_a = x_b\)

\[ L_S \approx L = 600\text{m} \]

Thus we can find expression for the other properties of the platform.

Hence new \(a = L^2_s - \frac{h^2}{2h} \)

\[ L^2_s = h^2 + 2ha = L^2 \]

i.e \[ L^2_s = L^2 = h^2 + 2ha \]

\[ a = \frac{(600^2 - 250^2)}{2 \times 250} = \frac{360,000 - 62,500}{500} = 595\text{m} \]

\[ \therefore \text{New } a = 595\text{m} \]

And new \(T_h = \text{Horizontal Pretension} \)

\(T_h = aw \)

From \(a = \frac{T_H}{W} \)

\[ T_H = 595 \times 1 = 595\text{KN} \]
New $X_A$ due to movement is

From

$$L_s = a \sin h \left( \frac{x}{a} \right),$$

we can state

$$a L_s \left( \frac{L_s}{a} \right) = X_A$$

$$X_A = a \sin h^{-1} \left( \frac{L_s}{a} \right)$$

$$X_A = 595 \times \sin h^{-1} \left( \frac{600}{595} \right)$$

$$X_A = 595 \times 0.8873$$

$$X_A = 527.945 m$$

Hence, the platform moved by a distance

$$527.945 - 503.22 = 24.725 m$$

This is also the movement of the fair lead point on the platform at anchor A.

At the initial pretension $T_H$ of 595KN, $X = 25 m$

$\therefore$ This movement caused a reduction in $X_B$ by

$$503.22 - 24.725 = 478.495 m = 479 m$$

Hence, new $X_B$ is 479m. The quest now is to solve for a tension at B, which is also the effect of the environmental force on the platform to move the anchor A that will cause this New $X_B = 479 m$ on anchor B.

This has to be solved iteratively by assuming values for pretension at anchor B, until the target value of $X_B = 479 m$ is achieved.

Then, the effective environmental force on the platform to move anchor A will be the difference between the initial pretension of 595KN at $X = 25 m$; and the tension at B due to the reduced length in $X_B$.

To achieve this, we shall use the following equation.

$$a = \frac{T_{H_B}}{W}, \quad L_s = \sqrt{h^2 + 2ha}$$
Catenary mooring system shows that the catenary system is no suitable for deep waters. Therefore energy automation must be closely examined and different energy producing methods must be sought such as energy from renewable energy sources (RES).

The final design of the mooring system shows that the catenary system is not suitable for deep waters. Also in the mooring system analysis the three limit state criteria is considered. Catenary mooring systems are serious alternative to deepwater mooring system.

Finally, future research will evolve around, the design of offshore mooring system for a wave energy converter (HYBRID METHOD). However, this will give rise to other technical issues such as the structural behaviour of the vessels. Therefore energy automation must be closely examined and different energy producing methods must be sought such as energy from renewable energy sources (RES).

**REFERENCES**


Young-Bok Kim (2003) Dynamic Analysis of multiple body floating platforms coupled with mooring lines and risers” PhD Dissertation, Civil Engineering Department, Texas A & M University Texas.

APPENDIX (Some Stability graphs for WB)

Fig. 8: Center of gravity versus draft

Fig. 9: Displacement versus draft

Fig. 10: Metacentric radius versus draft
Fig. 11: Moment per cm trim versus draft

Fig. 12: Metacentric height versus draft