Mooring and Hydrostatic Restoration of Scorpio 300 Drillship

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ABSTRACT
This dissertation evaluates the Mooring and Hydrostatic restoration of SCORPIO 300 Drillship; this entails determination of mooring stiffness, minimum line length, maximum line tension and the required size of anchor to keep the vessel at station. A single point moored vessel was modelled and analysed using MATLAB programming and computation of the Equipment Number. Results show that the required minimum length of Mooring Line Ls is 1264.9 m, the maximum Tension, Tmax is 1.3 MN and the coefficient of the hydrostatic restoring force in surge is 1770.7 N/m. This surge stiffness is required to keep the vessel at station. Equipment Number, EN for this vessel is obtained as 953. Its corresponding Equipment Letter is v, and, the corresponding characteristics for the required anchor (and how many of such), chain cables, towlines and mooring lines are known from Equipment Table.

Keywords-MOORING, HYDROSTATIC RESTORATION, SCORPIO 300 DRILLSHIP, MATLAB

I. INTRODUCTION
A drillship is a merchant vessel designed for use in exploratory offshore drilling of new oil and gas wells. It can also be used for other scientific drilling purposes. In most cases, the vessels are used in deepwater and ultra-deepwater applications, equipped with the latest and most advanced dynamic positioning systems. The first drillship was the CUS S I, designed by Robert F. Bauer of Global Marine in 1955. The CUS S I had drilled in 400 feet deep waters by 1957 (Schempf, 2007). Robert F. Bauer became the first president of the Global Marine in 1958 (Schempf, 2007).

Mooring systems has to be designed to keep a floating offshore structure in the open sea in precise position (Douglas et al., 2013). The system that may keep a floating structure in position can be either a passive or an active one (DP) or a combined system (assisted DP). In marine operations it is important to keep a precise position. For instance, when conducting a drilling operation one wishes to minimize the movements of the drilling riser, because to much movement can cause the riser to fail. Thrusters and mooring systems are used to withstand environmental loads which arise from waves, wind, and current.
A mooring system is composed of a number of cables which are connected to the floating vessel (Inegiyemiema et al., 2014). They are oriented in a radial fashion around the mooring point. The lower ends of the cables are attached to the seabed with anchors. 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. In carrying out the dynamic analysis of mooring system it is important to understand the floating structure (FPSO, 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 (Michael, 2013).

ANALYTICAL CALCULATIONS
Analytical Calculations are done to evaluate the mooring & hydrostatic restoration of scorpio 300 drillship. Doing this analytical calculation involves the evaluation of mooring stiffness, minimum line length, maximum line tension and required size of anchor to keep the vessel at station to enable her carry out the operation.

II. MATERIALS AND METHODS
a. MATERIALS:
The materials used in this research work are the relevant ship data needed for dynamic analysis of an offshore barge vessel in sea waves, which include: ship dimensions (like length, beam, depth and draft) and their proportions and displacement. The design and analysis conducted in this study was done using a marine engineering computer tool called MATLAB, which also constituted as part of the materials used in this study. After the design of the Scorpio 300 drillship vessel was modelled with the computer aided design (CAD) software, the drillship vessel was subjected to the environmental condition in which it is to operate. The MATLAB program was used to model the mooring stiffness for simulation. This analysis showed the dynamic response of the Scorpio 300 drillship vessel mooring system in the surge motion. The dynamic analysis was a necessary procedure to follow to determine the minimum length of the mooring line and the maximum tension in the mooring line as well as the coefficient of the hydrostatic restoring force. The equipment number was used to evaluate and select the suitable size and number of anchors required for the mooring system.

b. METHODS
Mooring and hydrostatic parameters
A. Single point mooring
Components of forces along tangential and normal directions:

Tangential components:  
\[ d\mathbf{T} = w\sin\theta \, ds \]
Where \( T = T - \rho g \, Z \)
\( w = \text{weight/length of cable line in water} \)
\( A = \text{Cross Sectional Area of Cable} \)
\( \rho = \text{Density of water} \)
\( g = \text{Acceleration due to gravity} \)
\( Z = \text{free surface} \)

Normal Components  
Where \( W = \text{weight/length of cable line in water} \)
Triangular representation of forces acting on the mooring line

\[
\frac{WS}{T_H} = \sinh\left(\frac{WX}{T_H}\right) \quad (2)
\]

Where \( W \) = weight/length of cable line in water

\( T_H \) = The horizontal component of cable tension at waterline

**Triangular representation of Forces acting on the Mooring Line for catenary method**

\[
\frac{ds}{dx} = \sqrt{1 + \left(\frac{dz}{dx}\right)^2} \quad (3)
\]

\[
\frac{dz}{dx} = \sinh\left(\frac{WX}{T_H}\right) \quad (4)
\]

Where \( h \) = water depth

\[
\begin{align*}
S &= \frac{T_H}{W} \sinh\left(\frac{WX}{T_H}\right) \\
WS &= \sinh\left(\frac{WX}{T_H}\right)
\end{align*}
\]  

(5)

**A. Maximum Line Tension**

\( T_{\text{max}} = T_H + wh \quad (6) \)

Where \( T_{\text{max}} \) = Maximum Line tension

**B. Minimum Line Length**

\[
l_s = \sqrt{h^2 + 2ha} = h\left(1 + \frac{2a}{h}\right)^{1/2} \quad (7)
\]

Where \( a \) – distance from waterline amidship to the upper deck at side

\[
l_s = h\left(\frac{2T_{\text{max}}}{wh} - 1\right)^{1/2} \quad (8)
\]

Where \( l_s \) = Minimum line length

**C. Horizontal Distance of the Vessel from the anchor point**

\[
x = 1 - h\left(1 + \frac{2a}{h}\right)^{1/2} + \cosh^{-1}\left(\frac{h}{a} + 1\right) \quad (9)
\]

Where \( x \) = horizontal distance of the vessel from the anchor point

\[
C_{11} = W\left[\cosh^{-1}\left(\frac{h}{a}\right) - 2\left(1 + \frac{2a}{h}\right)^{1/2}\right]^{-1} \quad (10)
\]

Where \( C_{11} \) = mooring stiffness or hydrostatic restoring coefficient

**Equipment Number**

Equipment Number is a dimensionless parameter used to determine the size and number of anchors and chain cables for a new ship. However, it is important to remember that the anchoring equipment determined in accordance with the “Equipment Number” is intended for temporary mooring of a vessel within a harbor or sheltered area, when the vessel is awaiting berth, tide, etc. The equipment is, therefore, not designed to hold a ship off fully exposed coats in rough weather or to stop a ship which is moving or drifting.

Furthermore, this anchoring equipment is designed to hold a ship in good holding ground. In poor holding ground, the holding power of the anchors will be significantly reduced.

**Evaluation of Equipment Number**

The equipment number (TheNavalArch, Team; 2019) is given by the formula:

\[
EN = \Delta^{2/3} + 2BH + 0.1A \quad (11)
\]

Where \( EN \) = Equipment Number
\[ \Delta = \text{Mass Displacement} \]

\[ B = \text{Breadth} \]

\[ H = \text{Effective height} \]

\[ A = \text{Area} \]

Table 1: Equipment Table, General (IACS, 2021)

<table>
<thead>
<tr>
<th>Equipment number</th>
<th>Equipment letter</th>
<th>Number</th>
<th>Mass per vessel (kg)</th>
<th>Total length (m)</th>
<th>Diameter and steel grades</th>
<th>Steel or fibre ropes</th>
<th>Minimum breaking strength (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-40</td>
<td>a</td>
<td>2</td>
<td>120</td>
<td>192.5</td>
<td>12.5</td>
<td>180</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>3</td>
<td>120</td>
<td>192.5</td>
<td>12.5</td>
<td>180</td>
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Table 1: Equipment Table for Fishing Vessels & Seales (Marine Engineering, 2018)

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<tr>
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</thead>
<tbody>
<tr>
<td>30-39</td>
<td>a_d</td>
<td>2</td>
<td>80</td>
<td>105</td>
<td>11</td>
<td>150</td>
<td>0.8</td>
</tr>
<tr>
<td>40-49</td>
<td>a_d</td>
<td>2</td>
<td>120</td>
<td>192.5</td>
<td>12.5</td>
<td>180</td>
<td>0.8</td>
</tr>
<tr>
<td>50-50</td>
<td>a_f</td>
<td>2</td>
<td>120</td>
<td>192.5</td>
<td>12.5</td>
<td>180</td>
<td>0.8</td>
</tr>
<tr>
<td>60-60</td>
<td>a_f</td>
<td>2</td>
<td>120</td>
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<td>12.5</td>
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<td>a_f</td>
<td>2</td>
<td>120</td>
<td>192.5</td>
<td>12.5</td>
<td>180</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Table 2: Equipment Reductions for Service Restriction Notations

<table>
<thead>
<tr>
<th>Class notation</th>
<th>Stockless bower anchors</th>
<th>Stud-link chain cables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Mass change per anchor</td>
</tr>
<tr>
<td>R2</td>
<td>2</td>
<td>-10%</td>
</tr>
<tr>
<td>R3</td>
<td>2</td>
<td>-20%</td>
</tr>
<tr>
<td>R4</td>
<td>2</td>
<td>-30%</td>
</tr>
<tr>
<td>RE</td>
<td>2</td>
<td>-40%</td>
</tr>
</tbody>
</table>

Alternatively:

<table>
<thead>
<tr>
<th></th>
<th>Number</th>
<th>Mass change per anchor</th>
<th>Length reduction</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>R3</td>
<td>1</td>
<td>+40%</td>
<td>-40%</td>
<td>No red.</td>
</tr>
<tr>
<td>R4</td>
<td>1</td>
<td>No change</td>
<td>-50%</td>
<td>No red.</td>
</tr>
<tr>
<td>RE</td>
<td>1</td>
<td>-20%</td>
<td>-60%</td>
<td>No red.</td>
</tr>
</tbody>
</table>

The 3-D Model & Dimensions of SCORPIO 300 Drillship

![3-D Model of SCORPIO 300 Drillship](image)

Table 4: Principal dimensions of Scorpio 300 Drilling Vessel Length

<table>
<thead>
<tr>
<th>S/No</th>
<th>Dimensions</th>
<th>Size (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Length (L)</td>
<td>59.1</td>
</tr>
<tr>
<td>2.</td>
<td>Breadth (B)</td>
<td>16.459</td>
</tr>
<tr>
<td>3.</td>
<td>Depth moulded (Dm)</td>
<td>4.2672</td>
</tr>
<tr>
<td>4.</td>
<td>Mean Daught (D)</td>
<td>1.7572</td>
</tr>
</tbody>
</table>

Environmental Data

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean minimum temperature</td>
<td>23°C</td>
</tr>
<tr>
<td>Minimum temperature</td>
<td>18°C</td>
</tr>
<tr>
<td>Mean temperature</td>
<td>31°C</td>
</tr>
<tr>
<td>Maximum temperature</td>
<td>41°C</td>
</tr>
<tr>
<td>Ground temperature</td>
<td>25-27.5°C</td>
</tr>
<tr>
<td>Humidity</td>
<td>100%</td>
</tr>
<tr>
<td>Average annual rainfall</td>
<td>3800 mm</td>
</tr>
<tr>
<td>Mean maximum hourly rainfall</td>
<td>100 mm</td>
</tr>
<tr>
<td>Maximum wind speed</td>
<td>128 km/hr</td>
</tr>
<tr>
<td>Design wind speed</td>
<td>35.6 m/s</td>
</tr>
</tbody>
</table>

Figure 2: 3-D Model of SCORPIO 300 Drillship
(The wind speed for a 3 second gust speed at the height of 10 metres)
Wind speed for flare readiation calculations: 10m/s.
Design water depth: 1000m

III. RESULT AND DISCUSSIONS
LINE TENSION DISTRIBUTION

To obtain the surge hydrostatic restoring force coefficient required to keep SCORPIO 300 Drillship at station while carrying out its operation, the tension distribution is first obtained. Considering the size of this vessel, we apply a horizontal tension of about 300 kN at the fairlead. With a selected mooring line weight per unit length of 1 kN/m, the total line length of 1500 m is utilized in a water depth of about 1000 m of the Gulf of Guinea where the drillship is operating. The quotient of the horizontal tension to the weight per unit length of the mooring line is therefore 300 m. With the above specifications, the tension distribution is obtained using Equation 3.11 and this is shown below (Figure 4.4). The tension increases parabolically with the horizontal displacement of the vessel from the anchor point.

![Line Tension Distribution](image)

Figure 3: Line Tension vs Horizontal Displacement, X from the anchor

Figure 3 shows the effect of the vertical displacement on the Line tension. The line tension varies linearly with the vertical displacement. Superimposing these two graphs on each other, it can be observed that the tension is equal at about 840 m of the displacements (both horizontal and vertical).
Figure 4: The Effect of Vertical Displacement on the Line Tension

Figure 5: Effects of Displacements on the Line Tension

The horizontal distance of the vessel from the touchdown point, $X_c$ is 643.7690 m while horizontal distance of the vessel from the anchor point, $X$ is 878.8579 m. The required minimum length of Mooring Line $L_m$ is 1264.9 m. The maximum Tension, $T_{\text{max}}$ is 1.3 MN. Result also shows that the coefficient of the hydrostatic restoring force in surge is 1770.7 N/m. This surge stiffness is required to keep the vessel at station.
EFFECT OF WATER DEPTH ON THE MAXIMUM TENSION, $T_{\text{max}}$

Figure 6: Effect of water depth on the Maximum Tension

Figure 10 shows the effect of water depth on the maximum tension on the line. Maximum tension is directly proportional to the water depth provided the horizontal tension at the fairlead is constant. When the water depth is 700 m, the maximum Tension is 1 MN, and when water depth is 1000 m, the maximum tension is 1.3 MN and so on.

CONCLUSION

Therefore, the coefficient of the hydrostatic restoring force is a function of the weight per unit length of the mooring line, the horizontal component of the line tension and the water depth. This is required in the evaluation of surge response of a moored floating structure.

The computed Equipment Number for SCORPIO 300 is 953 which is EN 910-979 (from Table 3.1. Its corresponding Equipment Letter is v. This gives the required number of anchors as 2, with a mass of 2850 kg per anchor. The stud-link chain cable, Towline and Mooring characteristics are also found from the Equipment Table.

The first objective of this research which is to determine the coefficient of hydrostatic restoring force in the surge motion was achieved. For the second objective, which is to determine the required minimum length of the mooring line was also realised and achieved as 1264.9m with a maximum tension of 1.3MN and the third objective which is to determine the equipment number for the vessel was also achieved.

REFERENCES

(2) ABS Guidance Note on the Application of Fiber Rope for Offshore Mooring, 2011
(3) ABS Rules for Building and Classing Single Point Moorings, 2014


