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Design and Analysis of a Mooring System of a Drillship

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ABSTRACT
This study presents a Mooring analysis of SCORPIO 300 Drillship. Itdemonstrates the 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 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, Analysis, Mooring System,Scorpio 300 Drillship

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 theCUSS I, designed by Robert F. Bauer of Global Marine in 1955. The CUSS 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).

Figure 1: The first drillship CUSS I (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 (Inegiyemiemaet 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

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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).

II. LITERATURE REVIEW

The low frequency motions of moored floating vessels had been investigated by a number of researchers in the last few decades.

Made some background studies, empirical measurements and gave some theoretical explanations of the drift forces acting on a moored floating vessel in waves. Furthermore, an analytical procedure for calculating the slow drift oscillations and peak mooring forces which are extremely essential in practice was illustrated.

The influence of the force on the motions of moored vessels and the loads in the mooring system were favourably compared to the results of model tests in irregular waves. Pinkster's works undoubtedly enhanced the understanding of the phenomenon, with vital formulations deemed to be very invaluable in both the frequency and time domain computations. Though his formulations are based on linear assumptions, they are more suitable and preferable to model-test measurements at the initial design stage.

Recent literatures show that a lot of attention has been paid to the problem of conducting mooring and hydrostatic restoration of offshoredrillship. Many authors are professionally engaged in offshore mooring system for vessel or ship, dynamic analysis of calm buoy-based steel offloading line system and design of deepsea mooring lines (Douglas et al., 2013; Song, et al., 2014.

Adl.samad (2009) evaluated the performance of catenary mooring system. Nitonyeet al. (2013) conducted stability analysis for the design of 5000-Tonnes offshore work and subsequently John (2013) studied vessel mooring system. These studies, however, addressed the problem of conducting dynamic analysis of a mooring system for an offshore pontoon barge, but in a restricted manner.

Zhang et al. (2015) conducted dynamic analysis of the mooring system for a floating offshore wind turbine spar platform. Based on the 5 MV wind turbine of a certain renewable energy institute in America, the model of a floating offshore wind turbine spar platform mooring system was established by Orcaflex. By calculating the load on the wind turbine, the hydrodynamic analysis of the wind turbine mooring system was researched and the mooring tension of the mooring system was analyzed in different load conditions. With the change of different fairlead position and different layouts of the fairleads, the optimization design of the mooring system was given.

Inegiyemiemaet al. (2014) designed a mooring system for an offshore structure: a case study of 5000 tonnes offshore work barge (WB). They stated that stability and dynamic positioning of any floating structure is essential during offshore activities hence it is 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. Their study was 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 were 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 was adopted.

III. ANALYTICAL CALCULATIONS

Analytical Calculations are done to evaluate the mooring analysis 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.

IV. 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

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Volume 5, Issue 3 March 2023, pp: 1341-1349 www.ijaem.net ISSN: 2395-5252

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.

V. METHODS

Mooring analysis parameters

A. Single point mooring

Components of forces along tangential and normal directions:

Tangential components:

$$d\mathbb{T} = w\sin\theta ds \qquad \text{(Error! Bookmark not defined.)}$$

Where:

$\mathbb{T} = T - \rho g A z$

T = line Tension

A = Cross Sectional Area of Cable

ρ = Density of water

g = Acceleration due to gravity

Z = free surface

Normal Components

Where:

W = weight/length of cable line in water

Triangular representation of forces acting on the mooring line

$$\frac{ws}{T_H} = \sinh\left(\frac{wx}{T_H}\right) \qquad (2)$$

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

$$\frac{ds}{dx} = \sqrt{1 + \left(\frac{dz}{dx}\right)^2} \qquad (3)$$

$$\frac{dz}{dx} = \sinh\left(\frac{wx}{T_H}\right) \qquad (4)$$

Where:

h = water depth

$$\left.\begin{aligned} s &= \frac{T_H}{w}\sinh\left(\frac{wx}{T_H}\right) \\ \frac{ws}{T_H} &= \sinh\left(\frac{wx}{T_H}\right) \end{aligned}\right\} \qquad (5)$$

A. Maximum Line Tension

$$\mathbf{T_{max} = T_H + wh} \qquad (6)$$

Where T_{max} = Maximum Line tension

B. Minimum Line Length

$$\left. l_s = \sqrt{h^2 + 2ha} = h\left(1 + \frac{2a}{h}\right)^{1/2} \right\} \qquad (7)$$

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

$$\mathbf{l_s = h\left(\frac{2T_{max}}{wh} - 1\right)^{1/2}} \qquad (8)$$

Where $\mathbf{l_s}$ = Minimum line length

C. Horizontal Distance of the Vessel from the anchor point

$$\mathbf{X = l - h\left(1 + \frac{2a}{h}\right)^{\frac{1}{2}} + a\cosh^{-1}\left(\frac{h}{a} + 1\right)} \qquad (9)$$

Where X = horizontal distance of the vessel from the anchor point

$$\mathbf{C_{11} = w\left[\cosh^{-1}\left(1 + \frac{h}{a}\right) - 2\left(1 + \frac{2a}{h}\right)^{-\frac{1}{2}}\right]^{-1}} \qquad (10)$$

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

(D)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:

$$\mathbf{EN = \Delta^{2/3} + 2BH + 0.1A} \qquad (11)$$

Where:

EN = Equipment Number

Δ = Mass Displacement

B = Breadth

H = Effective height

A = Area

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$$\mathbf{H} = \mathbf{a} + \sum_{i=1}^{n} \mathbf{h_i} \quad (12)$$

(E) **Morrison's Equation**

Morrison"s equation mathematically describes the relationship between hydrodynamic and drag forces i.e. F_H and F_D respectively, as shown in equation 13.

$$F = F_H + F_D \quad (13)$$

Where:

F_H = Hydrodynamic force

F_D = Drag force

(F)Catenary Equation

Catenary Mooring systems of barge vessels take the simple catenary shape. This is mathematically expressed in equation14as:

$$\mathbf{y} = \frac{\mathbf{H}}{\mathbf{w}\left[\cosh\left(\mathbf{w}\frac{\mathbf{x}}{\mathbf{H}}\right)[-1]\right]} \quad (14)$$

Where:

W=Weight per unit length

H=Horizontal component of tension

(V)Types of Mooring Systems

There are various types of mooring arrangements (Kamal et al., 2016), but six are discussed below. They include: i. Catenary Anchor Leg Mooring System

ii.Taut leg Mooring System

iii. Semi-taut Leg Mooring System

iv. Spread Mooring System

v. Single Point Mooring System

vi. Dynamic Positioning Mooring System

Catenary Anchor Leg Mooring System

The catenary mooring system is the most commonly used system in shallow water. It gets its name from the shape of the free hanging line as its configuration changes due to vessel motions. At the seabed, the mooring line lies horizontally; thus the mooring line has to be longer than the water depth. Increasing the length of the mooring line also increases its weight. As the water depth increases, the weight of the line lessens the working payload of the vessel. In that case, synthetic ropes are used. As water depth increases, conventional, catenary systems become less and less economical.

i. Taut leg Mooring System

The tout leg system typically uses polyester rope that is pre-tensioned until taut. The rope comes in at a 30-to-45-degree angle on the seabed where it meets the anchor (suction piles or vertically loaded anchors), which is loaded vertically. When the platform drifts horizontally with wind or current, the lines stretch and this sets up an opposing force.

ii. Semi-taut Leg Mooring System

The semi-taut system combines taut lines and catenary lines in one system. It is ideally used in deepwater.

iii. Spread Mooring System

A spread mooring system is a group of mooring lines distributed over the bow and stern of the vessel to anchors on the seafloor. The vessel is positioned in a fixed heading, which is determined by the sea and weather conditions. The symmetrical arrangement of anchors helps to keep the ship on its fixed heading location. The spread mooring system does not allow the vessel to weathervane, which means to rotate in the horizontal plane due to wind, waves or current. Spread mooring is versatile as it can be used in any water depth, on any vessel, in an equally spread pattern or a group.

v. Single Point Mooring System

A single point mooring system connects all the lines to a single point. It links subsea manifolds connections and weathervaning tankers, which are free to rotate 360 degrees. The single point system includes a buoy, mooring and anchoring elements, product transfer system and other components.

vi. Dynamic Positioning Mooring System

Dynamic positioning does not use mooring lines. Instead, a computer controls the vessel's thrusters and propellers to maintain position. DP can be used in combination with other mooring systems to provide additional redundancy.

For the purpose of this study, the catenary mooring system is chosen for the dynamic analysis.

Catenary Anchor Leg Mooring System

The catenary mooring system is the most commonly used system in shallow water. It gets its name from the shape of the free hanging line as its configuration changes due to vessel motions. At the seabed, the mooring line lies horizontally; thus the mooring line has to be longer than the water depth. Increasing the length of the mooring line also increases its weight. As the water depth increases, the weight of the line lessens the working payload of the vessel. In that case, synthetic ropes are used. As water depth increases, conventional, catenary systems become less and less economical.

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Catenary mooring system is the most common mooring system in water with a depth less than l500m, which consists of a group of lines combined of chain and wire rope. The restoring force of catenary mooring system is mainly provided by its own weight. There is enough length of mooring line resting on the seabed to avoid the anchor bearing vertical load. With the requirement to operate in increasing water depths, traditional catenary mooring system becomes more and more unsuitable (Dove et al., 2000).

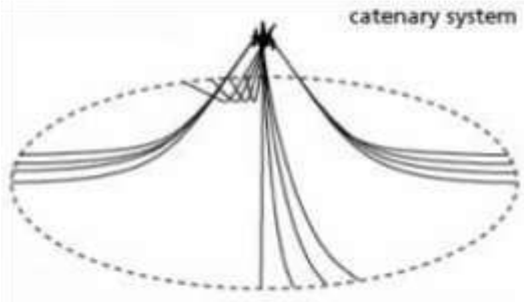

Figure 2:Typical catenary mooring layout (Source: Kamal et al., 2016)

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

Equipment number	Equip-ment letter	Stockless bower anchors		Stud-link chain cables				Towline (guidance)		Mooring lines 1) (guidance)		
				Total length	Diameter and steel grade			Steel or fibre ropes		Steel or fibre ropes		
		Number	Mass per anchor kg	m	NV K1 mm	NV K2 mm	NV K3 mm	Minimum length m	Minimum breaking strength kN	Number	Length of each m	Minimum breaking strength kN
30-49	a0	2	120	192.5	12.5			170	88.5	2	80	32
50-69	a	2	180	220	14	12.5		180	98.0	3	80	34
70-89	b	2	240	220	16	14		180	98.0	3	100	37
90-109	c	2	300	247.5	17.5	16		180	98.0	3	110	39
110-129	d	2	360	247.5	19	17.5		180	98	3	110	44
130-149	e	2	420	275	20.5	17.5		180	98	3	120	49
150-174	f	2	480	275	22	19		180	98	3	120	54
175-204	g	2	570	302.5	24	20.5		180	112	3	120	59
205-239	h	2	660	302.5	26	22	20.5	180	129	4	120	64
240-279	i	2	780	330	28	24	22	180	150	4	120	69
280-319	j	2	900	357.5	30	26	24	180	174	4	140	74
320-359	k	2	1020	357.5	32	28	24	180	207	4	140	78
360-399	l	2	1140	385	34	30	26	180	224	4	140	88
400-449	m	2	1290	385	36	32	28	180	250	4	140	98
450-499	n	2	1440	412.5	38	34	30	180	277	4	140	108
500-549	o	2	1590	412.5	40	34	30	190	306	4	160	123
550-599	p	2	1740	440	42	36	32	190	338	4	160	132
600-659	q	2	1920	440	44	38	34	190	371	4	160	147
660-719	r	2	2100	440	46	40	36	190	406	4	160	157
720-779	s	2	2280	467.5	48	42	36	190	441	4	170	172
780-839	t	2	2460	467.5	50	44	38	190	480	4	170	186
840-909	u	2	2640	467.5	52	46	40	190	518	4	170	201

International Journal of Advances in Engineering and Management (IJAEM)
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Table 2: Equipment Table for Fishing Vessels &Sealers(Marine Engineering, 2018)

Equipment number	Equipment letter	Stockless bower anchors		Stud-link chain cables			Towline (guidance)		Mooring lines (guidance)		
					Diameter and steel grade		Steel or fibre ropes		Steel or fibre ropes		
		Number	Mass per anchor	Total length	NV K1	NV K2	Minimum length	Minimum breaking strength	Number	Length of each	Minimum breaking strength
			kg	m	mm	mm	m	kN		m	kN
30-39	a_0f_1	2	80	165	11				2	50	29
40-49	a_0f_2	2	100	192.5	11				2	60	29
50-59	af_1	2	120	192.5	12.5		180	98	3	80	34
60-69	af_2	2	140	192	12.5		180	98	3	80	34
70-79	bf_1	2	160	220	14	12.5	180	98	3	100	37
80-89	bf_2	2	180	220	14	12.5	180	98	3	100	37
90-99	cf_1	2	210	220	16	14	180	98	3	110	39
100-109	cf_2	2	240	220	16	14	180	98	3	110	39
110-119	df_1	2	270	247.5	17.5	16	180	98	3	110	44
120-129	df_2	2	300	247.5	17.5	16	180	98	3	110	44
130-139	ef_1	2	340	275	19	17.5	180	98	3	120	49
140-149	ef_2	2	390	275	19	17.5	180	98	3	120	49
150-174	f	2	480	275	22	19	180	98	3	120	54
175-204	g	2	570	302.5	24	20.5	180	112	3	120	59
205-239	h	2	660	302.5	26	22	180	129	4	120	64
240-279	i	2	780	330	28	24	180	150	4	120	69
280-319	j	2	900	357.5	30	26	180	174	4	140	74
320-359	k	2	1020	357.5	32	28	180	207	4	140	78
360-399	l	2	1140	385	34	30	180	224	4	140	88
400-449	m	2	1290	385	36	32	180	250	4	140	98
450-499	n	2	1440	412.5	38	34	180	277	4	140	108
500-549	o	2	1590	412.5	40	34	190	306	4	160	123
550-599	p	2	1740	440	42	36	190	338	4	160	132
600-659	q	2	1920	440	44	38	190	371	4	160	147
660-720	r	2	2100	440	46	40	190	406	4	160	157

Table 3: Equipment Reductions for Service Restriction Notations

Class notation	Stockless bower anchors		Stud-link chain cables	
	Number	Mass change per anchor	Length reduction	Diameter
R2	2	- 10%	No red.	No red.
R3	2	- 20%	No red.	No red.
R4	2	- 30%	- 20%	- 10%
RE	2	- 40%	- 30%	- 20%
Alternatively:				
R3	1	+40%	- 40%	No red.
R4	1	No change	- 50%	No red.
RE	1	- 20%	- 60%	- 10%

Table 4: Table of Offsets for the SCORPIO 300 Barge

	St	0	1	2	3	4	5	6	7	8	9	10
	x	**0**	**5.8**	**11.6**	**17.3**	**23.1**	**28.9**	**34.7**	**40.5**	**46.3**	**52.1**	**57.9**
WL	**Z**				**Half Breadths**							
0	0.82	6.7	6.7	6.7	8.23	8.23	8.23	8.23	8.23	8.23	8.23	7.6
1	1.53	6.7	6.7	6.7	8.23	8.23	8.23	8.23	8.23	8.23	8.23	7.6
2	2.73	6.7	6.7	6.7	8.23	8.23	8.23	8.23	8.23	8.23	8.23	7.6

International Journal of Advances in Engineering and Management (IJAEM)
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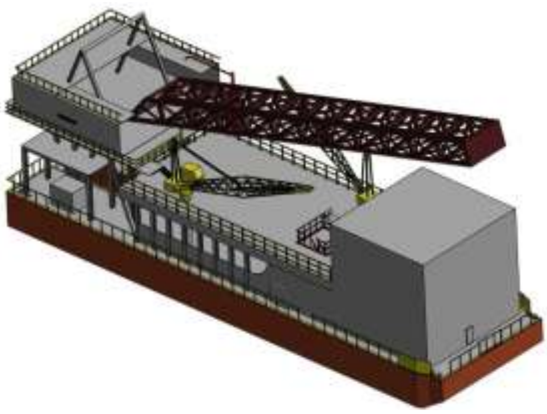

Figure 3: 3-D Model of SCORPIO 300 Drillship

Table 5: Principal dimensions of Scorpio 300 Drilling Vessel Length

S/No	Dimensions	Size (m)
1.	Length (L)	59.1
2.	Breadth (B)	16.459
3.	Depth moulded (Dm)	4.2672
4.	Mean Daught (D)	1.7572

Environmental Data
General
The information below forms the environmental basis of the design
Terrain
Odidi is situated in the Niger Delta, Nigeria. The facilitates are located on land, where heavy rainfalls are regularly in the rainy season. (April to October)
Ambient Temperatures:

Mean minimum temperature:	23^{o}C
Minimum temperature:	18^{o}C
Mean temperature:	31^{o}C
Maximum temperature:	41^{o}C
Ground temperature	25-27.5^{o}C
Humidity	100%
Average annual rainfall	3800 mm
Mean maximum hourly rainfall	100 mm
Maximum wind speed	128 km/hr
Design wind speed	35.6m/s

(The wind speed for a 3 second gust second gust speed at the height of 10 metres)
Wind speed for flare readiation calculations: 10m/s.
Design water depth 1000m

VI. 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

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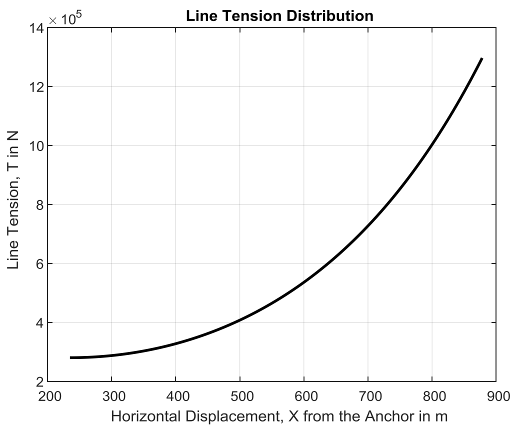

Figure 4: Line Tension vs Horizontal Displacement, X from the anchor

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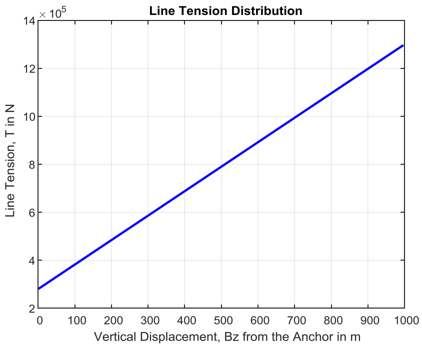

Figure 5: The Effect of Vertical Displacement on the Line Tension

Figure 4. 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).

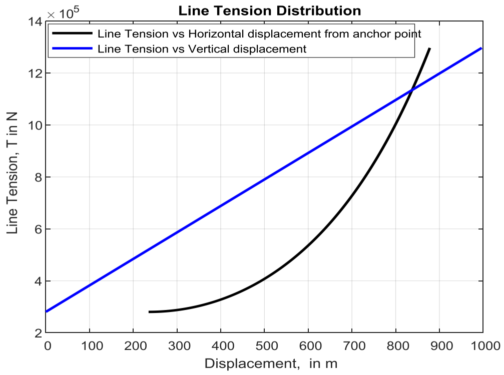

Figure 6: Effects of Displacements on the Line Tension

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_s is 1264.9 m. The maximum Tension, T_{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_{max}

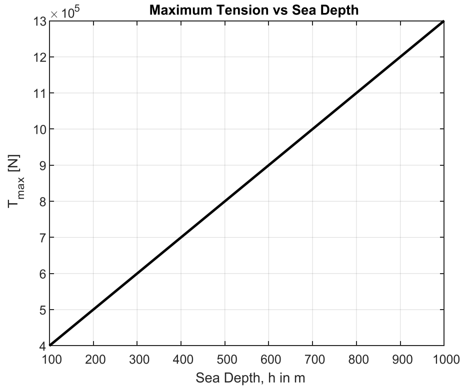

Figure 7: Effect of water depth on the Maximum Tension

Figure 7 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.

Curves of Form

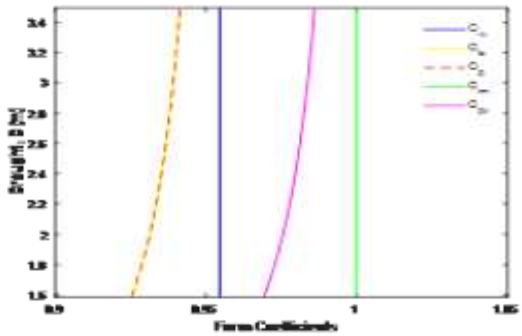

Figure 7: Curves of Form showing how the Form Coefficients change with Draughts.

From Figure 7, the block coefficient (C_b) and the prismatic coefficient (C_p) of the vessel are equal and have a minimum value of 0.9253 and a maximum value of 0.9413, with an average value of 0.9354.

VII. CONCLUSION

This research carries out mooring analysis of SCORPIO 300 Drillship.The study is necessitated by the need to evaluate the required minimum length of the mooring line,the maximum line tension and the effect of water depth. This research was done using an Engineering computer tool called MATLAB.

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

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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 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.

The waterplane area and the midship section area coefficients have constant values of 0.9547 and 1 respectively. The vertical prismatic coefficient ranges from 0.9692 to 0.9860 with an average value of 0.9798.

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