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# Analysis of the Effect of Sinker on Bearing Capacity of Anchor in Calm Buoy Mooring System: Case Study of SBM Pengapon Semarang

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## ABSTRACT

*The addition of sinkers on the mooring line is generally used to support the anchor in maintaining its position in extreme environmental conditions. In this study, the authors will analyze the effect of sinkers on the mooring line tension and the bearing capacity of the anchor. The sinker variations in this analysis are 10, 15, and 20 tons, which will be added to the asymmetric mooring line of CALM Buoy SPM Pengapon Semarang. The type of anchor SPM is Stevpris MK III on soft clay soil type. The authors first analyses the line tension in each environmental loading condition and then analyses the anchor's bearing capacity. The analysis results show that the largest tension occurs in line 3 without a sinker in DEC conditions with an environmental load direction of 314.24 deg, 1,301.19 kN (End A) and 1,310.43 kN (End B). In the analysis of the holding capacity of the anchor, the authors refers to the SOF ABS Class 2019 and the charts of Appendix D2 and D6 API RP 2SK. The results indicate that the gradation of weight and position of the sinker causes the line tension between the sinker and the fairlead to increase linearly, with an average percentage increase of 1.35%. Meanwhile, the bearing capacity of the anchor, which includes required holding capacity, anchor weight, and estimated drag distance/fluke length, decreased with an average percentage of 7.46%, 15.39%, and 4.79%. Based on the consideration of the End A tension analysis results in the DEC condition, it is stated that the 20-ton sinker in position 1 is a suitable variation of the sinker in this SPM Pengapon Semarang case study.*

**Keywords:** *Sinker, Bearing Capacity, Tension, Holding Capacity, Anchor*

## 1. INTRODUCTION

The increasing world demand for oil and gas energy requires humans to continue to innovate science and technology for efficiency in oil and gas exploration and exploitation. One of the production and transportation facilities often in use in the oil and gas industry is ship crude/product oil tanker. This building has a special ability to store and distribute oil to oil storage tanks onshore in loading and unloading crude oil storage tanks. The large draft of the ship does not allow this building to lean directly on the pier. From that, we need a mooring technology that can make the tanker that does not move on the move. The mooring system commonly used is single-point mooring. One type of SPM is the Catenary Anchored Leg Mooring Buoy.

As the basic foundation of an SPM, the anchor must have sufficient strength to maintain its stability and the floating structure anchored to the SPM. The ability of the anchor to hold the structure (holding capacity anchor) is influenced by the weight of the anchor, the penetration depth, and the anchor used [1]. In the SPM-type catenary mooring system, the most suitable type of anchor recommendation is a drag anchor. In some extreme conditions, it is necessary to have other components to help reduce the movement of the anchor and keep it in the desired position. Adding other components, such as sinkers, can help reduce the pulling force of the anchor so that the anchor stays in position. In addition to increasing anchor stability, the presence of sinkers can also reduce the need for anchors and depth of penetration during installation. However, the lack of case studies regarding the addition of sinkers in the SPM mooring line has attracted the author's attention to carry out this analysis. Therefore, in this study, the structure of the SPM mooring line will be modeled with a sinker added, and the effect of the addition of a sinker on the mooring line on the bearing capacity of the anchor can be known.

Moreover, it can be a reference for determining the efficiency of the SPM mooring line by comparing the strength of the variation in anchor requirements added with sinkers. The objectives of this study are to compare tension mooring lines due to variations in ballast (sinker) on conditions of the DOC and DEC and to determine the changes in the bearing capacity anchor on the mooring line due to the influence of sinker variations.

## 2. LITERATURE REVIEW

In certain conditions with extreme environmental loads, each component in the mooring system must have good strength to withstand the load of the surrounding environment. One of the important components that must have sufficient resistance in maintaining the structure of the mooring system is the anchor. Several studies on anchor capacity in maintaining the position of the mooring system have been carried out. The anchor holding capacity is closely related to the need for anchor weight. Relationship between anchor holding capacity and anchor weight requirements based on anchor type and soil type [3]. The shear force due to soil adhesion can also affect the need for anchor-bearing capacity [1]. The anchor holding capacity can also depend on the depth of anchor penetration, the mechanical properties of the soil, and the dimensions and type of anchor used [1].

Most mooring systems generally use a drag anchor type. The drag anchor performance significantly influences the floating system’s reliability, integrity, and operational safety [4]. However, in some cases with extreme environmental conditions that require the system to have high stability, adequate drag anchor holding capacity is also required. Therefore, the anchor requires other components to support its capacity. One of the components in question is the sinker. Research on this matter is still considered to be minimal and needs to be further developed.

### 2.1 CALM Buoy

This CALM Buoy is a fairly popular and widely used offshore loading terminal with over 500 systems installed. CALMs are typically between 20 and 100 meters in water depths and are connected to a coastal storage facility (tank farm) or an offshore production platform via subsea pipelines. The Catenary Anchor Leg Mooring (CALM) Buoy consists of a body buoy supported by several catenary chain legs anchored to the seabed.

### 2.1 Basic Theories of Floating Structure

Each floating building produces an oscillatory motion response due to the wave excitation force within six degrees of freedom [5]. The resulting structural motion response consists of translational movements (surge, sway, and heave) and rotational movements (roll, pitch, and yaw), as shown in the figure below.

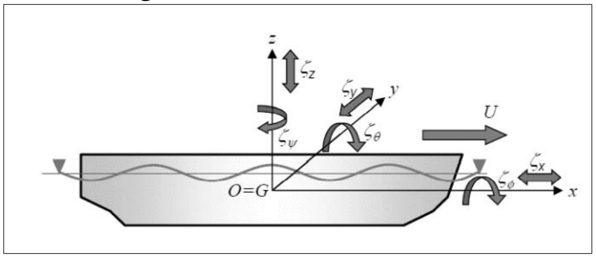


Figure 2.1 Degrees of Freedom of Floating Structure

### 2.2 Response Amplitude Operators

RAO is a tool for transferring wave forces into a dynamic response to the structure's movement, commonly known as the transfer function [6]. The following equation can express the response of the RAO motion to the translational motion.

$$RAO = \frac{\zeta k_0}{\zeta_0}(m/m) \qquad (1)$$

With,
$\zeta k_0(\omega)$ : Wave amplitude (m)
$\zeta_0(\omega)$ : Amplitude of movement in a certain mode (m)

The equation below expresses the response of RAO movement to rotational movement of roll, pitch, and yaw.

$$RAO = \frac{\zeta k_0}{k_w \zeta_0} = \frac{\zeta k_0}{(\omega^2/g)\zeta_0}(rad/rad) \qquad (2)$$

With,
$k_\omega$ = wave number
$\zeta_0$ = wave amplitude (m)
$\zeta_{k0}$ = amplitude of movement in a certain mode (m)
g = due to gravity (9.81 m/s$^2$)

### 2.3 Tension Mooring Line

The floating structure that moves causes a tug on the mooring line. The calculation of the mooring line voltage can use the frequency domain approach [7]. In this frequency domain approximation, the value of tension is given below.

$$T_{max} = T_{mean} + T_{lf(max)} + T_{wf(sig)} \qquad (3)$$

With,
$T_{max}$ : maximum tension on the mooring line
$T_{mean}$ : mean tension on the mooring line
$T_{lf(max)}$ : significant single amplitude low frequent tension
$T_{wf(max)}$ : significant single amplitude wave frequent tension

The maximum limit of the tension line can also be determined based on the mooring line's Minimum Breaking Load (MBL). The MBL value refers to the type or grade of the mooring line originating from the company. It is also necessary to check the strength of the line to determine whether the mooring line has met the safety criteria for operation. The standard safety factor criteria in each analysis condition are stated in the table below [7].

Table 2.1 Strength Factor Of Safety ABS

| Mooring System Condition | | Environment Condition | Strength Factor of Safety (FOS) | |
|---|---|---|---|---|
| | | | Quasi-Static | Dynamic Analysis |
| Mobile Mooring & Permanent Mooring | All Intact | DEC | 2.00 | 1.67 |
| | One broken line (at new equilibrium position) | DEC | 1.43 | 1.27 |
| | One broken line (Transient) | DEC | 1.18 | 1.05 |
| Mooring Terminal | All Intact | DEC | NA | 2.5 |
| | All Intact | DOC | NA | 3.00 |
| Fiber Rope Mooring Line Component | All Intact | DEC | NA | 1.82 |
| | One Broken Line | DEC | NA | 1.43 |

The equation for determining the value of the safety factor itself is shown below.

$$SF = \frac{MBL}{T_{max}} \quad (4)$$

With,
$SF$ : Safety Factor
$T_{max}$ : Maximum tension on mooring line
$MBL$ : Minimum Breaking Load

## 2.4 Anchor Holding Capacity

Determining the *Required Holding Capacity* can refer to the value of the *strength factor of safety* (FOS) ABS Class 2019 and the maximum line tension at the *anchor point* using the following equation.

$$R_{anchor} \geq F_{anchor} x\ FOS \quad (5)$$

With,
$R_{anchor}$ : required holding capacity anchor
$F_{anchor}$ : maximum load at anchor
$FOS$ : strength safety of factor

## 3. METHODOLOGY

The methodology in this study was based on certain steps. The first step is to determine the background and formulation of the research problem, followed by a literature review. The literature review method aims to collect data, journals, and standards supporting research work. Then, the following work is done.

1) Structure Modeling

After validating the CALM Buoy and ship models, an RAO analysis will be carried out on each model using MOSES software.

2) RAO Analysis on Structure

At this stage, the authors modeled the CALM Buoy mooring system with and without sinkers, consisting of stand-alone SPMs and SPMS with a ship moored to the buoy.

3) Analysis of Mooring Line Tension

The model is then subjected to a dynamic analysis using Orcaflex software to obtain the tension value in each analysis condition.

4) Analysis of Anchor Bearing Capacity

This analysis refers to API RP 2SK to determine the required holding capacity anchor weight and estimated anchorage distance of Stevpris MK III.

## 4. ANALYSIS AND DISCUSSION

### 4.1 Tanker Models

The authors Modeled the 35,000 DWT tanker using the MOSES 3D diffraction theory software, input the hydrostatic data and validating the model based on the ABS Class 2019, with the following results.

Table 4.1 Validation of Ship Model

| Parameter | Unit | Data | Moses | Status | Error |
|---|---|---|---|---|---|
| Deadweight (DWT) | ton | 35,000 | 34,999 | OK | 0,00% |
| Displacement | m | 43,703 | 43,345.9 | OK | 0,82% |
| CB | m | 0.77 | 0.78 | OK | 1.49% |
| *LPP* | m | 174 | 174 | OK | 0,00% |
| *LOA* | m | 179.70 | 179.70 | OK | 0,00% |
| *Breadth* | m | 30.03 | 30.03 | OK | 0,00% |
| Draught | m | 10.06 | 10.06 | OK | 0,00% |
| Depth | m | 12.70 | 12.70 | OK | 0,00% |

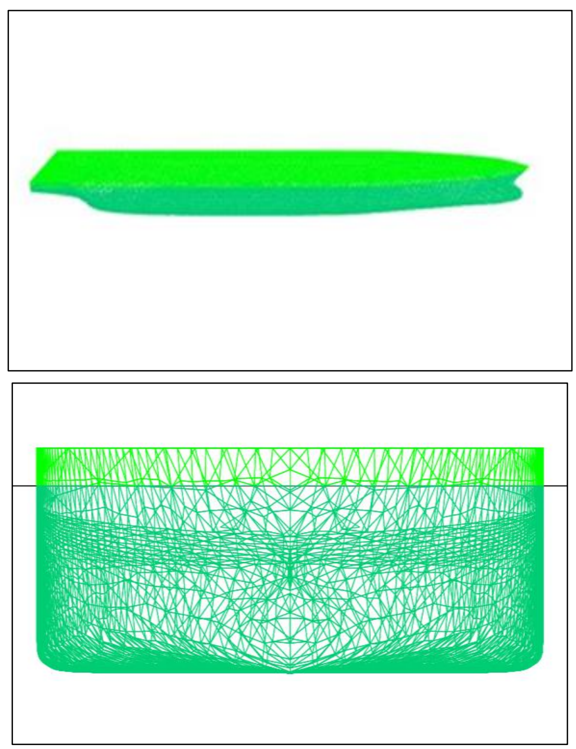

Figure 4.1 Ship Model

## 4.2 Buoy Models

Body buoy modeling is done using MOSES Editor software. Suppose the results meet the validation standards [8]. In that case, the software's output, in the form of RAO and the buoy body's hydrostatic properties, can be used as input for modeling the mooring system in the Orcaflex software. The results of modeling and validation are shown in Table 4.2 below.

Table 4.2 Validation of Buoy Model

| Parameter | Unit | Data | Moses | Status | Error |
|---|---|---|---|---|---|
| Displacement (Δ) | ton | 132,89 | 132,59 | OK | 0,22% |
| Diameter *buoy* | m | 8 | 8 | OK | 0,00% |
| Diameter *skirt* | m | 11,24 | 11,24 | OK | 0,00% |
| *Buoy Height* | m | 3,7 | 3,7 | OK | 0,00% |
| *Skirt Height* | m | 0,8 | 0,8 | OK | 0,00% |
| Draft | m | 1,8 | 1,8 | OK | 0,00% |
| VCG | m | 2,22 | 2,22 | OK | 0,00% |

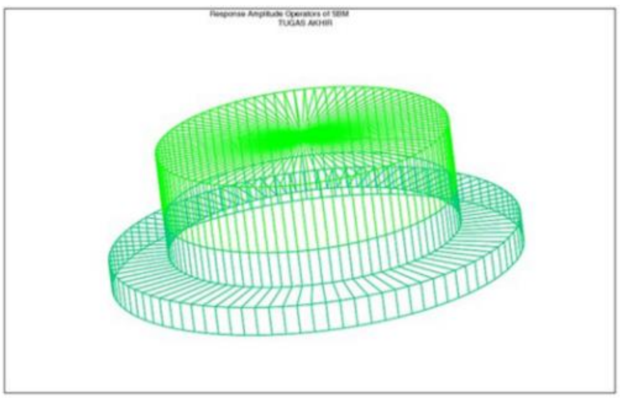

Figure 4.2 Buoy Body Model

## 4.3 RAO Analysis on Structure

The results of Response Amplitude Operators are structural motion responses in free-floating conditions in regular waves. The resulting structural motion response consists of translational movements (Surge, Sway, and Heave) and rotational movements (Roll, Pitch, and Yaw). The results of the RAO Buoy are as follows.

Table 4.3 Maximum RAO Buoy-*Free Floating*

| RAO RECAPITULATION ON BUOY | | | | | | | |
|---|---|---|---|---|---|---|---|
| Motion Mode | | Unit | Maximum RAO | | | | |
| | | | 0° | 45° | 90° | 135° | 180° |
| Translation | Surge | m/m | 0.98 | 0.69 | 0.00 | 0.69 | 0.98 |
| | Sway | m/m | 0.00 | 0.69 | 0.98 | 0.69 | 0.00 |
| | Heave | m/m | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 |
| Rotation | Roll | deg/m | 0.00 | 4.61 | 6.52 | 4.61 | 0.00 |
| | Pitch | deg/m | 6.61 | 4.63 | 0.09 | 4.62 | 6.54 |
| | Yaw | deg/m | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

The results of the MOSES software output in a 35,000 DWT tanker RAO with full load conditions are as follows.

Table 4.4 Maximum RAO Tanker *Free Floating*

| RAO RECAPITULATION ON 35,000 DWT Tankers | | | | | | | |
|---|---|---|---|---|---|---|---|
| Motion Mode | | Unit | Maximum RAO | | | | |
| | | | 0° | 45° | 90° | 135° | 180° |
| Translation | Surge | m/m | 0.99 | 0.70 | 0.06 | 0.70 | 0.99 |
| | Sway | m/m | 0.00 | 0.70 | 0.99 | 0.70 | 0.00 |
| | Heave | m/m | 0.99 | 1.00 | 1.59 | 1.00 | 0.99 |
| Rotation | Roll | deg/m | 0.00 | 2.49 | 3.56 | 2.47 | 0.00 |
| | Pitch | deg/m | 1.11 | 1.27 | 0.19 | 1.28 | 1.10 |
| | Yaw | deg/m | 0.00 | 0.48 | 0.05 | 0.42 | 0.00 |

## 4.4 Mooring System Modeling

The mooring system modeling uses Orcaflex software to describe the actual condition of the mooring layout so that tension analysis can be carried out using this model. The following is data on the location of anchors and mooring line properties of SPM Pengapon Semarang.

Table 4.5 Anchor Coordinates

| Buoy Anchor Coordinates | | | | |
|---|---|---|---|---|
| Object | UTM WGS.84 | | GEOGRAPHIC | |
| | Easting | Northing | Longitude (T) | Latitude (S) |
| SPM | 436 996.76 | 9 238 580.08 | 110°25’ 47.02” | 6°53’ 17.43” |
| Anchor 1 | 436 770.96 | 9 238 727.84 | 110°25’ 39.56” | 6°53’ 12.78” |
| Anchor 2 | 437 160.99 | 9 238 834.45 | 110°25’ 52.31” | 6°53’ 09.19” |
| Anchor 3 | 437 134.74 | 9 238 441.56 | 110°25’ 51.63” | 6°53’ 21.93” |
| Anchor 4 | 436 853.34 | 9 238 429.82 | Two 110°25' 42.34" | 6°53’ 22.11” |

Tabel 4.6 Mooring Line Properties

| Mooring Line Component | | |
|---|---|---|
| Parameters | Unit | Data |
| Line 1 and Line 4 | | |
| Type | - | Studless - Chain |
| Grade | - | Grade R4 |
| Diameters | mm | 58 |
| Minimum Breaking Load (MBL) | kN | 3,627.95 |
| Line 2 and Line 3 | | |
| Type | - | Stud link - Chain |
| Grade | - | U3 |
| Diameter | mm | 58 |
| Minimum Breaking Load (MBL) | kN | 2,600 |
| Panjang | m | 55 |
| Line 2 dan line 3 | | |
| Type | - | Studless - Chain |
| Grade | - | Grade R4 |
| Diameter | mm | 82.5 |
| Minimum Breaking Load (MBL) | kN | 6,974.77 |
| Hawser | | |
| Type | - | Rope |
| Grade | - | Polypropilene |
| Diameter | inch | 9 |
| Minimum Breaking Load (MBL) | ton | 504.803 |

The mooring line will also add variations of ballast, namely 10 tons, 15 tons, and 20 tons. Below is the result of modeling the mooring system with sinkers using Orcaflex software.

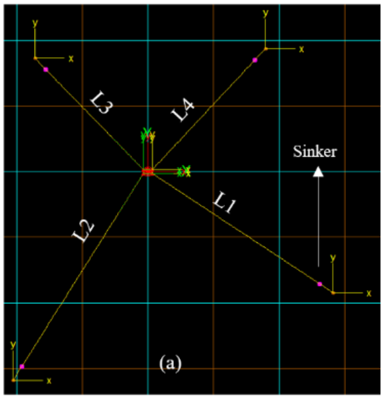


Figure 4.3 *Mooring System* at DEC conditions

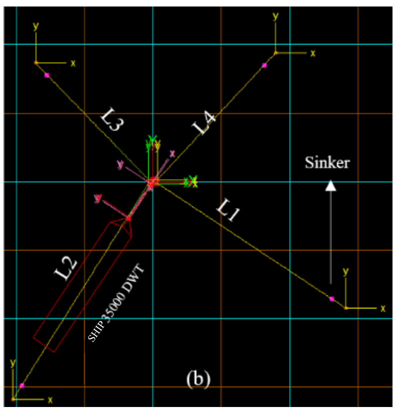


Figure 4.4 *Mooring System* at DOC conditions

## 4.5 Touch Down Point Mooring Line

This study's determination of position variations refers to the farthest touch-down point on each mooring line before the sinker is added. These results are obtained from the simulation of DOC and DEC conditions without sinker with time domain simulation of 600s on Orcaflex software. In the simulation of DOC conditions, the direction of the environmental load for the 10-year return period is assumed to be headsea or towards the front of the ship, with the ship's position in line with the mooring line. Meanwhile, in the simulation of DEC conditions, the direction of the environmental load for the 100-year return period is assumed to be in line with the mooring line. The following is the result of the touch-down point analysis.

Table 4.6 Touch Down Point Mooring Line

| Condition | Touch Down Point Mooring Line From fairlead (m) | From anchor (m) |
|---|---|---|
| DEC Inline L1 | 117.71 | 88.29 |
| DEC Inline L2 | 74.86 | 119.14 |
| DEC Inline L3 | 144.36 | 49.64 |
| DEC Inline L4 | 165.66 | 40.03 |
| DOC Inline L1 | 144.50 | 60.50 |
| DOC Inline L2 | 147.14 | 58.86 |
| DOC Inline L3 | 117.71 | 88.29 |
| DOC Inline L4 | 88.29 | 117.71 |

Based on these results, the authors varied two sinker positions in DOC conditions and three positions in DEC conditions. Position 1 is as far as 20 m from the anchor point, position 2 is as far as 40 m, and position 3 is as far as 60 m.

## 4.6 Mooring Line Tension Analysis

1) DOC Condition

The results from tension analysis in these conditions are due to the influence of sinkers.

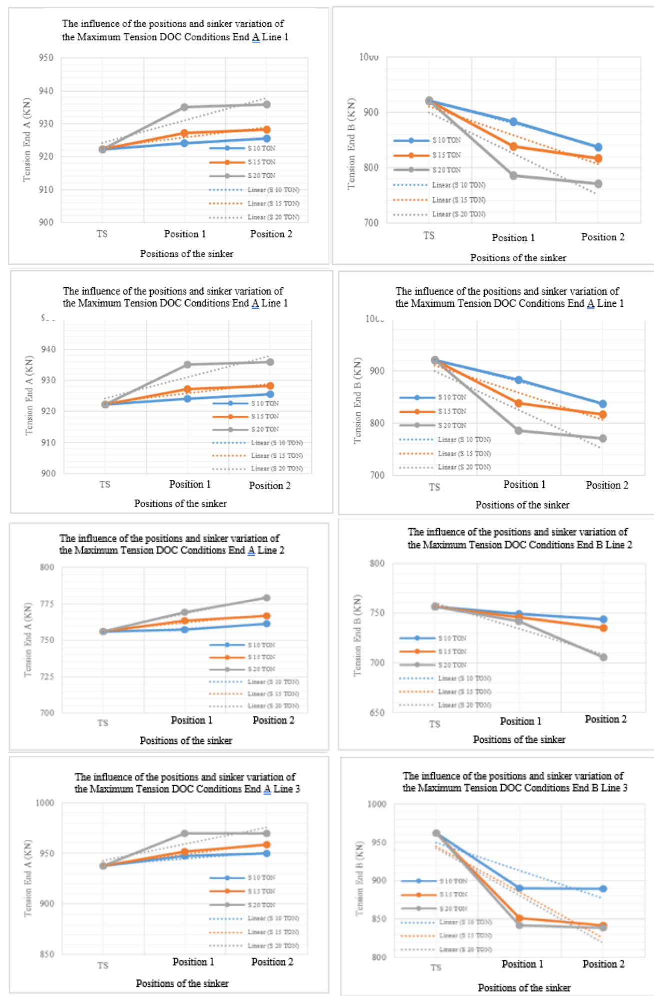


Figure 4.5 *Tension Mooring Line* at DOC Condition

So, based on these results, it is known that the maximum tension occurs at L3 in the direction of loading 326.27 deg with the ship's position on line 1, which is 937.25 KN at End A and 961.74 KN at End B. It is also known that at End A, tension (the line between sinker and fairlead) increased linearly with each weight gradation and sinker position. Meanwhile, the result of End B tension (the line between the sinker and anchor point) shows a linear decrease in each weight variation and sinker position.

2) DEC Condition

In the DEC condition tension analysis, the variation of sinker position is three positions. Due to the influence of sinker variations, the following results from the tension mooring line in DEC conditions.

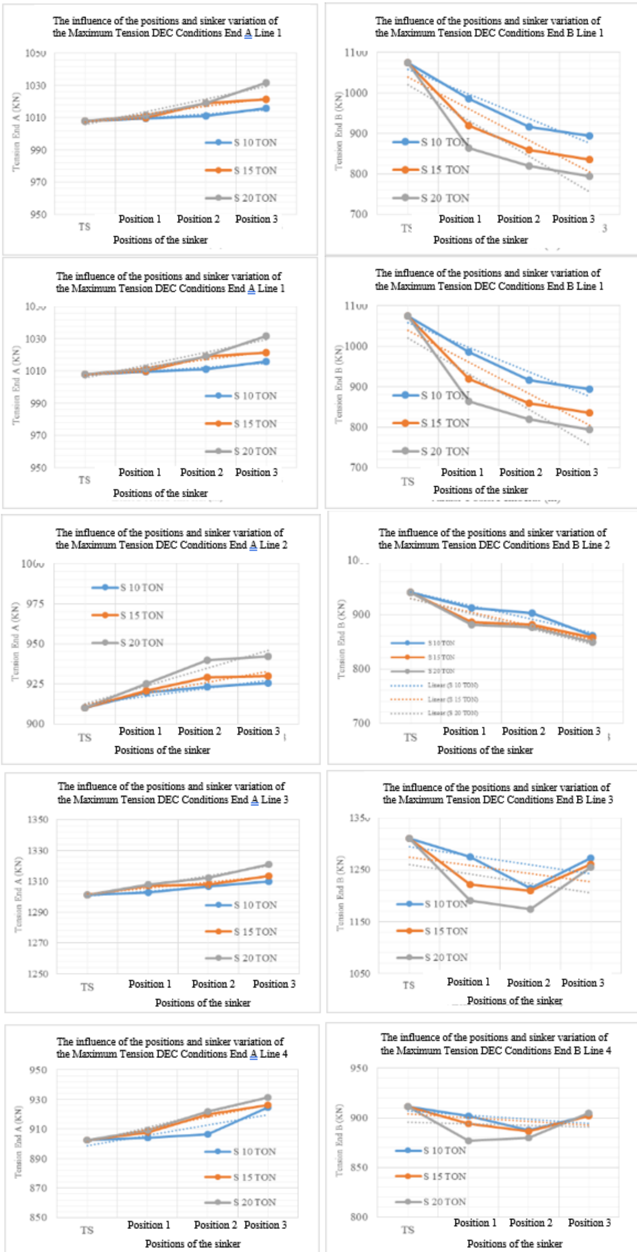


Figure 4.6 *Tension Mooring Line* at DEC Condition

The largest tension in the DEC condition occurs at L3 with an inline environmental load direction L3 (314.24 deg) of 1,301.13 KN at End A and 1,310.43 KN at End B. It is also known that the tension in End A (the line between sinker and fairlead) increases linearly at each weight gradation and sinker position. Lines 1 and 2 show a linear decrease in each weight and sinker position. While on lines 3 and 4, the decrease did not occur linearly. It is because the placement of sinkers in positions 2 and 3 are close and even intersect with the touch-down point line. On line 3, the largest decline occurred in the sinker 20 tons in position 2. In line 4, the largest decrease occurred in the sinker, with 20 tons in the third position.

## 4.7 Analysis of Anchor Bearing Capacity

The maximum tension results in the DEC condition tension analysis are then used to determine the bearing capacity requirements of the SPM anchor. Several parameters must be analyzed to determine the anchor's bearing capacity, including required holding capacity, anchor weight, and estimated drag distance/fluke length.

The required holding capacity is determined by multiplying the maximum tension with the Factor of Safety (FOS) by ABS Class 2019. The FOS value under DEC conditions is 2.50. The following results are obtained.

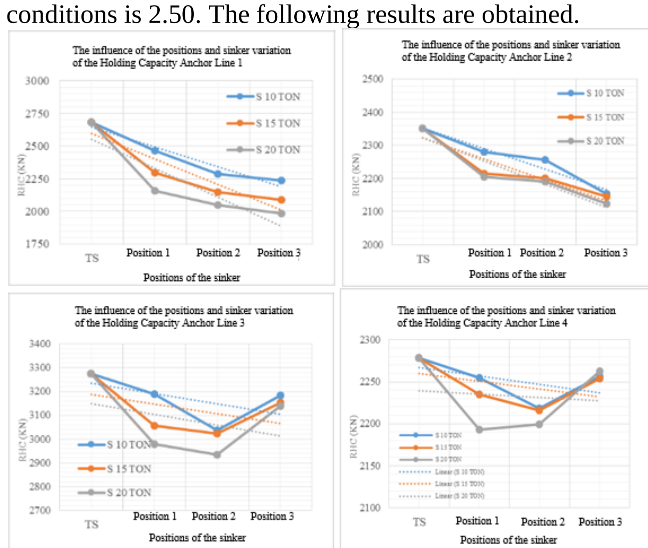


Figure 4.7 *Tension Mooring Line* at DOC Condition

In determining anchor weight and estimating drag distance/fluke length, refer to Appendix D2 and D6 graphs of API RP 2SK. The graph in Appendix D2 shows the relationship between holding capacity and anchor weight on soft clay soil types. Meanwhile, Appendix D6 shows a graph of the relationship between holding capacity and estimated drag distance/fluke length. Both charts refer to the type of anchor used. In this case study, the anchor type of SPM Pengapon Semarang is Stevpris MK III. Below are the analysis results of the anchor weight requirements and an estimate of the drag distance/fluke length due to the influence of sinkers on each mooring line.

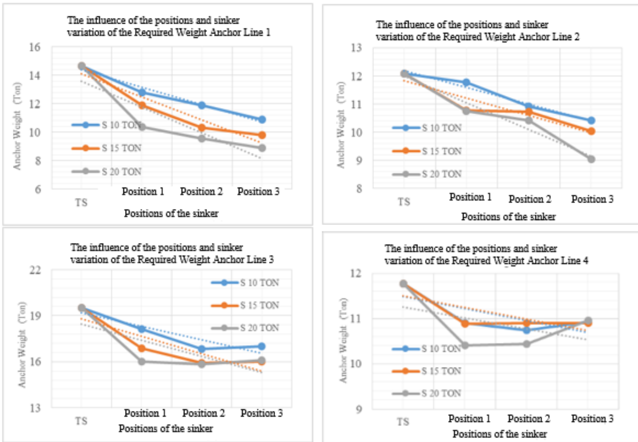


Figure 4.8 *Weight Anchor*

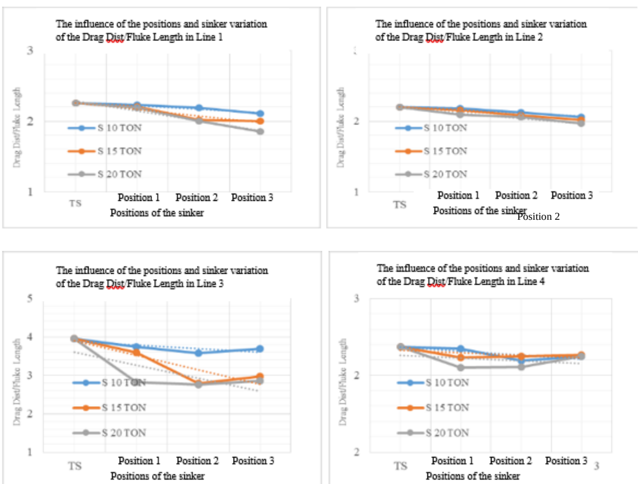


Figure 4.9 *Estimate Drag Distance/Fluke Length*

Based on the graph trend above, it is known that there is a decrease in the bearing capacity of the anchor due to the addition of sinkers on the mooring line. It is because the sinker can reduce the maximum tension at the anchor point or End B, as shown in the previous tension analysis, where the tension at End B is a reference in this case study to determine the bearing capacity of the anchor. However, a linear decrease in the bearing capacity of the anchor only occurs in line 1 and line 2. While in line 3 and line 4, the decrease is not linear. The above results show that in line 3, the largest reduction of needs on the bearing capacity of an anchor occurs on a sinker 20 tons in position 2, while in line 4, it occurs on adding a 20-ton sinker in position 1. Here, the authors show the overall analysis table done to determine the optimal weight variation and sinker position, which does not lead to a large increase in tension End A. Further explanation can be seen in the table below.

Table 4.7 The Effect of Sinker on Parameter Analysis at L1

| The Effect of Sinker on Parameter Analysis at L1 | | | | | |
|---|---|---|---|---|---|
| Mooring Line Conditions | Tension at Fairlead-Sinker (KN) | Tension at Anchor-Sinker (KN) | Required Holding Capacity (KN) | Anchor Weight (Ton) | Drag Dist/Fluke Length |
| L1A | 1,008.09 | 1,073.85 | 2,684.62 | 14.67 | 2.26 |
| L1B | 1,009.46 | 985.62 | 2,464.05 | 12.79 | 2.24 |
| L1C | 1,010.09 | 919.25 | 2,298.13 | 11.91 | 2.21 |
| L1D | 1,011.56 | 863.72 | 2,159.30 | 10.36 | 2.03 |
| L1E | 1,011.32 | 915.42 | 2,288.54 | 11.91 | 2.19 |
| L1F | 1,018.95 | 858.73 | 2,146.83 | 10.32 | 2.02 |
| L1G | 1,019.02 | 819.61 | 2,049.03 | 9.55 | 1.99 |
| L1H | 1,015.99 | 894.54 | 2,236.35 | 10.89 | 2.11 |
| L1I | 1,021.57 | 834.83 | 2,087.08 | 9.77 | 2.01 |
| L1J | 1,031.87 | 793.34 | 1,983.36 | 8.91 | 1.86 |
| Average | 1,015.79 | 895.89 | 2,239.73 | 11.11 | 2.09 |

Table 4.8 The Effect of Sinker on Parameter Analysis at L2

| The Effect of Sinker on Parameter Analysis at L2 | | | | | |
|---|---|---|---|---|---|
| Mooring Line Conditions | Tension at Fairlead-Sinker (KN) | Tension at Anchor-Sinker (KN) | Required Holding Capacity (KN) | Anchor Weight (Ton) | Drag Dist/Fluke Length |
| L2A | 910.17 | 940.52 | 2,351.30 | 12.09 | 2.20 |
| L2B | 919.60 | 911.59 | 2,278.98 | 11.77 | 2.19 |
| L2C | 920.84 | 886.01 | 2,215.01 | 10.77 | 2.16 |
| L2D | 925.05 | 881.59 | 2,203.98 | 10.60 | 2.09 |
| L2E | 923.07 | 902.65 | 2,256.63 | 10.91 | 2.13 |
| L2F | 929.13 | 880.65 | 2,201.62 | 10.73 | 2.09 |
| L2G | 939.81 | 876.22 | 2,190.54 | 10.41 | 2.06 |
| L2H | 925.62 | 860.94 | 2,152.34 | 10.41 | 2.06 |
| L2I | 930.02 | 857.82 | 2,144.55 | 10.05 | 2.02 |
| L2J | 941.95 | 849.14 | 2,122.86 | 9.05 | 1.97 |
| Average | 926.53 | 884.71 | 2,211.78 | 10.68 | 2.09 |

Table 4.9 The Effect of Sinker on Parameter Analysis at L3

| The Effect of Sinker on Parameter Analysis at L3 | | | | | |
|---|---|---|---|---|---|
| Mooring Line Conditions | Tension at Fairlead-Sinker (KN) | Tension at Anchor-Sinker (KN) | Required Holding Capacity (KN) | Anchor Weight (Ton) | Drag Dist/Fluke Length |
| L3A | 1,301.19 | 1,310.43 | 3,276.08 | 19.53 | 3.96 |
| L3B | 1,302.86 | 1,275.27 | 3,188.17 | 18.12 | 3.74 |
| L3C | 1,307.20 | 1,221.89 | 3,054.71 | 16.90 | 3.60 |
| L3D | 1,308.17 | 1,190.90 | 2,977.24 | 16.03 | 2.83 |
| L3E | 1,306.95 | 1,214.07 | 3,035.18 | 16.85 | 3.58 |
| L3F | 1,308.08 | 1,209.18 | 3,022.96 | 15.94 | 2.79 |
| L3G | 1,312.14 | 1,173.59 | 2,933.98 | 15.85 | 2.76 |
| L3H | 1,309.87 | 1,273.09 | 3,182.73 | 16.99 | 3.69 |
| L3I | 1,313.45 | 1,260.79 | 3,151.97 | 16.01 | 2.98 |
| L3J | 1,320.92 | 1,255.40 | 3,138.51 | 16.10 | 2.86 |
| Average | 1,309.08 | 1,238.46 | 3,096.15 | 16.83 | 3.27 |

Table 4.10 The Effect of Sinker on Parameter Analysis at L4

| The Effect of Sinker on Parameter Analysis at L4 | | | | | |
|---|---|---|---|---|---|
| Mooring Line Conditions | Tension at Fairlead-Sinker (KN) | Tension at Anchor-Sinker (KN) | Required Holding Capacity (KN) | Anchor Weight (Ton) | Drag Dist/Fluke Length |
| L4A | 1,301.19 | 1,310.43 | 3,276.08 | 19.53 | 3.96 |
| L4B | 1,302.86 | 1,275.27 | 3,188.17 | 18.12 | 3.74 |
| L4C | 1,307.20 | 1,221.89 | 3,054.71 | 16.90 | 3.60 |
| L4D | 1,308.17 | 1,190.90 | 2,977.24 | 16.03 | 2.83 |
| L4E | 1,306.95 | 1,214.07 | 3,035.18 | 16.85 | 3.58 |
| L4F | 1,308.08 | 1,209.18 | 3,022.96 | 15.94 | 2.79 |
| L4G | 1,312.14 | 1,173.59 | 2,933.98 | 15.85 | 2.76 |
| L4H | 1,309.87 | 1,273.09 | 3,182.73 | 16.99 | 3.69 |
| L4I | 1,313.45 | 1,260.79 | 3,151.97 | 16.01 | 2.98 |
| L4J | 1,320.92 | 1,255.40 | 3,138.51 | 16.10 | 2.86 |
| Average | 1,309.08 | 1,238.46 | 3,096.15 | 16.83 | 3.27 |

Table 4.11 Average Percentage of Sinker Effect on Each Parameter

| Average Percentage of Sinker Effect on Each Parameter | | | | | |
|---|---|---|---|---|---|
| Mooring Line | Tension at Fairlead-Sinker (KN) | Tension at Anchor-Sinker (KN) | Required Holding Capacity (KN) | Anchor Weight (Ton) | Drag Dist/Fluke Length |
| L1 | 100.76% | 80.14% | 80.14% | 67.91% | 92.03% |
| L2 | 101.77% | 93.69% | 93.69% | 86.80% | 95.13% |
| L3 | 101.43% | 98.15% | 98.15% | 91.88% | 96.84% |
| L4 | 101.43% | 98.15% | 98.15% | 91.88% | 96.84% |
| Average | 101.35% | 92.53% | 92.53% | 84.61% | 95.21% |

Table 4.12 Explanation of Mooring Line Conditions

| Conditions | Description |
|---|---|
| A | Without Sinker |
| B | Sinker 10-ton Position 1 |
| C | Sinker 15-ton Position 1 |
| D | Sinker 20-ton Position 1 |
| E | Sinker 10-ton Position 2 |
| F | Sinker 15-ton Position 2 |
| G | Sinker 20-ton Position 2 |
| H | Sinker 10-ton Position 3 |
| I | Sinker 15-ton Position 3 |

Based on these results, it is known that adding a sinker as a whole can reduce the bearing capacity of the anchor but also increase the line tension between the sinker and the fairlead. The average percentage increase at the tension line between the sinker and fairlead is 1.35%. Meanwhile, there is a downward trend between line 3 and line 4. That is, the maximum decrease in the two lines is not linear. Then, in determining the optimal weight variation and sinker position in reducing the bearing capacity of the anchor and not increasing the End A tension too much, the authors classify which conditions have decreased below the average. So, based on the overall analysis table on each line, it is known that condition D is the optimal variant for weight and sinker position. Condition D in question is the addition of a 20-ton sinker in position 1.

## 5. CONCLUSION

Based on the results of the analysis that has been carried out above, several conclusions are obtained that occur due to variations in the position and weight of the sinker, including the following:

1) DOC Condition

In the tension analysis, the DOC condition produces the largest tension that occurs on mooring line 3 without sinker in the direction of loading 326.27 deg with the ship's position on line 1, which is 937.25 KN at End A and 961.74 KN at End B.

The tension mooring line variations in sinker weight (10, 15, and 20 tons) in positions 1 and 2 showed a linear decrease in the line tension between the sinker and anchor. In contrast, in the line tension between the sinker and fairlead, there was a linear increase in each weight gradation and sinker position. The result of the percentage increase in line tension between sinker and fairlead is 1.25%. In contrast, the percentage reduction in line tension between the sinker and anchor is 5.8%.

2) DEC Condition

In the tension analysis, the DEC condition produces the largest tension that occurs on mooring line 3 without sinker in the direction of loading 314.24 deg or inline L3, which is 1,301.19 KN at End A and 961.74 KN at End B. The results of the Tension mooring line analysis with variations in sinker weight (10, 15, and 20 tons) in position 1, position 2, and position 3 show that there is an increase in the tension in the line between sinker and anchor linearly at each weight gradation and sinker position by 1.35% throughout the mooring line.

While the effect of the sinker on the line tension between the sinker and anchor shows a change in the form of a decrease, a linear decrease only occurred in lines 1 and 2 but not in lines 3 and 4. This effect is because the placement of sinkers in positions 2 and 3 are at the touch-down points of the two lines.

On line 1 and line 2, the percentage decrease is 9.4%, and the maximum reduction in tension occurs by adding 20 tons of sinker at position 3. On line 3, the percentage decrease is 4.6%, with the maximum reduction occurring at the sinker of 20 tons at position 2. In line 4, the average percentage decrease is 1.5%, with the maximum decrease occurring when a 20-ton sinker is added to position 1. So overall, the decrease in tension in the line between the sinker and anchor is 7.46% for each weight gradation and sinker position.

3) The Bearing Capacity of Anchor

The largest need for anchor bearing capacity occurs in line 3 without a sinker, with a required holding capacity value of 3,276.08 kN for an anchor weight of 19.53 tons and an estimated drag distance/fluke length of 3,955.

Adding weight variations and sinker positions on the mooring line decreased the need for anchor-bearing capacity. The average percentage reduction in required holding capacity is 7.56%, the anchor weight requirement is 15.39%, and the estimated drag distance/fluke length is 4.79%. Then, by considering the increase in tension in the rope between the sinker and fairlead in each mooring line, the most optimal weight variation and sinker position are determined by adding a 20-ton sinker in position 1.

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