

Numerical Analysis of Mooring Buoy for Securing N219A Aircraft in The Anchorage Area

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Abstract. The development of Indonesia's N219 aircraft in recent years has been carried out on a significant scale. Likewise, developing an amphibious version known as the N219A aircraft continued. Considering that Indonesia is an archipelagic country that has potential in many sectors, such as marine tourism, the N219A aircraft is designed to be able to land on the water. Consequently, facilities are needed for the aircraft to be secured safely. The analysis of determining the configuration of the length of the anchor line on the mooring buoy to secure the N219A aircraft was carried out by varying the line length of the rope to 50 meters, 60 meters, and 70 meters by FAA recommendations. Based on the numerical calculation, the anchor line configuration with a length of 60 meters has maximum tension with allowable criteria according to API RP 2SK in intact and damaged conditions. The anchor line configuration also has a maximum offset value that is shorter than other configurations. Therefore, the result obtained from the analysis of the N219A aircraft's anchor spacing for the sea conditions of Gili Iyang, Sumenep, Madura, and East Java is 118.18 meters.

1 Introduction

As a nation blessed with a vast archipelago and its natural beauty, Indonesia undoubtedly deserves to be a prime tourist destination for both local and international travellers. The potential of Indonesia's maritime tourism is one of the alternatives that can be developed in the future, as it has been proven to support improving the well-being of coastal communities¹. However, the current inter-island access can only be achieved through maritime transportation modes, such as wooden boats, which have limitations regarding time-consuming travel distances². Meanwhile, facilitating airports for aeroplanes is not feasible for islands with limited runway space and high costs.

Amphibious aircraft emerge as an alternative choice for tourists to visit the islands relatively quickly, allowing them to explore Indonesia for a more extended period. Not only that, but amphibious aircraft can also serve various sectors. Aside from tourism, they can function as transportation vehicles to transport goods and logistics to and from the 3T (outermost, lagging, frontier) islands that are difficult to access by land travel opening up

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opportunities for regional development and economic growth³. Moreover, they can be used for evacuations during sea technical issues, accidents, or unforeseen events in maritime areas, providing a relatively quick response.



Fig. 1. N219A Aircraft³.

Amphibious aircraft are equipped with floats that allow them to land and take off from bodies of water, including rivers, lakes, and seas. Indonesia's archipelagic nature makes it a suitable mode of transportation. The N219A aircraft are a development of the N219 aircraft, fitted with floats to enable water landings. Numerous studies have been conducted to support the successful development of the N219 amphibious aircraft, such as the study conducted by Nugroho et al., which discussed fatigue prediction of floats amphibious aircrafts by taking into account stresses due to heave and pitch motion and applied it to the Palmgren-Miner formula and obtained a predicted service life of 11.5 year assuming the aircraft operates 4 hours per day⁴. Another study was carried out by Arianti et al., which discussed the prediction of hydrodynamic impact loads when landing on the water by applying a slamming load approach by analyzing the pressure that occurs on the float's aircraft when landing at several variations of trim and heel angles and obtained results that the greater the trim or heel angle, the greater the pressure occurred by the floater⁵. Studies related to alternative flight and landing test scenarios for the N219A aircraft have also been carried out by Prijambodo et al. for the water conditions of Karimun Jawa⁶ and continued with a study of the potential for amphibious aircraft suitable for developing marine tourism in Gili Iyang, Madura which was studied by Shabrina et al.⁷.

By Post-Flight Safety Procedures for Amphibious Aircraft⁸, securing the aircraft during loading and unloading operations to mitigate environmental factors such as wind, currents, and waves is achieved through mooring using heavy hooks to anchor the aircraft to the seabed. This mooring serves the purpose of preventing the amphibious aircraft from drifting away. However, there are alternative methods in the Post-Flight Safety Procedures for amphibious aircraft, such as tying down. Tying down the amphibious aircraft eliminates the issue of anchor drag. Tying down refers to securing the aircraft to a mooring buoy connected to a heavy anchor or mooring it at a dock.

The option of mooring the Amphibious Aircraft to a mooring buoy can be considered when the N219A aircraft lacks a ready dock facility and the amphibious aircraft's floats cannot directly beach in unfriendly coastal conditions that might damage the floats. Therefore, this paper discusses the analysis of mooring lines on mooring buoys used for mooring the N219A aircraft when anchored in the anchorage area.

2 Methodology

Analyzing the mooring lines from the mooring buoy to secure the N219A aircraft was carried out in several stages, starting from modelling the floats of the N219A aircraft, validation with mesh sensitivity, mooring line modelling, maximum tension analysis and maximum offset

analysis. The time domain analysis method completes numerical simulations in determining mooring analysis. Although, time domain analysis requires more time during the simulation.

2.1 Structure Modeling

2.1.1 N219A Aircraft Float Modeling

Representing the N219A Aircraft model in the hydrodynamic analysis is limited by modelling the float at full draft conditions of 0,740 m with a displacement of 6,937 tons. The floats dimension data analyzed can be seen in Table 1 below, which was obtained from previous research. This research discusses the prediction of hydrodynamic impact loads from aircraft floats when landing on the water surface⁵. This modelling was conducted to determine the free motion of floating structures caused by the hydrodynamic behaviour of the structure's interaction with sea waves.

Table 1. Dimension of N219A Aircraft’s float⁵.

Item	Value	Unit
Length Over All (LoA)	9.902	m
Length Water Line (Lwl)	9.457	m
Length Between Perpendicular (Lpp)	9.902	m
Beam (B)	1.308	m
Depth (H)	1.315	m
Draft (T)	0.740	m

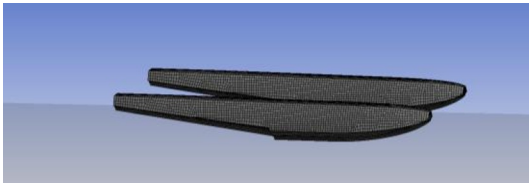


Fig. 2. N219A Aircraft Float.

The hydrodynamic components that occur from the floating structure motion phenomenon consist of internal and external components. The internal part comes from the motion of the floating structure, which influences the wave conditions around it or the radiation component. The radiation component consists of inertia, damping, and stiffness forces. Meanwhile, the external part consists of propagation wave excitation and fluid interaction with the buoyant structure or what is known as diffraction force⁹. These components are then arranged into the equation of motion as follows:

$$[(m + m_a)\ddot{\zeta} + c\dot{\zeta} + k\zeta] = F e^{-i\omega t}$$

(1)

Where:
m = the mass of the floating structure

- m_a = the added mass
- c = damping
- k = stiffness
- $F e^{-i\omega t}$ = excitation wave forces

The solution to the equation of motion in equation (1) above for regular waves is expressed as a free motion characteristic commonly called the Response Amplitude Operator (RAO). RAO is defined as the ratio of the motion and wave amplitude. According to Djamniko, the motion response is divided into two, namely translational motion mode and rotational motion mode¹⁰. In translational motion modes, namely surge, sway, and heave, the RAO motion response is the ratio between the amplitude of the structure motion and the wave amplitude, which is written in equation (2). While the rotational motion modes are roll, pitch and yaw, the RAO motion response is a comparison between the amplitude of the structure's motion and the slope of the wave (the product of the wave number and the amplitude of the incident wave), which is written in equation (3).

$$RAO = \frac{\zeta_{k0}}{\zeta_0} \quad (m/m) \tag{2}$$

$$RAO = \frac{\zeta_{k0}}{k_w \zeta_0} = \frac{\zeta_{k0}}{(\omega^2/g)\zeta_0} \quad (rad/rad) \tag{3}$$

2.1.2 Validating

Mesh sensitivity is a form of validation of numerical simulations. The aim is to ensure that the grid/mesh used in the numerical simulation does not have significantly different values . So, it can be identified that the mesh with the convergence value is the most accurate mesh for further analysis. This helps improve the quality of research while reducing computational costs by avoiding unnecessary iterations due to inaccurate simulations¹¹. The mesh sensitivity that carried out in this study includes analysis of RAO, added mass and damping results for meshing of 0.080, 0.100, 0.120, 0.150, 0.200, 0.275, and 0.400.

2.2 Mooring Line Modeling

2.2.1 Mooring Buoy Modeling

The mooring buoy which was analyzed as the terminal for the N219A aircraft which was temporarily anchored in this anchorage area was modeled directly in Orcaflex 11 software. The size of the mooring buoy which was analyzed had dimensions as in Table 2 below with a displacement of 0.5 tons.

Table 2. Dimension of Mooring Buoy

Item	Value	Unit
Outside Diameter (OD)	1.000	m
Height (H)	2.300	m
Draft (T)	1.150	m

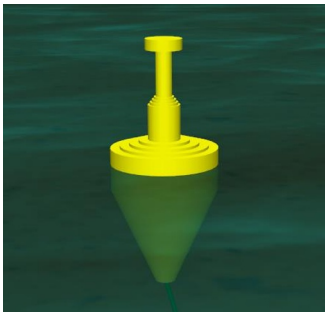


Fig. 3. Mooring Buoy

2.2.2 Environmental Load

Environmental data including wave height, current speed and wind speed were obtained from a study of research written by Shabrina et al⁷ which was located in the waters of Gili Iyang, Sumenep, Madura, East Java. The depth of the waters studied in this analysis is 10 meters. More clear environmental data can be seen in Table 3.

Table 3. Enviromental Data of Gili Iyang, Sumenep, Madura, East Java⁷

Item	Value	Unit
Significant Wave Height	0.600	m
Wind Velocity	2.572	m/s
Current Velocity	0.900	m/s

The JONSWAP (Joint North Sea Wave Project) wave spectrum is widely used in the design and analysis of offshore structures that will be operated in Indonesian waters. This is because archipelagic waters are closed waters. Based on a number of studies, it is recommended to use γ parameter of around 2.0 to 2.5¹⁰.

$$S_z(\omega) = \alpha g^2 \omega^{-5} \exp\{-1.25(\omega/\omega_0)^{-4}\} \gamma^{\exp\left\{-\frac{(\omega-\omega_0)^2}{2\tau\omega_0^2}\right\}}$$

(4)

3 Result and Discussion

This mooring analysis was carried out using the Ansys Aqwa software and with a license owned by ITS. Meanwhile, the Orcaflex 11 software license is held by DIRI BRIN, located in BRIN Said Djauharsjah Jenie Science Area, Surabaya. Ansys Aqwa software was used to obtain diffraction from the N219A aircraft floats in free-floating conditions. Meanwhile, Orcaflex 11 software is used for mooring analysis, namely, knowing the tension of the mooring lines and the offset of the floats of the N219A aircraft when moored in the mooring buoy. The N219A aircraft floats is defined as a vessel on Orcaflex, while the mooring buoy on Orcaflex is defined as a 6D Buoy. The analysis was carried out because the anchor being studied was assumed to be fixed on the seabed.

3.1 Structure Responses (Free-Floating)

RAO produced by Ansys Aqwa software is divided into 5 (five) loading directions, namely 0°, 45°, 90°, 135°, and 180°. The direction of loading (heading) regarding the N219A aircraft floats is divided into five loading angles, namely 0° (following seas), 45° (stern quartering seas), 90° (beam seas), 135° (bow quartering seas), and 180° (head seas) as seen in Figure 4. In Figure 4 it can be seen that the 0° direction indicates that the load hitting the N219A aircraft floats comes from the rear of the N219A aircraft floates, while the 180° direction comes from the front of the N219A aircraft floats. These RAO characteristics are needed as input for mooring system analysis in Orcaflex 11.

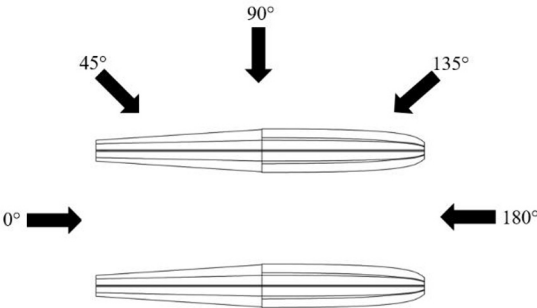


Fig. 4. Heading for Analysis RAO

The N219A floats RAO generated by the Ansys Aqwa software will be divided into vertical (heave, roll and pitch) and horizontal (surge, sway and yaw) motion RAOs. RAO of vertical motion will have a more dominant influence on the stability of floating buildings and seaworthiness compared to RAO of horizontal motion¹². Numerical simulations carried out in Ansys Aqwa have been validated using mesh sensitivity analysis on the RAO, added mass and radiation damping output results which are input for further analysis. The graph of the mesh sensitivity analysis can be seen in Figure 5 below.

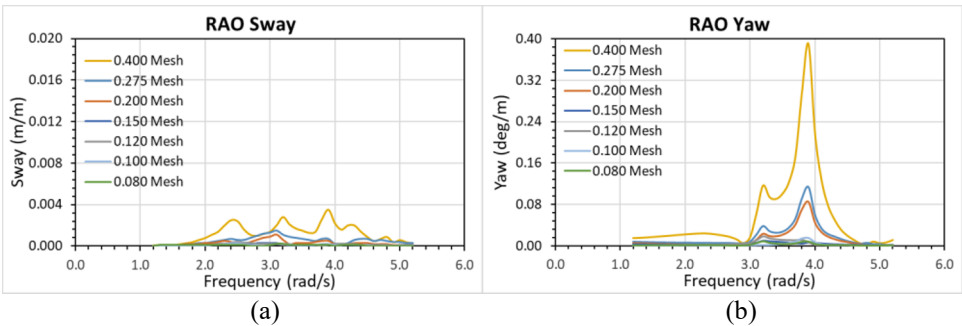


Fig. 5. Mesh Sensitivity; (a) Sway Motion; (b) Yaw Motion

3.2 Mooring Tension and Offset

3.2.1 Maximum Tension of Mooring Line of N219A Aircraft

After the operation, the N219A aircraft, which has floats on its legs, still requires security facilities, known as a mooring buoy, when anchored near the coastal area. This mooring buoy is permanently placed in a specific water location. The mooring system configuration of the

N219A aircraft float, which is analyzed in Figure 6 below, consists of the N219A aircraft float, which is moored to the mooring buoy. The mooring buoy is moored with a single mooring called an anchor line at the anchor point on the seabed. However, the anchor capacity was assumed to be fixed on the seabed. The mooring buoy has two mooring lines, which are used to hook the end of the float so that it is in the correct position around the mooring buoy. These lines are called the starboard line and portside line.

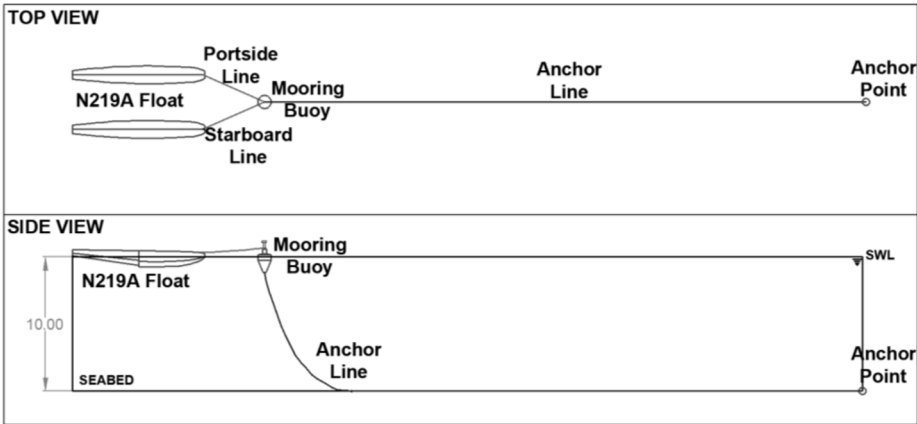


Fig. 6. Configuration of The Mooring System of The N219A Aircraft Floats

A mooring cleat at each end of the float functions as a mooring place for the two ropes. The mooring cleat on the float was analyzed 0.18 meters from the float's bow, as seen in Figure 7 below.

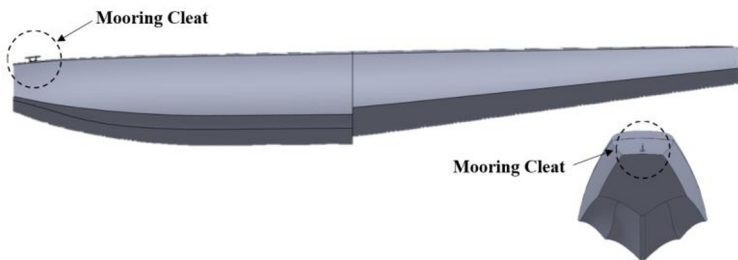


Fig. 7. Mooring Cleat of N219A Aircraft Float

The material for the anchor line uses a rope with a diameter of 0.0125 meters with a length of 50 meters (1st configuration), 60 meters (2nd configuration), and 70 meters (3rd configuration). Each configuration is given three loading directions, namely 90°, 135°, and 180°. This rope length configuration was chosen based on recommendations from the FAA regarding the length of the anchor line between five and seven times the water depth¹³.

Table 4. Anchor Line Properties

Item	Value	Unit
Diameter of Studlink Chain	0.0125	m
Weight in Air	0.0340	kN/m

Displacement	0.0044	kN/m
Weight in Water	0.0290	kN/m
Minimum Breaking Load (MBL)	184.094	kN

The analysis results found that the maximum tension value occurred in the first configuration, namely on the anchor line with a length of 50 meters of 121,563 kN, which was moored on the mooring buoy. Meanwhile, the maximum tension on the anchor line with a length of 60 meters and 70 meters has a tension below the MBL value of the chain for each simulated loading direction. This occurs because the mooring buoy, which has an anchor line length of 50 meters and a heading condition of 135°, experiences quite large movements, which caused the mooring buoy to align with the N219A Aircraft. The anchor line attached to the lower buoy experienced maximum tension due to the incident, which happened at 483 seconds. Consequently, anchor line with length 50 meters does not meet the criteria of API RP 2 SK. The tension values per configuration can be seen in Table 5 and Figure 8 below.

Table 5. Maximum Tension for Anchor Line

Heading (°)	Maximum Tension		Maximum Tension	Safety Factor	Remark
	at Buoy (kN)	at Anchor (kN)			
1 st Configuration (Anchor Line with Length 50 Meters)					
180	1.319	1.594	1.594	115.465	pass
135	121.563	59.939	121.563	1.514	fail
90	1.324	1.012	1.324	139.074	pass
2 nd Configuration (Anchor Line with Length 60 Meters)					
180	0.817	0.971	0.971	189.632	pass
135	2.424	2.330	2.424	75.959	pass
90	1.231	0.917	1.231	149.511	pass
3 rd Configuration (Anchor Line with Length 70 Meters)					
180	1.673	1.899	1.899	96.920	pass
135	1.816	1.821	1.821	101.091	pass
90	1.194	0.783	1.194	154.129	pass

The material for the starboard line and portside line uses nylon rope with a diameter of 0.012 meters with a length of each rope of 5 meters which can be seen more clearly in Table 6 below.

Table 6. Portside and Starboard Line Properties

Item	Value	Unit
Diameter of Nylon Rope 8 Strand	0.0120	m
Weight in Air	0.0009	kN/m
Displacement	0.0008	kN/m
Weight in Water	0.0001	kN/m
Minimum Breaking Load (MBL)	20.0680	kN

The maximum tension value that occurs on the starboard line and portside line is within safe limits according to the API RP 2SK criteria because it has a Safety Factor value above 1.67 for intact conditions and a Safety Factor value of 1.25 for damaged conditions¹⁴. The tension values for the starboard line and portside for each environmental loading can be seen more clearly in Table 7 and Table 8 below.



Fig. 8. Numerical Simulation of N219A Float and Mooring Buoy

Table 7. Maximum Tension for Starboard Line

Heading (°)	Maximum Tension for Starboard Line		Maximum Tension	Safety Factor	Remark
	at Float Mooring Cleat (kN)	at Mooring Buoy (kN)			
1 st Configuration (Anchor Line with Length 50 Meters)					
180	0.442	0.443	0.443	45.325	pass
135	1.042	1.041	1.042	19.260	pass
90	0.739	0.739	0.739	27.150	pass
2 nd Configuration (Anchor Line with Length 60 Meters)					

180	0.394	0.393	0.394	50.953	pass
135	0.906	0.907	0.907	22.130	pass
90	0.739	0.739	0.739	27.150	pass
3 rd Configuration (Anchor Line with Length 70 Meters)					
180	0.646	0.645	0.646	31.070	pass
135	0.904	0.904	0.904	22.201	pass
90	0.743	0.742	0.743	27.027	pass

Table 8. Maximum Tension for Portside Line

Heading (°)	Maximum Tension for Portside Line		Maximum Tension	Safety Factor	Remark
	at Float Mooring Cleat (kN)	at Mooring Buoy (kN)			
1 st Configuration (Anchor Line with Length 50 Meters)					
180	0.445	0.445	0.445	45.083	pass
135	0.479	0.470	0.479	41.900	pass
90	0.357	0.357	0.357	56.253	pass
2 nd Configuration (Anchor Line with Length 60 Meters)					
180	0.432	0.432	0.432	46.455	pass
135	0.452	0.452	0.452	44.419	pass
90	0.357	0.357	0.357	56.253	pass
3 rd Configuration (Anchor Line with Length 70 Meters)					
180	0.552	0.550	0.552	36.345	pass
135	0.432	0.432	0.432	46.427	pass
90	0.369	0.369	0.369	54.315	pass

3.2.2 Maximum Offset of N219A Aircraft

The anchorage area of the N219A aircraft can be seen from the radius of the anchor point to the farthest end of the swing of the N219A aircraft itself. The swing of the N219A aircraft moored to the mooring buoy when exposed to environmental loads can be obtained from the results of numerical simulations using Orcaflex software. Determining the anchorage area is essential in planning post-operation support facilities for the N219A aircraft. This aims to provide sufficient space for the amphibious aircraft to swing without hitting surrounding obstacles. In order to determine the maximum number of amphibious aircraft that can moor at the mooring buoy installed in that anchorage area. The size of this anchorage area depends on the dimensions of the amphibious aircraft, where the distance between anchor points must not be less than twice the length of the anchor line plus 38 meters, as recommended by the U.S. Advisory Circular-Department of Transportation¹³. From the simulation results for each configuration, it was concluded that the longer the anchor line of the mooring buoy, the wider the anchorage area would be, which would result in a decrease in the number of mooring buoys in securing amphibious aircraft.

Table 9. Maximum Offset of N219A Aircraft

Line Length (m)	Heading 180 deg	Heading 135 deg	Heading 90 deg	Units
50	29.96	25.06	4.12	m
60	40.09	34.85	14.12	m
70	50.10	44.80	24.12	m

Table 9 above is a recapitulation of the maximum offset of the N219A Aircraft when exposed to environmental loads, causing the aircraft to swing away from the anchor point. The analysis results show that the longer the anchor line, the further away the plane is. In the anchor line configuration with a length of 50 meters, the farthest position is at 29.96 meters, but in this configuration, the maximum tension exceeds the allowable limit. In the anchor line configuration with a length of 60 meters and 70 meters, the farthest position is 40.09 meters and 50.10 meters from the anchor point. However, the farther the offset, the fewer mooring buoys that can be installed in that area. Therefore, the anchor line configuration with a length of 60 meters is the most suitable configuration for the sea condition that have been analyzed. An illustration of anchor spacing can be seen in Figure 9 below.

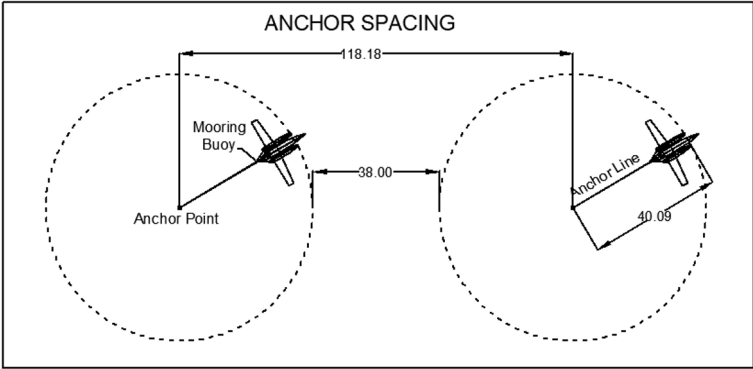


Fig. 9. Anchor Spacing for N219A Aircraft

4 Conclusion

Based on the results of numerical simulations in this study, it was determined that a mooring buoy with a displacement of 0.5 tons could be used to secure the N219A aircraft. This mooring buoy is connected to a single anchor line on the seabed using a studlink chain measuring 0.0125 meters by FAA recommendations. It was found that the tension value on the anchor line with a length configuration of 60 meters and 70 meters had a safe limit by the API RP 2SK tension criteria for each heading.

An anchor line configuration with a line length of 70 meters has a greater offset when compared to an anchor line configuration with a length of 60 meters when viewed from the radius of the anchor point location. It was concluded that the mooring buoy configuration with an anchor line length of 60 meters was more effective for application in the environmental conditions of Gili Iyang, Sumenep, Madura, East Java, with an anchor spacing of 118.18 meters.

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