Dynamics Analysis of Single Buoy Mooring in Malaysian Waters

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Abstract The research is carried out to study the behaviour of the Deepwater Offloading Single Buoy Mooring (SBM) as well as the mooring line after combining polyester to the existing mooring line design. The first mooring line is consisting of chain and spiral strand wire which is becomes current practice in oil and gas industry. The second mooring line is designed by introducing polyester into the system. Static analysis is carried out by using lump mass method which is proposed by Wingerie (2008). There are 2 mathematical software have used for static analysis which are Mathcad and Matlab. Both of the mooring designs are then be analysed in ANSYS AQWA for dynamic analysis.

Keywords Single buoy mooring · Mooring designs · Dynamic analysis

1 Introduction

In the paper a catenary anchor leg mooring (CALM) buoy moored in a water depth of 1,200 m is considered. The purpose of this CALM buoy is to provide an offloading point for transferring oil from an floating production storage offloading (FPSO), which is moored at a distance of approximately 1 nautical mile, to a shuttle tanker. In this analysis, the total length required is calculated using static analysis and the overall performance of mooring system will be analysed in ANSYS. Comparison between 2 types of mooring line will be analysed. The first type consists of chain and spiral strand rope whilst the second type will be combination among mooring chain, polyester and spiral strand.

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2 Objectives

i. To design the mooring line which is a combination of chain, spiral strand and polyester in a mooring line to reduce the risk of mooring failure due to corrosion effect.
ii. To determine the horizontal offset of Single Buoy Mooring after polyester rope is added to the mooring line segment.
iii. To compare the performance between both of the mooring line design using results gained from dynamic analysis in ANSYS AQWA.

3 Environmental Factors

In this study the Single Buoy Mooring would be used at Malaysian sea water and the water depth chosen was 1200 m which is located at Kikeh, Sabah (see Fig. 1). The significant wave height is considered as 6.31 m and wave period equals to 13.1 s.

Fig. 1 Kikeh field location, Sabah, Malaysia waters

4 Problem Statement

Steel wire rope and chain have been used for mooring floating offshore production systems since their introduction nearly 30 years ago. A survey carried out by Noble Denton Europe Limited (2006) has shown that a lot of serious incidents associated with floating production system have occurred in the past, including loss of station. According to Chapline et al. (2008), service life of mooring line can be influenced by the local conditions. Warmer tropical sea water has become the main factor that deteriorated the service life of mooring line due to corrosion.

5 Synthetic Fibre

The key advantage of using the synthetic fibre ropes over chains and wires is their relatively low in cost. The comparative cost and mass analysis of several single-line catenary and taut-moored arrangements including several different anchor configurations has been carried by Ridge et al. (2010). The comparison highlight about the advantages to replace conventional mooring chains by using lightweight but durable mooring components. For example, the ability of nylon to reduce peak loadings would allow smaller gauge mooring chain to be used in anchor-chain- surface buoy-rope-device configurations. The study noted that the reduced by 88 kg/m and the cost by over RM450,000 per mooring line (estimated) can be achieved by adopting this design to the overall mass of the system. These reductions would partly be attributable to the specification of lower capacity components, such as anchors. Clearly in practice the feasibility of using a particular mooring system and actual cost savings that are achieved will depend on the case in question.

6 Mooring Configurations

According to Joshua (2013), there are many types of mooring configurations used for offshore structures, and they range from simple passive moorings to complex active systems. The three main configuration categories are single-point moorings, spread moorings, and dynamic positioning systems. Single point moorings utilize one mooring line, and can have one or more anchors. They are often used for deep-water meteorological buoys or small floats. They offer a large amount of compliance for dynamic wave environments, but they have large watch circles and do not provide directional control. To support a wide range of offshore structures, spread mooring is used because of their design to use multiple mooring lines and anchors. Their complexity can be greatly varied and the designs of the line are either catenary lines, tensioned lines or the combination of both lines. They usually have less compliance and a larger underwater footprint however; they offer directional control and typically have much smaller watch circles than single points mooring. To change and control mooring configurations, dynamic positioning systems such as winches or thrusters is used to utilize active controls. Single point or spread mooring is used and they are often very complex. The system is used for the large offshore structures, such as oil-rigs or floating wind turbine.

7 Analytical Calculations of Static Forces

Usually, mooring line consist of different types of material especially for deep water application. It may be combined with one another to withstand environmental force and secure the floating structure. In this study, there are 2 types of mooring line would be analysed. The first type is chain—wire and the latter is chain-polyester-wire connection. In static analysis, 2 methods were used to find the initial parameter before dynamic analysis is carried out. These 2 methods are analytical solution and element solution which were proposed by Wingerie (2008). The results from both solutions are compared to validate the data. As referred to Fig. 2, the line is segmented into 2 parts, 1 being chain part whilst being the wire part.

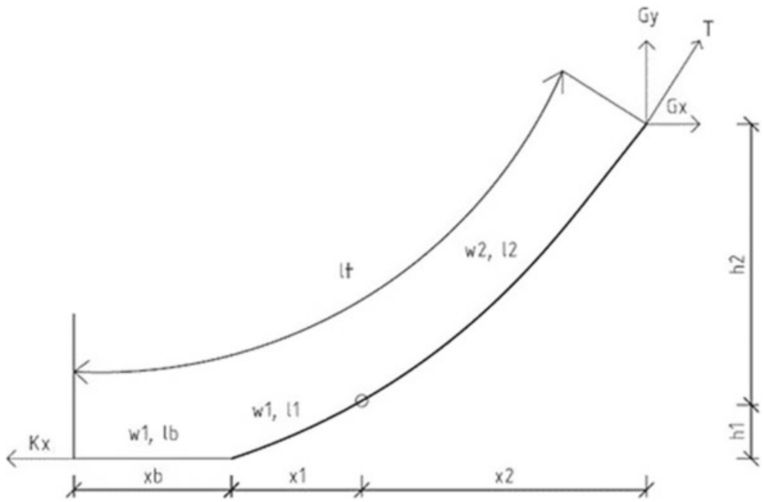

Fig. 2 Mooring line segment

Table 1 Buoy parameters

Parameter	Value (m)
Buoy hull diameter	17
Skirt diameter	21
Buoy height	7.65
Draft	5.65
KG	3.40
K*xx*	4.39
K*yy*	4.39
K*zz*	6.01
Fairlead radius	9.5

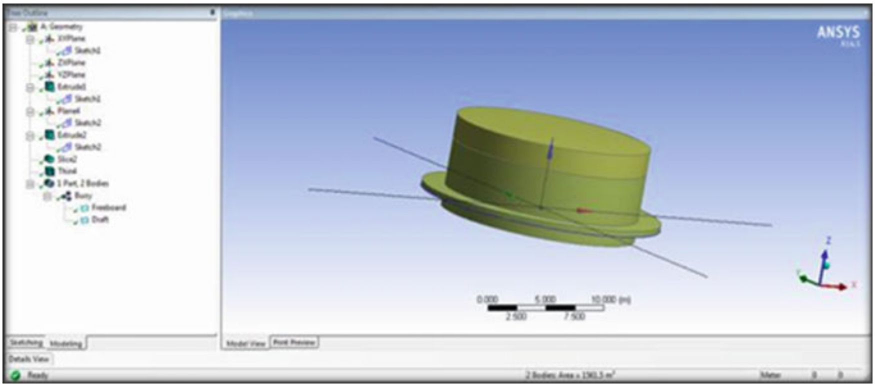

Fig. 3 Buoy construction completed

8 Buoy Construction

The buoy is divided into 2 part which consist of freeboard and underwater part. The buoy has cylinder shape for both parts that make it easy to construct. It was constructed by using Ansys modeler. The parameter of the buoy is as in Table 1. Figure 3 shows the buoy design after the construction process was completed.

9 Equation of Motion

The response X of a structure in waves is calculated by solving the equation of motion in the frequency domain for unit wave amplitude, in Eq. (1):

$$[-\omega^2(M_s + M_a(\omega)) - i\omega B(\omega) + C]X(\omega) = F(\omega) \tag{1}$$

Where;

M_s is structure mass
M_a is added mass (frequency dependent) B is damping (frequency dependent)
C is hydrostatic stiffness
F is wave force (incident and diffracting forces).

10 Mooring System Simulation

Estimation of mooring system is found from AQWA program as well. The procedure has the following simplification:

i. Cables are semi-taut/taut during the analysis i.e. they have a defined pre-tension.
ii. The sea bed will be considered as horizontal at the location of the anchors.
iii. The cable is modelled with a fixed number of elements.
iv. Inline dynamics (along the line of the cable) is included.
v. Sea bed friction is ignored.

11 Irregular Wave

Irregular Wave Group: In addition, it can be added to the Hydrodynamic Diffraction system when Linearized Tube Drag is specified for the analysis (only a single irregular wave can be used in the Hydrodynamic Diffraction system, and no Cross Swell should be specified).

12 Dynamics Analysis of Mooring Lines

In this study, dynamic analysis is conducted by using ANSYS AQWA. The buoy is constructed by using ANSYS MODELER and all the input parameters are defined. This is including the environmental condition and material properties for all the mooring line. The buoy is analysis by using DNV requirement for mooring design. There are 3 types of mooring design analysis which are:

i. An ultimate limit state (ULS) to ensure that the individual mooring lines have adequate strength to withstand the load effects imposed by extreme environmental actions.
ii. An accidental limit state (ALS) to ensure that the mooring system has adequate capacity to withstand the failure of one mooring line, failure of one thruster or one failure in the thrusters' control or power systems for unknown reasons. A

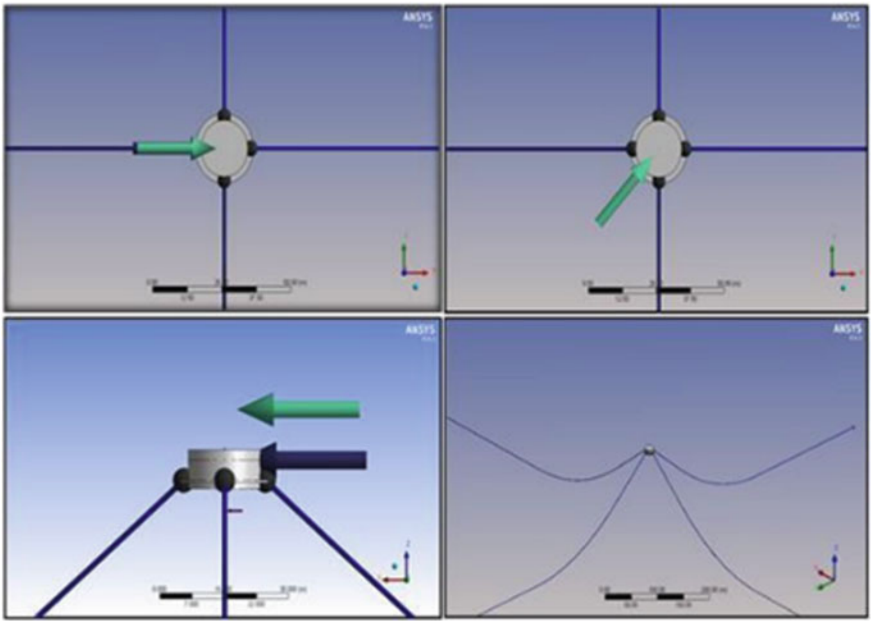

Fig. 4 Forces applied to buoy and mooring lines

single failure in the control or power systems may cause that several thrusters are not working.

iii. A fatigue limit state (FLS) to ensure that the individual mooring lines have adequate capacity to withstand cyclic loading.

iv. Since there is time and information constraint during this study, the student has focused to only the ultimate limit state design. Generally, the force applied to the buoy and mooring line is directed from different angle as shown in Fig. 4.

13 Mooring Simulation

Usual options for the mooring simulation analysis are taken into consideration:

i. Head Seas;
ii. Quartering Seas;
iii. Beam Seas.

In this analysis, the researcher had focused on heads seas and quartering seas only because the effect on beam seas will be similar as in head seas. This is due to the geometry shape of the buoy. The buoy has cylinder shape so that it would give constant projection area for any load of direction.

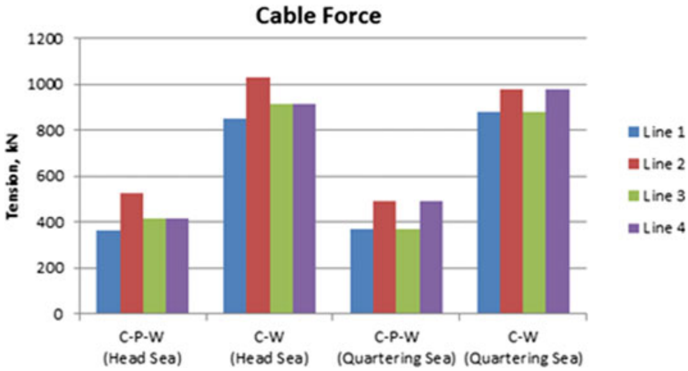

Fig. 5 Maximum tension on each mooring line

13.1 Tension of Mooring Lines

There are two important points that should be taken into account. Firstly, if the environmental load is directed to 0° which is head seas, line 2 will incur highest tension because the line is in line with the load direction. Secondly, if the load direction is 45°, line 4 will experience highest tension but the value is lower than the first case. The tensions on all 4 lines are distributed quite even in quartering seas. Refer to the bar chart (Fig. 5); the tension of each line for each case is presented in order to get clear perspective before further comparison is made.

14 Hydrodynamics Performance

Whereas the total length and tension of the mooring line are analyzed, hydrodynamic motion of the buoy is compared for both design. The performance of mooring line is translated by the rotational and translational motion of the buoy since couple dynamic analysis between mooring line and buoy are carried out by using ANSYS. The comparison is made only for head seas direction because the characteristics from other angles are quite similar due to the symmetrical shape of the buoy.

15 Results and Discussions

The metacentric height (GM) for the buoy is 2.4 m and restoring moment is about 9.872 kN.m/degree. Metacentric height is measured from the centre of gravity to the metacentre of the buoy. Positive value of metacentric height is required to show the stability of the buoy when external force is applied to the body. There are 3 types of GM characteristics of a floating structure or body including:

i. GM less than zero, which means it has negative value. In this condition, the buoy is considered as unstable equilibrium. The uprighting moment produced becomes less than zero. In other words, the buoy doesn't have initial stability and when external force is applied onto the buoy, it will incline to a certain angle and then it will tend to heel over and finally it will capsize. There is no restoring moment which will restore the buoy to an upright position.
ii. GM is equal to zero, thus the uprighting moment is equal to zero. In this case, the buoy is considered has initial stability but after environment load is applied to the buoy, it will remain in the same angle of heel until another external load is applied. This happens when the KM equals to KG. The position of the buoy (angle of heel) can be determined by the amount of load applied to the buoy since there is no countering force from the buoy.
iii. GM more than zero. Thus the uprighting moment would be positive value. The buoy is considered in stable equilibrium. The buoy would able to return to its initial state although external load is applied to the buoy. The restoring moment will restore the buoy its original position. However, the amount of load should be less than the restoring moment, otherwise, the buoy might capsize. GM should always become positive to provide stable condition. When the GM is comparatively high, thus the righting moment at small angle of heel will also be comparatively high. It means that, larger or higher moment is required to incline the buoy.

As stated in DNV Offshore Standard for offshore loading buoys, the GM shall be positive. There is no specific value mentioned in the standard since there is no person working on board for 24 h like offshore platform.

16 Conclusions

From this research, several important conclusions can be stated. Polyester has generated a big impact toward dynamic performance of the buoy. Polyester has achieved a better performance compared to the chain—spiral strand mooring line after couple dynamic analysis had been carried out.

It provides shorter horizontal excursion as well as less rotational and translation motion. It is an important criterion in mooring design because aggressive hydrodynamic motion would lead to lost host connection. Besides that, excesses horizontal offset would generate extra tension to the riser connection that could result in riser failure, thus big disaster might be happen.

It also generates lower total cable force that result in lower equipment specification. These reductions would partly be attributable to the specification of lower capacity components, such as hawser, anchor, shackle, etc.

The polyester should be considered for deep water mooring because of its excellent performance and it would be able to reduce the risk of failure due to corrosion. Although it requires longer total mooring line, the overall benefits that we got is considerably worth it.

17 Recommendations

From this research, there are several characteristics that can be improved and enhanced in order to achieve a better result and analysis. In addition, it is also crucial so that any improvement towards the design and configurations may be developed in a way to reduce the surge responses.

First and foremost, to improve the validity of the hydrodynamic response calculated and estimated using both of the analysis (statics and dynamics), it is vital that a model analysis is made in the wave tank. Its function to test the designs of the buoy and mooring line in a real life manner where researcher can observe and analyze the hydrodynamic characteristics thoroughly.

Moreover, couple dynamic analysis between FSO, SBM and mooring line should be made to get a better mooring design. However, FSO's dynamic motion was not included due to the higher processor memory required to run additional floating structure model in the analysis.

According to OS E-301, there are 3 types of mooring design analysis. In this analysis, the researcher had focused on the ultimate limit state analysis. The remaining 2 analysis; accidental limit state and fatigue limit state analysis should be carried out to determine the overall performance of mooring line.

Finally, environmental data such as seabed or soil condition can be added into the analysis. It would enable the friction effect between the laid mooring line and seabed may be calculated. However, during the research, seabed frictions have been neglected due to difficulties to gain the information and time constraint during the research.

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