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FPSO MOORING CONFIGURATION BASED ON MALAYSIA'S ENVIRONMENTAL CRITERIA

Mazlan Muslim and Md Salim Kamil
Marine and Design Technology Section, University Kuala Lumpur MIMET, Lumut, Perak, Malaysia
E-Mail mazlanm@unikl.edu.my

ABSTRACT

For floating offshore structures or referred to as floaters, the mooring system is vital for station keeping. One of the mooring system used in the FPSO (floating production storage offloading) vessel is the turret system. A turret is a device directly built into the moored vessel for the purpose of weathervaning and attached to the seabed by catenary anchor lines. There are two types of turret used in the construction of FPSO which are the internal and external turret. This analysis involve the designing and performing hydrodynamic analysis for the FPSO based on local environmental criteria. For the research, the analysis involved mooring analysis of the anchor lines tension by using specific engineering software, ANSYS. The result will suggest the ultimate mooring configuration that is suitable for the area of research.

Keywords: FPSO, turret system, hydrodynamic analysis, mooring configuration, ANSYS software, environmental criteria.

INTRODUCTION

In order to relate the mooring configuration in the Malaysian exploration scene, local environmental loads are taken into account by using wind, wave and water depth when running the analysis by using the ANSYS software.

FPSO that utilised external turret are normally converted from tanker. Thus the hull structure of the tanker can be arranged from similar design by using the MAXSURF software. The reference vessel is in accordance with the main particulars of the FPSO Kikeh. The main reason of choosing the FPSO Kikeh is the vessel is the first of its kind operated in Malaysian waters for the deep water exploration exploration.

OBJECTIVES

The objectives of the paper are as follows:

- To design the tanker and the external turret structure to develop the FPSO model;
- To make an analysis based on the hydrodynamic diffraction and time response based on different mooring configurations;
- To suggest the ultimate mooring configuration based on the area of research environmental criteria.

TANKER HULL STRUCTURE

The reference vessel used for the analysis is in accordance to the main particulars of the FPSO Kikeh, see Figure-1. The main reason for choosing the FPSO Kikeh is that it was the first such vessel that is operated in Malaysian waters for the deep water hydrocarbon exploration. The FPSOs are generally ship shaped floaters with provisions for storing and offloading of oil simultaneously. They may be designed to weathervane so that they always face the weather, minimizing roll and heave motions. In environments such as South East Asia the FPSO may be spread moored to face one direction at all times. Oil production is through either flexible risers or riser towers with flexible jumpers, see Figure-2.

TURRET STRUCTURE

The turret designed shall follow the standard from the American Petroleum Institute (API). In order to obtain the design of the turret, collaboration with the company that had been involved in the FPSO Kikeh design and construction is required. The turret mooring was introduced in 1986 which opened the door for the FPSOs into more severe environments.

PRESSURE AND MOTION

The pressure and motion results will provide an overview of the visualization and display a number of results generated from ANSYS after the hydrodynamic analysis had been completed. The frequency and direction options can give the user the freedom to set the frequency, direction and incidence wave amplitude. Each input parameter can define the result desired based on the environmental criteria needed.

HYDRODYNAMIC TIME RESPONSE

Regular waves are defined as the waves that have same frequency, wavelength and amplitude. On the other hand, irregular wave can be viewed as the superposition of a number of regular waves.

Figure-1. FPSO Kikeh under construction. Turret structure is shown on the bow of the vessel.

MOORING CONFIGURATION

This analysis will suggest the ultimate mooring configuration for the FPSO station keeping system. The criteria will also consider the costs involved, safety and operational elements. By comparing all the mooring configuration, the tension pattern can be defined in graphical method that can differentiate significant tension produced at the mooring lines. The local environmental data also will be used to ensure its compatibility with the Malaysian hydrocarbon exploration.

The converted FPSOs often offer the shortest and the cheapest path to initiate production. Their main limitations include a lack of ability to operated dry trees, and technical feasibility of mooring in very deep water in harsh environments. The turret assembly can become very complicated and difficult to integrate with the hull.

HULL GIRDER STRUCTURE

Tankers have evolved to length (L) to breadth (B) ratio of about 6.1 that gives a good compromise between the enclosed volume and the resistance to forward motion. The FPSOs are not required to move forward; consequently resistance is not an issue.

However, in a weathervaning mode the hull slenderness ratio (L/B ratio) serves to present a low frontal area to the prevailing environment and assists in the natural weathervaning motion. A low slenderness ratio results in more favourable motions and mooring behaviour over a shorter and more bulky hull. A shorter hull would however offer savings in steel weight and possible cost reductions. Hull breadth to depth (D) ratio comparison is a different prospect since FPSOs, unlike tankers, are not constrained by maximum drafts, so the typical 2:1 ratio for B/D can be optimized. This helps structural design and seakeeping by increasing freeboard whilst permitting greater bow submergence to reduce slamming.

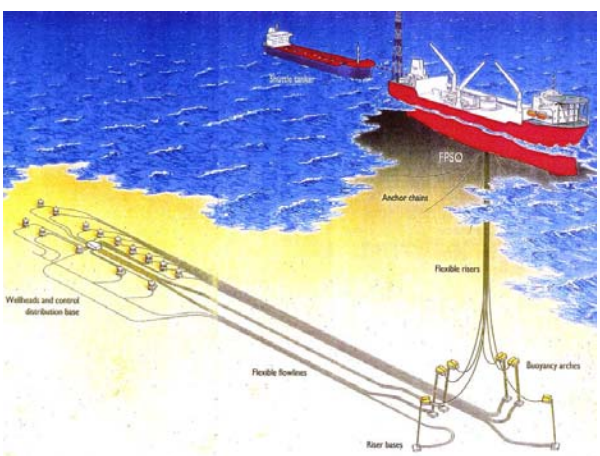

Figure-2. FPSO typical layout including subsea installations, typical internal turret system.

TURRET SYSTEM

The moored part of the turret is fixed relative to the sea bottom such as flexible risers are suspended from this fixed part and are connected to Pipe Line End Manifold (PLEM) arrangements or directly to wellheads. A swivel connects the flexible risers to the fixed piping mounted on the vessel.

An external turret mooring system can be used in moderate to severe environments, see Figure 1. For harsh environments, consideration must be given to protection of risers from wave damage and this could be a limiting factor. The typical limit on the number of risers shall be about 20.

The external turret which is located at the bow of the tanker is used to locate the position of mooring attachment. The design can be achieved by referring to the general arrangement obtained earlier by using SOLIDWORKS software. The turret structure will add some additional 35 m for the overall length of the vessel. At early stage it might not be necessary to design the complex turret system but enough with more basic design to ensure the meshing process is much easier.

An internal turret mooring system has the turret inside the vessel, see Figure-2. This system can also be used in moderate or harsh environments. The typical limit on the number of risers shall be about 100. Integration of the turret into the hull is an important consideration in the structural design of the associated vessel's hull structure.
In the selection of the turret system in any particular case, a variety of features and related cost-vs-benefit tradeoffs must be considered, including the following:

- Environmental conditions;
- Water depth;
- Installation complexity;
- Operation and maintenance;
- Safety and reliability;
- Capital and operating costs;
- Downtime;
- Emergency repairs.

FPSO Kikeh

The FPSO's hull is made of thick mild steel with 35 mm bottom plates that provide superior fatigue characteristics for a 20-year offshore field life, see Figure 1. The design premise was for FPSO Kikeh to remain on site during the 20-year field life without the need to drydock, providing many years of service for this key Malaysian deep water development.

Kikeh's water depth is 1,341 m located at offshore Sabah, northwest of the island of Labuan, see Figure-3.

FPSO MAIN PARTICULARS

Length overall: 372.11 m
Length between perpendiculars: 320 m
Beam: 54.5 m
Depth: 27 m
Draft: 21 m
Gross tonnage: 122,129 GT
Speed: 16 knots
Deadweight: 273,408 tonnes

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Figure-3. Kikeh field.

Turret moored FPSO

A turret moored FPSO is designed as a Single Point Mooring (SPM) that allows the FPSO to weathervane about the mooring system, in response to the environment. This weathervaning ability allows the vessel to adapt its orientation with respect to the prevailing environmental direction to reduce the relative vessel-environment angles and the resulting load on the mooring. This also allows for a more optimum offloading orientation than that with a spread moored system. The riser systems are also supported within the turret structure.

MOORING SYSTEM INSTALLATION

Installation of deep water mooring system presents numerous engineering challenges both in terms of installing the individual anchor legs and in hooking up the vessel. This is further complicated in harsh offshore environment oilfield due to the presence of persistent swell and the unpredictable nature and intensity of squalls.

FPSO DESIGN PROCESS

The design process starts after the entire dimension of tanker and turret has been gathered. The tanker hull was designed by using the MAXSURF software. All dimensions are based on the FPSO Kikeh main particulars. The turret is designed by using the SOLIDWORKS software. Both the tanker and turret structures then are combined by using RHINOCEROS software.

MOORING TYPES

There are three mooring configurations involved in this paper. There are 4 mooring, 8 mooring and 12 mooring. The layout are developed in the ANSYS AQWA software based on the coordinates in three dimensions that include x, y and z axis. Firstly, at the seabed the anchor are positioned at 1350 m water depth by using the coordinate function. Then, total up to 12 anchors shall be arranged to set up the station keeping layout for the vessel, see Figure-4.

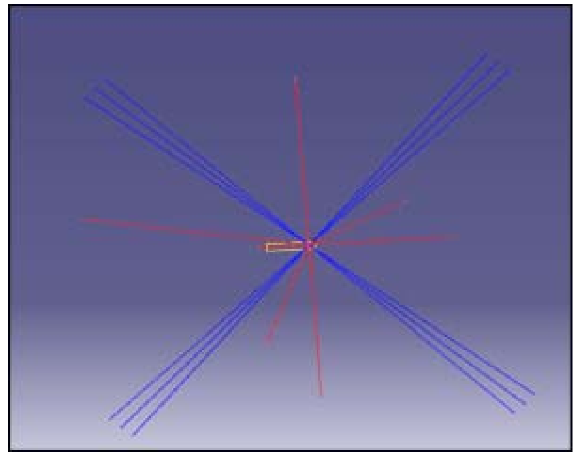

Figure-4. Mooring and riser, view at horizontal projection.

The position of mooring attachment shall be located under the turret structure by using coordinates. It also requires up to 12 mooring attachment to be connected to the anchor at the seabed. Then the cable will be set up from the mooring attachment to the anchor. The process will be continued with all mooring configuration type. The type of cable will use the nonlinear catenaries that are more suitable for deep water exploration and production. The joint articulation will be added to link all the cables for weathervaning purpose. The joint articulation type that is suitable for the external turret FPSO is hinged type because it can be rotated and aligned.

HYDRODYNAMIC DIFFRACTION ANALYSIS

AQWA Hydrodynamic Diffraction provides an integrated environment for developing the primary hydrodynamic parameters required for undertaking complex motions and response analyses. Three-dimensional linear radiation and diffraction analysis may be undertaken with multiple bodies, taking full account of hydrodynamic interaction effects that occur between bodies. While primarily designed for floating structures, fixed bodies such as breakwaters or gravity-based structures may be included in the models.

MALAYSIAN ENVIRONMENTAL CRITERIA

The input parameter data comprise of water depth, wave height, wave period and wind speed are needed to run the simulation in ANSYS AQWA software. All the data needed can be obtained through the Malaysian Meteorological Department (MMD).

DISCUSSIONS OF RESULTS

At 0^0 directions of wave and wind subjected to the FPSO, the maximum difference between 4 and 12 mooring is 5.44 kN. The 12 mooring configuration has lower tension produced at each cable. For both layout,

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cable 1 has the highest tension followed by cable 2, 3 and 4. This is because, at 0^0 directions, cable 3 and 4 distracted from the environmental load subjected to them by the FPSO structures.

At 45^0 directions of wave and wind subjected to the FPSO, the maximum difference between 4 and 12 mooring is 16.49 kN. The 12 mooring configuration has lower tension produced at each cable. For both layout, cable 1 also has the highest tension followed by cable 2, 3 and 4. This is because, at 45^0 directions, the 3 m wave condition has increased about 70% to 5 m wave height when slamming at the starboard of the FPSO. An increase in wave height will significantly increase the wave loading produced. Thus, the tension at cable 1 will be much more higher than other cables installed.

At 90^0 directions of wave and wind subjected to the FPSO, the difference of tension produced at cable 2 for both mooring layout is 46.92 kN. The difference for both configurations are the highest reading for all analyses. It shows that the 12 mooring has better mooring capabilities than 4 mooring lines.

At 135^0 direction of wave and wind subjected to the FPSO, the difference of tension produced at cable 2 for both mooring layout is 40.71 kN. The difference for both configuration are the second highest reading for all analyses. It is proved that the 12 mooring configuration will lower the mooring tension produced when subjected to the environmental load. Cable 1 has lower amount of tension because of the wave spectrum has significantly become negative when slamming at the bow of the FPSO. This will result in lower wave load applied to the cable 1.

At 180^0 direction of wave and wind subjected to the FPSO, the difference of tension produced at cable 2 for both mooring layout is only about 5.90 kN. Each cable has balance tension produced; this will indicate that all cables are not distracted by any structure except for cable 4. Cable 1 and 2 have higher tension than cable 3 because of the wave applied to the cable 3 is opposite to the mooring attachment while for the cable 1 and 2 are facing the loading from the edge of the mooring attachment.

For the 8 mooring configuration, the tension produced at each cable is quite similar to the 12 mooring configuration. It shows that, for the moderate Malaysia's environmental criteria the 8 mooring layout is more suitable for the domestic deep water operation. The results for 8 mooring also indicate that the wave and wind directions have same impact of tension when subjected to the mooring lines.

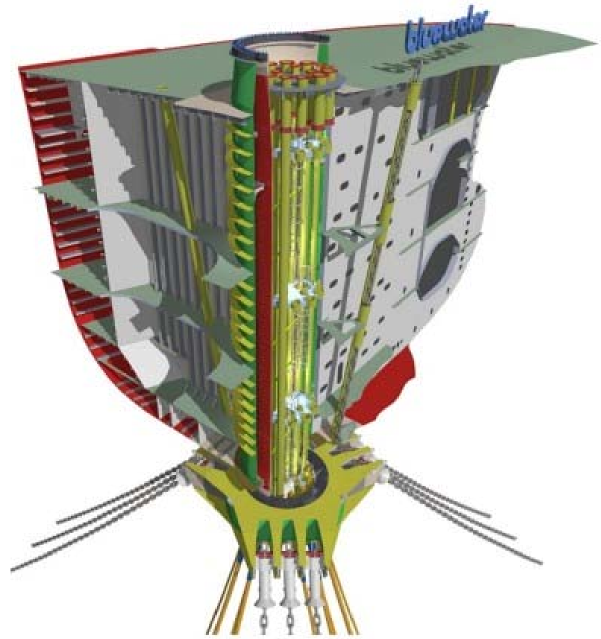

Figure-5. Internal turret mooring system.

CONCLUSIONS

From the results produced by using ANSYS AQWA software we can conclude which mooring configuration that is suitable for operation in Malaysian deep water exploration. Each mooring configuration has its own pro and contra that will reflect its limitation. The results focused on the hydrodynamic time response analysis only.

Experience has shown that the insufficient attention to the mooring design at this stage can have a negative impact on the system at a later stage.

In term of longer period, the fatigue cyclical loading to the anchor lines can contribute to the chain breakage. This will result to higher costs to recover all the damages that will be affected to the production process due to repair works that need to be done.

For the 8 mooring configuration, it is the ultimate layout for the FPSO station keeping system.

For the 12 mooring configuration will include all systems of mooring to the vessel load transfer system including the installation of anchor leg components, fairleads and chain stopper. This is because the installation of deep-water mooring system presents numerous engineering challenges both in terms of installing the individual anchor legs and in hooking up the vessel.

It is also important to ensure yawing or twisting is minimized during FPSO hook-up and tensioning, as the long-term performance of mooring components under permanent twist is not well understood. Experience has shown that with the right procedures and equipment that the amount of twist in the anchor legs can be minimized to one or less turn every 1000 m of mooring line length.

In conclusion, the FPSO shall be operated in Malaysian waters specifically on the deep and ultra-deep water condition need 8 number of anchor lines for its

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station keeping system after considering the costing elements, factor of safety and the software analyses results.

Figure-6. Spread Moored System.

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