

On the Study of Hybrid Riser with Integrated Tether for Extreme Offshore Conditions in the Gulf of Guinea

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Abstract: This study presents the optimization of the hybrid risers in deepwater applications by the integration of a tether. It analyses the feasibility, impact and essence of attaching Polyester tether to the buoy of a conventional hybrid system using the Gulf of Guinea (GoG) wave conditions, and adopting a water depth of 1800m. The sensitivity of the convectional hybrid riser (CHR) and Tethered-Hybrid Riser system (THRS) were also analyzed and compared to observe its response with respect to effective tension and maximum von Mises stress. The findings reveals that the effective tension and stress experienced a 2.5% and 6.4% reduction for the fixed standing hybrid riser (FSHR) and flexible jumper, respectively; for the THRS when compared to the CHR configuration (with 10-years wave return period). The results also show that there should be appropriate vessel control in order to maintain the best response when in service over 10-year and 100-years extreme conditions. Hence, the Tethered Hybrid Riser System (THRS) yields a significant improvement when compared to the CHR.

Keywords: Tethered Hybrid Riser, Conventional Hybrid Riser, Fixed Standing Hybrid Riser

1. Introduction

1.1. Background

Internationally, in the last 10 years, the exploration, production and development in the deep water (> 500m depth) has expanded, this has accounted for more than half of the global oil and gas reserves. The statistical evaluation from 2005 to 2009 by Information History Service (IHS) on discovery recorded that ultra-deepwater (> 1500m depth) accounted for 41% of the total newly discovered reserves. However, despite these huge advances, setbacks such as technological challenges, harsh environmental conditions, production cost, etc; limits the overall offshore operations. Hence, there is still room for improvement.

One of the major challenges encountered in offshore oil and gas operations is the link between the floater and subsea structures on the seabed (Marine riser and mooring lines). Riser systems are used to transport fluids (or serve as service

line as in the case of umbilical (UFL)) between a well head or subsea structure(s) on the seabed and a fixed platform (or a floating vessel) on the free surface. However, challenging factors such as the hydrostatic pressure, current, ocean waves and vessel's motion pose a difficult challenge for riser design engineers.

1.2. Riser Systems

According to Mungall, et al. [1], a production riser system is a fluid communication system which usually includes multiple conduits through which various produced fluids (for instance, oil, gas, water, etc.) are transported between the production facility at the water surface and the seabed. Though, used for export / off-loading lines, fluid injection lines; some riser system can also serve as service, electrical and hydraulic lines.

There are primarily two kinds of risers, they are rigid and flexible risers; the hybrid riser is the integration of these two

kinds of riser system [2]. A typical riser system is composed of the conduit (riser body), interface with floater and wellhead, Components, and Auxiliary.

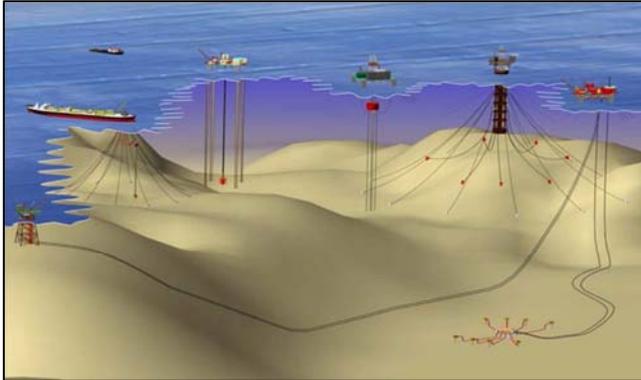


Figure 1. Different Riser Systems [3].

1.2.1. Flexible Riser System

The typical structural configuration of a flexible pipe consist of an inner most layers of interlocked metallic construction to prevent collapse of the internal pressure sheath or pipe, steel helically wound and interlocked layers to support the internal pressure sheath, increase resistance to internal and external loads and mechanical crushing loads, and polymer sealing layers to provide fluid integrity, protection from corrosion and abrasion [4]. Due to the structural configuration and the different material used to make the wall of the riser, the flexible riser (when compared to the equivalent steel riser) has a low relative bending to axial stiffness. Other advantages include the ability to be stored in long lengths of reels, hence reducing transportation and installation cost. The Flexible riser configurations can be grouped as free hanging catenary, wave configuration (lazy wave, steep wave, plaint wave) and S-type configuration.

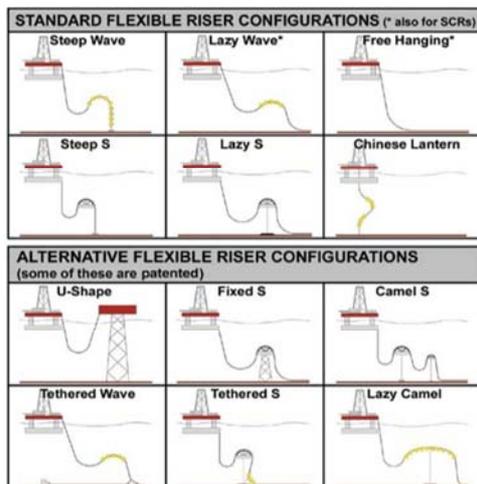


Figure 2. Various flexible riser system configurations. [5].

1.2.2. Rigid Riser System

This type of riser system can be classified into Steel catenary riser (SCR), Top Tension Riser (TTR). SCR is a riser system which has one end of the rigid submerged riser

curved upward in a catenary form from the touchdown point to the floating production unit by a flex-joint [6]. The first SCR to be installed with a semi-submersible was applied in the Marlim field offshore Brazil [7]. Also, in 2004, oil and gas export SCRs were installed in the Bonga Oil field on an FPSO in West Africa.

TTR allows direct access to subsea wells from a floating production unit (or platform for drilling, work over or completion operations) [8]. This concept consists of the main riser tensioning system such as RAM tensioners, tensioners deck, traditional hydraulic tensioners and counterweight; Riser guides / Centralizers; Keel joint at keel; Surface well / Bop stack on a production tress and jumpers; Stress Joint and tie back connector; Vortex Induced Vibration (VIV) Suppression devices.

1.2.3. Hybrid Riser System

The Hybrid riser system is a combination of a jumper (steel or flexible) and a standing vertical riser. The major advantage of this concept is that it accommodates the relative motion between the floating production unit and the standing riser by joining them with flexible jumpers; it also gives a clearer and organized subsea layout which is principal in field development [9]. The hybrid riser system can come in the following configurations:

a) The Bundle Hybrid Riser System

This was first installed in Green Canyon Block 29 of the Gulf of Mexico (GoM) in 1,529ft of water depth; this type of hybrid riser can incorporate efficiently 10-12 lines in a single structure in the year 1988 [10]. According to Dale and Karunakaran [11], this concept has reduced installation cost and number of risers, however, the challenge of routing the flowline, pipe expansion, thermal/flow assurance are encountered.

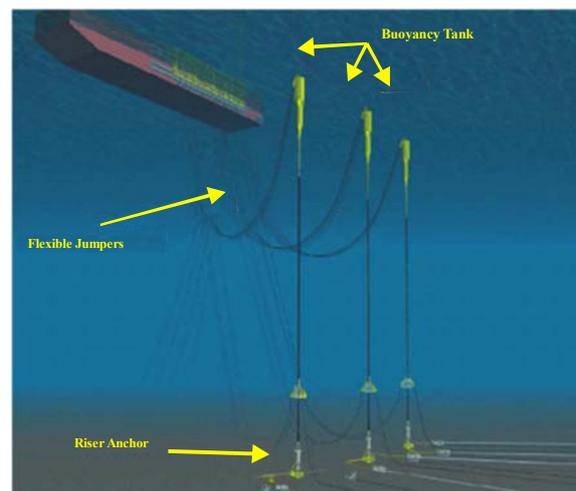


Figure 3a. Bundled Hybrid Riser Diagram [3].

b) The Single Line Offset Riser (SLOR)

The SLOR employs a vertical steel riser section that is linked to the host vessel via a flexible pipe jumper. The key advantage of this hybrid arrangement is that the vertical riser response is largely decoupled from the vessel motions and

hence becomes less susceptible to fatigue damage. However, since the SLOR are well spaced to allow for large deflections (as a result of the current loading) the number of SLORS that can be accommodated in a particular field could be limited and not enough [11]. In 2004/2005, Exxon installed the first SLOR in Kizomba A and B in water depth ranging from 3,300 to 4,200ft [10].

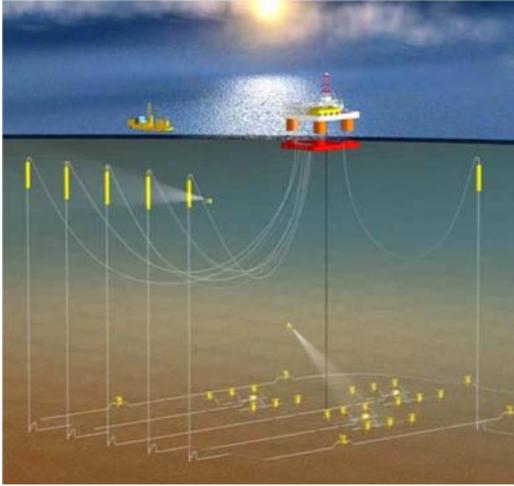


Figure 3b. SLOR Production System arrangement [12].

2. Methodology

In this design analysis, standard design codes for riser system was used, as this gives the criteria, requirement and guidance on the structural design and analysis of all riser systems exposed to static and dynamic loading for use in the oil and gas sector. Det Norske Veritas (DNV) [13] DNV-OS-F201 Offshore Standards for dynamic risers and American Petroleum Institute [14] API RP 2RD standards for risers attached to floating systems will be used as reference code. This design codes are embedded in Orcaflex which is the FEA tool adopted here. Orcaflex FEA tool is a marine program developed for static and dynamic analysis of offshore structures (risers, mooring lines), global analysis, installation and towed systems [15].

Using the Orcaflex FEA tool, preliminary analysis with respect to maximum von Mises stress and Effective tension was carried out on a Tethered Hybrid riser as well as the conventional hybrid riser.

2.1. Tethered Hybrid Riser Design

The model consists of a vertical rigid steel pipe of length 800m with an outer diameter of 12.75 in (0.324m) anchored to the seabed and offset by 950m from the vessel static position, it is tensioned by means of a cylindrical buoyancy-Can of 30m by 5m which is 970m below sea level; this provides the required uplift force. A flexible jumper of length 1600m and diameter of 12.75 in (0.324m) connects the rigid riser to the vessel. A tether is integrated into the system to station keep the buoyancy device in position during extreme events.

The objective of the analysis is to obtain riser response

(both for THR and HR) by applying Gulf of Guinea environmental conditions and FPSO heading; to check the performance of the Tethered Hybrid riser (THR) against the convectional hybrid riser (CHR) system.

2.2. Environmental Data

The water depth used in this analysis was 1800m, with sea water density of 1025kg/m^3 . The submerged buoy is located 970m below the sea surface. This system configuration adopted in this study is similar to that of Andueza et al [16] in the design of an Ultra-Deep-water steel hybrid riser concept for offshore Brazil.

The wave condition was modeled by random (irregular) waves, Ochi-Hubble waves, spectrum in order to accommodate the behavior of the riser system. Significant wave height $H_s = 6.21\text{m}$ and $H_s = 8.23\text{m}$ for 10-years and 100-years recurrence period, respectively, with a corresponding the pitch $T_p = 7.65\text{s}$ and $T_p = 8.07\text{s}$, respectively. The current profile of GoG includes a surface current speed of 1.0m/s and 1.22m/s, respectively, with corresponding seabed values of 0.38m/s and 0.46m/s, for 10-years and 100-years recurrence, respectively.

2.3. Flowline Data

2.3.1. Riser Material

The riser steel material should have adequate strength, fracture toughness and weld-ability. It should not yield under stress or fail due to mechanical load; the riser material adopted is X65 (65,000Psi) carbon steel pipe with a density of 7.85te/m^3 for the flexible jumper.

Table 1. Riser Size and Mechanical properties.

Parameters	Value	Unit
Pipe Line length FSHR	800	m
Outer Diameter FSHR	0.330	m
Inner Diameter FSHR	0.229	m
Pipe Line length Flexible jumper	1600	m
Outer Diameter Flexible jumper	0.324	m
Inner Diameter Flexible jumper	0.273	m
Torsional Stiffness FSHR	73.231E3	kNm^{-2}
Axial Stiffness FSHR	9.312E6	kN
Bending Stiffness FSHR	95.9E3	kNm^{-2}
Bending Stiffness Flexible jumper	56.339E3	kNm^{-2}
Axial Stiffness of Flexible jumper	5.022E6	kN
Torsional Stiffness Flexible jumper	43.338E3	kNm^{-2}

2.3.2. Tether Data

The buoyancy acting on top of the standing riser is held by a pre-tensioned tether which serves as station keeping. According to American Petroleum Institute [17] the application of polyester material for the tether than steel is to lower the maximum tension and offset; the application of polyester lines brings about reduced damping than the use of steel lines, this is due to the inability of the polyester line to become catenary under wave frequency motion. Tether (Tensioned Rope) mechanical properties include: diameter = 0.043m, weight in air $W_a = 0.016\text{kN/m}$; weight in water $W_w = 0.0016\text{kN/m}$; Axial stiffness = 295kN; Torsional stiffness = 80kNm.

2.3.3. Vessel Properties

A turret moored Floating Production Storage and Offloading (FPSO) unit of 241.78m in length was adopted in this analysis, the vessel motion characteristics (six degree of freedom, Heave, Surge, Sway, Roll, Pitch, and Yaw) and response is very important in this design as the Hybrid riser's integral parts comprising of the flexible jumper, standing riser, buoyancy can and tether are linked to the vessel.

For these analyses, the Hybrid riser system was specified with the following Load types:

- Wave return periods: 10-years (6.21m height at 7.65 seconds); 100years (8.23m height at 8.07 seconds);
- Wave direction: 0°, 90°, 180° and 270°;
- Current speed: 1.0m/s, 1.22m/s;
- Vessel headings: 0°, 22.5°, 45°, 67.5°, 90°, 112.5°, 135°, 157.5°, 180°.

3.1.1. Sensitivity of Fixed Standing Hybrid Riser (FSHR) for 10-Years Wave Period

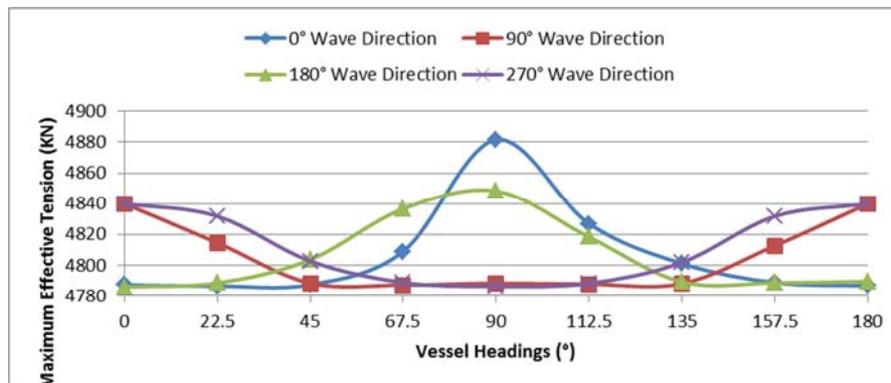


Figure 4. Effective top-end Tension of the FSHR for 10-years wave period for different wave directions.

From figure 4 above, the highest effective tension on the FSHR while varying vessel heading (V) and wave direction (W) is 4881.6kN (at 0°(W), 90° (V)) its minimum value is 4785.9kN (at 180°(W), 0°(V)). The following vessel headings yielded the highest effective tension at a specific wave direction; for 0°wave direction (90° (V)); for 90° W (0°(V); 180°(V)); for 180° W (90°(V)); while for 270° W (0°(V); 180°(V)).

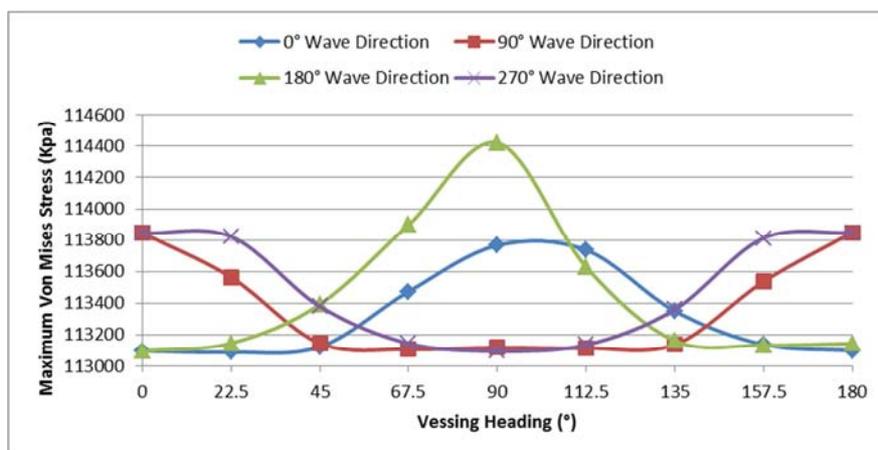


Figure 5. Maximum von Mises Stress at top end of the FSHR for 10-years wave period.

Figure 5 reveals that the maximum von Mises stress on FSHR for 10-year wave return is 114421.3kPa (at 180°(W), 90°(V)), while its minimum value 113088.1kPa occurred at

3. Results and Discussion(s)

This section shows the effective tension and maximum von Mises stress occurring at the top end of the FSHR and flexible jumper of a CHR and a THR while varying wave direction and vessel heading; it is aimed at displaying the vessel headings to be avoided during a particular wave direction. This section further shows a comparison between a CHR and a THR with respect to the maximum von Mises stress and effective tension.

3.1. Design Analysis of Conventional Hybrid Riser Without the Integrated Tether

The sensitivity of the top end of the FSHR and flexible jumper of the conventional Hybrid riser with respect to effective tension and maximum von Mises stress were carried out.

0°(W), 22.5°(V). The same vessel headings which yielded highest effective tension above also resulted to highest von Mises stress, hence, attention should be given to the vessel

headings adopted to ensure that they do not impose high stress and tension on the riser system

3.1.2. Sensitivity of Flexible Jumper (for 10-Years Wave Period)

The same load case applied to the FSHR was also applied to the top end of the flexible jumper to check its effective

tension and von Mises stress response to variation in wave direction and vessel headings. Variations in the values of effective tension and stress obtained at the FSHR and at the flexible jumper should be noted; as this shows the part of the riser system more vulnerable to tension or stress as the case maybe.

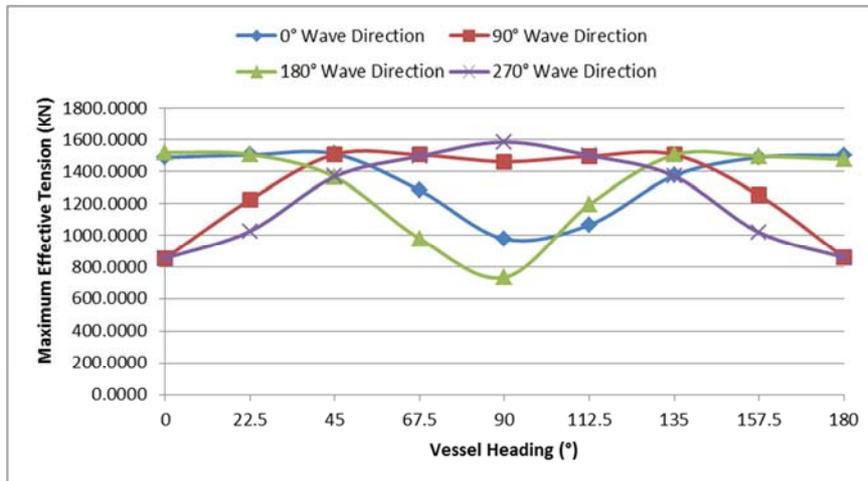


Figure 6. Maximum Effective Tension of the flexible jumper for 10-years wave period.

Based on the highest effective tension at the top end of the flexible jumper, figure 6 shows that a highest value of 1585.2kN (at 180° (W), 0° (V)) and a lowest value of 733.6kN (at 180°(W), 90°(V)) was observed from the

simulation. It can also be deduced from this figure that the vessel heading(s) yielding the highest effective tension are 45° and 180° (for 0° W); 45°and 135° (for 90°W); 22.5°and 135° (for 180°W); 90° (for 270°W).

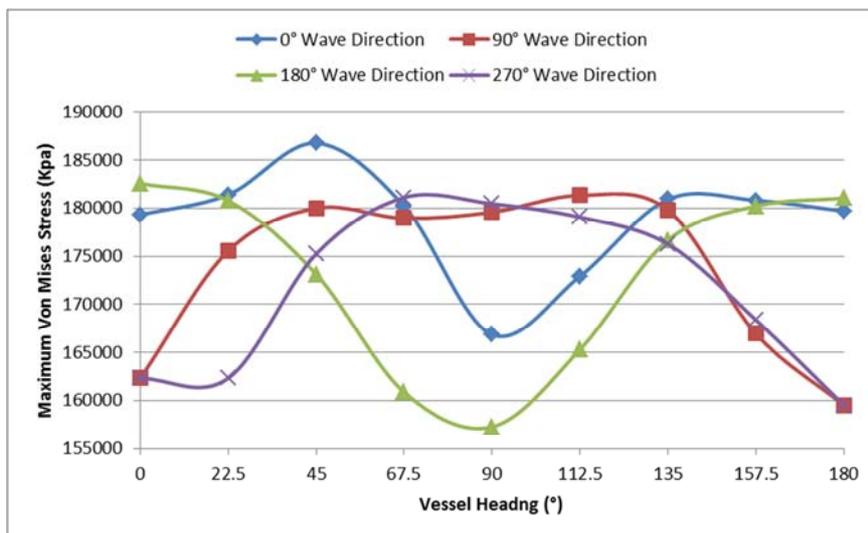


Figure 7. Maximum von Mises stress of the flexible jumper for 10-years wave period.

Considering figure 7 above, the highest von Mises stress on Flexible Jumper for 10-years wave return is 186751.5kPa (at 0°(W), 45°(V)); while its minimum values is 157253.9 kPa (at 180°(W), 90°(V)). The vessel heading yielding highest von Mises stress are as follows, 45° (for 0°W); 112.5° (for 90°W); 0° (for 180°W); and 67.5°(for 270°W).

3.2. Design Analysis of Tethered Hybrid Riser (THR)

The hybrid riser with the integration of a tether system was

studied using the same load cases as that of the convectional hybrid riser. The tether is attached to the buoy to deliver stability and also to ensure that the design tension limit of the system is not exceeded in case of accidental scenarios which might cause damage to the system or buoy.

3.2.1. Sensitivity of Fixed Standing Hybrid Riser (FSHR) with Integrated Tether

With the incorporation of a tether to the conventional hybrid riser, analysis of the effective tension at the top end of

the FSHR is shown below.

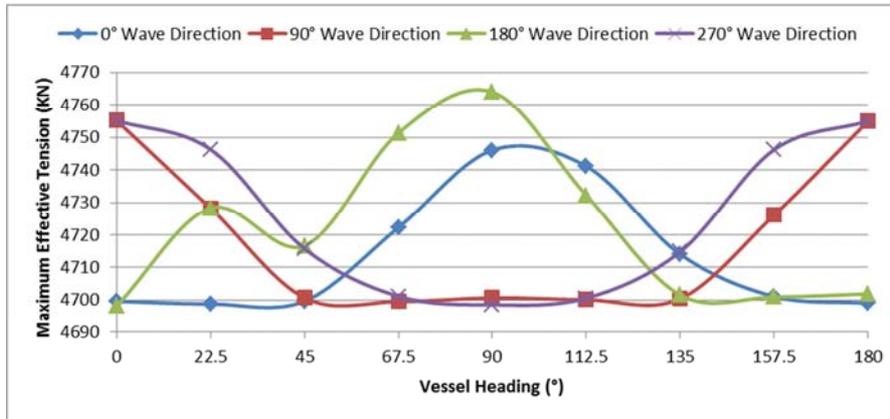


Figure 8. Effective Tension on the FSHR in THRS for 10-years wave period.

It can be deduced from figure 8 that the highest effective tension 4763.99kN occurred at 180° (W), and 90° (V). Hence, there was a reduction when compared to that of a CHR (4881.6kN). Also, figure 8 above shows that the lowest effective tension 4698.3kN occurred at 180°(W), and 0°(V) has a reduced value when compared to 4785.9kN of the CHR; This reduction in tension can be attributed to the incorporated tether system to the CHR.

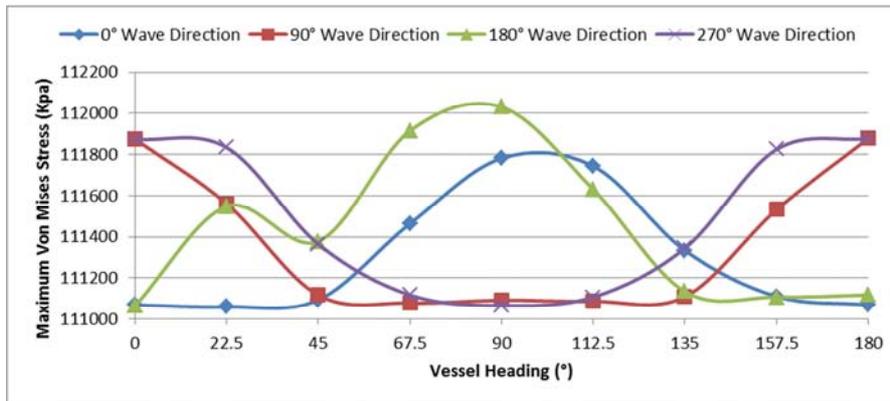


Figure 9. Maximum von Mises stress on the FSHR in THRS for 10-years wave period.

The graph in figure 9 reveals that for a THRS, the highest von Mises stress on FSHR for 10-years wave return is 112031.2kPa (at 180°(W), 90°(V)); while its minimum value 111058.9kPa occurred at 0°(W), and 22.5°(V). These values in comparison with those of the CHR (114421.3kPa (Max.) and 113088.1kPa (Min.)) shows a reduction in stress.

3.2.2. Sensitivity of the Flexible Jumper for Hybrid Riser with Integrated Tether

The analysis of the effective tension and maximum von Mises stress on the flexible jumper of a THR were also carried out in the simulation. The graphs below summarize the results.

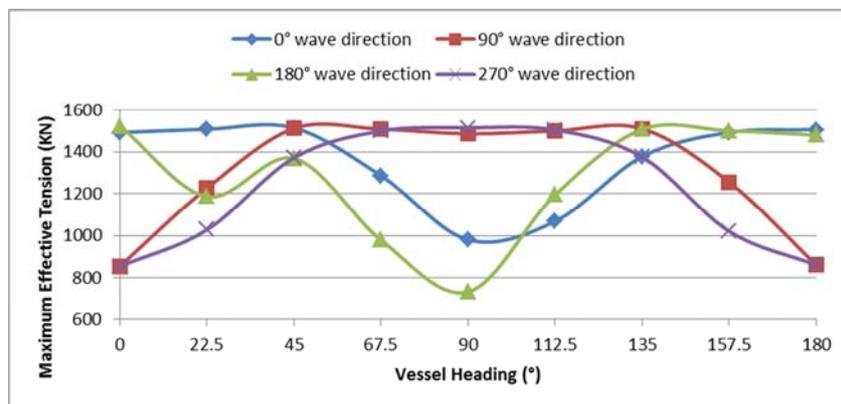


Figure 10. Effective Tension of flexible jumper in THRS for 10-years wave period.

Figure 10 shows a reduction in the value of effective tension acting on the flexible jumper components of CHR compared to THR, with the CHR values being greater. Whereas THR showed a maximum effective tension of 1515kN at 270°(W) and 90°(V) with minimum of 732.95kN at 180°(W) and 90°(V); CHR showed a maximum effective tension of 1585.2kN and a minimum of 733.6kN.

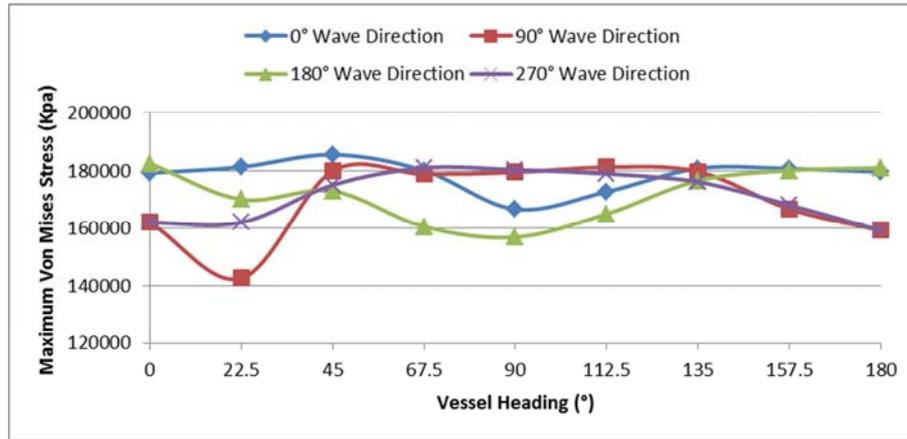


Figure 11. Maximum von Mises stress of flexible jumper in THRS for 10-years wave period.

The THR’s Flexible Jumper in figure 11 above reveals that the highest von Mises stress for 10-years wave return is 185567.0kPa, this occurred at 0°(W) and 45°(V); while its minimum value 142600kPa occurred at 90°(W) and 22.5°(V). There was also a reduction in the value of the von Mises stress as compared to the CHR.

4. Conclusion

This study investigates the optimization of the hybrid riser to improve its performance, stability and efficiency by the integration of a tether to act as station keeping and to ensure that the design tension limit of the FSHR is not exceeded. From the study, it was observed that maximum von Mises stress on the FSHR for a CHR was 114MPa with a tension of 4881kN as compared to the THR system which yielded 112.0MPa and a tension of 4763.0kN; hence, a 2.5% reduction in the stress and tension was observed. The CHR’s flexible jumper had a maximum von Mises stress of 186.7MPa while that of the THR riser was 185.5MPa, hence, yielding a 6.4% reduction; their effective tensions were 1585.0kN and 1515.0kN respectively (yielding a 4.6% reduction). Also, vessel headings yielding lower tension/stress should be adopted as this will help to preserve the integrity of the riser system.

Nomenclature

- CHR: Conventional Hybrid Riser
- DNV: Det Norske Veritas
- FEA: Finite Element Analysis
- FPSO: Floating Production Storage
- FSHR: Fixed Standing Hybrid Riser
- GoG: Gulf of Guinea
- GoM: Gulf of Mexico
- IHS: Information History Service

- THRS: Tethered Hybrid Riser System
- SCR: Steel Catenary Riser
- TTR: Top Tension Riser
- SLOR: Single Line Offset Riser
- THR: Tethered Hybrid Riser
- FEA: Finite Element Analyses
- VIV: Vortex Induced Vibration
- H_s: Significant Wave Height
- T_p: Wave pitch
- W_a: Weight in air
- W_w: Weight in water

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