MODU Installed Free Standing Hybrid Risers

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ABSTRACT

P51 (Marlim Sul) and P52 (Roncador) developments are both considering the single-line free standing hybrid riser (FSHR) design as an option for the 18 in. oil export riser systems. This paper provides the background on the front end engineering designs carried out to achieve confidence that the concept is feasible for both developments, and explains the main features of the design that take best advantage of local practices and Petrobras capabilities.

The world's first single-line hybrid risers have been installed in West Africa. The evolution to the South Atlantic design is discussed, as well as the main design drivers in the Brazilian environment.

KEY WORDS:

Free Standing Hybrid Riser (FSHR); MODU; Deep water

INTRODUCTION

Petrobras deep water developments of Marlim Sul (1255m) and Roncador (1800m) will both be producing from taut moored semi-submersible platforms P51 and P52, respectively. The high expected production rates of these units require 18inch oil export pipelines. Hence, for flow and pigging compatibility, their export risers shall also have that same diameter. This large bore specification combined with the deep water sites put these applications outside the feasibility range of solutions such as flexible pipes and steel catenary risers (SCRs). Both these solutions present high top tension loads for installation and operation. The fatigue damage in the touch down zone (TDZ) of SCRs and the lateral buckling failure mode in flexible pipes are further design limitations currently only solved by the use of heavier pipes which further compromise top tension loads in a negative design spiral.

The free standing hybrid riser system is an attractive alternative solution for this kind of application due to its much reduced dynamic response - as a result of significant motion decoupling between vessel and riser – and due to the small vessel interface loads that it presents when compared with SCR or flexible pipe solutions.

Five water and gas injection FSHRs have recently been installed in West Africa offshore Angola. The design of these risers has some key differences to the current Petrobras design, each of which offers different design and operational advantages.

The Petrobras oil export FSHRs are developed to be installed from a semi-submersible mobile offshore drilling unit (MODU) due to the availability of such vessels already working in the Campos Basin. The MODU drilling derrick and its handling tools are well suited for the FSHR installation.

This paper presents a technical appraisal of the oil export FSHRs designed for Roncador and Marlim Sul fields, describing the key components and outlining the main differences to the recently installed West African FSHRs. It addresses the response under extreme storms, long term fatigue loading and VIV (vortex induced vibration), and identifies the driving factors behind each response. Concerning installation, it highlights the considerations involved in the utilization of a MODU.

RISER DESCRIPTION

General Arrangement

There are a number of variants to the FSHR design. The one described below is the base case considered for both P51 and P52 oil export risers.

The FSHR consists of a single vertical steel pipe connected to a foundation pile at the seabed. The system is tensioned using a buoyancy can, which is mechanically connected to the top of the riser. The riser pipe runs through the bore of the buoyancy can, which is located below the mean water level (MWL) out of the wave and high current zone. At the top of the buoyancy can is a gooseneck assembly, to which a flexible jumper is attached linking the riser to the vessel, thus essentially decoupling the freestanding riser from the vessel motions.

The riser base may typically be offset from the vessel by more than

200m, depending on the water depth and the vessel excursions. The length of the flexible jumper is configured such that it gives comfortable departure angles at the vessel and at the gooseneck that minimise the coupling between vessel motions and vertical riser.

Figure 1 shows the Petrobras FSHR General Arrangement.

Foundation System

The FSHR foundation consists of a drilled and grouted pile, to which the riser is connected via a high integrity connector. The riser has a rigid base connection.

Lower Riser Assembly

The lower riser assembly consists primarily of the lower offtake spool, and the lower taper joint. The offtake spool is a component with an internal flow path that exits from the side of the spool. Attached to the side of the spool is an induction bend. A base jumper is attached to the end of the induction bend by either a horizontal or a vertical connection system.

Attached to the top of the offtake spool is the lower taper joint. This is a high specification component designed to control the bending at the base of the riser where it is connected to the stiff offtake spool body.

Buoyancy Can

The FSHR is tensioned by an nitrogen filled buoyancy can. A central pipe runs through the centre of the can and acts as the main structural element in the buoyancy can. Internal bulkheads are used to divide the can into sub-compartments.

The riser pipe is attached to a load shoulder on the top of the buoyancy can, and thus the upthrust generated by the buoyancy can is transmitted directly to provide tension in the riser string.

Keel Joint

At the base of the buoyancy can, where the riser exits from the central structural pipe, a keel joint arrangement is used on the riser to control the bending moment transferred into the riser string due to offsets and motion of the riser. The keel joint arrangement is similar to that used for some production risers on dry tree production platforms, however it is simpler as there is no requirement for riser axial motion (stroke) to be accommodated.

Gooseneck Assembly

The gooseneck assembly provides fluid off-take from the freestanding riser to the flexible jumper. It comprises an induction bend and is structurally braced back to a gooseneck support spool at the base of the assembly to react the loads generated on the assembly by the flexible jumper.

The bends in the gooseneck, offtake spool and base jumper are typically configured as 3D or 5D radius bends. These can allow the passage of pigs, and prevent flow restrictions.

Flexible Jumper

A flexible jumper is used to transfer fluid between the riser and the vessel. Bend stiffeners are used to restrict the bend radius of the jumper at the vessel and gooseneck termination points.

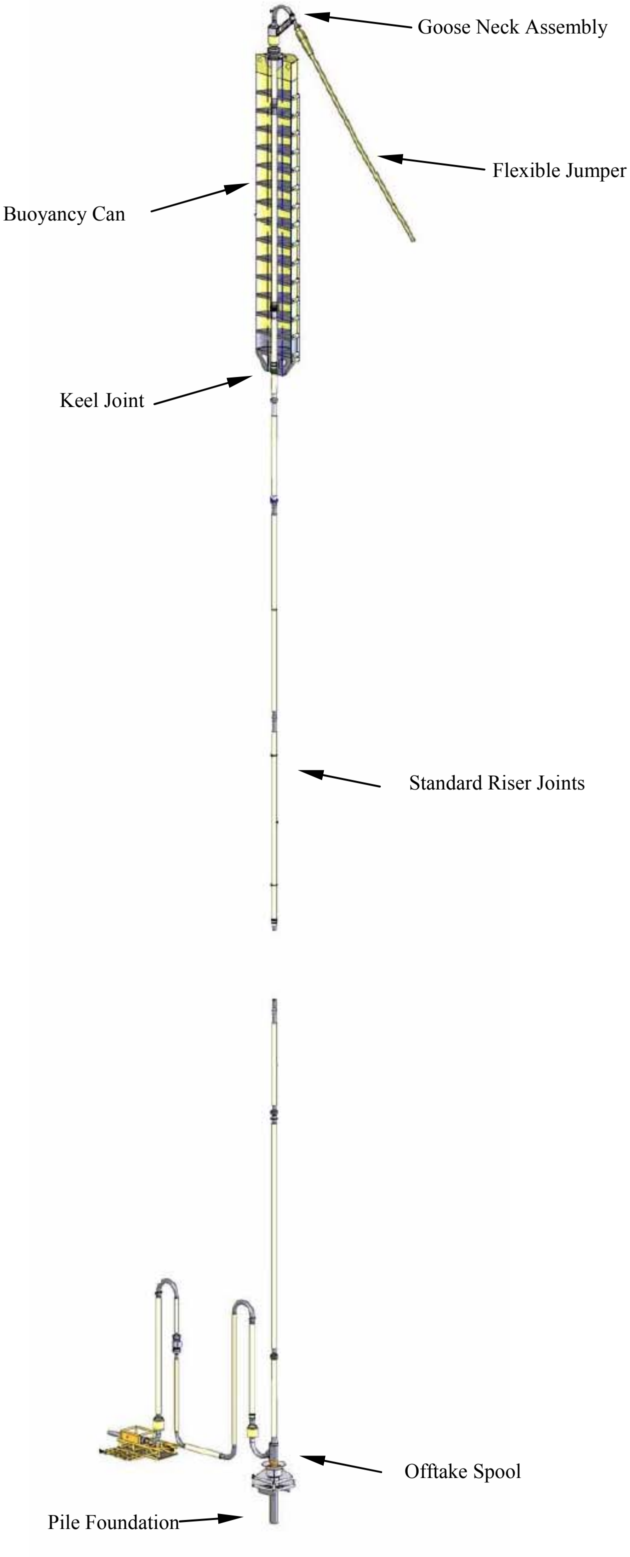

Figure 1 – Petrobras FSHR General Arrangement

DIFFERENCES FROM THE WEST AFRICAN DESIGN

A sketch of the West African arrangement is provided in Figure. 2.

The position of the gooseneck in relation to the buoyancy can is the main difference between the West African and Petrobras FSHR designs. In the earlier design, the gooseneck is positioned below the buoyancy can and the vertical riser is tensioned by the can via a flexible linkage.

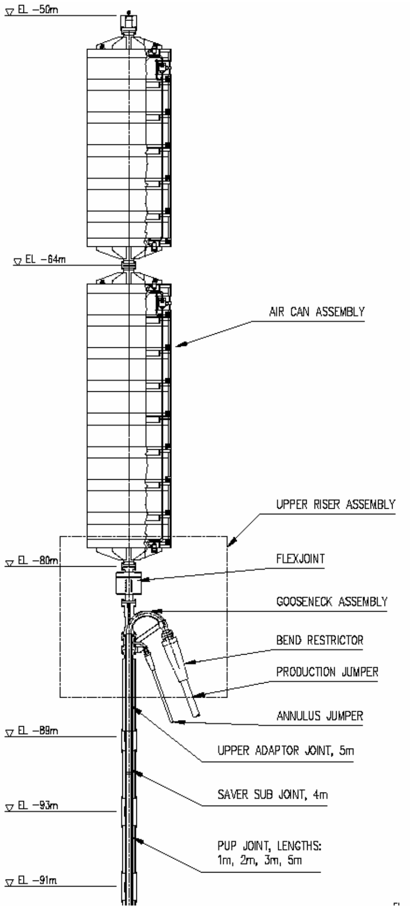

Figure. 2 – Sketch of Gooseneck Arrangement Similar to the West African FSHR.

This arrangement simplifies the interface between the buoyancy can and vertical riser, and allows pre-assembly of the flexible jumper to the gooseneck before deployment of the vertical riser. However, in the event of flexible jumper replacement or repair, an elaborate jumper disconnection system needs to be employed below the buoyancy can.

Current positioning of gooseneck by Petrobras at the top of the buoyancy can allows for independent installation of vertical riser and flexible jumper. A flexible pipe installation vessel can install the flexible jumper at a time of convenience. This minimizes the risk of damage to the flexible jumper during installation as the procedure is similar to that of a shallow water flexible riser with the first end at the top of the buoyancy can. Given that Petrobras has available to them flexible pipe laying vessels working on their extensive flexible pipe network, this design feature is preferred.

This design also facilitates and minimizes the time for flexible jumper retrieval in case of damage, in service, to any of its components such as stiffener, end-fittings or pipe outer sheath.

On the other hand, in order to endow the Petrobras FSHR design with the aforementioned installation and replacement flexibility, it is necessary to have a continual vertical riser string right through the centre of the buoyancy can to provide a connection hub for the flexible jumper at the top. This arrangement introduces interfaces between the riser string and buoyancy can which have to be carefully analysed and engineered. In addition, installation analysis has also to be conducted to assess the loads on the riser string during deployment through the buoyancy can.

Another difference between the Petrobras and West African FSHR designs is the riser foundation. The West African FSHRs have gravity assisted suction piles. This has the advantages of being installable from many different vessels types and promoting local fabrication contents. The Petrobras design makes use of what a MODU does best: drilling, and grouting, like well casings, to provide an anchorage which is reliably dependent on the length of conductor pile used.

Lastly, instead of an anchor latch that incorporates a flexible elastomeric elements joint, the Petrobras design uses a tapered stress joint in the riser string immediately above the riser foundation. This is owing to cost consideration and that a taper joint imposes less movements on the rigid base jumper which is already subjected to significant pipeline expansion loads.

DESIGN APPROACH

The design of an FSHR typically involves an upfront global analysis of the riser to optimise the riser configuration, layout and base tension, usually from clearance (from adjacent ‘handing’ components) considerations. Following the selection of the riser configuration, global storm and fatigue analyses are conducted to define the functional loading on the critical riser components, and the fatigue details and SCFs required for such components.

The detailing of a number of critical components is then required, including the taper joints, gooseneck, offtake spool and base jumper. In addition, the buoyancy can is designed such that it is capable of producing the required upthrust, and that it is structurally sound and capable of withstanding both the differential pressures and the loading from the riser itself.

While a reasonable degree of effort is required in the detailed design of these components, the FSHR benefits from the fact that the overall system design is robust and is relatively insensitive to many parameters. This allows a relatively conservative design approach to be adopted for the upfront global riser design, with allowances for parameter sensitivities and design changes included in the overall system. In addition, due to the robust design of the riser, the same, or largely similar designs can be repeated for a number of FSHRs, thus enabling the components to be designed in a single design cycle, and ultimately allowing fast track designs to be achieved.

RISER RESPONSE AND DESIGN DRIVERS

The FSHR system is designed and analysed in accordance with API-RP-2RD.

Extreme Storm

The extreme storm response of an FSHR is largely quasi-static. As the riser and buoyancy can are located away from the wave zone and surface current region, the direct wave loading on the system is low. The flexible jumper connecting the riser to the vessel reduces the dependency of the system to vessel excursions and 1st order motions.

The riser response is driven largely by vessel offset and current, resulting in an increase in loading at the gooseneck and also at the riser base. This can be accommodated by local strengthening of the gooseneck and lower riser assembly. High loading may also be experienced where the riser exits the base of the buoyancy can, hence careful design of the tapered keel joint is required.

Where the flexible jumper is attached to the vessel and the gooseneck, bend stiffeners are used to control the rotation between the jumper and the vessel / riser connection.

Plots of a typical effective tension and bending moment distribution along the riser length under extreme storm loading are presented in Figures 3 and 4, respectively.

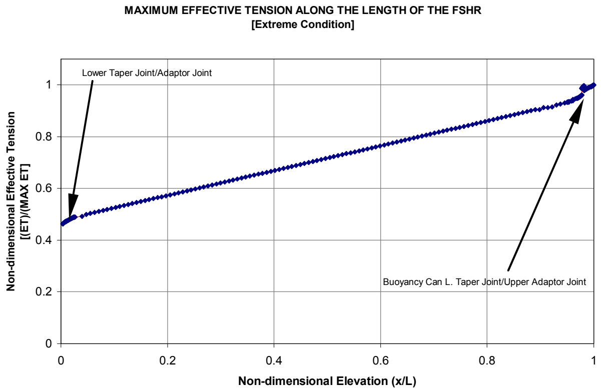

Figure 3 – Typical Effective Tension Distribution in an FSHR

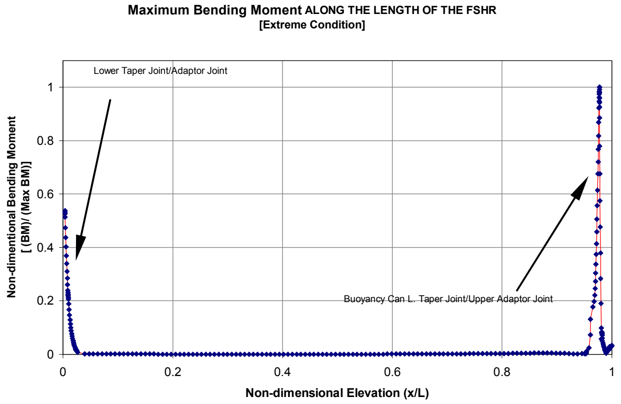

Figure 4 – Typical Bending Moment Distribution in an FSHR

Figure 5 presents the resultant von Mises stress to yield strength ratio along the riser length. It is seen that along the majority of the riser string, the stress shows a gradual linear increase towards the top of the riser, which is mainly due to axial tension (Figure 3) and hoop stress in the riser. At both ends of the riser however bending loads are seen in the system (Figure 4), but are accommodated using locally thickened or tapered components which control the curvature and stresses. That is why the stresses at the top assembly are lower than at the riser line pipe in spite of higher bending moments and axial tension near the buoyancy can.

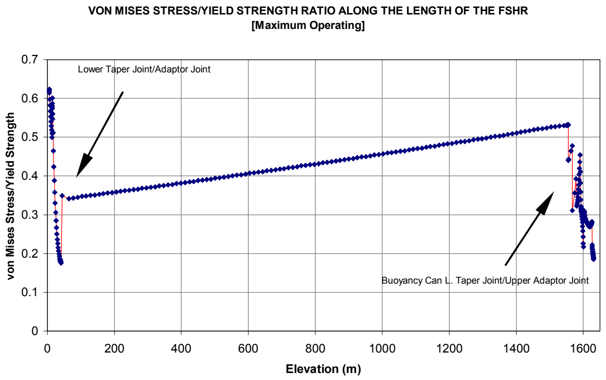

Figure 5 – Typical von Mises Stress in an FSHR

Along the vertical riser string, the stresses are practically static, barely affected by quasi-static loads (current and vessel offsets) or dynamic loads (wave and 1st order vessel motions). The deeper components, such as the lower taper joint, is not sensitive to dynamic loads, but the quasi-static loads induce significant stress amplification, thus driving the design of such components. The upper riser component designs are dictated by both quasi-static and dynamic loads.

Wave Fatigue

The long term dynamic wave loading on the system is very low. The majority of the riser motion is associated with the quasi-static vessel offsets, which gradually alter the configuration of the flexible jumper and thus the loading on the riser.

A typical plot of the wave fatigue life along the riser length is presented in Figure 6. It is seen that the life along the length of the riser is very high, however fatigue 'hot spots' do occur at certain critical locations. These locations are at the lower taper joint, and at the bottom of the buoyancy can. To achieve the required life at these locations, refinement of the locally thickened joint designs are sometimes necessary. It is essential that welds are either avoided, or high quality welds are used, and that stress concentrations are minimised in these regions through good design practice.

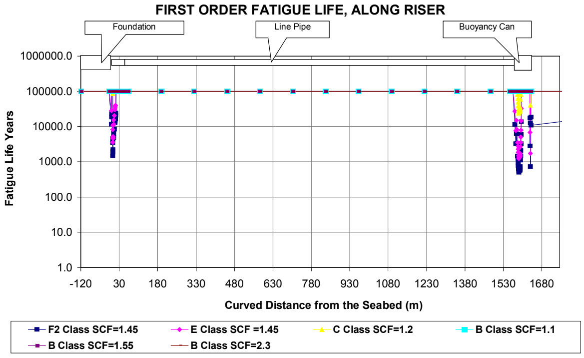

Figure 6 – Typical FSHR First Order Fatigue Life

Vortex Induced Vibration (VIV)

The VIV response of an FSHR generates fatigue damage that is low along the majority of the riser length, but high at the two ends of the vertical riser. The critical region for VIV damage tends to occur in the riser string just below the buoyancy can interface. A plot of a typical VIV response is presented in Figure 7

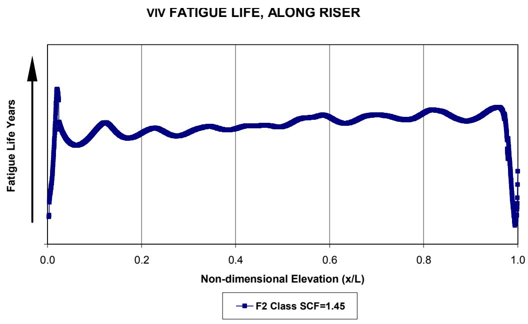

Figure 7 – Typical VIV Fatigue Life Distribution in an FSHR

It is necessary to design the components at the locations of peak fatigue damage such that they are capable of withstanding the predicted stress cycling. Generally, locally thickened components can be designed, or refined, to give adequate fatigue performance, and the use of strakes is not necessary.

Clearance

Riser clearance can become an issue if a FSHR is positioned close to a mooring line, flexible riser, SCR or umbilical which are configured in a catenary configuration. Due to the significant differences in configuration and stiffness of these systems, the relative deflections under extreme vessel offsets can result in interference.

However, it is often possible to tailor the configuration of an FSHR to avoid specific interference problems occurring. By adjusting parameters such as the base tension, the offset between the vessel and riser base, the elevation of the buoyancy can or the length of the flexible jumper, the interference problems can be minimized.

INSTALLATION

The FSHR lends itself to installation using a drilling derrick, with the riser joints being passed vertically into the derrick prior to being connected at the drill floor.

The handling and connection of the buoyancy can to the riser may be the most challenging aspect of the installation, This can be achieved by keel hauling the buoyancy can underneath the MODU, hanging it from the drilling riser tensioner chains and running the riser string through the buoyancy can (see Figure 8). Due to the vertical installation of the riser string, fatigue damage accumulation is not generally a consideration, and the bending stress acting on the riser joints as they are suspended in the rotary table is typically the limiting installation factor.

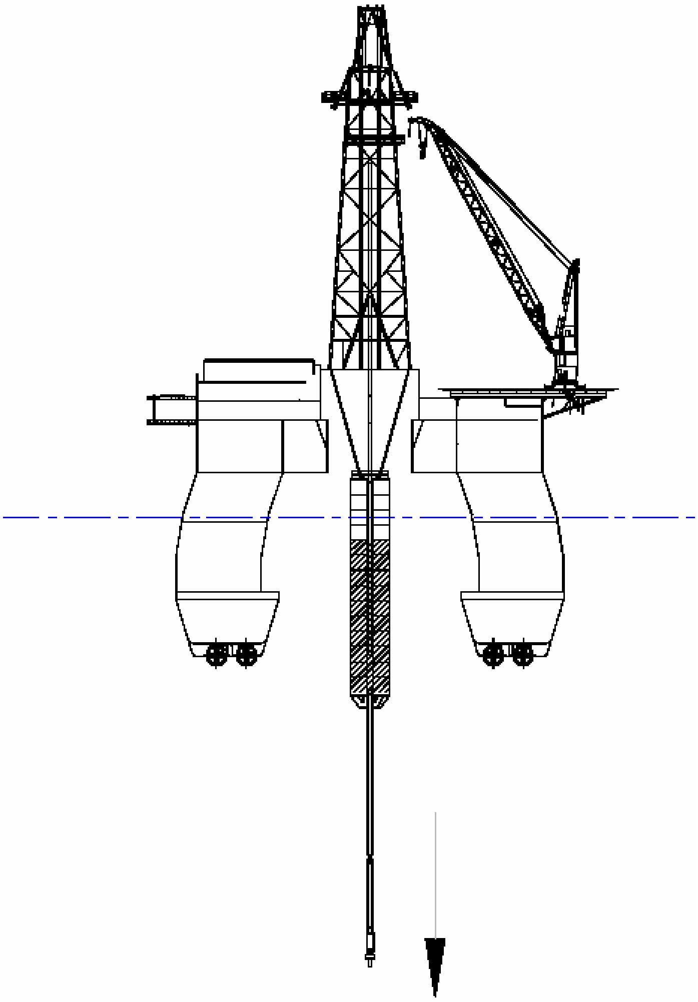

Figure 8 –Riser Joints Run from Drill Floor through The Buoyancy Can

After all riser joints are made up and run through the buoyancy can, a riser handling string is then attached to the top connector mandrel profile at the top last upper joint and the riser string is lowered through the drill floor and landed on the top of the buoyancy can, where a fixed connection between the riser and the buoyancy can is made. The buoyancy can is then released from the drilling riser tensioner chains, and the entire riser system is lowered using the riser running string (Figure 9). The bottom of the riser is landed on the foundation pile, and the riser is locked down using an ROV. The buoyancy can is de-watered and the riser allowed to free-stand. The riser remains water filled at this stage.

The flexible jumper is then installed independently by a flexible pipe Lay Support Vessel in a standard installation procedure.

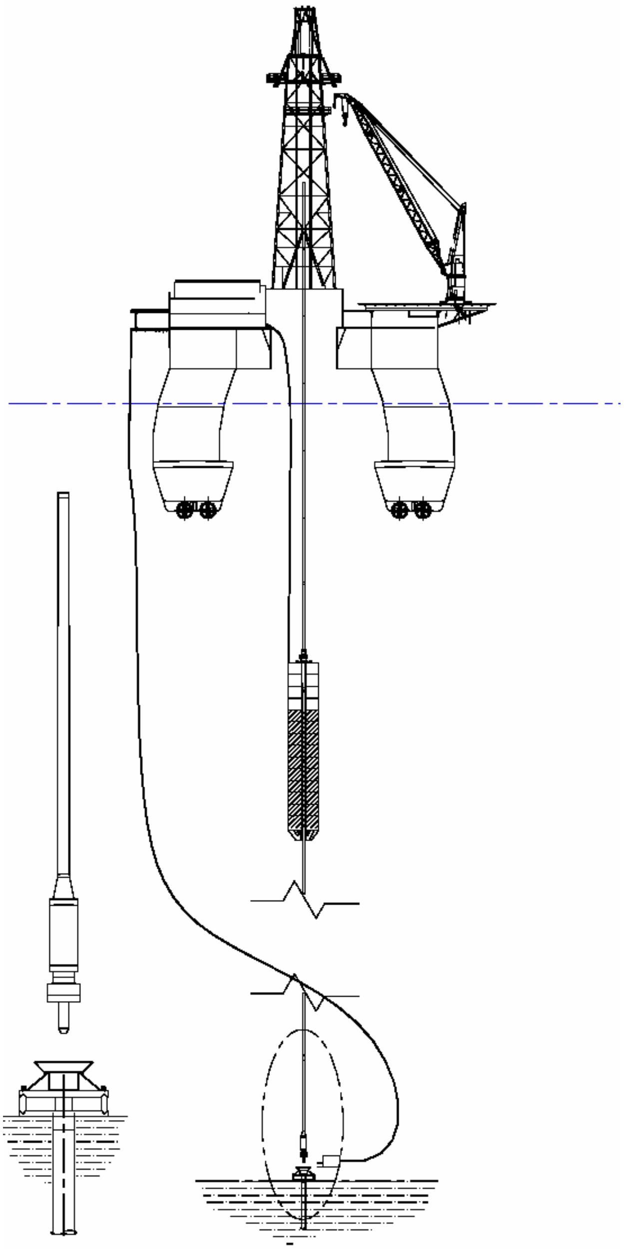

Figure 9 – Riser Positioned Above Foundation Prior to Stab-in.

CONCLUSIONS

In the FSHR design concept, the location of the buoyancy can below the wave and high current zone, and the use of the flexible jumper to decouple vessel motions from the vertical riser greatly reduces the system dynamic response, resulting in a robust riser design particularly suited to deep water applications. The design is relatively insensitive to severe environmental loading and non-heave optimised host vessels when compared to SCRs and flexible risers. The robustness allows the riser to be conservatively analysed, and allowances for design changes and uncertainties to be included upfront in the design process, thus giving greater confidence in the overall system design.

Building on the experience gained from designing the West African predecessors, the P51 and P52 oil export FSHRs have been developed in a single design cycle.

It can be said that the FSHR concept extends the reach of deep water riser feasibility as it avoids the main technical problems faced by other solutions.

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