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**THE EVOLUTION OF FREESTANDING RISERS**

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## ABSTRACT

Deepwater riser selection is a complex evaluation of technical and commercial project drivers. The free standing hybrid riser (FSHR) has evolved in the last 10 years through major use in West Africa and is now gaining serious consideration in other deepwater provinces. The key benefit of the free standing riser is that the steel riser vertical section is offset from the vessel using flexible jumpers, thereby decoupling the riser from vessel dynamic motions.

Early FSHR configurations took the hybrid bundle tower form. The very first free standing riser system, installed in 1988, consisted of the Placid hybrid bundle in the Gulf of Mexico. In the late nineties, a hybrid bundle tower was chosen for the Girassol development in West Africa. Since then, the industry has sanctioned numerous developments using multiple single line freestanding risers. Optimization of the FSHR is continuing with new concepts such as the Grouped SLOR developed to offer the combined benefits of both the bundle and single line multiple arrangements.

This paper will describe how the FSHR configuration has evolved to meet increasing industry demands over the past 10 years and will discuss the future of this type of riser system. Increasing applications in ultra deepwater regions, hurricane prone locations and tiebacks to existing payload limited production vessels will be discussed with riser system architecture described including interfaces with the vessel and seabed.

## INTRODUCTION

The FSHR has gained recognition within the industry over the past 10 years and will remain one of the primary riser system options for operators. Although the configuration has been modified through the years, the key design benefit of this system is that the steel riser vertical section is offset from the vessel using a flexible jumper, thereby de-coupling the riser from vessel dynamic motions. This enables the use of a steel riser system used in conjunction with a non-heave optimized vessel in areas of the world with harsh environmental loading. Another reason operators are drawn to the FSHR arrangement is the option to pre-install the riser which provides flexibility in terms of overall project schedule.

The original FSHR took the form of a bundle arrangement. The hybrid bundle consists of a single vertical tower, which serves as the conduit for well fluids up to the floating production facility and for processed fluids back to export pipelines. The tower can contain various numbers of production, export, water injection and service lines enclosed within thermal insulation and syntactic foam buoyancy. The hybrid bundle arrangement has been used in fields including Placid Green Canyon and Garden Banks in the Gulf of Mexico, and Girassol, Rosa Lirio and Greater Plutonio in West Africa. All but the first hybrid bundle tower riser have been beach fabricated and towed to site.

An alternate FSHR arrangement is the single line offset riser (SLOR), which was developed as an alternative to the

bundle arrangement that could be readily installed from an offshore construction vessel. The SLOR utilizes a single steel pipe to transport well fluids to the platform and can also be coated with thermal insulation. The SLOR arrangement has been used in a number of field developments including Exxon's Kizomba A and B fields in Angola and Petrobras' P-52 field in Brazil. Future SLOR developments currently in the design phase include BP's Block 31 NE in West Africa and Cascade/Chinook in the Gulf of Mexico. The SLOR can consist of a single pipe or a pipe in pipe design if gas lift or water injection is desired during the later stages of the riser design life. Unlike a bundle tower riser, using multiple SLORs on a field development has the benefit of critical production and service lines being separated and thus reduces the risk of systematic failure in the event of one riser having a structural issue. A summary of all freestanding risers installed to date is provided in Table 1.

Deepwater developments often require the use of non-heave optimized vessels, which are unsuitable for top tensioned riser systems or steel catenary risers (SCR) in harsh environments. In addition, the water depths, temperatures and pressures associated with some developments present design challenges that flexible risers cannot meet. In these cases, the FSHR presents a feasible riser system alternative for subsea developments.

Recently, newer developments with the requirement for a larger number of risers and tiebacks to existing developments have been identified. This presents significant design challenges with respect to vessel payload, seafloor layout and the requirement for a large number of riser attachment locations on the vessel. The Grouped SLOR concept is presented, which provides a solution that is developed to optimize riser/vessel interface and seabed layout.

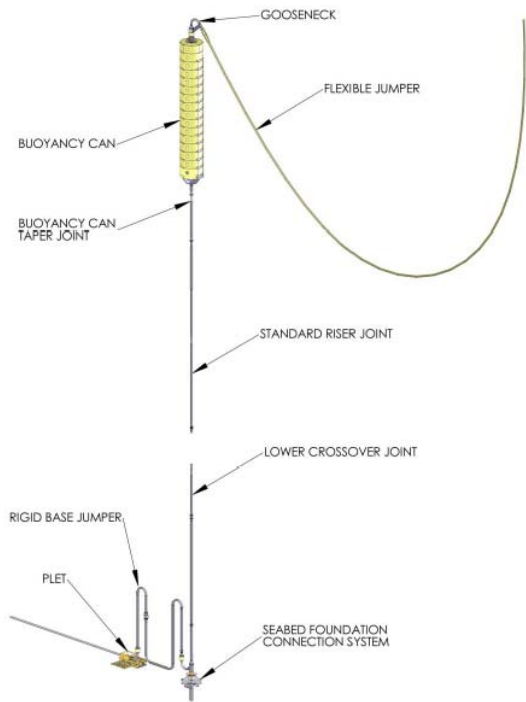
## FSHR ARRANGEMENT

The FSHR is a vertical section of pipe tensioned by a near surface steel buoyancy can that is connected to the top of the riser. The riser is tied back to the vessel via a flexible jumper as shown in Figure 1. A typical arrangement consists of the following key components:

- Upper riser assembly - includes the structural connection between the riser pipe and tether chain or flexible joint, which transfers tension supplied by the aircan. Alternatively, if the off-take is above the aircan as shown in Figure 1, the riser pipe can be routed through the center of the aircan and terminated at an upper bulkhead. The termination location is dependant on installation requirements.
- Gooseneck - allows for the connection and flow path between the flexible jumper and riser.
- Flexible jumper - transfers fluid between the riser and vessel.

- Upper tapered stress or flexible joint – utilized below the upper assembly or aircan to mitigate high stresses due to bending loads imposed by the flexible jumper and aircan.
- Lower tapered stress or flexible joint - mitigates high stresses imposed by vessel offsets at the base of the riser.
- Lower riser assembly - includes an offtake spool connected to a rigid base jumper providing access to the flowline.
- Foundation pile - can take the form of a suction pile, driven pile or jetted conductor depending on installation vessel capabilities and base riser configuration.

The riser base is typically offset from the vessel by approximately 600ft to 1,000ft based on the water depth and vessel offset range in extreme storm conditions. The flexible jumper is typically 1.4 to 1.6 times the riser base offset, with a departure angle of between 10-15 degrees [1]. The aircan is installed at an estimated 150ft to 650ft below mean water level in order to avoid wave and current loading.



**Figure 1– Typical FSHR Arrangement**

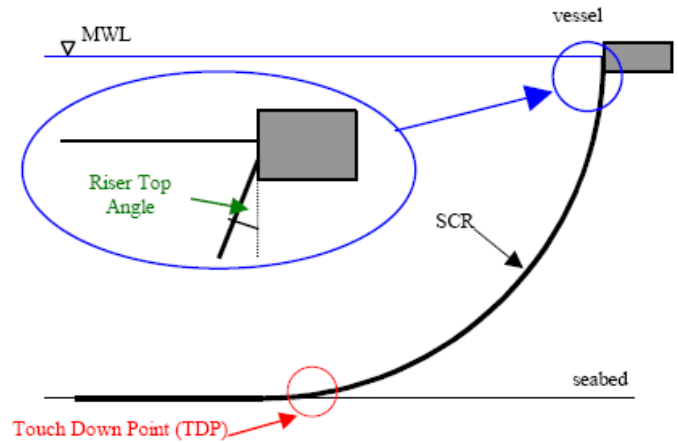
**ADVANTAGES OF FREESTANDING RISERS VERSUS OTHER RISERS**

Deepwater developments often require the use of non-heave optimized vessels, which are unsuitable for top tensioned riser systems. In addition, the water depths, temperatures and pressures associated with some deepwater developments present design challenges that flexible risers cannot meet. Flexible catenary riser applications are currently limited to 2,000m water depths and 10,000psi pressures as stated by leading flexible manufacturers. Flexible riser technology is currently being advanced due to the requirements for higher

pressure ratings, larger diameters and deeper water depths. However, these improvements are yet to be field proven and also result in higher cost due to more complex manufacturing and high end materials. Hence, riser system selection is often a choice between SCRs and FSHRs for deepwater subsea developments.

An SCR is mechanically and structurally simpler than a FSHR. A schematic is shown in Figure 2. An SCR consists of steel pipe connected to the vessel by a flex joint or stress joint and is allowed to free hang in a catenary configuration.

The SCR is a simple design, however the dynamic response of the riser is very sensitive to vessel motions and can lead to unacceptable fatigue response and very stringent offshore fabrication requirements. The FSHR requires more up front component design but the system performs much better in terms of riser dynamic response to vessel motions.



**Figure 2 – Typical SCR Arrangement**

The dynamic response in terms of strength and fatigue performance of the SCR and FSHR vary significantly. The extreme storm response of a FSHR is predominantly quasi-static and dependant on hoop stress due to internal pressure. As the aircan is typically located below the wave loading and high surface current zones, the direct impact of the environment is low. The riser response is primarily driven by large vessel offsets due to current or wind. This may deflect the riser in the direction of the vessel offset resulting in increased loading at the riser base and gooseneck. However, this can be accounted for by designing tapered stress joints or using a flexible joint, which can accommodate the bending loads or rotations respectively at these locations.

The extreme strength response of an SCR is highly dependant on the vertical motion at the riser attachment location. As the SCR is directly connected to the vessel, the riser is subjected to the heave response of the vessel. This can cause compression in the touch down zone, which in turn results in high stresses. Additional areas of uncertainty regarding SCR response include trenching, soil stiffness and

impact of seabed friction, which are difficult to quantify during design analysis.

The key benefit in terms of riser response of the FSHR versus an SCR is the fatigue response due to first and second order vessel motions. Due to the fact that the FSHR is decoupled from the vessel motions via a flexible jumper, the long term dynamic loading on the FSHR is very low. Wave fatigue lives are typically in the order of thousands of years for a FSHR versus fatigue lives in the order of tens to hundreds of years for SCRs.

Fatigue hot spots for a FSHR occur in the lower riser either at the base of the riser in the lower stress joint or in the rigid base jumpers where a flexible joint is used. At the top of the riser, high fatigue loading is found at the bottom of the buoyancy can. These fatigue hot spots can be designed out by proper design of stress joints. It is essential that welds are avoided in areas of critical loading or high quality welds are used, which result in low stress concentration factors and minimal defects.

For an SCR, the fatigue hot spots occur at the vessel attachment and the touch down zone. Low fatigue lives at the top of the SCR can be mitigated by use of a thick walled extension piece between the flex joint and first weld. To improve TDP response, a thick walled riser section or high quality welds made offshore during installation must be used.

Clearance, is another key type of riser response to consider. The FSHR can sometimes present significant challenges due to difference in stiffness between the FSHR and adjacent structures. The relative difference in deflection of the FSHR and adjacent risers, mooring lines or umbilicals under extreme vessel offsets can result in clashing. FSHR clashing can be mitigated by varying base tension, elevation of the aircan, length of flexible jumper or location of the FSHR foundation with respect to the vessel [1].

## DESIGN DRIVERS

The design drivers of a FSHR consist of the riser cross section design, fabrication and installation methods to be used. Options available during concept selection involve hybrid bundle tower or single line offset configurations; beach or installation vessel fabrication; and final installation by tow out and upending or deployment from a pipeline installation vessel.

The choice of hybrid bundle or single line riser may require the consideration of many factors such as previous experience of the Operator or riser EPCI bidder with a particular configuration, cost, spatial restrictions to accommodate multiple riser lines, local content, local resources available for beach fabrication, and weather window available for tow out of beach fabricated riser.

Once the choice between hybrid bundle and single line riser is made, the riser system design and upper and lower assemblies are defined through global riser analysis and compatibility with the installation method. All hybrid bundle towers to date, except the first Placid tower, have been beach fabricated as the cross section lends itself well to this type of

construction method. The volume of syntactic foam is calculated to provide a neutrally buoyant riser during tow. In addition, hybrid bundle towers have been towed out complete with top aircan assembly attached. In this configuration and installation method, the flexible jumper offtake is located above the aircan allowing for easy access by divers or ROV during make up and can allow access of intervention tools. This type of upper arrangement is shown in Figure 3. The riser runs up through the aircan and is supported at the top of the aircan where the buoyancy force from the aircan is transferred. The dramatic change in bending stiffness between the base of the aircan and riser requires a tapered stress joint to ensure bending stress levels remain within design allowable limits.

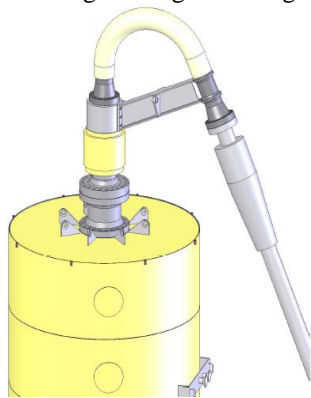
All SLOR configurations to date have been installed by an installation vessel although it is feasible to beach fabricate and tow out a SLOR much like a hybrid bundle riser. The location of the surface jumper offtake assembly can be either above or below the aircan but it is noted on installation of SLORs to date that the offtake has been placed below the aircan, as shown in Figure 4, to better facilitate installation from a subsea construction vessel with a J-lay tower. Such a vessel is able to weld the riser string using the J-lay tower, whilst using its on-board crane capacity to handle the aircan assembly and connect the riser string to the aircan using either a chain tether assembly or some type of articulated connection assembly such as a flexible joint.

The base of the SLOR requires careful consideration regarding the installation vessel heave compensation capability. A subsea pipeline installation vessel requires a base connection method that allows for some level of heave motion at the riser base. The Roto-Latch connection or equivalent has been used on many SLORs to date. It is a self-guiding, self-actuating latching system with the benefits of an integral flexible joint assembly used on many TLP tendon installations. This type of connector works well with an installation vessel that cannot compensate for vessel heave motions. Likewise, it also benefits foundations such as suction piles that cannot tolerate high levels of bending load. In such a configuration, the lower offtake spool required for rigid jumper connection is placed above the base connector and integrated flexible joint. The rigid jumper therefore must be designed for dynamic loading as the base of the riser rotates about the flexible joint.

An alternative base arrangement that eliminates dynamic loads into the rigid jumpers requires the use of a tapered stress joint above the offtake spool and the use of a wellhead type connector below the offtake spool at the interface of the pile connection. Such an arrangement avoids the large rotations at the base of the riser due to current loading and vessel offsets. Hence, the rigid spool does not require any special fatigue design and instead a lower tapered stress joint much like that used on spar or TLP vertical risers is sufficient to manage stresses at the base of the riser. The foundation needs to accommodate significant bending loads and hence driven, grouted or jetted piles are most suitable for the lower tapered stress joint base configuration. The use of a wellhead type

connector requires good heave compensation on the installation vessel when landing the riser and hence, this lower configuration is more suited to vessels that have heave compensated derricks or installation methods that can minimize riser heave at land out.

Apart from the very first FSHR installed at Placid, all subsequent FSHRs have used the flexible joint base arrangement with suction pile foundation, which have been best suited to the installation approach of either tow out and up end in the case of hybrid bundle risers or deployment from deepwater subsea construction vessels with J-lay tower in the case of SLORs. Petrobras' P-52 export SLOR is the only FSHR that depart from this trend in that it uses a tapered stress joint and wellhead connector at the base. The installation was facilitated by using a special pull down system on the seafloor to make up for lack of heave compensation on the Deep Blue installation vessel in conjunction with a drilling vessel pre-installation a grouted pile with wellhead connector profile [5]. Such an approach avoided a large diameter dynamic rigid jumper at the base of the riser that would be prone to significant strength and fatigue design challenges.



**Figure 3 – Jumper Offtake above Buoyancy Tank**



**Figure 4 – Jumper Offtake below Buoyancy Tank**

## **BUNDLED RISER TOWERS**

Placid Oil installed a bundle hybrid riser in Green Canyon block 29 of the Gulf of Mexico in 1,529ft water depth in 1988. This was the first installation of a rigid freestanding riser. The riser supply and design was provided by Cameron Offshore Engineering. The hybrid riser structure used in Green Canyon 29 was upgraded and reused on the deeper Garden Banks field (2,096ft) by Ensearch in 1994. The Garden Banks hybrid bundle riser is shown in Figure 5.

The riser was tied back to a semi-submersible and consisted of a bundle arrangement, which housed 48 production and annulus lines from each well, 2 oil and 1 gas export lines and the control lines. According to Fisher et al, the riser structural base was welded to the template in order to transfer loads through the template into the piles and soil [2]. A collet connector provided the connection between the riser base and template. The lower riser assembly consisted of a fully forged titanium taper stress joint used to mitigate bending loads. The Placid riser consisted of twenty six 50ft joints of flanged high strength steel. These joints were made up with internal air chambers and encased in syntactic foam modules that provided buoyancy and also guided and supported the annulus, production and sales lines. Each joint was equipped with an external air valve in order for an ROV to adjust the air levels. The upper riser package provided the connection point between the rigid riser pipe and the flexible jumpers tied back to the vessel [2].

The concept was developed to be cost effective and well adapted to operate in the Gulf of Mexico [3]. The drawback of this arrangement was that all the lines ran through one tower resulting in a systematic risk if the tower was damaged. This first generation FSHR was designed for a large number of flow paths and was installed through the moonpool of a drilling vessel. Due to the large diameters, complexity of design and high weights associated with this system, installation was very expensive.



**Figure 5 – Garden Banks FSHR**

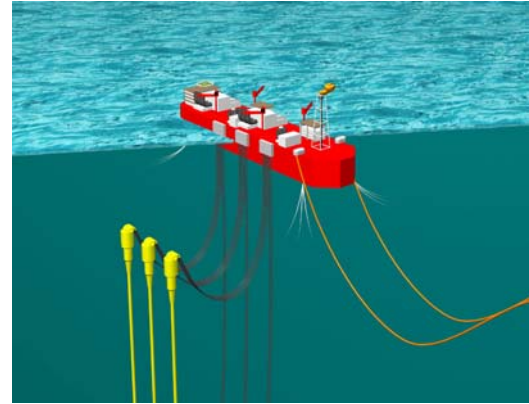
Total E&P installed their first FSHR in 2001, used in conjunction with a spread moored FPSO in 4,430ft water depth, offshore Angola. The general field layout is shown in Figure 6. The Girassol FSHR is considered a 2<sup>nd</sup> generation hybrid bundle riser tower.

The field consists of 3 hybrid bundle risers, each with 12 lines consisting of production, injection, gas lift and service lines. A typical hybrid bundle riser cross section similar to Girassol is shown in Figure 7. A key element of the bundle riser tower cross section is the central structural pipe typically 20 inches in diameter, which provides the axial and bending stiffness necessary to resist the applied loads from the aircan, environment and vessel offsets. The peripheral riser service lines are supported from the top of the riser and provide additional bending stiffness and weight, which must be compensated by buoyancy from syntactic foam modules and the aircan. Typically, syntactic foam volume is determined on the basis of having the riser cross section neutrally buoyant during tow out to site.

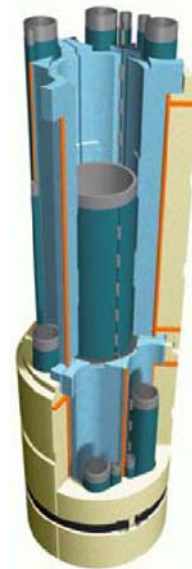
The key design change between the 1<sup>st</sup> and 2<sup>nd</sup> generation FSHR is that the riser tower is laterally offset from the vessel. This provides the advantage of improved response to vessel motions and removes the need for a tensioner, which is required to maintain proper relative position between the vessel and the riser. In addition, the 2<sup>nd</sup> generation FSHR used for Girassol was fabricated at an onshore site and installed by tow out and upended unlike the first Placid hybrid bundle riser, which was installed from a drilling vessel [4]. The Girassol approach provided cost savings as a result of weight reduction, a simplified design, local content in Angola, and reduced time to installation compared with the Placid approach.

The Girassol FSHR configuration consists of a tapered stress joint as the interface between the riser and aircan, and a Roto-latch flexible joint provides the connection to the suction pile foundation. The syntactic foam modules are made up of thermal insulation inside the core and buoyancy at the outer edge. The flexible jumper offtake to the vessel is located above the aircan, where diver access is available for make up. The top of the aircan is positioned 50m below the water line.

The grouping of all production and service lines in one hybrid bundle riser tower can increase risk in the event of a structural failure of the central member. Additional disadvantages of the bundle riser arrangement include inability to perform an external inspection of the lines for bundles such as Girassol where all the lines are encased in thermal insulation and complex peripheral line support terminations at either end of the riser.



**Figure 6 – Girassol FSHR Field Arrangement**



**Figure 7 – Girassol FSHR Cross Section**

Total installed Rosa Lirio in 2007, offshore Angola in 4,430ft water depth. Rosa Lirio consisted of one hybrid bundle riser tower tied back to the Girassol spread moored FPSO. The bundle riser tower consists of four pipe in pipe production risers, 2 water injectors and four gas lift lines. The hybrid bundle riser tower was fabricated on the beach and surface towed to site. The entire assembly is encased in syntactic foam, which holds the peripheral service lines together around a central steel 18-in pipe and provides the buoyancy to reduce the weight and top tension requirement. The pipe-in-pipe production lines have dry thermal insulation in the annulus.

BPs Greater Plutonio was installed in 2007 offshore Angola in 4,300ft water depth and is considered a third generation hybrid bundle riser tower. According to V. Alliot et al, the concept of encasing the riser strings in thermal insulation such as in the Girassol bundle configuration was abandoned for technical and commercial reasons [3]. The individual riser pipes are located on the bundle outer diameter and are independently coated with thermal insulation as shown in Figure 8, as an example of this type of bundle arrangement.

The cross section shown is not the final configuration used for the Greater Plutonio Bundle. The buoyancy consists of two half shells closed around the core pipe by bolts fitted into the foam. This represents an improvement over the Girassol design, which used pre-tensioned Kevlar straps to compensate for foam compression at depth and has the added benefit of avoiding seawater circulation inside the bundle [3]. The key benefits of the Greater Plutonio FSHR configuration include the following:

- Avoids the need to design hot and wet insulation
- Eliminates convection design issues
- Ease of fabrication and assembly
- Allows general visual inspection of production lines

There is a single tower for the entire field production resulting in a compact field layout with respect to risers and flowlines and this is traded with having no redundancy in the event of structural failure of the riser tower.

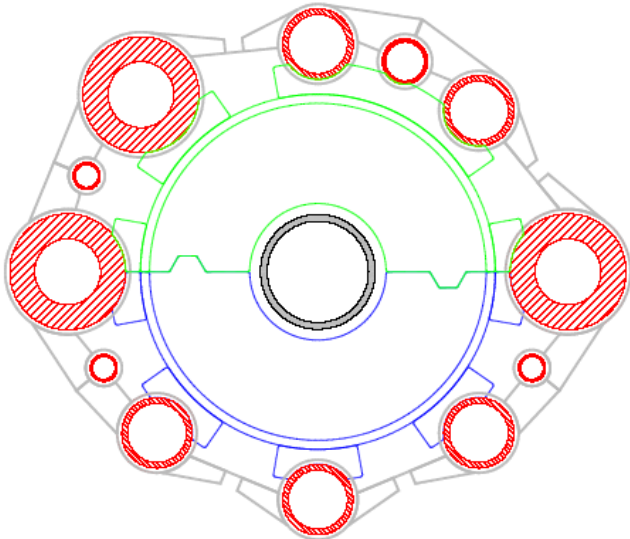


Figure 8 – Greater Plutonio FSHR Cross Section [3]

### SINGLE LINE OFFSET RISERS

Exxon installed Kizomba A and B in 2004/2005 offshore Angola in water depths ranging from 3,330 to 4,200 ft. Kizomba A was the first field to use SLOR technology. The Kizomba risers were installed from a vessel with a J-lay tower (the Saipem Field Development Ship) and are tied back to an FPSO.

The SLOR consists of a single steel pipe surrounded by wet thermal insulation. SLORs can be used for production, export and injection purposes. A schematic of a typical SLOR cross section is shown in Figure 9. The Kizomba A development is made up of three water injection SLORs and two gas injection SLORs.

Kizomba B was the first development to use the concentric offset riser (COR), which is a pipe in pipe freestanding riser surrounded by wet thermal insulation as shown in Figure 10. The COR was used on Kizomba B because production with gas

lift was required. The outer annulus of the COR is utilized for gas injection.

The Kizomba SLOR and COR configurations have a tether chain as the interface between the riser and aircan and a Roto-latch flexible joint provides the connection to the suction pile foundation. The offtake jumper at the top assembly is below the aircan.

Multiple SLORs provide redundancy in that if there is structural failure of one line, it does not compromise production or service through the remaining lines.

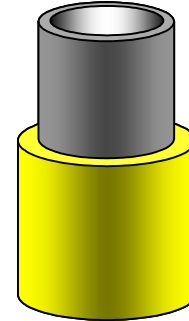


Figure 9 – SLOR Cross Section

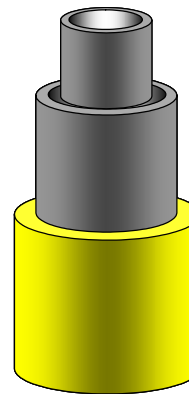


Figure 10 – COR Cross Section

Petrobras installed the P-52 SLOR in 2007 offshore Brazil in 5,906ft water depth. The SLOR was installed by Technip's Deep Blue using its J-lay to weld the riser string. The 18in FSHR is used to export oil from the Roncador FPU in the Campos Basin.

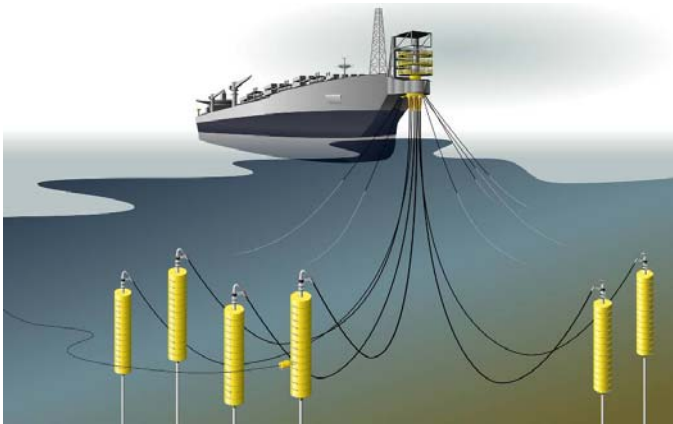
According to Lacour et al, the SLOR was chosen to reduce vessel payload and for schedule related reasons linked to the benefit of pre installation. In addition, the SLOR was also chosen due to the harsh environmental conditions in the Campos Basin making a large diameter SCR challenging with a semi-submersible host vessel [5].

The P-52 SLOR configuration has a tether chain as the interface between the riser and buoyancy can, and a taper stress joint provides the connection to the foundation. A lower tapered stress joint base configuration reduces the design complexity of the rigid spool by minimizing dynamic motions at the base of

the riser, which would have been challenging for this large diameter export line. A novel installation arrangement using a pull down system consisting of a wire routed through two foundations to the Deep Blue installation vessel was used to mitigate the heave motions of the installation vessel during land out of the riser on a preset grouted pile [5].

BP plans to install multiple SLORs offshore Angola in Block 31 NE in 6,890ft water depth. Currently installation is scheduled for Q3 2010. The SLORs will be tied back to a turret moored FPSO. The field will be made up of 9 SLORs, which represents the largest number of SLORs in a single field to date. All risers will be installed from Heerema's Balder using the J-lay tower for welding the riser string.

Petrobras plan to install 5 SLORs in the GoM in 8,531ft water depth. This will be the deepest water depth for a SLOR development. The SLORs will be tied back to an FPSO with a disconnectable turret, as shown in Figure 11. The advantage being that during a hurricane the turret can be disconnected from the vessel and lowered to a depth that is out of the high wave loading zone.



**Figure 11 – FSHRs Tied back to Turret Moored FPSO with Disconnectable Turret**

## THE FUTURE OF THE FSHR

The FSHR steel riser pipe is supported by an aircan versus the vessel and hence there are no significant limitations regarding water depth. Vessel payload is also not a concern. FSHRs offer an attractive alternative for payload limited vessels such as TLPs or Spars or for vessels without pre-installed flexible joint receptacles. FSHRs can be used for ultra deep water applications because the design is independent of the vessel.

The Grouped SLOR concept is a riser solution that is developed to optimize riser/vessel interface and seabed layout. It uses a buoyant frame to guide the FSHRs, which constrains all risers to move collectively and this effectively eliminates clashing concerns. As the riser spacing can be greatly reduced compared to a conventional SLOR, seabed arrangement is

optimized without losing the benefit of the SLOR concept [6]. A Grouped SLOR field layout is shown in Figure 12.

The Grouped SLOR, which has been referred to as an open bundle hybrid, consists of multiples lines in close proximity. Enough distance is maintained between the risers to facilitate installation, inspection and maintenance. The individual SLOR design is similar to a standard FSHR arrangement, with the riser pipe running through the center of the buoyancy tank. The main modification is the addition of a stem joint between the top of the buoyancy tank and the gooseneck connector. This is used to guide the riser through the frame as shown in Figure 13.

Various design considerations need to be taken into account when considering the Grouped SLOR design. The SLOR or COR used as part of the Grouped SLOR concept can be installed by either installation vessel or tow out from beach. One of the key parameters to account for during installation analysis is the variation in seabed bathymetry to ensure proper space out of the top elevation of the aircan within the guide frame.

The hydrodynamic stability and proximity of the aircans and risers to one another is critical to ensuring the stability of the Grouped SLOR system. A typical Grouped SLOR arrangement with four SLORs requires 5-6m diameter aircans with 2D spacing, resulting in a 1D airgap between them. This system would require a 50m long guide frame. CFD analysis and model test has confirmed the hydrodynamic response of the Grouped SLOR arrangement [6]. Where possible, field developments using the Grouped SLOR arrangement should consider similar size lines with similar size aircans in order to prevent torsional loads on the system from uneven current drag loading.

The option of using threaded and coupled connections for SLORs can provide an additional benefit of cost savings in terms of installation. Risers made up with threaded connections can be installed with a drilling vessel, which may have lower day rates and no mobilization cost if the Operator can divert the vessel from its normal drilling activity. When considering total system cost, the fast installation rates of threaded connections with potentially lower cost drilling vessels can yield a lower total installed cost than that of an equivalent welded system. However, the use of threaded connections is only viable from a cost perspective when drilling vessel rates are available and at a reasonable cost. In addition, a significant step change in Operator contracting strategy is required to enable installation contractors that have vessels with capability to install risers with threaded and coupled connections to bid on SLOR installation contracts [7]. Currently, only the flowline practice of using welded connections and associated pipeline installation vessels is considered for SLORs.

The primary concern with the use of threaded connections for dynamic applications is the introduction of leak paths. The use of threaded connections for dynamic riser applications has been qualified through TRF JIP [9] and has an extensive track record on Spar and TLP dry tree risers. An additional benefit of

using threaded connections with SLORs is weight reduction due to the possibility of using high strength steels. High strength steels limit the ability to weld due to the fact that hardening of the substrate material is problematic. The use of high strength steel with threaded connections can reduce wall thickness requirements by 30% resulting in a more efficient riser design. This will result in smaller aircan and further cost savings [7].

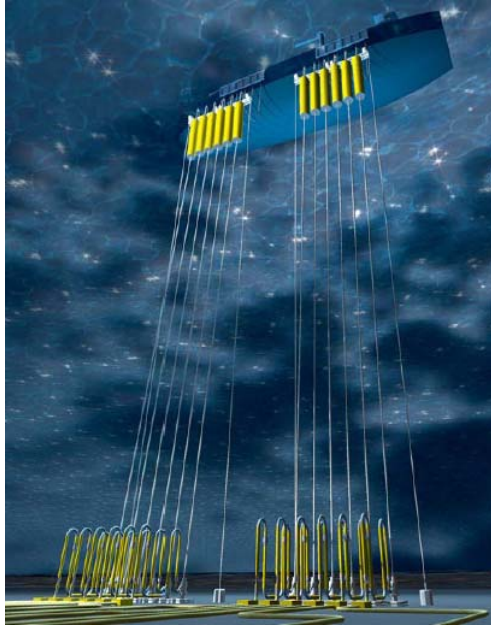


Figure 12 – Grouped SLOR

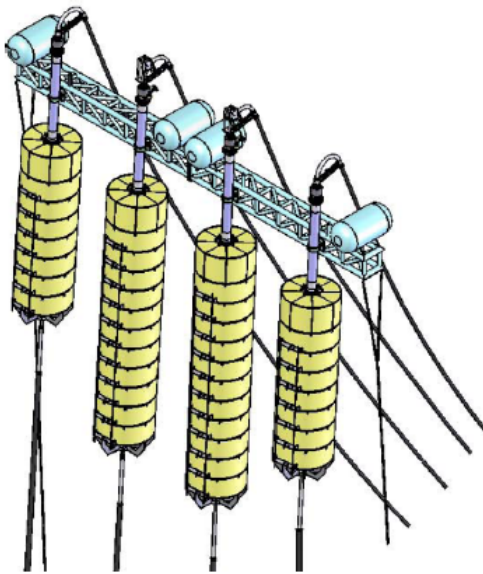


Figure 13 – Typical Grouped SLOR Arrangement

## CONCLUSIONS

As the industry moves into ultra deep water, operators will be looking for field proven solutions to optimize field developments. The FSHR has a long standing track record that has evolved over 20 years.

The application has proven to be an optimum choice for field developments in regions of the world with harsh weather conditions and for vessels with limited payload capacity. Whether in the form of a bundle or a single line freestanding riser, the FSHR has evolved to meet industry demands.

The key aspects of FSHRs and the enabling technology that will ensure the future of the free standing riser include:

- The FSHR decouples the riser from vessel motion therefore improving riser response and introducing more flexibility in the design;
- The FSHR simplifies vessel interface and reduces payload;
- The design drivers of a FSHR revolve around the cross section design, fabrication and installation method to be used;
- All bundle risers to date other than Placid have been beach fabricated and towed to site;
- All SLORs to date have been installed by deepwater installation vessel with J-lay towers to weld the riser string;
- The majority of the FSHRs installed to date use an articulated base arrangement with a suction pile accommodating dynamic rigid base jumpers although it is noted that the P-52 export SLOR has opted for rigid base jumpers;
- FSHR technology is rapidly maturing and establishing a credible track record using various component technologies and installation methods;
- Threaded installation provides potential for large cost savings for SLOR application;
- The Grouped SLOR concept provides an attractive field development alternative for optimizing riser/vessel interface and seabed layout.

## REFERENCES

- [1] J. McGrail, F. Lim, 2H Offshore Ltd. – “SLOR v SCR for Deepwater Applications Technical Appraisal”, ISOPE 2004.
- [2] E.A. Fisher, H.P. Hackett, Cameron Offshore Engineering Inc.. – “World’s First Rigid Free-Standing Production Riser”, Oceans 1988.
- [3] V. Alliot, J.L. Legras, Stolt Offshore S.S. “Lessons Learned from the Evolution and Development of Multiple Lines Hybrid Riser Towers for Deep Water Production Applications”, OTC 2005.
- [4] S. Hatton, F. Lim, 2H Offshore Ltd – “Third Generation Deepwater Hybrid Risers”, Worldwide Deepwater Technologies, June 1999.

- [5] Lacour, Luppi, Espinassi, Pattedoie, Song, Technip; Vinicius da Costa Mello, Adolfo Guilherme Velten Filho, Francisco Edward Roveri Petrobras “ Development and Installation of Roncador P52 18” FSHR in Campos Basin, 1800 m Water Depth”, MCE DWD 2008.
- [6] N. Dale, S. Hatton, 2H Offshore Ltd.; D. Karunakaran, SS7. “The Grouped SLOR – Design and Implementation” OMAE 2007.
- [7] D. Walters, R. Thethi, 2H Offshore Inc. “A Step Change – Application of Threaded and Coupled Connections”
- [8] Hatton, Lim, 2H Offshore Ltd. “Hybrid Riser Foundation Design and Optimization”, OTC 2005.
- [9] 2H Offshore Engineer Ltd, Woking, UK. “High Strength Steel Review – TRF JIP” June 2000.

Freestanding Riser	Type	Status	Owner/Field Operator	Yr Installed	Region	Water Depth		Vessel	Num of Towers	Installation Method
						(ft)	(m)			
Green Canyon 29	Bundle	De-commissioned	Placid Oil Company	1988	GoM	1,529	466	Semi-Submersible	1	Production Platform Drilling Rig
Garden Banks 388		De-commissioned	Ensearch	1994	GoM	2,096	639	Semi-Submersible	1	
Girassol		Operating	Total Elf	2001	Angola	4,430	1,350	Spread Moored FPSO	3	Surface Tow
Rosa		Operating	Total Elf	2007	Angola	4,430	1,350	Spread Moored FPSO	1	
BP Greater Plutonio		Operating	BP	2007	Angola	4,300	1,311	FPSO	1	
Kizomba A	Single Line	Operating	Exxon	2004	Angola	3,330 to 4,200	1,006 to 1,280	Spread Moored FPSO	NA	J-Lay Vessel
Kizomba B		Operating	Exxon	2005	Angola			Spread Moored FPSO		
Block 31 NE		Detailed Design/Execute	BP	-	Angola	6,890	2,100	Turret Moored FPSO		
P-52		Operating	Petrobras	2007	Campos Basin	5,906	1,800	Roncador FPU		
Cascade/Chinook		Detailed Design/Execute	Petrobras	-	GoM	8,531	2,600	Turret Moored FPSO with a disconnectable Submerged Turret Production Buoy		

**Table 1 – Summary of Freestanding Risers**