Recent Developments in the Freestanding Riser - The Grouped SLOR

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ABSTRACT

Increasing day rates of the riser installation vessels and their limited availability has a significant influence on riser concept selection for deepwater field developments offshore Southeast Asia. Risers are complex dynamic structures and the design of riser systems are primarily governed by loading from the environment and from the motions of the host platform. Typical deepwater field developments have a complex seabed well architecture with multiple risers and umbilicals installed along with the vessel mooring lines which impose spatial constraints. This paper presents the Grouped SLOR (Single Line Offset Riser) technology, which is an evolution of freestanding riser technology, that provides significant benefits to overcome many technical and operational challenges posed to upcoming deepwater field developments.

The Grouped SLOR is essentially a grouped bundle of freestanding risers attached to a buoyant frame and attached to the production platform via flexible jumpers. The Grouped SLOR design draws upon the advantages of the conventional hybrid bundle riser tower and SLORs. The flexible jumper decouples the platform motions from the risers thus the risers have excellent fatigue performance. The buoyant guide frame allows each riser to stroke independently but enables the risers to move collectively and therefore eliminates the risk of clashing. The design allows a number of risers to be installed in a compact spatial arrangement and thus results in improved flowline routing at the seabed and flexible jumper routing at the vessel interface.

The Grouped SLOR design offers significant reduction in vessel payload since the vessel is only required to support the weight of the flexible jumper. The ability to utilize a low cost vessel provides a significant benefit for deepwater developments in Southeast Asia.

This paper describes the Grouped SLOR configuration and highlights the technical and operational benefits of implementing the Grouped SLOR system.

INTRODUCTION AND BACKGROUND

Deepwater oil and gas field development pose significant challenges due to the field complexity and often stretching the limits on the existing riser technology. In addition, the existing riser solutions present high top tension loads for installation and operations and thus posing a limitation on the host platforms.

Large deepwater developments typically have a complex and congested seabed layout adjacent to the production vessel. This is due to the large number of risers and umbilicals often required to meet production and export requirements and the mooring lines, and thus imposing spatial constraints. This poses significant constraints on the riser design to achieve an acceptable riser arrangement whilst ensuring that clashing with neighboring structures is avoided.

The freestanding hybrid riser system, in both the bundle and single line arrangements, is a configuration that has been widely used in West Africa, as shown in Figure 1. The free standing riser is an attractive solution due to the reduced riser dynamic response from decoupling between vessel and riser, reduced vessel payloads compared to steel catenary risers or flexible riser solutions, and the ability for pre-installation, thus taking it off the critical path. 2H Offshore has had tremendous success with the standalone hybrid riser concept, the SLOR. Operators have successfully fabricated and installed the SLOR in deepwater developments offshore Africa and Brazil.

For larger deepwater developments the SLORs present a spatial constraint due to large deflections from the current loading and require larger clearance with the adjacent
structures such as risers, umbilicals and mooring lines. In order to optimize the seabed real-estate and riser/vessel interface, a Grouped SLOR system is developed, which is a group of 2 or more SLORs collectively guided through a buoyant frame, as shown in Figure 2.

**FIGURE 1 – TURRET MOORED FPSO WITH SLOR™**

**FIGURE 2 – GROUPED SLOR™ (6-RISER ARRANGEMENT)**

**RISER DESCRIPTION – SLOR**

The SLOR consists of a single vertical steel pipe connected to the foundation pile at the seabed and tensioned using a buoyancy can at the top. The top of the buoyancy can is typically located 50-100m below the mean water level. The SLOR is generally situated 100-500m away from the vessel depending upon water depth and the vessel excursions.

The foundation pile is either suction pile, driven or drilled and grouted pile. The bottom assembly of the SLOR is connected to the foundation pile using a high integrity connector and terminated with an offtake assembly. The offtake assembly is connected to a flowline via rigid jumper. The bottom assembly connection to the foundation pile is achieved by roto-latch (or any flex element) or using a tapered stress joint.

The riser pipes are usually casing grade steel pipes and will be constructed by welding the double-joint pipes and associated components. The riser is supported by nitrogen filled buoyancy can at the top. A central pipe (bore) runs through the center of the can and is divided into multiple compartments using internal bulkheads. The riser pipe is attached either to the top of the buoyancy can through a load shoulder or to the bottom of the buoyancy can using chains or flex element. In the case of rise pipe attached to the top of buoyancy can, a keel joint is used at the base of buoyancy can where the riser exits the bore, to relieve the bending moment transferred to the riser pipe due to offsets and dynamic motions.

Connection between the vessel and the riser is achieved using a flexible jumper via a steel gooseneck assembly connected to the top of the riser pipe. The flexible jumper is connected to the vessel through an I-tube assembly with adequate bend stiffeners to minimize fatigue damage. The gooseneck and flexible offtake can be located either above or below the air can depending on the installation strategies. The bends in the gooseneck, offtake spool and base jumper are usually configured with 3D or 5D radius bends to allow pigs and prevent any restrictions in the flow passage.

The pipe-in-pipe version of the SLOR configuration is COR (Concentric Offset Riser) is usually used for production risers. The outer annulus is used for gas lift purposes. The gooseneck is modified to allow access to the outer annulus so that the gas can enter the COR via a flexible jumper which is injected into the production flow at the base of the riser through a gas lift crossover forging.

Several SLOR and COR systems have been successfully
installed in West Africa with more upcoming deepwater developments implementing these riser solutions.

RISER DESCRIPTION - GROUPED SLOR

General Overview
The grouped SLOR is also referred to as an open bundle hybrid. The arrangement consists of 2 or more SLORs bundled together with optimum distance between the risers to avoid clashing during installation, operation, including removal and reinstallation if necessary. The buoyancy can arrangement in the tethered top frame is shown in Figure 3 and Figure 4. The grouped SLOR configuration is designed for both 4-SLOR and 6-SLOR arrangements.

![FIGURE 3 - GROUPED SLOR™ (4-RISER ARRANGEMENT)](image)

The grouped SLOR design has many familiarities with the generic SLOR design, with the exception of an elongated central bore of the aircan stem. The SLOR aircan with the stem attached is shown in Figure 5. The elongated stem/bore of the aircan between the aircan and gooseneck connector is to guide the riser to guide through the top frame. The riser pipe is attached to the top of elongated stem and effectively the aircan upthrust is applied on to the riser pipe at the connector location.

The aircans are typically 5-6m in diameter, with a 2D centerline spacing between the aircans when attached to the top frame. The length of the aircan depends on the water depth, the weight of the riser to be supported, and the required overpull. For typical developments in 1000-1500m water depth with the riser base tension of 150Te the aircan length will vary between 10-25m.

![FIGURE 4 - GROUPED SLOR™ TOP FRAME (6-RISER ARRANGEMENT)](image)

Guide Frame Arrangement

The top guide frame is a key component to which the individual SLOR tubulars are attached. The guide frame is a truss structure fabricated using steel tubulars. The light weight of the guide frame enables installation using a low cost installation vessel or barge.

The top frame is typically 45m long for a 4-SLOR arrangement, and if required, it is designed to be capable of handling in 2 sections with a flange connection in the center of the frame.

The guide frame is tethered to the seabed using spiral strand steel wire ropes connected to either end of the frame. The tether connection to the seabed is achieved through a suction pile foundation attached to the tether ropes using a steel chain. The steel chains also aid in achieving an uniform level of the top frame to account for any inaccuracies in the pile foundation mudline elevation. In order to avoid frame rotation, the tethers are splayed from the guide frame to the seabed.

The guide frame is fitted with additional buoyancy tanks that are welded to the top of the frame on either ends, as shown in Figure 6. The tanks can be sealed air tanks or syntactic foam filled, and are configured to provide 50Te base tension in the tethers at all times. Also, the buoyancy tank arrangement allows the guide frame to be towed during installation.

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The elongated stem above the buoyancy cans are held within the frame using a receptacle. The receptacles are bolted on to the frame and it consists of open/close mechanism with two arms, as shown in Figure 7. Upon riser installation, the receptacle gates are closed using ROV and locked in place using a pin through the central opening.

The riser stem strokes within the receptacle due to thermal, pressure, vessel static and dynamic offsets, and during different stages of installation. The inner surface of the receptacle is equipped with ultra-high molecular weight polyethylene (UHMWPE) bearing pad to resist wear between riser stem and the receptacle, over the duration of the field life.

The length of the elongated stem above the buoyancy can is designed to account for the entire range of riser stroke motions relative to the guide frame receptacles that are expected to see during the field life, so that the riser stem does not hit either the gooseneck connector at the top or the buoyancy can connectors at the bottom.

Global Finite Element Analysis

The Grouped SLOR provides the advantages of the individual SLOR or COR system by decoupling the vessel motion and riser response, and hence have excellent fatigue response.

The maximum displacement of the guide frame is a function of water depth and typically varies between 2% - 6% of the water depth for water depths varying between 800m and 2000m. The guide frame will be located 100 - 150m away from the vessel, and hence guide frame excursion is within allowable limits.
The guide frame rotation is less than 1.5 degree for ultra deepwater development of 2000m under normal operating condition for 4 SLOR arrangement.

The largest guide frame/riser stem interface loads is less than 10Te, which is well within the bearing capacity of the UHMWPE wear pads.

The Grouped SLOR response depends on the individual SLOR operating conditions within the group. Typically the risers with similar service conditions such as production/injection are installed opposite to one another to balance the frame response. For example, if a field has two 10in production risers, and a 10in gas injection and 10in water injection riser, it would be preferable to put the two production risers in the middle of the frame, and the two injection risers on the outside, or vice versa, such that the frame loads are relatively balanced.

**Computational Fluid Dynamics (CFD) Analysis**

The top of the buoyancy cans are located 50-100m below the mean sea level. Although the buoyancy cans are located away from the high current speed regions which usually occurs near the surface, the effect of current loading is considered due to the large diameters of the buoyancy cans. The fluid flow around the buoyancy cans determine the optimum spacing between the cans and hence the stability of the Grouped SLOR configuration.

The snapshots of CFD analysis to study the flow field around the buoyancy cans are shown in Figure 8. The drag coefficients obtained for both inline and cross-flow current loading on each of the buoyancy can for 4-buoyancy can arrangement is shown in Figure 9.

The CFD analysis results confirmed that the maximum drag coefficient experienced by the buoyancy cans is less than 2.0. Typically the buoyancy can lengths are about 5-6D and therefore the end effects reduce the drag experienced.

The buoyancy can centerline spacing of 2D provides the best response in terms of drag loading and VIV loading. Also, 2.0D centerline spacing allows a simplistic guide frame design. Considering the relatively low-cost of the guide frame, the buoyancy can spacing can easily be increased for development where high extreme currents are seen.

**Model Testing**

In order to further confirm the hydrodynamic response of the buoyancy can arrangement, scaled tow tests were conducted at MARIN’s test center in Holland. The test setup is shown in Figure 10.

The tow tests were conducted for a range of current velocities and for different buoyancy can centerline spacing ranging from 1.5D to 3.0D representing full scale spacing.

Tow test results confirm that the buoyancy can drag coefficients vary between 1-1.5, and are less than 2.0 assumed in the design analysis, for 2D centerline spacing. Finite element analysis suggests that the drag coefficients should be as high as 16.0 in order to generate clashing between the buoyancy cans. Therefore, the present arrangement with 2D centerline spacing provides stability under extreme current loading mitigating any chance of clashing.
 Foundations

The single suction pile required for the SLOR foundation, and the frame tether foundation can be installed from an anchor handling vessel. The foundations are positioned such that the SLORs splay out at the seabed, increasing the 5m or so spacing at the frame to approximately 25m spacing at the seabed. The increased spacing at the seabed allows for ease of installation of flowline PLETs and rigid jumper spools and avoids any congestion at the seabed real-estate. The analysis confirms that the Grouped SLOR response is not compromised if the suction pile needs to be repositioned due to any inaccuracies that may occur during foundation pile installation.

Frame Installation

The frame can be installed prior to SLOR installation. The frame can be towed out from an anchor handling vessel or lifted off the back of a barge.

Once the guide frame arrives at the target location, the tethers, lead chain, and a ballasting chain are subsequently attached on the guide frame from the installation vessel and/or tug boat. The frame is lowered to the target depth between 50 and 100m below mean sea level controlled using the length of the ballast chain released. An ROV is used to connect the tether with chain attachment to the suction pile. Since the guide frame buoyancy tanks are sealed, no further ROV intervention is required and the ballast chain can simply be released from the frame.

SLOR Installation

The SLOR can be installed using either J-lay, reel-lay or towed out.

For J-lay and reel-lay installation method, the bottom assembly is welded to the bottom riser pipe, and the remainder of riser pipes are welded in double joints and are either run-in, or reeled off a spool until the keel joint is reached. The keel joint is then welded to the riser pipe and then the wear stem connection is made.

The buoyancy can and wear stem are flanged together as the riser is subsequently threaded through the buoyancy can stem to integrate the two assemblies.

In order to connect the SLOR bottom assembly to the foundation pile, two methods can be employed. The first method involves free-flooding the buoyancy can and supporting the entire riser and flooded buoyancy can by

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the installation vessel crane. A pull-down assembly can then be used to latch the SLOR into the pile, subsequently filling the buoyancy cans with inhibited nitrogen using ROV.

In the case of vessel crane capacity is not high enough to carry the entire weight of riser and flooded buoyancy can, a number of compartments can be designed to withstand collapse loads that could incur at its operating depth. These compartments will be air filled and the additional buoyancy generated can assist during installation and inhibited nitrogen is pumped using ROV upon the installation is complete.

The SLOR should be separated from the frame by at least 10% of the water depth to avoid clashing during installation, as shown in Figure 11. Using a winch or chain along with a guide rope each SLOR is pulled in to receptacle in the guide frame. The ROV then closes each gate and inserts a pin to lock the receptacle gate.

Flexible Jumper Installation

The flexible jumpers are installed once each SLOR is installed in the frame. The pre-installable benefit of the Grouped SLOR system is apparent, as the riser can be installed prior to the arrival of the FPSO. The gooseneck with flexible jumper is connected lowered using a vessel and an ROV to activate the connector located at the top of the guide frame. The flexible jumper is then reeled out and passed to the FPSO where it is pulled in to the I-tube and terminated.

The complete grouped SLOR arrangement upon installation is shown in Figure 12.

CONCLUSIONS

The Grouped SLOR system provides a well developed and attractive riser solution for large deepwater field developments. The proposed system provides significant advantage in reducing seabed layout complexity, improved flowline routing and capacity for future tie-ins whilst incorporating all the merits of the freestanding riser.

The Grouped SLOR is the enabling solution for mid-water to deep-water field developments.
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