Innovative Hybrid Riser Concept for FPSO's

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1 INTRODUCTION

To meet the challenges of deepwater West of Africa, DORIS Engineering and Stolt Comex Seaway have developed a new concept of flowlines and risers. The technical work presented hereafter was carried out jointly with STOLT COMEX SEAWAY for installation aspects, and 2H OFFSHORE Engineering for riser dynamic analysis.

The concept illustrated on **Slide 1** was developed for a spread-moored FPSO in 1400m water depth offshore Angola and consists of:

- a hybrid riser tower combining steel and flexible pipes
- subsea flowlines installed by on-bottom tow in a pressure-balanced bundle

Main drivers in the concept selection are the water depth, stringent insulation requirements ($U \leq 1.0$ W/m^{2}K), and low cost. Notations are detailed at the end of this paper.

2 HYBRID RISER TOWER

2.1 Hybrid Riser Tower Selection

In the large water depth of 1400 m steel catenary risers were the initial contenders for seabed-to-surface connections. However, the insulation requirements associated with the development of shallow reservoirs (**Slide 2**) would necessitate several inches of coating on the riser pipes; current external coatings such as HDPU (high density polyurethanes) have a density around 800 kg/m3 giving a low submerged weight for the riser (20 to 30 kg/m) in operation. As a result, the riser is hydrodynamically unstable: it experiences large lateral excursions under current load, and axial compression in the lower section near the touch down point due to vessel heave and roll.

An alternative of pipe-in-pipe riser has been discarded because of its high material and installation cost. As for flexible pipes, they cannot meet the stringent insulation requirement (**Slide 3**).

The hybrid riser on the other hand requires syntactic buoyancy for floatation; this material has excellent thermal insulation properties and can thus serve two purposes; it is the ideal solution for a large number of insulated risers in extreme water depth.

2.2 Hybrid Riser Tower Description

A hybrid riser tower was first installed by Placid on the Green Canyon Block 29 project (GOM) and later recovered and deployed by Enserch on the Garden Banks Block 388 development (Reference 1). Recent published work on the hybrid riser (Reference 2) has shown that the concept can be applied to much deeper water with a semi-sub or FPSO-based development.

Slide 4 illustrates the principle of the hybrid riser tower which consists of:

- a seabed hinge allowing 3D rotation of the tower subjected to wave and current loading
- a current section of risers in a bundle around a central structural pipe surrounded by syntactic buoyancy
- a buoyancy tank at the riser top providing an uprighting moment (inverted pendulum) for the riser tower
- an array of flexible pipes linking the tower top to the FPSO with individual lines

Main developments carried out for the hybrid riser West Africa include:

- the use of syntactic buoyancy as an insulation material giving U-values of 0.6 to 0.8 W/m^2K for the production lines (**Slide 5**)

- insertion of water or gas injection lines, gas lift lines, service lines with the production lines in the bundle providing a unique configuration for all risers in the field
- detailed design of the buoyancy tank with a taper joint connection to the structural central pipe (**Slide 6**)
- connection of the flexible jumpers to the top of the tank to allow easy installation and retrieval of the jumpers.

The production lines are suspended at the top of the tank and allowed to expand freely at the bottom of the riser; a spool piece connection to the flowline bundle (**Slide 7**) provides flexibility for vertical expansion and tower rotation.

2.3 Hydrodynamic behavior

Hydrodynamic behavior of the hybrid riser was analyzed in two stages:

a) by analytical methods using FLEXCOM3D for dynamic analysis
b) by model tests in a deep basin in Southern France to confirm analytical results

A total of 42 loadcases were analyzed to combine extreme wave, current and vessel excursions (**Slide 8**). Results show for West Africa conditions that while the hybrid riser has a compliant quasi-static behavior (i.e. follows the vessel excursions), it has very little dynamic response to wave loading and vessel motion (**Slide 9**). Hence, fatigue is not dimensioning; indeed, because the riser bundle is designed for installation conditions (**Slide 10**), it has low stress levels during operation.

In the test basin, all dimensioning loadcases were modeled and matched closely with the dynamic analysis. However, some phenomenons were observed that were not identified by computer analysis such as the jumper behavior under transverse loading with shielding effects from the FPSO hull.

VIV analysis was carried out using SHEAR 7 software to determine fatigue damage and requirements for suppression strakes.

Results show that VIV fatigue life is significantly higher than the field life and that VIV suppression is not required (**Slide 11**).

Modal analysis shows that the maximum natural period is around 60 sec, much less than the vessel second order motion ; 2nd, 3rd, and 4th order periods are about 29, 20 and 15 seconds respectively. Energy input from wave loading is therefore small.

Fatigue analysis of the hybrid riser for first order wave motion and second order drift motions was carried out assuming F2-class welds with SCF of 1.3 for critical welds. First order fatigue analysis shows very little damage for the risers ; **Slide 12** illustrates the upper riser section between the buoyancy unit and the bundle section. The minimum unfactored fatigue life in the area of damage concentration is 475 years. Second order vessel motion does not induce fatigue damage.

A clearance analysis has been carried out for the flexible jumpers ; it shows that various lengths are required for the jumpers to avoid interference. They are laid out in two horizontal planes with 2.5 m horizontal spacing at the connection point near the vessel keel.

Slugging loads in the flexible jumpers were analysed with software RIFLEX ; it shows vertical displacements of the riser during slug passage but within acceptable range of flexible jumpers bending radius.

2.4 Buoyancy Tank Design

The buoyancy tank is designed to take-up the weight of the inventory in the production or injection risers, and provide an uprighting moment for vertical stability of the riser. The tank is 40 m long, for a displacement of 1200 m^3 and includes 19 water tight compartments. It is filled by inert gas during operation. The maximum overpressure on the tank wall is about 3.5 bars.

The tank weighs 350 tonnes in air and can be fabricated in a shipyard. It is connected to the riser bundle section by a taper joint. The taper joint is 12 m long, in X-65 carbon steel.

2.5 Hybrid Riser Installation

The hybrid riser tower is pre-fabricated on-land and transferred in a floodable ditch for launching; it is installed by surface tow to site with two tugs, under a maximum significant wave height of Hs = 1.5m parallel with the string. This condition is giving the highest stress levels in the tower/bundle connection.

Once on site, the tower is submerged below the sea-surface and upended in a controlled-manner; it is then pulled over its anchor base and latched in place as for a TLP tendon. The base is a suction-driven friction pile of about ø6m with 20m embedment.

Detailed installation sequence will be illustrated by an animation presented during the conference.

3 FLOWLINE BUNDLE

3.1 Flowline Bundle Selection

Slide 13 shows various concepts of insulated flowlines; external coatings cannot provide the require U-value in 1400m water depth; pipe-in-pipe systems are a viable alternative for insulation but expensive to procure and install.

Insulated flowline bundles have been installed in the Gulf of Mexico such as on the Troïka field (Reference 3). These bundles are pressurized with an inert gas to reduce the wall thickness of the carrier pipe; the internal pressure is usually close to the maximum hydrostatic pressure experience in the field. As a result, the carrier pipe must be designed for internal pressure on the beach prior to tow. At approximately 1000m water depth, this conventional method is no longer cost-effective as the carrier pipe becomes too heavy to tow.

Furthermore, experience has shown that compressed gas deteriorates dramatically the insulation performance of such bundles. It is then important to maintain the annulus in pressure equilibrium with the outside.

3.2 Flowline Bundle Description

A new concept of pressure-balanced bundle has been developed (**Slide 14**) consisting of several flowlines encased in syntactic buoyancy shells providing buoyancy and insulation; this assembly is inserted in a thin jacket pipe (typically 6.4mm thick) and the annulus is filled with inhibited water. There is a permanent pressure equilibrium between the annulus and the outside so that the jacket pipe does not experience hydrostatic pressure. It serves only as an envelope for installation by on-bottom tow.

The bundle diameter is determined to meet installation conditions driven by submerged weight criteria (**Slide 15**); typically for two 8-inch flowlines a 30-inch carrier pipe is required. Flowlines are laid in pair to provide a pigging loop to each subsea manifold.

This arrangement has excellent thermal performance with U-values of 1.0 W/m^2K or less; furthermore, if one of the line is shut-down, hydrates cannot form as the adjacent line in production maintains a high temperature by proximity (**Slide 16**).

The syntactic buoyancy is the same as that used for the hybrid riser bundle and is similar to that used on drilling risers or mid-water buoyancy units for flexible risers (see properties **Slide 17**).

An advantage of the syntactic buoyancy is the excellent heat retention characteristics which provides long duration before cool down below the hydrate formation temperature of 20°C; **Slide 18** shows durations in excess of 48 hours which cannot be achieved by pipe-in-pipe systems or external coatings.

A service line for MeOH distribution at the manifold is included in the flowline bundle; an additional service line is also provided to allow hot water heating of the production lines in the event of hydrate formation. With 90°C injection temperature on the FPSO, a flowline section at 4°C located 7.8 km away can be warmed up to 20°C (above the hydrate formation temperature) in less than 4 hours.

4 ADVANTAGES OF THE CONCEPT

The hybrid riser concept provides a number of advantages over catenary risers (steel or flexible) that are:

1. Low vertical tension on the FPSO

For 13 risers between 8-inch and 14-inch, the total vertical load is estimated at about 150 tonnes compared to about 2000 tonnes for catenary risers (estimate); this eliminates ballast requirements on the FPSO and simplifies the supporting structure.

2. Low horizontal tension on the FPSO

For the same reason, the horizontal load on the FPSO is negligible while with catenary risers it requires additional mooring lines unless risers are evenly distributed on both sides of the vessel and installed at the same time on either side.

3. Early production date

With the hybrid riser concept, all flowlines, risers and subsea connections can be carried out before the vessel arrives on site, thus allowing immediate production start of all pre-drilled wells. This advantage is significantly compared to conventional pipes with catenary risers which require at least 30 to 45 days of installation. This schedule advantage is of paramount importance for large production, long life fields.

4. Excellent insulation properties

If insulation is required, the hybrid riser concept provides overall heat transfer coefficients of about 0.5 to 1.0 W/m^2K and long durations before coll down to ambient temperature.

5. Easy installation of piggy-back lines

If gas-lift at the riser foot is required, or service lines must be laid, these "piggy-back" lines can be included in the hybrid riser tower at no fabrication/installation cost; this is unlike catenary risers for which a piggy-back configuration is difficult to design, analyze, and install in a congested array of multiple risers.

6. Excellent dynamic behaviour

Because the hybrid riser is designed for installation conditions, it has very low stress levels in operation; there is no fatigue concern for the steel lines unlike for SCR's.

7. No Field Congestion

The concept can accommodate injection lines, eliminating any congestion in the water column, in the direct vicinity of the vessel

8. No mobilization of large pipelay vessel

All flowlines and risers can be installed with local tugs (Gulf of Guinea) and one construction vessel for subsea works such as umbilical lay and diverless connections. There is no need to mobilize a J-lay spread or large construction lay vessel as for the catenary option.

9. Less severe slugging

Due to the presence of the flexible jumpers, severe slugging in the hybrid riser results in smaller slug sizes than with catenary risers thus reducing topside requirements.

10. Possible reversibility

The presence of a hot-water line in the hybrid riser allows reversibility in case of hydrate formation; this is not feasible with catenary risers of pipe-in-pipe systems

REFERENCES

Ref. 1 : Offshore Engineer : "Renewed Riser at Heart of GB 388"; by Adrian Cottrill, p38-40, August 1994.

Ref. 2 : OTC 8523 : "Low Cost Deepwater Hybrid Riser System"; by S.A. Hatton, 2H Offshore Engineering, Ltd., Houston, 1997.

Ref. 3 : OTC 8848 : "Troïka - Towed Bundle Flowlines"; by M. M. Beckmann et al., Manatee Inc., Houston, 1998.

NOTATIONS

U : overall heat transfer coefficient measured with respect to the internal diameter of the production flowline