

RESTRAINED HYBRID BUOYANT RISER TOWER FOR DEEPWATER DEVELOPMENTS

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1 INTRODUCTION

Hybrid Risers are considered as a suitable option for Deepwater fields developed using FPSO and subsea well heads because they have low sensitivity to the environmental and operational constraints: they can bear significant currents, sea states and FPSO motions over large water depths (1,000m and over). Furthermore, the surrounding syntactic foam provides high thermal insulation to the production flowlines over the water column.

However, the piping connections located at the top part of the risers are usually underwater, inducing high design, operational and maintenance constraints for the fluid link to the FPSO, an area where the velocity of the production fluid is large and may induce erosion.

Moreover, the nominal distance between the FPSO and the Hybrid Riser should be carefully selected to avoid any interference considering the FPSO and the Tower maximum relative displacement. Current loading on umbilicals and free hanging flexible jumpers of different weight over diameter ratios must also be considered for possible interference.

The concept of a Restrained Hybrid Buoyant Riser developed by ETPM and 2H [Ref. 1] under a contract for the WADO¹ group takes advantage of the recent Hybrid Riser design developments [Ref. 2] but eliminates underwater lines and connectors by linking directly the tower top to the FPSO by means of an articulated yoke structure in air (see figure 1). As a main advantage, this configuration allows to locate all the piping connections above the water level, thus offering potential for reducing maintenance cost. The yoke comprises a buoyancy tank which provides tension to the top of the riser tower and is linked to the FPSO side by a hinge.

The basic concept described here is designed for 2,500m of water depth for environmental conditions typical of those of the Gulf of Guinea. A 1,000m water depth has been also analysed and some basic results for this case will be listed when relevant.

The Restrained Hybrid Buoyant Riser main features are described in the followings.

2 Concept Description

2.1 Riser Column

The column is a bundle of flowlines placed around a central structural pipe (carrier pipe) extending from a riser base on the sea bottom, up to above water. It is surrounded by syntactic foam which provides the necessary buoyancy and the required thermal insulation.

¹ WADO (West Africa Deep Water Operators) includes BP Amoco, Statoil, Elf, Exxon and Shell.

2.2 Tower / FPSO Connection

The tower top is forced to follow the FPSO in horizontal directions by means of a yoke structure located on the FPSO side, so that the fluid link between flowlines and FPSO piping is entirely located above water and easily accessible (figure 2).

Yoke Description

The yoke is a triangular-shaped frame structure in the horizontal plane (see figure 3). The distance between the Riser and the FPSO has been set at 50m. The buoyancy tank is located 28.5m below the top plane of the yoke, at mid distance between the FPSO and the riser. It is cylindrically designed with a total buoyancy of about 3,000 kN to provide tension to the top of the riser tower.

Mechanical Connections at either ends of the Yoke

The yoke is connected to the FPSO side at two points by horizontal hinges which allow rotational motion parallel to the FPSO longitudinal axis. The structural connection between the tower top and the yoke is an universal joint with either metal to metal bearing surfaces or elastomeric pads. It allows access to the central core pipe of the tower for inspection (figure 4).

Link between Flowlines and FPSO Piping

The concept allows the ESDVs to be located directly at the top of riser flowlines. The tower can then be isolated from the piping on the FPSO and the yoke, in case of emergency.

For the fluid connection between the tower and the FPSO, two types of systems have been considered.

In the first option, flexible jumpers handle the fluids between the tower head and the FPSO (see figure 5).

The second option includes rigid piping and either elastomeric flexjoints (see figure 6) or a series of swivels between the riser top and the yoke. The yoke and the FPSO are linked through swivels aligned along the yoke / FPSO rotational axis

The fluid link with flexible jumpers is field proven and thus advisable when there is no problem with fluid composition (corrosion).

Hard piping can be made of Carbon steel or Corrosion Resistant Alloy as dictated by the well fluid.

The design of the fluid link between tower top and FPSO depends on the maximum angle variation between the yoke and the tower (refer to section 3.4).

The maximum relative angle range is discussed in section 4.4 of this paper together with proposals for reducing the yoke/top tower of tower maximum relative angle.

2.3 Bundle Arrangement

The study has been carried out considering the following data (see figure7):

- one 6.625” x 0.43” gas injection line,
- two 10.75” x 0.81” water injection lines,
- four 10.75” x 0.72” production lines,
- four 6” OD umbilicals
- one 20” x 0.625” to 1.125” carrier pipe.

Syntactic Foam

The quantity of syntactic foam is determined by thermal insulation requirements i.e. a U value below $1 \text{ W} / \text{m}^2 / ^\circ\text{C}$ and the weight of the lines filled with their production fluid and the carrier pipe during the production life. Since the characteristics of the foam must be selected to suit the external pressure, the foam volume and the riser tower diameter vary accordingly. The following table summarises the column external diameter that have been selected to meet the design criteria.

Water depth (m)	Density (t/m ³)	Thermal conduction (end of life) (W / m ² / ° K)	Column diameter (m)
0 to 500	0.42	0.08	1.7
500 to 1000	0.46	0.11	1.8
1000 to 1500	0.55	0.15	1.9
1500 to 2000	0.60	0.18	2.0
2000 to 2500	0.65	0.21	2.1

Table 1: Insulation Efficiency over Water Depth

Thermal loss calculations have shown that the insulation thickness is adequate, even for the case of only one line producing assuming that seawater convection is prevented by a combination of device such as seals in vertical and horizontal gaps between foam blocks. The total buoyancy load due to the syntactic foam is about 24 MN for the 2,500 W.D. case and 9 MN for 1,000m. It is transmitted by means of shear keys welded on the carrier pipe.

Flowline Supporting System

The tension applied by the yoke at the tower top is not sufficient to withstand the whole weight of flowlines and umbilicals, which amount to 17 MN for the 2,500 W.D. case and to 7MN for 1,000m. Lines cannot be supported at the tower top only, as in the “conventional” hybrid riser tower of reference 2 (this would induce unacceptable compression in the carrier pipe). They have therefore to be attached to the latter at regular interval. In order to cope with the differential axial expansion between flowlines and the carrier pipe, flowlines have to include flexible joints which may be elastomeric joints (see figure 8) or “Chinese lanterns”.

2.4 Bottom Tower

On the seabed, the tower is linked to the foundation base through a flexjoint coupled with a connector as found in TLP tethers. For a 2,500 m water case design case, the tension on anchor is about 6,200 kN.

3 Static and Dynamic Behaviour of the Tower

In-place analyses have been conducted with MCS FLEXCOM-3D software to investigate extreme loadings and motions, and Fatigue due to waves. VIV was assessed using the MIT programme SHEAR7. Main results are listed below.

3.1 Extreme storm analysis

From this analysis, it is concluded that acceptable stresses are found in the riser for any loading case. The thickness of the carrier pipe has to be increased at the tower top.

3.2 Fatigue Damage due to VIV

The minimum VIV fatigue lives occur in the upper section of the tower where the effective tension is the lowest. It is concluded that, with the considered current profiles and their probability of occurrence, VIV suppression strakes are required over the top third of the tower.

3.3 Fatigue Damage due to Waves and First Order FPSO Motion

The lowest fatigue life is found at the tower top. A greater wall thickness and high quality welds are needed over the 100m top section of carrier pipe.

3.4 Yoke/Tower Relative Angle

As mentioned in section 2.2, the design of the fluid link between the riser tower and the FPSO depends primarily on the maximum angle between the tower and the yoke. Static and dynamic analyses have been conducted to investigate parameters that affect this relative angle. The yoke angle and the tower top angle are discussed successively below.

- The nominal draft of the FPSO has been set to 15.50m, maximum draft and minimum draft to 24.50m and to 10.50m respectively (total draft variation 14m). The maximum vertical motion of the yoke on FPSO side is in the order of ± 4 m. This results in an absolute angle variation of the yoke of $\pm 15^\circ$. The yoke angle is also slightly affected by the set down of the top of tower due to lateral loading acting on the column.

- The tower top angle is primarily due to the current load. It is directly linked to the top tension. The tank being located significantly far below the yoke, its position relative to

the FPSO and the column depends on the yoke angle. Consequently the tension acting on the tower top greatly varies with the yoke angle and thus also the tower top angle. The maximum static and dynamic angle is found for the minimum FPSO draft configuration, where the tank is the furthest from the tower. The corresponding configuration is shown on figure 9, for the case of near current, which pushes the tower away from the FPSO. Analyses of several buoyancy tank and yoke length show that a 50m long yoke and a 300 t buoyancy tank are necessary to keep a safe distance between the tank and the FPSO or the tower. Waves do not have a significant effect on tower top heave.

The following table summarises the yoke and top of tower angles for the 2,500m water depth case. The angle sign convention is shown on figure 10.

Case	FPSO Draft (m)	Column Base Tension (T)	Column Top Tension (T)	Tower Top Angle (°)	Yoke Angle (°)
Static	15.5	617	140	0	0
Near Current	15.5	622	136	-13	5
Near Current	24.50	651	168	-11	-7
Near Current	10.50	603	115	-16	12.2
Dynamic Near Current +Near Wave	15.5		90 / 180	-10/-22	+10/0

Note: The angle of the top tower refer to the vertical axis, the yoke angle to the horizontal axis.
Dynamic case angles are given as absolute variation

Table 3: Relative Tower / Yoke Motion Summary

Several options have been considered to reduce further the maximum angle between the top of the tower and the yoke.

One of the most promising solution, inspired from the above results and the discussion about the tank efficiency, is to place the buoyancy tank not between the FPSO and the Hybrid Riser but on the other side of the tower. This configuration is illustrated on figure 11.

For the same buoyancy tank, the results are given in the table below. The tower top is located here 40m from the FPSO and the tank axis 20m further.

Case	FPSO Draft (m)	Column Base Tension (T)	Column Top Tension (T)	Tower Top Angle (°)	Yoke Angle (°)
Static	15.5	847	360	0	0
Near Current	15.5	857	368	-5.4	1
Near Current	24.50	869	381	-5.2	-11
Near Current	10.50	849	360	-5.5	8
Dynamic Near Current +Near Wave	15.5		310 / 430	-3./-10.5	+7.5/-4.6

Note: The angle of the top tower refer to the vertical axis, the yoke angle to the horizontal axis.
Dynamic case angles are given as absolute variation

Table 4: Relative Tower / Yoke Motion Summary for Yoke opposite to the FPSO Configuration

Maximum Tower / Yoke Angle Range

The maximum angle ranges are given below for the two yokes configurations described above.

Tank Location	Case: 2500m Water Depth
Tank between FPSO and Tower	74°
Tower between Tank and FPSO	58°

Table 5: Maximum Relative Tower / Yoke Angle Range

Calculations performed for the 1,000 W.D. give similar angles. It is noticeable that the 14m draft variation accounts for about 25° in the angle range. An FPSO designed and operated to minimise the draft variation would greatly reduce the constraints for the design of the fluid connection between the tower and the FPSO.

4 Installation of the Restrained Hybrid Buoyant Riser

The installation can be carried out as for classic Hybrid Buoyant Towers currently designed. The main installation steps are listed below.

- Fabrication of the tower in a yard close of the field (welding of the core pipe and the flowlines, foam blocks assembly)
- Transportation to the field using surface or near surface towing (the carrier pipe and some lines are water flooded to reach the necessary submerged weight for near surface towing)
- Upending operation
- Connection of the tower to the sea base which is pre-installed
- Deballasting of the 20” carrier pipe using compressed air

However, some features are specific to the concept.

- The yoke can be installed vertically on board the FPSO at the ship yard and deployed on site. Alternatively, it could be installed by a crane when the FPSO is on site
- The upending operation is more complex since the riser tower is longer (2,515.5m) than the water depth (2,500m) thus involving specific operations. The tower top needs to be lifted above the surface with derrick barge at the end of the upending operation and when the bottom tower is connected to the base.
- To connect the tower top to the yoke, the FPSO is set at her lower draft enabling the support arm of the yoke to be as low as possible.
- When connected to the yoke, the riser top should be lowered carefully to prevent any damage on the piping

5 Conclusion

The various studies carried out by ETPM and 2H showed that the proposed Restrained Hybrid Buoyant Riser is a feasible technical solution for the development of deepwater fields for a West Africa production scenario.

Some technical issues will require particular attention at basic design stage (e.g. support of flowlines, relative expansion between the flowlines and the 20” core pipe, fluid connection and piping, maximum rotation angles between the yoke and the tower).

The main advantage of the concept described in the is that it takes advantage of the progress made in buoyant riser that are currently designed and of that dry connections between the tower top and the FPSO are located above the water surface.

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ETPM and 2H further acknowledge that the opinion contained herein does not necessarily reflect the position of each WADO member.

REFERENCES

Ref. 1: WADO : “Restrained Hybrid Buoyant Riser” and “Restrained Hybrid Buoyant Riser – Additional Work”, by ETPM SA and 2H Offshore Ltd for WADO Task Force, Rev. 03, 1999.

Ref. 2: D.O.T 1998: “A Cost Effective Concept for Deepwater Insulated Flowlines and Risers”, by F.Thiébaud, V. Alliot and S. Hatton, New Orleans, 1998.