



OTC 8523

## Low Cost Deepwater Hybrid Riser System

S.A. Hatton 2H Offshore Engineering Ltd.

Copyright 1997, Offshore Technology Conference

This paper was prepared for presentation at the 1997 Offshore Technology Conference held in Houston, Texas, 5-8 May 1997.

This paper was selected for presentation by the OTC Program Committee following review of information contained in an abstract submitted by the author(s). Contents of the paper, as presented, have not been reviewed by the Offshore Technology Conference and are subject to correction by the author(s). The material, as presented, does not necessarily reflect any position of the Offshore Technology Conference or its officers. Electronic reproduction, distribution, or storage of any part of this paper for commercial purposes without the written consent of the Offshore Technology Conference is prohibited. Permission to reproduce in print is restricted to an abstract of not more than 300 words; illustrations may not be copied. The abstract must contain conspicuous acknowledgment of where and by whom the paper was presented.

### Abstract

The design and analysis of a cost effective multi flowpath production riser for deep and ultra deep water floating production systems is presented. The design is based on a bundled concept using beach fabrication and installation by near surface tow. The study has been funded by the DeepStar project and addresses water depths between 1300 and 2200m in the Gulf of Mexico. The riser is designed to interface with a semi submersible production vessel but may also be used with an FPSO with minor modifications.

The design approach minimises the riser steel weight and buoyancy requirements and achieves an optimum dynamic response through an efficient structural design and buoyancy distribution. This maximises riser flexibility and minimises hydrodynamic wave loading.

### Introduction

The definition of 'Deep water' changes every year. Operators are currently developing reservoirs in water depths up to 1500m and have drilling campaigns planned for depths beyond 2000m. Production technology for such water depths is likely to center on semi submersible and ship shaped floating production systems which are well established in shallower water depths.

The riser systems, used to transport production fluids between the seabed and vessel, will become an increasingly important aspect in deep water developments. Risers are dynamic systems which operate at high pressures and temperatures often with corrosive fluids. Consequently, risers are technically complex and the materials and methods of manufacture and installation make them costly. These issues are compounded as water depths increase due to higher loads and lengths involved making riser system selection and optimization even more complex.

Deep water developments to date have largely extended shallow water, flexible riser, technology through the development and application of new materials and manufacturing techniques. However, extending a successful shallow water solution to deep water is not necessarily the most economic or technically preferable approach. Whilst in shallow water high pipe flexibility is required to accommodate vessel motions, in deep water stiffer pipe may be considered due to the beneficial effect of water depth on riser system compliancy.

In recent years new riser arrangements have been conceived to meet the challenge of deep water, offering significant commercial and technical advantages over conventional riser systems. These new riser systems utilize steel pipe which has a relatively low cost compared to flexible pipe. The importance of these new riser systems is significant. Commercially, they provide an alternative to the flexible riser but more importantly, in many cases, they provide a technical solution where no feasible solution exists with flexible pipe.

The two most promising riser concepts are the hybrid riser [1,4] and the steel catenary [2, 5]. Both concepts can be configured in a number of ways depending on application and even combined as in the case of the Tension Leg Catenary (TLC).

Whilst new riser configurations provide the industry with design solutions the selection of the most appropriate configuration for a particular application is complex, being dependent on many inter-related issues. The following sections discuss the design and development issues associated with a hybrid riser system and highlight the important design issues which should be considered during the riser selection process.

## Hybrid Riser Background

The hybrid riser is the first practical alternative to the full depth flexible riser to be implemented. In principle, it is a vertical bundle of steel pipes supported by external buoyancy. Complicity is provided by the use of short flexible pipe jumpers located near the surface to accommodate motions between the vessel and top of the riser.

The first hybrid riser was installed on Placid's Green Canyon development (469m). The riser was recently refurbished and extended in length for use on Ensearch's Garden Banks development (670m) [4, 7], see Figure 1. The main section of the hybrid riser consists of a central structural tubular, around which syntactic foam buoyancy modules are attached. Peripheral production and export lines run through the buoyancy modules and are free to move axially to accommodate thermal and pressure induced extension. The central structural member is connected to the riser base by a hydraulic connector and stress joint. Peripheral lines are connected to hard piping on the riser base interfacing with subsea flowlines via diverless pull-in porches. Near the surface flexible piping is connected between the upper goosenecks on the riser and porches on the pontoons of the semi submersible.

The hybrid riser implemented by Ensearch is installed in a similar manner to a drilling riser ie. individual joints are assembled from the semi submersible to form a vertical string. This process is complex due to the size and weight of the riser joints and costly due to modifications required to the installation vessel and long installation durations. The latter limits the practicality of the concept for harsh environments and deeper water where weather windows are shorter.

## Optimized Hybrid

An alternative installation method proposed in [1] uses a near surface tow of a prefabricated riser bundle which is upended at the offshore site. Studies show this approach to be technically feasible and reduces the cost of installation due to the shorter installation duration and low cost installation spread. Furthermore, the approach allows the steel weight and buoyancy requirements to be reduced which enhances the riser response and reduces the capital cost. These beneficial features offer improved scope for using the hybrid concept in deep water and a wide range of environments.

The DeepStar hybrid riser is a development of this concept aimed at deep and ultra deep water (1300-2200m) in the Gulf of Mexico. The base case is for 1300m depth and sensitivities are conducted for 2200m. The riser is configured directly below a semi submersible production vessel (non offset). This allows the riser to be tethered to the vessel, reducing riser buoyancy requirements, base moments and length of the flexible jumpers. The latter is important not only from the cost aspect but also the effect of the weight and drag of the jumpers on the riser

response.

Unlike flowline bundles which are designed with a series of small diameter flowlines within a larger carrier pipe, the riser is designed with the smaller diameter lines arranged around the outside diameter of a central structural member. This arrangement offers the best compromise between design simplicity, structural stiffness, buoyancy, and method of fabrication.

The riser is configured to be near neutrally buoyant during installation. Syntactic foam buoyancy is used along the length of the riser to supplement that provided by the central structural member. A typical cross section of the riser, Figure 2, shows the arrangement of the central can, buoyancy and peripheral lines. The buoyancy diameter ranges from 2116mm at the base to 1844mm at the top. The change in buoyancy diameter accounts for variation of buoyancy density and steel weight with depth.

The central structural member for the Deepstar application is 30 inches in diameter. The riser has 13 peripheral lines, summarized in Table 1. The average riser weight in air is 2880kg/m (steel and buoyancy) and the total steel weight, for the 1300m riser is 2200Te.

Key design issues include:

- Configuration of structural member
- Material selection
- Buoyancy type and distribution along length
- Accommodation of peripheral line thermal expansion
- Method of peripheral line support
- Inspection philosophy
- Riser and peripheral line VIV suppression
- Thermal insulation
- Vessel interface requirements (semi or FPSO)
- Quick disconnect requirement (QDC)
- Ease of fabrication and assembly
- Installation procedures
- System risk and reliability
- Failure modes
- Capital and installation costs
- Redundancy and expandability

These issues are discussed in the following sections with reference to Figures 3 and 4:

## Structural Design

The diameter of the central structural member is relatively small compared to the buoyancy diameter. This produces a relatively flexible structure compared to configurations where the peripheral lines are located inside a larger diameter structural member. The small diameter member is also more resistant to hydrostatic collapse which is important near the base of the riser.

The wall thickness of the central member increases with depth to resist the increasing hydrostatic pressure. This also produces a riser which has a minimum bending stiffness near the top, unlike previous designs, which promote an even curvature along its length when loaded. This reduces the peak stresses and loads that typically occur at the riser base.

In ultra deep water hydrostatic collapse of the central member is increasingly difficult to prevent without specifying impractically large wall thicknesses. Three solutions to this problem are identified:

- Further reductions in the diameter
- Venting the central member and air filling with a cascade system at ambient pressure
- Using a composite structure

Reducing the diameter provides benefits but the reduced bending stiffness causes handling problems during launch. Venting the central member and cascade air filling prevents the problem of collapse but introduces the complexity of an air can system and prevents internal inspection. The use of a composite structure is preferred and is currently under evaluation. The arrangement consists of a steel and concrete sandwich. The concrete resists hydrostatic collapse whilst the steel sections accommodate the axial loads. As tension in the riser is relatively small, the wall thickness of the steel sections can be small. This arrangement is particularly suited to ultra deep water as the diameter of the central member can be maintained, or even increased, near the base of the riser. This maintains the correct stiffness distribution along the riser for optimum response and minimizes the volume of syntactic foam buoyancy required at maximum depth.

### Buoyancy Type and Distribution

Buoyancy is provided by two components, the central member which is air filled and by syntactic foam which is evenly distributed along the riser length. This arrangement is different to existing designs which use large diameter air cans along the upper section and smaller volumes of syntactic foam along the lower sections where the cost of foam is highest. Some proposed designs eliminate the syntactic foam completely along the lower sections in an attempt to reduce the system cost. However, distributing the buoyancy evenly along the length has a number of important benefits :

- produces a smaller diameter in the wave zone and area of highest current thus reducing loading
- tension along the upper section can be maintained at a relatively low level which maximises compliancy and allows the riser to move sympathetically with the production vessel

- the buoyancy can be used to support and protect the peripheral pipes preventing vortex induced vibration (VIV)
- it reduces thermal losses
- simplifies riser installation by tow out

The distributed buoyancy configuration results in an even tension along the entire riser length. Analysis shows that this is efficient, requiring less total buoyancy than an arrangement using near surface air cans due to the higher hydrodynamic loading in the case of the latter.

The higher tension in the air can arrangement and intrinsically stiffer upper section results in higher base loads as deflections are concentrated near the base of the riser rather than evenly distributed along the riser length. This results in the need for a high specification taper joint, and foundations. Furthermore, the high upper riser tension and stiffness results in lower compliancy and results in a poor riser response, with respect to the vessel, complicating the jumper design and increasing their length.

A cost analysis of alternative buoyancy configurations combining syntactic foam and air cans demonstrates the cost effectiveness of the proposed approach. The use of distributed syntactic foam has further advantages over air cans as follows:

- Reduced design complexity
- Higher operational reliability
- Smaller maximum diameter which simplifies launch
- Neutrally buoyant during tow out
- No requirement for air up during installation

### Riser Materials

API standard steel grades X65 and X75 are selected offering a balance between strength and weldability, the latter being important for simplifying fabrication and achieving NACE compliance.

### Structural Member Internal Inspection

Internal inspection of the central structural member is possible during service by remote camera or intelligent pipeline pig. This is considered an important capability in view of the criticality of the central member to the structural integrity, long service life and inability for external inspection. To facilitate inspection a continuous internal bore, free from obstructions must be provided. Although the central member is fitted with isolation plugs to prevent flooding of the entire length in the event of rupture, these are designed to be removed on drill pipe or coiled tubing.

### Peripheral Line Support and Expansion

The peripheral lines are top suspended in tension rather than base supported in compression. This reduces loading on the buoyancy elements which must otherwise resist buckling of the lines. It should be noted that this approach does not have any effect on the total buoyancy requirement.

Expansion spools are required at the base of the riser, and at regular intervals along the riser, to accommodate expansion of the peripheral lines arising from thermal and pressure end cap effects. In ultra deep water, peripheral line expansion with respect to the central member can be up to 2000mm depending on production temperatures.

The proposed design uses compliant thermal expansion spools at equi-spaced elevations along the riser. The expansion spools use rigid steel pipe but provide sufficient compliancy due to their configuration which is similar to a 'Chinese lantern'. The use of multiple expansion spools along the riser length splits the total expansion between a number of spools and allows the weight of the peripheral lines to be transferred into the central member at regular intervals. Depending on current profiles, VIV suppression strakes may be a requirement on the exposed expansion spools.

### Connection and Sealing of Peripheral Lines

The all welded design places additional importance on the reliability of individual components, none more so than the peripheral line base connections due to their relative inaccessibility in service. Each peripheral line terminates at the base in an upward facing hub. Individual ROV installed rigid spools with hydraulic connectors each end are used to connect between the peripheral lines on the riser and template pipework. If required, the spools can be retrieved during service for inspection or replacement.

### Vortex Induced Vibration

The possibility of vortex induced vibration of the riser bundle is an important issue in high current environments such as the Gulf of Mexico. Analysis shows the requirement for VIV suppression strakes over the upper half of the riser. Whilst this increases the drag coefficient and thus loading, it is a proven way to control VIV response and resulting fatigue damage. Other methods of reducing VIV include profiling of the buoyancy modules and alternating buoyancy diameters. The latter may benefit from results of current studies on deep water drilling risers. The use of staggered or profiled buoyancy modules has the benefit of reduced drag and lower probability of damage during launch.

### Riser Top Assembly

Each peripheral line is terminated at the top of the riser bundle by goosenecks. These allow flexible jumpers to be connected in

a catenary configuration to the vessel. The goosenecks are located at a depth of 35m below the mean sea level. This elevation is selected as a compromise between increasing the length of the jumpers (and their cost), and minimizing the hydrodynamic drag loading. The tether from the production vessel is connected directly to the central 30 inch member where it exits from the top of the riser. A hydraulic connector and internal isolation plug is used to provide double isolation of the central member and access for internal inspection tooling.

### Emergency Quick Disconnect (QDC)

The design philosophy assumes the riser is not disconnected from the vessel during service however, disconnection is feasible if required. During normal service the riser is tethered to the vessel using a motion compensated tensioner that maintains a tether tension of approximately 100Te. This controls the response of the top assembly and supplements the tension provided by the buoyancy modules. However, the riser is able to free stand providing the peripheral lines are air filled. This provides an additional base tension of 300Te allowing the riser to accommodate significant current loading. Should it be necessary for the riser to remain disconnected during loop current conditions, additional temporary buoyancy in the form of air bags or foam may be required.

### Riser Base and Connector

The riser is connected at the seabed to a lightweight fabricated steel base piled to the seabed. The template is hexagonal in shape with flowline porches located around the periphery. Six 30 inch x 30m piles are used to react the riser loads but this is dependent on the local seabed conditions. A central high capacity hydraulic collet connector is machined integrally with the lower taper joint and provides a proven method for transferring riser loads into the riser base and foundation.

### Analysis

The riser is analyzed for a range of environmental load cases using both regular and random wave techniques. Analysis is conducted using FLEXCOM3D, a time domain, marine structures analysis package, and SHEAR7 for VIV assessment. Care must be taken to ensure the riser bundle is correctly equivalenced and de-equivalenced during the analysis process such that loads in the individual lines are correctly assessed. The flexible jumpers must also be incorporated in the model as their weight and drag has a significant influence on the response of the riser top assembly. Table 2 summarizes the key extreme storm results showing an acceptable response for all load cases. Table 3 presents a summary of the fatigue contributions along the riser length. It is concluded that a 250 year fatigue life can be achieved providing VIV suppression strakes are used on the top section of the riser and double side welding techniques are adopted for fabrication of the central structural member.

Tow analysis is conducted for both regular and random seas and upending analysis is conducted to develop offshore procedures. The resonant period of the riser during tow is well above the dominant installation wave period as a result of its long length, and weight. Analysis demonstrates the riser can be safely towed at up to 4 knots in seastates up to an Hs 2.8m.

### **Fabrication and Installation**

The key to the proposed riser design is the method of fabrication and installation. The riser is beach fabricated and launched in 3 sections using flowline bundle techniques. Flooding of the central member during launch is prevented by inflatable plugs located in the ends of each section. After launch, each section is flanged together at a protected shallow water site. The thermal expansion spools are fitted and the entire assembly pressure tested prior to tow out.

The riser is installed using a near surface tow and upended at the offshore site using low cost installation vessels. The tow duration is estimated to be 2-3 days and full installation can be achieved within a short duration, 7-10 days. The riser tow and upending procedure is developed to minimize offshore operations and ensure high reliability.

An alternative fabrication and launch method uses a low cost pipelay barge moored in a protected shallow water location. The central structural member may be fabricated and launched into the water over the stinger, complete with attached buoyancy modules. The peripheral lines can then be fabricated on the pipe barge and assembled into the floating bundle.

### **Offset Hybrid**

The proposed hybrid riser configuration is not suited for use with an FPSO even in a mild environment due to the inability to achieve an acceptable jumper response within the constraints of conventional turret dimensions. To overcome this problem the riser is offset from the vessel to increase the jumper length and improve the response.

Offset distances of 200-300m are necessary depending on water depth and vessel mooring stiffness. In the offset configuration the riser must self stand, as it is impractical to apply tension from the vessel. This requires additional buoyancy to be applied to the riser to resist current loading and prevent excessive riser deflections. The load applied by the jumpers to the top of the riser has a significant effect on both the mean offset and dynamic response of the riser as the total jumper weight on the tower is in the order of 500-600Te.

To provide additional buoyancy an upper air can is proposed which is installed from the semi after the main riser section has been towed out and upended. The air can is connected to the riser via an articulated flex joint which prevents the generation of high bending loads due to the action of current and wave

loading on the air can section. The peripheral lines are terminated below the air can. Analysis of this arrangement shows it is well suited for application with an FPSO (spread and turret moored) even in a harsh environment and depths of 2200m.

### **Line Numbers and Weights**

Studies have considered between 18 and 25 peripheral lines with diameters ranging from 6 to 12 inches. 25 lines is considered to be near the maximum number that can be practically accommodated in a single hybrid assuming that the majority of lines are of 10 and 12 inches diameter.

Hybrid risers with larger numbers of lines have a high weight (approx 8.0 Te/m) and require buoyancy diameters in excess of 3000mm. This is considered to be near the limit of what can be economically fabricated, assembled and launched.

Risers with high numbers of peripheral lines present problems at the base and vessel interface. Difficulties arise in configuring the flowline interface and surface jumpers. A smaller number of larger lines is preferred to a large number of smaller lines. Where a large number of lines is required the preferred solution is to split them between two separate risers located either side of the vessel. This approach can be attractive as it offers a number of benefits:

- allows jumpers to be routed to both sides of the vessel (turret or pontoon)
- simplifies the design of the riser top assembly and goosenecks
- simplifies fabrication and launch
- reduces the size of key components and eases manufacturability
- reduces the project risk due to redundancy
- allows a phased development to be considered

Splitting the riser into two has a cost impact but this may be acceptably small in view of other advantages offered. The key cost difference is the installation of two templates and two risers. This may be achieved at the same time to reduce costs or staggered to suite the project schedule.

### **Failure Modes**

Low tension in the riser and elimination of air can buoyancy results in a safer system in the event of structural failure of the riser. The tension in the central member at any point along the length is low enough to be accommodated by the peripheral lines in the event of failure, preventing the riser from rising to the surface and endangering the safety of the production vessel. Furthermore, the elimination of vented air can buoyancy excludes the possibility of a large release of air which may affect vessel stability and riser integrity.

## Production Scenarios and Applications

The hybrid riser is particularly suited to applications where wells can be drilled from a central location. The riser can then be installed directly adjacent to the subsea wells in a manner that allows simultaneous production, drilling or workover from the production vessel. This eliminates the high cost of a drilling and work over vessel but the cost of drilling facilities and impact on deck payload must be considered.

The other main benefit of the hybrid over steel catenary or flexible riser systems is it allows tight control of the flowline routing and seabed layout. Steel catenary and flexible risers have a large plan area and this, when combined with the vessel mooring pattern, neutralises significant portions of the seabed. If large numbers of risers are required, it may be necessary to distribute the risers radially around the vessel, particularly if a turret moored FPSO is considered, to prevent riser clashing and ensure a balanced load on the vessel and mooring system. As a result, it may not be possible to orientate the risers in the preferred direction ie. towards wellhead and therefore costly flowline detours may be necessary to route the riser to its final destination.

## Costs

The estimated installed cost of the 1300m DeepStar riser for use with the semi submersible is £26 million, Figure 5. The total hardware cost is £19 million, Figure 6. Buoyancy and flexible jumpers are the highest single cost items.

A cost analysis [5] conducted with flexible riser systems indicates installed cost savings in the order of 40-50%. When compared with a steel catenary riser system then the total cost is similar but highly dependent on the adopted catenary configuration and assumed installation costs.

The installed cost of an equivalent offset hybrid is £29 million which accounts for the higher cost of the jumper hoses and air can top assembly. The installed cost of a non offset configuration for 2200m is £37 million ie. a cost increase of only 40%.

## Conclusions

The hybrid riser is a competing technology for deep and ultra deep water applications and may be evaluated for use with a range of production vessels and environments. The use of an all welded design with installation by tow out and upending offers scope to reduce material and installation costs in deep water and improve dynamic response compared to existing configurations.

## Acknowledgments

The Author wishes to thank the support provided by the DeepStar committee and in particular Chris Carra of BHP and Wan Kan of Exxon.

## References

- [1] Hatton, S.A. - "Hybrid Risers - A Cost Effective Deepwater Riser System?" . The 2nd Annual International Forum on Deepwater Technology, DEEPTEC'95, Aberdeen, March 1995.
- [2] Howells H. - "Advances in Steel Catenary Riser Design". The 2nd Annual International Forum on Deepwater Technology, DEEPTEC '95, Aberdeen, March 1995.
- [3] Hatton, S.A. - "Rigid Risers for Tanker FPSO's". FPSO World Congress, Aberdeen October 1995.
- [4] Holley, P. and Cassity G. - "Development and Deployment of a Freestanding Production Riser in the Gulf of Mexico". The Deepwater Pipeline Technology Congress, Paris 1995.
- [5] Hatton S. - "Catenary and Hybrid Risers for Deepwater Locations Worldwide" Advances in Riser Technologies Aberdeen 1996
- [6] Garret D L - "Dynamic Analysis of Surface Towed Riser" ASME 486 1995
- [7] C. Cottrill - "Renewed Riser at Heart of GB 388' Offshore Engineer August 1994
- [8] 2H Offshore - "Low Cost Hybrid Riser" Project Report Prepared for DeepStar. 2H Report No: 1085-RPT-002 Rev 3 December 1996.

Function	OD (Inch)	No. off	Design Pressure (psi)
Production	8-5/8	6	5000
Gas Injection	8-5/8	2	5000
Water Injection	8-5/8	4	5000
Hydraulic Control	3/4	6	5000
Chemical Supplies	3/4	6	5000
Methanol	2-3/8	1	5000

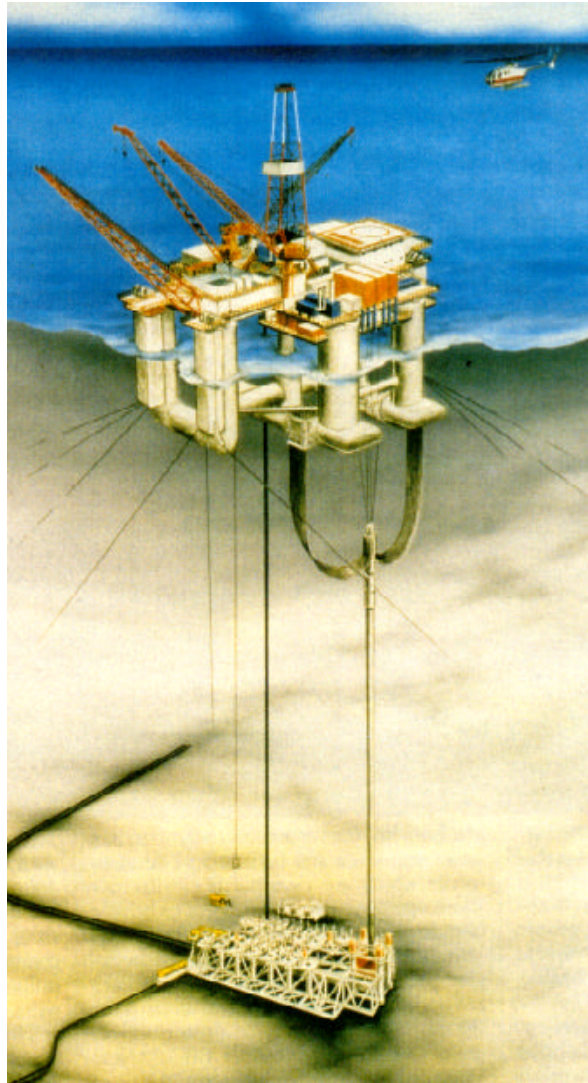
**Table 1 Riser Nos and Sizes**

Parameter	Vessel Offset (5%) Water Depth (Intact Mooring)	Vessel Offset (10%) Water Depth (Intact Mooring)	Vessel Offset 15% Water Depth (Failed Mooring)	Load Case
Max Base Tension (kN)	1399	1500	1725	API High Wave
Min Base Tension (kN)	1096	1270	1425	API High Wave
Max Base Moment (kNm)	2808	4143	5754	Loop Current Storm
Min Base Moment (kNm)	1070	2453	4111	API High Wave
Max Top Section Vm/Yield Stress	0.454	0.415	0.355	Loop Current
Max Mid Depth Vm/Yield Stress	0.328	0.328	0.325	API High Wave
Max Taper joint Vm/ Yield Stress	0.457	0.613	0.788	Loop Current Storm
Min Jumper Bend Rad. (m)	-	-	4.0	API High Wave

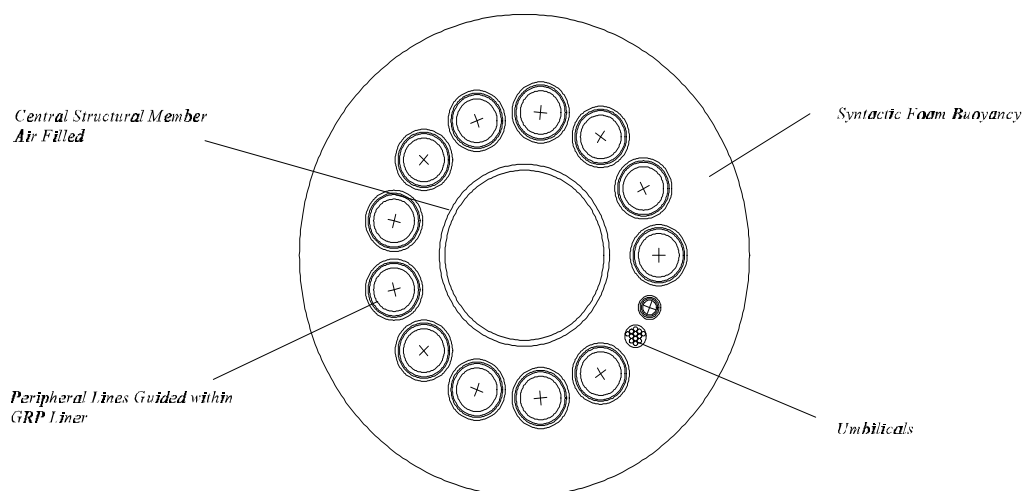
**Table 2 - Summary Extreme Storm Analysis Results**

Fatigue	Top	Mid Depth	Taper Joint
First Order Damage 1/Yr	0.138E-2	0.441E-4	0.801E-3
Second Order Damage 1/Yr	Negligible		
VIV Damage 1/Yr	0.15E-4	0.109E-4	0.162E-5
Total Damage 1/Yr	0.136E-2	0.55E-4	0.80E-3
Damage in 250 years	0.341	0.0137	0.20
Tow Out Damage	0.205E-2	0.377E-3	0.334E-3
Total Damage in 250 years	0.343	0.014	0.200
Factor of safety on 25 years	30	700	50

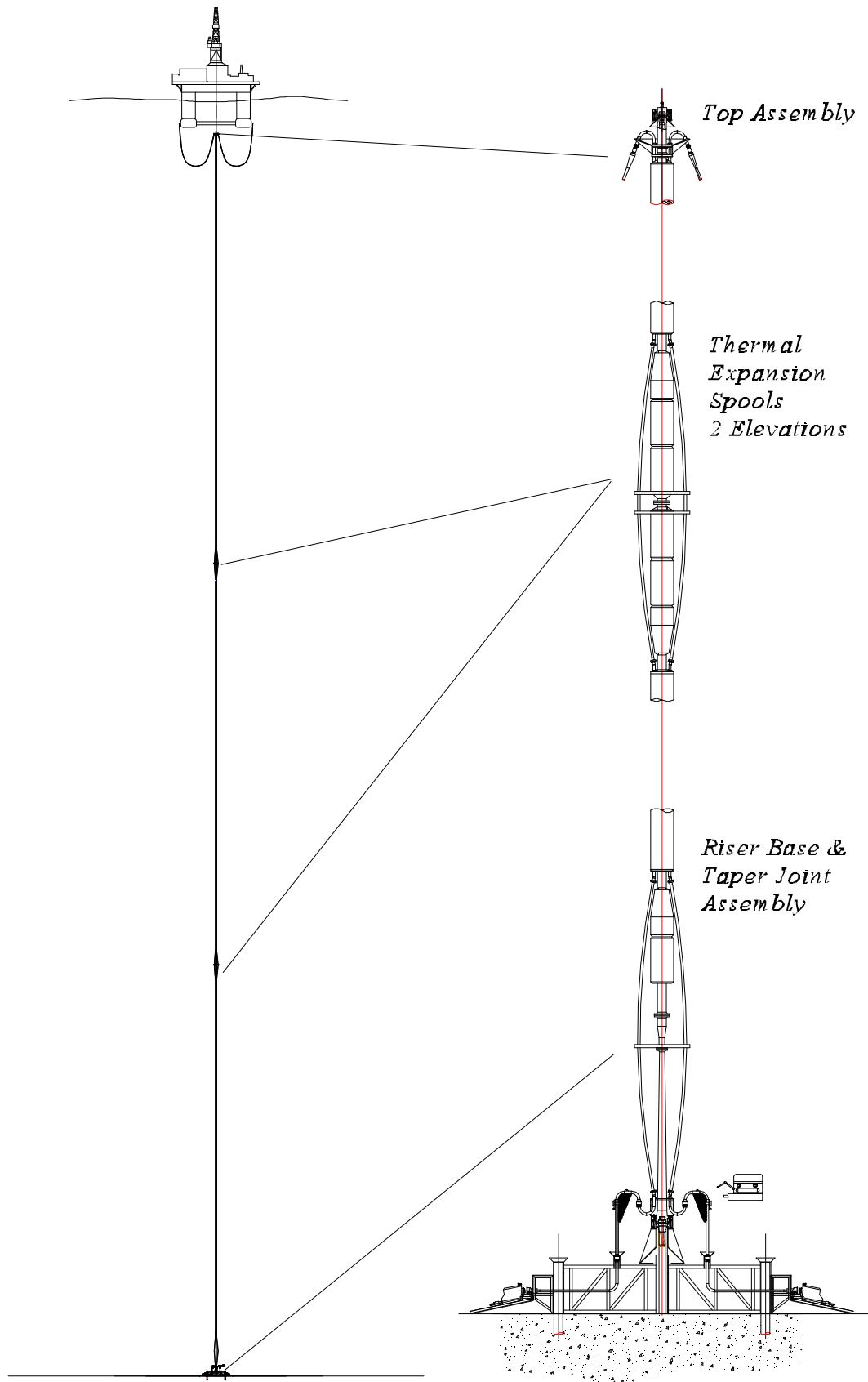
**Table 3 Fatigue Damage Summary**



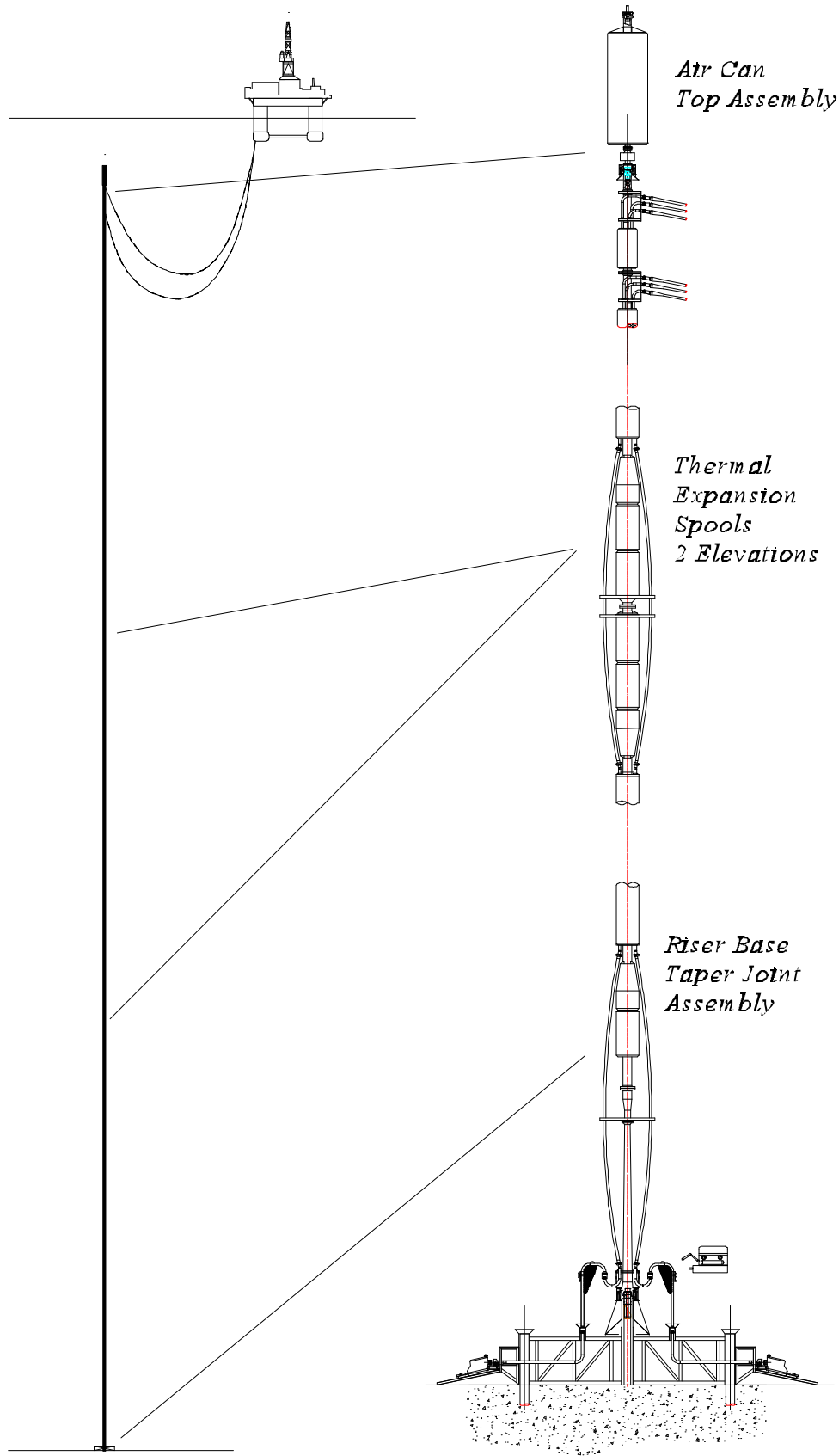
**Figure 1** Placid Riser Arrangement



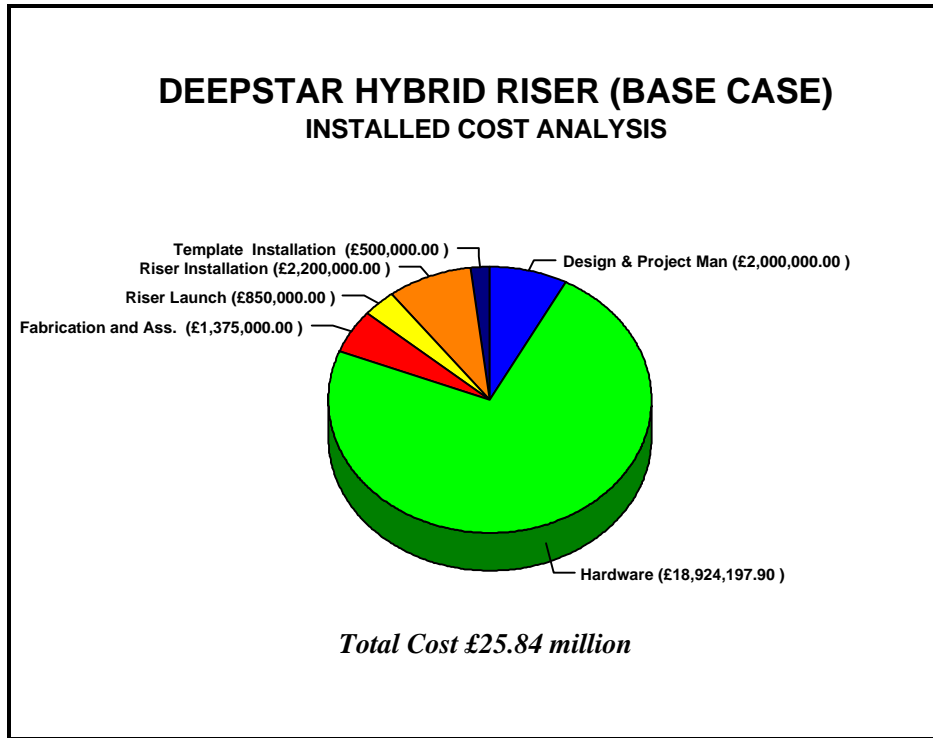
**Figure 2** Riser Section Arrangement



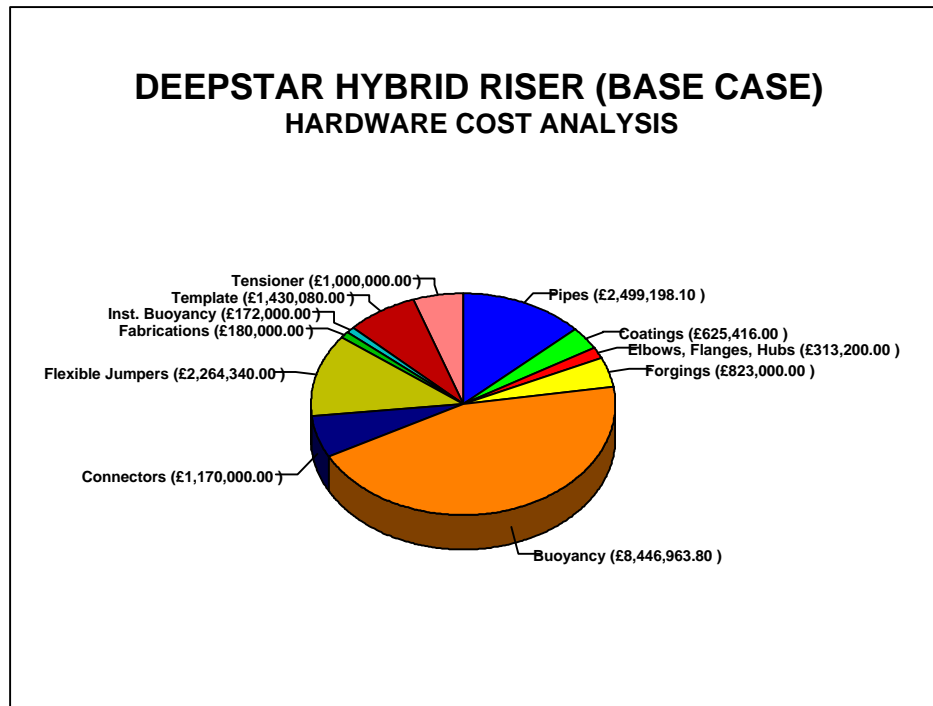
**Figure 3** Non Offset Hybrid Riser General Arrangement (1300m Water Depth)



**Figure 4** Offset Hybrid Riser General Arrangement (1300m Water Depth)



**Figure 5** Installed Cost Summary (1300m Water Depth)



**Figure 6** Hardware Cost Breakdown (1300m Water Depth)