RIGID RISERS FOR TANKER FPSOs

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SUMMARY

Recent development work on the subject of dynamic rigid (steel pipe) risers demonstrates that their scope of application extends beyond that of TLPs in mild environments. Steel catenary configurations can be used on tanker FPSO vessels even in harsh environments typical of the Atlantic Frontier. The potential cost savings over use of flexible risers is large. The technology is suited to a wide range of diameters and with correct material selection, can be used for aggressive and high pressure service conditions.

Two steel catenary riser configurations, which are developments of the steel catenary technology recently used on the Auger TLP in the Gulf of Mexico, are described and discussed. The configurations proposed are specifically developed for application with a tanker FPSO located in a harsh environment such as the Atlantic Frontier.

INTRODUCTION

Tanker shaped Floating Production Storage and Off-loading systems (FPSO) have been adopted for the exploitation of marginal developments and fields remote from existing infrastructure. Typically, a small number of subsea completions are involved, each individually tied back to the production vessel using flexible flowlines and risers. Produced oil is off-loaded using shuttle tankers and gas is either flared or re-injected. FPSO developments have exclusively used flexible riser systems, largely because field developments have been in relatively shallow water and also because of a lack of proven rigid riser alternatives. In general, riser diameters for these applications are small, 6-8 inches, which is well suited to flexible pipe and to the relatively small flow rates typical of these marginal fields.

Recently, tanker shaped FPSOs have been proposed for development of much larger fields, located in deep water, involving extensive subsea developments. The cost of the riser systems for these developments is significant compared to the total field development cost due to the number of lines required and service conditions. There has been increasing interest in steel catenary risers for these applications as they offer the potential for significant cost savings over flexibles due to the low unit cost of steel pipe compared to flexible pipe. The technology also allows larger diameters to be used allowing large flow areas and the number of risers to be reduced.

The following sections describe two rigid riser configurations suitable for harsh environment FPSOs. The paper evaluates the two configurations for application with different subsea and flowline configurations. Key mechanical design issues and material selection for different service conditions are discussed and budgetary costs for a range of typical field application are also presented.

FPSO RISER DESIGN ISSUES

The main challenge when designing risers for tanker FPSOs is the higher motion response compared to a TLP or semi-submersible. Even if the turret is located near the centre of motion, high heave, pitch and roll motions must be accommodated by the risers. The riser design problem is compounded by the use of "soft" mooring systems which allow vessel excursions up to 30% water depth. To accommodate such large offsets, the risers must be highly compliant to prevent overstressing.

Installation of FPSO risers is more complex than on a semi or TLP as there is less space within the turret and high conjestion below, as a result of the large number and close proximity of risers and mooring lines.

RIGID RISER CONFIGURATIONS

Rigid risers such as drilling risers are normally vertically tensioned by hydro-pneumatic systems that compensate for relative motion between the riser and vessel. On an FPSO, vessel offsets and dynamic motions can be so large that this approach is impractical, as stroke ranges up to 50m can be experienced. However, if the riser is configured in a catenary, the riser becomes highly compliant and motion compensation at the vessel can be eliminated.

Single drape catenaries, as used on the Auger TLP, are particularly simple and cost effective, Figure 1. Although they are suited to a wide range of applications, including FPSOs, they cannot accommodate harsh environments or static vessel offsets above 15% water depth unless the environment is mild and wave frequency vessel motions are small. Typically, for an FPSO in medium to harsh environments with conventional mooring system design, the single drape catenary configuration must be modified to increase its compliancy and improve its dynamic response. The addition of external buoyancy, in a similar manner to that adopted for flexible risers is proposed, forming a buoyant steel catenary riser which is suited to harsh environments and larger vessel offsets.

BUOYANT STEEL CATENARY RISERS

General Configuration

The addition of external buoyancy to a single drape catenary modifies its static shape and dynamic response. Depending on the buoyancy distribution and seabed end constraint "lazy wave" or "steep wave" configurations can be produced, Figure 2.

The steep wave configuration approaches the seabed vertically whilst the lazy wave approaches the seabed horizontally. The steep wave is suited to applications where the riser terminates at a subsea manifold or completion whilst the lazy wave is suited to applications where the riser extends along the seabed as a pipeline.

The compliancy of these systems is graphically illustrated by Figure 3 showing the vessel at at the extreme failed mooring line, (30%) offset positions. Figure 4 illustrates how the use of buoyancy on a 20 inch diameter 650m water depth riser increases the ability to accomodate higher offsets and more extreme environments.

The designer must select the optimum pipe length, buoyancy distribution, vessel and base angles to ensure that the pipe minimum bend radius is not exceeded. Typical stress utilisation factors, consistent with regulatory requirements, are 0.8 yield and 1.0 yield for intact 100 year storm and failed mooring line conditions respectively.

In the near condition, high bending occurs in the hog and sag bends and in the far condition high tensions are generated. The latter can result in high back tensions in the lazy wave configuration or high base moments in the steep wave configuration and this must be accomodated within the design of the subsea termination.

The effects of a range of internal fluid densities, buoyancy water absorbtion and pipe material loss due to corrosion must be considered during the design to ensure that the riser maintains an acceptable response during all service conditions thoughout its service life, up to 25 years.

Applications

Even in a harsh environment the buoyant steel catenary is suited to a wide range of potential applications as illustrated in Figure 4 which shows the lower water depth limit against diameter. The graph assumes a harsh environment and an FPSO with an internally mounted turret located mid way between the midships and bows. The figure shows that in a water depth of 650m a 20 inch diameter riser can be configured. At the other extreme, a 4 inch catenary riser can be configured in as little as 150m of water.

Mechanical Design

The buoyant catenary can be assembled by welding or threading individual riser joints. The latter is recommended, particularly for diameters up to 16 inches, where readily available premium casing couplings can be used. These have proven strength, pressure integrity and fatigue resistance. Premium couplings eliminate welding, offering improved fatigue lives and lower hardware and installation cost. For diameters greater than 16 inches, weld on mechanical couplings or beach fabrication with tow out need to be considered.

Turret interfaces are typically similar to those used for flexible risers. Generally, both steep and lazy wave buoyant steel catenaries have similar turret interface loads to flexible risers of a similar size. Diameters larger than 12 inches may produce loads greater than that normally assumed in existing turret designs and therefore local strengthening is a possible requirement.

A flex-joint is specified at the interface between the riser and turret to accommodate differential angular motions. Top angles depend on vessel extreme offset and dynamic response and vary from +/-5 degrees for a deepwater calm environment to +/- 30 degrees for a harsh environment. Flex-joints are developing a track record for this type of service and can accommodate a wide range of fluid types and pressures. An important benefit is that the flex-joint is located near the surface and can therefore be readily inspected and replaced should problems be experienced.

The buoyant catenary riser can be connected directly to the subsea completion or manifold without the need for a costly intermediate flowline. This provides a reliable arrangement as there are no intermediate subsea connections. As the cost of the steel pipe is relatively low, large step out distances can be accomodated at small additional cost, using the lazy wave configuration. If the step out distance is small, ie. less than 1.5 times the water depth, the steep wave configuration should be adopted. This has the advantage of eliminating the seabed touch down.

Material Selection

Conventional API steel grades can be used. Normally, 65ksi material is adequate with the option to use up to 80ksi material in highly stressed locations if required. The use of upset threaded couplings as opposed to welding makes the use of 80ksi materials practical whilst maintaining good fatigue resistance.

The use of titanium for catenary riser applications has been much discussed with its benefits of higher strength, low modulus of elasticity, corrosion resistance and lower density. The latter allows buoyancy costs and vessel loads to be reduced. However, whilst the material has some technical advantages, the cost is some 30 times greater than steel and the total installed riser cost over 50% greater than an equivalent steel system. Consequently, titanium is not generally recommended unless the water depth and riser diameter combination is outside the acceptable range shown in Figure 5.

Steel catenary and buoyant catenary risers are particularly suited to applications involving one or a combination of the following service conditions:

- High pressure (10,000 psi)
- High temperature (100 deg. C)
- High CO_2 content
- High H_2S content

For these applications a range of corrosion resistant alloys may be selected depending on actual service conditions. For very extreme environments, it is recommended that a bimetalic or internally clad pipe consisting of an inconel 625 or 825 internal liner with an API grade X65 backing pipe is used. This provides excellent resistance to general corrosion, pitting, crevice and cracking. It is highly cost effective when compared to either solid inconel or titanium pipe.

Installation

Installation of buoyant catenary risers is conducted using a technique similar to J lay of pipelines. The steep wave configuration is initiated vertically at the subsea completion, using ballast weights, and laid to the production vessel. The lazy wave can be initiated at either the vessel or subsea end.

The type of installation vessel will depend on whether the riser is fabricated or assembled using mechanical connectors and also on the environment. In a mild environment the riser may be fabricated offshore using a low cost lay barge, as on Auger.This is not considered suitable for a medium to harsh environment where weather windows are smaller and high weld quality is required to achieve acceptable fatigue lives. Weld quality is dependednt on accurate control of welding parameters and careful inspection which is difficult to achieve offshore.

If fabrication is proposed for medium to harsh environments, reel installation or tow out should be considered. Reel installation is well suited to small diameter lines, up to 10-12 inches and towed installation is recommended for larger diameter lines.

Threaded assembly is recommended for diameters up to 16 inches, installed from either a semi or DSV with a workover derrick. Installation procedures can be readily developed by existing analysis techniques which are well developed. During installation the shape of the riser is controlled by the position of the vessel and rate at which the riser is paid out or lowered in a similar manner to pipeline installation.

ANALYSIS

Analysis of buoyant catenary risers is conducted using time domain techniques. This is shown to be a requirement due to the non linear dynamic behaviour. Optimisation of riser parameters such as buoyancy distribution, length of the riser pipe and end contraints is required to achieve acceptable storm response.

Fatigue is a critical issue which must be carefully evaluated on an individual riser basis, addressing first and second order damage and vortex induced vibration (VIV) response. Experience shows that acceptable performance can be achieved using an iterative process of specifying wall thickness, catenary length/stiffness, material grade, weld fatigue detail and vortex suppression devices.

Critical stress locations occur immediately below the turret and in the hog and sag bends. Dynamic response at the seabed touch down point or subsea completion is small compared to a single drape catenary due to the additional compliancy and damping provided by the mid water-arch.

VIV response of buoyant catenary systems is an area requiring development and testing as there is currently no VIV software available for buoyant catenary systems. Typically these systems have low tension along long sections and the tension varies depending on the buoyancy distribution.

The following design loads and performance data are typical for a range of riser applications for both configurations described.

Riser Diameter (inches) Location Water Depth (m)	**Peak Vessel Effective Tension (kN)**	**Mean Riser Top Angle (Degrees)**	**Max. Riser Top Angle Range (Degrees)**
12 West of Shetland 500	5,000	25	20
20 West of Shetland 800	9,000	20	15
26 Gulf of Mexico 800	10,000	15	10
30 Gulf of Mexico 800	20,000	15	10

Table 1 - Typical Design Criteria For Buoyant Steel Catenaries

COSTS

Typical hardware costs for steep wave steel catenaries are given in Table 2 below. The configurations are based on a harsh environment with a 20% intact vessel offset.

Diameter (inches)	**Water Depth (m)**	**Service Pressure**	**Pipe Grade**	**Hardware Cost (million)**
6	800	Production 5000psi	X65	£0.9
6	800	Production 5000psi	X65/Inconel 825 liner	£1.6
6	800	Production 5000psi	Ti (Grade 9)	£2.0
12	500	Gas Export 5000psi	X65	£1.6
20	500	Oil Export 3000psi	X65	£2.4
30	800	Oil Export 3000psi	X65	£6.5
30	500	Oil Export 3000 psi	Ti (Grade 9)	£12.5

Table 2 - Buoyant Catenary Hardware Cost Summary

CONCLUSIONS

Buoyant steel catenary risers are an important development for the future of FPSO systems. They significantly reduce the total cost of developments and allow HP/HT and sour service applications to be accomodated with high reliability.

Analysis tools and methods are well advanced allowing buoyant steel catenary systems to be readily configured.

Hardware and materials are proven in similar applications such that long term reliability is achievable.

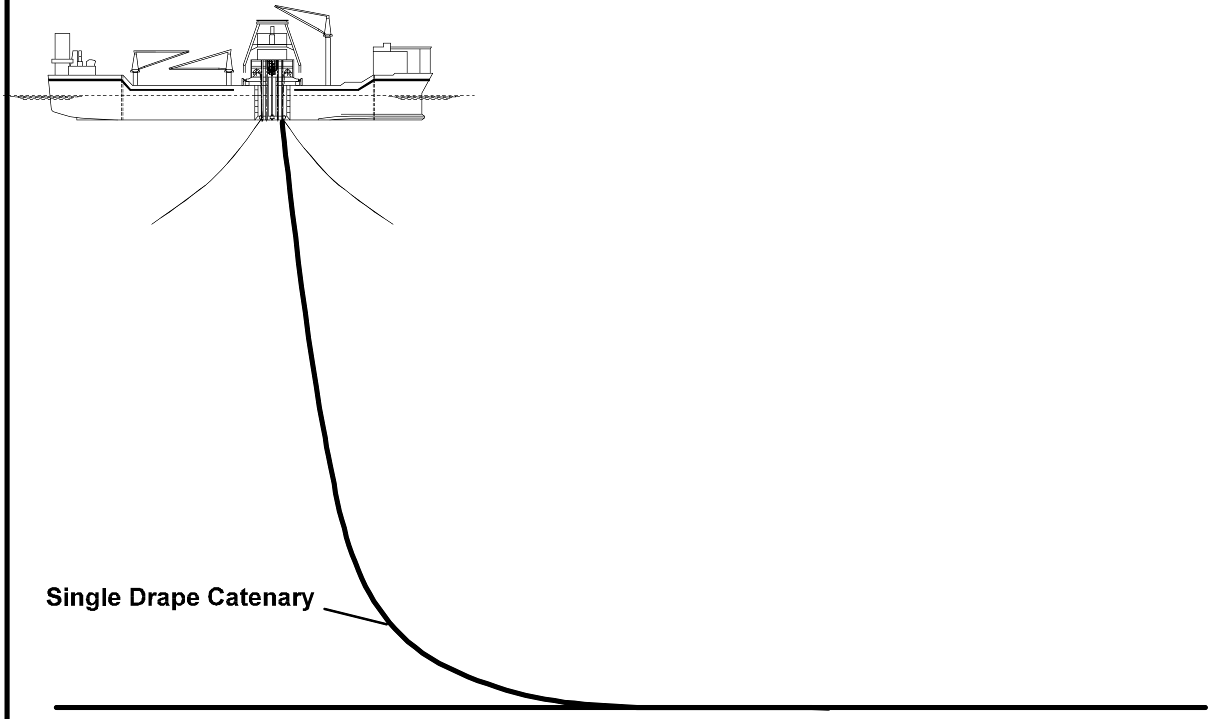

Figure 1 Single Drape Steel Catenary Riser Arrangement

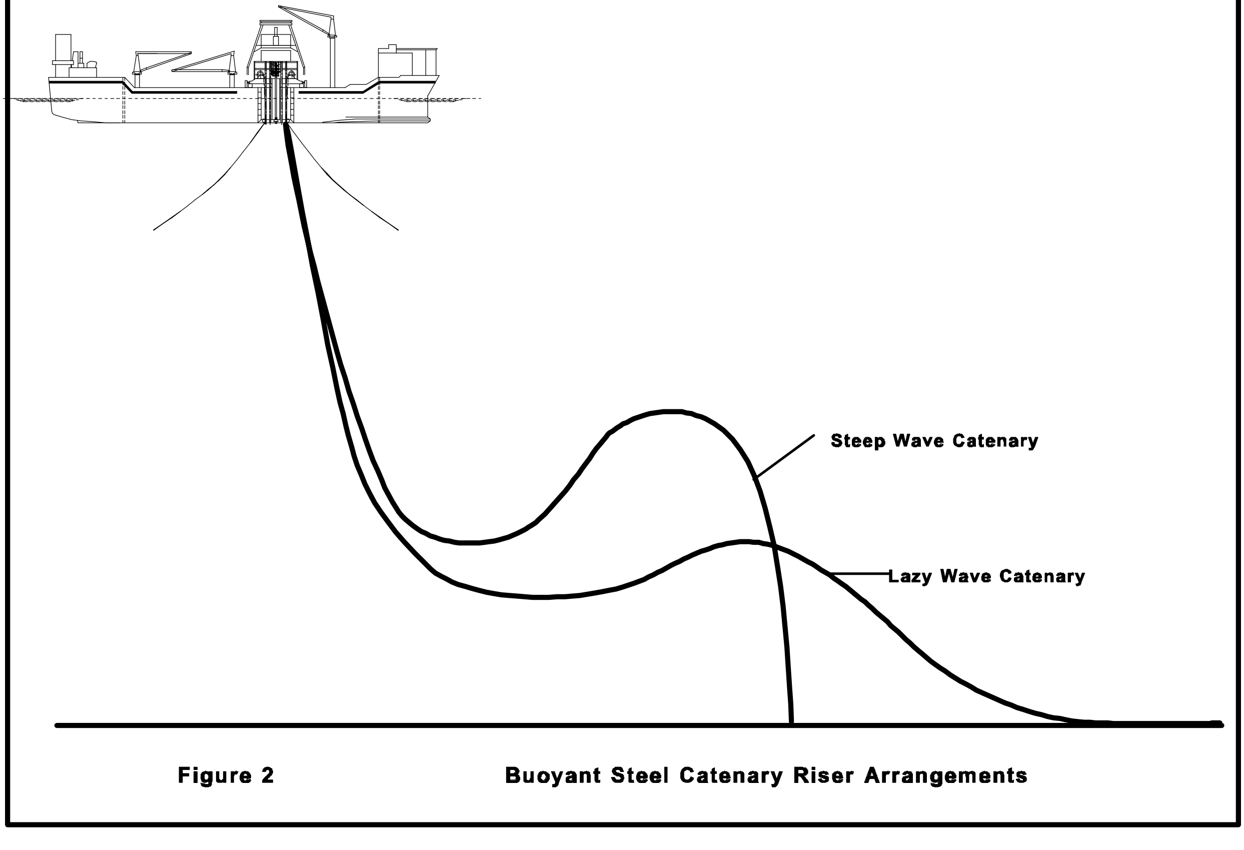

Figure 2 Buoyant Steel Catenary Riser Arrangements

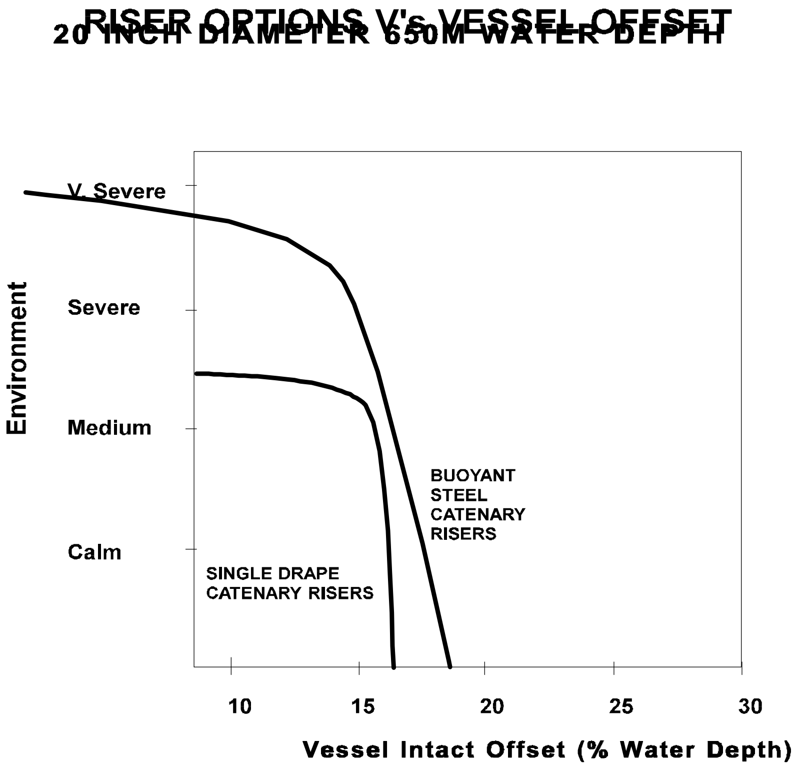
RISER OPTIONS V's VESSEL OFFSET
20 INCH DIAMETER 650M WATER DEPTH
Environment
V. Severe
Severe
Medium
Calm
BUOYANT STEEL CATENARY RISERS
SINGLE DRAPE CATENARY RISERS
10
15
20
25
30
Vessel Intact Offset (% Water Depth)

Figure 4

BUOYANT STEEL CATENARY APPLICATIONS

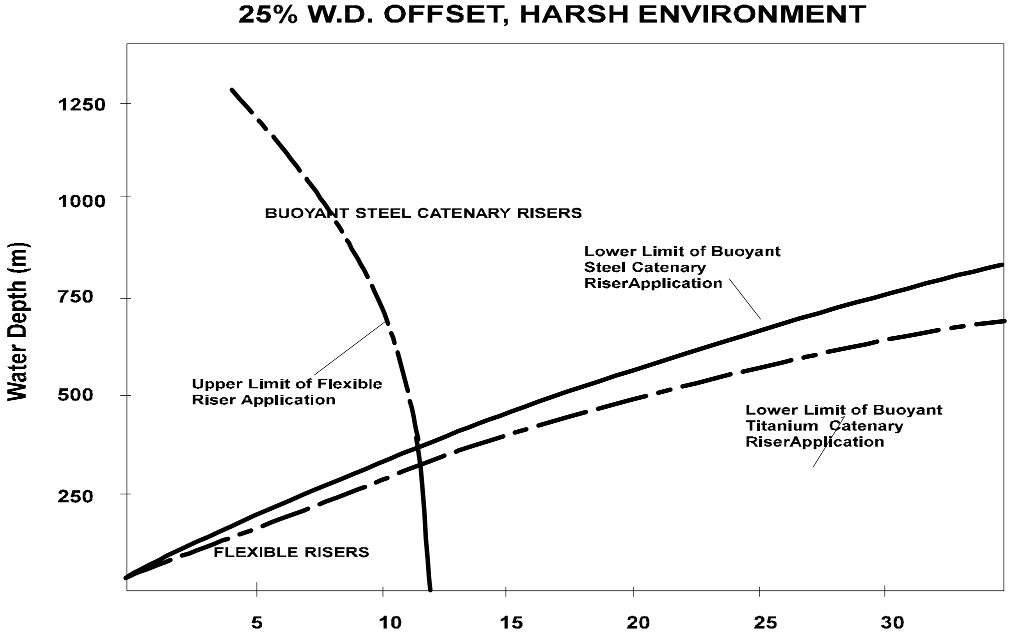

Figure 5