

LARGE DIAMETER RISERS FROM TANKER FPSOs

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SUMMARY

Recent development work on the subject of dynamic rigid (steel pipe) risers demonstrates they are suitable for tanker FPSO developments. The potential cost savings over use of flexible risers is large, and the technology allows large diameter risers, up to 36 inches, to be considered. Pipeline off-loading from FPSOs can be considered as an alternative to shuttle tankers. This is necessary for development of gas reserves and where existing infrastructure can be economically used.

Two large diameter rigid riser configurations are described and discussed. The systems are developments of steel catenary riser technology recently used on the Auger TLP. The configurations are suitable for a wide range of water depths and environments including 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 are small, 6-8 inches, which is well suited to flexible pipe and to the relatively small flow rates typical of these marginal fields. More recently, tanker shaped FPSOs are proposed for development of much larger fields, located in deep water and which involve extensive subsea developments. Higher production flow rates have led to the consideration of pipeline off-loading as an alternative to shuttle off loading and a demand for large diameter risers.

The maximum commercially available flexible riser diameter is 10-12 inches which limits the maximum flow rate that can be considered. Higher flow rates require the use of multiple flexible risers with subsea manifolding. This increases the total cost of the riser system which already represents a large proportion of the total development cost.

The following sections identify and describe two rigid riser configurations that can be used from an FPSO, located in a harsh environment, in diameters up to 36 inches. The paper discusses key design issues, mechanical configurations and presents budgetary costs for a range of typical field application.

LARGE DIAMETER RISER APPLICATIONS

Large diameter risers may be considered for pipeline off-loading from an FPSO as an alternative to shuttle off-loading. Pipeline offloading may be attractive where production rates are high, existing infrastructure is close by, environmental conditions result in low shuttle tanker utilisation or for developments involving substantial gas reserves.

A possible field development strategy may use shuttle tanker off-loading during the early life of the field and switch to pipeline off-loading when production rates increase. Revenue provided by early oil production is then available to finance installation of a pipeline system. Upfront capital expenditure is minimised and maximum flexibility is maintained by the operator, allowing export tariffs to be minimised.

Large diameter rigid risers can also be used for import service such as from a subsea manifold. This offers the opportunity to minimise the number of subsea flowlines and risers which can reduce total development costs and allow the riser/vessel turret interface to be simplified.

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. 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.

RIGID RISER CONFIGURATIONS

Rigid 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 are so large that this approach is impractical, as stroke ranges up to 50m can be experienced. However, if the steel riser pipe 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 they cannot accommodate large offsets above 15% water depth unless the environment is mild and vessel motions small. Typically, for an FPSO in medium to harsh environments the single drape catenary configuration must be modified to increase its compliancy and improve its response. Three ways in which this can be achieved are as follows:

- Addition of external buoyancy
- Addition of external weight
- Addition of mid length mechanical articulations such as flex-joints.

The two rigid riser configurations discussed in the following sections adopt these design methods. The first system (buoyant steel catenary) uses only external buoyancy to modify the response. The second system (bottom-weighted riser) uses all three methods allowing extreme environments and very large diameters to be considered.

It is difficult to generalise on the scope of application and limitations of the two systems, since many factors such as vessel RAO, turret position, current strength and profile affect riser performance. Both buoyant

catenary and bottom-weighted concepts have particular areas of application. Figure 2 summarises typical areas of application for a harsh environment FPSO which has a maximum excursion of 25% water depth. Figure 3 shows the effect of vessel offset and environment on riser configuration selection.

Our particular area of interest, for this paper, is in the diameter range 12 to 36 inches which is larger than commercially available flexible risers. It can be concluded from Figures 2 and 3 show that the bottom weighted riser system should be considered for very large diameter applications which are not deep enough for a buoyant catenary to be adopted. The bottom weighted riser system is also more suitable for applications in very harsh environments and where vessel offsets are expected to be greater than 20-25% (intact).

BUOYANT STEEL CATENARY RISER

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 end constraint "lazy wave" or "steep wave" configurations can be produced.

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 forming a pipeline.

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 threads can be used. These have proven strength, pressure integrity and fatigue resistance. Premium threads 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.

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 allows the use of 80ksi materials whilst maintaining NACE compliance and ensuring good fatigue resistance.

The use of titanium for this type of application has been much discussed with its benefits of higher strength, low modulus of elasticity and lower density. Whilst the material has some technical advantages, the cost is some 30 times greater than steel. Consequently, titanium is not recommended unless steel is demonstrated to be technically unacceptable for the particular application.

Turret interfaces are typically similar to those used for flexible risers. For large diameter risers, additional space for isolation valves must be provided and facilities for pig launching considered.

Generally, both steep and lazy wave buoyant steel catenaries have lower turret interface loads than 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 probable 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 proven 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 occur.

BOTTOM WEIGHTED RISER

General Configuration

The bottom weighted riser general arrangement is shown in Figure 4. A vertical riser section is connected to a horizontal section, located near the seabed, by a piggable rigid elbow. Flex-joints are used at each end of the vertical and horizontal sections to allow the riser to articulate and thus accommodated vessel motions and offsets.

A ballast weight is attached above the bottom elbow to maintain the vertical section in tension. The height of the elbow above the seabed is selected to ensure that the horizontal section does not impact the seabed during the extreme vessel excursions.

The vertical section of the riser is supported from the vessel in a similar manner to the buoyant steel catenary described above. A flex-joint is used at the vessel keel to accommodate angular motions resulting from offset, heave, pitch and roll.

At the seabed end of the horizontal section, the riser is connected to the seabed pipeline via a piled pipeline end manifold. Seabed tethers are connected between the base elbow and foundation piles as illustrated. The purpose of the tethers is to maintain tension in the horizontal section and provide resistance to lateral load conditions.

Mechanical Design

The vertical section of the riser is assembled offshore from individual joints. Weld on mechanical couplings such as compact flanges are necessary as large riser diameters preclude the use of threaded couplings.

The horizontal section is fitted with external buoyancy to provide near neutral buoyancy in production mode. The horizontal section is therefore fabricated onshore and towed out using a surface tow method.

The vertical section is fabricated from steel pipe with a 65ksi yield strength. The horizontal section is fabricated from seam welded titanium grade 9 pipe which has a yield strength of 74ksi. Titanium offers improved response of the horizontal section due to:

- Light weight so inertia and drag forces are minimised
- High flexibility
- Fatigue resistance

The three equi-spaced base tethers are manufactured from polyester rope. The length and pretension of the tethers are selected to provide the required response in the bottom riser section and ensure that the tethers are not over-stressed. Additionally, fatigue resistance of the tethers under constant loading is critical.

The angular specification of the flex-joints is dependent on maximum vessel offset and production fluids. For offsets up to $\pm 25\%$ water depth angular rotations up to ± 25 degrees are required. Specification of flex-joint elastomers must be developed to suit production fluids and service conditions. If there is high pressure gas, elastomer selection with resistance to explosive decompression is required. Internal bellows units may be considered to prevent production fluids contacting the elastomers in particularly severe service conditions.

The effect of low temperatures resulting from gas blow down must also be considered for gas applications and the effect on both steel and elastomer properties. Temperatures below -40 degrees C can be experienced resulting in increased angular spring rates for the flex elements.

ANALYSIS

Analysis of both riser types 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 and length of the riser pipes 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 stresses occur in the bottom-weighted riser immediately below the turret, due to tension and at the mid span position of the horizontal section due to bending. Figure 5 shows a typical structure plot for a 30 inch diameter West of Shetland application during a 100 year storm condition. The hydrodynamic drag and inertia of the horizontal section causes relatively large mid span deflections as the vessel heaves.

For the buoyant catenary, critical stress locations also 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.

Table 1 presents typical vessel interface loading for a range of bottom-weighted riser configurations for a 25% maximum vessel offset.

Riser Diameter (inches) Location Water Depth (m)	Max. Vessel Effective Tension (kN)	Max.Vessel Angle Range (deg)
24 West of Shetland 500	4,200	+/-28
30 West of Shetland 500	6,000	+/-30
24 West of Shetland 1000	6,400	+/-28
30 Gulf of Mexico 1000	9,000	+/-25

Table 1 - Typical Design Criteria Bottom Weighted Riser

Riser Diameter (inches) Location Water Depth (m)	Max. Vessel Effective Tension (kN)	Vessel Mean Angle (Degrees)	Max. Vessel Angle Range (kN)
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 2 - Typical Design Criteria Buoyant Steel Catenary

COSTS

Typical hardware costs for buoyant steel catenaries and bottom-weighted risers are given in Tables 3 and 4 below. The configurations are based on a harsh environment with a 20% intact vessel offset.

The buoyant steel catenary has a lower hardware cost than the bottom-weighted riser due to the use of titanium in the latter and complexity of the base arrangement. The installation cost of the bottom-weighted riser is also higher due to additional components such as piles and tethers.

Diameter (inches)	Water Depth (m)	Service Pressure	Pipe Grade	Hardware Cost (million)
12	500	Gas 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 3 - Buoyant Catenary Hardware Cost Summary

Diameter (inches)	Water Depth (m)	Service Pressure	Pipe Grade	Hardware Cost (million)
24	500	Oil Export 3000psi	X65/Ti	£4.5
30	500	Oil Export 3000psi	X65/Ti	£7.1
30	800	Oil Export 3000psi	X65/Ti	£9.3

Table 4 - Bottom Weighted Riser Hardware Cost Summary

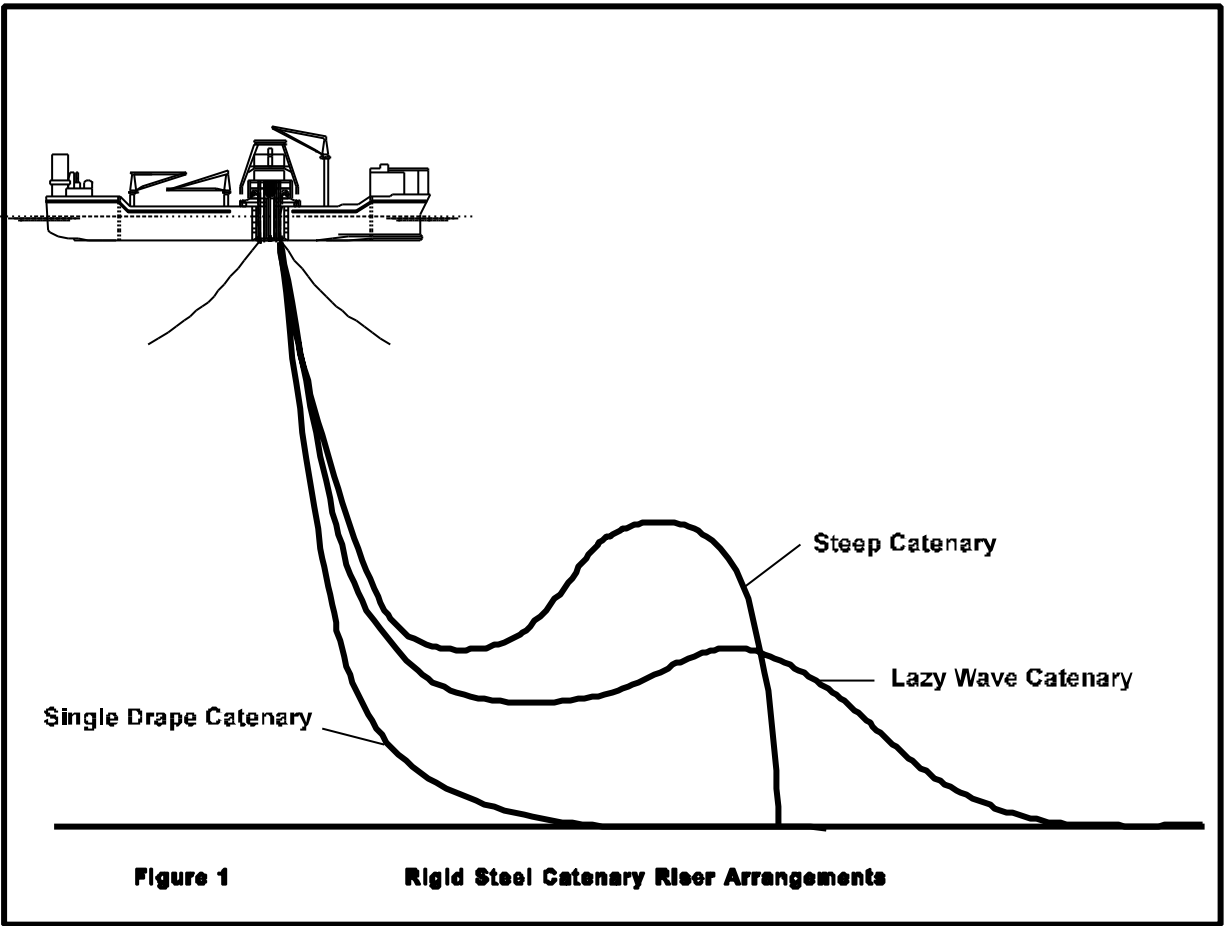
CONCLUSIONS

Large diameter rigid risers, up to 36 inches, are suitable for FPSO applications even in harsh environments. This provides an export alternative to shuttle tanker off-loading and can also be used for large diameter import.

The buoyant catenary is preferable for gas applications due to its use of a single flex element which is conveniently located at the vessel. Diameters up to 30 inches are feasible but high water depths are necessary.

The bottom weighted riser allows diameters up to 36 inches and is well suited to oil export/import applications.

The configuration is suited to relatively shallow water depths ranging from 300m to 800m, although it can be used in water depths up to 2000m.



FPSO RISER OPTIONS
25% W.D. OFFSET, HARSH ENVIRONMENT

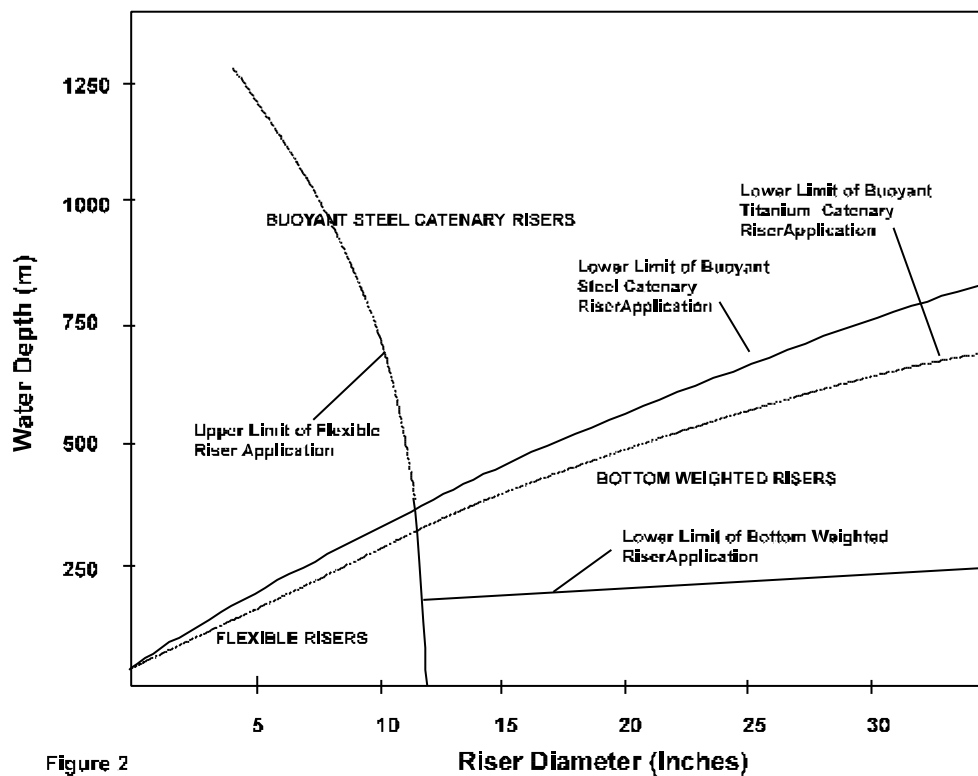


Figure 2

RISER OPTIONS V. VESSEL OFFSET

20 INCH DIAMETER 650M WATER DEPTH

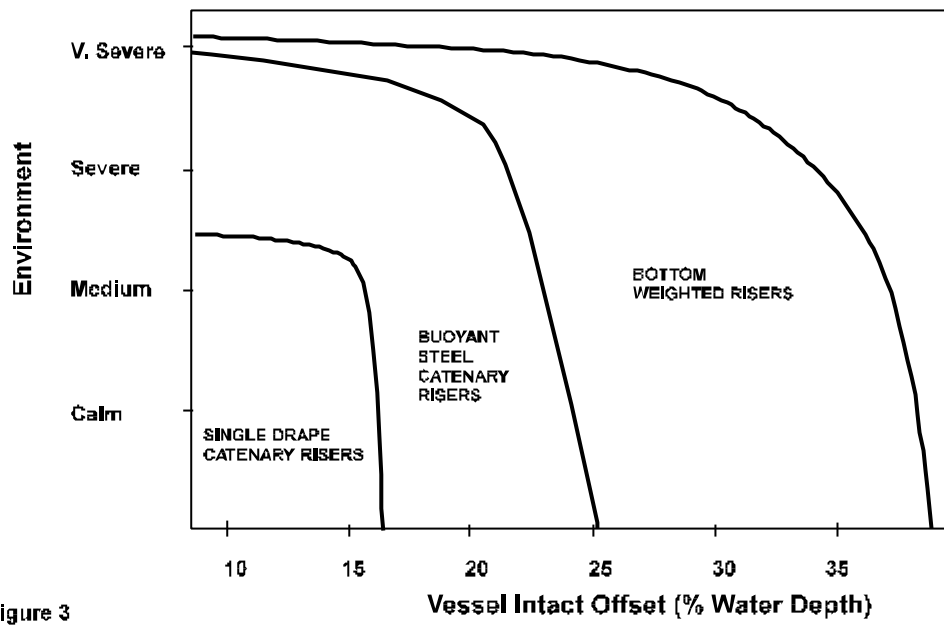


Figure 3

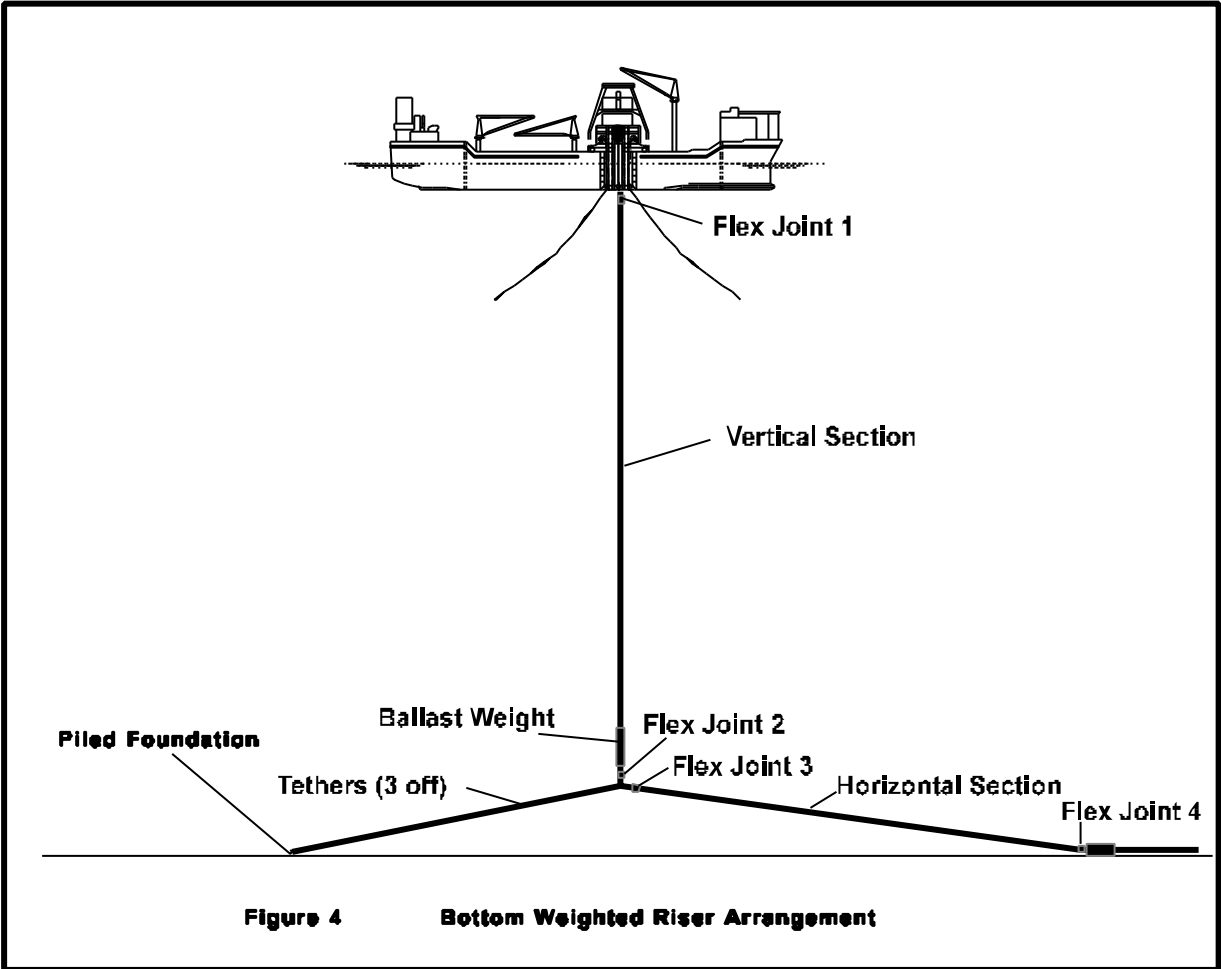


Figure 4 Bottom Weighted Riser Arrangement

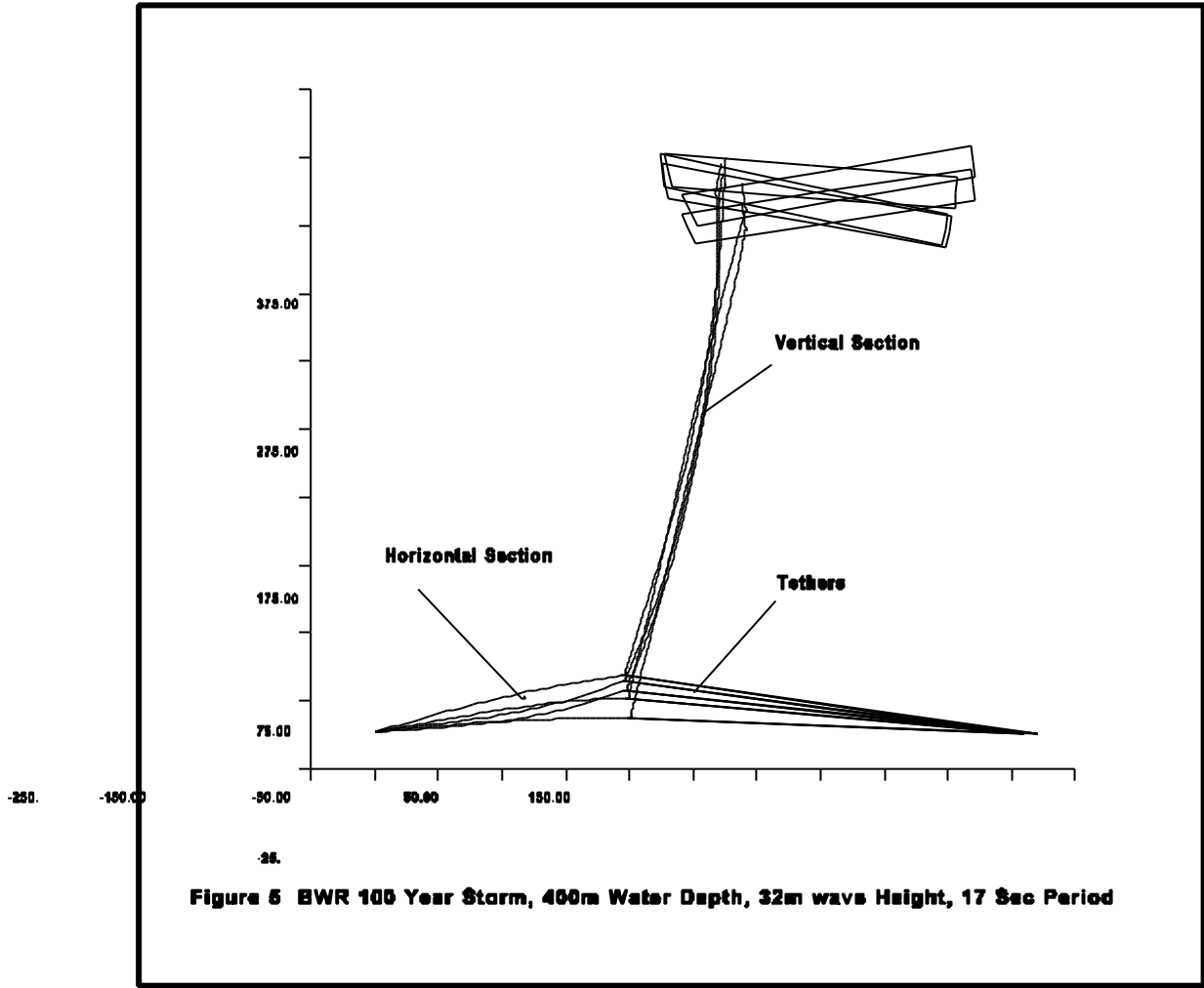


Figure 5 BWR 100 Year Storm, 400m Water Depth, 32m wave Height, 17 Sec Period