

ADVANCES IN STEEL CATENARY RISER DESIGN

by
Dr Hugh Howells

2H Offshore Engineering Limited
Woking, Surrey, UK

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INTRODUCTION

Riser systems can form a significant proportion of the development costs of floating production systems, which are increasingly being considered for current and future field developments. Steel catenary risers offer a low cost alternative to conventionally used rigid and flexible risers on floating platforms and can also provide economic riser design solutions for fixed platforms.

Steel catenary risers have already been installed on the Shell Auger TLP and the concept is proposed for the Mars and Ram-Powell TLPs. Work is also being carried out on the DeepStar project to investigate the use of steel catenary risers. Consequently, most of the development work carried out to date relates to deep water applications for the Gulf of Mexico. The applicability of the concept to other environments, different water depths and platforms other than a TLP is addressed in the current work.

2H Offshore Engineering have investigated the use of steel catenaries for BP Exploration and further developed the concept in-house. Single flowline and flowline bundle configurations have been considered with varied environmental conditions, water depths and platform type. The key findings of the work are described in this paper.

STEEL CATENARY APPLICATIONS

A summary of current and planned applications of steel catenary risers is given below. TLP's, such as Auger and Mars, are possibly the most favourable platforms on which to use steel catenaries. Platform motions due to wave action are mostly lateral, with a small degree of vertical movement or set-down from the inverted pendulum action of the tethers. Consequently, the nominal catenary shape does not change significantly. The large water depths of Auger and Mars are also beneficial in that dynamic excitation from wave action at the surface is damped as it travels to the seabed. Nevertheless, steel catenaries can be used in a much wider range of applications than deep water TLP's.

Development	Line Function	Size (inch)	Pressure (psi)
Auger TLP, 1994	Oil Export	12	3000
	Gas Export	12	3000
Mars TLP, 1996	Gas Export	18	2400
	Oil Export	14	2160
	Import	5	5000 (7300)
Ram-Powell TLP, 1997	Gas Export	14	2220
	Oil Export	12	2500
	Gas Import	8	6200
Marlim Semi, 1995/6	Export Test	10	2000-3000

Current and Planned Steel Catenary Riser Systems

Steel catenaries can be used as an alternative to other forms of rigid pipe, as on Auger, and as an alternative to

flexible risers, as being considered by Petrobras for the Marlim field. They may be used from both floating and fixed platforms. As a starting point for determining the scope of potential applications, allowable minimum bend radii of different pipe sizes should be considered. Though allowable bend radii reduce in the presence of other load components, such as tension and pressure, the catenary need not necessarily subtend an arc of 90 degrees from the seabed to the point of attachment to the platform. Based on the current work, the approximate minimum depths in which steel catenaries of different diameters can be used can be taken as twice the minimum bend radius.

Pipe OD (inch)	Minimum Bend Radius (m)
6	43
8	58
12	87
20	147
30	220
Assumes X65 material, allowable stress of 0.8 yield stress	

Steel Pipe Minimum Bend Radii

Some variations on the simple catenary pipe configuration are necessary to enable application of the concept on shallower waters and platforms other than a TLP. Details of these modifications are described below.

WHY STEEL CATENARIES?

The catenary export risers on the Auger platform have significant differences from conventional TLP export riser arrangements. At the seabed, the riser base, base connector and stress joint or flex joint are eliminated. At the platform, the riser is connected to the pontoon by way of a flex joint. The surface valve stack is statically mounted, removing the need for a hydropneumatic tensioner system and surface jumper hoses, and greatly simplifying access. By moving the risers out of the wellbay, the problems of designing to prevent interference with adjacent risers are also eliminated. Cost savings are made as a result of the simplified arrangement. As an alternative to rigid pipe solutions on fixed platforms, jumper spool tie-ins and caisson risers can be eliminated with an associated reduction in the offshore operations required for installation.

Steel catenaries also offer benefits as an alternative to conventional flexible risers. They can be suspended in longer lengths, removing the need for mid-depth arches or buoys. They can be used at pressures, temperatures and diameters which cannot be achieved by flexible pipe, allowing use of a smaller number of larger diameter lines, and are less costly. Furthermore, steel pipe is more adaptable for design purposes and has better availability than flexible pipe.

DYNAMIC ANALYSIS

The response of steel catenary risers in dynamic loading conditions is complex. Significant geometric nonlinearity can be exhibited near the attachment to the vessel and touchdown point on the seabed. A number of both general purpose and riser-specific programs are available to evaluate catenary behaviour. Due to the non-linearity of response, frequency domain methods used for analysis of rigid risers are unlikely to provide reliable results and non-linear time-domain methods are required. Much care and patience must be exercised when carrying out catenary analysis in order to obtain reliable results. Parametric analyses are generally required to ensure that modelling features such as element length, time step size, time step variation and convergence tolerances are suitable. Values of mass and stiffness damping, if used, must also be carefully selected. Many problems are encountered through inadequate assessment of modelling parameters and underestimation of the time required to produce meaningful results.

Analysis of storm conditions is carried out to optimise catenary length and geometry and take-off angle at the vessel. Consideration must be given to wave period and direction, current direction, tidal movements (in the

case of floating platforms) and installation tolerances. Regular wave analysis has been used in the current work, with random sea simulations to check key results. The most critical loading conditions generally occur when wave action is in the plane of the catenary. Worst case loading at the seabed touchdown point occurs when vessel offsets slacken the catenary. In the wave zone, maximum loading occurs when vessel motions are small, which for semi-submersible platforms and TLP's occurs with wave periods of approximately 10 seconds. Example catenary riser extreme storm displacement, rotation and bending moment envelopes, produced using FLEXCOM, are attached together with an example of the differences that can result through inappropriate modelling.

Evaluation of fatigue damage due to wave action is conducted using the same methods as used to determine storm response. Random sea loading is employed, as opposed to regular waves, in order that satisfactory statistical representation of behaviour is obtained. Fatigue damage may be calculated by summation of stress variation timetraces or linearisation using Fourier transformation of response. Using either approach, care must be taken to ensure that sufficient seastate durations are modelled and to demonstrate the validity of response linearisation between seastates of different magnitude and period.

Vortex induced vibrations (VIV's) may result in severe fatigue damage in many geographic locations where current velocities are high, including the Gulf of Mexico, West Africa and West of Shetland. Evaluation of response is often carried out using DnV guidelines. The VIV analysis program SHEAR, being developed at MIT through joint industry funding, is expected to offer improved estimation of response. Using both approaches, significant fatigue damage has been found in the locations identified above with an unmodified pipe surface profile. Vortex suppression devices, such as helical strakes are highly effective in suppressing vibrations, typically reducing vibration amplitudes by up to 80% of those found with an unmodified surface profile. The extent to which strakes, or similar devices are required, depends on the water depth and current conditions. The lower tension found near the bottom of the risers increases susceptibility to VIV's. However, extreme current velocities are often much lower near the seabed than at the surface. On catenary risers developed for West of Shetland applications, it has been found that suppression strakes are required over most of the riser length.

TOUCHDOWN POINT

The simple catenary is generally highly stressed near the touchdown point at the seabed. Storm loading results in an increase in the stress level, which may become unacceptable in extreme conditions. This problem is similar to that found in J-lay of steel and flexible pipe. In lay situations, however, weather limitations can generally be imposed. In long term applications, more severe weather conditions must be endured. Steps can be taken to improve response by optimising catenary length, but even very long, highly tensioned catenary shapes can have severe touchdown point bending moments. Further steps must therefore be taken to achieve acceptable response. The methods that have been investigated are as follows:

- Use of weights or chains
- Local use of higher strength material
- Use of one or more flex joints

Improvements can be made by use of one or a combination of the above. Local use of high strength steel is possibly the most straightforward approach and simply enables greater curvatures to be resisted. All other methods of response enhancement have the effect of controlling touchdown point geometry and hence the location of maximum curvature. Some additional assistance in control of touch down point response can be provided by vortex suppression strakes, which may be needed in high current applications. The strakes have the effect of increasing drag of the riser and tend to damp travelling waves initiated near the surface.

A further consideration in design of the touchdown point is wear or abrasion. Wave action and platform surge motion normal to the plane of the catenary can result in the riser being dragged laterally along the seabed. Prevention of damage can be achieved by increasing coating thickness or changing the type of coating used in the affected area.

VESSEL ATTACHMENT

Bending of steel catenaries near the water surface, as a result of wave action, can be both relieved and compounded by vessel motion. Differences between vessel and riser response can lead to high bending moments at the vessel attachment point. These may be accommodated by use of taper stress joints or flex-

joints, typically found at the base of vertical rigid risers. To avoid excessive loading on the platform, flex-joints form the preferable solution and have been adopted for the Auger TLP export risers.

A considerable amount of experience has been gained in the development and use of flex-joints for TLP risers. Of particular note are the high pressure flexjoints used on the Conoco Hutton and Saga Snorre TLP drilling risers. Some concerns exist regarding the possibility of damage to flex joints from explosive decompression of the rubber when they are used for gas flowlines. Such an event is not expected to be catastrophic, even though some surface damage to the flex elements may occur, but to alleviate these concerns, a design incorporating the use of bellows has been proposed by Oil States Industries for the Mobil Ram Powell TLP import lines.

INSTALLATION

Fabrication and installation can be carried out by all currently used and proposed methods of pipelay:

Welded pipe in S-lay	(Various)
Welded pipe with reelbarge	(Stena Apache, Northern Ocean Services Norlift)
Tow-out	(Costain, Rockwater)
Threaded connectors from semi or production vessel	(Hunting Merlin, NKK NKEL Premium)

The approach adopted may depend on design requirements such as fatigue life, design pressure, the need to use strakes or vessel availability. Welded connections, used with S-lay or J-lay installation, typically have less fatigue resistance than those made up with threaded couplings. Couplings such as Hunting's Merlin, being developed for pipeline applications and already used in TLP tethers, and NKK's NKEL premium threaded coupling, used in TLP production riser systems, have been developed for dynamic environments and provide good resistance to fatigue damage. Use of couplings for offshore make-up of flowline and riser can provide additional design flexibility, allowing decisions regarding field layout to be taken after production has begun. Tow-out may be a cost effective means of installation, provided pipe and coating weight combine to give a small submerged weight, in which case surface tow can be used with relatively inexpensive vessels.

COSTS

Assessment of the cost benefits of using steel catenary risers as alternatives to a number of conventional flowline/riser arrangements has been carried out. Approximate estimates of cost reductions that can be obtained are as follows:

12 to 20 inch TLP export riser	£1.5M
6 or 8 inch satellite tieback to jacket	£1.0M
6 to 10 inch FPS	50%

Cost reductions through use of a steel catenary as a TLP export riser result mostly from the reduced equipment requirements - no base, base connector, tensioner, centraliser or jumper hoses - and some saving in the operations required for flowline tie-in. For a satellite tieback to a jacket, the required hardware may be inexpensive and savings through use of steel catenaries stem largely from the reduction in offshore operations required. As an alternative to flexible pipe, cost reductions result largely from the difference in cost of the pipe, steel pipe being approximately 1/10th the cost of flexible pipe. Coating, installation and the need for flex-joints reduce this differential but significant benefits are still obtained.

In the estimates made above, no consideration has been given to benefits which may be gained from the lateral restoring forces offered by catenary risers. The assistance provided to the vessel mooring system may be significant if a number of steel catenary risers are deployed. No quantitative assessment of this benefit has yet been carried out, but combined riser/mooring system interaction is seen as an important area for further investigation.

CONCLUSIONS

Steel catenaries offer economical design configurations for flowline/platform interfaces across a broad

spectrum of platform types and environmental conditions. Catenaries can be used as an alternative to conventional arrangements of both rigid and flexible pipe. Riser response can be satisfactorily predicted, provided sufficient care is taken in modelling and analysis. The required hardware, such as flex-joints, couplings and installation equipment is well-developed and is readily available. Current use of the concept is limited to deep water applications, but the potential for cost reduction and design flexibility of the concept is expected to result in more widespread use of the catenary arrangement. Furthermore, in difficult conditions, such as high temperature, high pressure applications, steel catenaries possibly offer the only viable design solution currently available.