FLEXIBLE RISERS FOR TENSION LEG PLATFORM

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ABSTRACT

A review of recent use of flexible riser and flowline systems in conjunction with Tension Leg Platforms (TLP) is presented. Basis for the selection of flexible pipes over rigid pipe option on Conoco, Inc.’s Joliet project in the Gulf of Mexico and on Saga Petroleum’s Snorre project in the North Sea are highlighted. Dynamic analyses and design procedures for flexible risers are reviewed and illustrated by an engineering application. The assumed design case represents an 8-inch export flexible riser system to be installed on a TLP in 3000 ft water depth. The design of the 8-inch flexible pipe was conducted on the basis of multiphase flow transport, 4000 psi design pressure, a 15-year service life and the environmental conditions of the Gulf of Mexico.

NOMENCLATURE

\[ A = \text{flexible pipe cross-sectional area} \]
\[ H = \text{water pressure head} \]
\[ g = \text{acceleration of gravity} \]
\[ p = \text{fluid pressure} \]

Greek Symbols:
\[ \rho = \text{fluid density} \]

Subscript:
\[ i = \text{pipe internal properties} \]
\[ o = \text{pipe external properties} \]

FLEXIBLE PIPE SYSTEMS

Though flexible pipe as a marine product was introduced to the offshore market in the early seventies, it was not until 1978 that flexible risers were specified and installed in the Enchova field offshore Brazil (Machado, 1980) as part of a floating production system.

Since 1980, the use of flexible pipe has spread worldwide and is used in almost every offshore oil development today as witnessed in papers by Mahoney (1986) for North Sea application, Tillinghast (1990) for Gulf of Mexico, Gulf of Suez application, Tillinghast (1987) and Beynet (1982) for the Far East.

This type of dynamic application is typically used for floating production systems for high pressure production risers, export risers, chemical/water injection lines and gas lift lines. Currently, the main manufacturers of flexible pipes are Coflexip, Wellstream and Furukawa. At the present time, much interest in riser systems is shown by the operators as evidenced by papers by Beynet (1982) and Ashcombe (1990). Flexible pipeline systems are those recently completed in conjunction with Tension Leg Platforms and which are reviewed below. There has been increased use of TLP for offshore oil and gas production as TLP’s are being adapted to deepwaters. (Table 1).

References and Illustrations at end of paper
APPLICATION WITH TENSION LEG PLATFORM (TLP)

The flexible pipe export system for Conoco, Inc.’s Joliet project in the Gulf of Mexico is the first use of flexible pipe risers with a tension-leg well platform (TLWP) or a tension-leg platform (TLP). As reported by Tillinghast (1991), some of the merits of flexible pipe use were clearly demonstrated during the project installation phase where large diameter (8-inch, 10-inch) flexible pipes were abandoned in deepwater under threat of an approaching hurricane. The flexible pipes were later easily retrieved and installation was completed successfully. The flexible pipes were installed in water depths ranging from 930 to 1,760 ft in rough seabed conditions.

During 1992, flexible pipelines have proven their viability of use by adopting them in the flexible riser system at the Snorre-TLP which was installed in August 1992 in the Norwegian Sector of the North Sea. The riser system consists of seven individual risers passed from the flowline towhead in a free-hanging configuration up to the platform. The selection made by Saga to use flexible pipes is in parallel to Saga’s development plans of the Snorre field which will require the TLP relocation at later stages of production.

RISER DESIGN FOR TLP

Industry practice calls for several types of riser configurations typically used in conjunction with Floating Production/Loading Systems. The standard five configurations generally used are:

- Free-Hanging Catenary
- Lazy-S
- Lazy Wave
- Steep-S
- Steep Wave

Figure 1 illustrates these typical types of riser configurations. The figure also illustrates a schematic of a new riser configuration proposed by Wellstream for the Alcorn Linapacan Field Development Project. The choice of riser configuration is usually based on economic criteria, position of the wells, wave and current forces, motion response and excursions of the vessel or surface buoy as well. In the absence of TLP heave motion a Free-Hanging Catenary riser configuration would be the first choice.

To illustrate, design parameters impacting the suitability of a particular configuration for use with Tension Leg Platform, two riser design cases were studied which reflect the selection of a Catenary configuration versus a LazyWave configuration. (Fig. 2). The computer analyses were carried out at Wellstream’s engineering offices using computer program FLEXRISER-4 developed by Zentech, UK. Design basis which was used in computer analyses is listed in Table 2. The design structure of the flexible riser pipe is illustrated on Figure 3. The design of the 8-inch flexible pipe is based on multiphase flow transport, 4000 psi design pressure and a 15-year service life.

DESIGN CRITERIA

Efficient design of flexible riser systems is made possible by using computer-based solution techniques.

The design criteria of flexible riser systems is usually based on allowable pipe curvatures and tensions prescribed by the pipe manufacturer, clearances between the riser and other structures, and boundaries during its dynamic response. The allowable curvatures and tensions are based on full-scale test procedures and stress analysis carried out by the manufacturer. These limits ensure the pipe is not over-stressed when responding to dynamic loads and vessel motions. The system is generally designed so the pipe is tensioned throughout its dynamic response cycle. Minimum clearances are also specified to avoid clashing problems between riser and seabed, or riser and vessel, and between the riser or other adjacent risers, cables, or mooring systems.

DESIGN PARAMETERS AND PROCEDURES

The main problem in designing flexible riser systems is the large number of design parameters. The environmental conditions, vessel or calm buoy motions and riser properties are usually well-defined. The design procedure can be described as consisting of three stages.

First Stage

The first stage in designing a flexible riser system is determining an acceptable system layout. The first stage is based on static analysis. It is normal to carry out a parametric study assessing the effect of changing the design parameters (i.e., system geometry and length) on the static curvature and tension. Based on the results of this parametric study, the design selects a suitable range of system geometrics and lengths satisfying the design criteria. The parametric study will also assess the static effects of vessel offset (displacement of the top end) and the current loading in different directions.

Second Stage

The second stage in the design procedure is performing a dynamic analysis of the system to assess the global dynamic response. A system layout and length is chosen from stage one and a series of dynamic load cases are considered. These load cases combine different wave and current conditions, vessel or surface buoy positions, and riser contents in order to prove an overall assessment of the riser suitability in operational and survival conditions. The corresponding analyses are then carried out and dynamic curvatures, tensions and clearances are checked against the design limits.

The majority of riser dynamic analyses packages, including FLEXRISER-4, make use of the
“concept of effective tension” (Sparks. 1983). Sparks addressed the drilling riser case where the riser is essentially restrained. A catenary riser on the other hand turns 900 to meet the sea bed. It is subject to friction and can be subject to compression due to these conditions. This concept accounts for the effects of external and internal hydrostatic pressure acting on the internal and external surfaces of the pipe wall. It is the effective tension which controls the stability of the riser from the point of view of deflection. The relationship between effective tension, Teff, and the “true wall” tension, Twall, that acts on the pipe wall and contributes to stress in the pipe wall is:

\[ T_{\text{wall}} = T_{\text{eff}} + (p_i \pm \rho g H_i) A_i - (\rho g H_D) A_D \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots (1) \]

where:

- \( T_{\text{wall}} \) = Wall tension to be used for stress calculation in flexible pipe wall.
- \( T_{\text{eff}} \) = Effective tension as predicted by the riser analysis computer program.

The effective tension is independent from internal and external pressure. Given the effective tension, as predicted by the riser global analysis program, the true wall tension may be simply calculated from the equation (1). Since internal pressure affects the \( T_{\text{wall}} \), it is important to carefully note the internal pressure conditions in the pipe under the maximum load cases as well as the limiting operational conditions when pressure in the riser may be released or maintained.

**Third Stage**

The third stage in the design procedure is performing detailed static and dynamic analyses of local areas to design particular components. This stage is presented in a separate publication (Brown, 1989).

Key papers by operators in this regard are Out (1989), Boef (1990) of SIPM and de Oliveira (1985) of Conoco. This third stage of design also includes a question of life expectancy which has recently been addressed by Claydon, et al (1991).

**RESULTS OF RISER DESIGN**

In order to illustrate the potential and the limitations of adopting specific riser configurations, results are presented of riser dynamics analyses for two design cases of Catenary and LazyWave riser configurations. Snapshots of the riser configuration and distribution of axial force along the riser are shown in Figures 4-a/b and 5-a/b, respectively for the Catenary and LazyWave configurations. Although the riser top tension for the LazyWave configuration is only 100kN less than that for the Catenary, final selection of configuration will depend on the total allowable load exerted on the TLP and potential of risers interference.

**RISER SERVICE LIFE ANALYSIS**

Limits on the service life of a flexible riser are traditionally linked to weakening due to the wearing away of tensile wire metal from repeated pipe flexure as a result of environmental dynamic loading. Flexure changes the natural position of the tensile wires, giving the outer and inner tensile wires a tendency to slide across each other so as to wear away a small amount of metal during each flexure cycle. However, friction due to contact pressures will prevent this sliding unless the bend curvature is sufficiently great and the bend radius is correspondingly small. Moreover, when the wires are prevented from rubbing directly on each other as a result of lubrication or separation by an intervening plastic layer, there is a dramatic reduction in the wear that will occur if the wires do actually slide across each other. Finally, there is life degradation only when wire stress levels are high enough to bring fatigue failure mechanisms into play. If initially the wire stresses were not sufficiently high, they might become so later as a result of reduction of wire cross section due to the wearing away of metal. A preliminary life prediction analysis was completed for the 8-inch riser. There appears to be no chance of occurrence of the degradation process described above, and therefore there is no resulting limit to service life.

**ANCILLARY EQUIPMENT FOR FLEXIBLE RISERS**

**End Fittings.**

Each flexible pipe has an end fitting to connect one flexible pipe length to another or to the customer’s facilities. The end fittings are designed to terminate the ends of the layers, to maintain the integrity of the pipe structure and to provide a flange or other connection as required to mate with the customer’s production facilities. Each of the flexible pipe layers is individually terminated to maintain fluid-tight integrity and to sustain the imposed loads. The end fitting includes seals to ensure a reliable fluid-tight seal to the Flexbarrier internal thermoplastic layer and a seawater-tight seal to the Flexshield outer thermoplastic layer.

**Vent Valves.**

Gas venting is provided in flexible pipes to relieve pressure in the Flextensile annular space due to the volume build-up of gas that permeates through the Flexbarrier thermoplastic sheath. If pressure relief were not provided, the outer sheath of the pipe could rupture during service or retrieval. Permeation rates are quite low and gap channels between Flextensile wires are in general adequate to convey permeated gas to vent valves in end fittings. In the event the vent valves are insufficient to vent permeated gases, burst disks in the outer sheath are provided to prevent damage to large sections of the outer sheath.
Bend Stiffeners.
In order to prevent the flexible pipe from traversing beyond its minimum bend radius during severe storm conditions, bend stiffeners at the riser top connection are specified if it is required. The bend stiffeners consist of a polyether-polyurethane material and are designed specifically to meet the requirements of each project.

Cathodic Protection.
A cathodic protection system is specified to minimize galvanic corrosion to exposed steel. Sacrificial anodes are installed at each end fitting.

Distributed Buoyancy.
To provide for the distributed buoyancy specified in the riser analysis for LazyWave configuration, cylindrical buoyancy modules are specified. The modules are molded of rigid syntactic foam containing glass microspheres and fiberglass macrospheres encapsulated in a plastic resin. The modules are covered with an integrally molded fiberglass skin to protect against impact, abrasion and handling damage.

CONCLUSIONS
Although the market demand and apparent need for flexible pipes have been associated with floating platforms, vessels and buoys, the recent use of flexible pipeline systems with Tension Leg Platform has advanced the flexible’s horizon in the market place. As oil and gas production moves into the deeper offshore waters, development strategies may require the use of flexible pipe systems. These deepwater projects will require the development of materials and techniques whereby flexible pipes with these materials can be manufactured efficiently and economically. The most evident need is the availability of marine vessels and equipment that will be needed to install flexible pipe flowline and riser systems in water depths of 1000 meters and greater. The second area is to ensure technology development of foam materials to meet buoyancy and thermal insulation requirements in deep waters.

REFERENCES
American Petroleum Institute, 1987, “RP17B - Recommended Practice for Flexible Pipe,” Houston, TX.


### Table 1: TLP data comparison

<table>
<thead>
<tr>
<th>Platform name</th>
<th>Location</th>
<th>Operator</th>
<th>Water depth, m</th>
<th>Platform Displacement, t</th>
<th>Installation date</th>
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</thead>
<tbody>
<tr>
<td>Heidrun</td>
<td>North Sea Norway</td>
<td>Conoco</td>
<td>350</td>
<td>175.000</td>
<td>1995</td>
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<tr>
<td>Auger</td>
<td>Gulf of Mexico</td>
<td>Shell</td>
<td>870</td>
<td>70.000</td>
<td>1993</td>
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<td>Snorre</td>
<td>North Sea Norway</td>
<td>Saga</td>
<td>310</td>
<td>115.000</td>
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<tr>
<td>Jolliet</td>
<td>Gulf of Mexico</td>
<td>Conoco</td>
<td>535</td>
<td>17.000</td>
<td>1989</td>
</tr>
<tr>
<td>Hutton</td>
<td>North Sea U.K.</td>
<td>Conoco</td>
<td>145</td>
<td>70.000</td>
<td>1984</td>
</tr>
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### Table 2. Design Data for Catenary and LazyWave Flexible Risers

<table>
<thead>
<tr>
<th>Design parameters</th>
<th>Value</th>
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<tbody>
<tr>
<td><strong>Flexible Riser pipe data:</strong></td>
<td></td>
</tr>
<tr>
<td>Internal diameter, m</td>
<td>0.2</td>
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<tr>
<td>Outside diameter, m</td>
<td>0.3</td>
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<tr>
<td>Wt. in Air, kg/m</td>
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<tr>
<td>Axial Stiffness, N</td>
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<tr>
<td>Bending stiffness, Nm2</td>
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<td>Torsional Stiffness, Nm2</td>
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<tr>
<td><strong>Environmental data:</strong></td>
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<tr>
<td>Water depth, m</td>
<td>920</td>
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<tr>
<td>Max. Wave height, m (100y)</td>
<td>22</td>
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<tr>
<td>Wave Period, s</td>
<td>13</td>
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<tr>
<td>Top. Current Speed, m/s</td>
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<td><strong>TLP Excitation:</strong></td>
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<tr>
<td>Linear displacement, m</td>
<td>25</td>
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<tr>
<td>Surge Amplitude, m</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total buoyancy for LazyWave Riser, kN</strong></td>
<td>350</td>
</tr>
</tbody>
</table>
Figure 1  Typical Flexible Riser Configurations and Environmental Loadings

Figure 2 - Schematic of Riser Configuration Alternatives
Figure 3. Schematic of a Flexible Riser Pipe Structure

1 Flexbody (Interlocking Steel Carcass)- Stainless 316L
2 Flexbarrier (Polymer Pressure Barrier)-Nylon 11
3 Flexlok (Steel Hoop Strength Layer)-Carbon Steel
4 Flexwear (Polymer Anti-abrasion Layer)-Nylon 6/12
5 Fextendsile (Helical Steel Armor)-Carbon Steel
6 Flexwear (Polymer Anti-abrasion Layer)-Nylon 6/12
7 Fextendsile (Helical Steel Armor)-Carbon Steel
8 Flextape (Polymer Tape Barrier)-Fabric
9 Flexshield (External Polymer Layer)-Nylon 6/12
Figure 4-a  Snapshot of Catenary Flexible Riser (I)

Figure 4-b  Distribution of Axial Force along Catenary Riser
Figure 5-a  Snapshot of LazyWave Flexible Riser (II)

Figure 5-b  Distribution of Axial Force along LazyWave Riser