Application of Large Diameter Steel Lazy Wave Risers for Production Systems in Deepwater Norway

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Abstract
In the current low oil price market, innovative low cost solutions are necessary for development of new fields and late life recovery from existing fields. Steel Lazy Wave Risers (SLWRs) provide low cost alternatives to flexible risers and offer flexibility during design and late life for Floating Production Systems (FPS) in deepwater North Sea. While flexible risers are limited to a maximum of 16” inner diameter, steel risers are qualified for pipe diameters of over 24”, which can help reduce the number of risers tied-back to the FPS and lower development costs.

Deepwater fields in the North Sea greater than 400m water depth have traditionally been developed using flexible risers. The steel lazy wave riser (SLWR), a variation of the steel catenary riser (SCR) with added buoyancy near the touchdown point at the seabed, have recently been deployed in the GoM and Brazil for deepwater applications. Due to simplicity of design, good track record and qualified suppliers, fabrication and installation methods for SCRs, SLWRs have become a logical extension of the SCR for more severe environments and vessel motions. Harsh North Sea environments result in high FPS motions. Buoyancy installed on the SLWR helps decouple vessel motions at the riser touchdown, which ensures that the required strength and fatigue performance can be achieved.

Development of a 24in SLWR for a North Sea application in 850m water depth is discussed. The strength and fatigue response of the resulting riser arrangement is evaluated. The advantages and disadvantages of SLWR North Sea applications are assessed and costs for flexibles and SLWR’s compared.

Introduction
The majority of deepwater developments offshore Norway greater than 400m water depth have traditionally been developed using flexible risers. The relatively shallow water depth, low pressure and temperatures, good strength and fatigue performance make flexible risers very attractive. Most of the flexible risers in the North Sea have internal diameters from 6 to 12inches. However, for deepwater gas developments offshore Norway the application of flexible risers is limited to a qualified size of 16inch or less.

Large diameter steel catenary and steel lazy wave risers deployed from deepwater floating production systems are a potential low cost alternative to flexible risers for production and export of gas. Steel lazy wave risers are a variation of the steel catenary riser (SCR) with added buoyancy near the touchdown point at the seabed to decouple vessel motions in that region from those induced by waves and vessel motions at the surface in harsh North Sea conditions, which results in better strength and fatigue performance compared to an SCR.

This paper presents the evaluation of a large diameter 24inch SLWR for application in an 850m water depth offshore Norway for two types of floating production systems, a circular FPSO and a Spar. Multiple design iterations are carried out with varying wall thickness, hang-off departure angle and buoyancy distribution and the resulting riser arrangement is described. The resulting riser configurations and riser response for the two vessels are compared. Sensitivity to hang-off point
location is assessed for each FPS. The design challenges for SLWR’s in relation to installation and hydrotect are discussed and costs for flexibles and SLWR’s are assessed and compared.

**Design Parameters**

The key line pipe operational and environmental parameters considered for the design and assessment of the 24inch OD SLWR are given in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Diameter (OD) and Wall Thickness (WT)</td>
<td>OD: 610mm (24inch), WT: 32mm (1.25inch)</td>
</tr>
<tr>
<td>Internal Fluid Pressure</td>
<td>Nominal: 135bar; Hydrotect: 162bar</td>
</tr>
<tr>
<td>Internal Fluid Density</td>
<td>Nominal: 140kg/m³; Hydrotect: 1,025kg/m³</td>
</tr>
<tr>
<td>Significant Wave Height (Hs)</td>
<td>100-Year Return: 16m; 1-year Return: 11.5m</td>
</tr>
<tr>
<td>Wave Peak Period (Tp)</td>
<td>100-Year Return: 18s; 1-year Return: 15s</td>
</tr>
<tr>
<td>Vessel offset (% of water depth)</td>
<td>Extreme Strength: ±10%; Hydrotect: ±3%</td>
</tr>
</tbody>
</table>

**Floating Production Vessels**

Two different floating production system vessels are considered for the 850m water depth application: a generic circular FPSO and a truss Spar. The base case hang-off point for the circular FPSO is 16m below MWL and at the edge of the hull, a horizontal distance of 29m from the vessel CoG. An alternate hang-off location at 16m below MWL and close to the centre of the hull at 2m from the CoG is also considered. The base case hang-off location for the Spar is at the bottom of the hard tank 150m below MWL and a horizontal distance of 6m from the vessel CoG. An alternate hang-off location close to the Spar CoG at 50m below MWL and at the edge of the hard tank is also considered.

The two FPS are selected because of their significantly different motion characteristics. For the 100year storm wave, the FPSO has a heave range of 35m, surge of 30m and pitch of 15deg. Comparatively, the Spar has a significantly lower heave range of 9m. The surge of 27m and pitch of 11deg for the Spar are comparable to that of the FPSO.
Riser Configurations

Two SLWR configurations are developed for the 24 inch riser for the circular FPSO and Spar. The buoyancy upthrust and distribution length selected are based on being able to accommodate vessel motions and offsets ranges in storm conditions at extreme offsets and internal fluid variability. The driving criteria for selecting an optimised configuration are shown in Figure 1. The resulting riser configurations selected for the FPSO and Spar are provided in Figure 2. Owing to the moderate water depth of 850m, the selected riser configurations have a large hang-off angle of 18 degrees, 620m of distributed buoyancy section and a large horizontal distance between hang-off and touchdown point of approximately two times the water depth. This is necessary in order to accommodate the range of vessel offsets. When compared, the two configurations have the same hang-off angle and similar overall lengths. The sag bend section of the Spar configuration is 70m above the seabed, compared to 100m for the FPSO. A flex-joint is required at the riser hang-off for both vessels.

Figure 1 – SLWR Configuration Drivers

Acceptable stresses along the riser for storm conditions

Small buoyancy section to reduce cost

Acceptable levels of bending at TDP

Riser must not touch the seabed

Acceptable levels of compression at sag bend

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Strength and Fatigue Analysis Methodology

The strength and first order wave fatigue response of the 24inch riser is assessed in conditions typical of offshore Norway. Strength assessment is carried out for a 100-year return condition to evaluate extreme load response and a 1-year return condition to evaluate response for the hydrotest condition. Near and far vessel offsets of 10% water depth are considered as well as a 1% exceedance current with surface current speed of 0.88m/s.

First order wave fatigue analysis (FOF) is conducted for the circular FPSO to determine riser performance for long term loading and to get an indication of fabrication details that will be needed to meet fatigue design life requirements. The circular FPSO is selected for fatigue assessment as it has more onerous vessel motions. The analysis is conducted using the long term wave scatter data. A 75% exceedance background current with surface speed of 0.23m/s is considered for the fatigue analysis.

Strength Response – Circular FPSO

The strength response of the SLWR for the FPSO for the base case and alternative hang-off locations for the near offset are shown in Figure 3. The strength response is assessed using API-RP-2RD [1]. The von Mises stresses for the near offsets are 15% higher than for the far offsets and drive the strength response.

Owing to the optimisation carried out for the riser configuration, the maximum stress peaks in the SLWR are similar in the sag, buoyancy and touchdown sections of the riser. The dynamic effect due

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to the vessel motions coming from wave loading increases maximum stresses by 20% while stresses at the riser touchdown remain almost unchanged. These trends demonstrate the decoupling effect that the buoyancy section has on the riser response due to vessel motions. The strength response for the alternate hang-off location closer to the COG of the FPSO is slightly better and is attributed to the reduced pitch and pitch induced heave motions for the alternate hang-off location.

**Figure 3** – SLWR Strength Response for Circular FPSO

**Strength Response – SPAR**
The strength response of the SLWR for the Spar for the base case and alternate hang-off conditions for the near offset are shown in Figure 4. Strength response for the Spar is very similar to that found in the circular FPSO. The von Mises stresses for the near offsets are 20% higher than the stresses in far offsets and drive the strength response.

For the base case hang-off location at the bottom of the hard tank, the stresses below the riser hang-off drives the response. The high stresses are a result of porch movements resulting from vessel surge and pitch motions due to the hang-off point being some distance away from the vessel COG which is at about 50m below MWL. Moving the hang-off point closer to the COG results in a 15% improvement in the maximum dynamic stress compared to the base case. The benefit of moving the riser hang-off close the COG is limited to the top of the riser due to the decoupling effect of the lazy wave on the riser response. The dynamic effect due to the vessel motions coming from wave loading results in 10% higher stresses, which is lower than the 20% for the FPSO. This demonstrates the
benefits of the Spar in regards to improved riser performance resulting from more favourable vessel heave and pitch motion characterises.

**First Order Fatigue Response**
The fatigue life along the length of the riser for the alternate hang-off location is shown in Figure 5. The critical location for fatigue is at the top of the riser, below the hang-off point. The minimum fatigue life in the hang-off region is 50 years for a DNV E fatigue curve. The fatigue life improves significantly to 250 years for the DNV C1 curve [2]. The fatigue response in the rest of the riser including the touchdown region is acceptable and demonstrates the decoupling effect that the lazy wave has on the fatigue response.

The results demonstrate that for the fatigue performance at the hang-off to meet design requirements, a higher quality weld for the top section of the riser. It should be noted that consistently achieving C1 class welds offshore can be challenging from a schedule and cost standpoint as it increases the risk of weld cut outs. Hence, it is preferred to try and minimise the number of C1 class welds required. Alternatives include using a thicker wall pipe in the critical region or upset end pipe is required. Upset ends have been shown to be a potential solution for increasing fatigue life in a Joint Industry Project (JIP) and are feasible to manufacture [4].

The riser design at the hang-off can be improved by using a titanium taper stress joint or a FlexJoint integrated with a long tapered forging. Further optimisation of the riser configuration by varying the hang-off angle and buoyancy distribution can also potentially help improve fatigue performance.

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Following the trend from the strength response, the fatigue response is more favourable for the alternative hang-off location closer to the COG of the FPSO, as a result of reduced vessel pitch motions.

**Figure 5 – First Order Fatigue Response – Alternate Hang-off**

**Hydrotest Assessment**
Hydrotest of the riser during commissioning is a known challenge for gas risers. As the buoyancy arrangement is designed for a gas filled riser, when the riser is filled with sea water, the riser shape can change to a simple catenary with a reduced hang-off angle. This can result in severe bending loads and compression at the TDP. The von Mises stresses along the riser for the hydrotest case for a 1-year return environment are shown in Figure 6, for a riser configuration driven by gas filled conditions alone.

A proposed solution to mitigate against the high stresses at the touchdown region during hydrotest is to use removable buoyancy modules. Buoyancy modules would be temporarily installed on the riser via ROV to provide additional buoyancy for the duration of the hydrotest to control the shape of the riser. The additional buoyancy can be removed once the test is complete.

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Cost Assessment

Fabrication and installation activities are major factors in the costs for SLWRs and account for around 50% of total riser delivery costs with material and engineering costs making up the remaining 50%. Hence, installation method plays a key role in the costing. J-lay and S-lay are both available options for installation. If feasible, J-lay is the preferred option, as it is cheaper than S-lay.

Installation of strakes and buoyancy modules add to installation costs as they have the potential to become a bottleneck during installation. Hence their design and coverage should be optimised to reduce installation time and cost. This is less of a concern for S-lay as these activities can be conducted in parallel with welding. Since welding accounts for most of the installation time and costs, specification of high quality welds also increase installation costs as they increase the risk of weld cut-outs. Hence high quality welds should be minimised or avoided offshore.

For flexible risers, about 65% of total delivery costs come from material costs which is significantly higher than it is for SCRs and SLWRs. In current market conditions, installation costs are generally lower, which when combined with an optimised design can help bring down overall costs. Overall, when comparing costs for the similar size, SLWR risers are 20-30% cheaper than flexible risers.

The larger available diameters for SLWRs also provide even further saving for gas export compared to multiple smaller flexible risers.

Conclusions
Most of the deepwater developments in offshore Norway have traditionally been developed using flexible risers. However, their application is limited by size and cost. In the changing oil and gas market, large diameter SLWRs are a potential lower cost alternative for deepwater developments.

The selected SLWR configurations for the two vessels evaluated here are very similar as their behaviour is driven primarily by water depth and vessel offset range.

The SLWR configurations selected for the FPSO and Spar have acceptable strength performance. The stress peaks are similar in the critical regions for the optimised riser configurations. Moving the hang-off point closer to the COG, results in slightly improved strength response for the FPSO. However, this makes installation more difficult and may require hull modifications. For the Spar, moving the hang-off point closer to the COG, results in a significant improvement in the riser response resulting from reduced porch velocities. This is relatively easy to achieve through the use of an external hang-off point and external hard piping.

The critical fatigue response for the SLWR is below the riser hang-off point and is sensitive to the hang-off location and can be significantly improved if moved closer to the COG. The critical location for fatigue is located about 15m below the hang-off. The proposed options for improving fatigue response at the top of the riser includes specifying high quality welds, using thicker wall pipe, improving the design of the hang-off interface and further optimisation of the riser configuration. Based on the strength response of the Spar compared to the FPSO, a more favourable fatigue response is expected for Spar.

In field hydrotest is a regulatory requirement for steel risers and a known issue for gas risers. For the hydrotest case, to achieve the desired strength response, the use of removable buoyancy modules to temporarily provide additional buoyancy for the duration of the hydrotest is proposed. This technology is currently available and has a growing track record.

Fabrication and installation costs account for about half of the SLWR delivery costs. Hence, design and coverage of strakes and buoyancy modules should be optimised to reduce installation time and cost. In comparison, for flexible risers, material costs account for a majority of total costs. Overall, SLWRs are expected to be 20-30% cheaper than equivalent flexible risers. A further more significant cost benefit over flexible risers comes from being able to use large OD SLWRs instead of multiple smaller risers leading to even more significant cost savings.

Overall it is demonstrated that large diameter SLWRs are technically feasible in terms of strength and fatigue response and can be deployed from production systems with a wide range of motions in harsh offshore Norway environments. Some technology challenges exist in terms of fatigue response and hydrotest, which can be overcome through use of qualified solutions. Overall, large diameter SLWRs provide a viable low cost alternate solution for risers systems in offshore Norway.

References


Definitions

API  American Petroleum Institute
CoG  Centre of Gravity
DNV  Det Norske Veritas
FOF  First Order Fatigue
FPSO  Floating Production Storage and Offloading Vessel
Hmax  Theoretical Maximum Wave Height
Hs   Significant Wave Height
MSL  Mean Sea Level
SCF  Stress Concentration Factor
SCR  Steel Catenary Riser
SLWR  Steel Lazy Wave Riser(s)
TDP  Touch Down Point
TDZ  Touch Down Zone
Tp   Spectral Peak Period
VIV  Vortex Induced Vibration