Petrobras P-55 SCR Design - Challenges and Technical Solutions

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ABSTRACT

Petrobras are developing the Roncador field located offshore Brazil and plan to develop part of this field using the P-55 semi-submersible, located in approximately 1800 meters water depth. This paper presents the key engineering challenges, solutions, and lessons learned from the FEED analysis of selected steel catenary risers attached to the P-55 floating production unit (FPU).

KEY WORDS: SCR; VIV; P-55; P55; Campos

INTRODUCTION

The Roncador oil field, which contains an estimated 2.7 billion barrels of oil, is located in the Campos Basin offshore Brazil in a water depth of approximately 1800 meters. The Brazilian state oil company Petrobras plans to develop module III of the field using the semi-submersible P-55 vessel.

The tools and methods used by 2H in this analysis are described in this paper, as well as the obstacles and technical challenges overcome during the design of this system. It is considered that these lessons will have significant relevance to future SCR projects offshore Brazil and in other regions of the world.

Seven risers were selected for the FEED analysis. The criteria used for this selection were: magnitude of the induced vertical motions at top connection points; the need for high insulation properties and critical azimuths for VIV response. The previous experience of Petrobras in similar projects, as referenced, was particularly useful in the selection of critical risers.

Petrobras issued a technical specification covering all of the areas of analysis that should be performed for the SCRs design. For each selected riser a range of design activities is specified including wall thickness sizing, extreme storm analysis, engineering critical assessment (ECA), installation, wave fatigue, VIV fatigue and interference analysis on selected riser pairs.

According to the Petrobras technical specification, the SCR design was to be conducted over two separate analysis cycles. The main reason for this was to allow vessel mooring limits and design parameters, which were being updated during the course of the FEED, to be incorporated in the second analysis cycle. However, a secondary benefit was that lessons learnt and recommendations for improvement from the first cycle of the analysis could be employed in the second phase.

The objective of the work was to demonstrate feasibility of SCR configurations for the field development.

OUTLINE OF THE DEVELOPMENT

The Roncador oil field is located offshore Brazil in the Campos Basin in a water depth of approximately 1800 meters. The Brazilian state oil company Petrobras is planning to build the P-55 semi-submersible vessel in order to develop module III of the field.

Following a preliminary study conducted by Petrobras, steel catenary risers (SCRs) have been selected as the preferred riser configuration for the development.

The 20 SCRs connected to P-55 are divided into two separate groups:

Infield SCRs
- Thirteen 8-inch SCRs, and Steel Flowlines, with rigid diverless jumpers connecting the flowlines to the wet production christmas trees.
- Three 10-inch SCRs for three pairs of water injection wells.
- One 12-inch oil import pipeline from Module IV of the Roncador development to P-55

Export SCRs
- The export system comprises of two 12-inch oil pipelines, where the first is 50km long, from P-55 to the PRA-1 fixed platform installed in 100m water depth, and the second is approximately 8 km long, from P55 up to the vicinities of the P-54 floating production unit, which is also located in the Roncador Field.
- The produced gas will be exported via a single 12-inch pipeline.

The risers selected for FEED analysis are three production risers, one
water injection riser, both oil export risers and the gas export line. These risers cover the 4 different riser functions for the development, as well as the critical hang off locations and top angles at the vessel. As such they are expected to show the worst response of each riser type. A summary of the risers analyzed is shown in Table 1 and their locations relative to the vessel shown in Figure 1.

For the production and water injection lines, clad double seamed welded pipe is to be employed at the top of the risers and at the TDP in order to eliminate the effects of corrosion.

Table 1 - Risers Analyzed During FEED Analysis

<table>
<thead>
<tr>
<th>Riser Number</th>
<th>Function</th>
<th>Outer Diameter</th>
<th>Riser Top Angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Production</td>
<td>8inch</td>
<td>17</td>
</tr>
<tr>
<td>11</td>
<td>Production</td>
<td>8inch</td>
<td>20</td>
</tr>
<tr>
<td>17</td>
<td>Production</td>
<td>8inch</td>
<td>17</td>
</tr>
<tr>
<td>29</td>
<td>Gas Export</td>
<td>12.75inch</td>
<td>15</td>
</tr>
<tr>
<td>30</td>
<td>Oil Export</td>
<td>12.75inch</td>
<td>17</td>
</tr>
<tr>
<td>35</td>
<td>Oil Export</td>
<td>12.75inch</td>
<td>17</td>
</tr>
<tr>
<td>37</td>
<td>Water Injection</td>
<td>10.75inch</td>
<td>20</td>
</tr>
</tbody>
</table>

Figure 1 - Risers Analyzed During FEED Analysis

The Key Challenges Of The Project

The main challenges of the design are listed below and how these challenges were faced and overcome is addressed in the following sections of this paper.

- The reduction of fatigue damage at the Touch Down Point (TDP) to achieve acceptable fatigue lives.
- To minimize clad length and hence the cost of all infield risers;
- To minimize strake length in order to minimize installation time and costs;
- To optimize strake positioning to achieve the target design life of 250years;
- To account for damage spreading at the TDP due to low frequency vessel motions during VIV excitation;
- To obtain acceptable riser response during extreme storm conditions and maintain maximum stresses below allowable limits.

ACHIEVING ACCEPTABLE FATIGUE LlFES AT THE TDP

By far the biggest challenge of the project was meeting the 250year target fatigue life limit for all SCRs at the TDPs. As with all Steel Catenary Riser applications the TDP is subjected to enormous levels of cyclic bending as the riser lifts off and returns to the sea-bed with every wave and movement of the vessel at the surface. Fatigue analysis conducted in the first analysis cycle identified that if an engineering solution could not be found, fatigue lives at the TDP would be prohibitively small and the project unfeasible.

The causes of fatigue damage at the TDP are listed below. Some of the causes cannot be avoided, and some can only be avoided by using costly materials or accessories:

- **Vessel motions due to wave loading** – could not be altered in FEED;
- **Vessel motions due to low frequency wave loading** – could not be altered in FEED;
- **Vortex induced vibrations** - as a result of both long term and extreme currents passing over the riser – can be alleviated by VIV suppressant strakes;
- **Corrosion** in the inner wall of the SCRs – Can be discounted if corrosion resistant clad pipe is used.

Consequently, before considering costly approaches for improving fatigue life, it must be ensured that the analysis approach is not overly conservative and that the fatigue analysis accounts for mean offset and low frequency motions of the vessel which will move the TDP position over time, and hence distribute the damage at the TDP over a greater length of pipe.

Offsets and Low Frequency vessel Motions Under Fatigue Loading

The offset scatter and low frequency motions to be used in the wave fatigue analysis was obtained from the statistical treatment of the time series of the vessel motions, when the environmental loads of wave, wind and current are acting on the vessel, mooring lines and risers. These values were obtained using a coupled analysis model.

A coupled formulation incorporates in a single code and data structure, a hydrodynamic model for the representation of the vessel and a 3D finite-element model for the representation of the hydrodynamic and nonlinear structural dynamic behavior of the mooring lines and risers.

Due to the computational costs in the fully coupled methodology, the hybrid analysis procedure has been proposed to circumvent this problem, where the vessel movements are analyzed by a coupled form (considering mooring lines and risers modeled by a poor Finite Elements mesh) and the structural response of mooring lines and risers (with a refined mesh) by an uncoupled form, applying in each individual line the motions obtained from the coupled model.

Following the Hybrid procedure, that combines coupled and uncoupled formulations, the offsets were carried out by the mean of the time series and the low frequency motions by the filtering of the 1st order parcel of the original time series of the vessel motions.
Wave Fatigue

For the calculation of the wave fatigue damage, the best representation of the non-linear characteristics is obtained from random dynamic analysis in the time domain. For this design, 122 load cases with their respective percentage of occurrence, using bi-modal wave data and current profiles from the location were considered.

Thus, it is possible to determine the long term history of local stresses on the critical regions of the structure, in 8 distinct points of the cross section of the welded joints and identify all stress cycles and respective amplitudes.

VIV Fatigue Damage Spreading At the TDP

In order to account for the movement of the TDP as a result of movement of the vessel, low frequency vessel motions must also be applied during time domain wave fatigue analyses. However, accounting for low frequency vessel motions during VIV is more complex and is accounted for in the P-55 FEED study using the following methodology:

- For each riser the motion of the hang-off due to low frequency vessel motions and mean offset are determined and a histogram of hang-off motion created. Only hang-off motions in the plane of the riser (near and far) are considered in the histogram. Transverse motions are conservatively neglected;
- A combined hang-off histogram of near-far motion is created for each riser hang-off, considering low frequency motions from all fatigue seastates and their associated probability of occurrence;
- Static offset analysis is carried out for each riser to determine the relationship between vessel hang-off motion in the plane of the riser and change of TDP position;
- Using the derived relationship between hang-off movement and change in TDP position, the in-plane hang-off motion histogram is converted into a TDP movement histogram;
- The peak fatigue damage at the TDP is obtained from VIV analysis conducted using the software package SHEAR7, considering only the nominal TDP position.
- The nominal peak TDP damage is spread considering that the TDP position moves from the nominal position to the positions given in the histogram. The damage at each position is factored by its probability of occurrence.
- The final fatigue damage is summed for each element in the TDP region.

Using this technique fatigue lives at the TDP are shown to be approximately 4 times less severe than if TDP spreading is not considered. Typical profiles of spread and unspread damage are shown in Figure 2.

Vessel Active Mooring

Even accounting for spreading the damage due to VIV and wave effect at the TDP, high levels of fatigue damage are found at the TDP locations of all of the P-55 SCRs. In order to meet fatigue life targets, an active mooring system is required over the field life in order to help further distribute the damage at the TDP locations. The active mooring system concept proposed involves moving the vessel on its moorings slightly, in order to shift the nominal TDP position of each riser over the course of the field life.

Fatigue lives at the TDP can be improved by a factor of up to 4.7 times if the vessel nominal position is moved by just 14m in each of the 8 compass directions, as well as remaining in the nominal position for equal amounts of time over the 25 year life-span of the field, as illustrated in Figure 3. By moving the vessel position at the surface the TDP location on the sea floor also moves exposing a different section of pipe to the large fatigue loads found at this location. Hence, rather than concentrating the fatigue damage at the TDP in a short length of pipe, the damage is spread over a longer section of the SCR.

A typical distribution of fatigue damage at the TDP due to VIV loading alone is shown in Figure 4 considering no spreading of VIV at the TDP, spread VIV damage and spread VIV damage with active mooring.

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VIV Fatigue Analysis

It is common that in regions with high currents SCRs require VIV suppressant strakes in order to disrupt the current flow and prevent the formation of vortices around the pipe. Whilst the physical cost of the strakes themselves is relatively inexpensive, huge costs can be generated by the amount of time required to fit them during installation. As such it is necessary to minimize the length of strakes required to obtain acceptable fatigue lives.

Current Directionality in the Campos Basin

A phenomenon of the currents in the Campos Basin is that at depths greater than 500m the current is strongly Northerly, whilst closer to the surface current directionality is much more variable and may propagate in any direction.

Significant effort was used to try to obtain a means of modeling this effect using the VIV analysis tool SHEAR7. A number of methodologies were investigated, however a robust approach which could be justified as being representative of the conditions, whilst still being conservative was not obtained.

Consequently, the approach agreed upon was to apply all currents unidirectionally, both in-plane and out-of-plane of each SCR and choose the most damaging direction. Whilst both 2H and Petrobras consider this to be a particularly conservative approach to this problem, a more suitable alternative could not be found.

Strake Positioning

Severe VIV fatigue damage is found to occur at the TDP region of each riser, principally during extreme current conditions where higher mode numbers are excited. Acceptable VIV fatigue lives are only obtained by careful strake positioning.

Logically strakes are required at the top of the SCRs in the strong, near-surface currents, and are required less in deeper water depths where the currents are more benign. For the P-55 SCRs, VIV fatigue damage at the TDP was generated primarily by the strong 100year extreme currents which would consume significant amounts of the riser fatigue life.

During the first analysis cycle the required length of continuous strakes from the surface needed to suppress these currents was investigated, however the VIV fatigue life was only found to reduce significantly if almost the entire riser was covered in strakes. This would be too costly to install and an optimized strake configurations for each riser type was required.

Optimized strake configurations are obtained as a result of the following finding. The extreme currents in the Campos Basin are relatively sheared to a depth of around 1500m, however, the bottom 300m of the water column has a relatively uniform current speed. Due to the catenary shape of the SCRs, when considering out-of-plane currents, a significant proportion of the riser is located in this uniform current region as the riser stretches out along the seabed. Consequently, excitation of a single mode over a long section of riser can easily occur and this must be suppressed with strakes. For some risers, acceptable VIV fatigue lives are only achieved if a section of strakes is included near the base of each riser, at approximately 150m above the mudline. These strakes are required in order to disrupt the excitation of the relatively uniform current flow near the seabed. Rather than applying strakes along the entire length of the riser, by suppressing the excitation close to the seabed with a small section of strakes, a large section of bare pipe can be left before the strakes required near the surface, as illustrated in Figure 5.

Clad Pipe

The final measure required to obtain acceptable fatigue lives is to use clad pipe at the TDP regions of the Production risers which are exposed to corrosive internal fluid.

The effect of corrosion leads to the requirement of an additional safety factor to be applied to the fatigue life requirement of these risers. This increases substantially the standard target fatigue life of 250years. Achieving adequate fatigue lives which met the target fatigue life for risers operating with corrosive fluid was not possible even using an active mooring programme. Consequently, clad pipe is required at the TDP in order to remove the effects of corrosive internal fluid in this region.

More than half of total clad length specified for TDP region was due to uncertainties on vessel and TDP nominal positions, defined in the installation tolerances.

RISER EXTREME STORM RESPONSE

Extreme storm response of the P-55 SCRs is conducted using a rigorous load case matrix and methodology in order to capture all possible extreme sea-state conditions.

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The load case matrix comprised of 77 seastates incorporating concurrent wave and current loading directions from each of the 16 points of the compass and for vessels offsets in 8 directions.

A range of operational conditions are analyzed following API guidelines.

- Operational
- Hydrotest
- Extreme
- Accidental

In order to capture the most extreme vessel motions at the hang off location, the wave periods provided in the Campos Basin Metocean data are adjusted to provide both the maximum heave, roll, surge, sway and pitch motions and accelerations, at each of the riser hang offs using a process called the Design Wave Procedure. Use of this procedure is necessary due to the large number of load cases to be analyzed which dictates using regular wave analysis for economic and time saving reasons. In order to ensure that the critical vessel motions are captured using a regular wave approach, the Design Wave Procedure is employed to tune the wave periods to produce the maximum heave, roll, surge, sway and pitch motions and accelerations, at each of the riser hang offs.

Using this method, for each of the 77 waves analyzed, using a regular wave approach, the maximum vessel motions in the critical degrees of freedom are captured for analysis.

Despite analyzing adjusted periods of each wave Hs – Tp pair in order to obtain maximum heave, roll, surge, sway and pitch motions and accelerations, at each of the riser hang offs, analysis of the 13,440 load cases showed that the maximum stresses in the SCRs are similar for all of the maximum degrees of freedom analyzed. Generally the periods tuned to the maximum vessel heave motions produced marginally higher stresses in the risers. The final distribution of maximum stresses due to the different degrees of freedom analyzed is shown for the Water Injection Riser in Figure 6.

Whilst using random wave analysis in the frequency domain could be used as an alternative to this approach. However, considering the large number of load cases involved and the time restraints of the project, a regular wave analysis approach was deemed to be the best solution.

![Figure 6. Maximum Stresses Obtained with Different Vessel Motion Types](image)

**Directionality of Vessel Offsets**

During the first analysis cycle, uniform vessel offsets corresponding to the maximum offset of the vessel on its moorings during specified conditions were considered in each direction. However, during some operating conditions – specifically normal operating – maximum stresses in the riser were found to exceed allowable limits during far vessel offset conditions.

However, on inspection of the vessel mooring limits it was determined that the offsets being applied were overly conservative as the maximum vessel offsets applied were not necessarily realistic for all risers. The maximum vessel excursions due to mooring limits in the planes of the over stressed risers were found to be significantly smaller than the vessel offsets applied in the analysis.

In order to reduce the conservatism in the analysis, whilst still maintaining a realistic approach, based on the results of the mooring analysis, a matrix of maximum vessel offset for each riser in each direction was generated and used in the analysis. Using this method only the offsets permissible from the vessel mooring are considered, and not overly conservative offsets based on the maximum excursion, as illustrated in Figure 7.

![Figure 7. Directional Vessel Offsets](image)

**Clad Pipe Requirements Near Surface**

For the Production and Water Injection risers, which are both subjected to corrosive operating fluids and severe corrosion, a length of clad pipe is required in the upper section of the riser. The requirement for clad pipe is two-fold. The presence of clad pipe in this region prevents corrosion and hence reduces stresses in the pipe wall close to the flexjoint during extreme storm conditions when bending moments in the pipe are large. Additionally, further down the riser where bending moments are small, but fatigue damage due to axial tension cycles is significant, additional safety factor leads to insufficient fatigue life and causing longer clad lengths.

**Extreme Storm Analysis Key Findings**

The key findings of the extreme storm analysis are:

- The maximum infield riser stresses are below the API allowable limits for all loading conditions. The risers meet the API criteria.
• The maximum riser stresses are close to the allowable for Operational conditions, during which stresses are limited to a maximum of 0.67 of yield, for the Production risers. Maximum stresses occur at the top of the riser for far offset conditions, driven by the high tension in the risers as a result of the riser top angle and vessel offset. Conversely, the stresses at the TDP are low for all loading conditions due to the high riser top angles.

• The maximum flex-joint rotation was determined for the Water Injection SCR. This occurs during a vessel pontoon column has failed and the vessel is listing. During these conditions the listing of the vessel contributes most of the flex-joint rotation. Excepting conditions where a pontoon column has failed, the maximum flex-joint rotation is one third of the rotation found for the listing condition.

• All risers remain in effective tension along their length for all loading conditions, no compression occurs.

CONCLUSIONS

The key recommendations and conclusions from the P-55 FEED analysis conducted by 2H Offshore are as follows:

• In such challenging environments it is necessary to ensure that the analysis conducted is not overly conservative and should consider more realistic characteristics which may be beneficial to the response of the risers;

• VIV damage spreading at the TDP should always be considered when low frequency vessel motions are available;

• Realistic rather than overly conservative vessel offsets should be considered for extreme analysis;

• Maximum heave motions at the vessel hang-off are generally found to produce the critical stresses in the risers;

• Conducting the analysis in two or more analysis cycles allows lessons to be learnt during the course of the project to be incorporated at later stages;

• The sparing use of clad pipe is sometimes necessary in order to meet extreme stress and fatigue life requirements for corrosive internal fluid;

• Damage spreading at the TDP due to vessel active mooring can improve fatigue lives by a factor of approximately 4.

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REFERENCES


