Overcoming Installation Challenges to Wellhead and Conductor Fatigue

T. Lim, R. Koska, E. Tellier

OMAE
June 2013
OVERCOMING INSTALLATION CHALLENGES TO WELLHEAD AND CONDUCTOR FATIGUE

Tze King Lim
2H Offshore Engineering Pty. Ltd.
Perth, WA, Australia

Ryan Koska
2H Offshore Engineering Pty. Ltd.
Perth, WA, Australia

Elizabeth Tellier
2H Offshore Engineering Pty. Ltd.
Perth, WA, Australia

ABSTRACT

Subsea wells are typically drilled and completed using marine risers with subsea BOP stacks deployed from mobile drilling units. Wave and current induced riser motions are transferred to the wellhead, conductor and casing system which can then cause fatigue issues at the critical connectors and welds. In recent years, the risk of fatigue failure has increased due to the use of 5th and 6th generation rigs with larger BOP stacks, and longer well drilling and completion durations. During the design stage, the fatigue performance of the wellhead, conductor and surface casing is often overlooked.

During well construction, variations from design can occur in terms of wellhead stickup, wellhead lockdown and cement levels, both around the conductor and in the annulus between the conductor and surface casing. This paper describes analysis results showing the effect of these variations on the fatigue performance of the wellhead, conductor and surface casing. The recommended analysis load case matrix to account for these uncertainties is also presented, together with the need for as-installed assessments.

Recommendations on fatigue resistant designs with equipment configuration and specification options capable of meeting these challenges are presented. Wellhead monitoring and fatigue tracking strategies that can be implemented during drilling and workover operations to address these potential concerns and manage the risk are also discussed.

INTRODUCTION

Marine risers with subsea BOP stacks deployed from mobile semisubmersible drilling units or drillships are typically used for drilling and workover operations for subsea wells. A typical marine riser stack up is shown in Figure 1 together with the sources of riser motions. The riser is subjected to wave induced motions, both from direct wave loads on the riser and through vessel surge or sway motions. In addition, current flow past the riser can cause vortex induced vibrations (VIV). This occurs when the frequency of the vortices shed by current flow around the riser matches a natural frequency of the riser system, resulting in lateral motions of the riser of over a diameter in amplitude. These riser motions are transferred down to the BOP stack, wellhead and conductor. This can result in high fatigue accumulation at the critical welds and connectors shown in Figure 2 due to stress concentrations at these locations. Failure of wellhead systems can occur from excessive fatigue loading.

In recent years, the risk of fatigue failure has increased significantly due to the use of 5th and 6th generation rigs with larger BOP stacks, particularly for non-fatigue optimized wellhead and conductor designs in locations with soft soils. Furthermore, considerably more complex and hence longer duration drilling and workover operations are being planned to maximize well output, which increases the number of fatigue cycles. The fatigue performance of the wellhead, conductor and casing is often overlooked during the design stage, with analysis focusing on strength requirements. However, the fatigue performance of the wellhead, conductor and surface casing
needs to be considered prior to equipment selection, particularly in locations with soft soil and severe waves or currents.

**WELL CONSTRUCTION CHALLENGES**

The designer’s work is further complicated by variations from design which may arise during well construction. Wellhead stickup, wellhead lockdown and top of cement levels both around the conductor and in the annulus between the conductor and surface casing are difficult to control, and can have considerable effect on the fatigue performance. Analysis results from several 2H projects are utilized to quantify these effects.

**Wellhead Stickup**

An increased wellhead stickup can cause reduced fatigue lives at the wellhead, conductor and surface casing. A higher stick-up results in larger bending loads due to the longer lever arm between the BOP stack and the effective point of fixity of the conductor below the mudline. In addition, the position of the critical conductor and casing connectors below the mudline are moved closer to the region with peak bending loads, which are typically 0-5m below mudline for stiff soils and 5-12m below mudline for soft soils.

Example results for a conductor in stiff soil are provided in Figure 3. The results show that an increase in wellhead stickup of 1m can cause a factor of 16 reduction in fatigue life. This particularly severe result is because in stiff soil the bending loads change more rapidly with depth and a slight change in elevation can result in a large change in fatigue performance.

**Cement Level Around Conductor**

For drilled and grouted conductors, a cement shortfall around the conductor can lead to reduced fatigue lives due to loss of soil support around the top of the conductor. Similarity to an increased wellhead stickup, this results in higher bending loads at the critical conductor and casing connectors. Example results in Figure 4 for a well in soft soils shows that a 2m cement shortfall can cause a factor of 1.4 reduction in fatigue life. In this case, the effect of this change is less severe because the change in bending loads is smaller compared to stiff soils.

**Cement Level Around Surface Casing**

The cement level in the annulus between the conductor and surface casing has a large effect on the high pressure housing weld and the surface casing but does not significantly affect the conductor fatigue life. The casing connector fatigue lives are up to 2 orders of magnitude lower if the connectors are above the top of cement level, as shown by example results in Figure 5. This is due to the lack of lateral support provided by the cement, causing larger bending loads along the casing. The minimum fatigue life occurs when the top of cement is just below the connector, as bending loads are concentrated at this location from the lateral fixity provided by the cement. For the same annulus cement levels, the fatigue lives along the conductor are largely unchanged, as shown in Figure 6.

**Wellhead Lockdown**

Both rigid and non-rigid lockdown wellheads are utilized for subsea wells. Non-rigid lockdown wellheads may allow relative rotation between the high pressure and low pressure housings to occur if the annulus between the conductor and surface casing is not cemented, as shown in Figure 7. A rigid lockdown wellhead may also behave in this manner if the lockdown mechanism is not properly set or has failed. This causes more bending loads along the surface casing compared to a rigid lockdown wellhead, and hence causes lower fatigue lives at the high pressure housing weld and casing connectors.

If the annulus is cemented to surface, the fatigue lives for a non-rigid lockdown wellhead are similar to a rigid lockdown wellhead. This is due to the cement preventing relative motions between the high pressure and low pressure housings. Example results with rigid and non-rigid lockdown wellheads are shown in Table 1. However, this assumes that the cementing is performed as planned with a good bond, which may be difficult to obtain in practice.

**EFFECTIVE DESIGN APPROACH**

To account for the uncertainties in wellhead stickup, cement levels and wellhead lockdown, an approach which combines fatigue optimized design, an effective analysis load case matrix, an as-installed assessment and monitoring is proposed.

**Fatigue Optimized Design**

The wellhead, conductor and casing loads vary from well to well due to differences in metocean conditions, soil strength, drilling vessels and BOP stack size. Based on the results shown above and from previous work, [2,3], general recommendations for obtaining a fatigue optimized design are be made:

1) Position all welds and connectors away from the region of high bending loads 0-12m below the mudline. This includes all conductor and casing connectors, welds between the connectors and pipe, and any other welds for extensions, gimbal profiles, cement return ports, lifting lugs, anti-rotation tabs, etc. The connectors can be moved away from the region of high bending loads by utilizing longer first conductor or casing joint lengths or by welding extensions. The final assembly length however is subject to transportation and handling limitations.

2) Any connectors positioned in the region of high bending loads will potentially need to be of a fatigue resistant design depending on the soil, environment and drilling vessel. These connectors have specially designed thread profiles and features that reduce the stress concentration factors (SCFs). The fatigue performance of these
connectors has been proven through analysis and physical testing.

3) Any welds positioned in the region of high bending loads will need to be upgraded to fatigue resistant welds. The high and low pressure housing welds may need to be included in this category. This involves grinding flush the welds on the outside and inside to remove defects and possible crack initiation sites. This improves the weld quality from a typical E or F class weld to C1 class according to industry standards such as DNV RP C203, [4]. It should be noted that C1 class welds may be difficult to achieve for high strength materials used for wellhead housings and connectors. Vendors should be consulted to confirm that this weld quality can be obtained.

If the above changes are insufficient to achieve the required fatigue life, increases in conductor outer diameter or wall thickness can be considered.

**Effective Load Case Matrix**

When analysis of the wellhead, conductor and casing is performed during the design stage, considering the worst possible combination of stickup, cement levels and wellhead lockdown can be over-conservative and provide unrealistic results. Furthermore, the analysis results are subjected to a safety factor of 10 on fatigue life as recommended by API, [5].

The authors recommend a more practical approach which considers the baseline configuration instead of the worst case combination, and then perform sensitivities to determine the effects of the above variations. A typical load case matrix is provided in Table 2. Close collaboration with the drilling contractor is required to set realistic tolerances on these parameters to ensure that possible variations are captured. It is then important to verify that the installation is performed within this range of parameters as described below.

**As-Installed Assessment**

To confirm that the wellhead, conductor and casing system is installed within the range of parameters previously assessed, an as-installed survey is needed. Should the as-installed survey show that the range of parameters considered in the initial analysis are exceeded, additional analysis may be required to confirm fitness-for-purpose of the system.

Wellhead stickup and wellhead lockdown can be easily verified by performing visual inspections and by following correct installation procedures. Cement levels and bond strength are more difficult to assess. A cement to surface operation can be verified by visually confirming returns. However, the quality of the cement bond as well as top of cement levels which are below the surface will need to be interpreted from logs which may be inaccurate. Hence, cement level sensitivities are of greater importance during the design stage, and may need to be verified by monitoring methods described below.

**Monitoring and Fatigue Tracking**

Monitoring drilling riser and conductor systems is an important tool for verifying assumptions made during the design and installation stages, as well as tracking the actual fatigue accumulation at critical components with time. Several levels of monitoring are possible:

**ROV Surveys** – ROV observations are useful in detecting obvious deviations from the planned configuration, such as wellhead stickup and soil scour around the conductor. Any observed cyclic motions of the wellhead or BOP stack can also provide a qualitative assessment of the fatigue accumulation, and provide a rough verification of cement bond and soil assumptions. For example, observed motions which are higher than expected would indicate that soils are softer than anticipated or that the required cement level is not achieved. For longer duration wells, repeated ROV surveys can be used to identify changes in the well conditions over the drilling or completion campaign.

**Environmental Condition Monitoring** – Measurements of waves and currents are useful to verify the metocean loads. If more severe waves or currents are observed during the drilling or completion campaign, the fatigue performance of the critical components will need to be reassessed. If ROV surveys indicate BOP oscillations, analysis can be carried out with measured metocean loads to determine expected fatigue accumulation at critical components.

**Structural Monitoring** – Structural monitoring involves the direct measurement of component motions or strains using accelerometers, angular rate sensors and/or strain gauges. This allows for the component behavior to be measured and hence the actual fatigue accumulation to be tracked with time. An example monitoring system is shown in Figure 8. Comparing the measurements from multiple sensors along the BOP stack and wellhead against analysis predictions allows for parameters such as soil strength and cementing to be verified. An example showing the calibration of soil models is shown in Figure 9. In this example, four soil models are assessed analytically and Soil 2 provided the best match to measured motions at the wellhead and BOP.

Structural monitoring is most effective when correlated against environmental condition monitoring. The calibrated analysis model can be used to map the waves and currents to fatigue accumulation rates at the critical components.

**CONCLUSIONS**

Welds and connectors at the wellhead, conductor and surface casing are vulnerable to fatigue damage caused by wave and current induced marine riser motions. Uncertainties in
wellhead stickup, cement levels and wellhead lockdown can occur and can have a significant effect on the fatigue performance of these components.

An approach of combining fatigue optimized design, an effective load case matrix, as-installed assessment, and monitoring is proposed to account for these uncertainties. Recommendations for fatigue optimized designs include positioning connectors away from the region of high bending loads, using fatigue resistant connectors, and grinding welds flush. A load case matrix is presented which uses sensitivity studies to account for variations in the installation parameters.

An as-installed survey is required to confirm that the well is installed within the range of parameters assessed. Monitoring can then be used to verify any remaining uncertainties and allows for the actual fatigue performance to be tracked.

**NOMENCLATURE**

- BOP: Blow Out Preventer
- HP: High Pressure
- LFJ: Lower Flex Joint
- LMRP: Lower Marine Riser Package
- LP: Low Pressure
- MSL: Mean Sea Level
- PGB: Permanent Guide Base
- ROV: Remotely Operated Vehicle
- SCF: Stress Concentration Factor
- VIV: Vortex Induced Vibrations

**REFERENCES**


**TABLES**

<table>
<thead>
<tr>
<th>Location</th>
<th>Fatigue Lives (Days)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top of Cement Below Conductor Shoe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement to Surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Non-Rigid Lockdown Wellhead</td>
<td>Rigid Lockdown Wellhead</td>
</tr>
<tr>
<td>LP Wellhead Housing Weld</td>
<td>42.6</td>
<td>26.8</td>
</tr>
<tr>
<td>HP Wellhead Housing Weld</td>
<td>2.7</td>
<td>40.8</td>
</tr>
<tr>
<td>First Casing Connector</td>
<td>5.1</td>
<td>72.4</td>
</tr>
<tr>
<td>First Conductor Connector</td>
<td>4.9</td>
<td>4.6</td>
</tr>
</tbody>
</table>

**Table 1 – Effect of Wellhead Type and Cement Level in Annulus between Conductor and Surface Casing [2]**

<table>
<thead>
<tr>
<th>Soil Strength</th>
<th>Wellhead Stickup</th>
<th>Wellhead Lockdown (for Rigid Lockdown Wellhead)</th>
<th>Cement Around Conductor</th>
<th>Cement Around Surface Casing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>Nominal Set</td>
<td>Nominal</td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>Nominal Set</td>
<td>Nominal</td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td>Most Critical (Minimum or Maximum)</td>
<td>Highest Set</td>
<td>Nominal</td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nominal Not Set</td>
<td>Nominal</td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nominal Set</td>
<td>Lowest</td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nominal Set</td>
<td>Nominal</td>
<td>Worst (Just Below 1st Connector)</td>
<td></td>
</tr>
</tbody>
</table>

**Table 2 – Proposed Load Case Matrix**
FIGURES

Figure 1 – Typical Riser Stack-up and Sources of Motions

Figure 2 – Fatigue Critical Locations

Figure 3 – Effect of Wellhead Stick-up
Figure 4 – Effect of Cement Level Around Conductor

Figure 5 – Effect of Annulus Cement Level on Surface Casing Fatigue

Figure 6 – Effect of Annulus Cement Level on Conductor Fatigue

Figure 7 – Non-Rigid Lockdown Wellhead

Figure 8 – Example Structural Monitoring System
Soil 2 provides best match to measurements at PGB and BOP

Figure 9 – Example Soil Calibration using Monitoring Data