Influence of Construction and Deterioration on Platform Well Life Extension

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Abstract

One of the most common challenges faced by well operators worldwide is extending the lifetime of their aging platform wells. The initial well construction, operational loading and time-dependent deterioration of a well through field life are all key factors that need to be understood to establish the remaining capacity of a well. However, often these factors are not fully understood and consequently costly decisions to repair or abandon wells can be made unnecessarily, or in some cases critical wells or operations on wells are not identified, risking structural collapse of a well. To address these issues, this paper describes the factors that influence the integrity of the well, and presents advances in the approaches to understand and evaluate the condition of a well and hence better evaluate remaining capacity. Methods, Procedures, Process: Typically, corrosion of the casings is taken as the key parameter to establish a well’s remaining capacity. However, as demonstrated in this paper through an analytical evaluation, the axial loading in the well is another key parameter that needs to be understood. A range of factors affect the well axial loads based on well construction and deterioration is considered, including:

- Weight of casing hung off wellhead during installation
- Level of axial support provided by casing shoe
- Cement levels
- Changes to well configuration
- Changes to well service (Producer to Injector)
- Changes to operating temperatures and pressures through field life
- Corrosion and other deterioration of the conductor and casings

This information can, however, be difficult to obtain due to incomplete or inaccurate construction records or difficulties in taking direct measurements or inspecting a well. This paper demonstrates the influence of each of these variables on the capacity of the well, how the uncertainty in these variables affects this assessment, and consequently the overall uncertainties in establishing the remaining capacity of a well. Results, Observations, Conclusions: Having established the limitations and uncertainties of an analytical evaluation and the need to establish well axial loads, the paper also proposes a method to characterise the axial loads in a well, including a proposed technique for in-field measurement as an input to establishing a well’s on going fitness for service alongside corrosion measurements. Novel/Additive Information: Overall, the paper presents an improved approach to establishing the suitability of a well for life extension based on an improved understanding of the influence of well loads, with widespread application to aging platforms in the North Sea and globally.
Introduction

The North Sea has more than 200 fixed conductor platforms with an average age of 18 years. More than 50 facilities are 25 years or older. As these assets age, more degradation is expected, requiring more repair work to maintain their condition. In the current low oil price climate, operators are interested in extending the service lives of assets and maintaining production for longer periods than originally planned. Well conductor structural integrity evaluation is an important part of the operations to extend well life. Conductor structural integrity evaluation is dependent on a wide range of factors which can be difficult to quantify, the implication is that often conservative evaluations are made. Yet it is important to ensure these conservatisms do not underestimate the remaining structural capacity of the system as this may lead to unnecessary and costly repairs to equipment or to abandon equipment earlier. Similarly, in some cases the assumptions may lead to an overestimation of the remaining structural capacity, and critical wells or operations on wells are not identified, risking structural collapse of a well. To demonstrate these issues, this paper describes the factors that influence the integrity of the well, and uses an example case study to quantify effects. This paper focuses on the influence of corrosion, but also on the influence of the well construction approach and subsequent deterioration of the well on remaining structural capacity. A possible approach to better understand a well’s remaining structural capacity is also discussed.

Effect of Corrosion on Platform Well Structural Integrity

Conductor corrosion is a significant contributor to the loss of structural integrity on platform wells and as such, platform well conductors should be designed with conductor corrosion management in mind. This is often achieved through applying appropriate coatings and corrosion allowances. However, the coatings degrade in the splash zone within typically a 5-10 year period, allowing free corrosion of the conductor pipe. Cathodic protection may limit this, but in many cases, platform wells are not designed with cathodic protection. Code guidance, for example NORSOK M-501 [1], requires typically a 0.4mm / 0.015in per year corrosion allowance in the splash zone once the coating has degraded. The implication of this is that after 25 years of typical service life, over 30% of wall thickness of a well conductor may be lost. In many cases the assets are still producing past the end of their initial design life and therefore significant levels of corrosion can be present if no maintenance or repair is undertaken. With some assets proposed to be operated for up to 50 years, it is important in these cases to quantify the limitations on service life due to the presence of corrosion and mitigate as required through repair.

An analysis is undertaken based on a representative 30in x 0.875in wall thickness platform well conductor. This analysis is carried out with and without corrosion to demonstrate the influence of corrosion on the utilisation of strength design limits. Strength design may be based on a number of different internationally recognised design codes including API, DNV and ISO codes. The Baur and Stahl method is also commonly adopted [2] based on ASIC. In this example the work is completed based on API-RP-2A WSD [3]. The structural analysis considers the combined effect of axial and bending loads on the conductor.

Figure 1 – Conductor Preliminary Corrosion Assessment – Bending Moment Distribution Comparison

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For the un-corroded case, the conductor is assumed to have the nominal (as-installed) wall thickness. Whereas for the corroded case, a typical measured wall thickness profile is applied with significant wall thickness loss in the region near and above the splash zone. This analysis is performed using an extreme loading condition of a 100 year return period, with well production equipment and casing loads supported by a wellhead sat on the well conductor. The well casing loads are calculated based on a typical as-designed well casing program. This assumes that all casings are supported at the wellhead and that cement levels are as planned. Cold well loads are considered, as typically the highest compression in the conductor is found when the well is cool and not with the production thermal gradient.

The distributions of maximum bending moment and utilisation of the strength design limits are plotted in Figure 1 and Figure 2 respectively for the un-corroded and corroded cases. It is found that the bending moments from the two cases are very similar and follow the same trend. The difference in bending moment between the two cases is only due to the reduction in bending stiffness when the conductor wall is lost due to corrosion, which allows for additional deflection of the conductor.

Although the bending moments are not affected substantially, a sharp increase in conductor stresses is observed in the splash zone region for the corroded case. This demonstrates that the increase in stresses is primarily a result of the reduction in wall thickness due to corrosion and not the influence of stiffness changes. Note that the stresses from the two cases are nearly identical at the bottom section of conductor where no corrosion is present.

The recommendation in this scenario would be to carry out immediate repairs as the well no longer has sufficient safety margin remaining as the utilisation in the splash zone exceeds unity. Alternatively if repairs aren’t possible to the well, it may be decided to abandon the well. In both cases, this can be a costly decision.

**Conservatism in the Assessment**

This assessment described above is a typical one, but is often regarded as conservative as a number of worst case aspects are considered in parallel, namely, a severe environment, corrosion uniformly applied around the circumference and an attempt to consider worst case well casing loads. In order to extend the lives of wells, it may be necessary to consider and find methods to reduce these conservatisms.

Design codes mandate that the well integrity must remain intact even in the event of a severe storm. The codes require typically a 100 year storm condition to be achieved, but over the remaining life of a conductor this may never be experienced. However, the environment is difficult to predict and there is little that can be done to mitigate against such storms, so this design requirement must remain. In fact, recent changes to some design codes require new facilities to be designed to withstand 10,000 year conditions where substantial risks to the environment, people and reputation exist as a consequence of failure.

Assumptions on corrosion modelling are also made, but again are defined in the codes and as such code guidance is recommended to be followed.
Assumptions within the well casing axial loads can, however, be addressed, and therefore the influence of the axial loads is investigated further as these assumptions may lead to both conservative and under-conservative evaluations of a well’s remaining structural capacity.

**Effect of Well Construction and Deterioration on Axial Well loads**

Calculations carried out to determine the axial well loads supported by the example conductor described above, are typically based on the as designed casing arrangement. This is on the basis that the data for the as-installed well and the well’s current status is not known. The objective of these calculations is to identify the maximum axial well loads that may be present in the well so that these can be applied to the conductor structural integrity analysis.

The calculations of the axial loads on the well are based on a standard approach considering the weight of well equipment and the installation sequence. As each individual casing string is installed into the well, an axial compressive load equivalent to the sum of the landed equipment weight is distributed into pre-installed casings based on their relative axial stiffnesses. The equipment weight is based on the apparent weight of the installed casing, accounting for the casing’s mass, buoyancy effects from drilling mud and cement and any support at the casing shoe, and any surface equipment placed on to the well as part of the installation operation. After the casing is locked into the surface wellhead and the cement is set, a preload is locked into each of casing strings present. The calculation process is repeated for each subsequent casing string installed until the final preload in the conductor and each internal casing is known with the production tree and equipment installed to the well. The preload for each casing string is therefore determined as a complex function of the cumulative installation sequence, pipe fixity positions, pipe net weights, surface equipment loads present, casing shoe support present and the relative axial stiffness of each pipe.

As well as construction preloads, operating preloads should also be considered in the calculations used in a well structural integrity evaluation. The term construction preload is defined as the axial loads at the conductor and casings surface hang-off point prior to the application of thermal and pressure loads. The term operating preload is used to refer to the axial loads during operations with thermal and pressure effects taken into consideration. These thermal and pressure effects are due to production operations, injection operations or any other operational conditions that may be seen during the wells service life including eventual well kill and abandonment. For this assessment the operating loads are ignored for clarity, but there impact is discussed later in the paper.

However, by considering the as-designed well casing arrangement and corresponding axial loads for the structural integrity assessment, there is a key assumption made that the current well is the same as the originally planned well design. Yet in the majority of cases the current well is not the same as was originally designed for a variety of reasons. Hence, the calculations must consider the variability that may have occurred during installation and subsequent use and degradation.

In some cases it is clear that a well’s current status is not the same as the as-designed well, for example:

- Deviation from the as-designed well can be identified from records of the as-installed well casings and operational daily drilling records.
- The conductor has significantly slumped (i.e. the top of the conductor is at a lower elevation than the initial as-built condition) – this is a common problem due to issues with cementing the conductor or settlement of the conductor with time.
- The top of the casing is standing proud of the conductor – this is typically due to thermal growth of the well, but can also relate to slumping of the conductor
- Significant corrosion to the conductor or other access points to allow the top of cement in the conductor annulus to be measured.
- New or changed equipment is installed onto the well
- Structural damage has occurred, for example buckling of the conductor during cool down of a well or cut-outs to inspect the well.

Other aspects cannot be determined from the installation records or a visual inspection of the well. This includes for example:

- The as built or current top of cement depths for each casing string are often not known – there are many wells where the top of cement is not where it is intended to be and due to assets age this was never logged. Controlling the cement level accurately is difficult due to potential losses into the formation. Typically this leads to a cement shortfall, which can be up to several hundred meters. In the worst case, almost no cement is present within the annulus. Even where cement is seen to return to surface, slumping of cement can occur during the time it sets leaving a shortfall.
• Load sharing into wellhead and casing shoe – It is often the case that the amount of axial load shared by the wellhead or supported by the casing shoe is not accurately controlled during installation or is affected by installation problems, for example stuck casings or slippage of the casing when locking into the wellhead.

• Mudline suspension systems not engaged – where a sub mudline hanger is used, in some cases it is not possible to tell if the casings have been landed onto the sub mudline casing hangers and consequently additional load is redistributed through the wellhead.

Therefore, a number of uncertainties may be present in determining the current well loads as a function of construction and deterioration, some of which are difficult to quantify. This then leads to worst case assumptions having to be evaluated.

In order to evaluate the possible influence of this uncertainty, for the example 30in x 0.875inch conductor, a range of axial loading scenarios are considered. These are focused on the uncertainties in the cement level in the outer annulus and in the surface casing annulus compared with the planned cement level including cement shortfalls up to and including the worst case with no cement considered in the annulus. The calculated preloads are shown in Figure 3 for the example well on this basis. The preloads are found to vary between approximately 700kips and 875kips (up to 25% increase from minimum), excluding the anomaly case without cement. The no-cement case is found to have preload in excess of 1000kips (more than 40% increase from the minimum). Hence, a significant spread of loads is possible due to the uncertainty in the current well configuration. This uncertainty can increased further when other potential unknown factors are included in the calculations, many of which are difficult to establish from the well.

![Figure 3 – Preload Levels for Range of Cement Setups](https://www.2hoffshore.com)
Effect of Uncertainty in Preloads on Conductor Structural Integrity

The maximum stresses in the example 30in conductor are calculated for all combinations of preloads to account for the potential variability in the load. The stress distributions are plotted in Figure 4 with the same measured corrosion profile and the same storm loading condition.

The results show that the same high stresses are present at the corroded splash zone region, however, a significant spread in the stresses are found due to the uncertainties in the preloads. With the measured amount of corrosion considered, the maximum stress utilisations are observed to be significantly exceeding the design limits. In this case the well potentially requires an immediate repair as insufficient design margin remains. However, it is worth noting that the stresses from this preload are expected to be conservative, since this preload is calculated based on the assumption that no cement is found in all casing annuli, which is a worst case assumption and an unlikely scenario. When alternative preload scenarios are considered it found that the stress levels are reduced, with a maximum improvement on stress levels of more than 20% for the minimum preload. If the minimum load is valid then the well does not exceed the design limits and although remains highly utilised an urgent repair is not needed necessarily, but should be planned.

Based on a specific well arrangement, a wall thickness acceptability guideline chart for the conductor can be drawn from the analysis results obtained. The guideline chart is given below in Figure 5 for the example well, and can be used as a tool to decide whether any action or well repair procedure is required for the specific well if the corrosion level and conductor preloads are known.

Figure 4 – Conductor Stress Distribution with Preload Levels

Figure 5 – Wall Thickness and Preload Guideline Chart

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The chart presents a summary of the strength response of the conductor for a range of corrosion levels and preloads. The shaded area on the chart represents the preload variation. Three different zones are defined in the guideline chart based on the strength utilisation and the requirements for repair to the conductor. These zones are classified using different colours and their definitions are provided in Table 1.

<table>
<thead>
<tr>
<th>Colour Code</th>
<th>von Mises Stress / Yield Stress</th>
<th>Required Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>&lt; 0.6</td>
<td>No immediate action is needed. Monitoring of further wall loss is recommended.</td>
</tr>
<tr>
<td>Yellow</td>
<td>0.6 – 1.0</td>
<td>Stresses at elevated levels. Increase frequency of corrosion measurement. Repair of well may be necessary.</td>
</tr>
<tr>
<td>Red</td>
<td>&gt; 1.0</td>
<td>Stresses exceed pipe maximum capacity. High risk of failure. Well requires immediate repair.</td>
</tr>
</tbody>
</table>

Table 1 - Colour Coding used in Wall Thickness Acceptance Guideline

Once the remaining pipe wall thickness measurement is available, the corresponding strength utilisation can be determined from the plot based on the well loads. However, due to the variability in preload, the worst case assumption has to be made, unless supporting information is available to narrow the results down to a specific preload. As such it can be seen that in the worst case the well must be repaired after approximately 13% wall thickness loss, but in the best case a 37% wall thickness loss can be accommodated. If an annual corrosion rate of 2% per year is assumed, this is a potential service life difference of 12 years between best case and worst case preloads due to the variability in cement level alone. Hence determination of preload on the conductor is a key part of establishing the corrosion life remaining in the well and the need to repair to extend life.

**Approach to Establishing Preload**

As shown in the previous section the preload variations can change the conclusions when it comes to the remaining structural capacity and hence service life of the platform well conductor system. It is important to give special consideration to the preload level and ensure this is correctly understood. The sections above addressed the preload variations due to the changes in cement arrangement. However, further variation in preload is expected in conductors due to other factors. Temperature variation is the most common of these, with injector wells expected to have higher compression preloads than production wells. Production leads to casing expansion, relieving the conductor of some of its loads, whereas injection has the opposite effect. In addition to temperature variations the level of axial support provided by the casing shoe, friction with the soil downhole and changes to the operating pressures through the field life are factors which are likely to impact the preload. Therefore further challenges are present to calculate the actual preload in a well.

As an alternative to calculations, it is proposed that the preload level can be measured to potentially remove some of the uncertainties in the analysis to enable the life extension of assets.

A method which is being tested for use in measuring offshore conductors is a modified version of the method highlighted in ASTM E837 [4]. This is a hole drilling method which involves installing a rosette of strain gauges to the outside of the conductor and drilling a hole at the centre of the rosette partially through the wall thickness. The strain changes as the hole is drilled are measured and based on the strain relief the stress level in the conductor is estimated from which the preload can be determined. The measured preload and measured wall thickness can be used in conjunction with the guideline chart to establish that the well has sufficient residual capacity or requires repair.

This method has undergone preliminary qualification testing including measuring conductor preloads on an offshore platform well conductor, both for production and injection wells. In conjunction with onshore test verifications, the method shows promise in assisting the extension of conductor lives and delaying the requirement for repairs, however further qualification is still needed to establish the accuracy of the measurement and limitations of its use.

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Conclusions

When considering the life extension of platform conductors with increasing levels of corrosion, the detection of deterioration does not imply the immediate need for repair or abandonment. As a first line of defence, engineering assessments are required to understand the impacts of the construction and deterioration on the wells residual structural capacity, and identify the areas of uncertainty within these estimates. Taking measurements, such as corrosion levels and preload levels, identifies the actual system criticality and if required repairs needs. The following key conclusions are reached:

- Corrosion in the splash zone on well conductors can lead to over 30% loss in wall thickness as assets approach and go beyond their service lives.
- Life extension requires inspection and monitoring of the corrosion level to assess the remaining service life before corrosion becomes critical and repair or abandonment of the conductor is required.
- The axial loading on the well is required to be known to ensure the remaining structural capacity of the well is established accurately.
- In many cases due to the challenges in establishing the wells axial loading, key assumptions are made without assessing the potential variability there may be. Based on the typical uncertainties in the loads from well construction, deterioration and operations, it is shown that there could be a substantial variation in the estimates of residual service life of the well before corrosion becomes critical.
- The variability in the example well could be greater than 10 years based on uncertainty in the cementing alone. This implies that a well could be repaired unnecessarily, or there is an unidentified risk of immediate structural failure in severe weather or under future intervention operations.
- The paper proposes that addressing the failure risk and establishing remaining service life more accurately, requires new approaches to establishing the loading within a well. One such approach is proposed using a hole drilling technique, which is currently undergoing qualification testing. This has the potential to be a cost effective way to extend life or identify wells requiring urgent repair.

References