Ageing Offshore Well Structural Integrity Modelling, Assessment and Rehabilitation

R. Ramasamy - 2H
M. AlJaber, H. AlJunaibi - Zadco

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Ramesh Ramasamy, 2H Offshore Engineering Ltd.; Manea AlJaber and Hamad AlJunaibi, ZADCO

Abstract

Zakum Development Company (ZADCO) is operating Upper Zakum (UZ) Field offshore Abu Dhabi consisting several offshore wellhead platform towers (WHPT) which have been in service for over 30 years and evidence of severe corrosion has been found on majority of these well’s conductors and casings.

A major challenge faced by ZADCO is to repair corroded well’s conductor casing to prevent well structural collapse and extend the life further to allow for safe and planned retirement. The challenges faced during the assessment includes the absence of design basis, well age, data accuracy and drilling quality for 30 years, the challenges takes another dimension when factoring the number of wells and possible different configurations. They way forward was to categorise the wells into several groups with close design configurations and then reverse engineer the design basis to a build a structural model for that fits the various wells configuration to establish the minimum thicknesses to assure well’s structural integrity, and the requirement for life extension by suitable repair method.

This paper outlines the activities undertaken to design and implement an effective process for evaluating the structural integrity of aging well conductors considering over 6000 possible well configuration scenarios. The paper describes the engineering methodology involved in the integrity assessments for well conductor evaluation using analytical methods to assess the present strength and stability states of the conductor/casing assembly based on corrosion inspection data and the knowledge of existing cement elevations and operating conditions of the well. Operability guideline plots are generated to present the available safety margin of the aging conductor/casing system, and to enable well conductors with unacceptable structural integrity to be identified. Where safety margins are poor, repair solutions and mitigation methods are also developed for implementation on the affected conductors and casings.

A detailed rehabilitation flow-chart is also developed to assist engineers in the repair/replace decision-making process, with comprehensive guidelines for assessing and executing the rehabilitation steps for extended safe operations of ageing conductors, hence prolonging the well operating life.
Introduction

The increase in ageing offshore well conductor assets and the continued requirement to maintain operations beyond their original design life is beginning to be a major challenge faced by operators worldwide. This problem is further compounded by the limited availability of well construction records, unknown operational conditions and inadequate through-life maintenance.

Zakum Development Company (ZADCO) is responsible for the operation of a large number wells located on jacket platforms in the Upper Zakum (UZ) field offshore Abu Dhabi with an average water depth of 43m (138ft). Many of these wells have been in service for over 30 years and evidence of severe corrosion has been found in some of the well conductors as shown in Figure 1, including complete collapse on some more extreme cases. There are also reported observations on loss of cement in the internal annular space between the conductor and surface casing, leaving the surface casing exposed to seawater spray and eventual wall loss due to corrosion.

Establishing a fit for service solution and building the way forward was an imminent need for ZADCO in order to extend the life of the wells. The challenges faced during the assessment includes the absence of reliable design basis, well age, data accuracy and existing concerns on quality of drilling prevented the company from taking forward a solid rehabilitation program. The above challenge took another dimension when factoring the number of wells and possible different configurations which will cause a serious delay in planning the repair or even abandoning the wells. ZADCO team decided to conduct a special simulation study after categorizing the wells into several groups with close-to-design configurations and then reverse engineering the design basis to a build a structural model for that fits the various wells configuration to establish the minimum thicknesses value that will assure well’s structural integrity, and the requirement for life extension by suitable repair method.

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ZADCO established a taskforce team to carry out survey and inspection campaign, and to record all critical information for each well which includes, but not limited to, conductor thickness measurements – 4 thickness readings per meter height up to MSL, top of cement level in the well annuli, well configuration and materials based on drilling data. Since the above survey was estimated to take up to one year to complete, and due to the urgency, the team decided to propose a few pre-assumptions as a way forward for a specialised engineering study that will enable the company to categorize the wells into several groups according to their physical conditions. This resulted in over 6000 possible well configuration scenarios that need to be assessed to cover all offshore wells within the UZ field.

In line with this information, ZADCO has initiated a plan to carry out strength and integrity assessments of these conductors using the finite element (FE) analyses and identify the current strength state as compared to the as-built design limits in terms of conductor and casing wall thickness (WT). The conductor pipe WT from as-built design data were used to estimate the limiting capacity, whilst the current corroded WT were used to identify the in-place condition of these wells, and thus to be in a position to highlight the acceptability for continued operation or to propose repairs and/or abandonment plans. The annular cement shortfalls were also considered in these assessments and to cater for a wide range of possibilities in the top of cement (TOC) elevations in the well annuli.

Two well configurations were considered to accommodate for both conductor-supported and casing-supported wellhead scenarios resulting from soil consolidation and conductor settlement over the decades. For each well configuration, the wells were further grouped according to the TOC and well preloads, and these groupings represent almost every well in the UZ field, considering all possibilities of annuli cement degradations. For the casing-supported wellhead configuration, the absence of adequate TOC may result in the casing pipe buckling inside the wellbore, thus increasing bending stresses as a resultant of curvatures on the casing and the interaction with the conductor inner diameter and wellbore. This leads to the cement top-up assessments to identify the critical TOC for safe continued operation of the wells. The cement top-up assessment considers a range of cement bond strength sensitivity to account for heavily corroded pipe walls, with formation of rust flakes (Figure 2), which may resist the cement bonding hence rendering the entire cement top-up efforts ineffective. The conductor and casing repairing philosophy/strategy and methodologies can then be established once the well states are known from the strength assessments and also depending on the level of degradation of the conductors and casings. These repair strategies will be used as criteria and guideline for engineers to identify wells with integrity issues and require repair works.

![Figure 2: Formation of Rust Flakes Inside Conductor-Casing Annulus](image)

**Case Study**

A typical case considered in this assessment activity will be looked at, where the well layout and schematics are shown in Figure 3. The UZ well considered consists of 30in conductor, with a 13-3/8in surface casing hung from the surface wellhead on the platform, followed by the 9-5/8in inner casing and dual 3-1/2in tubings. The annular spaces between the conductor, surface and inner casings are ideally cemented, except in the presence of aquifers in the wellbore elevations. The surface wellhead and tree weight approximately 5Te in total. The ultrasonic WT measurement activity carried out around the conductor pipe from 1m below mean sea level (MSL) to the top of the conductor, spanning 16m total elevation is shown in Table 1 for one of the conductor pipe on a wellhead platform being considered, indicating the splash zone area to be very heavily corroded with more than half of the wall being lost over the years. The corrosion level below MSL is observed to be very minimal, if none at all, and hence the nominal WT of 22mm (0.875in) is assumed. For the surface and internal casings, a conservative average wall loss of 20% will be assumed throughout due to absence of measured data on these pipes.

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Figure 3: Well Layout and Casing Arrangements

<table>
<thead>
<tr>
<th>Elevation above Seabed (m)</th>
<th>WT Along Conductor Circumference (mm)</th>
<th>Mean WT Loss</th>
</tr>
</thead>
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<tr>
<td>Bottom</td>
<td>Top</td>
<td>0deg</td>
</tr>
<tr>
<td>26</td>
<td>28</td>
<td>16.0</td>
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<td>24</td>
<td>26</td>
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<td>15.3</td>
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<td>20</td>
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<td>18</td>
<td>8.7</td>
</tr>
<tr>
<td>12</td>
<td>16</td>
<td>11.0</td>
</tr>
</tbody>
</table>

Table 1: Conductor Wall Thickness Measurement

The environmental conditions are extracted from surveys carried out and identified for 1-year (operating) and 100-years (extreme) return periods for both currents and waves in the gulf area, shown in Table 2. The UZ field soil details are extracted from geotechnical surveys carried out in the UZ vicinity and shown in terms of the soil stiffness (P-y) curve in Figure 4.

Table 2: UZ Environmental Data
The various TOC elevations in the conductor-casing annuli were considered to cater for all possible scenarios in the wellbore, and are listed in Table 3. The shortfall of cements near the surface and also presence of aquifers are accounted for in these scenarios to estimate the weights and overall system stiffness. One extreme (anomaly) scenario was also considered for a case with no cement in the conductor and casing annuli at all, to establish a lower bound of the assessment.

The majority of the UZ wells are water injection wells, with no significant pressure and temperature variation, hence the operating pressure and temperature effects are ignored in the well residual preload calculations, due to their negligible contributions to overall well loads.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cement Elevation below RT</th>
<th>Annular Content</th>
<th>Scenario</th>
<th>Cement Elevation Below RT</th>
<th>Annular Content</th>
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</thead>
<tbody>
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<td>S1</td>
<td>12 / 40</td>
<td>1713 / 5621</td>
<td>Cement</td>
<td>12 / 40</td>
<td>3094 / 10150</td>
</tr>
<tr>
<td>S2</td>
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<td>1713 / 5621</td>
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<td>26 / 86</td>
<td>3094 / 10150</td>
</tr>
<tr>
<td>S3</td>
<td>40 / 132</td>
<td>1713 / 5621</td>
<td>Cement</td>
<td>40 / 132</td>
<td>3094 / 10150</td>
</tr>
<tr>
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<td>84 / 276</td>
<td>1713 / 5621</td>
<td>Cement</td>
<td>84 / 276</td>
<td>3094 / 10150</td>
</tr>
<tr>
<td>S5</td>
<td>12 / 40</td>
<td>914 / 3000</td>
<td>Cement</td>
<td>12 / 40</td>
<td>305 / 1000</td>
</tr>
<tr>
<td></td>
<td>914 / 3000</td>
<td>1652 / 5420</td>
<td>Aquifer</td>
<td>305 / 1000</td>
<td>3094 / 10150</td>
</tr>
<tr>
<td></td>
<td>1652 / 5420</td>
<td>1713 / 5621</td>
<td>Cement</td>
<td>914 / 3000</td>
<td>3094 / 10150</td>
</tr>
<tr>
<td>S6</td>
<td>12 / 40</td>
<td>305 / 1000</td>
<td>Seawater</td>
<td>12 / 40</td>
<td>914 / 3000</td>
</tr>
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<td></td>
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<tr>
<td></td>
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<td>1713 / 5621</td>
<td>Cement</td>
<td>1652 / 5420</td>
<td>1713 / 5621</td>
</tr>
<tr>
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<td>914 / 3000</td>
</tr>
<tr>
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<td>914 / 3000</td>
<td>Cement</td>
<td>610 / 2000</td>
<td>3094 / 10150</td>
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<td></td>
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<td>1652 / 5420</td>
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<td>3094 / 10150</td>
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<tr>
<td></td>
<td>1652 / 5420</td>
<td>1713 / 5621</td>
<td>Cement</td>
<td>1652 / 5420</td>
<td>1713 / 5621</td>
</tr>
</tbody>
</table>

Table 3: Annular TOC Scenarios

Analysis Methodology

The well axial preloads are first calculated based on overall well construction sequence and the pipe strings set depth, combined with the presence and interactions with annular fluids. The axial loading on the conductor and casings are evaluated for both the conductor-supported and casing-supported well configurations, for the entire range of TOC in the annuli, and the resulting axial compressions on the conductor and casing are presented in Figure 5. Wells within the same magnitude of loads are grouped together for more effective assessment, contrary to assessing each of the hundreds of wells in the field individually. There are 5 groups for the conductor supported wells and 4 groups for the casing-supported wells identified as shown in the plots, representing almost every well within the UZ field.
The commercial FE package FLEXCOM [1] was used to perform the transient nonlinear analyses on the wellhead conductor systems, with the casings modelled as multi-pipe-in-pipe (PIP) system with the gaps between individual strings, as shown in Figure 6. The model extends from the surface tree, down to the 6 degrees-of-freedom fixity at 50m below the seabed to adequately model the structural response, as no significant lateral motion is expected below this fixity. The conductor guides were modelled as lateral constraints with radial clearances where applicable. The environmental loads were modelled in the form of current profile and Stoke’s 5th Order waves (Table 2) with the hydrodynamic coefficients applied as per API RP 2A WSD [2]. Waves are considered to be omni-directional with no wave spreading, as this is anticipated to give conservative results. Marine growth and wall loss due to corrosion are also taken into account and modelled appropriately. The lateral soil stiffness is modelled using nonlinear soil springs as per the soil behaviour in Figure 4.

The loadcase matrix for the FE analyses of the well considers the TOC in both the conductor-surface casing annulus and the...
surface-internal casings annulus, preload grouping and the various conductor/casing corrosion levels, resulting in about 630 analyses files generated for a single well configuration being considered. The bending moment and effective tension obtained from the FE analyses are used to calculate the resulting von Mises stresses and the unity check (UC) was performed based on the material specified yield strength for uncorroded and corroded pipes. Based on the UCs for corroded pipes, the interpolated/extrapolated pipe WTs are evaluated to satisfy the minimum required utilization as per API RP 2RD [3]. This will now provide an indication of whether the well is within the code specified safe operating bounds for the wellhead conductor system, for both the well configuration.

For the conductor-supported well configuration, failure to meet the required WT based on the UC as per API RP 2RD criteria means the repair on the conductor has to be carried out either by installation of repair sleeves or complete sectional replacement of the conductor pipe.

As for the casing-supported well, the failure to meet the WT requirement is deemed more complex. A helical buckling check is performed for the surface casing inside the wellbore to assess the likelihood of failure of a corroded section of the casing in the event that buckling instability using equations obtained from energy analysis in [4] and [5]. From this assessment, the helical shape or curvature of the casing, as well as the settlement of surface wellhead is evaluated for the un-cemented free spans based on the various cementing scenarios, as shown in equations (1) and (2). The casing stresses resulting from the increased bending moment and casing eccentricities subjected to wellbore helical buckling are also evaluated to determine whether the corroded casing is overstressed for a range of wall thickness losses due to local corrosion on the conductor and casing.

\[
\Delta L = L \left[ \left( \frac{2\pi r}{p} \right)^2 + 1 - \frac{1}{2} \right] \quad (1)
\]

\[
p = \frac{8\pi^2 EI}{F} \quad (2)
\]

where:
- \( r \) = radial clearance of the casing and conductor/wellbore
- \( L \) = casing un-cemented free span
- \( \Delta L \) = wellhead vertical settlement
- \( p \) = helical pitch formation in the wellbore
- \( F \) = axial compressive force
- \( E \) = Elastic modulus
- \( I \) = Moment of inertia

The cement top-up assessment is then carried out following the identification of the critical shortfall which causes the surface casing buckling and wellhead settlement. A range of cement bond strength was considered, to account for the uncertainty of the cement bonding onto the heavily corroded conductor and casing surfaces, intensified further by presence of rust flakes as shown in Figure 2. These bond strengths were evaluated based on the conservatively derived characteristic strength in equation (3) [6] for a PIP configuration, and will represent the bond efficiency of the cement onto corroded steel pipes. The 80MPa (11ksi) compressive strength cement was considered for the top-up assessment, resulting in a bond strength range of 10kPa (1.5psi) to 200kPa (29psi).

\[
f_{buc} = KC_L(9C_S)\sqrt{f_{cu}} \quad (3)
\]

where
- \( f_{buc} \) = characteristic bond strength (or \( \tau \))
- \( f_{cu} \) = cement compressive capacity
- \( C_L \) = coefficient of cement length to casing diameter, conservatively taken as 0.7
- \( C_S \) = surface condition factor bond, taken as 0.5
- \( K \) = stiffness factor
- \( m \) = modular ratio of steel to cement
- \( t \) = wall thickness
- \( D \) = outer diameter

Following these assessments, the decision to repair the conductor and/or top-up of the annular cement can be made. Due to the heavy corrosion on the conductor and possible heavy corrosion on the surface casing, the impact on cement top-up over elevation above seabed needed to be verified for burst and collapse requirements as per API RP 2RD [3] for the conductor.
and casing respectively. This will also dictate the specific repair sequence to be undertaken, i.e. to repair the conductor prior to cement top-up or vice versa. A post top-up failure assessment was carried out to determine the requirement to top-up both the annuli to mitigate any failure resulting after cement top-up on the conductor and surface casing.

Results and Discussions

The series of FE analyses carried out on the loadcase matrix for the well configurations resulted in the extraction of bending moment and overall stress UC along the spans for conductor-supported and casing-supported configurations, for each of the preload group, corrosion levels and environmental conditions. The sensitivity of the conductor-supported well configuration towards the corrosion on the conductor pipes and the environmental loads were looked at to further understand the well behaviour, and found to be influenced greatly by the waves, in addition to the governing axial compressions from the different preload groups on the corroded conductor, as shown in Figure 7 (a) and (b) for a conductor-supported well configuration.

Based on this outcome, the minimum allowable WT on the conductor can be extrapolated and plotted against stress UC, indicating the API recommended limits, as shown in Figure 8. It can be observed for the conductor that the anomaly Preload Group 1 (extreme case with no cement in annuli) is the governing condition, and the more realistic case would be Preload Group 2 (with 2000ft cement shortfall on conductor annulus) highlighting a minimum required conductor WT of 10mm (0.42in) for safe continued operation under a stress utilization of 0.8, or 15mm (0.6in) WT under a more stringent 0.6 utilisation requirement. Similarly for the surface casing, the minimum required WT can be extrapolated and the extreme case of Group 1 is governing, whilst Group 2 (with 3000ft cement shortfall in the casing annulus) shows a minimum required WT of 6mm (0.25in) necessary on the surface casing for continued operation under the 0.8 utilisation factor.

The large cement shortfall inside both conductor (2000ft) and casing (3000ft) annuli resulted in the governing minimum WT requirement for both conductor and casing under the compression sustained by the conductor from axial well loading.

Figure 7: Conductor Stress UC Effect Due to (a) Corrosion Levels and (b) Preload Group (TOC)
The casing-supported well configuration was also looked at in the event that the wellhead had settled onto the surface casing due to settlement of the conductor bottom soil support over the many years in service. The casing-supported well distributes large percentage of the well loads through the surface casing, thus relieving the conductor from high stresses which was experienced in a conductor-supported well, and this is shown in Figure 9 (a). Once again the cement shortfall inside the casing annulus also governs the response of the corrode casing towards the well loads, as seen in Figure 9 (b).

The minimum required WT on the surface casing for the casing-supported well configuration can be presented and shown in Figure 10, indicating WT of 8mm (0.32in) and 9mm (0.37in) for the surface casing continued safe operations under the utilization requirement of 0.8 and 0.6 respectively, for the casing annular cement shortfall scenario of 1000ft.
In the event of a casing-supported well configuration, with large cement shortfall lengths, the casing may buckle within the conductor and wellbore annuli, forming a helical coiling just above the TOC. It is therefore critical to determine the maximum shortfall (or the minimum TOC elevation) allowable in the casing annulus for top-up requirement using Equations (1) and (2), and the results are shown in Table 4 for each of the possibly casing corrosion levels. For a nominal casing corrosion resulting in 20% average WT loss, the buckling calculation results indicate that the casing may be overstressed in the event of a helical buckle formation. The results also indicate that for cases where the cement shortfall is in the region of 150m (492ft), there is a risk of helical buckling occurring, if the corrosion level on these casings are unknown.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>No Corrosion</th>
<th>20% Corrosion</th>
<th>40% Corrosion</th>
</tr>
</thead>
<tbody>
<tr>
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<td>167.5 m</td>
<td>150.9 m</td>
</tr>
<tr>
<td></td>
<td>596.5 ft</td>
<td>549.5 ft</td>
<td>495.1 ft</td>
</tr>
<tr>
<td>Maximum Top Settlement</td>
<td>0.02 m</td>
<td>0.03 m</td>
<td>0.05 m</td>
</tr>
<tr>
<td></td>
<td>0.07 ft</td>
<td>0.10 ft</td>
<td>0.16 ft</td>
</tr>
<tr>
<td>Maximum Stress UC</td>
<td>0.84 m</td>
<td>1.04 m</td>
<td>1.46 m</td>
</tr>
</tbody>
</table>

Table 4: Wellbore Buckling Assessment on Surface Casing

The cement top-up assessment carried out for the range of cement bond strengths considered for both conductor and casing-supported wells based on the grout-steel and grout-soil shear resistance. The post top-up failure scenario at MSL was also considered to ensure the cement top-up is able to effectively mitigate the loading through alternative paths within the system. For the conductor-supported well configuration, the factor of safety (FoS) of the cement shear load against the bond strength used are shown in Figure 11, for cement top-up of conductor-surface casing (Annulus B) and the surface-internal casings (Annulus C) annuli. For an event of collapsed conductor at MSL, top-up of the C annulus is more effective in distributing the well loads from the conductor into the casing. Top-up of both B and C annuli imparts additional weight of cement into the system and is thus unnecessary.

For the casing-supported well, cement top-up of both annuli B and C are seen to be more effective in transferring the loads in the event of casing failure at MSL due to the dual load transfer path provided by the cement in both these annuli for the well loads on the surface casing, shown in Figure 12.
A conductor supported wellhead model with the conductor-casing annular TOC of 610m (2000ft) was selected for the repair strategy design under a 100 years environmental return period loads, and as a pilot study to establish the requirements for resources, costs, risks involved and the overall required repair duration. The repair criterion is based on the minimum conductor WT of 12.7mm (0.5in) required to sustain the well loads under the selected well’s Preload Group 5 shown in Figure 8 (a). Three categories are set to define the significance of well repairs to be carried out. For conductors not meeting this minimum WT requirement, immediate repairs are crucial and must be carried out immediately with well shutdown procedures in-place, and for WT between 12.7mm (0.5in) and 17mm (0.67in) the conductor repair are to be carried out for life extension. For conductors with WT above 17mm (0.67in), no action is required for continued service. This process is shown in Figure 13.

The proposed repair strategy on the conductor is to install repair sleeves (Figure 14) over the affected segment of the conductor, from the same nominal uncorroded as-built conductor WT, i.e. 22mm (0.875in). The important criterion for employment of sleeves is to ensure adequate WT remaining on the conductor for girth welding of the sleeves, as shown in Figure 14 to ensure the effective load transfer from the upper part of the conductor into the sleeve (by-passing the corroded conductor section), into the lower part of the conductor. The minimum WT was selected from a highly likely TOC and environmental condition to be 15mm (0.6in) based on a stress UC of 0.6, or alternatively WT of 10mm (0.4in) for a UC of 0.8. Failure to have this WT on the conductor at the sleeve welding girths can possibly lead to replacement of the entire conductor section with new 30in pipe instead, as described in the flowchart in Figure 13. The sleeves are installed in 3 segments to address any excessive ovality on the corroded conductor.

Figure 11: Cement Top-Up Assessment on Conductor (Conductor-Supported Well)

Figure 12: Cement Top-Up Assessment on (a) Conductor, and (b) Surface Casing (Conductor-Supported Well) Repair and Rehabilitation Strategy
The proposed conductor repair installation steps are presented in Figure 15 to Figure 20 for a typical conductor sectional replacement (Figure 15 to Figure 17) and ZADCO pilot well repair sleeves (Figure 18 to Figure 20). The installation of the repair sleeves which was selected for the ZADCO pilot well requires clear access to the affected region of the conductor where the sleeves are required to be installed. For the UZ conductors the existing complexities are in the form of heavy corrosion at splash zone (around MSL) and the presence of conductor lateral guide at this region. To install the sleeve it will
be necessary to plug the well below the heavily corroded section, and a cofferdam to be constructed around the conductor to provide access to the conductor in the splash zone region that is unaffected by waves. In addition, it will be necessary to remove the upper guide while the sleeve is being fitted, and for a replacement guide to be retro-fitted around the conductor once the sleeves are installed. These activities will add complexity and cost to the repair operation. The lifting requirement can be very critical in this repair, and the limited lifting capacities must be quantified to avoid any overstressing on the casing while the conductor is being repaired and is unable to support any axial loading from the well. Once the repair sleeve installations are completed, the conductor guides will be refitted and coating/painting will be applied to prevent further corrosion.

![Figure 15: Tensioning Support to Well Conductor via Lifting Equipment [7]](image1)

![Figure 16: Example of Conductor Cutting and Removal of Existing Annulus Cement [7][8]](image2)

![Figure 17: Example of Temporary Vertical Beams to Support Remaining Conductor Section [9][8]](image3)
To ensure a complete well integrity during extended operating life, the well annuli are recommended to be cemented to the surface. For the casing annulus cement top-up strategy for either B annulus only or B and C annuli can be done based on the remaining WT on the surface casing. A minimum WT on the surface casing of 10mm (0.4in) is required for top-up in B annulus only, and any WT less than 7mm (0.3in) shall be governing factor for top-up in both B and C annuli. During top-up, the conductor burst requirement and casing collapse requirement were also evaluated to establish an absolute minimum WT on both conductor and casing to be 2mm (0.08in) for an arbitrary 12m cement head and 6mm (0.2in) on the casing for 50m cement head columns. The annular cement top-up steps are summarized into a process flowchart shown in Figure 21.

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Ageing asset and its rehabilitation is now affecting almost every oil company worldwide. The assessment and repair of ageing wellhead conductors are now being considered at various levels from visual inspection programs to corrosion monitoring and measurement schemes. The in-place strength assessment of the conductors and casings must be carried out in order to identify the current fitness-for-service of these systems for continued operations, as compared to the as-built conditions. The minimum required WT on the conductor ad casing can be established for required material yield stress utilizations based on well grouping carried out for similar well arrangements, corrosion levels and TOC in the annulus. This will provide grounds for decision-making pertaining to the continued service of the well, or if any repairs are required. Based on the thousands of analyses carried out for every possible well conditions, a spreadsheet based software tool has been developed to assess the integrity level of any possible combinations of conductor/casing support, TOC, corrosion levels and environmental conditions against the allowable stress limits.

Additional cement integrity assessments were also carried out to determine the survivability of the cement column in the event of post top-up conductor collapse and the environmental loading are deemed to exceed the cement tensile capacity thus resulting in possible cracking on extreme fibres. The conclusion derived from this is that the conductor must be kept intact at all time for the safe continued operation of these wells, specifically the surface casing, as it is carrying all bending loads resulting from the environmental effects. For a post top-up casing collapse scenario however, with an intact conductor, the system has been verified to be safe and operable.

The repairs are proposed for the conductor by means of repair sleeves or complete sectional replacement where the WT are well below the allowable limit. The annular cement top-up is also proposed to mitigate well loads through alternative paths for any post-repair failures at unforeseen locations on the conductor and casings. The criteria for repair strategy selection has also been presented to allow for effective rehabilitation to be carried out considering various well state scenarios and range of cement-steel interface bonds. The methodology and criteria developed throughout this activity are represented as a process flowchart as shown in Figure 13 and Figure 21, and combined with the software tool for WT requirement assessment for each well condition, will be to provide a comprehensive guideline for integrity assessment, rehabilitation and way forward.

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