VOL. 12, NO. 10, MAY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

CRITICALITY OF CONDUCTOR/CASING INTEGRITY FOR AGEING OFFSHORE WELL LIFE EXTENSION

Ramesh Ramasamy, Zainah Ibrahim and Meldi Suhatril
Department of Civil Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur, Malaysia
E-Mail: ramesh.ramasamy@siswa.um.edu.my

ABSTRACT

The increase in ageing offshore wells 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. In many cases the large number of wells which may be required to be evaluated can also make the process of developing acceptable integrity procedures challenging. Defining an accurate understanding of the present condition of these assets is essential to ensure that the structural integrity of the well can be confirmed, and the acceptability of extending the life of the asset can be evaluated. This papers focuses on the criticality of the well integrity specifically of the conductor and surface casing corrosion and the deterioration of the annular cement due to ageing on shallow water injector wells. Several structural assessments techniques are proposed for evaluating the in-place strength of the corroded well structures under operational and environmental loads, including the detailed analysis on the annular cement deterioration and its ability to mitigate well loads, whilst providing sufficient barriers for the environment. The initial results of these assessments show allowable stress exceedance by more than 20% in some instances, indicating the requirement for immediate plugging and repair/rehabilitation work. Further refinementsare proposed in this paper to reduce the over-conservatisms built in the assessments including the development of non-destructive material hardness based well construction preload measurement tool. The combined use of this tool with integrity assessments listed in this paper will prove to be a streamlined approach to tackling ageing well integrity issues in this region, with lean resource consumption and effective life extension of ageing wells for continued operations.

Keywords: platform conductor, conductor preload, well integrity, life extension, cement top-up.

INTRODUCTION

In order to keep up with energy demands and the volatility of the oil price, operators have been looking to extend the service life of their offshore wells. A significant number of the offshore wells located in the areas such as the Persian Gulf and the North Sea are operating beyond their intended design life. A good maintenance program put in-place can ensure safe operation and continued fitness-for-purpose of these wells and their structural components. In the absence of this, and combined with demanding operating and environmental conditions, these wells can experience sever degradation and may result in catastrophic failures. An effective integrity program is expected to achieve complete zonal isolation throughout its service life, although not necessarily the case in reality. An ageing wellhead platform tower (WHPT), shown in

Figure-1[1], consists of conductors and wellheads to support the production or injection operations, accompanied by the typical well construction schematics. The wellhead, designed to be supported by the surface casing during installation is shielded from the environment by the larger diameter conductor pipe. In this essence, the surface casing is designed to resist the wellhead weight, and partial weights of the consecutive casing and tubing strings inside the wellbore, depending on the quality of the cement job. Several factors are identified as playing major roles in ageing offshore well integrity. The contributing factors, in order of criticality are corrosion of the conductor and casing outer/inner walls, cement shortfall inside annuli B and C, increased well equipment weight from new installations or workover activities, operating conditions of the well for either production or water injection, and the environmental conditions. These factors will expedite the deterioration of the well structures which can lead to conductor/casing collapse and resulting in wellhead settlement/drop onto the platform deck.

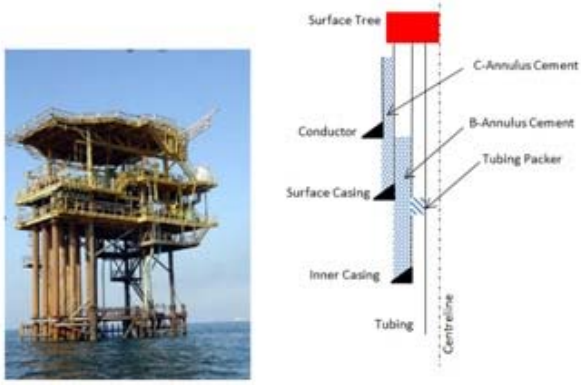

Figure-1.WHPT and well construction in a shallow water region [1].

Conductor/casing corrosion can be measured by means of ultrasonic thickness (UCT) wall measurement around the pipe circumference at each specified elevations, proving the measure of remaining wall thickness (WT). Although more recent advances have

VOL. 12, NO. 10, MAY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

presented magnetic and current imaging based corrosion measurement systems [2], a minimum of 8 point reading around conductor circumference at every 0.5m to 1.0m elevation is deemed adequate for predicting the sectional stiffness. Some shortfalls of the UCT method is the subsea inaccessibility, i.e. measurement only carried out down to the splash zone (SZ) region, usually at about 1m above mean sea level (MSL). A diver based inspection is then required to assess the subsea integrity of the conductor, marine growth etc., accompanied by a topside inspection program, which should also report presence of pitting and structural damages on the pipes, and will be used to assess the integrity state and remaining resistance.

The annular cement elevations or top-of cement (TOC) are critical in the distribution of the axial well loads into the casings and conductor, and consolidates the conductor-casing systems to provide an equivalent stiffness sufficient to resist the well loads. The presence of internal surface corrosion of the conductor and casing can result in flake formations which will affect the cement bond inside the annuli causing cement shortfall, and possibly leaving the conductor ID and surface casing OD exposed to further corrosion, and de-coupling of the section stiffness. The top-up of cement is required to overcome any downhole damages to the casings by providing an alternative load path for the axial well loads. Adequate cement bond strength [3] is critical to achieve an effective rehabilitation of the ageing well, primarily for load transfer from the inner casings into the conductor as needed.

The shallow water environment (< 20m water depth), in many locations presents almost mild conditions for wave height and current speeds, leaving the well largely under axial compression due to weight at the wellhead. This weight is a combination of the subsequent casing and tubing installed as proposed by Baur and Stahl [4] in proportion of their corresponding axial stiffness, analogous to compression springs in a parallel assembly, with approximately 3 times the effect as compared to the environmental contributions, based on past experience dealing with ageing wells in the Arabian Gulf [1]. The operating conditions for a producer well with substantial pressure and temperature, inadvertently relieves the compression in the conductor/casing system, making them more critical during shutdowns, although majority ageing wells could be water injection wells under virtually ambient conditions.

In a poorly maintained WHPT, the shortfall of annular cement (Figure-2) inside the conductor can present the risk of surface casing sinusoidaly or helically coiling/buckling inside the wellbore, based on similar behaviours encountered during coiled tubing operations [5]. The coiling of surface casing inside the wellbore can result in the vertical settlement or drop of the wellhead onto the platform deck or directly onto the top of the conductor, thus exposing the heavily corroded conductor pipe to excessive compression, and under cement shortfall, this can result in a catastrophic failure of the well. The proceeding section will focus on establishing the foundation and rationalisation of the conductor critical assessment in highlighting the in-place status and remedial plans towards extending the operating life of the ageing wells.

Figure-2. Cement shortfall inside ageing well [1].

Assessment considerations and methodology

The well drilling and installation sequence is of foremost importance in understanding the well behaviour. In a typical scenario, the conductor pipe will be drilled and installed, followed by the surface casing and the intermediate casing, completed by the tubing installation. At each of these casing being run, the annulus will be cemented to specific elevation to enforce safety barriers against the hydrocarbon from the environment. The wellhead will be installed onto the surface casing after its installation and cementation. The axial compressive load at the top of the conductor and surface casing can be evaluated at each stage by knowledge of the sectional and material properties, i.e. outer diameter (OD), inner diameter (ID) and elastic modulus to form the axial stiffness of each pipe. The absence of cement downhole cement logging data on an ageing well during its installation (possibly dating back to 60s or 70s) means that a multitude of scenarios need to be constructed for the TOC inside both B and C annuli (

Figure-1), ranging from completely un-cemented annuli (upper bound) and fully cemented annuli (lower bound) with several intermediate TOC combinations. This will result in a series of conductor/casing pipe axial loads or preloads for each TOC scenario, and for a typical shallow water system consisting of 30in (762mm) conductor, 13-3/8in (340mm) surface casing, 9-5/8in (245mm) intermediate casing and 3-1/2in (89mm) tubing, the maximum compressions on the 13-3/8in surface casing pipe can be conservatively estimated in equation (1), considering the wellhead and tree weight to be:

$$F_{13''} = M_{WH} + \left(\frac{K_{13''}}{K_{30''}+K_{13\frac{3}{8}''}}\right) M_{Tree} + \left(\frac{K_{13''}}{K_{30''}+K_{13\frac{3}{8}''}}\right) M_{10\frac{3}{4}''} + \left(\frac{K_{13''}}{K_{30''}+K_{13\frac{3}{8}''}+K_{10\frac{3}{4}''}}\right) M_{3\frac{1}{2}''} + \left(\frac{K_{13''}}{K_{30''}+K_{13\frac{3}{8}''}+K_{10\frac{3}{4}''}+K_{3\frac{1}{2}''}}\right) M_{Tree} \quad (1)$$

where:

$F_{13''}$ is the compression at the top of the 13-3/8in casing pipe in N;

VOL. 12, NO. 10, MAY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

M is the installed buoyant weights with the subscripts denoting the individual casing strings, wellhead (WH) and tree;
K is the axial stiffness of casing pipes, and is EA/L;
E is material elastic modulus in MPa;
A is cross sectional area in mm^2;
L is casing string effective span in mm.

The accurate computation of the corroded conductor section property is deemed crucial in establishing the remaining sectional stiffness of the conductor and is carried out by means of discretization. The conductor circumference is sub-divided into 0.5° sectors and the sectional properties such as cross sectional are and area moments are integrated across these sectors. Any damage or presence of pitting on the conductor can be approximated as a rectangular cut-out and assessed for buckling as per experimental findings in [7], and are shown in

Figure-3.

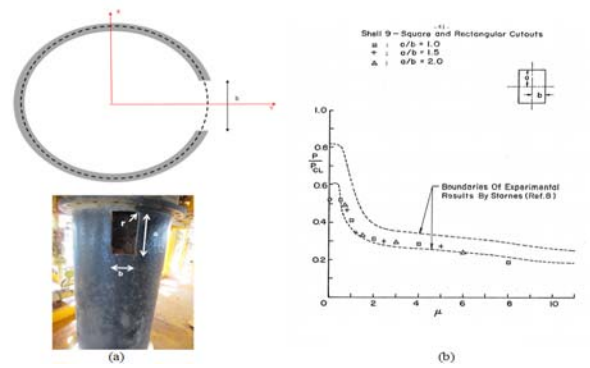

Figure-3. (a) Typical section damage, and (b) Collapse capacity [7]

Further assessment on the surface casing helical buckling using the energy method developed in [5] can be undertaken to evaluate the additional bending moment generated from the helical coiling inside the wellbore under cement shortfall, the subsequent addition in the bending stress and hence the wellhead vertical drop/settlement distance given by:

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

$$p = \sqrt{\frac{8\pi^2 EI}{F_{1S}'}} \quad (3)$$

where:
r is the radial clearance of the casing and conductor/wellbore;
L is the casing un-cemented free span;
ΔL is the wellhead vertical settlement;
p is the helical pitch formation in the wellbore under compression;
I is the section are area moment.

The buckling threshold highlighted by Baur and Stahl in [4] highlights the tendency of a system to buckling by computing the interaction ratios, but the method proposed by Wu and Juvkam-Wold [5] provides the post-buckling stresses in the casing, and inherently defines the minimum TOC for remedial works, i.e. by shortening the casing effective length to resist coiling under compression.

Well preload measurement

The well preload on ageing wells, is affected by the well construction sequence and quality of the cement job which contributes towards the inherent axial compression at the top of the surface casing, or at the top of the conductor in the event of vertical settlement of the wellhead which may be resting on top of the conductor. Analytical calculations, similar to that shown in equation **Error! Reference source not found.**) can be used to estimate the preload, but over-conservatisms are eminent, and can cause unnecessary remedial work and cost implications. Therefore, a specialised inspection technique consisting of non-destructive technique (NDT) is developed in this work. This method of measuring the material hardness using the rebound technique has been successfully used in [10], by calibrating the measured hardness of the specimen to an empirical relationship. Several variations of this philosophy has been carried out in the Heavy Structures Lab at the University of Malaya, consisting of different sensors, as shown in

Figure-4 and Figure-5.

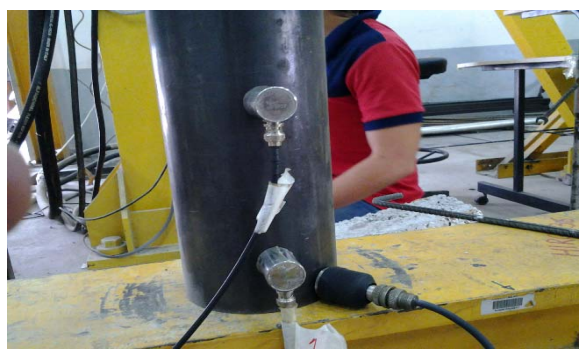

Figure-4. Use of acoustic sensors for measuring pipe preload.

Figure-5. Leeb hardness measurement for predicting pipe preload.

use of acoustical sensor and accelerometer to detect the vibrations produced by the rebounding Leeb hardness system is based on the theory that the elastic waves generated by the impact of the device is dependent upon the elastic stress field present in the specimen, caused by the preload. The uniqueness of the well system is that they are in fully compressive field. The laboratory calibration for a specimen of the same material grade as well strings (Grade-B with yield strength of 244MPa/35.5ksi) are shown for impact energy picked up by the acoustical emission (AE) transducers in Figure-6, the varying hardness and acceleration with preload in Figure-7.

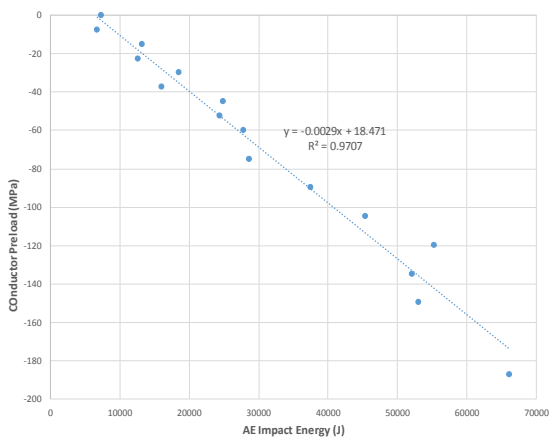

Figure-6. Calibration of preload to impact energy from AE transducers.

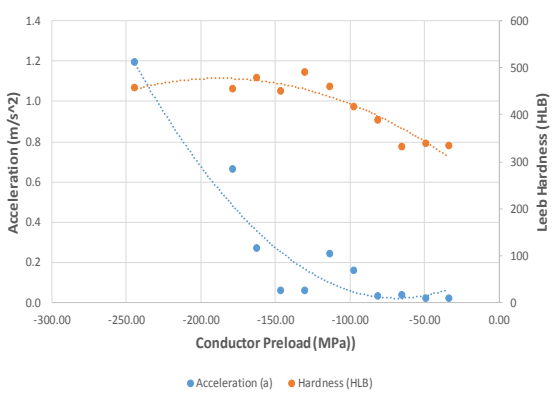

Figure-7. Measurement of hardness and accelerometer readings to varying preloads.

An empirical relation can be derived based on the vibration recording and the material hardness, and is presented in equation (4**Error! Reference source not found.**, and Figure-8 as follows:

$$Preload = 0.1HLB\,[a^2 - a + 5.8] + 146.3 \quad (4)$$

where:

HLB is the Leeb hardness value;

a is the acceleration reading.

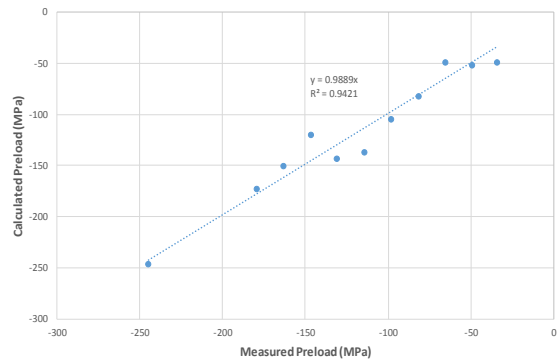

Figure-8. Preload comparison with empirical predictions.

The preload value obtained from the calculations or inspection techniques will be used to develop the guidelines for the well life extension philosophy and plans. This also relates to the existing cement level inside the well annuli, hence providing an insight into the top of cement (TOC) levels in ageing wells.

Ageing well life extension

The finite element (FE) model of the conductor and casing system can be constructed to assess the environmental effects in addition to the compression evaluated earlier in either an equivalent pipe model or a pipe-in-pipe model, which will provide the overall stresses on the casing and conductor for the corroded case as per API-RP-2A [6]. An operability guideline plot can be generated for several conductors' WT schematically shown in

Figure-9, indicating the required WT for the upper and lower bounds of the existing well preloads resulting from the two extreme TOC levels. The risk categorisation scheme is adapted into this plot to highlight the remedial action on conductors (or casings) based on the available WT and the corresponding stresses. The measured preload, abased on earlier presentation of various field/lab based methods can prove to be very useful in precisely determining the well integrity state, whilst reducing any over-conservatism.

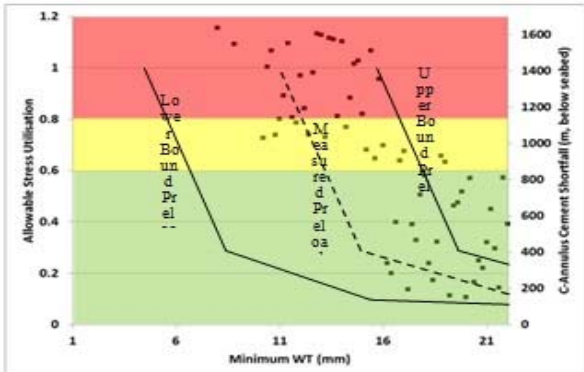

Figure-9. Operability guideline plot.

The operability plot functions on the basis of minimum and average WT of the pipes recoded during inspection, on the basis of mean area resisting axial compression and minimum area resisting the environmental bending. The criteria set forward to categorise wells for remedial actions must relate to these parameters also.

Remedial and rehabilitation

The rehabilitation for the life extension of ageing wells can be carried out in two stages: cement top-up of the inside annuli, and the repair of the conductor to resist the well axial load now acting on the conductor in the event of casing failure (wellhead drop). The cement top-up inside must consider the conductor ID heavy corrosion and rust flake formation, i.e. the cement- metal bond reduced capacity. The post cement top-up failure scenario must be considered, namely in the event of any post top-up failure occurring on the conductor or the casing, and the bond strength must be carefully selected to account for this. The grouting guideline provided in [3] considers the corroded pipe-in-pipe system, hence conservatively estimates the required cement bond to provide adequate resistance to well loads, and is as follows:

$$f_{buc} = KC_L(9C_S)\sqrt[-1]{f_{cu}} \quad (5)$$

$$K = \frac{1}{m}\left(\frac{D}{t}\right)_{cement} \quad (6)$$

where:

f_{buc} is the characteristic bond strength in MPa;
f_{cu} is the cement compressive capacity in MPa;
C_L is the coefficient of cement length to casing diameter, conservatively taken as 0.7;
C_S is the surface condition factor bond, taken as 0.5;
K is the stiffness factor;
m is modular ratio of steel to cement;
t is wall thickness in mm;
D is Outer diameter in mm.

The conductor repair is carried out either by reinforcing the outer wall to have sufficient stiffness for compressive loading, and provide an alternative load path form the heavily corroded conductor wall. This is done by means of a welded sleeve or a bolted clamp. The welded sleeve [1] requires more resources in terms of coffer dams and well shutdowns, whilst the clamp installation requires divers with bolt pretensioning tools. Clamps need to be lined with suitable materials such as neoprene or proprietary paint/coat to introduce high frictional coefficient to resist slips. The repair segment must encompass sufficient length of the conductor such that the welded/clamped location must have adequate WT remaining to provide an effective load transfer path without risk of sectional collapse/failure.

The most important factor in the remedial action for the conductor and casing is the magnitude of the compression from the well axial loads. Although conservative estimates can be derived in predicting the well axial loads, the residual measurement techniques proposed in this paper, or by ASTM [9]is effective in streamlining the wells for rehabilitation, especially if faced with hundreds of ageing well needing repairs by identifying the exact operability status in

Figure-9.

Summary

The development of the robust method in structural assessment and specialized inspection techniques of the ageing well integrity must bridge the gap between on-generic site inspections of the structural changes associated with the corrosion and cement deterioration with the consequences towards well exposure risks. These are used to develop an operability guidelines based on the remaining WT and resulting stresses to prolong the well life with sufficient margins. Novel NDT methods in well measurements are proposed to streamline the repair rationalization of wells to help reduce costs to operators, and this in turn allows the remedial steps to be taken to repair the conductor and strengthening the casing by annular cement top-up. A shallow water injector well case study on this can be found in [1] with successfully implemented repairs and life extension of a > 35 years old injection well in the Arabian Gulf, based on the assessment methodologies discussed this paper, and combined with the novel inspection strategies proposed here, will reduce excessive conservatisms built into code-based assessments and will provide a very cost effective solution for operator companies worldwide, i.e. streamlining the wells actually needing any repairs.

ACKNOWLEDGEMENTS

This research was supported by Fundamental Research Grant Scheme, Ministry of Education, Malaysia (FRGS - Project No. FP028/2013A).

REFERENCES

[1] Ramasamy, R., AlJaberi, M., AlJunaibi, H. 2014. Ageing Offshore Well Structural Integrity

Modelling, Assessment and Rehabilitation. ADIPEC, November 2014, SPE-171741-MS.

[2] S. Talabani, B. Atlas, M.B Al-Khatiri, M.R. Islam, An Alternate Approach to Downhole Corrosion Mitigation, J. Petroleum Science and Engineering, 26 (2000), 41–48.

[3] U.K Department of Energy - "Grouted and Mechanical Strengthening and Repair of Tubular Steel Offshore Structures". UK Department of Energy, Offshore Technology Report OTH 88 283.

[4] B. Stahl, M.P. Baur, Design Methodology for Offshore Platform Conductors, Offshore Technology Conference, 5/5/1980, Houston, Texas, 1980, OTC-3902-MS.

[5] Jiang Wu, H.C. Juvkam-Wold, Coiled Tubing Buckling Implications and Completing Horizontal Wells, SPE Drilling and Completions, March 1995, SPE-26336-PA.

[6] API – "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms". API-RP-2A WSD, 21st Edition, December 2000.

[7] J.H. Starnes, "The Effect of Cutouts on Buckling of Thin Shells.". Thin Shell Structures; pp 289-304; 1974.

[8] API – "Recommended Practice for Design of Risers for Floating Production Systems and TLPs". API-RP-2RD, 1st Edition; June 1998.

[9] American Society for Testing and Materials, ASTM E837 Standard Test Method for Determining Residual Stresses by the Hole-Drilling Strain-Gage Method, 2001.

[10] G. Loporcaro, S.Pampanin andM.V Kral, Experimental Validation of the Hardness Method to Estimate the Residual Ductility of Plastically Deformed Reinforcement, New Zealand Society for Earthquake Engineering (NZSEE) Conference, 2015.