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Structural Longevity of FPSO Hulls

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Abstract: The key challenge of managing Floating Production Storage and Offloading assets (FPSOs) for offshore hydrocarbon production lies in maximizing the economic value and productivity, while minimizing the Total Cost of Ownership and operational risk. This is a comprehensive task, considering the increasing demands of performance contracting, (down)time reduction, safety and sustainability while coping with high levels of phenomenological complexity and relatively low product maturity due to the limited amount of units deployed in varying operating conditions. Presently, design, construction and operational practices are largely influenced by high-cycle fatigue as a primary degradation parameter. Empirical (inspection) practices are deployed as the key instrument to identify and mitigate system anomalies and unanticipated defects, inherently a reactive measure. This paper describes a paradigm-shift from predominant singular methods into a more holistic and pro-active system approach to safeguard structural longevity. This is done through a short review of several synergetic Joint Industry Projects (JIP's) from different angles of incidence on enhanced design and operations through coherent a-priori fatigue prediction and posteriori anomaly detection and -monitoring.

***Keywords**:* Floating Production Storage and Offloading assets (FPSOs); Structural Health Monitoring (SHM); Non-Destructive Evaluation/Testing (NDE/NDT); Risk Based Inspection (RBI); Condition Based Maintenance (CBM).

1 Introduction

Firstly, this short paper will concisely outline current FPSO integrity management, after which the key paradigm of Structural Health Monitoring/Management is elucidated upon. Subsequently, the second chapter will briefly discuss the methodological constitutes, performed research and some key goals and outcomes of the current JIP's. The focus of the third chapter will be on the distinct opportunities these collaborative parallel projects for safeguarding FPSO structural longevity offer in terms of synergetic effects and mutual strengthening to further operationalize Risk- and Probabilistic based approaches to design, construction and operations, including Inspection Repair and Maintenance (IMR) practices. Finally, this short paper will conclude with recommendations for future research.

1.1 FPSO Integrity Management

At the present time, the outcome of the periodical and event-driven asset inspections provide input for the determination of the components' (compiled) Probability of Failure, which is combined with the Consequences of Failure to provide a risk profile and inspection scheme to prevent incidents, maintain a specific safety level and to enhance design and operational practices through feedback. In line with the aforementioned, in essence current Asset Integrity Management (AIM) models still consist of the a-priori determination of technical and organizational measures to ensure future economic system effectiveness and safety. Measure optimization is generally done by posteriori analysis on correlation and causality of usage, external influences and costs to improve the knowledge on physical system degradation, predict the future behaviour and further refine the measures accordingly.

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Logically, the challenges stated above are further aggravated by the inspection optimum paradigm; the intersection between the economic principle of reasonableness and the fact that unnecessary, disruptive and costly inspection and maintenance could result in unintended and expensive downtime, subsequent damage and inherent Safety, Health and Environmental (SHE) risks. Hence, best-practices should be deployed to approximate the optimum of efforts to limit these risks and safeguard structural longevity. Nowadays, a multitude of research efforts and attention are directed towards more integrated forms of inspection management and (conditional) Risk Based Inspection (RBI) in particular [1-13]. The necessity of this paradigm-shift has been highlighted very appropriately in the paper of Fragola and Bedford [14] as reliability practices shift from the dominant common, singular failures to the dependable from both un- and anticipated interactions between (sub)systems and the internal and external environment. In addition, the dominant problematic details (hot-spots) are progressively conversed with measures due to recently gained experiences. This requires a focus-shift to assure structural longevity.

1.2 Structural Health Monitoring

Although asset complexity is further intensified by in-situ (embedded) systems, technological breakthroughs in Sensing- and Information Technology also pose a significant advantage in monitoring through analysing and discriminating the a-priori and posteriori structural- and functional health of assets. The acquired data can pro-actively control predictive models to determine the current state and optimal moment for restoring structural and functional integrity, which is respectively referred to as Structural Health Monitoring (SHM) and the arising IMR-actions as Condition Based Maintenance (CBM).

The advantages of predictive, on-condition Asset Integrity Management are vast; the model of drivers for predictive IMR as constructed by Adams [15], graphically represented in figure 1, shows these perceived benefits [1]. In concreto, less downtime, minimal intrusion of the (sub)systems, the facilitation of a planned supply of maintenance resources and replacement before the actual failure, preventing subsequent damage [16], enhanced understanding of the design, modification of systems and equipment reliability [17] and less inspections and overall safer operations; lowering both the Capital Expenditures (CAPEX) and Operational Expenditures (OPEX).

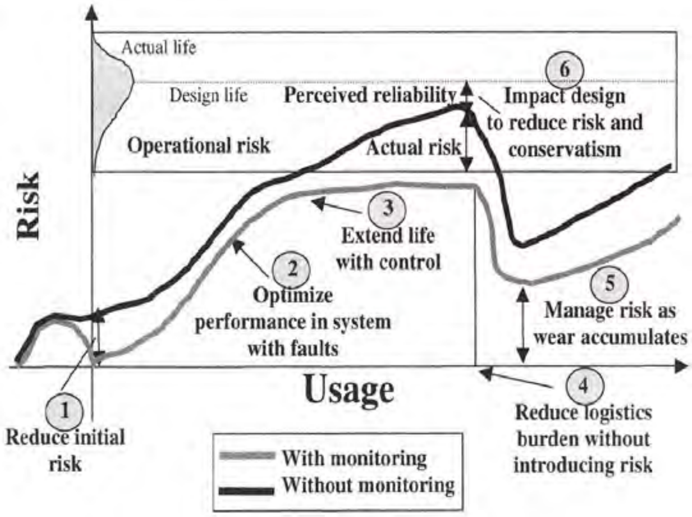

Figure 1 - Potential Impact of SHM (Adams, 2007)

Notwithstanding, as outlined in the review *'Loads for use in the Design of Ships and Offshore Structures*' by Hidaris et al. [18] research efforts into the structural loading and longevity of ship and offshore structures are fragmented on the computation of wave induced loads (47%), specialist ship structure topics such as cargo sloshing, bow slamming, green water etc. (32%) and 7% on fatigue loading of ships and 10% for specialist offshore structures. Finally, a limited amount of 5% is directed on wave load uncertainty modelling and validation (of which 45% relates to fatigue load calculations). It is evident that with SHM-systems and the empirical data obtained, all research efforts as stated above can benefit tremendously as well as operations to determine IMR-regimes from the basis of economical and SHE-performance. Such a combined bottom-up (operational research and optimization) and top-down approach (fundamental scientific research) provides for maximum knowledge valorisation: the foundation on which the most successful JIP's are built.

2 Methods and Joint Industry Projects

The Ship and Offshore Structures' section (S&OS) of Delft University of Technology manages and participates in several JIP's from different angles of incidence, but all contribute to the common goal of linking research and education in the field of structural longevity of ship and offshore structures [19]. This is achieved through enhanced design (4D Fatigue), a-priori fatigue prediction (Monitas), posteriori anomaly detection and mitigation (HITS) and defect monitoring (GrackGuard). The dominant consideration comprehends the vision that phenomenological complexity requires a holistic view and an appositely constructed research portfolio.

2.1 4D Fatigue

To this very moment, the fundamental references in the design of ship and offshore structures and the inherent fatigue resistance are directed from uni-axial and constant-amplitude testing [20-22]. Nonetheless, during real-life conditions, structures are subjected to multi-axial, variable-amplitude loading including non-proportional characteristics for specific details. Unfortunately, the usability of current multi-axial practices are restrained due to limited validation efforts and finite academic scope in testing, which can be reverted to the general engineering perception that uni-axial loading is the predominant factor. Recent research has shown that conventional uni-axial methods significantly overestimate the fatigue lifetime, and lifetime predictions of multi-axial methods show significant differences [23].

The 4D-Fatigue JIP focuses on improving the current practices and estimations by performing both numerical and experimental research. This is achieved through a testing campaign on key details, which suffer from local multi-axial and non-proportional loading. The goal is to define a multi-axial criterion and design tool to assess the knowledge gap and provide for better estimations in fatigue lifetime of welded joints in ship- and offshore structures and constitute a precursor to modification of the prevailing rules and regulations. In short, realistic test-specimens will be FEM-analysed including systematic variation of control variables and limited geometrical variables. The focus will be on variation of ratios and phases of different load components. The load spectra will be defined from analysis of in-service measurements [24].

2.2 Monitas

The Monitas system is developed as an Advisory Hull Monitoring System (AHMS), which takes advantage of both emerging (Fatigue Damage Sensors) and conventional techniques (such as Environment Data Acquisition Systems and Cargo Loading Monitoring) and comparable methodologies from a multi-domain focus, to successfully facilitate the incorporation of sensing abilities. It combines and implements the methodologies as a more generic integrated monitoring entity to model the fatigue lifetime consumption of ship- and offshore structures based on comparison between the design and the actual fatigue lifetimes calculated by the fatigue design tool. The actual lifetime is based on measured data, which includes operational settings, environmental conditions, and hydro-structural response. Hence, the Monitas system presents, explains, and provides advice on the fatigue lifetime consumption of FPSO's hulls [25-27].

Ultimately, apriory anomaly prediction allows for the reduction of operational costs and mitigation of both SHE-related and economical risks as deviations in fatigue lifetime consumptions are identified, anticipated and (re)acted upon through IMR-practices. Logically, the outcome will also trigger future design tool and -practise improvements. This will be further enhanced by a secondary project, as the system now predominantly focuses on current and historical environmental conditions, the impact of climate change - hence the discrepancy in design and future on-site sea-states - remains largely unexplored up to this moment. The university has commenced with future scenario-analysis to develop a methodology to evaluate the effect of climate change on sea-states to further enhance fatigue lifetime consumption estimations and design tools [28].

2.3 HITS

In addition to the aforementioned methods for assessing and predicting fatigue loading, the outlined knowledge gaps need to be accounted for as well as flaws in the design, construction and operational execution. Therefore, rules and regulations from authorities and stakeholders prescribe hull inspections and surveys to ensure the as-designed state and mitigate anomalies and risks through add-on measures. These anomalies are often the result of differences between the design and on-site operating context, higher than anticipated residual stresses, fabrication issues (such as misalignments, inadequate welding etc.) and system effects. The latter consists of the inter-dependency of parts, failure modes and mutual dependencies [1]. Hence, one must anticipate for non-ideal design, construction and operations. Consequently, inspections still prevail as a necessity.

The Hull Inspection Techniques and Strategies JIP (HITS) is initiated to provide for unambiguous industry guidelines on inspection procedures and -techniques. This is achieved by reviewing the multitude of existing guidelines from class societies, recommended practices and regulatory requirements to extract best-practices, identify and assess differences to derive robust inspection criteria, techniques and procedures for (e.g. regulatory, class society, company) criteria compliance. When more uniform practices become the industry standard, (censored) asset- and anomaly data can be shared, compared, interpreted and benchmarked more easily, providing empirical grounds for directed research efforts and enhanced design. Examples consist of the Bayesian updating of inspection findings and -schedules and the determination of the fatigue reliability of (un)inspectable joints c.q. details using structurally correlated inspection data. Both a valuable contribution, as disregard of structural findings and -correlation results in misunderstanding system reliability and inefficient use of beneficial information. Ergo, neglect of correlation on component level misjudges the reliability of (un)inspected components if system inspection information is available [29]. Hence, often, useful operational data is disregarded in operational decision-making and research.

2.4 CrackGuard

As outlined in the aforementioned JIP's, when coping with fatigue as a primary degradation mechanism, engineers must avoid fatigue cracks by thorough design and fabrication processes, and operators c.q. authorized bodies must periodically inspect structures for the presence of cracks. Cracks exceeding thresholds in terms of size, location and/or propagation rate and risk are repaired or mitigated, e.g. through the application of additional strengthening and/or stopper holes. Cracks of an acceptable length or judged as non-effective repairs (e.g. non-critical design error) must be followed-up during successive inspections. However, the complex nature of the phenomena makes it very difficult to estimate (near) future behaviour, which can be very capricious and - as stated - increasing inspection efforts and frequency pose both operational costs and risks.

The CrackGuard JIP hinges on the principle of Quantitative Non-Destructive Evaluation (QNDE) for non-destructive/disruptive in-service inspection and monitoring. Current practices, as deployed in the HITS-JIP are basically limited to visual detection. Typically, after detection anomalies are assessed with strain monitoring, ultrasonic, magnetic and/or radiographic testing [30]. This project consist of precompetitive research and development of an affordable system for monitoring detected and allowable fatigue cracks based on the most recent achievements in crack propagation, sensing technology and wireless communication in order to reduce the extend and scope of successive inspections, while providing valuable information on the capricious nature of crack propagation [31]. Ergo, the final link in the chain of JIP's - from design, conception and operation - for safeguarding the structural longevity of FPSO hulls.

Note that this short paper delineates the research portfolio and JIP interdependency from a bird eyes view. Please refer to references for more detailed information on the performed research and results.

3 Synergetic effects

Although the described JIP's greatly differ in approach, from both a strategic and academic top-down vision, as well as an operational bottom-up mode and from procedures and regulations to fundamental research; the absolute strength lies in the synergetic effects and mutual strengthening of the holistic approach on mastering fatigue degradation. The interdependency greatly invigorates the efforts: Monitas and 4D Fatigue provide data for CrackGuard and HITS (and vice-versa through feedback), the latter steers the operational usage and requirements of AHMS-applications and design practices, -tools and validation. Combined, (participation in) such a portfolio provides a much more solid basis for the implementation of Risk-Based Approaches as the combination of beneficial properties of the different methodologies is gained to provide data, to discriminate information and eliminate shortcomings from both perspectives. Hence, high levels of academic and professional participation between projects and direct valorisation into both operational and research practices.

3.1 Systems approach

The key methodological difficulty for safeguarding the structural longevity of FPSO hulls still lies in the collection of accurate data and the determination of the total accumulated fatigue damage for specific locations and (sub)systems [1]. The research efforts in the JIP's have demonstrated that with monitoring systems the inspection schedule can be optimized in such a way that the annual reliability index of a structural detail will not drop below its allowable threshold value [1, 13, 29] while improving the performance of IMR-practices.

The key overarching element consists of calibrating the probabilistic Fracture Mechanics model to the S-N approach [32] to keep the reliability model consistent with the conventional design method, to comply with rules and regulations and to provide for enhanced information on what, where and how to monitor and inspect. The methodology as proposed by the team consists of modifying two Fracture Mechanics parameters (primarily the geometrical faction, and secondarily the initial crack size) in such a way that the differences between the obtained reliability from both approaches are minimized [13]. This is an indispensable process for assuring the correct application, due to the inherent sensitivity of the reliability model. The combination of research and operational efforts and results from linking design, a-priori fatigue prediction and lifetime estimations, posteriori anomaly detection through empirical inspections and -monitoring with real-time monitoring of metocean and loading data closes the feedback-loop for continuous improvement of safeguarding structural longevity.

3.2 Recommendations

After this birds eye review of the conducted research and -portfolio of the S&OS section, this short paper concludes with recommendations for both future challenges, as well as the operationalization hereof:

I. Research from the JIP-portfolio has indicated that the uncertainty (Standard Deviation, c.q. Coefficient of Variation) and hence the credibility of the RBI-methodology can be greatly improved by parameter-tuning of the long term stress range distribution. Additional research should focus on enhancing the estimations of these parameters;

II. The assessment of the structural longevity of FPSO hulls should focus more on the combination of adverse effects due to system effects and compilations of failure modes, such as the incorporation of the effect of corrosion. A combination with the first recommendation and additional focus on both structural correlation and Bayesian updating of the findings are likely to further enhance longevity predictions;

III. The combination of several JIP's from very different angles of incidence, but on one overarching theme, has proven incredibly use- and powerful. To conclude, herewith a plea for strategic portfolio-management and research group composition with a clear spin-off and valorisation in both the industry as in the academic world.

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References

[1] Tammer, M.D., and Kaminski, M.L. (2013). Fatigue Oriented Risk Based Inspection and Structural Health Monitoring of FPSOs. Proceedings of the 23rd International Offshore and Polar Engineering Conference (ISOPE) pp. 438-449. June 30–July 5, 2013. Anchorage, Alaska, USA.

[2] American Bureau of Shipping (2003). ABS. Guide for surveys using Risk-Based Inspections for the offshore Industry. Houston, Texas, USA.

[3] American Petroleum Institute (2002). API580:2002-09. Risk Based Inspection [API Recommended Practice]. First edition. Washington DC, USA.

[4] Det Norske Veritas (2010). DNV-RP-G101:2010. Risk Based Inspection of Offshore Topsides Static Mechanical Equipment. Oslo, Norway: DNV.

[5] Det Norske Veritas (2010). DNV-OSS-300-3:2010. Risk Based Verification of Offshore Structures. Oslo, Norway: DNV.

[6] European Committee for Standardization (2008). CEN-CWA-15740:2008, Risk-Based Inspection and Maintenance Procedures for European Industry (RIMAP). Brussels, Belgium: CEN.

[7] Goyet, J., Rouhan, A., L'Haridon, E. and Gomes L. (2011). Probabilistic System Approach for Risk Based Inspection of FPSOs. In: OTC 22684 Proceedings of the Offshore Technology Conference. 4–6 October, Rio de Janeiro, Brazil.

[8] Health And Safety Executive (2001). HSE-363. Best practice for Risk Based Inspection as a part of plant integrity management. Norwich, UK: HSE.

[9] Lee, A.K., Serratella, C., Wang, G. and Basu, R. (2006). Flexible approaches to Risk-Based Inspection of FPSOs In: OTC18364 - Proceedings of the 2006 Offshore Technology Conference. 1 - 4 May 2006. Houston, Texas, USA.

[10] Norsok (2011). Z-008:2011 Risk Based Maintenance and Consequence Classification (third edition). Lysaker, Norway: Standards Norway.

[11] Ship Structure Committee (2002). SSC-421:2002. Risk-Informed Inspection of Marine Vessels (chairman Radm Pluta, P.J.) Washington D.C., USA: SSC.

[12] Straub, D. (2004). Generic Approaches to Risk Based Inspection Planning for Steel Structures. [online PhD dissertation]. Institute of Structural Engineering, Swiss Federal Institute of Technology, ETH Zürich. Available from: http://e-collection.library.ethz.ch/eserv/eth:1550/eth-1550-01.pdf

[13] Tammer, M.D., Kaminski, M.L., Koopmans, M. and Tang, J.J. (2014). Current Performance and Future Practices in FPSO Hull Condition Assessments. ISOPE [IN PRESS].

[14] Fragola, J.R. and Bedford, T. (2005). Identifying emerging failure phenomena in complex systems through engineering data mapping. Reliability Engineering and System Safety [90] pp. 247–260.

[15] Adams, D.E. (2007). Health Monitoring of Structural Materials and Components. Chichester, West Sussex, UK: John Wiley & Sons Ltd. ISBN: 978-0-470-3313-5.

[16] Houtum, van, G.J.J.A.N. (2010). Maintenance of Capital Goods [Inaugural lecture]. Department of Industrial Engineering & Innovation Sciences, Eindhoven University of Technology, The Netherlands.

[17] Williams, J.H. (1994). Condition Based Maintenance and Machine Diagnostics. London, UK: Chapman & Hall. ISBN: 0-4124-6500-0.

[18] Hidaris et el. (2013). Loads for use in the design of ships and offshore structures. Ocean Engineering. [IN PRESS]

[19] Kaminski, M.L. (2011), Ingenious Ship and Offshore Structures [Inaugural Lecture]. Delft University of Technology (TU-Delft). Oct. 5, 2011. Delft, The Netherlands.

[20] British Standards Institution (2005). BS7910:2005. Guide to methods for assessing the acceptability of flaws in metallic structures. London, UK: British Standards Institution.

[21] Bai, Y., 2003. Marine Structural Design. Oxford, UK: Elsevier Science Ltd.

[22] Horn et al. (2009). Report of Committee III.2 – Fatigue and Fracture. In: OTC17535 - Proceedings of the 17th International Ship and Offshore Structures Congress (ISSC). 16-21 August 2009. Seoul, Korea.

[23] Horn et al. (2012). Report of Committee III.2 – Fatigue and Fracture. Proceedings of the 18th International Ship and Offshore Congress (ISSC), Volume 1, edited by W. Fricke and R. Bronsart, September 9-13, 2012, Rostock, Germany.

[24] Besten, Den, J.H., Kaminski, M.L. and Huijsmans, R.H.M. (2013), Stress Intensity Factor Analysis Using Digital Image Correlation: A Post-Processing Approach Displacement Field Measurement for Crack Growth Parameters in an Aluminium MIG-welded T-joint. MARSTRUCT 2013, 4th International Conference on Marine Structures, March 25–27, 2013, Espoo, Finland.

[25] Kaminski, M.L. and Aalberts, P. (2010), Implementation of the Monitas System for FPSO Units. Offshore Technology Conference, May 3–6, 2010, OTC-20871. Houston, Texas, USA.

[26] L'Hostis, D., Kaminski, M.L. and Aalberts, P. (2010), Overview of the Monitas JIP. Offshore Technology Conference, May 3–6, 2010, OTC-20872. Houston, Texas, USA.

[27] L'Hostis, D., Cammen, Van der, J., Hageman, R. and Aalberts, P. (2013), Overview of the Monitas II Project. . Proceedings of the 23rd International Offshore and Polar Engineering Conference (ISOPE) pp. 455-462. June 30–July 5, 2013. Anchorage, Alaska, USA.

[28] Zou, T. and Kaminski, M.L. 2013. Possible Solutions for Climate Change Impact on Fatigue Assessment of Floating Structures . Proceedings of the 23rd International Offshore and Polar Engineering Conference (ISOPE) pp. 455-462. June 30–July 5, 2013. Anchorage, Alaska, USA.

[29] Berg, van den, D., Tammer, M.D. and Kaminski, M.L. (2014). Updating Fatigue Reliability of Uninspectable Joints using Structurally Correlated Inspection Data. ISOPE [IN PRESS].

[30] Horst, van der, M.P., Kaminski, M.L. and Puik, E. (2013). Methods for Sensing and Monitoring Fatigue Cracks and Their Applicability for Marine Structures. Proceedings of the 23rd International Offshore and Polar Engineering Conference (ISOPE) pp. 455-462. June 30–July 5, 2013. Anchorage, Alaska, USA.

[31] Horst, van der, M.P., Kaminski, M.L., Puik, E. and Lepelaars, E. (2014). Testing and Numerical Simulation of Magnetic Fields Affected by Presence of Fatigue Cracks. ISOPE [IN REVIEW].

[32] Paris, P. C., & Erdogan, F. (1963). A Critical Analysis of crack Propagation Laws. Journal of Basic Engineering 85(4) pp. 528-533.