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COMMITTEE V.7

STRUCTURAL LONGEVITY

COMMITTEE MANDATE

Concern for the structural longevity of ship, offshore and other marine structures. This shall include diagnosis and prognosis of structural health, prevention of structural failures such as corrosion and fatigue, and structural rehabilitation. Attention should be given to ongoing lifetime extension of existing structures. Focus shall be on methodologies for translating monitoring data into operational advice and lifecycle management. The research and development in passive, latent and active systems including their sensors and actuators should be addressed. Further, self-healing and smart materials should be addressed.

CONTRIBUTERS

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Floor Discussers:
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1. DISCUSSION

1.1 Official Discussion by Karl Stambaugh (United States of America)

Presented at the ISSC 2015 meeting held in Cascais Portugal, 7 to 10 September 2015

The authors of this report are to be congratulated for their comprehensive and timely overview of sustainment of ships and offshore structures. Because the report covers a broad spectrum on the topic, there is little to add in scope and much to build on to advance the highly beneficial work in the area of ship structural sustainment. My comments are based on experience in ship structural design and lifecycle management support obtained from working for the US Coast Guard Surface Forces Logistics Center, Naval Architecture Section.

I fully agree with the authors statements regarding the potential for structural reliability approaches being developed and proposed by many researchers; however, they have found few real commercial or military applications. This lack of application is in part due to reliance upon standard rule-based design approaches. While direct analysis approaches are gaining acceptance in ship structural design, their adaptation requires a new perspective on their use in long-term sustainment planning applications. The new perspectives must include time-based structural reliability, economic analysis of failure consequences, and cost-effective risk mitigation strategies. These concepts form the basis for risk analysis and the cost-benefit analysis of alternatives required to mitigate risk.

When viewed from a risk perspective, current rule-based approaches and many proposed reliability based approaches do not consider the current inspection capabilities, risks and economics of scale (i.e. the number of structural details in a ship) for maintenance, or the risk of severe failures if the structure is not adequately maintained. The author's correctly point out there is much work to be advanced in this area, especially for ship structures.

The authors review a wide range of monitoring technologies and indicate this is fertile ground for continued improvement in the processes used to design and maintain ship structures through their service life. This review includes technologies for monitoring both fatigue and corrosion. However, the authors leave quantified guidance on their applicability and cost effectiveness for the reader to explore. Furthermore, the forecasting of structural condition based on structure monitoring data is in some respects easier for fixed offshore platforms; however, ships often change operational location and heavy weather avoidance practices by operators influence forecasts of structural condition.

I would like to offer that risk and total ownership cost considerations provide a framework for evaluating the cost-benefit of risk mitigation strategies and form a framework to guide future research.

In the context of this discussion on benefits of ship structural reliability and risk-based assessments, would the authors like to comment on current and future contributions by ISSC in highlighting these important research topics?

1. Current obstacles (e.g. lack of accepted guidelines and unquantified uncertainties) and future motivations (e.g. lifecycle cost savings) associated with implementation of structural reliability and risk-based sustainment applications.
2. Role of construction and in-service inspection technologies required to advance reliability based sustainment approaches given unquantified probability of detection associated with current practices used for ship structures.
3. Approaches needed to assess initial imperfections and in-service damage in progressive failure needed to quantify risk and risk mitigation strategies prior to ultimate failure.
4. Most promising approaches for evaluating monitoring systems (e.g. cost effective and value of information approaches) used to guide quantified risk-based inspections and maintenance decisions relative to fatigue and corrosion degradation through the service life of ship structure.
5. Forecasting structural condition from response monitoring of ship structure given such factors as the assumed statistical independence of environmental conditions, the influence of the operator and changing missions. Do the authors have guidance on forecasting structural condition based on monitoring?
6. Finally, the authors do not address the cost impacts of ship disposal and related sustainable manufacturing on service life decisions and planning. Is there any guidance that may be provided in this area and recommendations for the next committee?

1.2 Floor and Written Discussions

1.2.1 Neil Pegg (Canada)

Did you consider structural longevity in terms of what the initial design life should be?

1.2.2 Torgeir Moan (Norway)

I would like congratulate the Committee and Official discusser for their excellent contributions and provide some comments on the Structural Integrity Management (SIM) of *offshore structures*. SIM needs to address different failure modes, e.g. relating to overload due to accidental events as well as degradation due to corrosion and crack growth etc. In this context I will comment on the important challenge of handling the risk associated with cracks in the life cycle. Traditionally this is done by design and inspection or monitoring. In the last 20–30 years the uncertainties associated with such phenomena and the associated decisions during design, fabrication, and operation are increasingly dealt with through risk management. As mentioned by the Committee, there has been a significant progress made on the development and application of Risk based inspection (RBI) of offshore structures—actually based on structural reliability methodology (SRM) (e.g. Madsen et al., 1987; Moan, 2005; Moan, 2007; Lotsberg et al., 2013). This is clearly a step forward. However, traditionally, SRM is based on account of normal uncertainties; i.e. the effect of "gross errors" is not included. The initial crack size in normal welded joints is of the order of 0.1–0.2 mm—as shown by calibration of fracture mechanics approaches to S-N curves (which are representative for true fatigue behaviour of welded joints; e.g. (Ayala and Moan, 2007). However, larger initial cracks do occur during fabrication, e.g. due to wet electrodes etc. (Moan, 2007; Vårdal et al., 1997). Hence, an initial crack of a depth of say 1–2 mm depth already represents a "gross error". Moreover, the reliability of nondestructive examination methods, especially underwater, typically corresponds to a mean detectable crack depth of 1–2 mm. It is also noted that a significant portion of the fatigue life with respect to a through thickness crack, when the crack is, say, 2 mm deep. For these reasons, it is important that additional mitigation actions are introduced in the inspection planning, than those planned through RBI. Obviously, this is also the case when the structure (such as piles) is not inspectable.

Hence, to manage the risk associated with failure modes involving cracks, it is necessary to adopt a broader risk management approach (Moan, 2014), e.g. in terms of:

- Using the leak before break—contingent upon a reliable leak detection and sufficient residual fatigue life beyond detectable crack size
- Reducing the crack growth rate by simply making the fatigue design criteria more restrictive [normally the acceptable fatigue (characteristic) damage for offshore structures varies between 1.0 and 0.1—depending on failure consequences and inspection plan]. This approach is more relevant for offshore structures than ships because the fatigue problems in platforms are confined to particular areas (joints).
- Design for a certain fatigue induced damage—even member failure—in terms of the Accidental Collapse Limit State (ISO19900, 1994; Moan, 2009) to ensure a certain damage tolerance. For instance, the Alexander Kielland catastrophe could have prevented at minor additional expenses by such an approach (Moan, 2007).

The choice of risk mitigation approach clearly depends on the character of crack growth and fracture, and hence the environmental conditions, structural layout etc. Moreover, a balance between risk reduction and expenditure is required. Regulators and the offshore industry have adopted the ALARP principle; i.e. to make the risk "As Low As Reasonably Practicable" to balance safety and expenditure (e.g. Vinnem, 2014).

1.2.3 Wolfgang Fricke (Germany)

The discussion by Torgeir Moan might leave some misunderstandings regarding the assumption of initial crack depths of around 0.1 mm and the probability of crack detection being close to zero for such cracks, resulting in the question how a sufficient safety can be achieved. In this context it has to be noted that the initial crack depth is just an assumption for fatigue design using the crack propagation approach in order to end up with a fatigue life corresponding to that obtained with S-N curves. The approach is also called "equivalent flaw size concept" defining an inherent flaw from which the crack propagation immediately starts.

However, the reliability of a structure requires not only a fatigue assessment for the operational lifetime of, say, 25 years, but also periodic inspections. These are particularly important to cover the errors occurring during design and fabrication, the latter resulting in larger initial flaws and defects, but below the size detected by non-destructive testing.

1.2.4 Kim Branner (Denmark)

First, I will like to congratulate the committee on the comprehensive report. In your presentation you stated that the renewable energy sector is too young to consider life extension (if I understood you correctly).

I do not completely agree with you on that. In Denmark two small offshore wind farms (Vindeby and Tunø Knob) have now exceeded their expected lifetime of 20 years and decommissioning and life extension is increasingly being discussed and worked on in the sector. An interesting area for offshore wind energy is repowering. Can a new wind turbine be installed on an old sub-structure? I recommend that the 2018 committee look into this area.

1.2.5 Jon Downes (United Kingdom)

I would like to congratulate the committee on their work which brings together a wide ranging area with many components into a very useful and interesting report. A large part of the report is rightly devoted to the methods for predicting the failure of components and the technologies including sensors, to enable this. As part of any long term maintenance strategy and lifecycle prediction, which the committee recognizes, the need to for inspection and corresponding information is also a key requirement. At present, visual inspection is the primary tool used within the marine industry. Would the committee be able to expand on their thoughts as to the adequacy of current inspection practices and if technologies might be available to enhance the usefulness of the data being retrieved through these visual inspections?

1.2.6 Stuart Cannon (Australia)

Thank you for a very informative and authoritative account of structural longevity. The members of the committee should be congratulated on their work. The report concentrates on methodologies to predict life of type and techniques for extending life. Some industries change operating profiles to extend life; a Grand Prix driver may slow up to ensure tyre life for a race. My question is whether restricting operating profiles is used within the maritime industry to ensure or enhance the life of the platform?

1.2.7 Mirek Kaminski (The Netherlands)

I would like to contribute to the discussion on uncertainty in fatigue lifetime prediction. We are used to presenting fatigue tests results in log-log coordinates and we are used to carry out the statistical analysis of these results in the same coordinate when defining the mean and the design S-N curve. In log-log coordinates the scatter of fatigue lifetime results looks small and acceptable. For D-class details, m = 3 and stresses in MPa the standard deviation of the log10 lifetime results is 0.21. The 95% scatter of log10 lifetime is then 4 x 0.21 = 0.84. This gives us lifetime scatter of 7 times! (10^0.84 = 7), e.g.: lifetimes of 3 years and 21 years are equally probable! Engineers and students should be aware of this uncertainty. My experience is that this uncertainty is often forgotten or not being realized. In my opinion, the reason for that is that the log-log coordinates mask that uncertainty. So, I recommend presenting the fatigue lifetime data in our engineering books and lectures in linear coordinates. Hopefully this would increase the awareness.

1.2.8 Ge Wang (United States of America)

Thank you, Mr. Chairman and fellow committee members for putting together a comprehensive report. The long list of references the Committee reviewed is a testimony of the great interest in this field of structural longevity. I am pleased to note that research and development remains healthy and active. The traditional topics of corrosion and fatigue/fracture are given enough attentions in this committee report. Apparently, there are advances in both academic research and practical application. The Committee has a larger coverage on the practical application. It is important to apply R&D achievements to improve our daily routines.

I support Section 5 on prevention and repairs. This is an area that deserves more attention now and in the near future. A few years back, we wrote a report under the Ship Structure Committee program that reviews current practice of fracture repair procedure for ship structures (Wang, et al, 2012 and John, et al, 2012). The U.S. Coast Guard had a need for upgrading their guidance on assessing the risk of fractures and deciding follow up actions. We proposed a risk-based approach to assess the risks that are applicable to different vessel types, and to take remedial actions in a more risk controlled manner. This is one example of how research project can be directly applied.

I would like to bring the Committee's attention to people. I have been deeply involved in Risk-Based Inspection (RBI) for FPSOs. RBI has been widely accepted in the offshore oil and gas industry. I feel fortunate to see RBI grow from a pure concept in early 2000's to an established program. It rationalizes the structural integrity management (SIM) for floating structures, topside, mooring system among other systems. Many advanced technologies that are covered in this committee have found application in the offshore RBI or SIM. And these applications have become the key to the rationalized inspection, maintenance and repair program.

One thing I learned from RBI projects is that we must be fully aware of the critical role that people play during the planning and execution process. The majority of the decision-making process is achieved at the initial project planning meeting. A RBI starts with a workshop that brings together various departments from many disciplinary areas. Most of the identified hazards are addressed with a decision by collective wisdom. Predictions using advanced tools such as fracture mechanics and reliability are called upon only when there is a lack of data or knowledge. The question is what if the collective wisdom is not comprehensive or possibly flawed in some cases. I would like to hear the Committee's opinions on the role that people play in the decision making process, and whether this needs to be addressed.

Finally, I am pleased to see that the Committee devotes efforts to cover monitoring, sensors and inspection techniques. I strongly believe that this matured industry is slowly but firmly moving towards a new era when the maintenance and inspection program are based on a combination of eye balling and timely condition monitoring.

2. REPLY BY COMMITTEE

2.1 Reply to the Official Discusser Mr. Karl Stambaugh

The members of committee V.7 thank Mr. Stambaugh for his thoughtful review of our report and quite agree with him that a new perspective is needed for long-term sustainment of marine assets. Owners and operators will need to have a sufficient business case for going beyond a reactive rule-based approach to maintenance and the adoption of a forward-thinking predictive approach. We agree with his comments and observations regarding limited application of structural reliability approaches. Although ship structural reliability technology has been steadily developed over the last several decades, real-world applications of it have been few, even where that approach could have a great benefit, such as planning for maintenance. There certainly is a need for time-based structural reliability, economic analysis of failure consequences, and cost effective mitigation strategies. The use of a risk-based perspective to support sustainment can have great value because risk and total ownership cost considerations provide a framework for evaluation the cost-benefit of risk mitigation strategies.

In response to Mr. Stambaugh's comments and questions, the following points are made.

Quantified guidance on the applicability and cost effectiveness of technologies for monitoring fatigue and corrosion is lacking in the literature. This is perhaps related to the committee's conclusion that laboratory-proven structural health monitoring techniques need to be expanded to address real structures, with more full-field testing of the systems to develop their full maturity. Without actual operating experience, the true effectiveness of such systems can only be estimated.

As Mr. Stambaugh pointed out, a new perspective is needed if structural reliability and risk-based sustainment applications are to be made. It will require forward-thinking owners and operators to demonstrate the effectiveness of such methods and then others may follow. The committee for ISSC 2018 should look for such experimental applications and bring forth the benefits that have been seen as an incentive for others to adopt the technology. In that regard, we hope that continued reporting of the U.S. Coast Guard projects on monitoring their ships will continue to be reported in the literature.

The committee sees no trend for improvements in construction quality in the near future without a clear incentive to do so. Implementation of structural health monitoring from the earliest stages of fabrication can demonstrate the payback that can be achieved through improvements in quality and thus provide owners an incentive to require more quality in construction.

The research to date that the committee has reviewed has not indicated any technologies for monitoring systems that would be cost prohibitive. However, several technologies promise cost reductions, such as remote rather than hard-wired sensors; systems for assembling, storing, and evaluating the large amount of data that can be accumulated; and fully automated advisory monitoring systems.

Forecasting of future operating conditions begins in the design and construction phases using estimates based on the intended service conditions of the ship, with that information going into a lifetime failure analysis. The most promising method for updating that lifetime prediction is the use of Bayesian updating using data from structural health monitoring systems, reflecting actual service conditions and structural response.

The committee has not specifically investigated the cost of ship disposal, and recommends that the 2018 committee investigate the subject. The cost of ship disposal is rapidly changing as the effect of regulations on environmental impact and worker safety are leading to a more controlled industry worldwide, and future cost may be far greater than in the past.

Again, we thank Mr. Stambaugh for his thoughtful comments, and look forward to the work of the Structural Longevity committee for ISSC 2018.

2.2 Reply to the Floor and Written Discussions

2.2.1 Reply to Neil Pegg

Considerations of structural longevity and initial design life are interrelated in terms of expectations of maintenance over the lifetime. In almost all cases, routine maintenance will include routine preservation of structure, although developing coatings technology promise lifetimes of coatings on steel of 20 years or greater, and often aluminum structure is left uncoated. However, with more traditional preservation techniques, replacement of corroded structure is part of the routine lifetime maintenance. Fatigue analysis during the design is aimed at having a low probability of crack initiation during a structure's lifetime, but designing to a lower probability of cracking will result in increased initial cost, which must be balanced against the possibly decreased cost of repairs during the structure's lifetime. The airframe community utilizes a fatigue budgeting approach such that operations and cyclic loads are tracked relative to the design assumptions, and the end of life is considered to have occurred when some predetermined fatigue life of critical joints has been achieved (e.g. 50% of the total fatigue design life). Life extensions beyond this may be made based on inspection and further analysis and testing. Tracking of a ship or offshore structures operational experience in terms of loading would allow a similar approach to be achieved, but without knowing exactly how a platform was loaded, it is difficult to made direct comparisons to the design assumptions and design life, aside from repair and material renewal to return the platform to an acceptable condition according to the governing ruleset.

2.2.2 Reply to Torgier Moan and Wolfgang Fricke

Much of the application of the technology of fatigue assessment that has developed over the last few decades has been applied in the design stage, with the objective of having a low probability of fatigue crack initiation over a desired lifetime. There is no certain methodology for transitioning between an S-N crack initiation analysis and a fracture mechanics-based crack growth analysis because S-N data are not based on a specific crack size that can be carried over into the crack growth analysis. The most viable method, as indicated by both Prof. Moan and Prof. Fricke is to select a small initial flaw size and conduct a fracture mechanics-based analysis, bypassing the S-N approach. However, with structural longevity studies, the emphasis in the literature, such as work cited of Frangopol, is on managing cracks once they have initiated by developing optimum inspection plans. Therefore, with crack growth analysis for structural longevity studies, the initial crack size is taken considering the probability of detection and the inspection method used. Inspection cycles are then planned to ensure that an inspection will occur before a crack can grow to a critical size. This methodology is just evolving as a research topic, and the committee was unable to discover actual applications to real structures, but the committee will continue to seek out any such practical applications in the future. The committee also appreciates the insight that lower cumulative damage allowances are more easily instituted in offshore structures for joint connections vs. ships, as well as the suggestion that damage tolerant structural design be considered in order to prevent accidental collapse.

2.2.3 Reply to Kim Branner

We appreciate Prof. Branner's comments concerning 20-year old wind farms. Perhaps the perspective is a result of some of us who come from countries where the installation of offshore wind farms is still being debated! We will suggest that the 2018 committee look into the technology that is being applied to assess the life extension and reusability of these offshore structures.

2.2.4 Reply to Jon Downes

Well, that is in fact one of the key questions for RBI. The outcome, hence Probability of (anomaly) Detection of visual inspection, greatly differs. The general criteria states 90% PoD for a 1 mm crack (Shinozuka, 1989), which is quite optimistic and we believe has not been validated in any in-service study. The major contributing factors are surveyor competence and inspection conditions (e.g. accessibility, cleanliness, lighting etc.). Studies show that even under more-or-less perfect inspection conditions and with sufficient surveyor training, the human limitations and sheer size and complexity of the structures (literally thousands of structural details) makes it virtually impossible to inspect everything thoroughly.

Additionally there is the principle of what is reasonably possible in terms of time/costs and posed risks during inspection. Hence, in our opinion, the adequacy of the current inspection practices for smaller size and less obvious defects and fatigue damage (predictions) is lacking.

As the question suggests; indeed at this moment recent studies focus on a more proactive approach to make a more clear link between a-priori fatigue prediction and posteriori anomaly detection through a Risk Based approach using Hull Structure Monitoring (HSM) with Advisory Hull Monitoring Systems (AHMS, such as used in the Monitas JIP, Kaminski, 2010) and Structural Health Monitoring (SHM) which measure a failure in progress, such as crack monitoring (CrackGuard JIP). Note that the latter asks for more structural redundancy to limit risks. Another example is the use of structurally correlated inspection data to reduce the burden of full inspection to a more thorough singular/local inspection (Berg, Tammer and Kaminski, 2014). Hence, more rational methodologies to steer the decision-making process based on quantifiable statistical (un)certainties. On the more practical end, database programs for better inspection data management emerge (such as BV's VeriSTAR AIMS) and provide for much better inspection schemes and focus.

However, when detected (and repaired), the updating process of structural reliability is not straightforward. In order to keep the reliability model consistent with the conventional design method based on the SN-approach, a calibration process on the Fracture Mechanics parameters is needed in such a way that the differences between the obtained reliability from both approaches are minimized (Tammer et al., 2014). Furthermore, in most approaches a 'perfect repair' is used as a starting point and the risk of brittle fracture often neglected. Hence, further research into both anomaly detection and Residual Lifetime is a necessity.

2.2.5 Reply to Stuart Cannon

In some studies of the application of structural health monitoring to manage service life such as the work cited by Frangopol et al., real-time guidance is offered to the operators of ships for the course and speed to be taken to reduce fatigue damage. At this time, the studies are only of a conceptual nature, but the committee will continue to seek actual applications of this technology to operating ships.

2.2.6 Reply to Mirek Kaminski

The committee agrees that the focus of fatigue analysis is on the lower probability limits for crack initiation, and the Log-Log scale does mask the inherent variability of S-N data. This means of communication does likely hinder the user community's ability to judge fatigue damage risk, but is standard practice to a degree that it would be hard to adjust without a strong basis. We are unaware of any papers or work addressing this question. Perhaps this is a useful topic for academic exploration and research, in order to build the business case for adjustment/modification of technical communications to designers and decision-makers?

2.2.7 Reply to Ge Wang

The committee commends Dr. Wang and his colleagues at ABS for producing that fine survey of current fracture repair techniques. Often the situation to which this work applies is when a crack is discovered either in a planned inspection or as an emerging situation. Then a decision must be made, often in a short time frame of the repair method to be applied. One of the objectives of structural longevity technology is to be proactive, anticipate problems, and be prepared to implement a solution when they occur.

The comments regarding the role of people is very important and worth inclusion in a holistic consideration of any decision-making exercise, including design and longevity activities. In our experience, the people in the room when decisions are being made, make all the difference. But the role of people also extends to the utilization of tools for design and analysis. The best and most accurate/precise computer code in the world can still be wrong if the user isn't as expert as the code developer assumed, and this isn't limited to computer codes. Even basic exercises such as determining the section modulus of a hull girder can lead to differing answers among 'trained' people. We will suggest that the role people play in longevity-related actions be considered in the 2018 committee.

3. REFERENCES

Ayala Uraga, E. and Moan, T. (2007) "Fatigue reliability-based assessment of welded joints based on consistent fracture mechanics formulations". *Int. Journal of Fatigue,* 29 (3), 444-456.

Berg, D. v. d., Tammer, M. D. & Kaminski, M. L. (2014) "Updating Fatigue Reliability of Uninspectable Joints using Structurally Correlated Inspection Data," International Society of Offshore and Polar Engineers, Busan, Korea

ISO 19900 (1994) 'Petroleum and Natural Gas Industries – Offshore Structures – Part 1: General Requirements', Int. Standardization Organization, London.

Lotsberg, I. et al. (2013) "Use of probabilistic methods for planning of Inspections for fatigue cracks in Offshore Structures", Rev. 2. DNV Report No. 2011-0666, DNV, Høvik, Oslo.

John, S.M., E. Khoo, J. Purcell, and G. Wang, ABS, China (2012). Classifying structural failure using "criticality class", RINA Conference on Managing Reliability & Maintainability in the Maritime Industry, London, UK, 25-26 January 2012.

Kaminski, M. L. & Aalberts, P. (2010) "FPSOs and Floating Production Systems: Implementation of the Monitas system for FPSOs," Offshore Technology Conference.

Madsen, HO, Skjong, RK, Tallin, AG, and Kirkemo, A (1987). "Probabilistic Fatigue Crack Growth Analysis of Offshore Structures, with Reliability Updating Through Inspection," *Proc. Marine Struct Symp*, Arlington, Virginia, pp 45–55.

Moan, T. (2005), "Reliability-based Management of Inspection, Maintenance and Repair of Offshore Structures", *Journal Structure and Infrastructure Engineering*, 1 (1), 33-62.

Moan, T. (2007). "Fatigue Reliability of Marine Structures – from the Alexander Kielland Accident to Life Cycle Assessment of Safety", ISOPE Keynote lecture, San Francisco, 2006, *J. ISOPE*, 17(1), 1-21.

Moan, T. (2009) "Development of accidental collapse limit state criteria for offshore structures". *Structural Safety*, 31 (2), 124-135.

Moan, T. (2014) "Safety of Offshore Structures", Keynote lecture. *Offshore Structural Reliability Conference*, American Petroleum Institute, Houston, USA, Sept. 14-16.2014.

Tammer, M.D., Kaminski, M.L., Koopmans, M. and Tang, J.J. (2014). "Current Performance and Future Practices in FPSO Hull Condition Assessments," Proceedings of the 24th International Offshore and Polar Engineering Conference (ISOPE). Busan, Korea.

Vinnem, J.E. (2014) "*Offshore Risk Assessment*", Springer, London.

Vårdal. O.T., Moan, T. and Hellevig, N.C. (1999) "Comparison between Observed and Predicted Characteristics of Fatigue Cracks in North Sea Jackets", Paper OTC 10847, *Proc. Offshore Technology Conf.,* Houston.

Wang. Ge, et al. (2012), "Review of current practice of fracture repair procedures for ship structures," SSC-462, Ship Structure Committee, http://www.shipstructure.org/pdf/462.pdf