STRUCTURAL RELIABILITY ANALYSIS FOR FIXED OFFSHORE PLATFORMS


Dr Ezanizam bin Mat Soom


Dr Mohd Khairi bin Abu Husain


Dr Noor Irza binti Mohd Zaki


Nurul Uyun binti Azman

The Structural Reliability Assessment (SRA) methodology was developed for the design or reassessment of offshore platforms. It applies an analytical technique where the criteria for design and reassessment are derived in terms of required platform collapse strength and corresponding failure probabilities. Criteria are derived by reducing the risk to a level that is "as low as reasonably possible" in accordance with ALARP principle.

Jacket platforms are one of the most commonly used fixed platforms in Malaysia. The selection of a fixed jacket platform is based on water depth, design impact, reservoir trajectory, drilling approach and production capacity (Bai, 2003). The fixed jacket platform such as wellhead platform or satellite platform is intended for the drilling of production wells in which the design is suited for the type of drilling rig, either jack-up or tender-assisted rig. Besides, the more prominent and integrated fixed jacket platforms usually intended for house living quarters and production systems are known as central processing and production platforms.

This article will discuss the type of quantified risk assessment, wave in-deck in conjunction to subsidence met-ocean changes, an overview of Structural Reliability Analysis (SRA), pushover analysis, the Probability of Failure (POF) and procedure for SRA for fixed offshore structures.

QUANTIFIED RISK ASSESSMENT

There are 2 types of quantified risk assessment: Qualitative and quantitative risk assessments. Quantified risk assessment is in conjunction with structural reliability analysis. According to Bai (2003), qualitative is subjective prioritisation based on a specific set of basic scenario rankings. It is also a study or method to identify all possible hazards that have the potential to cause damage (David Brown & William, 2007).

Quantitative assessment is a mathematical approach and emphasises the point risk estimate and the probability of distribution which is based on the risk-based assessment (Dziubinski *et al.*, 2006). Risk-based assessment uses design, analysis and the latest underwater and topsides inspection reports or data for reassessment. According to Spouge (1999), quantitative risk assessment is a valuable tool in the decision-making process as it allows experts to communicate and integrate, to quantify opinions and to combine these effectively with available statistical data.

WAVE IN-DECK SCENARIO

Wave-in-deck (WID) force is one of the main factors linked to structural integrity. It occurs when inundation of water affects the lowest deck (i.e. cellar deck) in which old and newly installed platform structures are affected. Many factors contribute to WID, such as seabed subsidence and the occurrence of extreme environmental conditions (Figure 1).

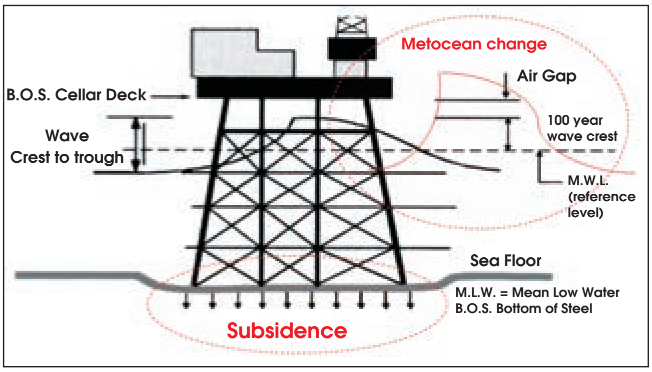

Figure 1: Elements (hazards) that contribute to risk

Subsidence needs to be carefully assessed during the design stage of the platform. This evaluation is essential to avoid a catastrophic incident due to conditions where the water level comes closer to the topside deck or, in other words, the loss of the air gap. Hence, there is a potential of a WID scenario at the affected platform (Amdahl & Holmas, 2016). Apart from subsidence, the air gap may also change due to the revised met-ocean criteria as the results from the use of the latest technology, gives higher accuracy compared to the previous ones (Azman, 2018).

In term of design criteria, the platform height is crucial to provide sufficient air gaps and to protect platforms from the most dangerous part of the storm. Offshore platforms can generally deal with wind and rainfall, but cresting waves can do real damage. The impact of stormy conditions

Figure 2: Actual photo of WID loading scenario

will lead to pressure in wave crests and cause WID load on the platform deck (Figure 2). The WID load can cause significant damage to the deck structures and potential to the collapse of the entire platform.

STRUCTURAL RELIABILITY ANALYSIS

Structural reliability analysis (SRA) methods are used to comprehensively assess the effects of uncertainties in load actions, resistances and modelling of certain parts of a structure and its performance. Structural reliability analysis offers assessments at the level of structural components and the entire structural system (Efthymiou *et al.,* 1998).

Fundamentally, structural system reliability focuses on issues such as redundancy, robustness with respect to damage and rate of inspection. Currently, the analysis method is available for efficient estimation of the reliability of common platforms under push overloadings. Structural reliability merely means the field of probabilistic analysis of structural behaviour, serviceability and safety (Abu Husain *et al.,*2014).

SRA is a superior approach in reliability assessment (RA), due to its extensive application. In reliability engineering, a simplified analytical procedure to evaluate the probability of failure for fixed offshore platforms subjected to extreme storm conditions, was established to assess the structural safety and to perform reliability analysis (Bea & Mortazavi, 1992). The procedure is similar to the concept of demand and supply or load and strength. Demand refers to the load model while supply refers to resistance model or strength model. SRA is used to estimate the integrity of an existing structure based on the pushover analysis (Fayazi & Aghakouchak, 2015). The component failure occurs due to several hidden potentials such as the redundancy integrity of the structure and load distribution.

The most commonly used procedure to evaluate the integrity and reliability level of an offshore platform is Global Ultimate Strength Assessment (GUSA) and Risk-Based Design & Assessment (RBDA), two domains of the structural reliability analysis being used in Malaysian waters.

Shell Global began its structural reliability analysis for offshore structure platform in the North Sea in 1999 using convolution method with the application of integrals formulation. PETRONAS developed GUSA in 2014 to evaluate and assess more than 100 ageing platforms under PCSB in Malaysian waters.

PUSHOVER ANALYSIS

SRA is performed after the pushover analysis to approximate platform reliability. An approximate reliability measure can be established through the determination of the return period of the environmental load which the structure can withstand the (lowest) calculated Reserve Strength Ratio (RSR).

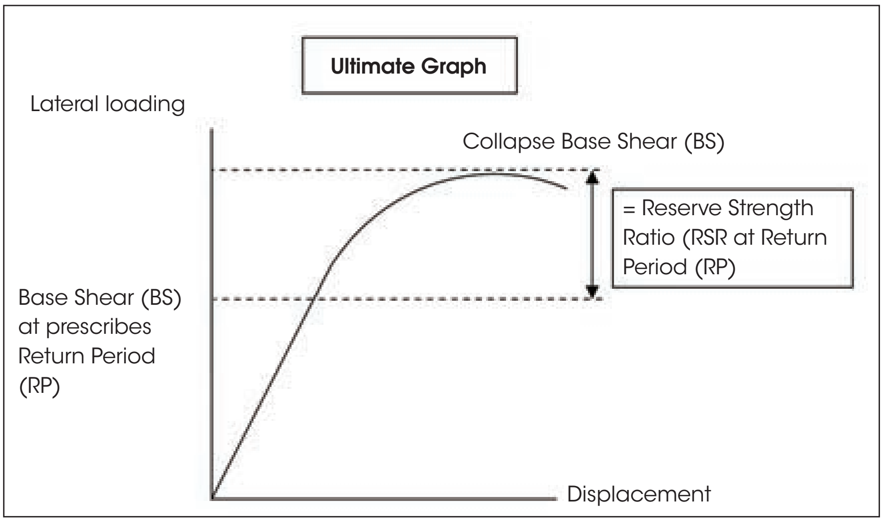

Figure 3: Reserve strength ratio and base shear at return period

The definition of reserve strength ratio at collapse can be subjective as it can be the first "significant" peak or the highest peak of the load-deformation curve. Currently (Figure 3), it is recommended to use the highest peak of the load-deformation curve as the "collapse" reserve strength ratio (Pueksap-anan, 2010).

PROBABILITY OF FAILURE

Probability is a degree of belief regarding the occurrence of an event, rather than the actual frequency. In contrast, the term reliability is defined as the complement of the probability of failure (POF) or precisely known as a probability of safety of the structure over a given period (Robert, 1999). POF for structural capacity can also be calculated by considering its uncertainty as determined from the nonlinear static pushover analysis that was established for probabilistic assessment of platforms under extreme wave loading (Cornell & Krawinkler, 2000; Jalayer, 2003; Moehle and Deierlein, 2004; Manuel *et al.,* 1998).

In general, the structures are more reliable as the POF value decreases. Typically, reliability can be expressed as 1 in 100 or 1 failure in 100 events of the POF. The inverse of coefficient of variance (COV) is known as reliability in statistical terms in which the reliability increases as the COV value decreases, i.e. standard deviation decreases (Naresh, 2007).The chance of a platform collapse due to extreme storms is quantified and can be compared with other risks to personnel offshore.

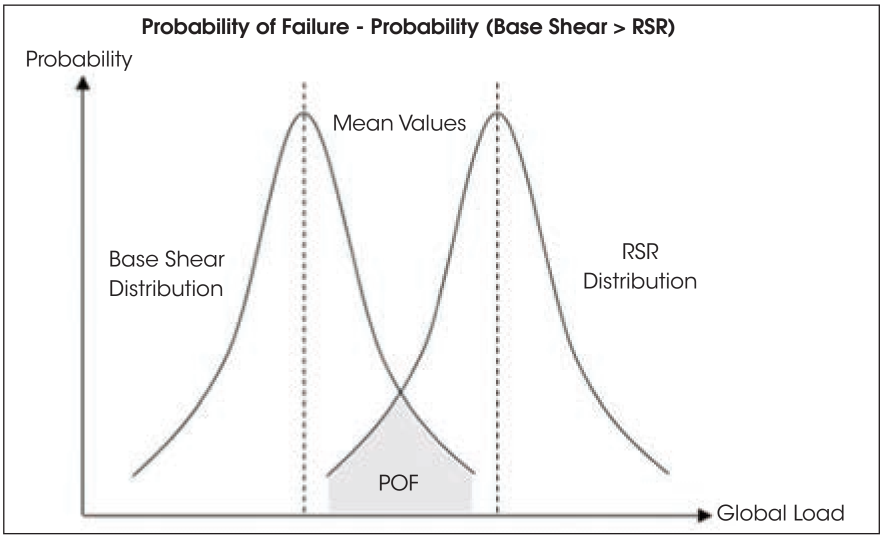

Figure 4: Probability of failure of base shear and RSR distributions

POF (Figure 4) is derived when the load distribution (base shear) is greater than the resistance distribution (RSR). Base shear and RSR derived from the pushover analysis is multiplied by a factor "bias" to obtain an accurate result as the mean value.

GENERAL PROCEDURE OF STRUCTURAL RELIABILITY ANALYSIS

The nonlinear structural analysis, using modern software such as Structural Analysis Computer Software (SACS) collapse or Ultimate Strength for Offshore structural Software (USFOS), is an alternative SRA procedure to obtain the reserve strength ratio based on ultimate base shear over the design of the return period. Commonly, the nonlinear analysis is verified by a static pushover analysis or nonlinear progressive collapse analysis.

SACS is used to model and verify the selected test structures. It is widely used in the industry, especially for fixed template offshore structures. It is capable of performing linear static analysis and comes with several code checks such as ISO (2007), API (2000) and NORSOK standard.

The USFOS computer package is used to perform the non-linear pushover analysis, which is widely adopted by the industry. Its capabilities include the modelling of non-linear element behaviour, non-linear material properties and plastic joint behaviour. At every load level, USFOS is able to calculate platform stiffness based on updated geometry.

SESAM software is used for modelling and wave load generation purposes. The software is suitable to be adopted in offshore structural designs such as fixed offshore structures and floating structures. Finite Element (FE) method has been adopted by the software, which is based on the displacement formulation. The software consists of several modules.

The analysis starts with test structures design data and model verification, followed by a conditional assessment of loads and resistance specific to each test structures, model and data analysis and conversion to SESAM GeniE for verification checks with SACS and pushover using USFOS. SRA is applied and reserve strength ratio, base shear and the probability of failure are calculated at the end of the analysis. Figure 5 shows the overall procedure.

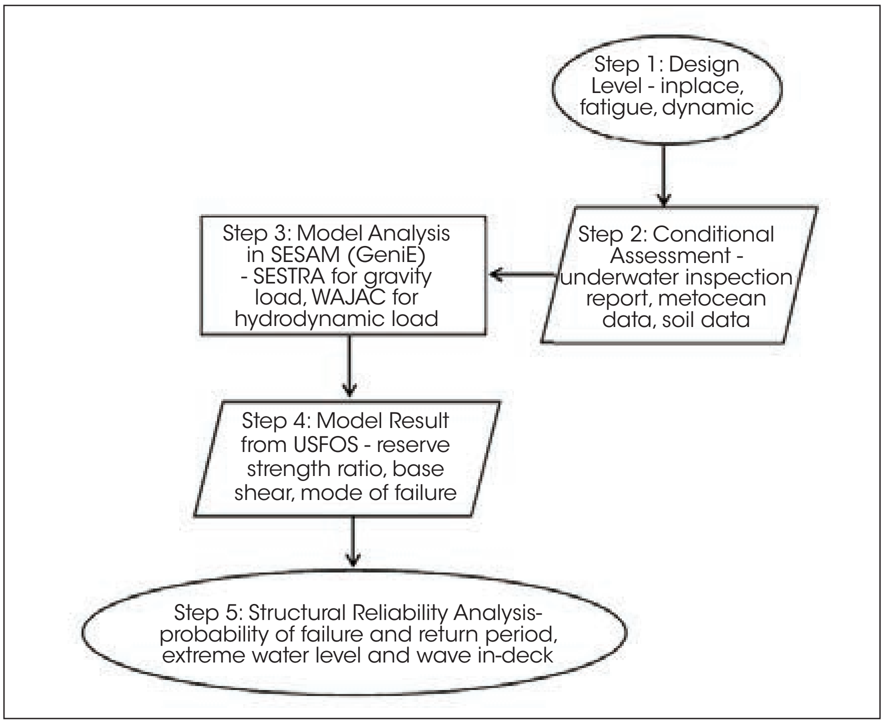

Figure 5: Overall procedure of structural reliability analysis

CONCLUSION

The concept of demand and supply or load and strength has been utilised through a simplified analytical procedure to evaluate the probability of failure for fixed offshore platforms subjected to extreme storm conditions. A probabilistic model is a combination of load model and strength model. Nonlinear analysis using USFOS is a method for determining the reserve strength ratio and type of failure. The methods allow estimating the duration period for an offshore structure platform to withstand the loading despite its current condition.

The effect of the probability of failure result is based on the experienced wave (several) which is subjected to the increment in wave heights. The structures with a loading exceeding the design prescribed return period (i.e., 100 years, 1,000 years and 10,000 years) can minimise the probability value up to model level with no gross error. The accuracy and effectiveness of this approach will assist the industry, especially operators, in decision-making and, more specifically, for outlining of action items as part of the business risk management. ■

REFERENCES

[1] Abu Husain, MK, Mohd Zaki, NI, Mallahzadeh, H and Najafian, G (2014), "Short-term Probability Distribution of the Extreme Values of Offshore Structural Response by an Efficient Time Simulation Technique". Ships and Offihore Structures Journal, l0, pp, 1-12.

[2] Amdal, J. and Holmas, T. (2016). "ISUM for Offshore Frame Structures". Busan, South Korea: Proceeding of the ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering (OMAE).

[3] Azman, N. (2018). "Structural Integrity of Fixed Offshore Platforms by Incorporating Wave in-Deck Load". Universiti Teknologi Malaysia, Kuala Kumpur, Master of philosophy.

[4] Bai, Y. (2003). "Marine Structural Design". Houston, USA: Elsevier Ltd.

[5] Bea, R. G. and Mortazavi, M. (1992). "Experimental Validation of ULSEA with Results from Frame Test"s. Honolulu, Hawaii: 7th International Offshore and Polar Engineering Conference (ISOPE).

[6] Cornell, C. A. and Krawinkler, H. (2000). "Progress and Challenges in Seismic Performance Assessment". PEER Center News.

[7] David Brown, F. and William Dun, E. (2007). "Application of Quantitative Risk Assessment Methodn to Emergency Response. Computers and Operations Research, 34, 1243-1265

[8] Dziubinski, M., Fratczak, M. and Markowski, AS. (2006). "Aspect of Risk Analysis Associated with Major Failures of Fuel Pipeliness". Journal of Loss Prevention in the Process Industries, 19, 399-400.

[9] Efthymiou, M., Wee, T. Y., Forristall, G. Z. and Graham, C. G. (1998). "Structural Integrity of the Forcados CLP Offshore Nigeria. EP 987-5686, Nigeria, Shell

[10] Fayazi, A. and Aghakouchak, A. (2015). "Reliability Based Assessment of Existing Fixed Offshore Platforms Located in the Persian Gul"f. Tarbiat Modares University: International Journal Maritime Technology.

[11] Jalayer, F. (203). "Direct Probabilistic Analysis; Implementing Non-Linear Dynamic Assessment". Stanford University: Ph.D. Thesis (CA, 244).

[12] Manuel, L., Schmucker, D. G., Cornell, C. A. and Carballo, J. C. (1998). "A Reliability-Based Design Format for Jacket Platforms Under Wave Loads". Marine Structures Vol. 11; 413-428.

[13] Moehle, J. P. and Deierlein, G. G. (2004). "A Framework Methodology for Performance Based Earthquake Engineering". Vancouver, Canada: 13th World Conference on Earthquake Engineering.

[14] Naresh, C. S. (2007). "LRFD for Substructures Concept of failure and Reliability Index".Canada: NCS Consultant, LLC: #01-0607-RO

[15] Pueksap-anan, P. (2010). "Sensitivity Study for RSR of Fixed Offshore Steel Type Platforms", Asian Institute of Technology, Thailand: Msc Thesis

[16] Robert, E. M. (1999). "Structural Reliability Analysis and Prediction". University Textbook. England: British Library Cataloguing in Publication Data.

[17] Spouge, J. (1999). "A Guide to Quantitative Risk Assessment for Offshore Installation". Norway: The Centre for Marine and Petroleum Technology.

Authors' Biodata

Dr Ezanizam bin Mat Soom *has 18 years' experience in the oil and gas industry. He is the offshore senior structural engineer at Sarawak Shell Berhad.*

Dr Mohd Khairi bin Abu Husain *is senior lecturer at Universiti Teknologi Malaysia, specialising in offshore structure modelling, hydrodynamic wave loading, wave mechanics and renewable energy.*

Dr Noor Irza binti Mohd Zaki *is senior lecturer at Universiti Teknologi Malaysia, specialising in ocean engineering, offshore structure modelling, hydrodynamic wave loading, wave mechanics and renewable energy.*

Nurul Uyun binti Azman *has 14 years' experience in the oil and gas industry. Currently pursuing her PhD at Universiti Teknologi Malaysia, she is also senior structural engineer at Brunei Shell Petroleum.*