

**TECHNICAL NOTE**

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**LIFETIME EXTENSION OF AGEING OFFSHORE STRUCTURES BY  
GLOBAL ULTIMATE STRENGTH ASSESSMENT (GUSA)**

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**Abstract:** Malaysia is the second largest oil and gas producer in Southeast Asia. Majority of jacket platforms in Malaysia have exceeded their design life with various types of underwater structure irregularities. Therefore, it is essential to address the reliability of the jacket platforms in Malaysia due to ageing, increasing environmental loading and demand to prolong the production for a further 25 years. The main purpose of this analyses is to determine the structure's risk level over its remaining service life which is a vital information in managing ageing facilities to cater for the demand of continuous production. Global Ultimate Strength Assessment (GUSA) methodology was used to support detailed reassessment applied in managing safety, integrity analyses and reliability by evaluating the existing platform's loading. It is a tool for high-end analysis of structures for Risk-based Assessment (RBA). In this paper, the reassessment of an ageing platform over 30-year-old, still in production is presented to demonstrate GUSA capability to perform the platform's life extension evaluation. The outcome from these analyses can effectively assist in understanding the structure platform's failure mechanism and correctly identify mitigation actions required. As part of the analyses, non-linear analysis and probabilistic model as practiced in the industry were used in order to get Reserve Strength Ratio (RSR) and Annual Probability of Failure (POF) results. The accuracy and comprehensiveness of this method will assist the industry, especially oil and gas fields' operators, in decision-making, specifically in identifying problem-oriented-solutions as part of their business risk management in managing ageing facilities.

**Keywords:** Risk-Based Assessment, probabilistic model, reliability engineering, reserve strength ratio, probability of failure.

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## 1.0 Introduction

In Malaysia, the offshore oil and gas industry is more than 100 years old. Its youthful economic exuberance has now given away to middle-aged restraint as the price of oil has

fallen and field-development and operating costs have risen. In finding ways of managing the various financial risks – together with hydrocarbon exploration and production at sea, the structural reliability assessment has introduced, i.e., a rational method of putting the economics and engineering of offshore structures into a context that takes due account of uncertainties, particularly those connected with severe ocean storms (Shell Research, 1993).

Offshore jacket platforms are commonly used in the oil and gas production in the shallow water depths of Malaysia. Over 250 installations have been operating for more than 20 years (Twomey, 2010). 48% of these platforms have already exceeded 25 years reaching their initial design life of 20 to 25 years (Shuhud, 2008). In view of the continuous production required beyond the design life, life extension of these installations is inevitable.

Development of the energy sector specifically in oil and gas with resources becoming scarce and challenging, added with growing development cost, has demanded oil and gas companies to enhance the recovery of oil and gas resources from developed fields and/or develop new discovery reserves from existing oil and/or gas platforms. In some cases with several contributing success factors, this approach has proven to give a significant reduction in development costs, resulting in good project economics, making it viable to recover more oil and gas resources (PETRONAS Research & Scientific Services Sdn. Bhd., 1999).

Utilizing existing platforms to recover and/or enhance oil and gas resources has its own challenges, mostly due to space limitation and structural integrity. Structural integrity is one of the major issues for ageing platforms, especially if major modifications are to be made and if fatigue concerns exist for jacket members. The modifications of these platforms result in higher loading, which the platform may not have been originally designed for (Nicholas *et al.*, 2006). Some studies on the reliability of Malaysian jacket platforms (M Fadly, 2011; Kurian *et al.*, 2012) and other types of platforms of the world (Shabakhty, 2004; Rajasankar *et al.*, 2003; Onoufriou and Forbes, 2001) has been undertaken in demonstrating fitness for the purpose of the structure and defining the optimum mitigation measures. Nonetheless, in Malaysian oil and gas industry reliability approach has become the common practice since late 90's.

There are issues of structural integrity and reliability, where major modification and fatigue concerns have given rise to significant changes to platform loading. Evaluation of possible life extension of ageing platforms will be required and structure failure is expected when the strength capacity cannot resist the applied load. Consequences of a failure can stop production until the previous limit of platform life, major underwater modification and decommission (American Petroleum Institute, 2007; American Petroleum Institute, 2010). The outcomes from GUSA analyses are required to give a high confidence level of structure strength for extended design life and additional years

of production. In this paper, the Probability of Failure (POF) of a 33-year-old existing jacket platform was investigated, to evaluate the possibility of another 25 year life extension by applying GUSA methodology.

This paper is composed of 5 sections. The following section is devoted to a brief review of Structural Reliability Assessment (SRA) in relation to Bow Tie and Risk-Based Analysis. Details description of GUSA with its main components (i.e., pushover analysis, failure mechanism, simplified method and ISO requirement) is presented in Section 3. Then, a general description of the test structure specification and metocean data is presented in Section 4. This is followed by the verification of GUSA outputs in Section 5. Finally, the conclusion and recommendations of this study are presented in Section 6.

## 2.0 Review Of Structural Reliability Assessment (SRA)

In reality offshore structures are exposed to random wave-induced forces in the ocean environment and a wide variety of environmental loads all of which exhibit a high degree of statistical uncertainty. The probabilistic procedures can account for the randomness of the loading by establishing the statistical properties of loads and responses and hence are necessary for risk-based assessment of these structures (Najafian, 2007). In the probabilistic method, the structure can be designed so that all the elements will have similar risks of failure during the service life of the structure. Alternatively, members and joints can be assigned different acceptable risks of failure depending on their importance in the overall safety of the structure (Abu Husain *et al.*, 2017).

Structural Reliability Assessment (SRA) can be performed at the level of structural components (Local) and the level of the whole structural system (Global). SRA method is used to assess the effects of uncertainties in the actions, resistances and modelling of (parts of) a structure and its performance. SRA is not normally undertaken as part of a new design but may be used during the initial design process to provide comparative data (Efthymiou *et al.*, 1998; A. Frieze, 2005). Hence, SRA is a measure of confidence that a system of components will serve its intended purpose. The SRA procedure also assesses the risk of failure in the light of prevailing practices, and field and experimental data, and to organize systematic thinking and analysis of uncertainties including those relevant to novel designs (A. Frieze, 2005). Furthermore, SRA certainly used in the (re-) calibration of partial action and resistance factors for special or unusual circumstances, in decision-making analysis as to support inspection and monitoring programmes and, in some cases, in structural assessment of existing structures (Efthymiou and Van de Graaf, 1997).

This assessment procedure is an approach which has been widely used in oil and gas industry for both onshore and offshore structures. Conventionally, the method used by some oil and gas companies focuses on nonlinear analysis using modern software to obtain Reserve Strength Ratio (RSR). RSR is based on ultimate base shear over the design of the return period. In practice, this is usually verified by a static pushover analysis or nonlinear collapse analysis. In some cases, reliability software is also used for calculating the reliability analysis of a fixed-structure-platforms.

Many technical papers have been issued over the last 30 years on SRA. Most of these came from universities and members of the industry, especially oil and gas fields' operators e.g. Shell, BHP, PETRONAS, etc. Shell was the pioneer in the industry when they started to introduce the Reliability-Based Design Assessment (RBDA) since early 1995 for all their facilities worldwide.

To date, there are two (2) types of recommended design practices that can be adopted in achieving the reliability-based structural design. American Petroleum Institute (API) provides API-WSD : Working Stress Design practice and API-LRFD : Load Resistance Factor Design practice. The API LRFD practice has a 'reliability based' format. As part of the analysis, this SRA provides a quantitative, decision-making methodology for assessing the integrity of new or existing offshore platforms under Risk-Based Analysis (RBA) (Efthymiou *et al.*, 1998).

It is important to note that the increasing numbers of ageing offshore structures in the South China Sea, especially in the region of Malaysian waters, come with various types of underwater structure anomalies, such as joint cracks, member flooding, shallow gas, subsidence, etc. Optimum mitigation measures shall be established through properly detailed structural integrity reassessment activities with an in-depth understanding of structural failure mechanisms (Ayob *et al.*, 2014a).

Bow-Tie is one of Health, Safety, Security and Environment (HSSE) tool support for As Low As Reasonably Practicable (ALARP) and normally used in oil and gas company to evaluate and manage the risk. Bow-Tie model is a powerful tool for communication about hazards and their control (Buijsingh, 2013). RBA is one of the important elements of Bow Tie under Control Barrier in avoiding the Top Event of platform collapse Figure 1 shows the elements in Bow-Tie.

PETRONAS has developed Global Ultimate Strength Assessment (GUSA), in use since 2012 in the region of Malaysian waters. It is important to note that this method is based on design code for fixed offshore structures utilising Probabilistic Models of load model (wave load) and load strength (load resistance).

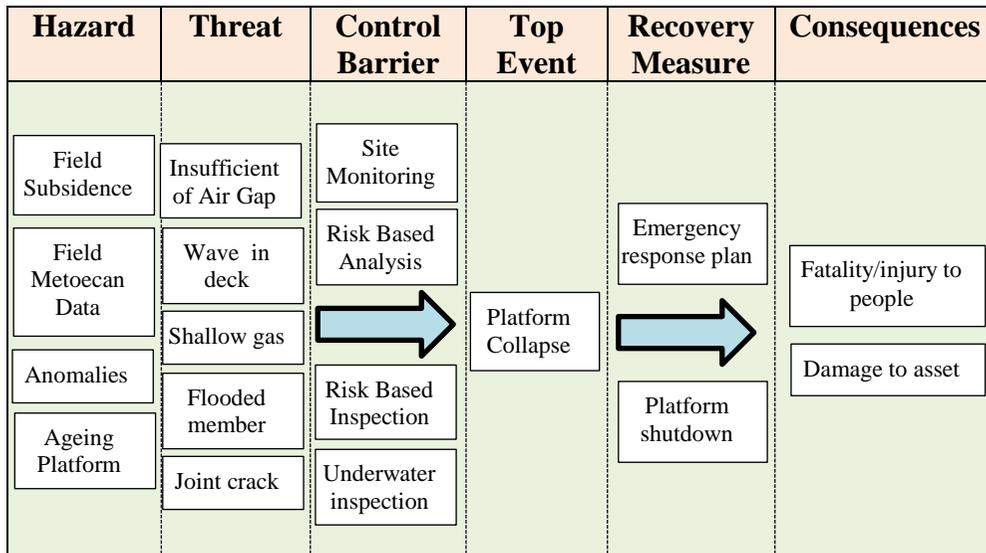


Figure 1: General Bow-Tie for Problem Statement.

### 3.0 Global Ultimate Strength Assessment (GUSA) Method

Global Ultimate Strength Assessment (GUSA) is a comprehensive methodology to support reassessment activities and is comprised of three integrated analyses, i.e. Nonlinear Plastic Collapse (NPC), Member Importance Analysis (MIA) and Structural Reliability Assessment (SRA) (Ayob *et al.*, 2014b). NPC normally called as pushover analysis using the software of Ultimate Strength for Offshore Structure (USFOS) (SINTEF Group, 2001). Results from these analyses will provide a better understanding of structures failure mechanism. Subsequently, problem-oriented-mitigation-action can be taken.

In this paper, only two elements will be calculated i.e. NPC for intact assessment and SRA for global analysis. Structural integrity consists of the following analyses to identify and verify the integrity of structure (PETRONAS Research & Scientific Services Sdn. Bhd., 1999):

#### i) Pushover analysis:

To establish the ultimate strength of the structure in minimum 8 and maximum 12 directions. The minimum 8 directions are used for 4, 6, 8 and 12 legged platforms while maximum 12 directions are used for Tripod and Monopod. The applied loading conditions are a combination of dead load, buoyancy and computed 100-years environmental condition. Nonlinearity of geometric, material and pile-soil-structure interaction are included in the analysis. The incremental load will automatically reverse if global instability is detected. This is one of USFOS process simulation

when stiffness is low.

RSR of the structure is retrieved at the structure’s collapse point. Collapse base shear is obtained by multiplying RSR with 100-year base shear in a specified direction as per defined in Eq. (1)

ii) Simplified Structural Reliability Analysis (SSRA):

Based on the results from pushover analysis, SSRA will determine an approximate reliability and Probability of Failure of the structure. This is defined by determining the return period of the environmental load the structure can withstand with the inherited RSR.

All data used for this analyses were validated. Reports, drawings and Structural Analysis Computer Software (SACS) models provided were checked and updated in ensuring all data culled e.g. geometrical properties, material properties and loadings were thoroughly verified and properly converted. Then the process continued with comparing the loads before and after conversion, followed by assigning the same set of metocean criteria to the converted model to crosscheck the base shear reading between SACS and USFOS models.

The SRA Method of GUSA is presented in the flowchart as Figure 2;

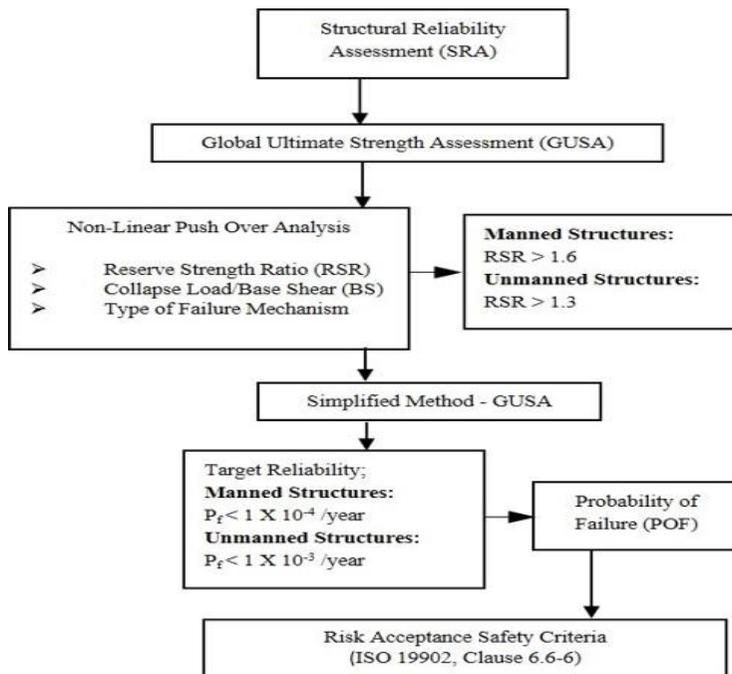


Figure 2: GUSA Procedure Flowchart.

### 3.1 Pushover Analysis - Reserve Strength Ratio (RSR)

The ratio between the metocean design loading (100 years return period) and collapse or ultimate capacity is termed as Reserve Strength Ratio (RSR) (Ayob *et al.*, 2014b). It can be defined as following Eq. (1).

$$RSR = \frac{\text{Collapse Base Shear}}{\text{Base Shear 100 years}} \quad (1)$$

USFOS has analyzed the global RSR values for the overall structural platform at minimum eight (8) and maximum twelve (12) different directions.

In general, Reserve Strength Ratio (RSR) is defined where the ultimate limit state or ultimate strength of a structure is presented by base shear at Return Period (RP) that a structure can withstand before the collapse (refer to Figure 3). It can be obtained when the structure is ‘pushed’ by applying incremental horizontal load or environmental load over its elastic limit to the inelastic region, causing plastic hinges until the structure collapses (Pueksap-anan, 2010). The environmental load applied in this study is wave, wind and current.

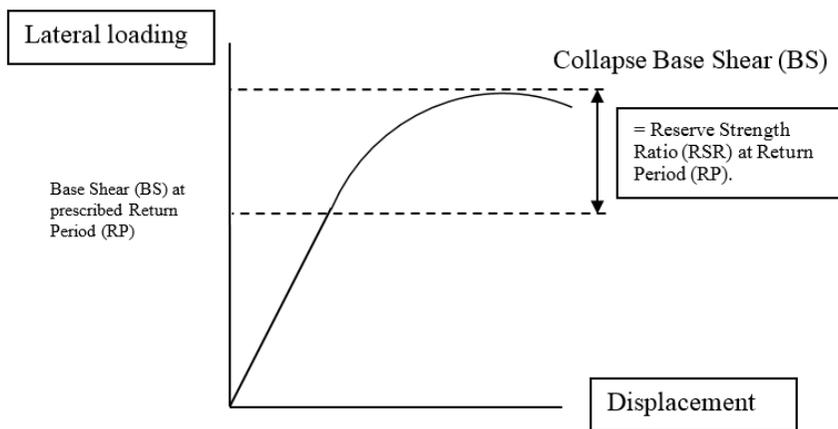


Figure 3: Reserve Strength Ratio (RSR) and Base Shear (BS) at Return Period (RP).

Structure platforms will be categorized as a manned or unmanned platform in determining its reliability level. In general, the manned platform is a platform that occupied by personnel for its operations which normally equipped with office facilities and accommodation complex. This includes for any bridged-link platforms to the manned platform. While unmanned platform normally a standalone and primarily operated remotely without the constant presence of personnel.

In order to evaluate the limitation of acceptable RSR in GUSA, the recommended engineering judgment: the minimum acceptance safety criteria for the requalification (PETRONAS Research & Scientific Services Sdn. Bhd., 1999) is as follow;

- Manned Structures: Reserve Strength Ratio (RSR) should be  $> 1.6$
- Unmanned Structures: Reserve Strength Ratio (RSR) should be  $> 1.32$

### 3.2 Structure Failure Mechanism

At present, failure mechanism is divided into two categories i.e. Member/Buckling Failure and Soil Failure. The Soil Failure is divided into two i.e., Soil Punch-through and Soil Lateral failure (refer to Ayob *et al.*, 2014b for a brief partial review). The possible wave height at each direction that causes any of the above failures is estimated according to the load level recorded during the pushover runs. Large size diameter of disks is presented high strength of soil layer while red colour of disks showed the status of sand layer as shown in Figures 4, 5 and 6. On the other hand, the red colour of piles and structures represent the overstress condition. The following figures show the differences between failure mechanisms, as demonstrated by USFOS software.

Figure 4 shows soil punch-through failure is the failure mechanism that occurs due to soil vertical capacity failure. Consequently, the jacket platform is punched-through at one side and pulled-out at another. As observed from Figure 5, the buckling failure occurs due to overstressed of structures' members. This will cause a plastic condition which finally could cause fractures. It also found that the designed structural redundancy is insufficient to sustain bigger base shear. Meanwhile, the Lateral Soil failure happened due to soil lateral capacity failure as shown in Figure 6. The pile structures bend to one side as a result of base shear and vertical load impact.

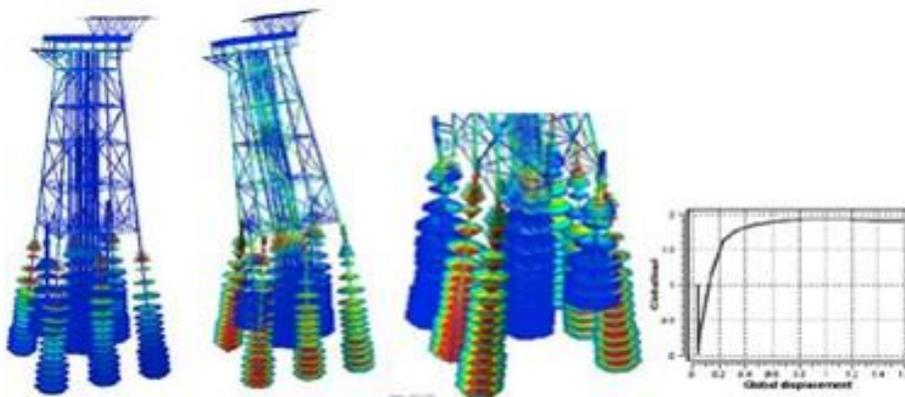


Figure 4: Punch-through Failure.

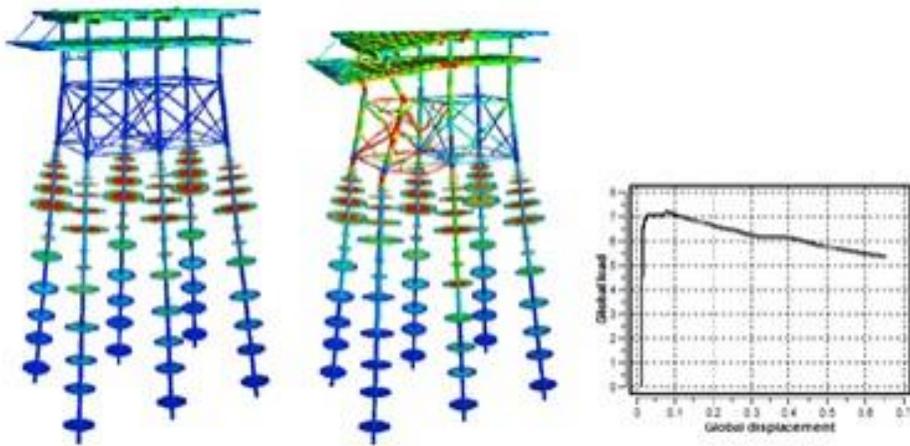


Figure 5: Buckling Failure.

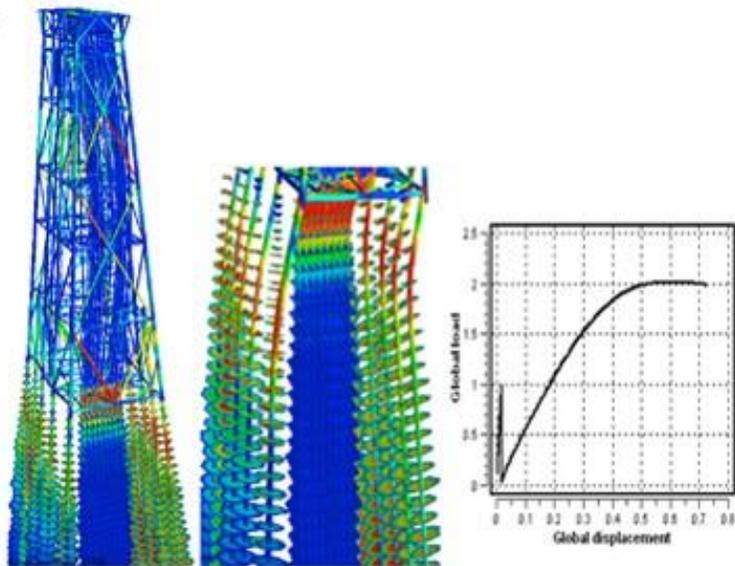


Figure 6: Soil Lateral Failure.

### 3.3 Simplified Method of Gusa in SRA Procedure

It is confirmed that structural system reliability focuses upon 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 typical platforms under push

overloadings. Structural reliability means simply the field of probabilistic analysis of structural behavior, serviceability and safety (Mat Soom *et al.*, 2015).

The primary purpose of structural reliability methods is to identify the truly critical members on the platform during their service life and to improve the structural strength by having additional members (if necessary). Normally inspection planning relies on probabilistic analysis or Risk Based Underwater Inspection (RBUI). The probability of structural failure is then evaluated by examining a limited number of significant sequences of member failures that produce the collapse of the structures (Mat Soom *et al.*, 2016). The structure will eventually survive, given the failure of one or more of its members.

Structural Reliability Analysis (SRA) was performed upon the push-over analysis to estimate the platform's reliability. An approximate reliability measure of the platform can be established through the determination of the return period of the environmental load which the structure can withstand with the (lowest) calculated RSR. The result of Probability of Failure (POF) (refer to Figure 7) is derived when the Load Distribution (base shear) is greater than the Resistance Distribution (RSR). Base shear and RSR derived from the push-over analysis is multiplied by a factor 'Bias' to obtain as an accurate result as the mean values. The bias represents the mean value of the ratio of the measured to nominal value. COV is the Coefficient of Variance of the ratio (Cossa *et al.*, 2012).

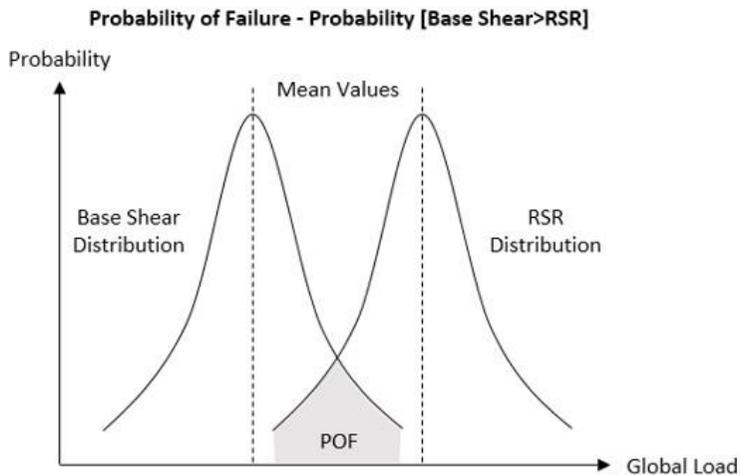


Figure 7: Probability of Failure of Base Shear and RSR Distributions.

The uncertainties exist in the extreme value distribution (load model) analysis based on measurement of the wave and current in certain return period. While, uncertainties exist in strength (resistance model) analysis based on typical material and structural elements testing result (Svein, 1978). Lognormal distribution can be obtained from analysis also by plotting the base shear vs collapse load result i.e. using formulation of mean, standard deviation and probability density function (DeCoursey, 2003).

The acceptable of target reliability for manned and unmanned in GUSA method as per the following;

- Manned Structures:  
@ Probability of Failure (POF),  $P_f < 1 \times 10^{-4}$  / year, should exceed than 1 in 10000 years
- Unmanned Structures:  
@ Probability of Failure (POF),  $P_f < 1 \times 10^{-3}$  / year, should exceed than 1 in 1000 years

The annual reliability calculation is based on the maximum annual load of wave and resistance. In considering the resistance ( $R$ ), and the maximum annual load, ( $S$ ), both lognormally distributed; safety margin ( $M$ ) is defined in Eq. (2);

$$M = \ln(R/S) \quad (2)$$

The annual reliability index ( $\beta$ ) is given by Eq. (3):

$$\begin{aligned} \beta &= \frac{\mu_M}{\sigma_M} = \frac{\mu_{\ln R} - \mu_{\ln S}}{\sqrt{\sigma_{\ln R}^2 + \sigma_{\ln S}^2}} \\ &= \frac{\ln \left[ \frac{\mu_R}{\mu_S} \sqrt{\frac{1+V_S^2}{1+V_R^2}} \right]}{\sqrt{\ln [(1+V_R^2)(1+V_S^2)]}} \end{aligned} \quad (3)$$

The  $\mu_M$  and  $\sigma_M$  are a mean and standard deviation for a safety margin respectively, in which  $\mu_R$  and  $V_R$  are the mean value and the coefficient of variation (COV) of the resistance respectively and  $\mu_S$  and  $V_S$  are the mean value and COV of the maximum annual load respectively.

The annual probability of failure ( $P_f$ ) is then given by the following Eq. (4) and where the function  $\Phi$  is cumulative frequency distribution of standard normal variate.

$$P_f = \Phi(-\beta) \quad (4)$$

3.4 ISO 19902 Requirement for Exposure Level

In order to make a comparative evaluation with the latest acceptance criteria currently used in oil and gas industry, International Organisation for Standardisation (2007), i.e. ISO 19902 Fixed Offshore Platform, provides the exposure level in accordance with its Clause 6.6. Based on the standard, the following Life Safety and Consequences are categorised as follows (International Organization for Standardization, 2007):

Life Safety categories:

- i. S1 - Manned non-evacuated (e.g. North Sea production platforms)
- ii. S2 - Manned evacuated [e.g. Gulf of Mexico (GOM) hurricanes]  
 Normally manned platforms except during environmental events. A platform shall not be classified ‘Manned evacuated’ unless:  
 A reliable forecast of an environmental design event is feasible.  
 Evacuation is planned prior to an environmental design event.  
 Sufficient time and resources exist to evacuate all personnel safely.
- iii. S3 - Unmanned  
 Platforms only manned during occasional inspection, maintenance and modification visits.

Consequences categories:

- i. C1 - High consequence category  
 High production; large processing facility; potential significant spills.
- ii. C2 - Medium consequence category  
 Minimal facility; facility can be shut-in; limited inventory.
- iii. C3 - Low consequence category  
 Minimal facility; facility can be shut-in; limited inventory; platforms support production departing from the platforms and low volume in-field pipelines.

Table 1 shows the exposure of POF level in Life Safety and Consequences Categories in accordance to ISO 19902: Clause 6.6. ISO performance standard for target reliability of POF highlighted under the Table 1 was introduced and practiced by Shell.

Table 1: Life-Safety Category vs Consequences Category.

| Life-Safety Category    | Consequence Category  |                         |                      |
|-------------------------|-----------------------|-------------------------|----------------------|
|                         | C1 - High Consequence | C2 - Medium Consequence | C3 - Low Consequence |
| S1 Manned no –evacuated | L1                    | L1                      | L1                   |
| S2 Manned evacuated     | L1                    | L2                      | L2                   |
| S3 Unmanned             | L1                    | L2                      | L3                   |

**Note:**

Target reliability for L1 category :  $POF = 3 \times 10^{-5}/yr$  (1 in 33,000yrs)  
 Target reliability for L2 category :  $POF = 5 \times 10^{-4}/yr$  (1 in 2,000yrs)  
 Category L3 is rarely used

#### 4.0 Test Structure Specification

As an overview, the test structure platform is an ageing drilling fixed jacket platform with a water depth of 26.7m. The general outline of the platform is shown in Figure 8. The platform is composed of six vertical-diagonal legs, where the diameter of each leg is 1.181m with a wall thickness of 31.75mm by design. The dimensions of the main deck platform is 29.8m x 11.89m.

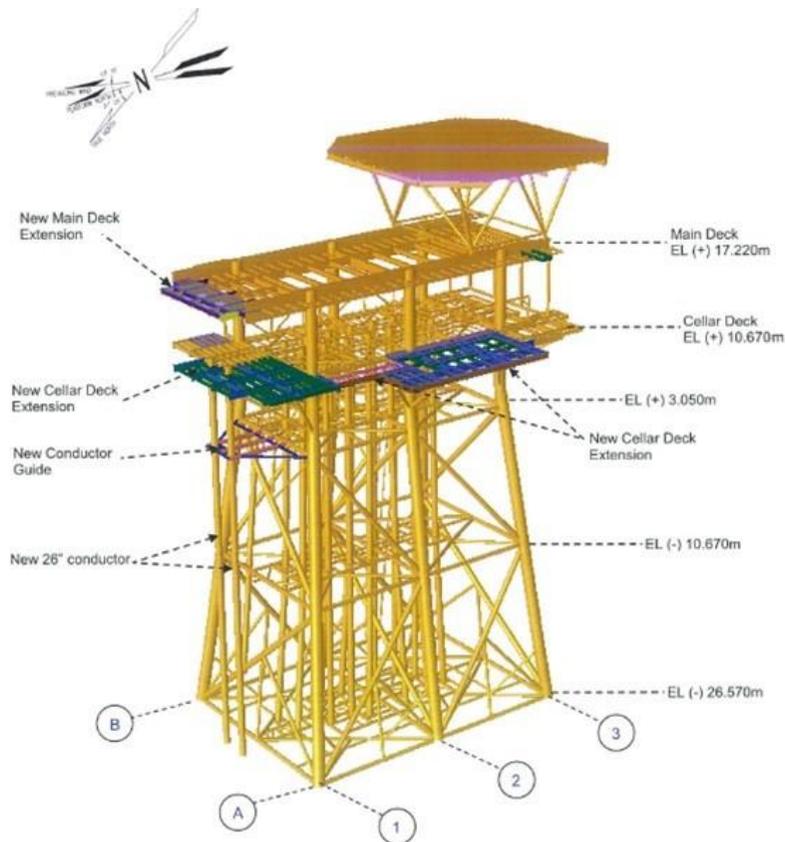


Figure 8: Specifications and Major Modifications of Platform.

GUSA method includes various process from early in-place design level, pushover analysis and POF. In order to run the analyses and assessment of GUSA, a method of procedure applied is presented in the flowchart as per Figure 9.

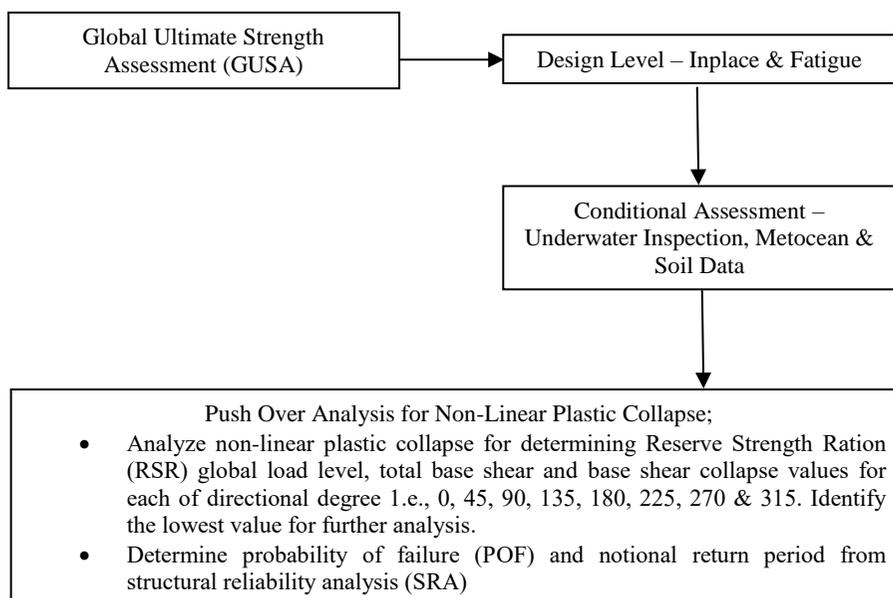


Figure 9: Flowchart GUSA Procedure.

This fixed structure platform, which is intended for drilling of production wells, is usually known as wellhead platform. The design of this platform has been suited to one type of drilling rig i.e., Tender Assisted Drilling (TAD) rig. It has been modified for a jack-up rig for its new installation of outboard conductor (MMC Oil and Gas Engineering, 2014). However, in this study, the TAD load is not considered in the linear and non-linear analysis. The overview of the test structure platform's specifications are summarized Table 2.

The metocean data was derived from existing SEAFINE hindcast data (Ayob *et al.*, 2014a; Ayob *et al.*, 2014b) and it is based on deep water hydrodynamic. Eight (8) directions corresponding to 0, 45, 90, 135, 180, 225, 270 and 315 degrees, as shown in Figure 10 have been established for this high-end analysis. Determination and selection whether the analysis will focus on the minimum or maximum water depth was conducted in the earlier stage of modelling using Super Structure Element Analysis (SESAM Genie). The metocean data used in this study given in Table 3.

Table 2: Test Structure Platform Specification.

| Features                | Description  |
|-------------------------|--|
| Field                   | East Malaysia  |
| Design Service Category | Drilling   |
| Design Safety Category  | Unmanned   |
| Previous RSR            | Current analysis baseline  |
| Installed               | 1981 (33 years)  |
| Water Depth             | 26.7m  |
| Platform Orientation    | Platform North is orientated at 31.42° (clockwise) relative to TN. |
| Deck Configuration      | Main Deck (+17.902m)&Cellar Deck (+11.649m)                        |
| Platform Brace Type     | VD-brace   |
| Leg                     | 6  |
| Number of Pile          | 6 – (Dia. 42”) – 76.5 m Penetration below mudline                  |
| Number of Riser         | 3  |
| Number of Caisson       | 1  |
| Boat landing            | 1  |
| Conductor               | 14 (Dia. 26”) and 2 outboards (Dia. 26”)                           |
| Bridge Link             | None (Standalone Platform)   |

Table 3: Metocean Data for Minimum and Maximum.

| Water Level                   | Minimum | Maximum |
|-------------------------------|---------|---------|
| Mean Sea Level (m)            | 26.70   | 26.70   |
| Highest Astronomical Tide (m) | -       | 1.20    |
| Lowest Astronomical Tide (m)  | -1.20   | -       |
| Storm Surge (m)               | -0.60   | 0.60    |
| Design Water Depth (m)        | 24.9    | 28.50   |

Attacking wave direction as shown in Figure 10 is based on the metocean data. For a 'rectangular' type of platform, a minimum of 8 attacking wave directions is required; 2 directions at both end-on, 2 directions for both broadside and 4 directions for each diagonal corner. For a 'triangular' type of platform, a minimum of 12 attacking wave directions is required, with an equal spacing of 30 degrees from each other. In this case study, the maximum or highest base shear and lower RSR were identified to give the most dominant effect at 180 degrees direction. This is shown in Figure 10 below:

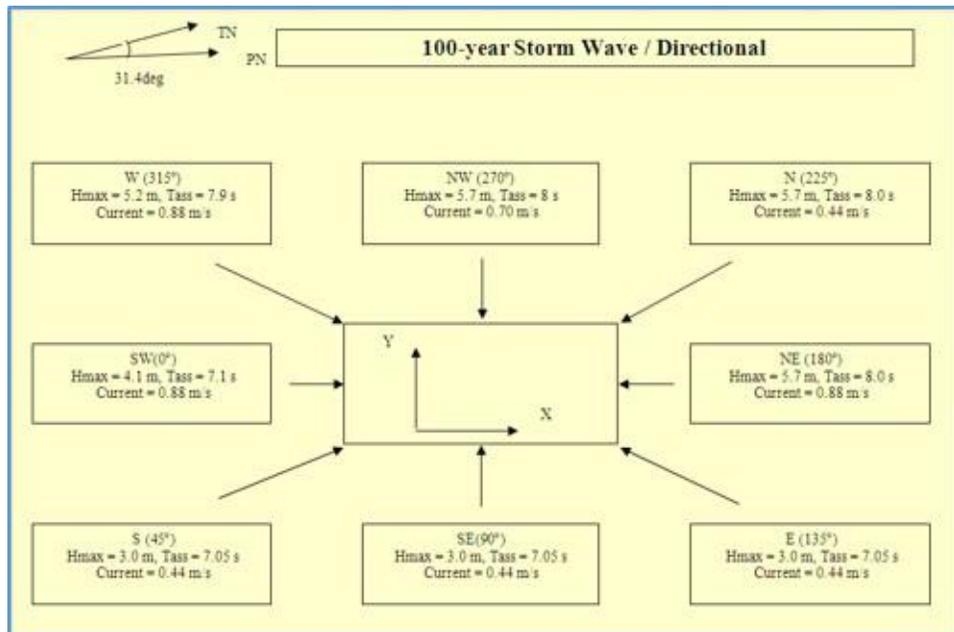


Figure 10: Meteocean Data for 100 Years Storm Directional.

### 5.0 Result of Reserve Strength Ratio (RSR) and Probability of Failure (POF) from GUSA Procedure

In this section, the outcome result from the analyses in Reserve Strength Ratio (RSR), Mode of Failure and Probability of Failure (POF) will be discussed in detail. The target reliability for level of exposure based on ISO 19902, introduced and practised by Shell will also be identified as to conform compliance with the latest industry applicable standard.

- i) It can be seen here that the result i.e. RSR collapse value (7.76), the reserve strength of the structure beyond the 100 years environmental load. In this case study, the most impactful attacking wave direction is at 180 degrees based on the highest base shear value (1.790MN).
- ii) It can be concluded that from the result of USFOS software it showed that Lateral Soil is the failure mechanism as shown in Figures 11 From the analysis it showed that most of the piles under the seabed are overstressed and dragged to one side due to highest Base Shear (BS) of attacking wave at 180 degrees direction.

However, the substructure of the platform was designed in high redundancy of the structures system—and robust enough to hold the impact from base shear up to 7.76 times of load factor for the case of 100 years return period. It showed that none of the

structures' members yielded first except for the piles and soil capacity were found to be the weakest part in this analysis.

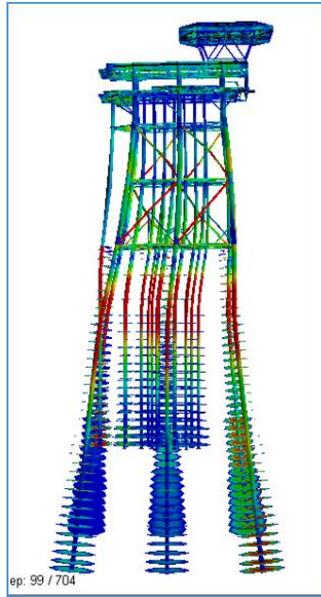


Figure 11: Lateral Soil Failure.

iii) The result of Simplified Method that has been calculated in this section showed that the Annual Probability of Failure (POF) subjected to return period per year, without TAD rig load. The result of POF is tabulated in Table 4. Standardized and data readiness for the given bias and COV factors were developed from hindcast 60-year data of  $H_s$  (significant wave) from 1940 to 2000. The bias and COV value has been calculated and established by PETRONAS based on data collected at locations in the region of Peninsula Malaysia Operation (PMO), Sarawak Operation (SKO) and Sabah Operation (SBO). The calculation was based on the Weibull Distribution Graph Analysis.

As presented in Table 4, the POF value for the test structure platform is  $1.71 \times 10^{-18}$ , which is much lesser than the acceptance criteria of  $1 \times 10^{-3}$  / year for unmanned platforms, thus meeting the acceptable target reliability for unmanned platforms under GUSA. As the POF value being significantly less than the acceptance criteria, this test structure platform is very unlikely to fail.

Table 4: Result of POF for GUSA.

| Failure Mode                                    | Soil                   |
|---|------------------------|
| Reserve Strength Ratio (RSR)                    | 7.76                   |
| 100-year characteristic load, Base Shear (MN)   | 1.790                  |
| Bias of the environmental load prediction model | 0.90                   |
| Bias of resistance                              | 1.15                   |
| Bias of environmental load                      | 0.64                   |
| COV of environmental load                       | 0.25                   |
| COV of resistance                               | 0.20                   |
| COV of load                                     | 0.25                   |
| Mean strength                                   | 1.03                   |
| Standard deviation of strength                  | 0.26                   |
| Mean strength to mean load ratio                | 15.44                  |
| Annual reliability index                        | 8.70                   |
| Annual Probability of Failure (POF)             | $1.71 \times 10^{-18}$ |

iv) In term of exposure level, in reference to ISO 19902 Clause 6.6 as per Table 1, it has been identified that the test structure platform is S3 as an unmanned platform in Life-Safety category; while in Consequence category it is in C2 as medium consequence category. Thus, the test structure platform's exposure of POF Level is categorised as L2. In view of ISO performance standard of POF, the result of  $1.71 \times 10^{-18}$ /year is less than introduced by L2 as per Table 1 i.e.,  $5.0 \times 10^{-4}$ /year (1 in 2,000yrs).

## 6.0 Conclusions

- The result suggests that the test structure platform's risk level met the industry standard minimum safety requirement for an unmanned platform. With high values in RSR as analyzed, an issue on ageing platform structures has not given any significant impact to the overall platform's integrity. The test structure can withstand - the additional 25 years of lifetime extension to cater for its continuing production.
- It can be concluded that the test structure platform is Extremely Reliable and Clearly Acceptable for Global Assessment and Analysis.
- In comparison with other RBA method, GUSA can only be applied on platforms' installed in Malaysian Waters as the bias and COV were calculated based on the three (3) regions in Malaysia.

- It is recommended for future analysis and or assessment to compare outcome result with other method used in the industry such as Risk-Based Design Analysis (RBDA), currently used by Shell.
- It is also recommended to conduct similar integrity assessment periodically as to conform ageing platforms' integrity in accordance to international and industry's standard.

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