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Global Ultimate Strength Assessment (GUSA) for Lifetime Extension of Ageing Offshore Structures

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ABSTRACT

Malaysia is the second largest oil and gas producer in Southeast Asia. The 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 and increasing environmental loading. Global Ultimate Strength Assessment (GUSA) methodology was established to support detailed reassessment applied in managing safety, integrity analysis and reliability by evaluating the ageing and existing platform loading. It is a tool for the high-end analysis of structures for risk based assessment and has been accepted by most of the major marine operators in the offshore industry. The main purposes of this analysis are to manage the structure's risk level over its remaining service life and to initiate cost efficient inspection or mitigation actions, if required. Probabilistic models which are derived from structural reliability methods with the result from pushover analysis, are used to determine the annual probability of failure of the structure over its remaining service life. The outcome of these analyses can efficiently assist in understanding the structure failure mechanism and correctly define relevant type of mitigations required. In this paper, the reassessment of an ageing platform over 30 years old, still in production is presented to demonstrate GUSA capability to perform life extension evaluation. Due to the demand to prolong the production for a further 25 years, it has been evaluated in design level analysis in early stage. With the major modifications such as extension deck for multipurpose pump and outboard conductors have given rise to overstressed and fatigue issues.

KEY WORDS: GUSA, Integrity and Reliability, Reserve Strength Ratio, Base Shear, Non-Linear Collapse Analysis, SESAM, USFOS.

1 INTRODUCTION

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 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 results in higher loading, which the platform may not have been originally designed for (Nicholas et al, 2006). Some studies on 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 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. Commonly, GUSA will be used to determine the capability of an ageing platform to withstand additional load and to prolong the production for several years of platform service, leading to successful stories of recovering more reserves from original or adjacent fields (PETRONAS Technical Standards (2012).

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 to a failure can be stop production until the previous limit of platform life, underwater major modification and decommissioning (American Petroleum Institute, 2007; American Petroleum Institute, 2010). The results from GUSA analysis are required to give high confidence level of structure strength for extended design life and additional years of production. In this paper, the probability of failure of a 33 year platform is determined, to evaluate the possibility of a 25-year life extension, with regards to impact of wave in deck and reliability of platform. The investigation was carried out by use of the GUSA procedure.

This paper is composed of 6 sections. Section 1 presents the background of the study, followed by a brief description of the assessed ageing structure in Section 2. A brief review of the GUSA integrated analysis procedure is presented in Section 3. Next, the outcomes of the analysis are discussed in Section 4. Finally, the conclusions and recommendations of this study are presented in Sections 5 and 6, respectively.

2 PLATFORM SPECIFICATIONS

The ageing structure is a fixed jacket platform in a water depth of 26.7m. The general outline of the platform is shown in Figure 1. The platform is composed of six vertical legs, where the diameter of each leg is 1.181m with a wall thickness of 31.75mm by design. The dimensions of the platform main deck are 29.8m*11.89m.

This fixed platform, which is intended for drilling of production wells, is normally known as a wellhead platform. The design of this platform has been suited with type of drilling i.e. tender assisted rig and being modified for jack-up rig for new installation of outboard conductor (MMC Oil and Gas Engineering, 2014). The overview of assessed platform specifications are summarized in the following table.

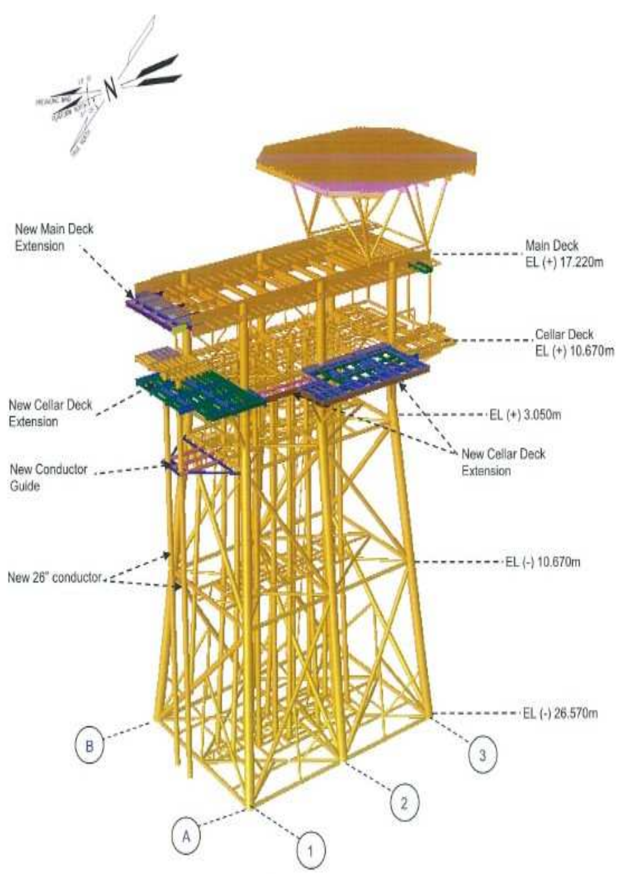

Figure 1: Specifications and Major Modifications of Platform.

Table 1: Ageing Platform Specification.

Features	Description
Field	Sarawak (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 mud line
Number of Riser	3
Number of Caisson	1
Boat landing	1
Conductor	14 (Dia. 26") and 2 outboard (Dia. 26")
Bridge Link	None (Standalone Platform)

3 GUSA INTEGRATED ANALYSIS

The non-linear plastic collapse analysis (NPC), member importance analysis (MIA) and structural reliability analysis (SRA) are the three main components of GUSA integrated analysis. In brief, the steps taken to evaluate the possible life extension of the 33 years ageing platform are as follows:

i) Conditional assessment from existing data provided by Operation Unit and detail design (at design level stage) (Ayob et al, 2014) and verification of the model from SACS to SESAM (Genie) software (Asian Geos Sdn Bhd, 2013; MMC Oil and Gas Engineering, 2014);
ii) Establish and analyses of the ultimate strength of the structure in 8 directions. Non-linearities due to geometric, material and pile-soil structure interaction are included in the analysis (American Petroleum Institute (2010);
iii) Evaluation of wave in deck by determining Reserve Strength Ratio (RSR) control from limitation of wave impact to cellar deck;
iv) Identify the type of structure failure mechanism and correctly define relevant type of mitigation required, and;
v) Finally, determine an approximate reliability and probability of failure of the structure. Determine the return period of the environmental load the structure can withstand with the inherited RSR.

For simplicity, the methodology flowchart of GUSA integrated analysis is presented in Figure 2.

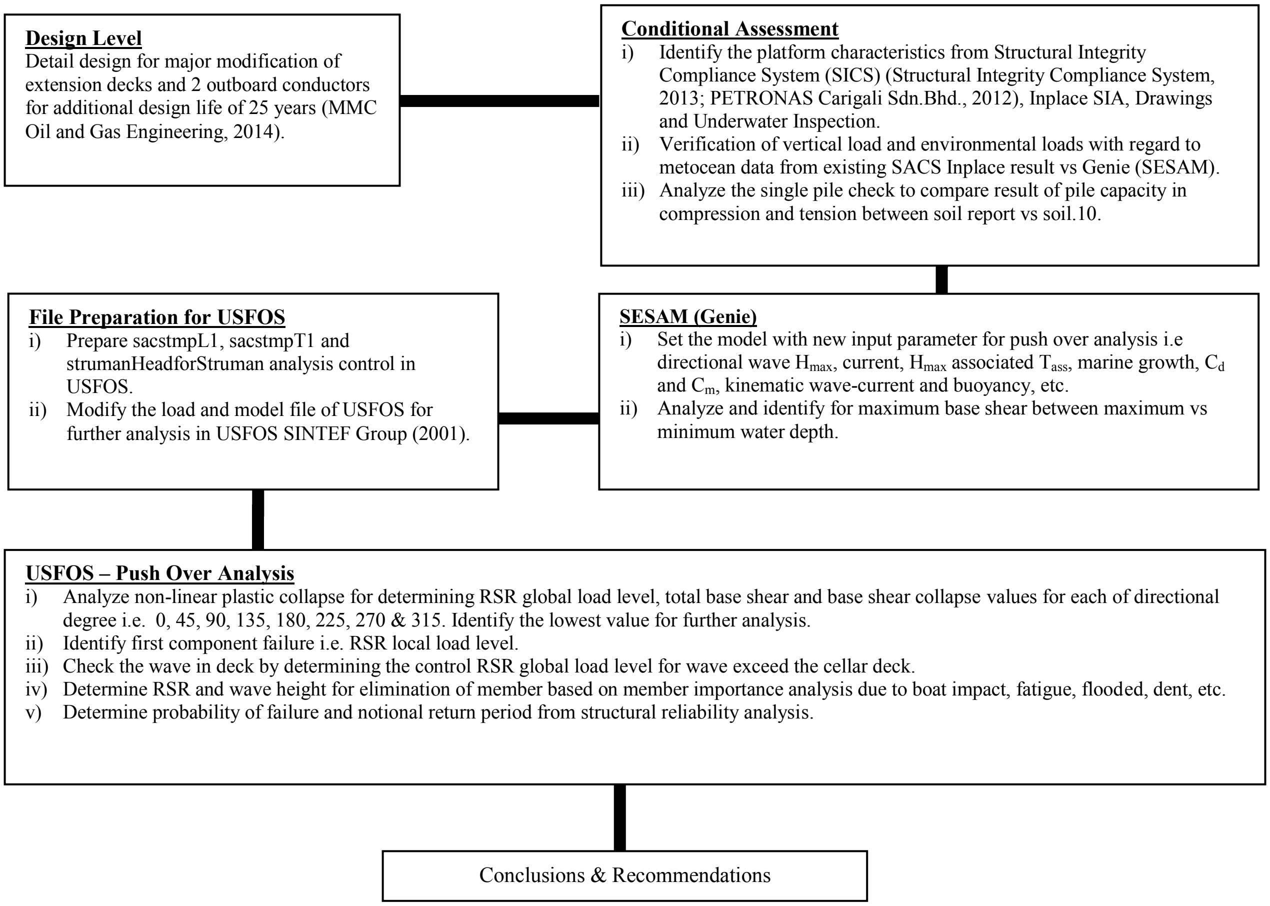

Figure 2: Flowchart on Analysis Procedure.

4 ANALYSIS AND RESULTS

4.1 Eight (8) Directional Metocean Data

The metocean data was derived using existing SEAFINE data 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 3, have been established for this high-end analysis. Determination and selection whether the analysis will focus on the minimum or maximum water depth shall be conducted in early stage of modelling as per Table 2.

Table 2**:** Metocean Data from Structural Integrity Compliance System (SICS) Analysis (Structural Integrity Compliance System, 2013).

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

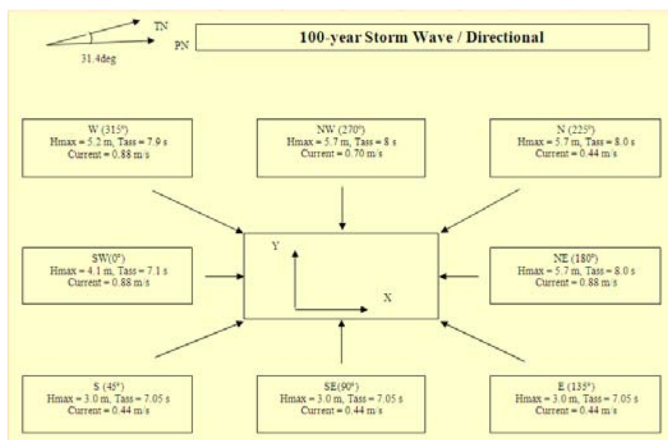

Figure 3**:** Metocean Data from Structural Integrity Compliance System (SICS) Analysis.

4.2 RSR Determination

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, 2014). USFOS has analyzed the global RSR values for overall structural platform at eight (8) different directions. The RSR measures the reserve strength of the structure beyond the 100 years environmental load (PETRONAS Research & Scientific Services Sdn. Bhd., 1999). For this case, the worst direction is 180 degrees based on high base shear value (1.790MN) and lower RSR collapse value (7.76). The mode of failure is soil lateral failure.

4.3 Result Wave in Deck

The RSR value is associated with a physical wave height and basically corresponds to the height where the wave hits the deck structure, which in this case is the cellar deck. Wave in deck loading is of dynamic nature. Basically, wave in deck is looking at preventing waves from hitting the deck. It is a requirement to check for the wave in deck and limiting the wave height impact to cellar deck resulting for RSR control value. The result can be categorized by comparing the H_{crest}, H_{max} and RSR for the 180 degree direction base shear, which has the lowest RSR value.

Table 3**:** Comparison of Wave in Deck (180 degree).

Items	H_{crest}	H_{max}	RSR
100-year Metocean	3.42	5.70	1.00
At limiting RSR	9.84	16.40	6.70
USFOS Result	10.67	17.79	7.76
API Wave Theory (Wave Breaking)	13.48	22.46	11.88

Table 3 shows the consequence of H_{max} and H_{crest} values in comparison with wave in deck for this case study at 180 degree direction of base shear. The H_{crest} (wave theory) according to RP 2A (American Petroleum Institute, 2007) is higher than the lower elevation of existing platform and USFOS result. USFOS results indicate that the H_{crest} is above platform cellar deck because the derived air gap is negative (-) 0.83m.

Figure 4 is tabulated from Table 3 above. Platform cellar deck is approximately (+) 10m above the surge level respecting to Mean Sea Level (MSL). Thus, limiting RSR is required for base shear attacks at below cellar deck as normal condition happens. RSR calculated of structure is retrieved at the structures collapse point below cellar deck.

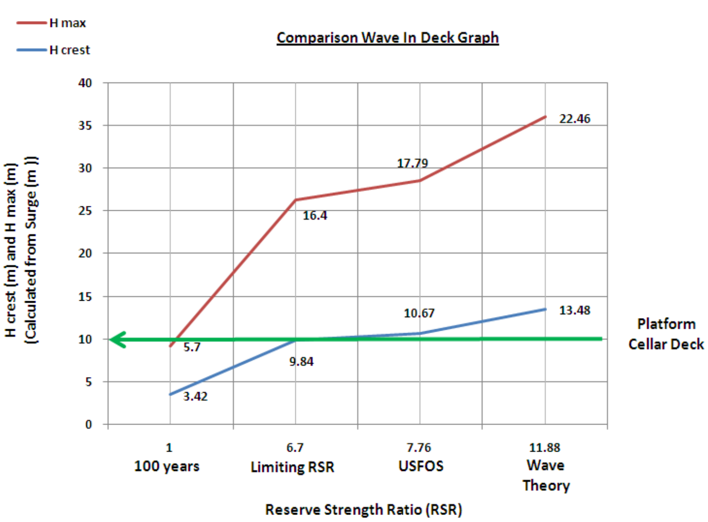

Figure 4**:** Wave in Deck Graph.

4.4 Simplified Structural Reliability

Basically, structural system reliability focuses upon issues such as redundancy, robustness with respect to damage and rate of inspection. Currently, analysis method is available for efficient estimation of the reliability of typical platforms under push over loadings. Structural reliability means simply the field of probabilistic analysis of structural behavior, serviceability and safety (Abu Husain et al, 2014).

The structural reliability methods in offshore design guidelines is used to identify the members that truly critical and determine if additional members can improve this situation. 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 collapse of the structures. The structure will eventually survive, given the failure of one or more of its members.

The Structural Reliability Analysis (SRA) was performed after the push-over analysis to approximate 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.

Probability of Failure (POF) (see Figure 5) 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 accurate result as the mean values.

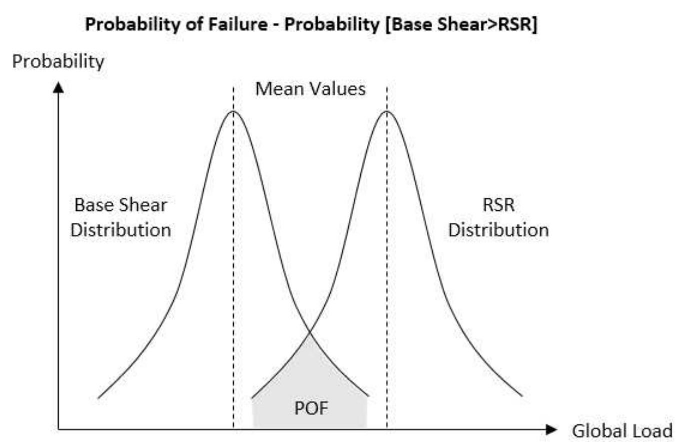

Figure 5**:** Probability of Failure of Base Shear and RSR Distributions.

A computational spreadsheet was developed to calculate the reliability values. Table 4 provides a summary of a platform's probability of failure calculated from the SRA procedure. As stated above, the SRA outcomes provide the following findings:

- annual probability of failure
- notional return period of the extreme environmental contributed to platform collapse

Table 4: Structure Reliability Assessment Spreadsheet.

Failure mode		Soil
Reserve Strength Ratio	RSR	6.60
100 year characteristic load, Base Shear (MN)	E_C	1.790
Bias of the environmental load prediction model	B_M	0.90
Bias of resistance	B_R	1.15
Bias of environmental load	B_E	0.64
COV of environmental load	V_E	0.25
COV of resistance	V_R	0.20
COV of load	V_S	0.25
Mean strength	$\mu_S = B_E \times B_M \times E_C$	1.03
Standard deviation of strength	$\sigma_S = \sqrt{(B_E \times B_M \times E_C)^2 x V_E^2}$	0.26
Mean strength to mean load ratio	$\frac{\mu_R}{\mu_S}$	13.14
Annual reliability index	$\beta = \frac{\ln\left[\frac{\mu_R}{\mu_S}\sqrt{\frac{1+V_S^2}{1+V_R^2}}\right]}{\sqrt{\ln\left[(1+V_R^2)(1+V_S^2)\right]}}$	8.18
Annual failure probability	$P_f \approx \sum_{i=1}^{n} \Phi(-\beta_i)$	1.37E-16

From the above table, it is shown that the Probability of Failure for this particular platform is 1.37 x 10^{-16}, which is less than the acceptance criteria of 1.0 x 10^{-3} for unmanned platforms, thus meeting the requirement for unmanned platforms. Due to the probability of failure being significantly less than the acceptance criteria, this platform is very unlikely to fail.

5 CONCLUSIONS

From the results of the global ultimate strength analysis, the following conclusions can be drawn:

- Lowest actual RSR for this platform is 7.76 at 180° direction. RSR limitation is applied based on the assumption that there would be Wave-In-Deck occurrences in all directions.
  - a) Failure Mechanism of this platform is Soil Lateral Failure.
  - b) Probability of Failure, POF = 1.37 x 10^{-16} < 1.0 x 10^{-3} for unmanned platforms. This platform has passed the minimum safety requirement for an unmanned platform (American Petroleum Institute, 2010).
- The platform risk level is able to meet the stipulated minimum safety requirement of an unmanned platform. Thus, with high values of RSR as analyzed, the issue of lower fatigue life or high fatigue damage with regard to major modification on the topside are not given any significant impact on infill project for additional extension of 25 years production from this platform.

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