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Reliability Assessment Model for Aging Jacket Structures in Malaysian Waters

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Abstract. As the world is progressing towards deeper water technology, jacket platform still remains as an important production structure for oil and gas in Malaysian shallow water regions. Besides the discovery of new oil and gas, enhanced oil recovery (EOR) allows more oil to be extracted from the old fields. As a result, service life of existing fixed jacket platforms need to be extended. The overall reliability of aged platform has to be reevaluated in order to monitor the integrity of the structure, and to prevent unexpected failures. Reserve Strength Ratio (RSR) is a widely adopted measure to quantify the ultimate strength of a structure. However, structural strength alone is inadequate to express a structure's reliability. Reliability is best defined as the probability that the extreme load will not exceed the ultimate strength of a structure. It can be expressed either in probability of failure or reliability index, which is the inverse normalized form of probability of failure. This paper presents the study of existing jacket platforms in Malaysia's three oil and gas operating regions. Relationship between probability of failure, reliability index and RSR has been formed to provide a simple reliability assessment model of jacket structure in Malaysia water regions.

Introduction

Fixed jacket platform is among the very first structure to be introduced in the offshore industry. The design of jacket structure is based on the response of components to the applied loads, where the ultimate goal is to ensure the level of safety is above the minimum requirements of relevant design codes. If a platform is put in service beyond its initial design life, a requalification process has to be conducted to check the safety of the platform. Among the many offshore jacket platforms being installed in Malaysia, more than half of them have already exceeded their design life.

Being introduced to the offshore field in 1980s, reliability assessment has become an increasingly popular tool for analyzing structural safety. A structure's reliability is usually measured as probability of failure and/or reliability index. Load and resistance are the two core variables that form the failure function in reliability analysis. If the maximum load exceeds the minimum capacity of the structure, load and resistance distributions will overlap and a nonzero probability failure will be formed. The overlap between the two curves provides a qualitative measure of the probability of failure.

Load as the name suggests, consist of gravity load (dead load, live load) and environmental load. On the other hand, resistance has to do with the reserve strength of a structure. RSR as the outcome of non-linear collapse (push-over) analysis is the indicator of the system strength for offshore jacket structure. The concept of reserve strength was first being introduced in Blume's 'Reserve Energy Technique'. [1] It is commonly defined as the ability of a structure to sustain loads in excess of the design value. In literature, RSR is measured in a variety of ways. One of such is the ratio of the ultimate platform resistance to the design load. RSR is also quoted as ratios of platform base shear or overturning moment. For different load case or load combination, various RSR will be generated. Besides, load case which produce the highest component utilization ratio does not necessary produces the lowest RSR.

After obtaining the basic variables, reliability analysis can be carried out. Reliability of a jacket platform is governed by the structural system and this system is the combination of series and parallel subsystems. For instance, jacket legs illustrate series or chain reliability system. When a member fails, the entire system fails. On the other hand, structural bracings are an example for parallel system. One bracing member failure does not cause immediate failure to the structure. Instead, the load carried by the failed member will be transferred to the other intact members in the group. [2]

There are two types of reliability analysis methods: approximate analytical methods such as first and second order reliability methods (FORM & SORM), and simulation method such as the Monte Carlo simulation (MCS). MCS is easy to use but requires great number of analysis to achieve good approximation of probability of failure. When the probability of failure is small (i.e., 10E-5), this method requires long computation time and takes up too much RAM. [3] Thus, FORM has been widely adopted by many researchers. [4] [5] [6] The FORM solution provides geometrical interpretation of reliability index as the distance between origin and design point in standard normal space. Anyhow, study conducted by Haldar and Mahadevan [6] has shown that if the number of simulation cycles is relatively large, results generated by Monte Carlo simulation would be similar to the FORM method.

Methodology

This paper mainly discusses the relationship between three important reliability parameters: RSR, reliability index and probability of failure, specifically for Malaysia water regions.

Three platforms located at the three oil and gas operating regions in Malaysia are studied. They are Platform A in Peninsular Malaysia Operations (PMO), Platform B in Sarawak Operations (SKO) and Platform C in Sabah Operations (SBO).

Met-ocean data at specific locations are obtained from the design report and recorded in Table 1. Only wave and current loadings are considered in this analysis.

Table 1: Location Specific Met-Ocean Data (Omni-Directional)

Platform	Wave Parameters		Current Speed [cm/s]		
	H [m]	*T [s]*	*1.0*D*	*0.5*D*	*0.01*D*
A	10.9	9.5	147	117	32
B	11.7	10.9	120	95	55
C	7.7	9.6	94	86	44

Pushover or collapse analyses are conducted to obtain the ultimate strength of each platform, which is recorded as Reserve Strength Ratio (RSR). Fixing gravity load acting on the structure, environmental load is gradually increased until the structure collapse or fail. Design base shear is acquired at load factor one while the base shear at structure's collapse is the ultimate strength. Calculation of RSR is given in Equation 1.

RSR = Collapse Base Shear (Ultimate Strength) / Design Base Shear. (1)

Next, by adopting First Order Reliability Method (FORM) for reliability analysis, structure's reliability is determined in the form of probability of failure and reliability index. Curve Fitting Tool (CFTOOL) in MATLAB is used to perform regression analysis so that relationships between RSR, probability of failure and reliability index can be generated.

Results

Results from the analyses are recorded in the following sections:

Resistance

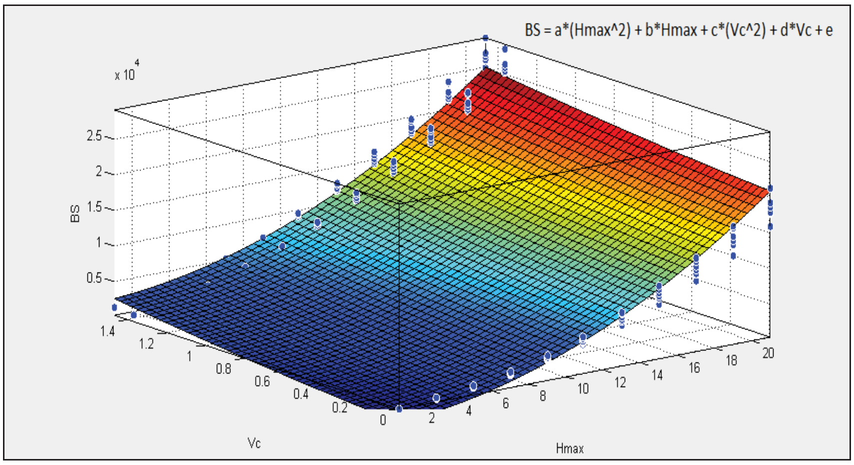
Resistance of a platform can be represented by the reserve strength of the structure, which is usually measured as Reserve Strength Ratio (RSR). In this study, RSR are obtained using collapse analysis and the results for the three platforms are recorded in Table 2.

Table 2: RSR at Different Direction

Dir [deg]	RSR Platform A	RSR Platform B	RSR Platform C
000	1.087	3.120	3.940
045	1.360	3.758	4.660
090	1.782	3.530	5.710
135	2.820	4.619	4.740
180	2.963	3.671	4.870
225	1.485	4.192	7.760
270	1.139	3.020	7.350
315	1.220	4.650	5.409

Load

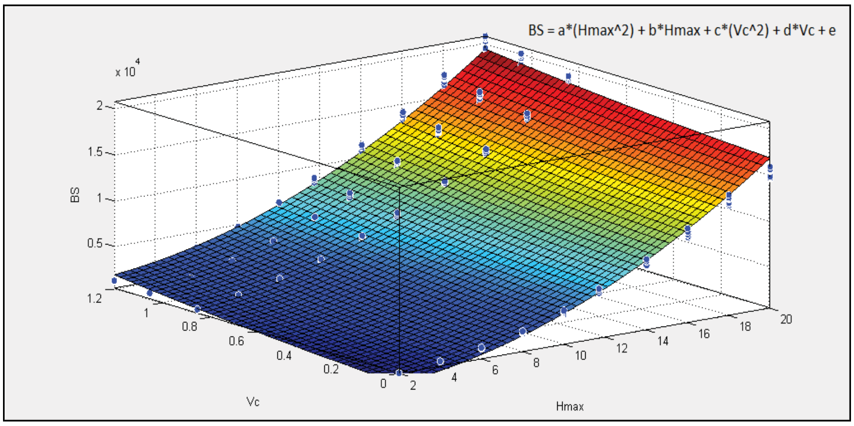
Response surface functions illustrating the effect of environmental loadings (wave and current) on the base shear (BS) of the structure are recorded in Figures 1, 2 and 3. Two-degree polynomial equation is selected to be the most suitable function describing the two parameters, which is given in the figure. Coefficients of each polynominal equation are tabulated as a – e, while BS, Hmax and Vc represent base shear, maximum wave height and current respectively. From the obtained R-square value for each function, it can be observed that all functions have confidence level more than 90%.



a	47.12
b	77.40
c	680.90
d	1837.00
e	-1708.00
R^2	0.97

$$BS = 47.12*(Hmax^2) + 77.40*Hmax + 680.9*(Vc^2) + 1837*Vc - 1708$$

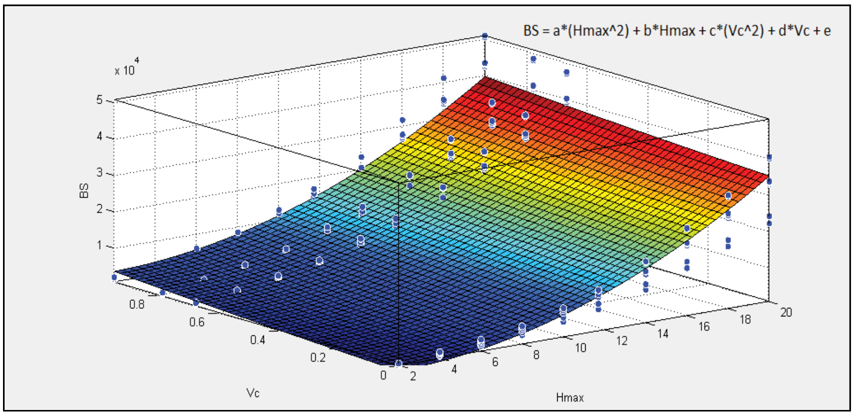
Figure 1: Response surface for Platform A



a	40.88
b	64.52
c	756.60
d	1199.00
e	-932.90
R^2	0.99

$BS = 40.88*(Hmax^2) + 64.52*Hmax + 756.60*(Vc^2) +$

Figure 2: Response surface for Platform B



a	105.20
b	-318.10
c	1259.00
d	3473.00
e	-653.90
R^2	0.93

$BS = 105.20*(Hmax^2) - 318.10*Hmax + 1259.00*(Vc^2) +$

Figure 3: Response surface for Platform C

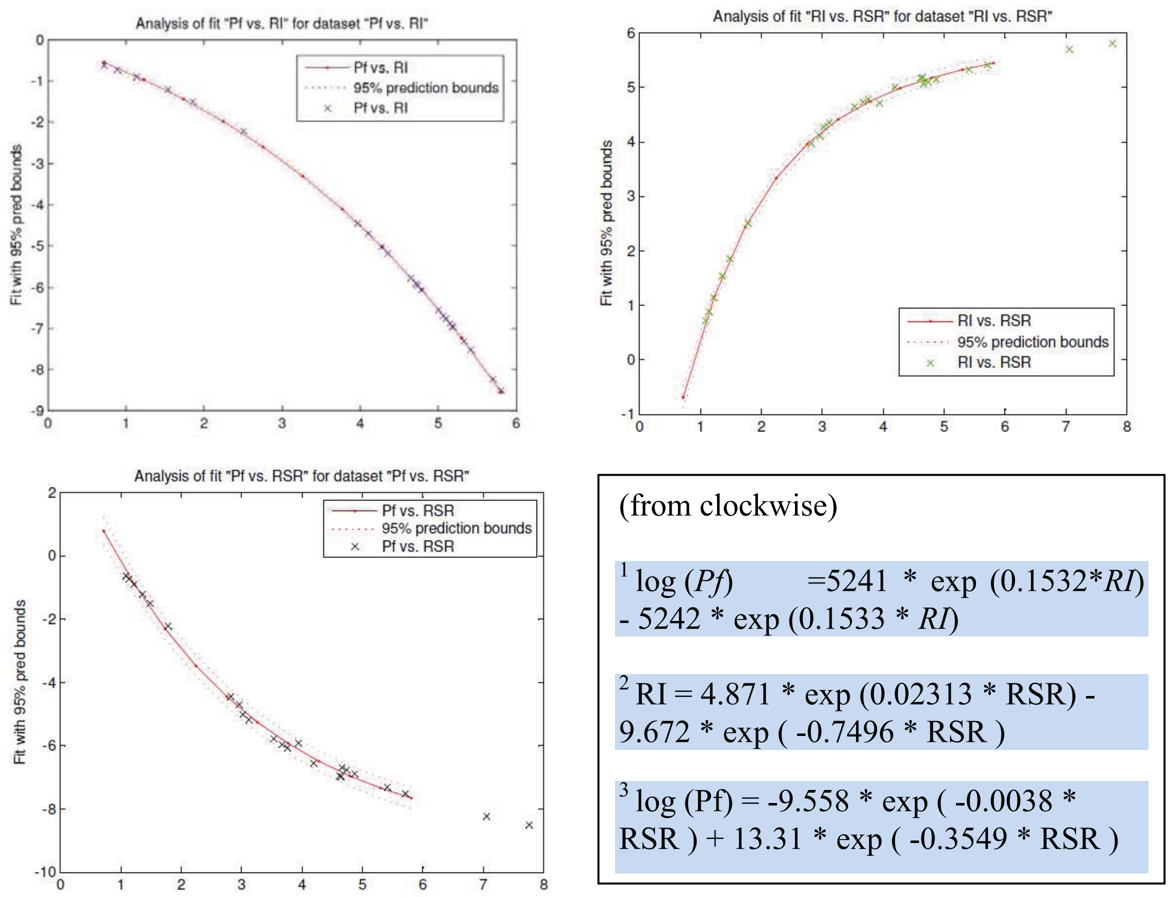
Reliability Analysis

Reliability analysis is an analysis that link resistance and load to the safety of a structure. By adopting the resistance and load variables in reliability analysis, the reliability of the structure can be found as reliability index and probability of failure. Reliability index (RI) and probability of failure (Pf) for the three platforms are tabulated in Table 3. Although environmental load acting on each direction is similar, the reliability varies due to the different resistance provided by each direction.

Table 3: Reliability Index & Probability of Failure

Dir [deg]	Platform A		Platform B		Platform C	
	β	Pf	β	Pf	β	Pf
000	1.09	2.36E-01	3.12	6.61E-06	3.94	1.22E-06
045	1.36	6.20E-02	3.76	8.51E-07	4.66	2.04E-07
090	1.78	6.09E-03	3.53	1.66E-06	5.71	3.04E-08
135	2.82	3.59E-05	4.62	1.13E-07	4.74	1.72E-07
180	2.96	2.01E-05	3.67	1.09E-06	4.87	1.31E-07
225	1.48	3.17E-02	4.19	2.81E-07	7.76	3.17E-09
270	1.14	1.87E-01	3.02	9.61E-06	7.35	5.92E-09
315	1.22	1.27E-01	4.65	1.06E-07	5.41	4.89E-08

Best fits describing connections between RSR, reliability index and probability of failure are plotted in Figure 4. 5% of upper and lower boundaries are outlined in the graphs as well. Exponential functions are found to be the most suitable equation for all the three relationships. The functions are given in the figure.



(from clockwise)

[1] log (*Pf*) =5241 * exp (0.1532**RI*) - 5242 * exp (0.1533 * *RI*)

[2] RI = 4.871 * exp (0.02313 * RSR) - 9.672 * exp (-0.7496 * RSR)

[3] log (Pf) = -9.558 * exp (-0.0038 * RSR) + 13.31 * exp (-0.3549 * RSR)

Figure 4: Relationship of probability of failure, reliability index and RSR at 95% confidence level check

Discussion

The met-ocean loadings at Platform C is the lowest as compared to Platform A and B. It can be predicted that the platform is safer than the other two. According to the results of the analyses, Platform C has the highest reserve strength ratio and reliability index (or lowest probability of failure). Environmental loadings do have distinctive effect to the reliability of a platform.

Besides, the RSR value for different platform direction varies. Platform A which is located at PMO has the lowest RSR value of 1.087 at 0° while Platform B (SKO) has its lowest RSR value, 3.020 at 270°. For Platform C (SBO), the lowest RSR value is 3.940 from 0°. There is a certain distribution of RSR values at different directions, differs for each platform. RSR distribution describes the strength distribution of the platform. The directions mentioned earlier are the weakest points for Platform A, B and C, and the RSR values at those directions have been used in reliability analysis.

Much as the RSR value presenting the strength of a structure, the reliability of a structure is affected by the loadings acting on the structure. Response surface analyses are performed to generate global response functions for the environmental load acting on the three structures. Polynomial functions are developed to link base shear and the incoming wave and current loadings.

Additional analyses have been performed to calculate the reliability of the structure as reliability index and/or probability of failure, using resistance and load failure function. The trend of reliability index comparison graph is similar to the one in RSR comparison. However, the reliability indexes for Platform B and C seem to be more even in the eight directions, generally because of the configuration of the structures. Platform A is rectangular shaped while Platform B and C are squared. Anyhow, it is observed that certain relationships can be developed for the three parameters, namely RSR, reliability index and probability of failure.

Three exponential fits plotted using MATLAB's Surface Fitting Tool include 'probability of failure versus reliability index', 'reliability index versus RSR' and 'probability of failure versus RSR'. All data used for the three graphs fulfills the 95% confidence level, which indicates that the generated equations are able to describe the relationship precisely. The first fit conveys a message that as the probability of failure gets higher, the reliability index becomes lower. Similar relation is found in the third fit that plots probability of failure versus RSR whereas the second fit has the opposite relationship. If the RSR value is high, the reliability index will be high too. RSR has an inverse relationship with probability of failure and a direct relationship with reliability index. The exponential equations generated enable simplified reliability assessment to be carried out. Without having to run complicated reliability analysis, the reliability of jacket platforms in Malaysia waters can be determined easily.

Conclusion

In this paper, the following conclusions are made from the results discussed above:

1. Met-ocean loadings affect the strength and reliability of a platform.
2. The RSR values of a platform vary with the direction of action of environmental load with respect to the orientation of the platform.
3. The RSR value has an exponential relationship with both the reliability parameters, namely reliability index and probability of failure.

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