Reliability of Jacket Platforms in Malaysian Waters

Pushover and Regression Analysis Methods in Obtaining Reserve Strength Ratio

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***Abstract*—Malaysian Oil and Gas Industry has been well established in the region. Over the years of producing oil and gas, the majority of jacket platforms in Malaysia have been encountering reliability issue due to aging and increasing environmental loading. Hence, there is a necessity to address the reliability of the jacket platforms in Malaysia. Authors have been studying on the current practice of reliability assessment method which is conducting pushover analysis on one particular platform at a time using all the updated and available data after investigations. This practice is time consuming and costly. By utilizing results from pushover analysis from platforms all over Malaysian waters, authors use regression analysis to produce a simplified reliability model. Considering the parameters such as water depth, air gap, storm wave height, braces system and regions, authors conducted regression analysis to obtain the Reserve Strength Ratio value as a reliability indicator. This could help to minimize time and cost needed for reliability assessment, provided the coefficient of determination is high.**

***Keywords*—Reliability, Pushover Analysis, Reserve Strength Ratio, Regression.**

I. INTRODUCTION

PETRONAS Carigali Sdn Bhd (PCSB) is currently operating about 200 jacket platforms. Of these over 60% have been in operation for more than 20 years, 20% of platforms have already exceeded 30 years with several others in the very near future reaching their initial design life of 20 to 25 years. With development of oil extraction technologies and further oil and gas fields' discovery, there are increasing demands to extend the life of these platforms. The scenario is that the jacket platforms being subjected to higher loading due to required modifications or upgrading and work-over-demands for which the platform may not been originally designed for [1]. An existing platform should undergo assessment process if there is addition of personnel, increased loading on structure, and damage found during inspection [2]. Furthermore, there are other challenges such as onerous code requirements; changes or increase in environmental met-ocean loading, presence of shallow gas and seismic or earthquake loading; again in which the platforms are not initially designed for. Therefore, there is a need to address the ongoing structural integrity of these platforms [1].

Lately some studies were conducted [3, 4] related to reliability of Malaysian jacket platforms as well as on the reliability of other types of platforms in the other parts of the world [5, 6, 7]. In late 90's, reliability approach was becoming the common practice in Malaysian oil and gas industry mainly due to better exposure to techniques, improvement in the computational system and better demand for such analysis. In fact, PCSB has a Risk Based Inspection (RBI) program which categories platform based on risk of failure and provides inspection recommendations accordingly. The current practice of RBI emphasized on the likelihood of structural collapse of a platform which is assessed from two factors namely: platform strength and extreme loading the platform is being exposed to. Pushover Analysis will provide RSR value to better assess the platform's integrity [8].

Oil and Gas Industry especially in Malaysia, needed this study in finding the reliability of the jacket platforms since the offshore operation in Malaysian waters is in the shallow water region, hence almost all of the offshore platforms are jackets. The Ultimate Strength Analysis by Pushover method which requires a lot of technical competency and time would be reduced to simply adhering to a formulation or step-by-step simple analysis used to obtain the RSR values on existing aging platforms as well as on the design of new platforms in all three different regions in Malaysia. Authors plan to formulate a relationship between RSR and other variables to produce a simplified prediction model using regression analysis.

II. PUSHOVER ANALYSIS

Pushover analysis is widely used in calculating the ultimate capacity as well as demonstrating the global instability of jacket platform [9]. Pushover analysis is a method to evaluate and provide estimation on the demands imposed on the structures and elements which is then comparing the estimation with the existing capacity to assess the acceptability of the design.

The processes is to first represent the structure in a two or three dimensional analytical model that take account for all important linear and non-linear response characteristic, then apply wave lateral loads in predetermined patterns that represent approximately the relative inertia forces generated at locations of substantial masses, and push the structure under these load patterns to specific target displacement levels [10]. Within any step, the program further selects a load sub-step size, by determining when the next stiffness change (event) occurs and ending the sub-step at the event. The structure stiffness is then modified and the analysis is performed on the next step until the entire load is being applied [11]. The internal forces and deformation computed at the target displacement levels are estimates of the strength and deformation demands, which need to be compared to available capacities [10]. Figure 1 below shows that the environmental load is being applied onto the jacket platform until it collapsed.

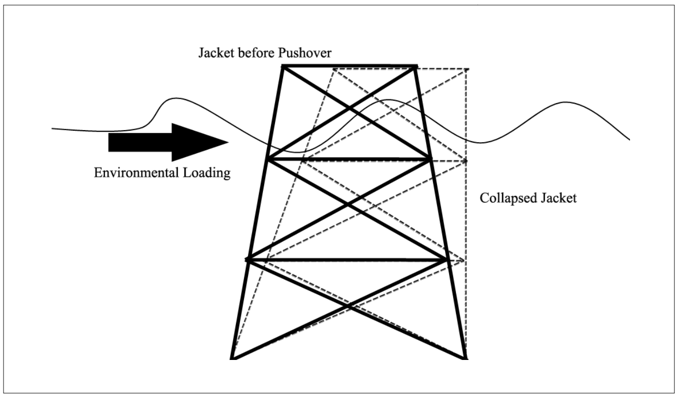

Fig. 1. Pushover Analysis by increasing the load factor of environmental loading until the structure collapse.

Some of the concerns about pushover analysis revolve around the load patterns, how far to push, and what is being evaluated [10]. The load is applied to the structure incrementally while the nodal displacements and element forces are calculated for each loads steps and the stiffness matrix is updated [12]. Since, the displacement corresponding to the collapse limit is somehow different for difference platform, [9] SACS software's pushover analysis introduces plasticity when the stress in a member reaches the yield stress. With plasticity in the pushover analysis, the stiffness of the structure will be reduced and additional loads due to continuing load increments will be redistributed to the adjacent member of the ones which already gone plastic. This process will continue until the structure as a whole is collapsed [12].

In order to determine the ultimate strength of the platform requires information not only on the "as-built" and "present" characteristics of the platform but also knowledge of many interacting parameters including platform configuration, foundation characteristics and the excitation forces on the platform [13]. Hence the analysis will be done based on the updated model files of jacket platforms and also the soil data.

Ultimate capacity of platform can be determined using non linear push over analysis in which all the factored gravity loads, D are applied first and then the un-factored environmental loads, E till the platform collapses. Resistance of collapse is represented by Equation 1 that provided the push over strength of the member [14].

$$R_{ult} = \lambda_{ult} E \tag{1}$$

Where R_{ult} = Ultimate resistance of platform; and
λ_{ult} = Factor which is increased until collapse [14].

Reserve Strength Ratio (RSR) is a measure of structure's ability to withstand loads in excess of those determined from platform's design and this can be obtained using the ultimate strength of the platform through pushover analysis. This reserve strength can be used to maintain the platform in service beyond their intended service life. Knowledge from the analysis can be used to determine the criticality of components within the structural system and used to prioritize the inspection and repair schemes [8].

III. Regression Analysis

The regression analysis is used for modeling and analyzing several variables and focus on is to formulate the relationship between a dependant variable and one or more independent variable(s). The regression analysis is utilized to calculate an function that fits the data and returns an array of values that describes the function. Using the results from the pushover analysis, formulas are derived for predicting the RSR. The purpose of regression analysis to establish a formulation between the variables to produce an equation such in a way that parameters such as wave heights, initial air gap, water depth, and brace system can be input into the formula and get the RSR value. The method using this simplified prediction model will be very useful to eliminate the lengthy process and costly work of conducting conventional reliability analysis [15].

Linear Regression is a process where the data is input as and curve fitting protocol is carried out in a way that the data will be represented by a linear function. This however could produce inaccurate analysis as the linear regression was carried out on transformed data which not represent the relationship of the independent variables with the dependant variable. For the data which are not described by the linear function, a method called iterative non-linear least square fitting can be implemented to fit a non-linear function to the data. Non Linear Regression analysis differs from Linear regression as non linear regression is a iterative process that recalculate the squared sum (SS) of the difference between data and fit with every iteration until reach the smallest possible value of SS, while linear regression produce the SS value in one single iteration without further iteration [16].

IV. Methodology

This paper discuss the methodology of pushover analysis to obtain the RSR value as an indicator to the reliability of a jacket platform in Malaysian waters and the subsequent method to perform non linear regression analysis to obtain the relationship formulae among the dependant variables and the independent variable.

Pushover analysis consists of three main parts which is data preparations, structural modelling and progressive collapse analysis. Sensitivity analysis is conducted and literature was referred to identify the parameters that bring significant impact to the structural integrity of the platform. Non linear regression is performed after indentifying the variables that is significant to RSR value. The aim is to produce formulae which can be easily changing the variables' value that can generate a RSR value which is satisfactory in terms of representing the real RSR value. The authors aim to produce a formulae using non-linear regression analysis that can represent all the jacket platforms in Malaysian waters.

Pushover Analysis

Platforms model files are presented in the form of SACS model files as shown in Fig. 2. The platform models that were used for pushover analysis are the real existing platform that have been installed and the model files were updated so that the model files represent the real existing platform as close as possible. The platform model files have been updated using the information gained from structural drawings, underwater report, anomalies report, pile driving record, soil and foundation report and metocean data [17]. Other than the structural properties of the jacket platform, the pile soil interaction (PSI) behaviour is modeled using non linear spring elements so that can be considered during the collapse mechanism in the pushover analysis to provide an analysis that is as close as possible to the real existing jacket platform [15]. The metocean data incorporated into the program to generate environmental loads to the structures. The metocean data of sample platform 'A' is shown in Table I and Table II.

TABLE I. 100-YEAR STORM CONDITION WAVE PROPERTIES FOR PLATFORM 'A' AT DIFFERENT DIRECTIONS.

100-Year Return Period/ Storm Condition for Wave					
Direction	**H_s (m)**	**T_z (s)**	**T_p (s)**	**H_{max} (m)**	**T_{ass}(s)**
N (0°)	6.3	8.3	11.7	11.7	10.9
NE (45°)	6.3	8.3	11.7	11.7	10.9
E (90°)	4.7	7.5	10.6	8.7	9.8
SE (135°)	3.4	7.4	10.4	6.3	9.7
S (180°)	3.4	7.4	10.4	6.3	9.7
SW (225°)	4.7	7.5	10.6	8.7	9.8
W (270°)	5.5	7.9	11.1	10.2	10.3
NW (315°)	6.3	8.3	11.7	11.7	10.9

Pushover analysis mentioned wave loading as the environmental loading being increased until the structure collapsed [9]. The dominant loading exerted on the offshore platform consist of wave and current loading [18]. Hence, it is essential to have the metocean data from all direction. However, situation where lacking directional metocean data for example platform 'A', compromises had to be made as such only wave properties is incorporated into the model as 8 different directions, and current and wind is incorporated as the same for 8 different directions. The metocean data used for analysis is 100-year return period as in Table I and Table II, to generate enough loading to make the structure collapsed [15].

TABLE II. 100-YEAR STORM CONDITION WIND AND CURRENT PROPERTIES FOR PLATFORM 'A'

100-Year Return Period/ Storm Condition for Wind & Current				
Wind Speed (m/s)		Current Velocity		
1-hour mean	20	Height Above Seabed		(m/s)
10-min mean	22	Surface	1.0*D	1.20
1-min mean	24	Mid Depth	0.5*D	0.95
3-sec gust	26	Near Seabed	0.01*D	0.55

Fig. 2. The jacket model of platform 'A'

The platform model file as shown in Fig. 2 is performed static linear analysis to assess the platform model against the 100-year storm condition as a checking whether the platform model is valid. The platforms are designed using 100-year return period metocean data as per mentioned in API code. Hence, if the platform failed the static linear analysis, the platform model has error or the platform itself has deteriorated to a level that it cannot sustain the 100-year storm condition anymore. Once the platform passed the static linear analysis in SACS software, the pushover analysis can be performed on the platform.

Pushover Analysis is carried out separately for eight selected loading direction using SACS software namely; N (0°), NE (45°), E (90°), SE (135°), S (180°), SW (225°), W (270°), and NW (315°). The self weight of the jacket platforms, buoyancy, installed equipments, live load are applied on the platform in the first phase of the pushover analysis with load factor of 1.0 [17, 18]. The second phase of the pushover analysis is applying the environmental load on the platform with increasing load factor until the platform collapsed. It should be noted that the wave theory used for analysis is Stoke's fifth order wave theory, wind drag force is in accordance to API RP 2A WSD and current's inertia and drag load is calculated using Morrison's equation [15].

Pile Soil Interaction is incorporated into the analysis using the PSI file during the analysis. PSI in SACS software analyzes the behavior of a pile supported structure subject to one or more static load condition. Finite deflection of the piles ("p-delta" effect) and the nonlinear soil behavior both along and transverse to the pile axis are accounted for. PSI first obtains the pile axial solution, and then uses the resulting internal axial forces to obtain the lateral solution of the piles. In general, soil exhibits nonlinear behavior for both axial and transverse loads; therefore an iterative procedure is used to find the pile influence on the deflection of the structure [12].

There are two main convergence criteria in for the pushover analysis using SACS software's progressive collapse analysis module [12, 15]:

1. Number of member sub-segment; members with plastic material properties are divided into 1-8 sub-segments along the member length.
2. Global stiffness iterations and convergence; a beam column solution is performed for each plastic member using the cross section sub-element details for any load increment. The global stiffness iteration is performed including any effects of connection flexibility and nonlinear pile-soil foundation effects. The software will determine the deflected shape of the structure and compare to the displacements of the previous global stiffness iteration. The stiffness iterations are repeated until the displacements and rotations meet the displacement and rotation convergence tolerances or the maximum number of global stiffness iterations per load increment is 20 and the default displacement and rotation tolerances are 0.01 inch or 0.01 cm and 0.001 radians.

Reserve Strength Ratio (RSR) can be determined as in Equation 2:

$$RSR = \frac{UC}{BS_{100}} \quad (2)$$

Where UC is the ultimate capacity (collapse base shear) and BS_{100} is design base shear loading on the jacket with respect to 100 year return period metocean loading. From SACS software, design base shear can be identified when the environmental load factor = 1.0, while collapse base shear is the maximum base shear upon collapse as shown in Fig.3.

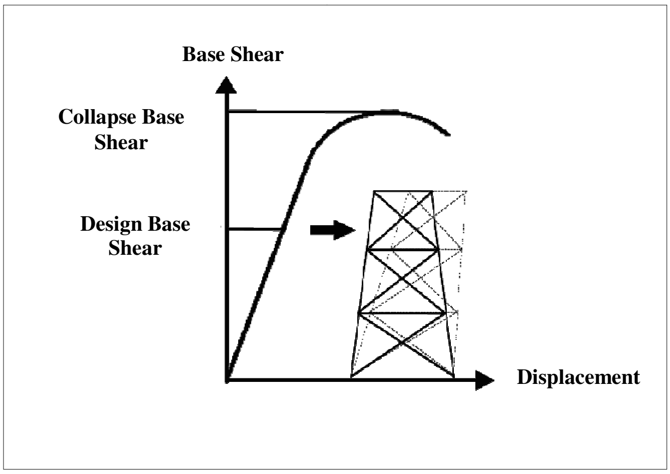

Fig. 3. Definition of Reserve Strength Ratio (RSR)

The 8 different direction of omni wave loading onto the platforms 'A' shows 8 different RSR values as in Fig. 4 with the most critical direction at 225° which has the lowest RSR at 4.001. Hence, the RSR of platform 'A' is classified as 4.001 as the lowest value of RSR is the most critical and representing the reliability of the platform.

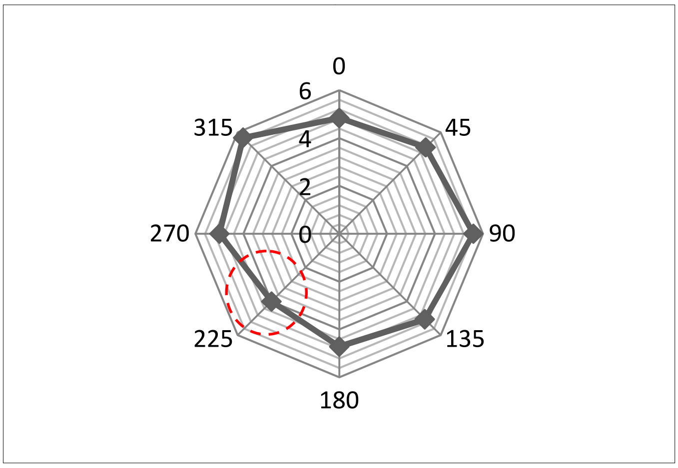

Fig. 4. RSR values of 8 directions of a platform.

The minimum acceptance safety criterion for RSR [19] is:

Manned Structures	=	1.50
Unmanned Structures	=	1.21

After pushover is completed, it is essential to identify RSR as dependant variable and the other key parameters such as water depth, initial air gap, wave height, bracing as independent variables for regression analysis. It is important that the data provided can be made up as a big sample so that the formulae produced can be used to represent all the platforms in Malaysian waters.

Regression Analysis

Linear Regression can be conducted by a curve fitting protocol in an Excel spreadsheet. The data was entered manually into the spreadsheet and the curve fitting protocol is carried out. The accuracy of fit data can be assessed by calculating the goodness of fit data which determines the least square. The residual value or the difference between the data and the linear fit function is squared to eliminate the positive and negative deviation, instead only considering the magnitude. This is known as Sum of Squares (SS) as in Equation 3.

$$SS = \sum_{i=1}^{n} [y - y_{fit}]^2 \tag{3}$$

The correlation index or coefficient of determination or also known as r^2 value expresses the proportion of variance in the dependant variable explained by the independent variables. Increasing r^2 value towards 1 show that the functions fit the data accurately and decreasing r^2 value towards 0 means that the function is less accurate in representing the data [19].

Regression analysis has been conducted in Microsoft excel by using the data consists of 113 platforms pushover analysis results. RSR value has been identified as the dependant variable while wave height, water depth and initial air gap is identified as the independent variables.

Authors were using Microsoft Excel 2007 to assess 2 different methods of performing regression in Excel. The first method (Method I) will be the regression data analysis package in Excel which produces a best fit linear function to represent the variables. The second method (Method II) would be the LOGEST function, also available in Excel, which can calculate an exponential curve to fit the data. The equation formulated would be in a form of exponential function.

The data was broken down into 4 groups according to the bracing system, namely X-bracing, K-bracing, VD-bracing and K,X bracing. At the end of the analysis, formulae to predict the RSR value by input varying the independent variable such as wave height, water depth and initial air gap is generated. The symbols of each variable in the formulae are shown in Table III and Table IV.

TABLE III. BREAKDOWN OF FORMULAE AND PARAMETERS FOR METHOD I

	Symbol	Remarks
1	y	RSR
2	$\beta_0, \beta_1, \beta_2, \beta_3$	Constant
3	x_1	Water Depth
4	x_2	Initial Air Gap
5	x_3	Wave Height

TABLE IV. BREAKDOWN OF FORMULAE AND PARAMETERS FOR METHOD II

	Symbol	Remarks
1	y	RSR
2	b, m_1, m_2, m_3	Constant
3	x_1	Water Depth
4	x_2	Initial Air Gap
5	x_3	Wave Height

Using the formulae generated by the regression analysis as in Table V and Table VI, variables can be input and obtain the RSR value straightaway from the formulae. The function generated using method I is a linear function and the function generated using method II is an exponential function.

TABLE V. FORMULAS DERIVED FROM MICROSOFT EXCEL REGRESSION ANALYSIS (METHOD I)

Formulae Format	
1	$y=\beta_0+\beta_1x_1+\beta_2x_2+\beta_3x_3$
K-Braced	
2	$y=2.1722-0.0202x_1-0.0409x_2+0.1385x_3$
X-Braced	
3	$y=1.3077-0.0025x_1+0.1782x_2-0.0102x_3$
VD-Braced	
4	$y=6.7666+0.0233x_1+0.3336x_2-0.8324x_3$
K,X-Braced	
5	$y=3.7599-0.0547x_1+0.0228x_2+0.2488x_3$

TABLE VI. FORMULAS DERIVED FROM MICROSOFT EXCEL REGRESSION ANALYSIS (METHOD II)

Formulae Format	
1	$y=b*m_1^{x1}*m_2^{x2}*m_3^{x3}$
K-Braced	
2	$y=2.0422*0.9927^{x1}*0.98325^{x2}*1.0532^{x3}$
X-Braced	
3	$y=1.5337*0.9994^{x1}*1.0613^{x2}*0.9975^{x3}$
VD-Braced	
4	$y=10.3559*1.0117^{x1}*1.1608^{x2}*0.7183^{x3}$
K,X-Braced	
5	$y=3.2192*0.9826^{x1}*1.0637^{x2}*1.0549^{x3}$

Correlation index from both methods is compared to each other as in Table VII to observe which method best describe the relationship of the independent variables with the dependant variable.

TABLE VII. COMPARISON TABLE FOR CORRELATION INDEX FOR TWO METHODS

Regression Analysis			
Data Analysis Package		LOGEST Function	
Group	Correlation Index	Group	Correlation Index
K	0.2934	K	0.2881
X	0.1794	X	0.1552
VD	0.3567	VD	0.3486
K,X	0.3447	K,X	0.5293

Case study is conducted using jacket platform 'A' which were shown earlier in the pushover analysis section. The platform is an X-braced structure and the parameters with results were shown as in Table VIII.

TABLE VIII. CASE STUDY TO COMPARE METHOD I AND METHOD II USING PARAMETERS OF PLATFORM 'A'

	Symbol	Remarks	Value
1	x_1	Water Depth	94.80m
2	x_2	Initial Air Gap	13.10m
3	x_3	Wave Height (worst direction)	8.70m
4	y	RSR Validated	**4.001**
5	y	RSR Method I	**3.319**
6	y	RSR Method II	**3.106**

V. DISCUSSION

Pushover analysis is a widely used method to assess the reliability of offshore jacket platform. By performing pushover analysis, the RSR obtained can be used as an indicator to the safety of the jackets. The higher the value of RSR, the safer or more reliable the platforms are.

It is noted that the data used for regression consists of RSR results from 113 platforms from the Malaysian waters. Jacket Platform 'A' used for pushover analysis and case study is not included inside the sample size for regression. This ensures that the real purpose of the simplified prediction model is served by using data from outside the sample size.

The linear fit function generated by regression data analysis package from Excel successfully estimates the RSR value of jacket platform 'A' as 3.319 as shown in Table VIII. However, this value compared to the RSR value from the actual pushover analysis has the percentage difference of 17.05%. Meanwhile, the LOGEST function from Excel which produces an exponential curve fit estimates the RSR at 3.106 as shown in Table VIII which has percentage difference at 22.37%.

The correlation index trend as in Table VII shows that the linear function has correlation index that is slightly higher than the exponential curve. With such vast varying variables which are not localized, it is believed that linear fit function better describes the relationship of all variables, proven in this case and this set of data.

It is recommended to use non-linear regression for expansion of this research work so that the function generated can better describe the relationship of the variables.

VI. CONCLUSION

The following conclusion can be made using the results provided from above:

1. Linear Function fit from regression is slightly better in describing the relationship between variables which are not localized.
2. Correlation Index from both methods is not satisfactory, mainly due to the large variation in the data.
3. Case study shows that estimated RSR using the prediction model is underestimating for this case.

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REFERENCES

[1] N.W. Nichols, Petronas Carigali Sdn Bhd; T.K.Goh, Petronas Research & Scientific Services Sdn Bhd; H. Bahar, Petronas Carigali Sdn Bhd, *Managing Structural Integrity for Aging Platform,* Proceedings, SPE Asia Pacific Oil and Gas Conference and Exhibition, Adelaide, Australia, No SPE101000, September 2006

[2] S. A. Kheiri, M.R. Bahaari, '*Evaluation of Ultimate Strength of Jacket Type Structures under Marine Loading*', Proceedings, 7th International Conference on Coasts, Ports and Marine Structures

[3] M. Fadly N. A., *Sensitivity Study of Environmental Load to Reliability Index for Malaysian Region*, M. Sc Thesis, Universiti Teknologi Petronas, Malaysia, 2011.

[4] V. J. Kurian, Z. Nizamani and M. S. Liew, 2012, *Failure Probabilities for Jacket Platform Subjected to Wave and Current*, International Conference on Civil, Offshore & Environmental Engineering 2012, Malaysia

[5] Shabakhty N., *Durable Reliability of Jack-up Platforms – The impact of fatigue, fracture and effect of extreme environmental loads on the structural reliability*, PhD Thesis, T. U. Delft, Netherlands, 2004

[6] J. Rajasankar, N. R. Iyer, T. V. S. R. Appa Rao, 2003, *Structural Integrity Assessment of Offshore Tubular Joints based on Reliability Analysis*, Elsevier, International Journal of Fatigue

[7] T. Onoufriou, V. J. Forbes, 2001, *Developments in Structural System Reliability Assessments of Fixed Steel Offshore Platforms*, Elsevier, Reliability Engineering System Safety 71, pages 189-199

[8] Narayanan Sambu Potty, Mohammad Kabir B. Mohd Akram, *Structural Integrity Management for Fixed Offshore Platforms in Malaysia*, World Academy of Science , Engineering and technology 58 2009

[9] A.A. Golashani, V.Bagheri, H.Ebrahimian, Tore Holmas, *Incremental Wave Analysis and Its Application to Performance-based Assesment of Jacket Platform* , Journal of Constructional Steel Research 67 (2011) 1649-4657.

[10] Krawinkler H , Standford University, *Pushover Analysis: Why, How, When, and When Not to Use It* , Proceedings, 1996 Convention, Structural Engineers Association of California, October 1996.

[11] Behrouz Asgarian, Mohammad Lesani, *Pile-Soil-Structure Interaction in Pushover Analysis of Jacket Platforms Using Fiber Elements,* Journal of Constructional Steel Research 65(2009) 209-218.

[12] SACS Software manual

[13] Cuneyt Capanoglu, Steve Coombs, *Requalification Process for Existing Platforms Implications of Newly Acquire Criteria on Mitigation,* Proceedings of Nineteenth (2009) International Offshore and Polar Engineering Conference Osaka, Japan, June 21-26, 2009

[14] V.J. Kurian, Z.Nizamani, M.S. Liew, M.M.A. Wahab, *System Reliability for Jacket Platform Subjected to Wave and Current Loads*, Department of Civil Engineering, Universiti Teknologi PETRONAS.

[15] Pattaradanai Pueksap-anan, *Sensitivity Analysis for RSR Offshore Steel Type Platforms*, M. Sc. Thesis, Asian Institute of Technology, School of Engineering and Technology, Thailand, August 2010.

[16] Angus M. Brown, *A Step-by-step Guide to Non-linear Regression Analysis of Experimental Data Using a Microsoft Excel Spreadsheet,*Computer Methods and Programs in Biomedicine 65 (2001) 191-200

[17] Group Technical Soulution (GTS) (2011), *Global Ultimate Strength Analysis for SBO Platform: SMJT-E*, Report ID: RD-PLE-CSP-RBI-S309

[18] Gerhard Ersdal, *Assessment of Existing Offshore Structures for Life Extension*, Doctorial Thesis, Faculty of Science and Technology, Department of Mechanical and Structural Engineering and Material Science, University of Stavanger, October 2005

[19] PETRONAS Research & Scientific Sdn. Bhd., *Structural Integrity and Inspection Analyses of Ageing Jacket Reassessment Basis*, Part1. Revision 01, 1999