Updating Failure Probability of Jacket Platform in Malaysian Waters

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ABSTRACT

Reliability analytical studies the uncertainties in load, geometry, material properties, operational environment and other uncertainties. Usually the system is performed under two conditions, specified service condition and specified period of time. Structure lifetime has its own limit state or constraint. When the design meets the requirement imposed on the structural behavior met within the range according to the code of standard, it is classified as satisfied and safe. In this study, the paper describes a method to determine the failure probability and evaluate the failure probability when the structure has experienced a wave loading by men of updating the probability using Bayesian method and truncation method of updating. This paper also brings about the variation of experienced wave height of RSR 1.0 and 1.5 at different direction on the failure probability of the selected jacket platform. This study found out that, the updated failure of probability shows a significant decrement when the experienced wave loading is increasing. The design probability of failure is 3.0 x10-5.Using RSR value of 2.0 gives a much lower failure probability and updated failure probability compared to the RSR value of 1.5. When the updating is made at RSR 1.5, the failure reduces down to 1 x 10-4 when the experienced wave height is at 15m, and met the requirement of the ISO 19902 code and consider safe for extension of life. This study is further discussed by evaluating the probability of failure at different current velocity profile to see the variation on the updating probability of failure.

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CHAPTER 1

1.0 INTRODUCTION

1.1 Background of Study

1.1.1 Overview

The fixed jacket platforms are the most common type of offshore structure in the offshore industry nowadays, which are used for both exploration and production of oil. There are plenty of development of fixed jacket platform in the offshore world, and all the recent development of this structure now follows the environmental condition of the region where it is built. A tubular jacket structure designed to support a variety of constraints such as weight of the topside, impact of the waves, pressure generated from the wind on the topside and also the flow of the current or water streams.

In recent year, pushover analysis is becoming a frequent method to be used in predicting the deformation demands for the evaluation of performance of new and existing of fixed jacket structure. Push over analysis gives a beneficial judgments on the many responses characteristic such as structural behavior, identification of critical members in which may contribute to failure of the jacket structure. The analysis is continuous until the design meets the specified criteria and any deficiencies are observed and revised. Structural Analysis Computer System (SACS) push over analysis is used to determine the corresponding base shear of jacket platform. In push over analysis. The platform is simulated in SACS to analyze the ultimate strength which indicate the benchmark for the comparison with the strength results from the static in place analysis to retrieve the Reserve Strength Ratio (RSR) value.RSR is an intimation of integrity of platform and every code of practice has its own minimum requirement of RSR value for reassessment of jacket platform.

Reliability analysis is an analysis of its limit-state function where we determine the lowest failure probability of the jacket platform system. If exceed, it is considered as unreliable. The uncertainties arise from the environmental load and resistances determine the characteristics of structural a platform. When a platform has experienced a load level higher than its design load and succeeded without any major damages on its structure, the level confidence of the structure will increase. By using the prior information from the experienced loading, we able to ascertain the update probability of failure. In Monte Carlo simulation, random number is generated and plugged into the load and resistance function for every trial. These random numbers are normally distributed in the range of 0 to 1. When the results of each trial are less than zero, it is considered as failure simulation. For each function, there will be a specific random variable required for each trial. Some analysis required a large number of samples and Monte Carlo sampling has often consumed much time.

1.2 Problem Statement

1.2.1 Problem background

The probabilistic model is used to assess the reliability of jacket system by checking the probability of failure based on the recommendation form the codes of practices. When a structure has been operating in some years, it has experienced a higher wave loading than a design loading. When a platform has experienced a load level higher than its design load and succeeded without any major damages on its structure, the level confidence of the structure will increase. Thus, re-assessment is required to evaluate the integrity of the structural platform for the extension of life. The statistical modelling such as Bayesian method or truncation method is needed to improve the probability of failure of the structure in order to translate this claim in a mathematical way.

During the design phase, an assumption is used against the uncertainty of environmental loading and material resistances based on the limited information and data available. Due to this, it may raise a question whether the jacket platforms are able to withstand the loading of 100 year return period while the code of practices requires 10,000 years of return period of environmental load or probability of failure of 10^{-4} for the assessment and extension of life. This method only considers the failure of probabilities and if the jacket structure cannot withstand with this much of a load or meet the requirement of probabilities of failure $10^{-4,}$ thus re-strengthening is required and require huge cost.

1.2.2 Problem description

The available information and data is only within ranges of 10-20 years, which is far from enough to assess the jacket structure with 10,000 year return period as required by the standard for extension of life. In fact, the loading pattern may vary as the wave height is increasing and weaker areas of the platform such as deck area may exposed to higher loading, thus leads to a reduction in capacity. For re-assessment, standard code ISO 19902 require The reserve strength ratio (RSR) shall be determined using the static ultimate strength analysis method in described in section 12.5 in the code to determine the best estimate of the system strength. The RSR shall be determined for all wave directions and the lowest value obtained shall be the structure's RSR. If the calculated probability gives less than the code required re-modification of jacket is required and this is totally not a feasible method to extent jacket structure’s life. When a structure is succeeded in carrying a certain experienced load level, it shows that the structure has sufficient structural safety and has proven its robustness and strength. But the main concern is whether this experienced load level is high enough to justify the safety of the structure while it is very rare that the offshore platform in Malaysia water have experienced wave load higher than the design load.

1.3 Research Objectives

The main objective of the study is to evaluate the probability of failure of jacket platform using ultimate limit state design and update the probability of failure using information from prior event that has been occurring. Based on the available data, the Monte Carlo simulation method is used to determine the reliability and the probability of failure with a design of 100 year return period. Bayesian method of updating is used to determine updating probability, by using a wave height value which produces value RSR of 1 and 1.5 which results from SACS push over analysis, and to be checked against the code of practice for extension of life. Following are the other objectives of this study:

1. To determine the value of wave height correspond to the RSR value of 1 and 1.5 based on SACS push over analysis in order to find the updated probability of failure.

2. To assess and compare the updated probability of failure by using different methods which are Bayesian and Truncation method.

3. To analyze the probability of failure and updated probability of failure at a different current velocity profile.

1.4 Scope of Study

The scope of work includes developing an uncertainty model for resistance and load of the jacket structure limited to the SKO water region. Monte Carlo Simulation of $1x10^7$ is performed to generate random variables for model uncertainty which to be included in the limit state equation. We study the standard codes of practice to come out with technical guidelines to develop the target reliability. The initial step is to gather all the parameters of the environmental load and resistance for the offshore platform in the region of Malaysia water. The information collected is used to extrapolate the extreme environmental event for wave height. A SACS push over analysis is conducted to determine the wave height correspond reserve strength ratio, RSR of 1. This data is used in updating probability of failure. Assemble the database components that represent various practical application codes. Using probability distribution functions, assess the uncertainty of all the variables that impact on the probability of failure. Perform the reliability analysis to assess the probability of failure of each calibration point and determine the reliability index. Accessibility of SACS model and MATLAB software are considered vital to evaluate the actual resistance and load effects of hundreds of random variables.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Probability of Failure

Random variables for load uncertainty were wind, wave and current. These random variables are considered as probabilistic and we have to figure it out the randomness of the load. Parameters of distribution are established first to find the mean, standard deviation, scale and shape factor for each random variable. From authentic data which was in the shape of 1-50 years, random variables will be extrapolated up to 1000-10,000 years, which is specified by ISO 19902 and API RP2A for reliability analysis of extension life of the existing platform. Metocean design conditions are very important and ISO 19900-1 suggests a few methods of considering the parameter of the design. A 100 year wave height along with 100 year wind speed and current speed is taken into consideration. These load uncertainties be evaluated by extrapolation of the individual environmental parameter which is considered independently. This will result in global extreme environmental action on the structure and a relevant global response which could be base shear or overturning moment with a return period of 100 years is to be considered. This method is an association of load uncertainties and significant structural response effect which is base shear.

The maximum load which can occur at any time during the life cycle of jacket is the most critical variable to be taken during design. ISO and API code require 100 year extreme conditions of the wave. Sometimes one sudden event may even exceed this condition (10,000 year return period). Thus, system reliability analysis was based on design, environmental condition of 10,000 years return period. Design criteria for environmental load are inherently uncertain for the design of jacket platform due to variability of climate.

First Order Reliability Method (FORM) has been used by mane researchers for reliability analysis. It provides geometrical interpretation where it transforms the basic component variables into a standard normal variables which may not normally distributed at first [1]. Another technique used to fine probability of failure and reliability index is by using Monte Carlo simulation. It will prompt large number of variable samples. If the limit state function is undeclared, the calculation will require a large number of simulations for precise function appraisal [2]. The probability of failure calculated by Monte Carlo simulation is defined as:

$$P_f = \frac{N_f}{N} \tag{1}$$

Where:

N_f = Number of failure

N = total number of simulation

However, this method used random sampling in which the random number generated in the cluster is not distributed uniformly over the whole design space. The approximated probability of failure depends on the sample numbers. Thus, when lower order of probability of failure is required, then the sample number used in simulation also needs to be higher in which will increase the computational cost [2]. The Monte Carlo method in particular can develop an excellent probabilistic model given that the data supplement by experience and personal judgments. More from this, the application of this method gives an insight of the behavior of the systems, but the limitation if this method is the computed result is treated as approximation given that a certain degree of confidence limit rather than exact values [3].

2.2 Bayesian Updating Probability of Failure

Using the approach of predictive Bayesian theorem tolerate with the detail of observable quantities such as environmental load, structures strength, number of cycles before failure. Bayesian approach takes into consideration of prior information and stochastic variation in previous events to establish an uncertainty distribution of the load and resistance. From Ersdal, used these Bayesian theorems by combining two or more probability distributions to identify random variables [6]. Bayesian network also can consider a multiple limit state function to formulate the possible updating probability of failure. Bayesian updating method is to numerically evaluate the posterior probabilistic model given that the prior model and the likelihood function of observation data. [5]. This updating is performed by using sampling techniques of Monte Carlo simulation [2], when the jacket experienced an extreme wave loading and has survived without any major damage, the uncertainty related to its strength should be decreased and updated. The updating can be done by men of Bayesian updating method by introducing a mechanical model consisting an equation and limit condition which describe the loading and material properties [4]. Some of the parameters in the function are uncertain and it is modelled as random variables. Bayes theorem required one to update a prior distribution f ‘(x) to a posterior probability, f “(x) distribution with existing data or from observations and judgments.

$$f''(\mathbf{x}) = \frac{L(\mathbf{x})f'(\mathbf{x})}{\int_{\mathbf{X}} L(\mathbf{x})f'(\mathbf{x})\mathrm{d}\mathbf{x}} \tag{2}$$

Where:

L(X) = likelihood function

F ‘(x) = prior distribution

F “(x) = posterior probability distribution

Form Ersdal, he modelled the failure function for ultimate collapse of the structure as equation 1 and the function condition is described in equation 2 below [6]:

$$G=R-W \tag{3}$$

$$Pf=P\ (g<0) \tag{4}$$

Where:

R = the resistance ultimate capacity of a structure which is describe as system basis. The capacity is assumed to be 100 year design loading (H100) and multiplied by RSR and model uncertainty factor.

W = approximated wave loading equation, where, H is an annual maximum wave height multiplied with coefficient fixed from curve-fitting model for specific jacket.

From Nizamani, same approach is used where the limit state function to determine probability of failure is denoted as equation (5) below [2]. When the load is higher than the resistance, the platform is considered as failed. For the calculation of probability of failure, the wave height value used in this model is a design wave height for both load and resistance model uncertainty. For the probability of survival as in equation (6), slight changes in wave height for load model uncertainty, where the wave height, H_R used is a corresponding wave that has a value of RSR of 1

$$g = \underbrace{B_i * RSR * c_1 * (H_d + c_2 * u)^{c3}}_{\textit{Resistance}} - \underbrace{A_i \ * c_1 * (H_d + c_2 * u)^{c3}}_{\textit{Load}} \quad (5)$$

$$g = \overbrace{B_i * RSR * c_1 * (H_d + c_2 * u)^{c3}}^{\textit{Resistance}} - \overbrace{A_i \ * c_1 * (H_R + c_2 * u)^{c3}}^{\textit{Load}} \quad (6)$$

Monte Carlo method is used in his study to calculate the probability of failure and survival, where the number if simulation is set to be 10^6. For every simulation, new wave height and new uncertainty factor is introduced and the respective probability is determined as below:

TABLE 1: Limit state function

Design Probability of failure (design wave height)	Probability of survival (experienced wave height)
- G = R-L - Pf = P (G < 0) - Pf = number of failures/ total number of simulation ***R= resistance , L= load***	- F = R-L - Ps = P (F >0) - Ps = number of survival/ total number of simulation ***R= resistance , L= load***

For the Bayesian updating, Ersdal use the method of Monte Carlo simulation, where, to find the updating, the number of simulations satisfying failure function (g<0) and survival function (f>0), divided by the number of simulations which satisfying the survival function [6]. From his paper, the result shows that the updated probability of failure (excluded gross error) decreases when the experienced wave height is increasing. This reason is explained by the fact that, the updated was based on both probability of failure and probability of survival.

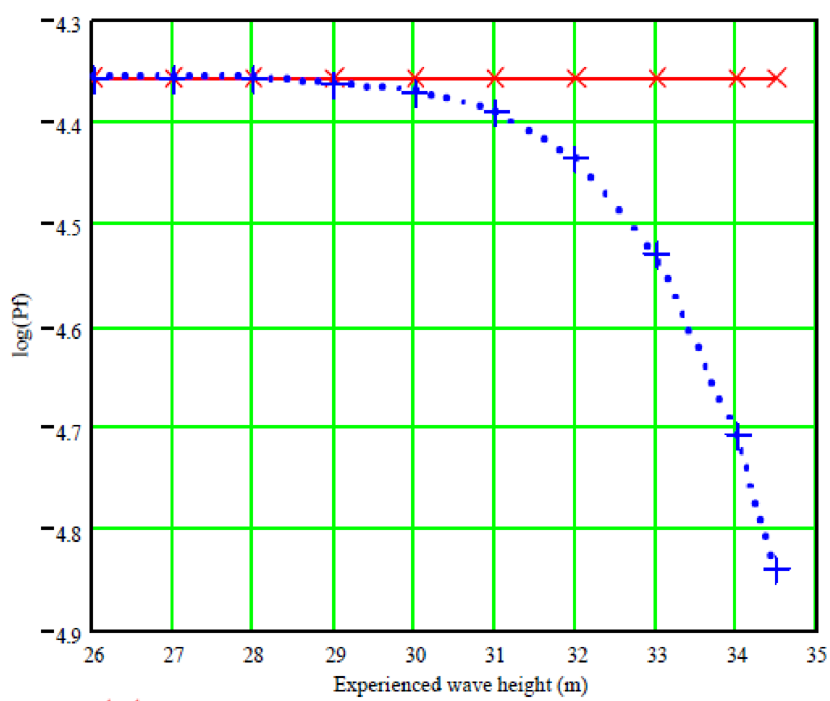

FIGURE 1 : Bayesian Updating of failure probability for Jacket at North Sea [6]

Common stochastic methods for reliability analysis are moment, based technique like FORM or simulation technique like Monte Carlo. FORM reliability has been used by many researchers in reliability analysis. FORM is also known as a semi-probabilistic reliability analysis method. The first step is to transform the basic variables which may not be normally distributed into the space of standard normal variables. It is the transformation of limit state surface in a given space of basic variables to a corresponding limit state surface in standard normal space. The limit state function is equal to g (X) =0, and then its reaching failure when g(X) < 0. The performance function of a system can be written as:

$$g(X_1, X_2, \cdots, X_n)\begin{cases} > 0 & \text{safe state} \\ = 0 & \text{limit state} \\ < 0 & \text{failure state} \end{cases} \tag{7}$$

When g(X) = 0, it is known as limit state surface and each X indicates the basic load or resistance variable. For ease of analytical development, all variables are transformed into their standardized form become g (X') = 0.

2.3 RSR Pushover Analysis

A collapse pushover analysis is implied to demonstrate the adequacy of the platform's strength and stability to withstand an overload form wave loading [2]. The author defined that reserve strength ratio (RSR) as the ratio of the ultimate lateral load capacity of the platform with its 100-year environmental loading which consider as design wave loading. He claimed that for a high consequence platforms, an RSR of 1.6 is required in limit state function while RSR 0f 0.8 for low consequence platform. [2][6].To determine the RSR value of jacket platform, one has to consider all directions and the lowest RSR should be pointed out as jacket's RSR value. More from this paper, RSR of 1.5-2.5 is used in this analysis to find the probability of failure and updating probability of failure. For the re-assessment of jacket platform, ISO code sets the requirement that, the offshore must succeed from the wave height of RSR 1.5 or 10,000 year return period in order to extend the life cycle of the jacket platform [14].

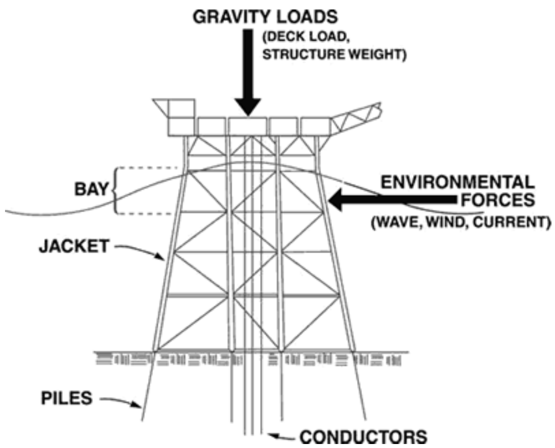

FIGURE 2: Component load of platform

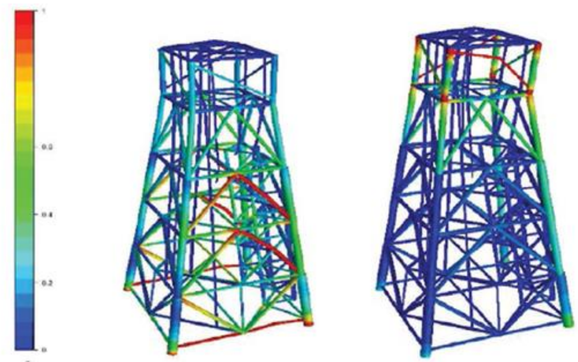

FIGURE 3: Pushover analysis of jacket platform

Pushover collapse analysis shows the behaviour of the structure of the jacket part in 2 or 3 dimensional model in which consider all vital characteristics of linear and non-linear analysis. It could be with PSI interaction or without PSI interaction. Figure 2 shows the loading exerted the jacket platform and in a push over analysis, the jacket is pushed at all different directions until a desired displacement is obtained. Figure 3 shows the after the pushover analysis is done, some of the members have in red colour indicated the failure or critical condition [2].

2.4 Truncation Method

Truncation means a slice off or simplified according to Oxford dictionary. When one tries to make an attempt to simple conclusion about bigger population, a truncation is used. It eliminates the unnecessary info or data by putting a limit at upper and lower boundary of the distribution. A distribution that is truncated is part of the original distribution (un-truncated) that is below or above the limit value. [17]

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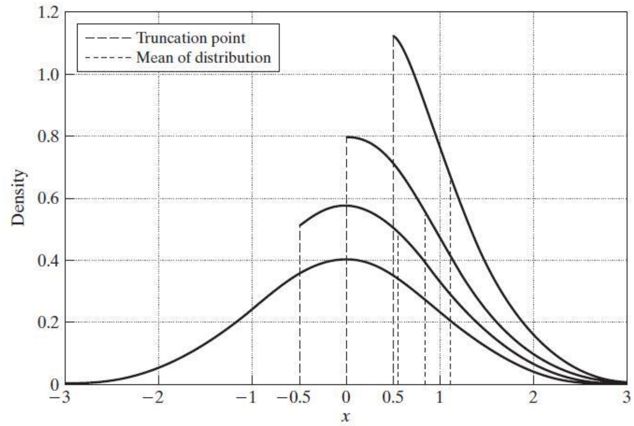

FIGURE 4: Truncation of normal distribution

The figure 4 above explains mathematically a way to eliminate the some of the lower tail value of the original distribution when one tries to analyse the extreme cases from the upper tail value by truncating at mean distribution value. Sometimes, the lower tail value does not give much effect on the overall distribution when it comes to the extreme event analysis [18].

2.5 Chapter Summary

As a conclusion, to determine the failure probability of a platform, limit state function of resistance and load is established and every platform has its own coefficient and design wave load based on respective environmental condition. An experienced wave height is obtained from the collapse pushover analysis by determining the wave height correspond to a certain RSR value required in the study. To determine failure probability, the Monte Carlo simulation method is applied where, set of 106 simulation is used. An updating of failure probability was made to check and to assess the jacket structure's reliability for the purposed of extension of life. Bayesian updating method is a popular method to be used by most of the researchers. This theorem, determine the updating of failure probability of posterior event B in which depend on the data and observation of prior event A and likelihood function of event B based on event A. When statistical information and judgmental observation is available, updating probabilities can be determined. Truncate method is applied to truncate the distribution to a certain value when updating of probability of failure is made.

CHAPTER 3

3.0 METHODOLOGY

3.1 Outline

Below is the outlined the flow chart of project activities for this study. SACS software push over analysis is applied to find the RSR value and its corresponding wave height. Monte Carlo simulation is fixed at 10^6, and from this simulation, probability of failure and survival are found. Then, by applying the Bayesian theorem and truncation method, update probability of failure is achieved. The flow diagram below shows the steps taken for this study so far.

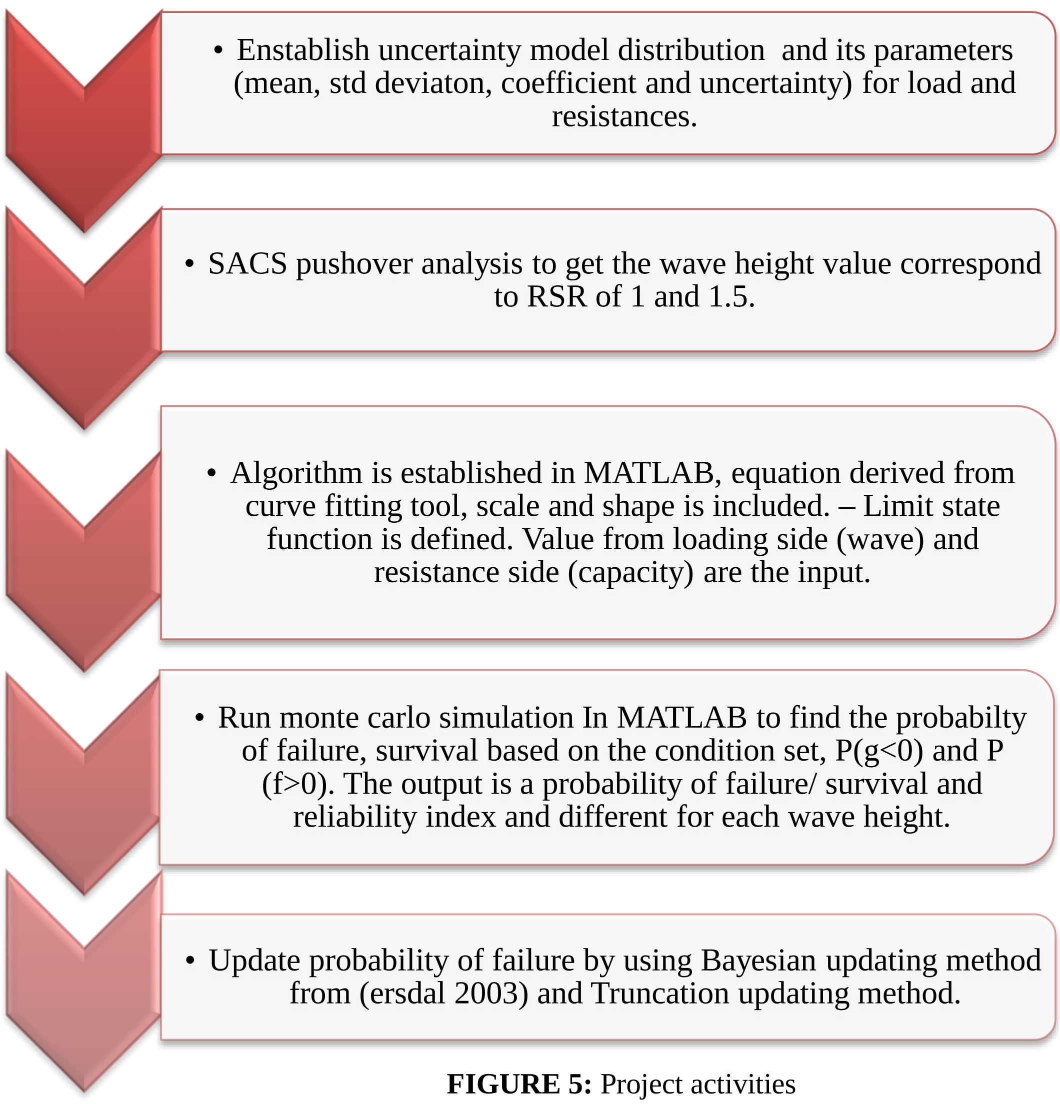

FIGURE 5: Project activities

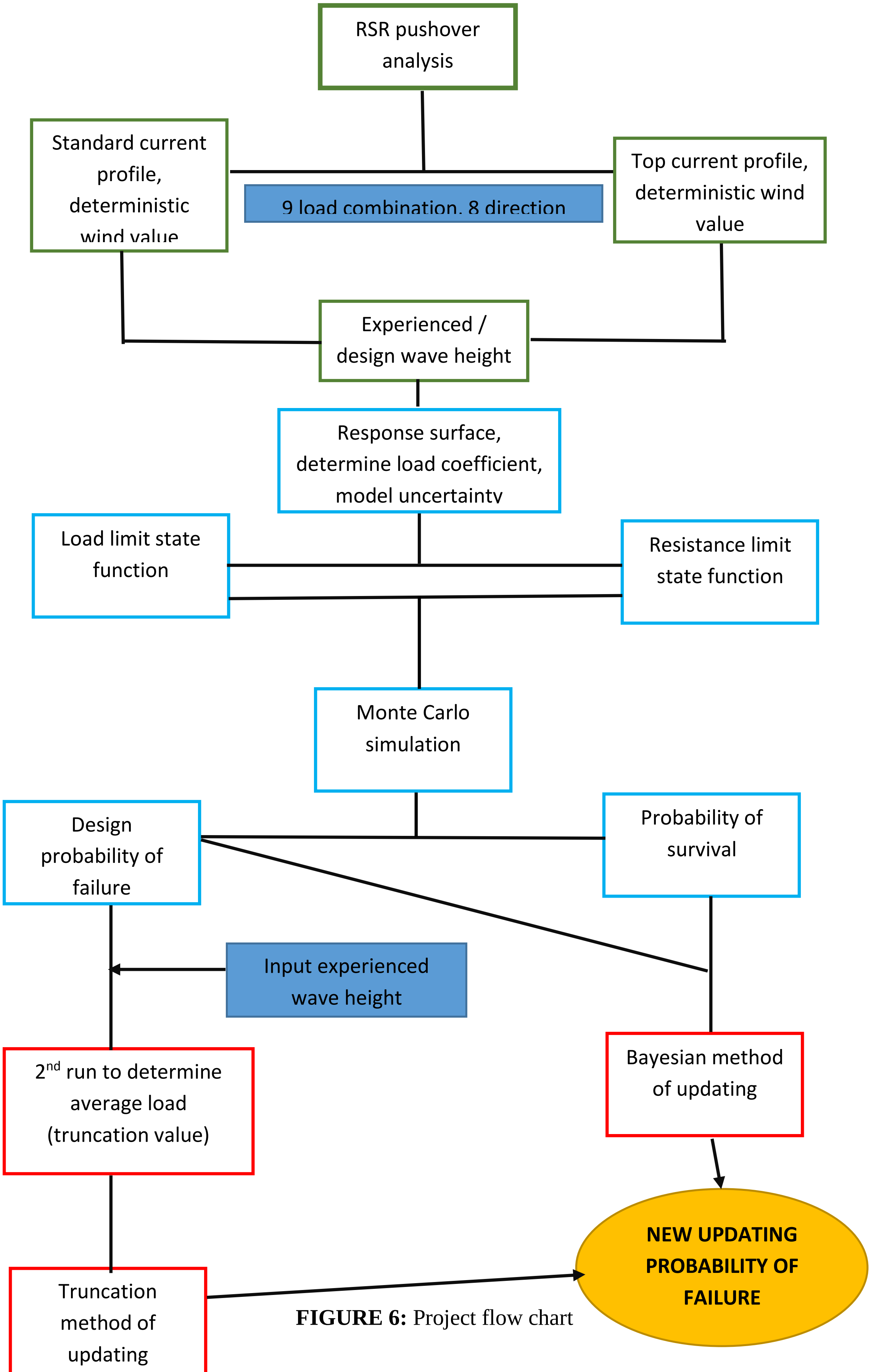

FIGURE 6: Project flow chart

3.1 Bayesian Method

The uncertainty model for wave load:

L=Ai.*((c1.*(Hd.^2))+(c2.*Hd)+(c3.*(Ub.^2))+(c4.*Ub)+(c5.*(Wb.^2))+(c6.*Wb)+c7) (8)

Uncertainty model for resistance (for probability of failure):

R= Bi.*RSR.*((c1.*(Hd.^2))+(c2.*Hd)+(c3.*(Ub.^2))+(c4.*Ub)+(c5.*(Wb.^2))+(c6.*Wb)+c7) (9)

Uncertainty model for resistance (for probability of survival):

W= A1i.*((c1.*(Hdu1.^2))+(c2.*Hdu1)+(c3.*(Ub.^2))+(c4.*Ub)+(c5.*(Wb.^2))+(c6.*Wb)+c7) (10)

TABLE 2: Limit state condition used for failure and survival probability

The limit state equation for probability of failure	The limit state equation for probability of survival
• G = R-L • Pf = P (G < 0) • Pf = number of failures/ total number of simulation	• F = R-W • Ps = P (F >0) • Ps = number of survival/ total number of simulation

Monte Carlo simulation randomly generates samples as per their probability distribution. For every simulation, new load and resistance model uncertainty is introduced and the number of simulations is set to be 10^6 as this is the maximum simulation that MATLAB software can operate. The higher the simulations the more accurate results it will be. For failure function, the term "number of failure" means that, the load (L) value exceeds the resistance (R) value, and the G value is less than zero. Cumulative of this number of simulations is dividing by total simulation to get the approximate probability of failure.

The reliability index can be determine by following equation:

$$\beta = \phi^{-1}(Pf) \tag{11}$$

Where:

β = Beta value, reliability index

ϕ = cumulative distribution function for the standardized normal variables

The parameters of the stochastic model:

TABLE 3: Stochastic model parameters

Parameter	Description	values
Ai	Load uncertainty model	Normally distributed: • Mean = 1.0 • Std Deviation = 0.15
RSR	Reserve Strength Ratio	Fixed at 1.5 and 2.0

C1, C2, C3, C4, C5, C6, C7, Ub,Wb.	load coefficients from Response Surface from Voon's paper model	c1 = 0.04232
		c2 = 0.09672;
		c3 = 2.298;
		c4 = 0.9034;
		c5 = -0.04453;
		c6 = 0.9760;
		c7 = 0.2843;
		Ub = 1.20;
		Wb = 24.00;

Bi	Resistance model uncertainty	Normally distributed: • Mean = 1.0 • Std Deviation = 0.1
Hd	Design wave height	Fixed at 11.7 m (design wave variable manually)

Hdu	Experienced wave height	Value of wave height when RSR of 1. May varies also, starting from design load value.10, 000 year return period wave height value.

In this study, to determine update probability of failure, Bayesian method from Ersdal paper is used. When the probability of failure, Pf and probability of failure is known, then we can find the updated probability of failure according to the equation below after including both information.

$$P_f^U = P(g \leq 0 \mid f > 0) = \frac{P(g \leq 0 \bigcap f > 0)}{P(f > 0)} \tag{12}$$

Comments:

The number of simulations that satisfying failure function, Pf (G<0) and survival function Ps (F>0), divided by the number of simulations satisfying survival function Ps (F>0). Ersdal, claimed that, to see any significant difference in the probability of failure, the experienced wave loading of 1000 and 10,000 year return period is to be used in survival function. When the experienced wave loading is less or equal than the design load, it does not change the updated failure probability.

3.3 Truncation Method

Another method of updating failure probability besides Bayesian theorem that can be considered is truncation method. Updated based on truncation has less effect on the failure probability when compared to Bayesian. This is due to, when updating is made, it's only focused on the resistance uncertainty model, while Bayesian method considers both load and resistance uncertainty model when updating is made. The reason why truncation doesn't consider a load uncertainty model is due to there is no additional information is obtained concerning the wave distribution. To update this distribution, it requires a sufficient number of waves and large amount of simultaneous measurement of jacket load. Even though the wave height is known due to uncertainties in load model, but it is not accurate and perfectly known. The best we can conclude is the capacity of the jacket structure is increasing in the knowledge of succeeded in carrying the load from extreme wave event. The simulation method for truncation is performed by truncating the resistance density function and be repeated based on this new truncated distribution. The approach is quite similar but it saves time of simulation. At the end of the study, a consistent model of updating failure of probability should be developed and further research these two methods is required. We used the same limit state function as Bayesian method and run 10^6 Monte Carlo simulation.

The limit state equation for probability of failure:

First run:

G = R-L (same as limit state function used in Bayesian method)

Run the load limit state function only

Input experienced wave height value into the load limit state function here, run the Monte Carlo simulation, and get the average value of the loading. (Let say, “x”)

2nd run:

G = R-L

Run the load limit state function and resistance function simultaneously

Re-run the Monte Carlo simulation for both function but the resistance limit state function, with “x” as the truncation value. Any value of simulation of R function that less than this truncation value is set equal to any random value that more than the truncation value. The input for the wave height is the design wave height.

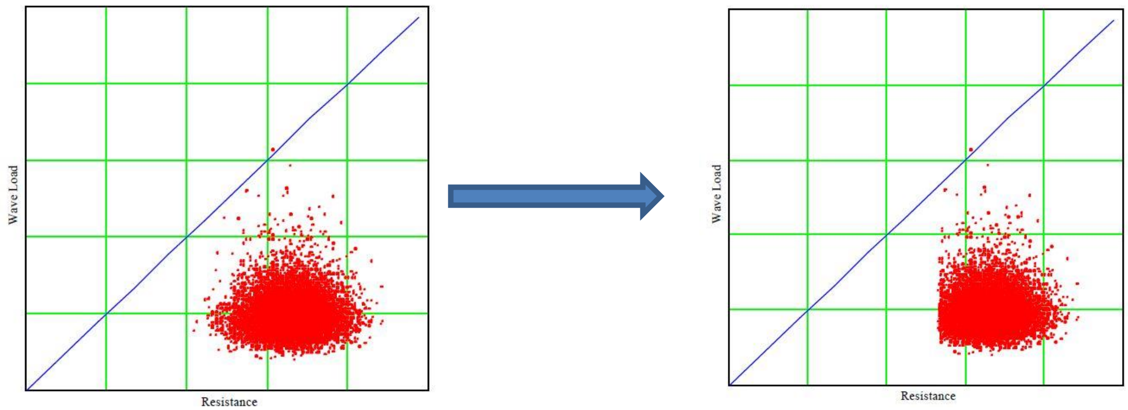

FIGURE 7: Changes in the distribution of the simulation.

3.4 RSR Collapse Pushover Analysis

The load result from extreme storm is vital in the design of offshore jacket platform. This load combination is generally the dominant factor contribute to the global base shear. Wave height is the primary parameter in the classification of sea states, which is calculated from peak to trough. The actual selection of design wave height is a matter of engineering knowledge and judgment. Jacket platforms are most sensitive to wave forces rather than current and wind force due to peak response always occurs at the time of maximum wave height. In reference of API RP2A LRFD, only wave parameter is to be considered for reliability analysis and calibration of environmental load factors. Mean bias and coefficient of variation (COV) is set up to a certain value and mean bias was normally around 0.7-0.8 while COV is around 37%. This is same as for wind, therefore, only wave is taken into consideration for reliability analysis. Weibull distribution fits well with significant wave height as this wave force is the dominant metocean variable. In real sea waves, it comes from many directions simultaneously. During the transition period between 2 monsoons, the direction becomes unstable without any clear prevailing direction. The highest significant wave height reported in deep water South China Sea during tropical cyclone is 9.5m. The table below shows the maximum wave height and the water depth range of the respective platform in Malaysia water retrieved from [2].

TABLE 4: Wave height and depth for respective location

Location	Design wave (Hmax) with return period of 100 years		Water depth (m)	
	minimum	maximum	minimum	maximum
PMO	4.6	10.9	60	79.2
SBO	2.3	7.7	36.9	59.1
SKO1	3.0	9.9	46.0	95.0
SKO2	4.7	11.7	46.0	95.0

From this small amount of data, we have to estimate the extreme value of the tail end of distribution of design wave uncertainties which results from a large storm condition for example 10,000 year return period. In this condition, the probability of occurrence is extremely small but still the possibility is there. The COV for annual extreme wave loading was more that 50% in the North Sea. In Malaysia water region, it is predicted that it will have due to low mean value compared to regions outside Malaysia water [2].

Besides estimating the extreme value, we also can conduct collapse pushover analysis to determine the extreme value of wave height correspond to reserve strength ratio (RSR) of 1.0. For the assessment, the ISO code requires the platform to survive the wave height of RSR correspond to 1.5 or 10,000 year return period.

$$\text{(RSR)}= \frac{Failure\ Base\ Shear\ (MN)}{Design\ Base\ Shear\ (MN)} \tag{13}$$

In SACS analysis, the jacket is pushed (by mean of environmental loading i.e. wave) by members of the jacket part is failing as a group or individually. The jacket platform is pushed till a desired displacement or collapse is obtained. The wave height is increased until the design base shear value is equal to the ultimate base shear, or RSR =1 and RSR 1.5.

FIGURE 8: F9 platform

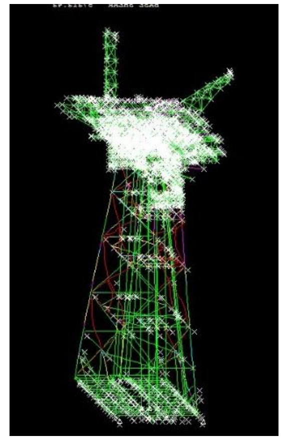

FIGURE 9: F9 platform after pushover

In pushover analysis, we are considering 9 cases of live load and storm load combinations. For every load combination, it has different wave height value that will give a RSR of 1.0 and 1.5 with different direction of wave.

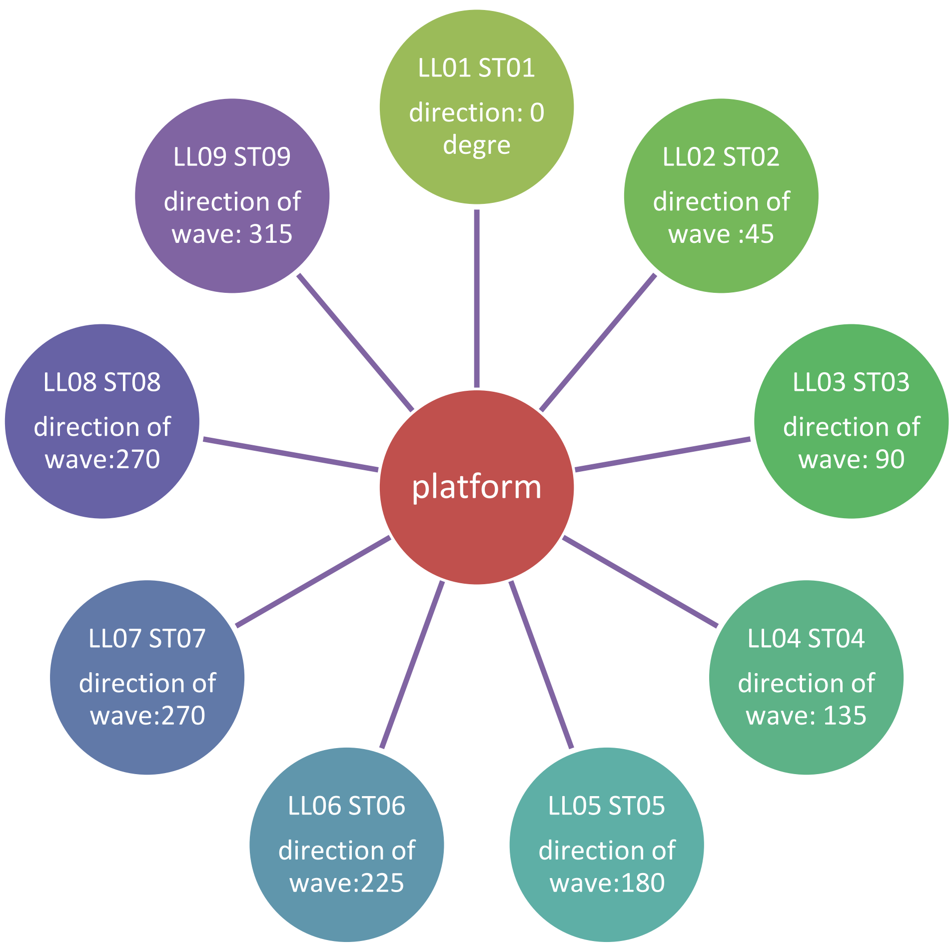

FIGURE 10: Load direction and combination

For load combination 08 and 09, it has the same direction of the wave. In pushover analysis, we fixed the current value and consider the wind load as deterministic. For the design base shear, we take the value of base shear that correspond to load factor of 1.0 at storm load and for the failure base shear, we refer to the load case and load factor that correspond to the first member failure.

**** NON-LINEAR COLLAPSE ANALYSIS (LOAD SEQUENCE 1) ****

NSLV	INC.	LOOP	LOAD CASE	LOAD FACTOR	*DEFLECTION* DIFF.	JNT	DOF	ROTATION DIFFERENCE	** DEFLECTION ** MAXIMUM	JNT	DOF	% OF IMPACT ENERGY
2	1	1	DL	0.200	0.0012	351	DX	0.0000004	-0.664	8013	DZ	
2	1	2	DL	0.200	0.0000	8013	DZ	0.0000000	-0.664	8013	DZ	
4	2	1	DL	0.400	0.0024	351	DX	0.0000009	-1.327	8013	DZ	
4	2	2	DL	0.400	0.0000	8013	DZ	0.0000000	-1.327	8013	DZ	
6	3	1	DL	0.600	0.0036	351	DX	0.0000013	-1.990	8013	DZ	
6	3	2	DL	0.600	0.0000	8013	DZ	0.0000000	-1.990	8013	DZ	
8	4	1	DL	0.800	0.0049	351	DX	0.0000017	-2.653	8013	DZ	
8	4	2	DL	0.800	0.0000	8013	DZ	0.0000000	-2.653	8013	DZ	
10	5	1	DL	1.000	0.0061	351	DX	0.0000022	-3.316	8013	DZ	
10	5	2	DL	1.000	0.0000	8013	DZ	0.0000000	-3.316	8013	DZ	
12	6	1	LL08	0.200	0.0058	9463	DX	0.0000102	-3.199	8013	DZ	
12	6	2	LL08	0.200	0.0000	7406	DZ	0.0000000	-3.199	8013	DZ	
14	7	1	LL08	0.400	0.0119	7406	DX	0.0000210	-5.102	7422	DZ	
14	7	2	LL08	0.400	0.0000	7406	DZ	0.0000000	-5.103	7422	DZ	
16	8	1	LL08	0.600	0.0186	7406	DX	0.0000319	-7.501	7406	DZ	
16	8	2	LL08	0.600	0.0000	7406	DZ	0.0000000	-7.503	7406	DZ	
18	9	1	LL08	0.800	0.0253	7406	DX	0.0000428	-9.901	7406	DZ	
18	9	2	LL08	0.800	0.0000	7406	DZ	0.0000000	-9.904	7406	DZ	
20	10	1	LL08	1.000	0.0320	7406	DX	0.0000538	-12.299	7406	DZ	
20	10	2	LL08	1.000	0.0000	7406	DZ	0.0000000	-12.304	7406	DZ	
22	11	1	ST08	0.200	0.0218	9045	DY	0.0002150	-12.532	7406	DZ	
22	11	2	ST08	0.200	0.0000	1023	DY	0.0000000	-12.529	7406	DZ	
24	12	1	ST08	0.400	0.0217	9045	DY	0.0002205	-14.243	1023	DY	
24	12	2	ST08	0.400	0.0000	1023	DY	0.0000000	-14.226	1023	DY	
26	13	1	ST08	0.600	0.0215	9045	DY	0.0002215	-19.925	1023	DY	
26	13	2	ST08	0.600	0.0000	1023	DY	0.0000000	-19.908	1023	DY	
28	14	1	ST08	0.800	0.0212	9045	DY	0.0002220	-25.607	1023	DY	
28	14	2	ST08	0.800	0.0000	1023	DY	0.0000000	-25.590	1023	DY	
30	15	1	ST08	1.000	0.0210	9045	DY	0.0002640	-31.289	1023	DY	
30	15	2	ST08	1.000	0.0000	1023	DY	0.0000000	-31.272	1023	DY	
32	16	1	ST08	1.200	0.0210	9045	DY	0.0002218	-36.971	1023	DY	
32	16	2	ST08	1.200	0.0000	1023	DY	0.0000000	-36.954	1023	DY	
34	17	1	ST08	1.400	0.0294	458	DX	0.0002207	-42.653	1023	DY	
*** MEMBER 502- 458 HAS LOCAL BUCKLING FAILURE AT SEGMENT 1												
35	17	1	ST08	1.400	2.2658	458	DX	0.0015949	-42.709	1023	DY	
36	17	2	ST08	1.400	1.4034	458	DX	0.0013677	-42.736	1023	DY	

FIGURE 11: Screenshot from log report pushover analysis

The above figure is the screen shot of the log report in a SACS pushover analysis. We take the value of design base shear in load case of storm load factor of 1.0 (blue box) and the failure base shear at load case exactly first member failure (red box). For every experienced wave height value, it has a different load case number for first member failure, but normally, for design base shear, it has same load case number which is 15. To get the RSR value, use the equation (13) above and repeat the analysis until we get the RSR of approximately 1.5 and 1.0.

3.6 Project Timeline -GANTT CHART

The following is a representation of the project time line throughout the Final Year Project, where the Key Milestones are highlighted out in the Gantt chart.

NUM	task	duration	WEEK1-2	WEEK3-4	WEEK5-6	WEEK7-8	WEEK9-10	WEEK11-12	WEEK 13-14	Sem break 2 week	WEEK 15-16	WEEK 17-18	WEEK 19-20	WEEK 21-22	WEEK 23-24	WEEK 25-26	WEEK 27-28
1	report progress				EXTENDED PROPOSAL		PROPOSAL DEFENSE		INTERIM REPORT					PROGRESS REPORT		DISSERTATION REPORT & VIVA	
2	Selection of FYP title																
	RESEARCH GATHERING PRELIMINARY STUDY																
3	Understanding of scope of project and review on references / amendment of scope of project, discussion with sv																
5	Understanding of tools (distribution function i.e. Gumbell Weibull,monte carlo simulation MATLAB																
6	enstablish load and resistance uncertainty model and its parameter (from response surface)																
	UNCERTAINTY MODELLING OF LOAD AND RESISTANCE																
9	Enviromental load for SACS, retrieving system base shear, RSR value and wave height, extrapolation																
10	MATLAB software -monte carlo simulation, determine probabilty of failure by using several distribution function form several papers to see the comparison of the result																
	EXTENDED RESEARCH ON BAYESIAN THEOREM / TRUNCATION METHOD																
12	Byesian updating probabilty of failureand extensive research on truncation method to find updating probabilty of failure																
14	Plotting of graph for reliability analysis and calibration of load factor																
	COMPILATION OF RESULT																
15	Analysing and discussion on findings /plotting graph																
16	Conclude and documentation of finding																

FIGURE 12: Gantt chart

3.7 Key Milestone

TABLE 5: Key Milestone for FYP II

PROPOSED WEEK	KEY MILESTONE
Week 1-3	Continuing research and reading, get familiar with MATLAB software
Week 4-6	Start drafting report, collecting and gathering research paper related to project through library website and SV. Understanding codes used in MATLAB, RSR analysis.
Week 6-7	Submission progress report (ACHIEVED). Research still ongoing
Week 8-10	Scope of study is getting narrower. Level of understanding is wider. Lots of discussion with SV and reading.
Week 11-13	Drafting dissertation. Preparing for Pre-SEDEX.
Week 13-14	VIVA presentation
Week 14	Submission Final report

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 Experienced Wave Height

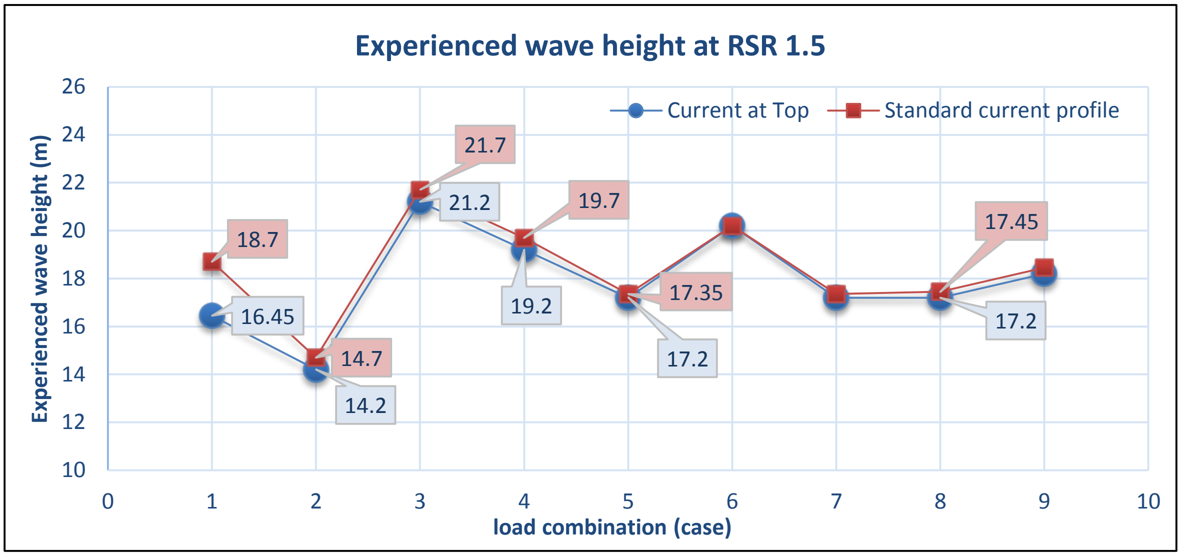

FIGURE 13: Comparison of wave height for two different current profile at RSR 1.5

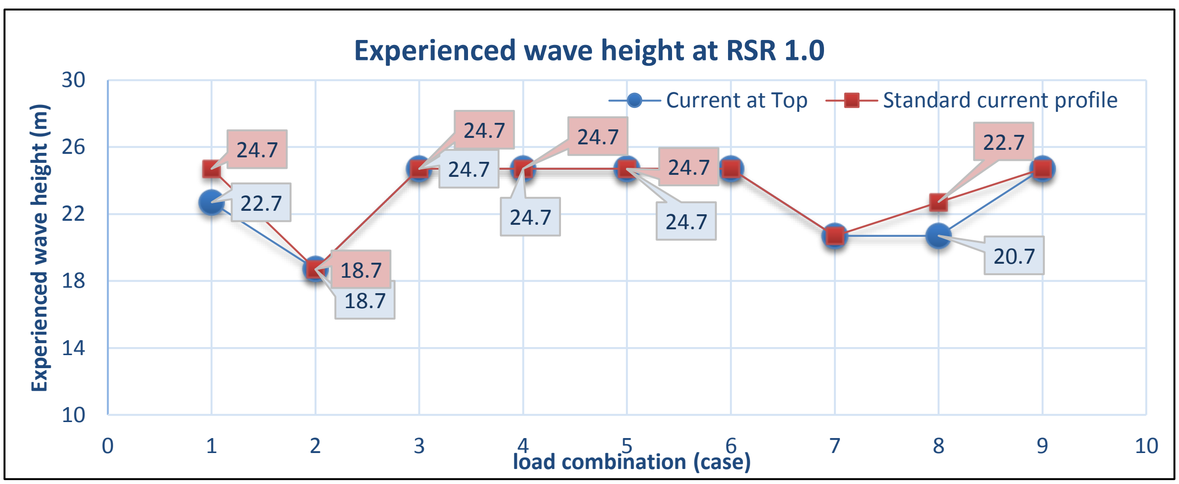

FIGURE 14: Comparison of wave height for two different current profile at RSR 1.0

In SACS analysis, the jacket platform is pushed till a desired displacement or collapse is obtained. The wave height is increased until the design base shear value is equal to the ultimate base shear, or RSR =1. From figure 13 above, it shows a comparison of experienced wave height at RSR 1.5 for two different current profiles. Current at top means that, all the current profile for every level, such as bottom, middle and top is set same as current on the top. In this case, the current velocity at the top is 1.20 m/s^{2}. In general, the experienced wave height for standard current profile (based on

API code) is higher in all cases compared to current at the top. For RSR 1.5, the highest wave height recorded during pushover analysis is 21.7m at case 3 (wave direction of 90 degrees). Based on figure 14, when the experienced wave height is increased more until achieved RSR 1.0, we can observe that, most of the cases have constant value which is 24.7m for both current profiles. Only in case 2 where it has slightly lower value of wave height correspond to RSR 1.0, which is 18.7m for both current profile as well.

In SACS analysis, the jacket platform is pushed till a desired displacement or collapse is obtained. The wave height is increased until the design base shear value is equal to the ultimate base shear, or RSR =1. To meet the requirement of the ISO code, the experienced wave height for RSR 1.5 is much lower than RSR 1.0 as shown. The wave height obtained is considered as experienced wave and is used to determine the probability of failure and survival which will be discussed later. In this pushover analysis, wind load value is set deterministic according to the code, and this analysis also is without considering the pile soil interaction. It much or less explain why we have higher values of experienced wave height of RSR 1.0 almost double than the design wave height or 1/3 of the depth of the water (94.6 meter).

4.2 Bayesian Method

RSR used in limit state function = 2.0, **Design wave height** = 11.7m, **Model uncertainty** (mean =1.0, COV =0.1 for resistance, COV =0.15 for load)

TABLE 6: Probability for RSR 2.0

Experienced wave height (m)	F9 (failure)			F9 (survival)			intercept	Bayesian Update probability of failure, Puf (X / Y)	log (Puf)
	No. simulation of failure P(G<0)	probability	Log (pf)	No. simulation of survival (x) P(F>0)	probability	Beta	simulation (y) P(G<0 ∩F>0)		
7	312	0.0000312	-4.50584540	10000000	1.0000000	inf	312	0.0000312	-4.505845406
8	293	0.0000293	-4.53313238	10000000	1.0000000	inf	293	0.0000293	-4.53313238
9	303	0.0000303	-4.51855737	10000000	1.0000000	inf	303	0.0000303	-4.518557371
10	296	0.0000296	-4.52870828	9999997	0.9999997	inf	295	2.95E-05	-4.530177854
11.7	300	0.0000300	-4.52287874	9999692	0.9999692	-4.4087	283	2.83009E-05	-4.548200188
12	324	0.0000324	-4.48945499	9999268	0.9999268	-3.7951	298	2.98022E-05	-4.525751944
13	341	0.0000341	-4.46724562	9992461	0.9992461	-3.1749	270	2.70204E-05	-4.568308698
14	331	0.0000331	-4.48017200	9946173	0.9946173	-2.5495	190	1.91028E-05	-4.718902408
15	312	0.0000312	-4.50584540	9735686	0.9735686	-1.9361	96	9.86063E-06	-5.006095325
16	275	0.0000275	-4.56066730	9110233	0.9110233	-1.348	48	5.2688E-06	-5.278288247
17	322	0.0000322	-4.49214418	7840592	0.7840592	-0.7871	21	2.67837E-06	-5.57212956
18	320	0.0000320	-4.49485002	6022706	0.6022706	-0.2599	8	1.32831E-06	-5.876701676
19	304	0.0000304	-4.51712641	4077199	0.4077199	0.332	4	9.81066E-07	-6.008301918
20	353	0.0000353	-4.45222529	2449912	0.2449912	0.0905	2	8.16356E-07	-6.088120489
21	313	0.0000313	-4.50445566	1329281	0.1329281	1.1124	1	7.52286E-07	-6.123616797
22	295	0.0000295	-4.53017798	665835	0.0665835	1.5023	0	0	#NUM!
23	348	0.0000348	-4.45842075	316197	0.0316197	1.8579	0	0	#NUM!
24	325	0.0000325	-4.4881166	144102	0.0144102	2.1859	0	0	#NUM!
25	294	0.0000294	-4.5316526	65019	0.0065019	2.4851	0	0	#NUM!

RSR used in limit state function = 1.5, **Design wave height** = 11.7m, **Model uncertainty** (mean =1.0, COV =0.1 for resistance, COV =0.15 for load) Monte Carlo simulation fixed at 1E+7.

TABLE 7: Probability for RSR 1.5

Experienced wave height (m)	F9 (failure)			F9 (survival)			Interception of simulation (y)	Bayesian Update probability of failure, Puf (X / Y)	log (Puf)
	No. simulation of failure P(G<0)	probability	Log (Pf)	No. simulation of survival (x) P(F>0)	probability	Beta	P(G<0 ∩F>0)		
7	91921	0.0091921	-2.03658526	9999998	0.9999998	inf	91919	0.009191902	-2.036594622
8	91873	0.0091873	-2.036812102	9999998	0.9999998	inf	91871	0.009187102	-2.036821470
9	92170	0.009217	-2.035410413	9999858	0.9999858	inf	92082	0.009208331	-2.035819089
10	92502	0.0092502	-2.033848877	9997977	0.9997977	inf	91754	0.009177257	-2.037287127
11.7	92195	0.0092195	-2.035292631	9907636	0.9907636	4.4087	80548	0.008129891	-2.089915281
12	91405	0.0091405	-2.039030047	9842981	0.9842981	-3.7951	75557	0.007676231	-2.114851941
13	91933	0.0091933	-2.036528568	9315635	0.9315635	-3.1749	55937	0.006004636	-2.221513293
14	91869	0.0091869	-2.036831011	8038200	0.8038200	-2.5495	33559	0.00417494	-2.379349797
15	91983	0.0091983	-2.03629243	6028915	0.6028915	-1.9361	16986	0.002817422	-2.550148041
16	92033	0.0092033	-2.036056421	3851748	0.3851748	-1.348	7416	0.00192536	-2.715488145
17	91362	0.0091362	-2.039234402	2114197	0.2114197	-0.7871	2953	0.001396748	-2.854882005
18	92539	0.0092539	-2.033675198	1027125	0.1027125	-0.2599	1114	0.001084581	-2.964738109
19	91992	0.0091992	-2.036249939	454612	0.0454612	0.332	399	0.000877672	-3.056668000
20	91737	0.0091737	-2.037455466	189422	0.0189422	0.0905	133	0.000702136	-3.153578777
21	91866	0.0091866	-2.036845193	76643	0.0076643	1.1124	57	0.000743708	-3.128597640
22	92062	0.0092062	-2.035919595	30568	0.0030568	1.5023	14	0.000457995	-3.339138989
23	92260	0.009226	-2.03498655	12165	0.0012165	1.8579	8	0.000657624	-3.182022126
24	92338	0.0092338	-2.034619536	5089	0.0005089	2.1859	4	0.000786009	-3.104572460
25	91994	0.0091994	-2.036240497	2124	0.0002124	2.4851	2	0.00094162	-3.026124517

Interpretation

From the result above, the probability of failure is determined by using two values of RSR at the limit state function which are 1.5 and 2.0. The value of design wave height used was 11.7m. From this available information, a random sample of 10^7 is generated and a simulation is run in MATLAB, in which a new model uncertainty of load and resistances in introduced, resulting a new load and resistance for every simulation. To determine the probability of failure based on Monte Carlo simulation, a cumulative failed simulation, (G<0) is divided by the total simulation to get the approximate value of failure probability. From the rough observation, it can be seen that, RSR 2.0 gives a lower value of failure probability which is within a range of 3.0 x 10^{-5} (-4.5 log value) compared to RSR 1.5 which is around 9.0 x 10^{-3} (-2 log value).

To determine the updating failure probability, we use a Bayesian theorem as per discussed in the methodology. This method was used by Ersdal 2003 and the updating probability has the same trend was observed in Ersdal study. By using a simple IF statement in MATLAB, we can loop the simulation in order to determine how many simulations that this tow function which are failure function denotes by G = R-L and survival function, F= R-W will fall into this condition, ($G<0 \cap F>0$). The code below will capture the interception of the simulation and when this value is divided by the total number of simulations that satisfying F>0 it will get the approximate update failure probability.

```
disp (sum(G<0));
disp (sum(B>0));

intercept = 0;

for i = 1:Nsim
    if(G(i)<=0 && B(i)>0)
        intercept = intercept+1;
    end
end

disp (intercept);
```

From the table, we also can observe that when the experienced wave is increasing, the number of intercept simulation is decreasing until it reach 0 at value of 25m wave height, where the condition is not valid anymore. Even though the RSR analysis is still in progress, but author confident enough that the RSR value of 1 will have a wave height around this range 20-25 m.

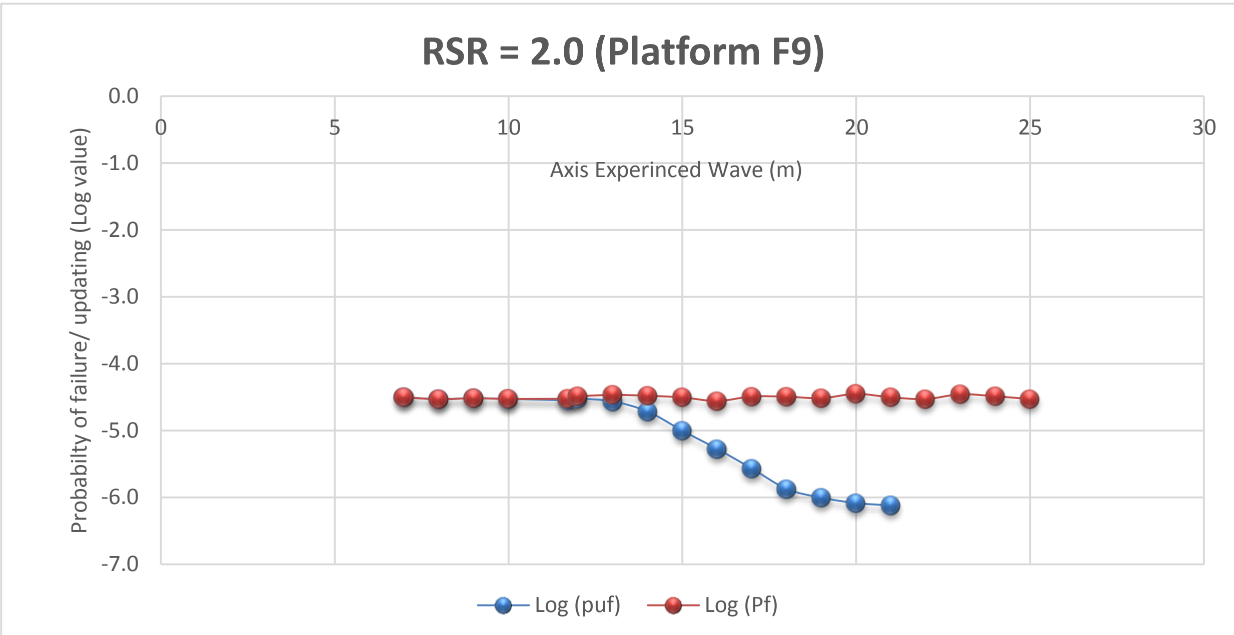

FIGURE 15: Graph of updated failure probability for RSR 2.0

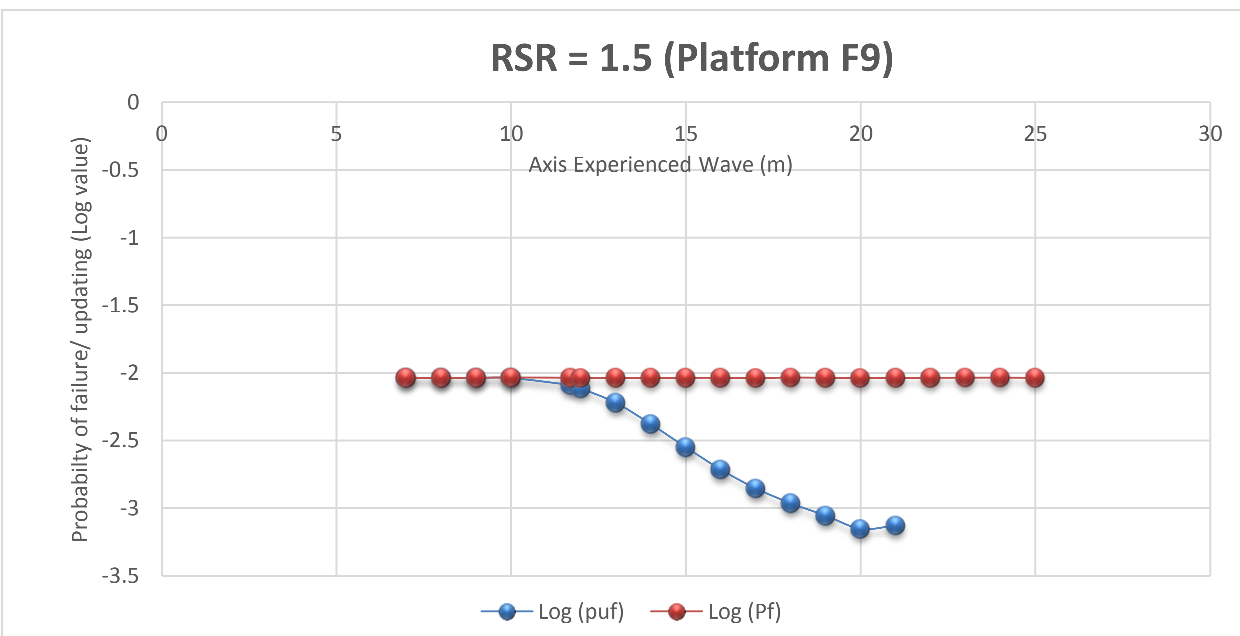

FIGURE 16: Graph of updated failure probability for RSR 1.5

Result of update probability of failure for RSR 2.0 and 1.5 is shown in figure 15 and 16. The graph shows that the update probability of failure is decreased when the experienced wave in increasing. It shows a significant decrement at the experienced wave load of 15m and above. The graph also shown that, when the experienced wave loading is equal or less than the design wave height, there are no significant changes in the probability of failure. The updating of failure is made to prove that, the jacket is able to resist a load at certain levels of experienced wave loading. When a value of RSR 2.0 is used, it shows an updated probability of failure much lower than RSR of 1.5.

4.3 Truncation Method

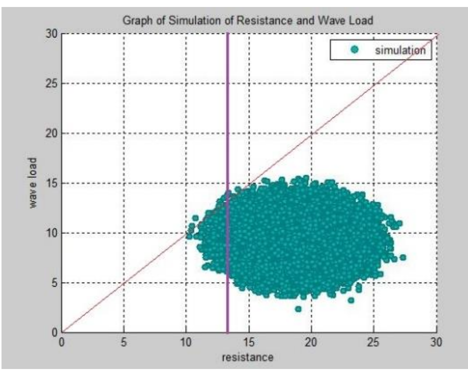

FIGURE 17: Original simulation

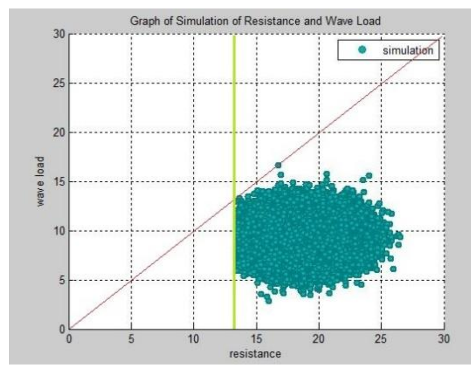

FIGURE 18: Truncation simulation

The above figures are the result from MATLAB simulations for truncation method. The truncation value for each run is different for every experienced wave height used. The resistance value that falls below the truncation line will be shifted to the other side and to be equalized with any random resistance value. Then, we re-run the simulation to get the new updating probability of failure by using the same limit state function as Bayesian method. Figure 17 shows the original simulation before the truncation is made. There are quite of number of simulation fall below the truncation limit. The first run of the simulation is just want to determine the average loading value (let say, z value) when experienced wave height is used from the RSR of 1.0 and 1.5 results from pushover analysis. Once we get the value, second run was done and set the lower limit of the resistance function at this z value. The figure 18 shows the distribution of the 2nd run after truncation was made. Modification of algorithm was made by using a simple if statement and looping to loop the simulation if the resistance value yield lower than the truncation limit.

The truncation value can be determined as table below:

TABLE 8: Probability of failure from truncation

experinced wave height (m)	failure probability (Truncation Method)			Updating probability of failure (Truncation Method)				
	No.simulation of failure P(G<0)	probability	Log (pf)	truncation resistance value (truncate at mean load value at experinced wave)	no. of truncated simulation	no.of re-simulation of failure P(G<0)	probability	log (pf)
7	329	0.0000329	-4.482804102	5.2028	0	329	0.0000329	-4.482804102
8	300	0.00003	-4.522878745	5.9345	0	300	0.00003	-4.522878745
9	330	0.000033	-4.48148606	6.7503	0	330	0.000033	-4.48148606
10	337	0.0000337	-4.472370099	7.6522	0	337	0.0000337	-4.472370099
11.7	319	0.0000319	-4.496209317	9.3772	4	316	0.0000316	-4.500312917
12	325	0.0000325	-4.488116639	9.7065	11	319	0.0000319	-4.496209317
13	306	0.0000306	-4.514278574	10.861	122	280	0.000028	-4.552841969
14	332	0.0000332	-4.478861916	12.0995	1912	208	0.0000208	-4.681936665
15	327	0.0000327	-4.485452247	13.424	22719	78	0.0000078	-5.107905397
16	333	0.0000333	-4.477555766	14.8328	182152	8	0.0000008	-6.096910013
17	318	0.0000318	-4.49757288	16.327	977172	0	0	#NUM!

The table above shows the design probability of failure and the updating probability of failure at different experienced wave height. The number of failure simulation (G<0) is constant and design probability of failure is almost the same because we are only considering design wave height in load and resistance function. When updating was made, we can see that for every experienced wave height used, it has different truncation resistance value and its increases when the experienced wave height is increased. When the experienced wave height is equal to the design wave height (in this case is 11.7m) and below, we can observed that, the truncated simulation is zero, means that, no resistance function value is lesser than the truncation value. But when the experienced wave height is higher than the design value, the number of truncated simulations is slowly increasing and it means that, there is some resistance value that less than the truncation value. Once the random realization was made for all the truncated value, we re-run again the analysis to determine the new probability of failure. The number of simulations of failure has somehow decreased when the experienced wave height higher than the design. The trend is same as the Bayesian method earlier. From that, we able to determine the updating probability of failure by dividing the failure simulation after truncation with the total simulation and plot the graph to compare with the design probability of failure as shown below. Updating based on truncation has much less effect on the probability of failure.

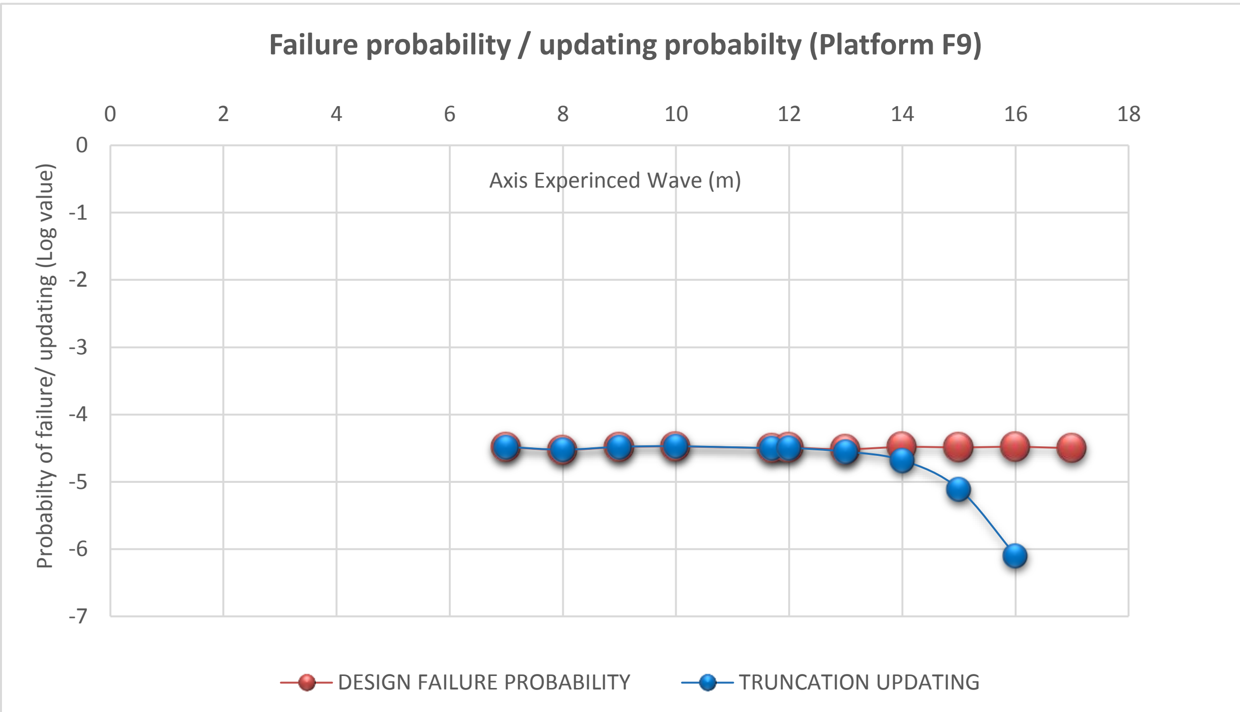

FIGURE 18: graph updating probability of failure based on truncation

Updating based on truncation has much less effect on the probability of failure. The updating is only applied to the resistance distribution. When the experienced wave is reach 15m, the updated probability is start decreasing significantly.

4.4 Sensitivity Analysis of Coefficient of Variation (COV)

TABLE 9: RSR and COV variation

RSR value	COV of load uncertainty	Probability of failure	log (Pf)
1.0	0.1	0.4997000	-0.3012907
1.5		0.0028000	-2.5528420
2.0		0.0000042	-5.3767507
2.5		0.0000000	inf
1.0	0.15	0.4997000	-0.3012907
1.5		0.0092000	-2.0362122
2.0		0.0000339	-4.4698003
2.5		0.0000001	-7.0000000
1.0	0.2	0.44980000	-0.3469805
1.5		0.02280000	-1.6420652
2.0		0.00020590	-3.6863437
2.5		0.00000008	-7.0969100
1.0	0.25	0.5002000	-0.3008563
1.5		0.0432000	-1.3645163
2.0		0.0009060	-3.0428718
2.5		0.0001330	-3.8761484

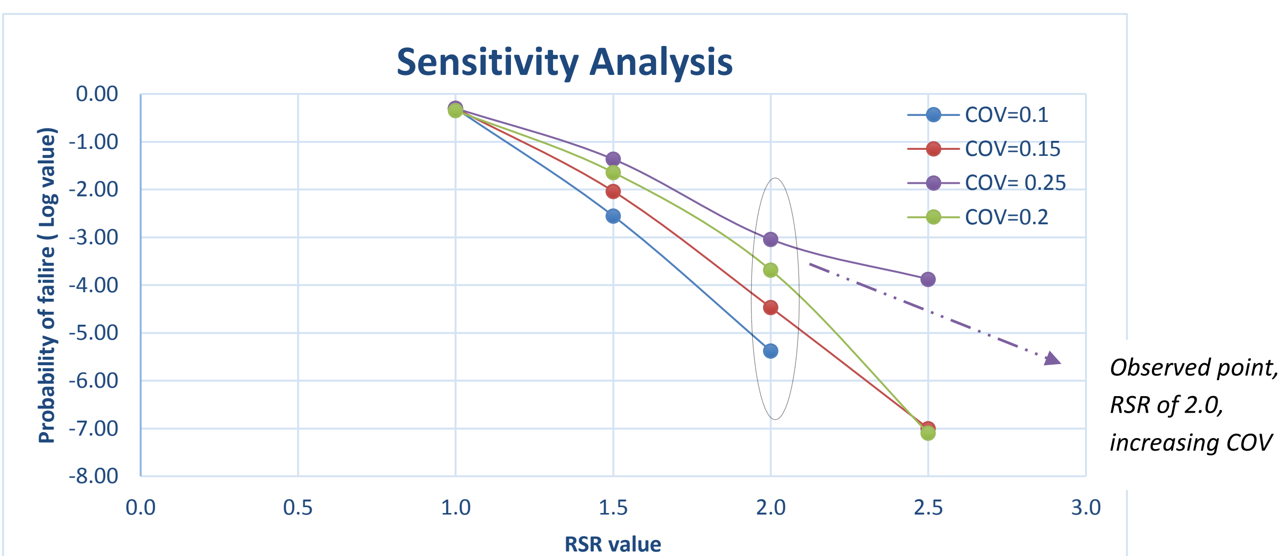

FIGURE 20: Graph of failure probability with respect to COV variation

In this study, the structure is evaluated at RSR value of1.5 and 2.0 and the coefficient of model uncertainty is normally distributed with mean value of 1.0 and a COV of 0.1 for resistance and 0.15 for load as recommended [2][6]. A certain range of COV of load model uncertainty between 0.1 to 0.25, and RSR value at range of 1.0-2.5 is evaluated to see the changes in failure probability.

At COV of 0.1, the probability of failure is decreasing when the RSR value is increasing. The risk of the platform to fail become lower at high RSR value due to the wave height strike the platform is within the safe design. The higher the RSR, the lower the yield wave height. If we analyze in other perspective, at fixed RSR value let say, 2.0 the failure of probability also is decreasing when the COV value is increasing.

CHAPTER 5

5.0 CONCLUSION

Author able to determine the failure probability and updated the structural failure probability based on experienced wave loading for one jacket platform, F9. The aim of this analysis to determine the reliability of the structure when the structure has experienced a wave height of RSR 1 from the SACS push over analysis. When this structure able to withstand with this load without any major damage, the level of confidence of this structure is increased. In order to prove the safety of this structure, the design probability of failure is to be checked in the code of standard. The code of practice requires 10,000 years of return period of environmental load or probability of failure of 10^{-4} or wave height corresponds to RSR 1.5 for the assessment and extension of life.

Based on the result, RSR value used in limit state function in 1.5 has a failure probability of 9.0 x 10^{-3} in which higher than the desire by the code of standard. A minimum RSR value of 2.0 has a failure probability of 3.0 x10^{-5} and can be given extension of life. When updating was made using Bayesian method, the platform also is considered as safe as the updated failure of probability value is much lower, approximate 1 x 10^{-5} to 1 x10^{-7}. When the experienced wave load reaches 15 m and above, it shows a significant decrement of failure probability when the updating was made. For RSR of 1.5, the updated failure probability only reach 1 x 10^{-4} when the experienced wave height is around 20m. Updating based on truncation has much less effect on the probability of failure. The updating is only applied to the resistance distribution. When the experienced wave reaches 15m, the updated probability is starting decreasing significantly.

The different COV values of the uncertainty load model give different values of failure probability. In this study, the range of COV value used is varied within a range of 0.1-0.25. At fixed RSR of 2.0, when the COV becomes higher, the probability of failure becomes lower. At COV of load model of 0.1 and RSR of 2.0, it shows a failure probability of 1 x 10^{-6}, means it is already considered safe according to the standard code without requiring an updating.

As a conclusion, when updating was made using Bayesian and the truncation method at experienced load level, the probability of failure of jacket platform is decreasing and meet the requirement of the ISO 19902 code and proven for extension of life.

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