A RELIABILITY ANALYSIS OF A MALAYSIA JACKET PLATFORM

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Dedicated to my beloved family and Bernard for their unfailing support…

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ABSTRACT

After several decades of development, structural reliability technologies are maturing and becoming one of the essential assessment and design tools in the offshore industry. The objective of the thesis is to quantify the level of structural reliability of the jacket structure in the Malaysia waters. Offshore structural reliability analyses are dependent upon the environmental loads assumed to act on the structure. The modeling of environmental loading is based on the wave climate of Malaysia waters. The joint probability density function for the significant wave height and spectral peak period is modelled. Response of the structure under environmental loading was investigated by using the time domain simulation. Necessary simulation time steps are established. Interaction ratios of the members were computed based on the API RP2A-WSD to determine the level of stress utilisation of the members. From here, critical members of the jacket structure were identified. The probability failure of the critical members and other structural members of interest was determined by using the Hasofer and Lind reliability index. The fluctuation in loads and variation material properties were accounted in the assessment. For many cases failure of one component will not results in the collapse of the whole structure. Thus, system reliability analysis was carried out by using the pushover method. The system was modeled as series of parallel sub-system and the reliability of the system was evaluated by using the simple bound. The failure path of the structure was identified. Deterministic system effects of the structure were analyzed to study the redundancy of the structure, which were quantified by the reserve strength and the damage tolerance ratio. From here, the level of reliability of the jacket structure is quantified, and it serves as a reference for the evaluation of reliability-based design of jacket structures in Malaysia waters.

ABSTRAK

Setelah melalui beberapa dekad, bidang keboleharapan struktur telah berkembang dengan pesat. Ia bukan sahaja menjadi satu takat penilaian keselamatan struktur tetapi telah menjadi satu teknik rekabentuk yang penting dalam bidang kejuruteraan luar pantai. Objektif kajian ini, adalah untuk menyelidik tahap keboleharapan struktur luar pantai yang terletak di perairan Malaysia. Dalam kajian keboleharapan struktur luar pantai, pembebanan alam sekitar yang dikenakan ke atas struktur merupakan salah satu faktor utama yang perlu diberi pertimbangan yang sewajarnya. Dalam kajian ini, sumber-sumber pembebanan alam sekitar yang dimodel adalah bergantung kepada keadaan cuaca di luar pantai Malaysia. Taburan kerangkalian bergabung untuk ketinggian ombak and tempoh puncak ombak dimodelkan. Dari sini, respons struktur semasa pembebanan alam sekitar dinilai dengan menggunakan simulasi berorientasikan masa. Tempoh simulasi yang optimum ditentukan. Dari analisis tegasan, unsur-unsur yang kritikal dikenalpasti. Untuk tujuan ini, nisbah kadar tegasan telah dikira dengan menggunakan kod API RP2A-WSD untuk mengukur kadar penggunaan tegasan. Unsur-unsur kritikal yang telah dikenalpasti, kemudian digunakan untuk analisi keboleharapan struktur. Kebarangkalian kegagalan dikira dengan menggunakan Indeks Keboleharapan Hasofer dan Lind. Selain unsur yang kritikal, unsur lain yang penting juga dinilai keboleharapannya. Variasi pembebanan dan ciri-ciri bahan juga diambil kira dalam analisis ini. Dalam kebanyakan kes, kegagalan satu elemen tidak akan menyebabkan kegagalan seluruh struktur, maka analisi keboleharapan perlu dijalankan untuk mengkaji tahap keboleharapan seluruh sistem struktur luar pantai berikut. Keboleharapan sistem dijalankan dengan menggunakan teknik peningkatan beban berperingkat sehingga seluruh struktur tersebut gagal. Maka aturan kegagalan struktur dapat dikenalpasti. Kemudian, sistem tersebut telah dimodel dengan mengunakan sistem selari yang terdiri daripada sub-sistem sesiri. Keboleharapan sistem tersebut dinilai dengan menggunakan teknik had mudah. Selain itu, kesan sistem boleh-tentu juga dijalankan untuk mengkaji kebolehan struktur tersebut bertahan apabila kegagalan berlaku dari segi tegasan baki dan nisbah kerosakan. Dari analisi ini, takat keboleharapan struktur luar pantai di Malaysia boleh dianggarkan, maka keputusan yang diperoleh dapat dijadikan sebagai rujukan untuk aplikasi rekabentuk struktur luar pantai yang berdasarkan konsep koboleharapan.

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LIST OF SYMBOLS

A	-	Wave amplitude
A_I	-	Frontal area for inertia coefficient
A_D	-	Frontal area for drag coefficient
A	-	Area
BS	-	Base Shear
a_k	-	Magnitude of one sided JONSAWP spectrum
c	-	Celerity
C_M	-	Inertia Coefficient
C_D	-	Drag Coefficient
C_S	-	Shape Coefficient
d	-	Water depth
D	-	Diameter
D_L	-	Nominal dead load
DTR	-	Damage tolerance ratio
E	-	East
f	-	Force per length
f_a	-	Output of axial stress generated from Ansys V.6.0
f_b	-	Output of bending stress generated from Ansys V.6.0
F_y	-	Yield strength
F_b	-	Allowable bending stress
F	-	Total force
g	-	Gravitation acceleration
$g<0$	-	Failure state
$g(X_1, X_2, ..., X_n)$	-	Limit state function
H	-	Wave height
$H_{1/3}$	-	1/3 of wave height

$H_{1/10}$	-	1/10 of wave height
H_{max}	-	Maximum wave height
H_s	-	Significant wave height
k	-	Wave number
K	-	Kuelegan-Carpenter number
L	-	Wave length
L_L	-	Nominal live load
m_{Ymax}	-	Mean value of mean maxima
MWL		Mean Water Line
N( )	-	Normal distribution
N	-	North
Nss	-	Number of sea-state realisation
Nss_{req}	-	Number of sea-state (simulation) required
n	-	Total data
OTM	-	Overturning moment
P	-	Probability of failure
P_o	-	Probability of occurence
R	-	Resistance
Re	-	Reynolds number
R_N	-	Nominal resistance
RIF	-	Residual resistance factor
RSR	-	Reserve strength ratio
R_u	-	ultimate lateral load capacity of platform
s	-	Total wave elevation (from mean water line to sea bed)
S	-	Loading
S_N	-	Nominal loading
S_R	-	reference lateral loading
$S_w(\omega)$	-	Sea surface spectrum
$S_F(\omega)$	-	Force spectrum
t	-	time
T	-	Wave Period
T_{min}	-	Minimum time interval
T_p	-	Spectral peak period

T_r	-	Return period
T_Z	-	Zero crossing period
U	-	Uniform wind velocity
u	-	Horizontal water particle velocity
U_{TS}	-	Surface current velocity
U_{TZ}	-	Current velocity at any depth
v	-	Vertical water particle velocity
V_{Ymax}	-	Covariance of the maximum response in a single sea-State
$V_{\eta max}$	-	Covariance of maximum wave crest elevation
W_L	-	Nominal environmental load
x	-	distance of wave propagation along x-axis
X_i	-	Discretized wave history
X_R	-	Modeling accuracy for resistance
X_S	-	Modeling accuracy for loading
y	-	Wave elevation
Y(y)	-	Wave crest elevation function
$\overline{Y_{\max}}$	-	Mean maxima estimate
$Y_{\max_{mean}}$	-	Mean maxima response generated from the Weibull 3-parameter
Z	-	Failure surface
z	-	Elevation of wind speed
z_R	-	One hours mean speed at the elevation of 10m
z_S	-	One hours mean speed at the elevation of 20m
$\Lambda(\alpha)$	-	Periodicity function
$\overline{\alpha}$	-	unit normal vector
β	-	Reliability Index
Φ	-	Partial resistance factor
$\Phi(\ )$	-	Standard normal probability
ϕ	-	Potential function
γ_D	-	Load factor for dead load
γ_L	-	Load factor for live load
γ_W	-	Load factor for environmental effects

γ	-	Peakedness parameter
λ	-	Wave length
η	-	Vertical water particle acceleration
η_h	-	Transition point for LONOWE model
η_p	-	Wave profile
$\eta(t)$	-	Gaussian wave elevation
η_{max}	-	Crest height
ρ	-	Mass density of water
ρ_a	-	Density of air
μ_R	-	Mean of resistance
μ_S	-	Mean of loading
μ_Z	-	Mean of failure function
$\mu_{T\|H}$	-	Mean spectral peak period given significant wave height
ω	-	Wave frequency (in radian)
ω_k	-	Circular frequency
σ_R	-	Standard deviation of resistance
σ_S	-	Standard deviation of loading
σ_Z	-	Standard deviation of failure function
$\sigma_{\overline{Y\max}}$	-	Standard deviation of mean maxima
$\sigma_{T\|H}$	-	correlation coefficient between the significant wave height and the zero crossing period
θ	-	Wave phase angle
θ_k	-	Random phase
ξ	-	Horizontal water particle acceleration

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter discusses on the overview of the thesis. It gives a brief introduction to the title, research objectives, scopes of study and the thesis organization.

1.2 Problem Background and Motivation

The field of offshore structural reliability analysis is of particular importance at the present, considering that a number of changes that are taking place within the offshore industry. The changes include the introduction of the Load Resistance Factor Design Code (API-RP 2A LRFD, 1993) and the ISO developments. There is also an increasing appreciation within the industry of the potential benefits from the use of these techniques especially after the applications in the area of optimized inspection planning (Onoufriou, 1999). Apart from that, the introduction of goal setting regime that allows more flexibility in the way offshore platforms are design and assessed has also proliferated the reliability based assessment.

The above mentioned changes and the increasing need to address life cycle planning issues such as the Inspection, Maintenance and Reliability (IMR) planning have created a wider acceptance framework for reliability assessment methods. A number of developments in the area of reliability analysis and the increasing hardware capacity make the use of these techniques more feasible at the various stages of the life of a platform.

Although there is an increasing recognition within the industry of the significant potential safety and cost benefits from the application of offshore structural reliability analysis, there is varying degree of confidence in the methods due to the various uncertainties in this type of analysis. Moreover, the outcome of the analysis is highly dependent upon the user competency and the assumptions made. It is generally recognized that structural problems are often nondeterministic. Moreover, structures are designed and built despite imperfect information and knowledge. In short, problems of structural design must be resolved in the face of uncertainty and as a consequence, risk, which is the probability an adverse event that will occur. In order to quantify the risk, random variables such as the loadings and resistance of a structure pertaining to the limit state have to be determined.

The research in the field of offshore structural reliability is still in its stage of infancy in Malaysia compare to the countries in Europe or United States. Though the advancement of the reliability analysis has reach to a level of maturity, the published results of the application of reliability analysis on the offshore structures in Malaysia is scarcely available.

In reliability assessment, few issues have to be addressed, such as the loading probabilities, variation in the resistances and the methodology adopted in the analysis. In the loading probabilities, environmental loading is the main concern due to its randomness. In order to capture the randomness, the evaluation of environmental loading has moved from the deterministic approach to the probabilistic approach by adopting the joint environmental model. These models are well established in the Gulf of Mexico and the North Sea, where extensive database on the oceanographic condition are at disposable. However, the weather in the Malaysia waters is rather calm and not as extreme as the weather in Gulf of Mexico or North Sea. Therefore the application of the models which are developed in other region will results in the over-design of the offshore structure. French *et al*. (1992) has noted that the design environmental criteria for the platforms in South East Asia are usually increased, in some cases by as much as 60% during the life of the platform due to the scarcity of data during the construction of the platforms. Therefore there is a need to formulate the design criteria of the environmental design parameters for a specific location to ensure that the structures built are safe and economical.

Compared to the loading properties, the issue of variation in the structural resistance is inconsequential as study has proven that the resistance can be treated deterministically in structural analysis without affecting the results enormously (Sigurdsson, *et al*., 1994). However, the methodology which is adopted in the reliability assessment plays an important role in determining the results of the analysis as different methods produce different results. Major development in structural reliability methodology started in the sixties to develop the tools for quantifying the effects of uncertainties. At present, there are many methods that are well developed to assist the calculation of structural reliability. For component reliability analysis, methods such as First Order Reliability Method (FORM) and the Second Order Reliability Method (SORM) are widely used for the assessment. While for structural system reliability analysis, the method ranges from the component based approach to the more complex one such as the full probabilistic analysis. Among the well-known theory, which are formulated for the system analysis are the branch and bound method and the beta unzipping method (Thoft-Christensen and Murotsu, 1986). The selection of method depends on other factors such as internal and external constraint. Internal constraint would be the uncertainties associated with the data, while the external constraint would be the expertise of the analyst and the availability of computational tools. Consequently, each case is unique and the methodology adopted has to be based on the needs of the case study and the resources that are available.

Based on the above background, the research problems covered within this thesis are summarised as follows;

i. What are the design environmental criteria for the offshore structures in the Malaysia waters by accounting the randomness of the loadings?
ii. How reliable is the offshore structure that is built in the Malaysia waters?
iii. For the present case study, what is the best method to be adopted considering the limited resource in data and computational efforts?

1.3 Research Objectives

The research objectives are as follows:

- To determine the environmental loading conditions at the location of the jacket structure.
- To study the response of the jacket structure under environmental loadings, i.e. wave, wind and current.
- To identify the critical members in the jacket structure.
- To investigate the level of reliability of the offshore structure in Malaysia's waters.

1.4 Scope of Study

The scopes of work were divided into three parts. The platform which was used in this study is assumed to be a new platform, not in service conditions. Therefore deterioration of the platform was not considered. It checked the soundness of the design of the structure from the reliability point of view.

The first part focused on the modelling of environmental parameters. The environmental loading condition is modelled based on the met-ocean data obtained for the Malaysia waters. Modelling works were carried out to predict the extreme condition of the ocean weather. The environmental parameters considered in the modelling work were the wave and wind loading.

In the second part, the scope of work focused on the response of the structure under environmental loading conditions. The environmental loads are imposed on the structure. The simulations studies are carried out in the dynamic, time domain analysis by taking into account of the probabilistic fluid loading by using a Finite Element Software, ANSYS. From the simulations, the critical members are identified and the utilisation ratios of the structural members are calculated.

The final part of the study focused on the reliability analysis of the structure. A reliability program is written in Matlab to study the probability failure of the critical members and other members of interest. Parametric investigations are carried out to study the effects of the environmental loadings on the structural members. From the component reliability analysis, the study proceeds to the system reliability analysis. The probability failure of the structure is investigated. The system effects analysis are also included, to study the level of redundancy of the structure.

1.5 Thesis Organisation

This thesis consists of eight chapters proceed by the introductory chapter. Chapter Two contains the reviews on the related literature and theories pertaining to reliability analysis. The development of reliability assessments, theories and the applications in the offshore industry are expounded concisely. In addition to the review of reliability analysis, theories of wave loading and structural analysis are also discussed to give a clearer picture on the analysis of offshore structures.

Chapter Three discusses on the modeling work of the environmental parameters where the platform is located. The modelling works are presented with the theories of joint probabilities, bivariate distributions and the theory of design wave. The design environmental parameters, which are determined and applied in the structural analysis

Chapter Four presents the response of the structure under environmental loading conditions. The methodology and theories which are adopted are discussed. Comparisons are made on the results based on the methodologies adopted. Results from the structural simulation studies and the utilisation ratio of critical members are presented.

The component reliability analysis is presented in Chapter Five. The chapter begins with the discussion on the methodology which are adopted, the loadings and the resistance parameters. The details on the computation of the reliability index are discussed thoroughly. The chapter is concluded with the presentation of results and general discussion.

Chapter Six focuses on the system reliability of the structure. The failure path of the structure is identified for every direction and this forms the system reliability of the structure by using the series of parallel sub-system. The chapter documents the steps and theory adopted in the analysis. Apart from this, it contains brief discussion on other methodologies, which are adopted by other researchers. The chapter is concluded with the studies on the system effects on the redundancy of the structure.

Chapter Seven encapsulates the work and the general discussion of the whole thesis. It compares the results, which are obtained with the findings of other researchers.

Finally the thesis is concluded with the final chapter, the conclusion, which comprises of the summary of the works and recommendations for further research.

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