DERIVATION OF EXTREME NON-GAUSSIAN STOCHASTIC OFFSHORE STRUCTURAL RESPONSES USING FINITE MEMORY NONLINEAR SYSTEM

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DEDICATION

My sincere thanks to Allah and to my family, especially my husband, Zulhilmi Abdullah, my daughter, Zulaikha Zulhilmi and my parents for their continuous support and encouragement. Special thanks also to my colleagues as well as all my friends whose help and support has allowed me to complete this research successfully. Thank You

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ABSTRACT

For offshore structural design, the load due to wind-generated random waves is usually the most important source of loading. A nonlinear wave analysis is recommended to represent a realistic ocean wave for an accurate prediction of extreme offshore structural response. Nevertheless, the contribution of nonlinearity especially due to the wave-wave interaction leads to a complex solution. In fact, the random wave load itself experienced a nonlinearity due to the drag component of Morison's load, the effect of load intermittency around the member in the splash zone, and the presence of current; which result in a non-Gaussian offshore structural response. The most accurate and versatile method for predicting the statistical properties of extreme responses on a subjected load is the Monte Carlo time simulation method, which can account for all sorts of nonlinearities without introducing any approximations. However, it is computationally very demanding due to its complex procedure in simulating the structural response as reliable results require a very large number of simulations. Therefore, a simple method using finite-memory nonlinear system (FMNS) has been introduced by previous researchers and is proven to improve the efficiency of evaluating offshore structural responses without sacrificing its accuracy. The method is, however, only applicable based on the linear wave analysis. Hence, by taking advantage of the efficiency of FMNS method, a new model needs to be developed by integrating the FMNS method with a nonlinear wave analysis for a more reliable result. It is the derivation of non-Gaussian stochastic offshore structural response using finite-memory nonlinear system, known as FMNS_{NL} (subscript *NL* indicates nonlinear). In the model development process, the surface elevation is generated first according to a nonlinear wave analysis with at least second-order wave. Then, two components of system are introduced, in which the first component enabled the transformation from a reference surface elevation to a second-order linearized quasi-static responses, while the second component involved the development of nonlinear function based on the relationship of second-order nonlinear and linearized quasi-static responses. Four models have been developed, in which the best model can produce an output of approximate values of second-order nonlinear quasi-static response that is very close to its corresponding values obtained using Monte Carlo time simulation method and will then be used for further examination. Based on the correlation coefficient between those two methods, the best relationship with value of 0.9783 was obtained by model 4 on the drag-induced quasi-static base shear for high significant wave height. The procedure of model development based on those two components is examined for all sea state conditions with H_s = 5, 10 and 15 m, and with the presence of current, $\overline{U}$= 0 m/sec and ±0.90 m/sec. As a result, the relationship of model 4 fits the data better for all cases. It should be noted that this investigation of in-service analysis is carried out only for quasi-static structure by neglecting the dynamic effect. Based on the result of the short-term analysis, FMNS_{NL} method provided a good accuracy of prediction of 100-year responses compared with the corresponding prediction using Monte Carlo time simulation method for all cases. A comparison has been made according to the ratio of prediction between FMNS_{NL} and Monte Carlo time simulation methods. Overall, the accuracy level achieved by FMNS_{NL} method is in the range of 82% to 99.8%, in which the accuracy level improved with the presence of positive current and vice versa with negative current. The same conclusion is valid for long-term analysis since the accuracy performance of FMNS_{NL} followed exactly as previous analysis for short-term distribution. Without the presence of current along the wave propagation, the accuracy level of FMNS_{NL} method is in the range of 80% to 96%. If there exist a current with the same direction of the wave (positive current), the accuracy improved with an increment of 1% to 7%. However, the opposite direction of current (negative current) provided a severe impact on its prediction with a reduction of 1% to 18% of accuracy. Hence, the method of FMNS_{NL} can then be used with an excellent efficiency and accuracy to determine the extreme offshore structural response. With that, the offshore structure is towards optimization that leads to cost reduction and preservation of safety.

ABSTRAK

Bagi reka bentuk struktur luar pesisir, beban akibat gelombang rawak yang dijana oleh angin biasanya merupakan beban yang paling utama. Analisis gelombang ketaklelurusan disyorkan untuk mewakili gelombang lautan yang sebenar untuk ramalan tepat mengenai tindak balas struktur luar pesisir yang paling tinggi. Namun begitu, analisis gelombang yang bersifat ketaklelurusan disebabkan oleh interaksi antara gelombang membawa kepada penyelesaian yang kompleks. Sebenarnya, beban gelombang rawak itu sendiri mengalami ketaklelurusan kerana komponen seretan di persamaan Morison, kesan beban terputus di zon permukaan air, dan kehadiran arus; yang menghasilkan tindak balas bersifat bukan Gaussian. Teknik yang paling tepat dan serba boleh untuk meramalkan tindak balas statistik yang paling tinggi pada beban yang dikenakan adalah teknik simulasi masa Monte Carlo yang dapat menjelaskan segala macam beban yang bersifat tak lelurus tanpa memperkenalkan perkiraan. Walau bagaimanapun pengiraannya sangat rumit kerana prosedurnya yang kompleks dalam mensimulasikan tindak balas struktur disebabkan jumlah simulasi yang sangat besar diperlukan bagi mendapatkan keputusan yang tepat. Oleh itu, kaedah yang mudah dengan menggunakan sistem tak lelurus ingatan terhingga (FMNS) telah diperkenalkan oleh penyelidik terdahulu, dan terbukti dapat meningkatkan kecekapan menilai tindak balas struktur luar pesisir serta menjamin ketepatannya. Akan tetapi kaedah tersebut hanya diaplikasikan berdasarkan analisis gelombang lelurus. Oleh itu, dengan memanfaatkan kecekapan kaedah FMNS, model baru perlu dibentuk dengan mengintegrasikan kaedah FMNS dengan analisis gelombang bersifat ketaklelurusan untuk hasil yang lebih sahih. Ini adalah hasil tindak balas struktur luar pesisir bukan Gaussian menggunakan sistem tak lelurus ingatan terhingga yang dikenali sebagai $FMNS_{NL}$ (simbol *NL* merujuk kepada ketaklelurusan). Dalam proses membentuk model, ketinggian permukaan air dijana terlebih dahulu mengikut analisis gelombang ketaklelurusan dengan sekurang-kurangnya gelombang tertib kedua. Kemudian, dua komponen sistem diperkenalkan di mana komponen pertama membolehkan transformasi dari ketinggian permukaan air ke tindak balas statik tertib kedua yang lelurus, manakala komponen kedua melibatkan pembentukan fungsi tak lelurus berdasarkan hubung kait tindak balas statik tertib kedua yang tak lelurus dengan yang lelurus. Empat model telah dibentuk, di mana model terbaik dapat menghasilkan hasil dari tindak balas statik tertib kedua tak lelurus yang paling hampir dengan nilai yang diperoleh menggunakan kaedah simulasi Monte Carlo dan seterusnya akan digunakan untuk uji kaji selanjutnya. Berdasarkan pekali korelasi antara kedua-dua kaedah tersebut, nilai 0.9783 diperoleh oleh model 4 pada tindak balas statik daya ricih yang disebabkan oleh seretan untuk gelombang signifikan yang tinggi. Prosedur pembentukan model $FMNS_{NL}$ berdasarkan kedua-dua komponen tersebut telah dijalankan untuk semua keadaan laut dengan H_s = 5, 10 dan 15 m, dan dengan kehadiran arus, $\overline{U}$= 0 m/saat dan ± 0.90 m/saat. Hasilnya, korelasi model 4 lebih sesuai dengan data untuk semua keadaan. Perlu diingat bahawa penyelidikan analisis dalam perkhidmatan ini hanya dilakukan untuk struktur statik dengan mengabaikan kesan dinamik. Berdasarkan hasil analisis jangka pendek, kaedah $FMNS_{NL}$ memberikan ketepatan ramalan yang baik untuk tindak balas 100 tahun berbanding dengan ramalan yang sama menggunakan kaedah simulasi Monte Carlo untuk semua keadaan. Perbandingan telah dibuat mengikut nisbah ramalan antara kaedah simulasi $FMNS_{NL}$ dengan Monte Carlo. Secara keseluruhannya, tahap ketepatan yang dicapai dengan kaedah $FMNS_{NL}$ berada dalam lingkungan 82% hingga 99.8%, di mana tahap ketepatan bertambah baik dengan kehadiran arus positif dan sebaliknya dengan arus negatif. Kesimpulan yang sama dapat dibuat untuk analisis jangka panjang kerana tahap ketepatan kaedah $FMNS_{NL}$ adalah sama seperti analisis sebelumnya untuk pengagihan jangka pendek. Tanpa kehadiran arus sepanjang penyebaran gelombang, tahap ketepatan kaedah $FMNS_{NL}$ berada dalam lingkungan 80% hingga 96%. Sekiranya wujud arus dengan arah gelombang yang sama (arus positif), ketepatannya bertambah dengan kenaikan 1% hingga 7%. Walau bagaimanapun, arah arus yang berlawanan (arus negatif) memberi impak yang teruk terhadap ramalannya dengan pengurangan ketepatan 1% hingga 18%. Oleh itu, kaedah $FMNS_{NL}$ boleh digunakan dengan kecekapan dan ketepatan yang sangat baik untuk menentukan tindak balas struktur luar pesisir yang ekstrem. Dengan itu, struktur luar pesisir menuju ke arah pengoptimuman yang membawa kepada pengurangan kos dan pemeliharaan keselamatan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

API	-	American Petroleum
BS	-	Base Shear
DFT	-	Discrete Fourier Transform
ETS	-	Efficient Time Simulation
ETU	-	Efficient Threshold Upcoming
FFT	-	Fast Fourier Transform
FMNS	-	Finite-memory Nonlinear System
FORM	-	First Order Reliability Method
FOSM	-	First Order Second Moment
GDP	-	Gross Domestic Product
GNI	-	Gross National Income
ISO	-	Industrial Standardized Organization
JONSWAP	-	Joint North Sea Wave Project
LHS	-	Latin Hypercube Sampling
MC	-	Monte Carlo
MWL	-	Mean Water Level
NKEA	-	National Key Economic Area
OTM	-	Overturning Moment
PCT	-	Principle Component Technique
PDF	-	Probability Distribution Function
PM	-	Pierson Moskowitz
QRA	-	Quantitative Risk Analysis
SA	-	Simulated Annealing
SORM	-	Second Order Reliability Method
SRA	-	Structural Reliability Analysis
USFOS	-	Ultimate Strength for Framed Offshore Structures

LIST OF SYMBOLS

A	-	amplitude
$\hat{\hat{R}}$	-	approximate value on (nonlinear) offshore structural response
r	-	correlation coefficient
r^2	-	coefficient of determination
$\bar{U}$	-	current
C_D	-	drag coefficient
$\tilde{R}''_{L,d}$	-	drag-induced second-order linearized quasi-static responses
$\tilde{R}''_d$	-	drag-induced second-order (nonlinear) quasi-static responses
z	-	elevation from seabed
e_r	-	extreme value residues
ee	-	error
g	-	gravitational acceleration
$\tilde{R}''_i$	-	inertia-induced second-order (nonlinear) quasi-static responses
$\tilde{R}''_{L,i}$	-	inertia-induced second-order linearized quasi-static responses
C_M	-	inertia (mass) coefficient
T_z	-	mean zero upcrossing period
m	-	metre
F	-	Morison’s force
$g(\tilde{R}''_L)$	-	nonlinear function
ω_p	-	peak angular frequency
γ_p	-	peak enhancement
φ	-	phase angle
e	-	relative surface roughness
SS_{res}	-	residual sum of squares
Re	-	Reynold number
H_s	-	significant wave height
$\eta(t)$	-	surface elevation
$\eta''(t)$	-	surface elevation second-order analysis
$G_{\eta\eta}$	-	surface elevation frequency spectrum

SS_{tot}	-	total sum of squares
f	-	wave frequency
H	-	wave height
T	-	wave period
L	-	wave length
d	-	water depth
ϑ	-	wave direction
k	-	wave number
u, v	-	water particle velocity
$\dot{u}$	-	water particle acceleration

CHAPTER 1

INTRODUCTION

1.1 Introduction

The oil and gas industry is the engine of the world economy. Its production, especially in the energy sector, contributes about 4.6% - 6.5% to the global economy, with gross domestic product (GDP) ranging from $77 trillion to $107 trillion as of 2014 (Deloitte, 2014). Currently, with the rising global demand for energy resources, the oil and gas industry is facing a massive challenge as its resources are declining.(Deloitte, 2015; Veolia, 2016). All major oil and gas operators (i.e. PETRONAS, SHELL, ARAMCO, etc.) are focusing on minimizing the operational cost of oil and gas platforms and enhancing their performance (Stacey *et al.,* 2008; Ayob *et al.,* 2014; Deloitte, 2014; Fayazi and Aghakouchak, 2015).

As an alternative to high development costs, oil and gas operators are looking forward to improving their recovery of oil and gas resources from developed fields, and to develop discovery reserves from existing oil and gas platforms, which will result in good project economics and would allow recovery of more oil and gas resources. Globally, there are 497 operational offshore platforms, with 184 located around the North Sea region (Statista, 2018). However, as reported by John & John (2008), there exist around 110 fixed platforms which are older than 20 years, in the Norwegian and UK sectors. Stephen (2014) claimed that at the Southern North Sea, 70 installations are older than expected. In Malaysia, 42.5% of 360 platforms have operated for more than 30 years, as recorded in 2017, and the percentage is expected to steadily increase with time (Health and Safety Executive, 2017; Mat Soom, 2019; Zawawi, 2020).

In general, a platform is classified as an ageing structure when it has operated beyond its initial design life of 20 to 25 years. Although it is not merely about the physical age, the risk of ageing begins once the platform enters the sea. Thus, aging is measured according to the platform's condition and its structural integrity. Based on regular inspection, a platform with ageing symptoms requires a decision on whether to decommission or extend its service life (Palkar & Markeset, 2012). Referring to the current record, the decommissioning in the North Sea was estimated at £24 billion between 2018 and 2022, while in the Asia-Pacific region, the potential cost for this could rise above £78 billion (Rowe, 2019). Therefore, life extension is more economical and productive than decommissioning platform (Clyde & Co, 2016). However, the reassessment of structural integrity is required to verify whether the requirements of serviceability and global safety (unity check) are fulfilled based on the structural reliability analysis (Khan *et al.,* 2019).

Structural reliability analysis (SRA) methods are used to comprehensively assess the effects of uncertainties in the load actions, resistances and modelling of certain parts of a structure and its performance. SRA offers assessments at the structural components level as well as the entire structural system. Additionally, SRA may be useful in the (re) calibration of partial action and resistance factors for exceptional or unusual circumstances, decision analysis to support the inspection and monitoring programs, and situations where the structural assessment of existing structures is needed. Hence, accurate information on the design level, and ultimate strength of the platform under normal (operation) and extreme loading conditions are essential to support the details of reassessment (Stacey *et al.,* 2008; Fayazi and Aghakouchak, 2015).

An offshore structure is subjected to several categories of loads; accidental, permanent, deformation, live, and environmental loads (Chakrabarti, 2005). However, according to the API standard design code (2014) for fixed offshore platforms, an extreme environmental condition is the main parameter in formulating the platform design load according to its service life. Wind generated random wave loads are the major consideration in the design stage, while wind load itself only contributes less than 5% of total environmental loading (Hagen, 1996, Varma, 2014). Thus, an iterative method with an accurate wave load model is necessary (Zhang, 2015).

The reliability analysis of fixed offshore structures can be measured either through deterministic or probabilistic methods. While these structures can be designed by exposing them to extreme regular waves for a 100-year return period (Holmager, 2010; Hafez *et. al*., 2012; Mallahzadeh et al., 2014; Mat Soom et al., 2015; Abu Husain, 2015), it is much more satisfactory to use the probabilistic approach to account for the inherent randomness of the wave loading. The evaluation of extreme offshore structural responses can be carried out using a linear or nonlinear analysis based on the selected wave theory (Teng & Ning, 2009; Isobe, 2013; Varma, 2014).

Linear wave theory is the most frequently used as it is the most straightforward wave theory that allows the boundary condition to be linearized (Chakrabarti, 2005). However, it is well known that there exists a nonlinearity of the wave loading due to the drag component which gives a significant effect on both the frequency spectrum and probability distribution of extreme response values (Zheng, 2013; Abdel Raheem, 2014). Furthermore, structural dynamics effects, the presence of current and load intermittency in the splash zone also increase the complexity of the problem. This provides limitations on the applications of linear wave theory since some of the nonlinearities cannot be explained when higher order terms are excluded (Chen, 2014). As a solution, the nonlinear wave approach is more applicable. In line with the development of scientific knowledge on the nonlinear wave, several researchers have come out with various methods to perform a reliability analysis of offshore platforms, which will be discussed in detail in Chapter 2.

1.2 Problem Statement

Structural integrity assessment is essential to ensure that the operation of an offshore platform has fully satisfied the requirement of serviceability according to its lifespan. The evaluation needs to be carried out for an all limit state, and according to the framework (Aeran *et al.*, 2017), one of the critical processes is in the evaluation of loading and structural analysis. These include operational loads that are recommended based on the design standards, and environmental loads which contribute mainly by wind-generated random waves. Here, the 100-year return period of extreme offshore structural responses is applied for ultimate limit state assessment based on the requirement by code of practice.

It is advisable to analyze the structure based on linear wave analysis as a preliminary analysis to ascertain the overall integrity of the structure. Based on a probabilistic approach, the structural analysis can be evaluated using time, frequency or probability domain (Najafian *et al.*, 1995; Cheng, 2002; Najafian, 2007c; Zheng, 2013; Abu Husain, 2015). Referring to the design standard code of practices API-RP2A (2014) and ISO19902 (2010), frequency domain analysis is commonly applied in offshore oil and gas industries to analyze extreme wave responses as it is computationally more efficient (Zhang, 2015; Rahmati, 2016; DNV.GL, 2018).

In cases where the preliminary analysis results are found to be severe with plenty of critical conditions (i.e., overstressed member), performing a nonlinear wave is recommended for more detailed structural analysis. In fact, simulations based on linear wave theory give significant underprediction compared to nonlinear analysis (Agarwal & Manuel, 2011; Zheng, 2013; Natarajan, 2014). However, it becomes complicated when dealing with the nonlinear wave simulations, in which the wave profile is generated based on the combination of first and second order wave components, where the second wave experiences twice the wave frequency. The solution becomes cumbersome when a large number of elements are used to obtain a reliable higher-order wave force and its structural response (Deo, 2013). However, it provides an accurate prediction in the simulation of extreme response values (Alberello *et al.*, 2014; Chen, 2014; Saeedfar & Abd Wahab, 2015; Adcock, 2015).

Recently, researchers have shown an increased interest in the prediction of statistical properties of offshore structures according to nonlinear wave in a stochastic nature. Ersdal (2005) and Puskar et al. (2006) first examined a primary concern on loading assessment which led to structural failure using nonlinear analysis with the aid of Ultimate Strength for Framed Offshore Structures (USFOS) to enhance its efficiency. Later, Ebrahimian et al. (2014) provided a more detailed study of contributing factors that influence uncertainty in the evaluation process. However, the weakness in the frequency domain technique is due to its reduced accuracy when dealing with a complex nonlinear mechanism such as more extreme met-ocean conditions (Armstrong *et al.,* 2017). In such situations, time domain analysis such as the Monte Carlo time simulation will be chosen due to their level of accuracy (Swain & Schmeiser, 1987; Norouzi, 2012; Catelani *et al.,* 2014).

However, time domain techniques are not efficient as tens of thousands of realizations need to be committed to remove the sampling variability (Abu Husain *et al.,* 2016). This leads to computational demand and consequently, a huge investment cost. Most researchers focus on improving the efficiency of the time domain technique by integrating the Monte Carlo procedure with other methods such as Latin Hypercube Sampling (LHS) and Simulated Annealing (SA) approaches that aim to optimize the sample size (Helton *et al.,* 2006; Vořechovský & Novák, 2009; Ebrahimian *et al.,* 2014). Later in this research, an advanced method has been developed for better accuracy and efficiency on the prediction of probabilistic responses based on time domain technique such as new wave theory (Tromans *et al.,* 1991; Cassidy, 1999; Cassidy *et al.,* 2001), efficient time simulation (ETS) (Abu Husain, 20013; Lambert *et al.,* 2013; Mallahzadeh *et al.,* 2014) and finite-memory nonlinear system (FMNS) (Najafian, 2007a, 2007b; Najafian & Mohd Zaki, 2008; Mohd Zaki *et al.,* 2013; Mukhlas *et al.,* 2016), with its corresponding development. However, most of the methods had been developed based on linear wave theory.

Hence, the existing research work can be grouped into two; the fundamentals of nonlinear wave theory that use frequency domain in the probabilistic analysis, and the development of the time domain method for better efficiency. There is a lack of studies focusing on nonlinear wave modelling with an efficient method for full probabilistic analysis. With the most attentive development of FMNS method, a new model needs to be developed to integrate the current development of FMNS (Mukhlas *et al.,* 2018) with nonlinear wave model. As mentioned before, there exists a nonlinearity of the wave loading due to the drag component, which has a significant effect on both, the frequency spectrum and probability distribution of extreme response values (Zheng, 2013; Abdel Raheem, 2014). Furthermore, the structural dynamics effect, and the presence of current and load intermittency in the splash zone also increases the complexity of the problem. Yet, the contribution of nonlinearity due to the wave-wave interaction leads to a more cumbersome solution. Hence, this research will take advantage of the efficiency of the finite-memory nonlinear system (FMNS) that is able to reduce the computational effort by using an appropriate model to transform the surface elevation into approximate responses without sacrificing its accuracy. Details of the development of the model will be discussed. The most appropriate model can then be used with excellent efficiency and accuracy to determine the extreme offshore structural response. With that, the structure is optimized, leading to cost reduction.

1.3 Aim and Objectives of the Research

This research attempts to develop an efficient model in the prediction of 100-year responses for a non-Gaussian stochastic analysis of the offshore structure without sacrificing its accuracy. In particular, the objectives are as follows:

1. To investigate the significant impact of considering all nonlinearities in the evaluation of a non-Gaussian stochastic offshore structure

2. To develop a new model for the prediction of short-term 100-year responses for a non-Gaussian stochastic offshore structure

3. To validate the accuracy and efficiency of the new model by comparing it with the corresponding result from Monte Carlo time simulation technique for both, short-term and long-term 100-year extreme responses

1.4 Scope of the Research

The selection of a suitable offshore platform was made based on the water depth. A fixed offshore platform is fit for a depth of up to 400 m (also known as shallow water), and a floating offshore platform is used for deeper depths. The industry commonly uses fixed offshore platforms for oil and gas production (Edvard, 2013; Technip, 2014). Locating a fixed offshore platform in shallow sea waters is still feasible and as a result, this research focused mainly on simulating the short-term and long-term probability distribution of extreme response values of a quasi-static fixed offshore platform according to the nonlinear random wave theory (structural data obtained from Atkins Ltd). It was also tested with and without the presence of a current (assuming $\overline{U}$= 0.0 m/s and $\overline{U}$= $\pm$0.9 m/s as 1.0 m/s is the highest record of current at the north sea region (Moghimi *et. al.* 2005)). The environmental data chosen in this research is based on the extreme environment experienced by the structure (for North Sea region provided by Safety and Health Executive, UK), while the probability distribution of extreme response values was analysed based on the first excursion of failure due to the first upcoming extreme response.

This research focuses on the condition of North Sea due to available access data and its extreme condition that fits with the aim of research. However, the structure will be tested for various conditions of sea state (low, moderate, and high significant wave height with H_s = 5 m, 10 m, 15 m, respectively). This is important to measure the workability of the model development to the local offshore platform that is located at the South China Sea region. There are three operating regions located in Malaysian waters, which are Peninsular Malaysia Operation (PMO), Sarawak Operation (SKO) and Sabah Operation (SBO). The hydro-meteorological environment represent by the NALL spectrum has classified South China Sea as a partially developed sea with a highest significant wave height of 5 m (Chu *et. al.*,2003; Khaidzi, 2016).

1.5 Significance of the Research

This research could be of benefit to academics as well as the industry. Regarding academic, the findings from this research could enable the development of a new procedure for an accurate and efficient technique in the derivation of extreme non-Gaussian stochastic offshore structural response for further study. From the industry perspective, in general, the new methods can be used as an aid in the design and analysis of real offshore structures with high efficiency without sacrificing accuracy.

As previously mentioned, the oil & gas industries are experiencing a rise in global demand. As the cost of development is high, oil & gas operators are looking for ways to improve the recovery of resources from existing oil and gas platforms by extending their service life. It is the more economical and productive option since decommissioning requires a significantly large cost. However, structural integrity is a significant issue to ensure that the platform is operating well with a minimum chance of failure.

The non-Gaussian stochastic model from this research offers a more efficient nonlinear analysis procedure based on time domain method that has a significant impact on the integrity of the offshore structure. Since the technique provides a promising accuracy, the confidence level of analysis is dependently increased, which compensates for the low factor of safety during the assessment of structural analysis. With that, the structure is more optimized, leading to cost reduction.

Moreover, the developed model is robust and generic, which is assessable generally for all kinds of offshore structures (i.e., oil & gas platform, wind turbine, renewable energy equipment, etc.). In fact, it can also be applied for aerospace and other industries that are involved in the same concept of reliability required for optimization.

1.6 Thesis Outline

This thesis comprises of five chapters, namely the introduction, literature review, evaluation of extreme offshore structural responses, analysis and discussion of 100-year extreme offshore structural responses, and conclusion with recommendation. Chapter 1 outlines the aims and objectives of this research based on the problem encountered in the industry, then focuses into the specific scope of the study to ensure its completeness.

Chapter 2 discusses in detail the fundamental theory throughout the process of design and analysis of offshore structures that allows for the preservation of its reliability over the design life. Since the structure is subjected to the nonlinearities of random wave loading, accurate prediction of the statistical properties of its extreme response values is required. Therefore, several techniques will be discussed here in developing the probability distribution of extreme response values.

Chapter 3 is the simulation procedure part. An overall research flowchart is presented. According to the objectives of this research, a demonstration of the evaluation of extreme offshore structural responses based on linear and nonlinear wave theory using Monte Carlo time simulation method is done to investigate the importance of considering the nonlinearities in the analysis. This is followed by the model development of new approach due to the computational effort of Monte Carlo, by taking advantage of the efficiency of the finite-memory nonlinear system. Then, a full procedure based on the appropriate model in simulating a non-Gaussian stochastic offshore structural response is developed with a more efficient approach using a finite-memory nonlinear system known as the FMNS_{NL} method, according to short-term and long-term probability distribution.

Chapter 4 focuses on the analysis and discussion on the prediction of the 100-year response based on the evaluation of short-term and long-term probability distribution. The prediction has been examined using both Monte Carlo time simulation and FMNS_{NL} methods. The short-term distribution analysis is an initial indicator to observe the accuracy and efficiency performance of the FMNS_{NL} method in predicting the 100-year extreme offshore structural responses, compared to the corresponding prediction using Monte Carlo time simulation method. The examination has been done according to low, moderate and high sea state conditions. Since it has provided a promising result, the analysis is proceeded with the long-term distribution analysis that considers the whole sea state condition based on the Forties Fields of the North Sea due to its occurrences of extreme waves. The analysis has also considered the contribution of current along the wave of propagation, either in the same or opposite direction. Additionally, the performance of FMNS_{NL} method has been evaluated based on its hydrodynamic components; inertia-induced, drag-induced and total responses. To discover the importance of considering the nonlinearity in the FMNS_{NL} method, a comparison with FMNS method has also been examined.

In the last chapter, which is Chapter 5, the conclusion and recommendations will be covered. This thesis has been concluded according to the listed objectives, while recommendations are based on the promising results that can be done for future work. In addition, the output of this research has also been summarized and categorised according to the publication of journals, conference proceedings, innovation for award and intellectual property.

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