OPTIMUM PERIOD OF STRUCTURAL HEALTH MONITORING FOR AGEING FIXED OFFSHORE PLATFORM

MUHAMMAD ANIQ RAZIN BIN ZULKIFLI

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Razak Faculty of Technology and Informatics
Universiti Teknologi Malaysia

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DEDICATION

This thesis is dedicated to my parents, Zulkifli Mohd Hashim and Rosnah Mohamad Lidin, who have supported me in all aspects of my life since the beginning. It is also dedicated to my wife, Nurfarzana Ahmad Tajuddin, who has kept me focused and motivated throughout this study.

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ABSTRACT

The industry of oil and gas began in Malaysia in the early 1900s and has evolved over 115 years. Since 1990, Malaysia's gasoline consumption has increased at an annual rate of 7.2%, reaching 44.9 Mtoe in 2008. The expected demands of oil and gas are increasing from 2010 up until 2026. The oil and gas operators are pressured to improve their recovery of oil and gas resources hence needs to extend the operation of the platform beyond its design life. In order to do that, reliability engineering has become a common practice in the Malaysian oil and gas industry to access the integrity and requalification of offshore platform in the late 1990s. The common design life of the fixed offshore structure ranges between 20-30 years. In 2019, PETRONAS operates over 200 fixed offshore structures in Malaysian waters, which over half of them have outlived their design lives. Various standards and guidelines are introduced globally to ensure the extended lifetime of the fixed offshore platforms are safe to be used. However, the current development of structural health monitoring is focusing on the development of the technology and only limited guidelines and standards are discussing on the optimum or recommended duration for the monitoring. In this study, structural health monitoring (SHM) and Wave Radar system are used to collect data for acceleration of the platform and the height of wave hitting the platform which utilizes vibration based-damage detection. The data is then converted using Fast Fourier Transform to convert the time domain signal into a frequency domain signal. The output of the conversion is used to measure the impacts of different SHM duration assessments on the accuracy of the results hence determining the most optimum duration for the SHM assessment period. Six (6) test platforms were selected with four (4) different types of platform were analysed which are one-legged, three-legged, four-legged, and six-legged to fulfil perspective 1 that focused on impacts of monitoring period on different platforms' specifications. Meanwhile, another two (2) four-legged platform were analysed to fulfil perspective 2 which focus on the data reliability of the study. The platform's more robust structure reduces its susceptibility to environmental changes. One-legged platforms require a 16-day SHM campaign to assess structural health with 99.71% accuracy. SHM campaigns for three-legged platforms take 14 days to reach 99.53%. This study proposes that four-legged platforms should be monitored for 10 days to achieve 99.52% accuracy. The six-legged SHM platform reaches 99.59% accuracy in two days. This study confirmed that the optimum monitoring period for static platform (i.e., 4-legged and 6-legged) is shorter compared to dynamics platform (i.e., 1-legged and 3-legged platforms) to fulfil higher level of accuracy. Engineers can use the optimum monitoring period proposed as a benchmark to define the limit for monitoring periods, optimising SHM costs for offshore structures and improving accuracy. Future SHM deployment costs could be reduced by improved accuracy and measurement period.

ABSTRAK

Industri minyak dan gas bermula di Malaysia seawal tahun 1900 dan terus berkembang selepas 115 tahun. Sejak 1990, penggunaan petrol di Malaysia telah meningkat pada kadar tahunan sebanyak 7.2 peratus, mencecah 44.9 Mtoe menjelang tahun 2008. Permintaan minyak dan gas di seluruh dunia dianggarkan untuk terus meningkat dari 2010 hingga 2026. Operator minyak dan gas tertekan untuk memulihkan sumber minyak dan gas bagi membolehkan mereka untuk melanjutkan operasi pelantar yang telah melebihi jangka hayat reka bentuknya. Untuk tujuan itu, kejuruteraan kebolehpercayaan telah menjadi amalan biasa dalam industri minyak dan gas Malaysia untuk menilai integriti dan kelayakan semula pelantar luar pesisir sejak tahun 1990-an. Jangka hayat reka bentuk biasa bagi platform luar pesisir tetap adalah antara 20 hingga 30 tahun. Pada 2019, PETRONAS mengendalikan lebih 200 pelantar luar pesisir tetap di perairan Malaysia, yang mana lebih separuh daripadanya telah melebihi hayat reka bentuk mereka. Pelbagai piawaian dan garis panduan diperkenalkan di seluruh dunia bagi memastikan lanjutan bagi jangka hayat pelantar luar pesisir adalah selamat untuk digunakan. Walau bagaimanapun, perkembangan semasa Pemantauan Kesihatan Struktur memberi penumpuan kepada pembangunan teknologi dan hanya garis panduan dan piawaian yang terhad membincangkan mengenai tempoh optimum yang disyorkan untuk pemantauan. Dalam kajian ini, Sistem Pemantauan Kesihatan Berstruktur (SHM) dan Radar Gelombang digunakan untuk mengumpul data bagi pecutan pelantar dan ketinggian ombak yang membadai pelantar menggunakan kaedah pengesanan kerosakan berdasarkan getaran. Data tersebut kemudiannya ditukar menggunakan kaedah jelmaan Fourier pantas untuk menukar isyarat domain masa kepada isyarat domain frekuensi. Keluaran penukaran digunakan untuk mengukur kesan penilaian tempoh SHM yang berbeza terhadap ketepatan keputusan seterusnya menentukan tempoh paling optimum untuk tempoh penilaian SHM. Enam (6) platform ujian telah dipilih dengan empat (4) jenis platform yang berbeza telah dianalisis iaitu satu-kaki, tiga-kaki, empat-kaki dan enam-kaki untuk memenuhi perspektif 1 yang memfokuskan kepada kesan tempoh pemantauan terhadap spesifikasi platform yang berbeza. Sementara itu, dua (2) lagi platform berkaki-empat telah dianalisis untuk memenuhi perspektif 2 yang memfokuskan kepada kebolehpercayaan data kajian. Struktur platform yang lebih teguh mengurangkan kerentanannya terhadap perubahan persekitaran. Platform satu-kaki memerlukan kempen SHM selama 16 hari untuk menilai kesihatan struktur dengan ketepatan 99.71%. Kempen SHM untuk platform berkaki-tiga mengambil masa 14 hari untuk mencapai 99.53%. Kajian ini mencadangkan platform berkaki-empat perlu dipantau selama 10 hari bagi mendapatkan ketepatan 99.52%. Platform SHM berkaki-enam mencapai ketepatan 99.59% dalam dua hari. Kajian ini mengesahkan bahawa tempoh pemantauan optimum untuk platform statik (iaitu, berkaki-4 dan berkaki-6) adalah lebih pendek berbanding dengan platform dinamik (iaitu, platform berkaki-1 dan berkaki-3) untuk memenuhi tahap ketepatan yang lebih tinggi. Jurutera boleh menggunakan tempoh pemantauan optimum yang dicadangkan sebagai penanda aras untuk menentukan had bagi tempoh pemantauan, mengoptimumkan kos SHM untuk struktur luar pesisir dan meningkatkan ketepatan. Kos SHM pada masa hadapan boleh dikurangkan dengan meningkatkan ketepatan dan tempoh pengukuran.

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LIST OF ABBREVIATIONS

ANN	-	Artificial Neural Network
BLSRP	-	Buoyant Leg Storage and Regasification Platform
CM	-	Condition Monitoring
EC	-	Eddy Current
FBG	-	Fiber Bragg Grating
FFT	-	Fast Fourier Transform
FT	-	Fourier Transform
FM	-	Fracture Mechanics
IVHM	-	Integrated Vehicle Management System
MEMS	-	Micro Electro Mechanical System
NF	-	Natural Frequency
NP	-	Natural Period
NDT	-	Non-Destructive Testing
OPEX	-	Operational Expenditure
ROV	-	Remote Operating Vehicle
SHM	-	Structural Health Monitoring
UM	-	Usage Monitoring
VMP	-	Various Monitoring Period
WSN	-	Wireless Sensor Networks

LIST OF SYMBOLS

F	-	Force
k	-	Stiffness of structure
m	-	Mass
NF_{20}	-	Average Natural Frequency for 20 days
NF_i	-	Natural Frequency for i-th day
r	-	Correlation Coefficient
T_0	-	Natural Period
F	-	Force

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The industry of oil and gas began in Malaysia in the early 1900s and has evolved over 115 years. In December 1910, the first onshore oil well, known as Miri Land Field, was discovered at Miri, Sarawak. The exploration of offshore began in Sarawak in 1961 with the discovery of more oil and gas fields including Patricia, Temana and West Lutong by Sarawak Shell Berhad. In 1974, Petroleum National Berhad (PETRONAS) took over the oil and gas industry on behalf of the Malaysian Government under the Petroleum Development Act 1974 (Potty & Akram, 2009). In 1976, a production-sharing contract (PSC) agreement was made between PETRONAS, Sarawak Shell Berhad, and Sabah Shell Berhad.

According to Islam et al. (2012), since 1990, Malaysia's gasoline consumption has increased at an annual rate of 7.2%, reaching 44.9 Million Tonnes of Oil Equivalent (MTOE) in 2008. The expected demands of oil and gas are projected in Figure 1.1 where two graphs were plotted, pre-pandemic and Oil 2021 forecast (IEA, 2021). The pre-pandemic forecast describes the increasing demands for oil and gas resources from 2010 up until 2026 while the Oil 2021 forecast projected the pattern of oil and gas resources demands after the spread of the Coronavirus disease. In Oil 2021 forecast, the decline in 2020 was caused by the coronavirus pandemic's economic and mobility consequences, which included extensive shutdowns around the world. However, due to the recovery from the global pandemic, the resource demands are projected to keep rising until 2026.

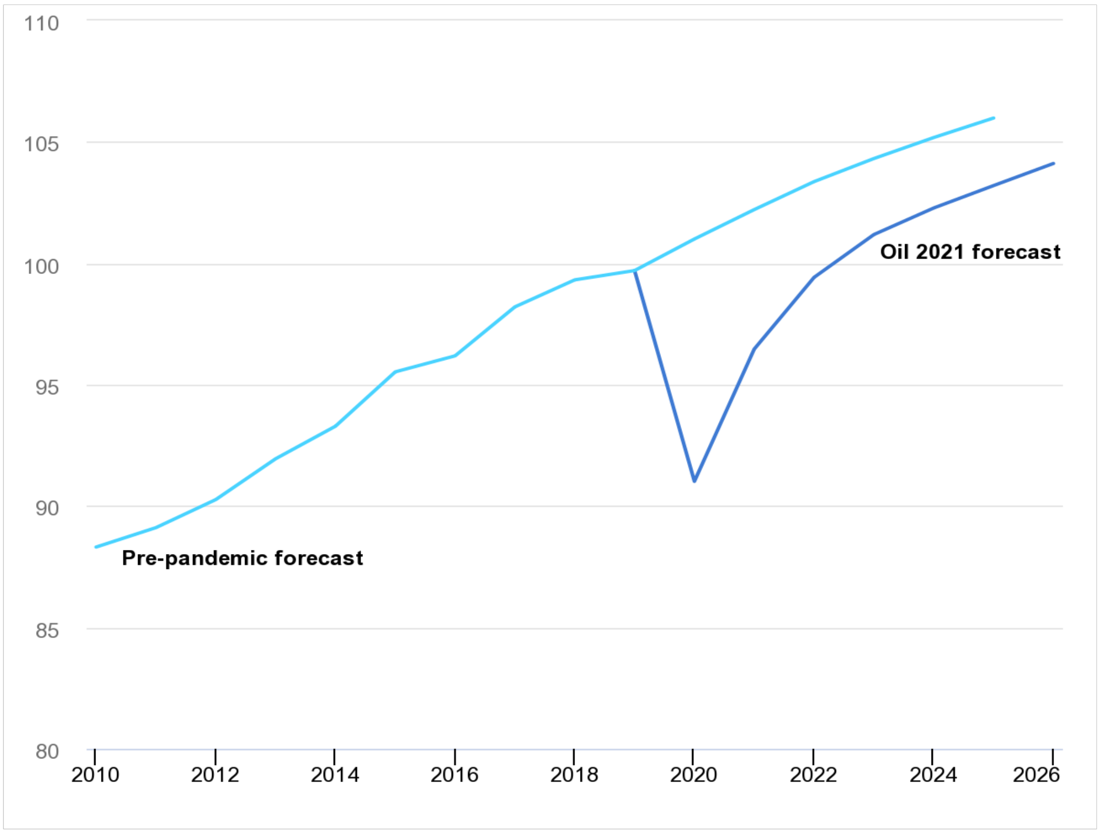

Figure 1.1 Expected demands of oil & gas - pre-pandemic and oil 2021 forecast (IEA, 2021)

The energy sector, specifically in oil and gas, is facing challenges as the resources are declining in recent years (Toews & Naumov, 2015; Arezki et al., 2017). The companies are pressured to improve their recovery of oil and gas resources from developed fields and the need to develop discovery reserves from existing oil and gas platforms since the development costs are rising and the demand for oil and gas has grown rapidly. This approach has resulted in a significant reduction in development costs, resulting in good project economics and the ability to recover more oil and gas resources (Hwang, 2015; Ng et al., 2019). Currently, the offshore production available is Peninsular Malaysia Operation (PMO), Sarawak Operation (SKO), and Sabah Operation (SBO). The majority of platform types include wellhead, drilling, gas compression, living quarters, vents, and risers. Reliability engineering has become a common practice in the Malaysian oil and gas industry to access the integrity and requalification of offshore platform in the late 1990s. The fixed type offshore structures, known as fixed jacket platforms, are commonly used in oil and gas production in the shallow water depth where the depth is no greater than 200m in Malaysia (Zawawi et al., 2012). Generally, a fixed platform is located in shallow water depth of less than 300 m (Mourad et al., 2001; Vestli, 2016)

1.2 Research Background

Currently, most platform structures have exceeded their design life (Shuhud, 2008; Ng et al., 2019). The typical design life of the fixed offshore structure ranges from 20 to 30 years (Ayob et al., 2014; Hwang, 2015; E. Soom et al., 2015; E. M. Soom et al., 2018; Azman et al., 2019). As of 2010, there are more than 191 installation platforms with fixed-type offshore structures in Malaysia (Twomey, 2010). A report in 2014 indicated that the ageing of the existing installation would increase to 78% in another 5 years (Bai, 2003; Ayob et al., 2014). According to the records, the oldest operating platform is 50 years old (Ng et al., 2019). Figure 1.2 shows that in 2019, PETRONAS operates over 200 fixed offshore structures in Malaysian waters, of which over 56% have been operating for more than 31 years and have outlived their design lives. Meanwhile, according to Zawawi et al. (2019), Malaysia has approximately 300 shallow water-fixed oil and gas platforms that have already served their purpose for almost two decades, with 48% surpassing their 25-year design life.

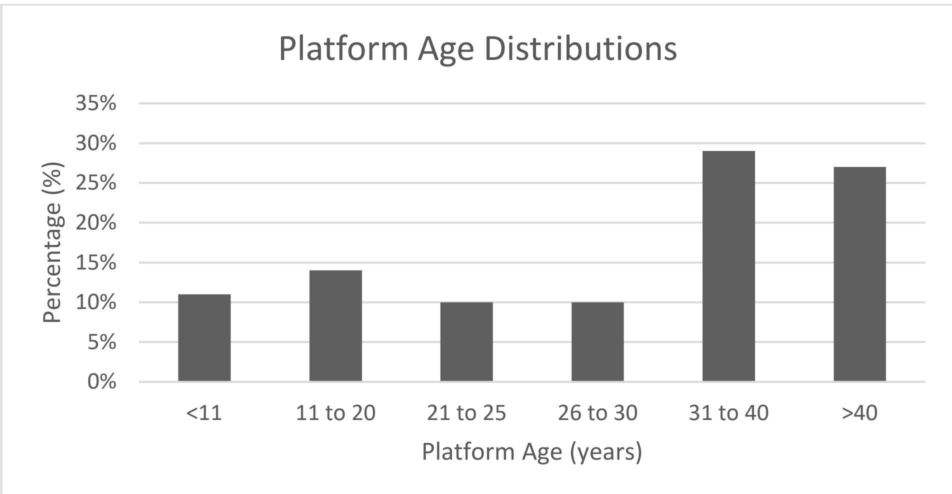

Figure 1.2 Age distributions of platforms owned by PETRONAS (Ng et al., 2019)

As continuous production is required beyond the design life, life extension of the installation is inevitable. Concurrently, effective requalification techniques have been established and implemented for these structures, as there is a need to extend the life of these building structures by at least another 25 years without endangering people's safety, asset integrity, or productivity (Ayob et al., 2014; Ng et al., 2019). Many National Oil Companies (NOCs) usually adhere to their own technical standards, which are adopting the American Petroleum Institute (API) guide to perform reassessment. According to the NOCs, the major goal of the reassessment is to forecast strength performance against high load and insufficient strength (Wahab et al., 2020). Major modifications and fatigue concerns have led to significant changes to platform loading issues of structural integrity and reliability. Hence, it is necessary to evaluate the possible life extension of ageing platforms where structure failure is expected when the strength capacity is unable to resist the applied load. Additionally, structural failure can stop production before the limit of platform life or decommission.

Structural health monitoring (SHM) is a process for the observation and analysis of engineering structures that utilizes data from onboard sensors to evaluate the health of a structure (Güemes et al., 2020). The benefits of structural health monitoring based on vibration signals are dramatic considering a large number of ageing oil and gas platforms worldwide. The idea of using vibration-based damage detection is attractive because it allows for a global structural condition evaluation of the structures at a given time. SHM systems have the potential to eliminate the costs of regular periodic inspections, and to provide more accurate evaluation for the condition deteriorating structure to better estimate remaining life and upgrades necessary to keep the structure sufficiently safe (Vestli et al., 2017; Palma & Steiger, 2020). SHM systems can provide a quick assessment of the damage level of a structure shortly after the occurrence of extreme loading events including earthquakes, explosions, and any sudden impact.

Figure 1.3 describes the difference between several maintenance strategies available in the current engineering practice. According to (Güemes et al., 2020), time-scheduled maintenance defines maintenance with a scheduled period, while condition-based maintenance is the same method as the SHM where the structural health of the structure is to be monitored using various technologies to decide on the needs to perform maintenance, and the corrective maintenance is to perform maintenance once any failure occurs on the structure (Hwang, 2015). The longer the time taken to perform maintenance for the structure, it may reduce the cost of maintenance of the structure, but the operators need to bear a higher risk of failure. Once failure occurs, the whole operation of the structure needs to be shut down until the maintenance or repair has been completed. The condition-based maintenance is considered a better option compared to time-scheduled maintenance as it could reduce the number of maintenance needed to be performed and only need to perform maintenance once the structure has started to reach extreme service loads and experience higher structural strength losses.

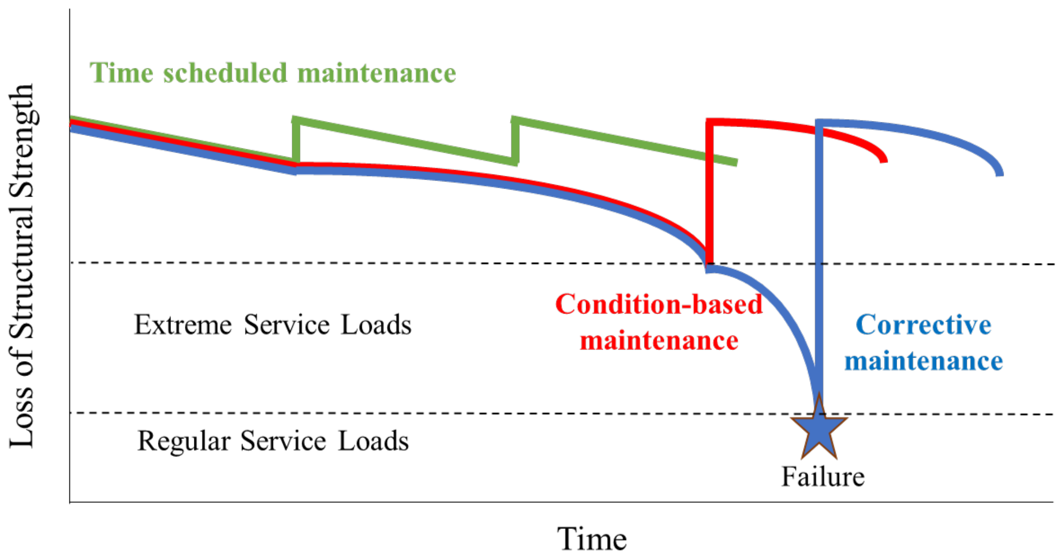

Figure 1.3 Maintenance strategies with/without SHM systems (Güemes et al., 2020)

The repetition of environmental loading hitting a structure such as wind and waves can cause fatigue which the fatigue failure is a frequent issue that poses risks to structural safety (Jia, 2018). For example, the failure of the bow door and the formation of opening moments around the deck hinges of the MS Estonia which sank on 28 September 1994 occurs as a result of repeated waves hitting the ship. Another famous incident regarding structural failure occurred in 1979 and 1980, with the Ranger I Jack-Up collapsing in the Gulf of Mexico and the Alexander Kielland semisubmersible collapsing in the North Sea ((Brkić & Praks, 2021). The incidents of structural failures due to the environmental loading hitting structures in the sea is not new and has gained the attention of the authorities globally hence resulting in the introduction of various guidelines and standards for designing and maintaining the structures located in the sea.

The vibration-based damage detection of the offshore platform is normally measured using accelerometers (Vestli, 2016). Dynamic properties of the platform can be derived from the acceleration response. These damage detection techniques also can be categorized as frequency domain methods and time domain methods. In the frequency domain methods, modal properties such as natural frequencies, accelerations, displacements, damping ratios, and mode shapes are identified (Chandrasekaran, 2019; Yang et al., 2021). The natural frequencies depend on the platform's mass and stiffness so that if the deck mass remains constant, or changes are quantified, the natural frequencies become a measure of the platform stiffness. The frequency domain methods might not be suitable for complex problems which require high-frequency resolution, local damage assessment, and nonlinear system identification (Koh & See, 1994). These methods cannot track abrupt changes when structural damage occurs during extreme loading events (Ghanem & Ferro, 2006). However, the frequency domain methods are reliable for the monitoring of structural health under normal conditions without any significant changes from the environment, dynamic loading, or the operational practice of the platform.

1.3 Problem Statement

Structural health monitoring (SHM) using vibration-based damage detection commonly uses a technique that examines the changes in measured structural vibration response (Güemes et al., 2020; Liu et al., 2020; Palma & Steiger, 2020). SHM with vibration-based damage detection is one of the most successful and well-established damage detection approaches (Avci et al., 2021). The approach normally uses the sensors that are located on the object of interest and reports continuously or periodically as an online monitoring system (Palma & Steiger, 2020). This method can be categorized as a part of a non-destructive technique (NDT) to detect changes in natural frequencies and mode shapes of the structure. The NDT method allows non-destructive material or component inspection to identify, locate, measure, and evaluate defects, assess integrity, quality, and composition, and quantify geometric characteristics without affecting usability or future use (Palma & Steiger, 2020). There are currently several NDT and damage detection approaches available for the SHM of civil structures.

According to Palma and Steiger (2020), SHM is particularly well suited for: significant structures that are vulnerable to long-term movement or degradation; novel construction technologies; improving infrastructure resilience, especially for bridges; and tackling the decline in construction and growth in maintenance needs. In recent years, many research papers focuses on requalification for life extension of fixed offshore platforms (Ayob et al., 2014; E. Soom et al., 2015; Moan, 2018; E. M. Soom et al., 2018). Due to the increasing demands for oil and gas resources, the researchers conducted the studies to develop proper findings on the possibility of the extension of service duration for the fixed offshore platforms beyond their design life.

The existing SHM guidelines for civil engineering structures primarily focus on bridges and offshore structures, where substantial repairs or replacements that need downtime are to be avoided (Palma & Steiger, 2020). According to Ayob et al. (2014); Palma and Steiger (2020); Wahab et al. (2020), the method of reassessment for the offshore platform is defined precisely in industry-adopted codes and standards such as the American Petroleum Institute (API), International Organization for Standardization (ISO), Petronas Technical Standard (PTS), and NORSOK codes. The prioritised topics and concern of the standards and guidelines focus on the design procedures to set up new platforms, technology development of the SHM system, data acquisition procedures, and the inspection methodology. According to Wahab et al. (2020), the reassessment guidelines proposed by existing codes and standards are considered still immature in terms of their general application and robustness to a diversity of platform design, operation, and environment. However, the current guidelines and standards have indeed covered the various aspects of inspection that shall be prioritised to ensure the safety of personnel and platforms are fit for use.

In the early years of SHM development, the major focus of the SHM system is on the instrumentation (Lynch & Loh, 2006; Daum, 2013; Sivasuriyan et al., 2021), technology development (Liu et al., 2020; Palma & Steiger, 2020; X. Li et al., 2022), and the validation of the system (X. Li et al., 2022) to ensure the system is reliable to be used as a monitoring tool. Various types of inspections have been studied and proven to be accurate and reliable throughout the years of SHM development (Mieloszyk & Ostachowicz, 2017; Güemes et al., 2020; Liu et al., 2020; Vidal et al., 2020; Sivasuriyan et al., 2021; X. Li et al., 2022). However, there are still numerous challenges to address in SHM. Since SHM technology is well-accepted globally, there are lots of information collected and available related to civil & infrastructure industry. One of the main problems that shall be raised concern is the determination of the optimum monitoring period to assess the structural integrity parameter of the offshore platform.

Globally, the standard practice for determining the number of days of monitoring depends on the operator itself. The monitoring period is influenced by the operator's budget, data requirements, data confidence, engineer expertise, and information regarding the safest time for monitoring a fixed offshore platform. The different inspection types depending on the inspection motives are stated in Table 1.1. According to ISO (2019), only the 'periodic' inspection type on day-month-year was explicitly defined in Table A.5 from the ISO 19901-9:2019(E). The standard made no recommendations for the duration of the inspection or the interval between each monitoring or inspection. Longer monitoring duration requires more manpower working time, equipment rentals, and higher numbers of data sets to be analysed.

Table 1.1 Function of inspection types (ISO, 2019)

Inspection motive	Inspection type				
	Baseline	**Periodic**	**Special**	**Post-Event**	**Post-incident**
Detection of degradation or deterioration	S	P			
Detection of fabrication defects or installation damage	P	S	S	S	
Detection of damage due to design uncertainties or errors	P	S	S	S	
Detection of damage due to environmental overload		S		P	
Detection of damage due to accidental event		S			P
Changes in functions or in permanent actions due to modifications		P			
Monitoring of known defects or repair effectiveness		P			
Change of operatorship			P		
Reuse			P		
Decommisioning			P		
National or regional regulations	As required.				
Key P: Primary purpose of inspection S: Secondary purpose of inspection					

By having a longer monitoring duration, the operational cost to monitor the health of the fixed offshore platform will increase. According to Hwang (2015), the operation and maintenance (O&M) phase consume more resources and labour than the building phase. Oil and gas majors and operating firms have recently shifted their focus to the enormous expenses associated with operation and maintenance. Thus, by having a proper guideline on the recommended monitoring period for SHM system deployment in a fixed offshore platform, the operators would be interested in ensuring the facility's integrity through efficient operation and proper maintenance, hence reducing their capital and operational expenditures for maintenance.

1.4 Aims and Research Objectives

The aim of this study is to determine the optimum monitoring period for structural health monitoring system deployment at fixed offshore platform. The objectives of the research are:

1. To measure the impacts of SHM duration assessment on the platform structural integrity parameters.
2. To evaluate the optimum SHM monitoring period for ageing offshore platform assessment.

1.5 Scopes of the study

The scopes of this research are focusing to assess one (1), three (3), four (4), and six (6)-legged fixed offshore platforms in Malaysian water. The platforms chosen in this study have been operating for more than 25 years of service life. The structural health monitoring assessment was done in a local environment with the condition of maximum wave height (H_{max}), significant wave height (H_s), and wind are based on the platforms which are located in the Malaysian water at Sarawak (SKO). This study will be utilizing standalone monitoring using the Structural Health Monitoring system for data collection which has at least 20-days of useful monitoring data. The data processing and analysis will be performed using Fast Fourier Transform to convert the time domain into the frequency domain. The process of data processing and data collection refers to the ISO 19902, NORSOK N-005, and NORSOK N-006. The findings of this study are only applicable only if there are no major modifications to the platform such as additional weight, any changes of operation, and extreme weather such as earthquake.

1.6 Significance of the study

This study utilized real-time monitoring data collected on-site to determine the optimum monitoring period for structural integrity assessment. The study was able to demonstrate ways industrial data can be utilized within an academic framework to provide conclusions that are applicable for application on-site. The outputs of this study are expected to be beneficial to assist operator on deciding the optimum measurement periods for SHM deployment which utilizes the vibration-based damage detection at their assets.

The findings of this study proposed the optimum monitoring period for different types of fixed offshore platform (monopod, 3-legged, 4-legged, and 6-legged). The monitoring period can be used as a benchmark for engineers to determine limit for monitoring periods which will results to cost optimization of SHM for offshore structure hence ensuring higher accuracy level of SHM. The impact on accuracy and measurement period has the potential to significantly reduce the overall cost of SHM deployment in the future. This is critical since it involves the operator's Capital Expenditure (CAPEX) and Operating Expenditure (OPEX).

1.7 Thesis Outline

This thesis consists of five chapter where the contents of each chapter are described in brief below.

Chapter 1 discusses on the introduction of the issue in general regarding the current problems faced by oil and gas operators and the solutions to overcome the issue. Once the problem statement is clearly revised, new research methods are proposed to fulfill the limitation of previous studies. The chapter comprises of the aims and objective, scope of the study and also the significance of the study. In brief, this chapter assists reader to fully understand the focused topics of the study.

Chapter 2 focuses on structural health monitoring (SHM) practice in offshore structures. Based on previous studies, the details of current state-of-the-art on SHM technologies, methods of SHM, current guidelines and standards, and reasons to perform structural health monitoring are explained in detail in this chapter. The findings from previous researchers and studies are concluded to identify the gap of the issue.

Chapter 3 describes the overall methodology of the study. The procedures and workflow of the research are clearly explained, and the methods of the study are stated in this chapter. Due to the gap identified in previous chapter, study on the correlation of parameters and the impact of different measurement period on the accuracy of the natural frequency of the offshore structure is performed.

Chapter 4 provides two main study which is the relationship study between Structural Health Monitoring parameters and the determination of the optimum monitoring period based on the accuracy of different monitoring period. The comparison of the platform data was made by comparing the output values mainly on the variable relationship, accuracy of different monitoring period, and the natural frequency itself.

Chapter 5 concludes the completion of each research objectives and summarizes findings of the study. The contribution of the output of this study are stated in this chapter where oil and gas engineers/operators could utilize the findings as a benchmark for the monitoring period to perform SHM of the fixed offshore structure.

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LIST OF PUBLICATIONS

Indexed Conference Proceedings

1. **Zulkifli, M. A. R.**, Husain, M. K. A., Zaki, N. I. M., Jaafar, A. B., Mukhlas, N. A., Ahmad, S. Z. A. S., Azman, N. U. (2022). Environmental impacts of utilization of ageing fixed offshore platform for ocean thermal energy conversion. In *Journal of Physics: Conference Series, 2259*(1), 012019. https://doi.org/10.1088/1742-6596/2259/1/012019 **(Indexed by SCOPUS)**