UNIVERSITI PUTRA MALAYSIA

EFFECT OF FATIGUE ON THE STRUCTURAL RESPONSE OF COMPLEX JOINT FOR OFFSHORE STRUCTURES

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By

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Project Submitted to the Department of Civil Engineering, Universiti Putra Malaysia, in Partial Fulfilment of the Requirement for the Degree of Master of Science

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Abstract of project presented to the Senate of Universiti Putra Malaysia in partial fulfillment of the requirement for the degree of Master of Science

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Chairman: Associate Professor Jamaloddin Noorzaei, PhD

Faculty : Engineering

Fatigue in offshore structures is caused by the cumulative effect of variable environmental loads experienced by the structure during its life. Both the global loading on the structure and the local loading on individual members contribute to fatigue damage. Fatigue damage is a highly localized phenomenon affected by local details in the structure. Fatigue failure occurs under repeated cycles of relatively low stress levels due to the growth of the internal cracks.

Fatigue analysis is normally perform on jacket (steel framed tubular structure connected to the sea bed by piles which are driven through piles on the outer members of the jacket) subjected to repetitive wave loading. However for this project, emphasis is placed on evaluation of fatigue damage on a semi-submersible topsides (steel framed structure above the mean sea level) subjected to inertia loads resulting from wave loads.

This project will focus on the classical method of fatigue analysis as well as the simplified fatigue analysis method. This project is mainly concerned with the fatigue damage experienced by the topsides complex joint subjected to inertia loads under the calm condition, extreme storm condition and damage storm condition. The main objectives are to demonstrate the applicability of using a simplified fatigue analysis spreadsheet in estimating the fatigue life of the complex joint. Besides that, calculation of hot spot stress by Finite Element Analysis and fatigue calculation based on Stress Concentration Factor (SCF) and S-N Curve is being performed. The fatigue remedy action and recommendations will also be addressed and discussed.

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I certify that an Examination Committee has met on 20th May 2008 to conduct the final examination of Chow Wan Han on her Master of Science project entitled " Effect of fatigue on the structural response of complex joint for offshore structures" in accordance with Universiti Putra Malaysia (Higher Degree) Act 1980 and Universiti Putra Malaysia (Higher degree Regulation 1981). The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This project submitted to the Senate of Universiti Putra Malaysia and has been accepted as partial fulfillment of the requirements for the degree of Master of Science. The members of the Supervisory Committee are as follows:

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DECLARATION

I hereby declare that the project is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

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Date:

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CHAPTER 1 : INTRODUCTION

1.1 GENERAL

Fatigue may be defined as a process of cycle by cycle accumulation of damage in a material undergoing repetitive stresses and strains (J. Petit et al., 1988). Fatigue generally does not occur under large loads which are able to cause immediate failure. Instead, fatigue occurs after a certain number of repetitive smaller loads or after the accumulated damage has reached a critical stage then failure will take place. The repetitive stress or strains experienced is commonly referred as stress or strain range which defined as the difference between a load peak and the subsequent valley.

Fatigue fracture undergoes three stages; namely initiation, slow growth and onset of unstable fracture (J. Petit et al., 1988). Fatigue failures usually originate at the surface. Once a crack is initiated, it grows slowly as the stress cycles are repeated, even if the stress level is below yield. When these cracks size become critical, unstable fracture occurs and may leads to catastrophic failures. Hence, the global structural response of the structures will be affected.

In many cases, design check due to fatigue is overlooked. In some cases, the design check was done by simply copying the previous design practice.

However, great caution is needed when this is practiced since environment conditions, material properties, joint type and details may differ compared to previous cases. Hence, proper fatigue check should be carried out for structures which are subjected to relatively low stress but high-cycle fatigue and relatively high stress but low-cycle fatigue conditions.

Fatigue capacity of complex joint should be given an utmost attention especially for semi-submersible platform which is subjected to dynamic loads resulting from the platform movement / motion.

1.2 BRIEF REVIEW ON OFFSHORE STRUCTURES

1.2.1 Jackup Rig

Jack-up platform was referred to as platform with three to four legs that can be lowered to serve as bottom support. The main platform deck will be those raised above mean sea level. However, the deck unit is water tight and has buoyancy and stability to serve as a transport unit with elevated legs during ocean transportation. The legs of the jack-up can be of perforated pipes with holes or truss-work (Barltrop et al., 1991). Jack-up is commonly used as a drilling platform.

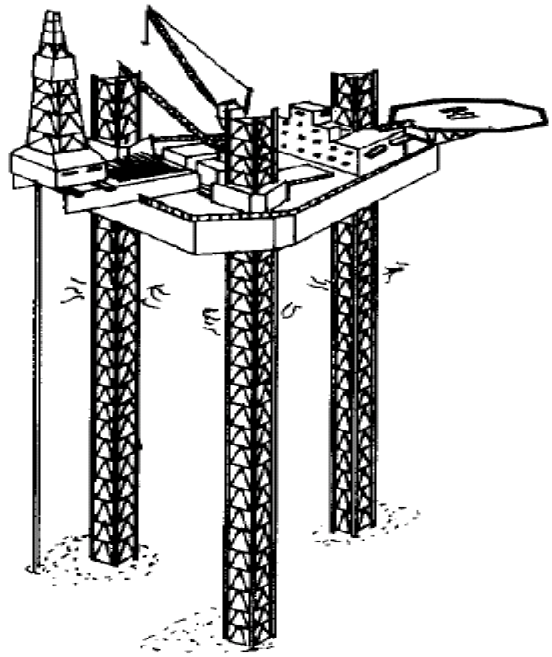

Figure 1.1 – c (Barltrop et al., 1991)

1.2.2 Semi-submersible platform

Semi-submersible is being classified as floating platform for water depth approximately more than 300m. A semi-submersible platform comprise of a decks, columns and pontoons. The semi-submersible was kept in placed either by a conventional spread mooring, taut mooring system or a dynamic positioning system. Spread moorings are system consists of lines with anchors at the ends. Whenever the buoyancy of a semi-submersible exceeds its weight, a pre-tension force system is adopted in the vertical cables. These vertical cables are able to eliminate the heave, roll and pitch motion of the platform induced by environmental loads. The platform does experienced surge, sway and yaw due to wave action but the vertical cables are reliable in keeping the platform permanently on station above subsea wells (Barltrop et al., 1991).

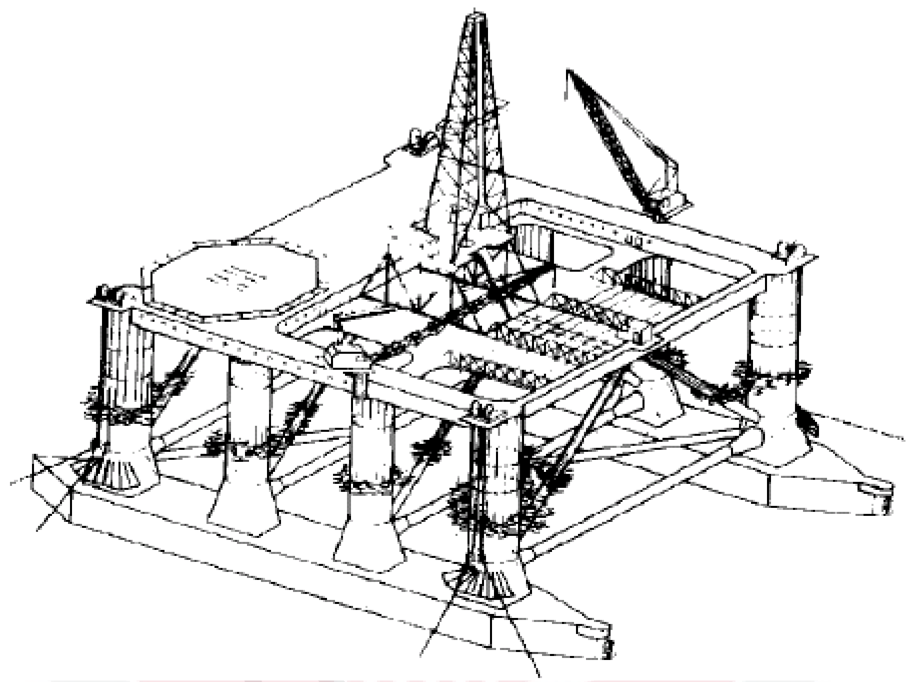

Figure 1.2 – Semi-submersible Platform (Barltrop et al., 1991)

1.2.3 Jacket platform

The jacket or “template” platform is truss-work tower consisting of tubular members with a deck on the top and piles into the sea beds. The decks loads were transferred to the foundation through the legs of which varies between four to sixteen. The jacket legs are stiffened by diagonal and horizontal bracing, which will carried some resultant horizontal forces. A typical jacket structures used for offshore oil drilling and production will encounter larger steady environmental forces from wind and current flows and from structure's self weight. Jacket will also be subjected to high levels of cyclic loads due to gravity waves; its sea bed equipment will be working in the presence of very high sea water pressure and the steel in the structures will have to survive sea water corrosion for long periods since large parts of the jacket structure will be difficult to accessed and maintained. Most of the jacket platform in the world was located in shallow waters. Jacket Platform is being classified as fixed offshore platform (Barltrop et al., 1991).

Figure 1.3 – Jacket Platform (Barltrop et al., 1991)

1.3 PROBLEMS STATEMENT

Fatigue induced failure is commonly found in offshore structure. For example, fatigue failures were experienced in an art horizontal brace in a Jackup drilling rigs operating in North Sea in 1967. The stress concentration factor measured for the critical cylinder to flare knuckle transition was 4.7 and a cumulative Miner-Palmgren damage ratio of 2.18 was obtained (Almar-Naess, 1985). On the other hand, by using the mean value of more recent SN data, the expected damage ratio is found to be nearly an order of magnitude less than the calculated damage ratio. However, by recognizing the scatter in fatigue life estimates, the above results simply imply a reasonable correlation between calculated and actual performance. Besides the cyclic wave loadings, the other factor which contributed to the failure was due to abnormal weld defect and inadequate fatigue design check during that time. The rig eventually collapsed in the Gulf of Mexico because the cracks propagated in the aft were coincident with the structural main bulkhead (Almar-Naess, 1985). In short, fatigue cracks if is not treated properly at its initial stage may lead to catastrophic failure due to substantial increase in stress concentration around the cracks.

Besides, in March 1980 the accommodation of a semi-submersible platform capsized in the North Sea. The main factor which contributed to the failures was the failure of brace mainly due to a fatigue crack propagation followed by a rapid and instable fracture (Almar-Naess, 1985). Fractured mechanics analysis has managed to prove that crack growth in the brace had accelerated very quickly from the initial stage. However, the cracks were not being treated at that time, and eventually lead to failures of others adjacent braces and column. The subsequent loss of its column led to flooding and capsizing within 20 minutes (Almar-Naess, 1985).

Other than that, a fixed offshore platform (jacket) was also found to be experiencing partial fatigue failures in the North Sea. The failure involved the complete failure of three joints between the diagonal bracing and the main legs situated approximately below the lowest astronomical tide (LAT) (Almar-Naess, 1985). The bracing tubes were completely detached from the legs, resulting from the failure having occurred through the bracing tubes and initiated at the toes of the tube-to-leg welds. The results show that fractures were initiated at the outside circumference at the weld toe through low stress high cycle bending in the vertical plane. Hence, underestimating of vertical wave loads seems to be the cause of fatigue problems.

Thus, the effect on fatigue failure in offshore structures had been chosen as the topic of study for this thesis.

1.4 OBJECTIVES OF PRESENT STUDY

The primary objectives of the present study are:

i) To demonstrate the applicability of using a simplified fatigue analysis program in estimating the fatigue life of the complex joint compared to the classical method of fracture mechanics.

ii) To study the effect of fatigue damage on the complex joints.

iii) To show the versatility of the simplified fatigue analysis method with respect to different joint details.

In a nutshell, this thesis will emphasized on the practical implications of fatigue design criteria for offshore structures.

1.5 SCOPE OF WORKS

The scope of works of this present study includes:

1) To review methods suitable for fatigue life calculation with emphasis towards the topsides joints of a semi-submersible platform.
2) To estimate the fatigue life by Finite Element Method based on the hot spot stress calculation using Abaqus Software version 6.6.1.

3) To developed a simplified fatigue analysis program that is able to provide an accurate estimates of fatigue life experienced by the joints.
4) To verify the developed simplified fatigue analysis program by checking it against the classical method by fracture mechanics.
5) To demonstrate the versatility of the developed simplified fatigue analysis program with respect to different types of joint details.

1.6 ORGANIZAION OF THE PROJECT

The review of literature regarding environmental loads on ocean structures , dynamic response of floating structures, stress concentration factors (SCF) by hot spot stress and comprehensive spectral fatigue analysis approach are presented in **Chapter 2.**

Chapter 3 presents the detailed classical method based on fracture mechanics and simplified fatigue analysis utilizing S-N curve methodology in estimating fatigue life of simple and complex joints of offshore structure joint connections. This includes the theoretical background on classical method and simplified fatigue analysis method.

Chapter 4 presents the design basis and design assumptions used in the analysis. Besides, it also presents the analysis results from both the classical and simplified fatigue analysis methods. The type of elements adopted for the detailed finite element model is also being discussed. Several parametric studies are carried out concerning the variation in tubular sizes and thickness.

Chapter 5 demonstrates the applicability of using a simplified fatigue analysis program in estimating the fatigue life of the complex joint compared to the classical method of fracture mechanics. Besides, it also demonstrates the versatility of the simplified fatigue analysis program with respect to different types of joint details. The effect of fatigue on the complex joint behavior is also being discussed.

Finally the thesis is summarized and concluded in **Chapter 6** with some recommendations for future research.

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