UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A COMPUTER PROGRAMME FOR THE STATIC ANALYSIS OF JACKET OFFSHORE STRUCTURES SUBJECTED TO WAVE AND CURRENT LOADING

SAMSUL IMRAN BIN BAHROM.

DEVELOPMENT OF A COMPUTER PROGRAMME FOR THE STATIC ANALYSIS OF JACKET OFFSHORE STRUCTURES SUBJECTED TO WAVE AND CURRENT LOADING

By

SAMSUL IMRAN BIN BAHROM

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Partial Fulfilment of the Requirement for the Degree of Master of Science

April 2006

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

DEVELOPMENT OF A COMPUTER PROGRAMME FOR THE STATIC ANALYSIS OF JACKET OFFSHORE STRUCTURES SUBJECTED TO WAVE AND CURRENT LOADING

By

SAMSUL IMRAN BIN BAHROM

April 2006

Chairman : Associate Professor Jamaloddin Noorzaei, PhD

Faculty : Engineering

Jacket structures are the most commonly used type of offshore structure in the world for oil and gas development. This thesis is concerned with the static response of a typical jacket structure subjected to wave and current forces using an innovative physical model of the soil-foundation-structure system. The motivation is to demonstrate the applicability of using a coupled finite-infinite element formulation to represent the far field media of the soil for offshore structural analysis.

Techniques to represent the environmental load and the physical model for static analyses of fixed slender offshore structures are reviewed. Based on the techniques suitable for engineering purposes, a computer code for calculating wave and current forces is written and its implementation into an existing multi-element finite element programme is outlined. For comparison purposes, the developed programmes are checked against a commercial software package through several model tests.

The range and versatility of the coupled programme is demonstrated through structural analyses of a typical jacket structure. The effects of different wave parameters, load combinations and a comparison of structural response assuming i) fixity at the base and ii) flexibility of elastic foundations are studied in detail with respect to displacements, axial forces and bending moments. The advantages and potential of using a coupled finite-infinite formulation for physical representation of the soil for offshore structural analysis are also pointed out and discussed.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk ijazah Master Sains

PEMBANGUNAN ATURCARA KOMPUTER UNTUK ANALISA STATIK STRUKTUR JAKET LUAR PANTAI TERDEDAH KEPADA BEBAN OMBAK DAN ARUS

Oleh

SAMSUL IMRAN BIN BAHROM

April 2006

Pengerusi : Profesor Madya Jamaloddin Noorzaei, PhD

Fakulti : Kejuruteraan

Struktur jaket adalah struktur yang paling biasa digunakan untuk pembangunan luar pantai. Tesis ini adalah berkenaan dengan reaksi statik sebuah struktur jaket tipikal yang terdedah kepada daya ombak dan arus dengan menggunakan model fizikal tanah-asas-struktur yang inovatif. Dorongannya adalah untuk menunjukkan keterterapan menggunakan pasangan formulasi unsur terhingga-tak terhingga untuk mewakili media jauh tanah kepada analisa struktur luar pantai.

Kaedah-kaedah untuk mewakili beban persekitaran untuk analisa statik serta cara-cara untuk memodelkan system struktur luar pantai jenis teguh telah dipertimbangkan semula. Berdasarkan kaedah-kaedah yang sesuai untuk kegunaan kejuruteraan, sebuah aturcara komputer untuk mengira daya ombak dan arus telah ditulis. Percantumannya ke dalam sebuah aturcara unsur terhingga-pelbagai juga telah dijelaskan. Untuk tujuan perbandingan, aturcara-aturcara yang dibangunkan ini telah diperiksa ketepatannya dengan sebuah pakej aturcara komersil.

Kebolehan serta julat aturcara yang dicantumkan itu telah ditunjukkan melalui analisa sebuah struktur jaket yang tipikal. Kesan-kesan parameter ombak, kombinasi beban serta perbandingan respons struktur dengan andaian i) kaki struktur adalah teguh ditapaknya dan ii) kefleksibelan asas diambilkira, telah dikaji dengan teliti dari segi pesongan, daya paksi serta momen lentur. Faedah serta potensi menggunakan pasangan formulasi unsur terhingga-tak terhingga bagi mewakili media tanah untuk analisa struktur luar pantai juga telah ditunjukkan dan dibincangkan.

ACKNOWLEDGEMENTS

I would like to express my sincerest gratitude and appreciation to my advisor, Assc. Prof. Dr. Jamaloddin Noorzaei, for his attention, invaluable guidance and for providing me with inspiration and motivation during the course of this study. Special thanks also go to my supervisors, Assc. Prof. Ir. Dr. Mohd. Saleh Jaafar, Prof. Dr. Waleed A.M. Thanoon and Assc. Prof. Dr. Shahrin Mohammad for always being accessible with friendly support.

I am grateful to Prof. Dr. J.R Chaplin (Southampton University, UK) for his helpful comments during the initial stages of this work. I am also grateful to Ir. Rafee Makbol (PhD candidate at Imperial College, UK) for providing the details of the structure used in this study and Mr. Shaharuddin Ismail (Senior Structural Engineer at MMC Oil and Gas) for making the SACS computer software available without which this study would have been exceptionally difficult.

Many people have helped me at various stages of this work, especially from the postgraduate room (too many to mention!). I would also like to extend my deepest gratitude to Mr. Khaled Bayagoob for his assistance in the initial programming aspects of this study. A global thanks to all my friends, especially: Johann, Khalid, Iskandar, Meor, Shairanizan and Zuhairin for your enjoyable company. To Haris, Adam and Hairol, I also thank you for your generous assistance.

Finally, my deepest thanks are given to my family for their continuous support, encouragement and prayers. It is to them that I dedicate this work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 General

Offshore technology has experienced a remarkable growth since the late 1940's, when offshore drilling was first used in the Gulf of Mexico. At the present time, a wide variety of offshore structures are being used, even under severe environmental conditions. These are primarily related to oil and gas recovery, but they are also used in other applications such as in harbour engineering and accommodation facilities (Reddy et al., 1991a). Difficulties in design and construction are considerable, particularly as structures are being located in ever increasing depths and are subjected to extremely hostile environmental conditions.

Offshore structures are quite different than those found onshore on account of sitting, size, forces acting on them and the nature of their foundations. The depth of water, foundation characteristics, and the nature and the size of the equipment to be installed on the platform deck determine the type, size and dimensions of the structure to be constructed. The components that make up any offshore structure could be classified as (Reddy et al., 1991a):

1) Superstructure – Houses the deck and functional equipment such as drilling equipment, processing plant, helicopter pad, personnel quarters etc.
2) Substructure – Supports the working space and transmits the load from the working space to the supporting foundation.

3) Foundation – Supports the sub and superstructure and transmits the load to the soil and hard rock beneath.

1.2 Classes of offshore structures

Before proceeding to describe the content of this thesis, it is appropriate to classify briefly, the wide variety of offshore structures that are in current use. The major offshore structures used in the various stages of oil recovery include mobile and fixed drilling platforms, as well as a variety of supply, work and support vessels (Sarpkaya et al., 1981). Ships and ship like marine vessels are also used extensively, but they are treated within the field of naval architecture and are not of primary concern in the present study.

1.2.1 Jack-up units

Jack-up units are mobile exploratory drilling rigs, usually for drilling oil and gas wells in water depths up to about 100 m (Ngo-Tran, 1996). A jack-up rig usually comprises of three legs that can be moved up or down as shown in Figure 1.1. The rig is floated to the well site with its legs elevated and when it reaches the site, the legs are lowered and jacked into the sea bottom to produce a foundation. A process of preloading is then started with water being pumped into ballast tanks in the hull, forcing the footings to penetrate deeper into the seabed. Once the ballast tanks are emptied, the hull is jacked to its operational elevation.

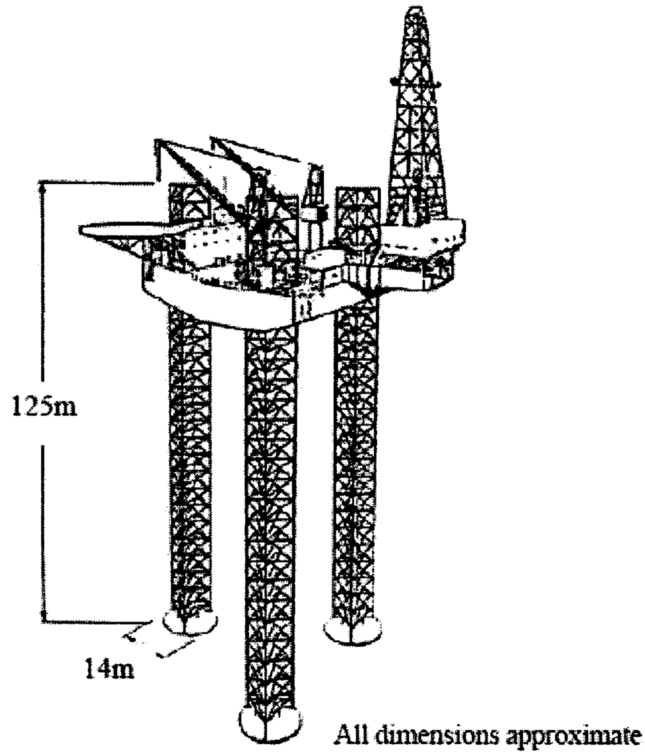

Figure 1.1: A typical three-legged jack-up rig (after Martin, 1994)

1.2.2 Jacket platforms

The jacket or template structure and extensions to them are the most common platforms in use (Sarpkaya et al., 1981). Jacket platforms are employed to meet the needs of offshore drilling and production operations. A typical jacket platform comprises of a space frame structure, with pipe piles driven through its legs. The superstructure or "topside" loads are directly taken by the piles and transferred to the soil. These piles must also be able to resist tension as the hydrodynamic forces on the structure have a tendency to cause overturning (Dawson, 1983).

Some jacket platforms may contain enlarged legs to provide for self-buoyancy during installation. Figure 1.2 shows a diagram of such a platform. These structures are typically built for water depths of 150 to 250 m. One of the world's tallest jacket platforms is the Bullwinkle platform, situated at the Gulf of Mexico in water depth of 492 m (Barltrop et al., 1991).

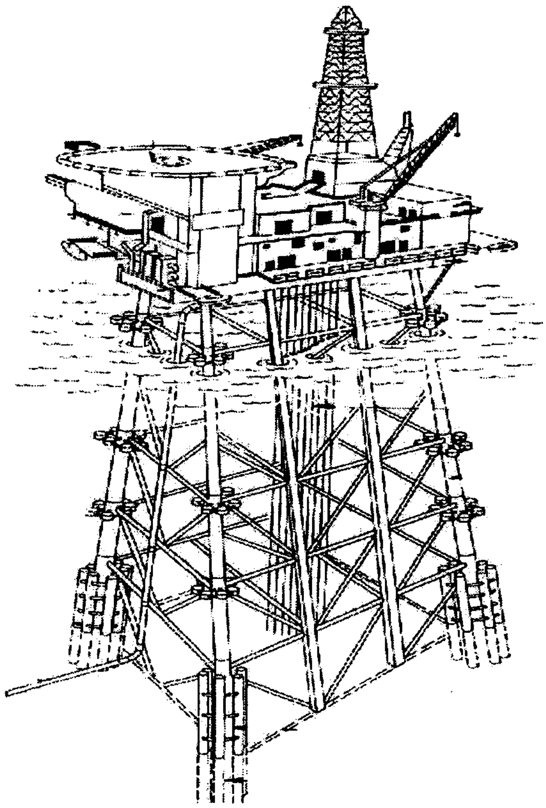

Figure 1.2: A typical jacket-type platform (after Patel, 1989)

1.2.3 Gravity platforms

Gravity platforms depend on their massive weight, rather than on piles, for their stability. They are thus suitable to sites with over-consolidated soils (Sarpkaya et al., 1981). Gravity platforms are usually constructed from concrete, although steel or combinations of both steel and concrete have also been used. The most familiar gravity platforms are comprised of a large base, which has the capacity for significant oil storage, and which supports a few columns as illustrated in Figure 1.3. A typical gravity platform may have a base diameter of 90 to 120 m, and have the capacity to store 1 million barrels of oil. Gravity structures can weigh over 850,000 tones and have been placed in water depths varying from 70 to 350 m (Reddy et al., 1991a).

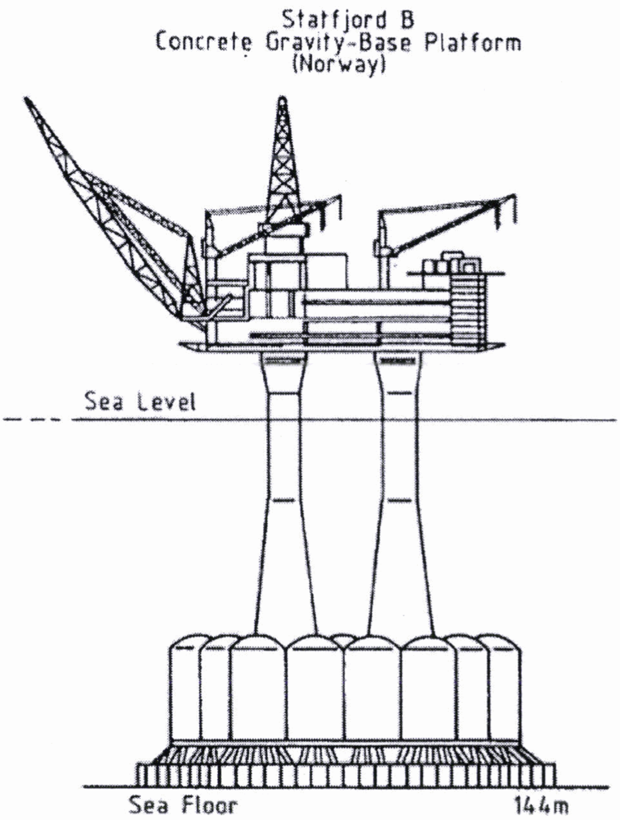

Figure 1.3: A typical concrete gravity platform (after Ngo-Tran, 1996)

1.2.4 Tension leg platforms

As offshore development moved beyond 300 m water depths, newer concepts for deep-water platform have evolved. Tension leg platforms, articulated towers and Guyed towers emerged as structures suitable for large water depths. All these structures are compliant, which is they move slightly with the waves instead of being rigid with respect to the wave forces. The tension leg platform (TLP) concept is a development of the semi submersible concept, in which heave, pitch, and roll responses are virtually eliminated while the platform is fairly free to move in the horizontal plane. TLPs could be anchored by a gravity base, driven piles or drilled and grouted piles. TLPs have been designed for water depths varying from 150 to 1500 m (Rajabi et al., 1985).

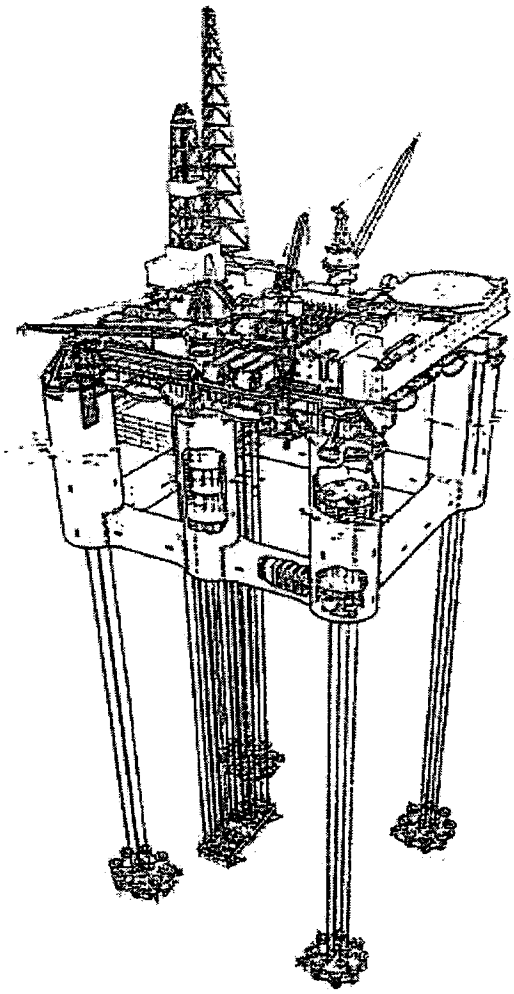

Figure 1.4: Hutton tension leg platform (after Rajabi et al., 1985)

1.3 Offshore structures in Malaysia

Malaysia's oil gas deposits are situated mainly offshore the states of Sabah and Sarawak (East Malaysia) and offshore the east coast of Peninsula Malaysia. Petroleum exploration of offshore Malaysia began in the 1950s with the introduction