Motion Responses of Float-over Installation Barge

by

Nur Zaidah Bt Mohd Yunos

Dissertation submitted in partial fulfilment of
the requirement for the
Bachelor of Engineering (Hons)
(Civil Engineering)

JANUARY 2011

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Motion Responses of Float-over Installation Barge

by

Nur Zaidah Bt Mohd Yunos

A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

____
(Muhammed Mubarak B Abdul Wahab)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources and persons.

NUR ZAIDAH BT MOHD YUNOS

ABSTRACT

'Motion Responses of Float-over Installation Barge'. This project is basically to investigate the motion responses triggered by the float-over installation barge that will execute in Caspian Sea, Turkmenistan. The model test has been developed to predict the installation barge motion responses, the load distribution between the barge and the jacket during the installation and the mooring lines tension. The installation barge model is fabricated based on 1:50 scale. The model test is subjected to regular and random waves with variations in value of water draft and wave directions in order to explore the 6 degrees of freedom of the barge (surge, heave, sway, pitch, roll and yaw). The total number of six experiments are carried out consist of regular and random wave; wave height; 0.01m and 0.0372 m; and wave period; 0.99 sec for both waves. All of the six experiments are subjected to 180° wave direction. Numerical analysis of the barge responses is subjected to heave and surge motions based on barge prototype conditions. The result of the numerical analysis and model test are presented in terms of RAO.

Acknowledgment

...In the name of Allah, the most merciful and gracious...

Special thanks to;

Supervisor;
Muhammad Mubarak B Abdul Wahab

Co – Supervisor;
Prof Dr Kurian V John
Dr Allan Magie

Family;
Mohd Yunos B Ariffin, Azimah Morni Bt Nee

Friends;
Nurul Husna Bt Baharuddin

Lab Technologist;
Meor Asniwan B Mew Ghazali, Mohamad Idris B Mokhtar

"The ingredients of an achievement lie on the commitment, patient, determination, good cooperation and the very well combination from all of us..."

- Thank you -

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS

Chapter 1: Introduction

Chapter 2: Literature Review

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Topsides vary in weight, size and configuration. Small topsides have been traditionally installed as one unit using low-capacity crane vessels and jack-ups. Medium to large topsides have been either modularised to facilitate installation with small crane vessels, or built as integrated topsides and installed either by means of heavy-lift crane vessels, which cost a lot or by floating them over the substructure.

Integrated topsides have become popular due to the reduced offshore installation, hook-up and commissioning durations. However, the weight and size of the integrated topsides installed to date has been limited by the capacities of the installation methods used. Although the "name plate" capacity exceeding 14,000 metric tons is being advertised in the market; the geometry, hook reach, the uncertainties in centre of gravity and the water depth restrictions limit the ultimate lifting capacity to a single piece of about 10,000 metric tons. In addition, floating cranes are sensitive to the prevailing weather conditions at the installation site. For a swell (long wavelength ocean surface waves) dominated offshore site, it is not unusual for a floating crane to be de-rated 40-50% from its rated lift capacity. If topside heavier than 10,000 metric tons is to be installed using floating cranes, it will have to be divided into smaller modules that can be lifted individually. In such a scenario, offshore hook-up and commissioning will need to be extended at a premium cost.

Existing technology allows for float-over deck installations of weight well in excess of that feasible with the largest crane vessels available to date, in sheltered as well as unsheltered or open waters. In recent years the concept of float-over installation has matured. With the help of a lengthening track record and benefits over lift operations, the float-over deck installation is taken into account as reliable means of installing the assets. In the eighties only about five float-over had been executed, while nowadays about five float-over are executed each year. The capabilities have developed such that they are competitive to crane vessels from two perspectives:

- Environmental conditions: Both crane vessels and float-over have now stringent wave height restrictions. Especially swell conditions are still problematic for both installation methods.
- Integrated deck weight: Crane vessels are available having lifting capacities up to 14,000 tons, while float-over have been executed up to 18,000 tons.

1.2 Problem Statement

In real life of practices, the 7575 metric tonne barge will transport and install ODP-A Topside onto its jacket in the Caspian Sea. Lot of challenges need to be faced before ODP-A stand on its jacket safely. The ballasting and de-ballasting process are not easy process since the tanks have the massive areas. The gaps between the barge and the jacket during the mating process are very small that any error cannot be toleranced and there is where fenders system is needed. The mooring system is strictly concerned in order to control the barge position and orientation as it enters the jacket. Caspian Sea is a huge land locked body of water, the external forces induced by ocean current, wind and waves are being concerned.

Model test is conducted in order to study the motion responses experienced by the barge to make sure the successfulness of the float-over installation operation. In designing the barge model, it is very crucial that the model is properly scaled (1:50) in such a way that it is able to show all the main mechanism and allow neglecting some of the particulars for minimalism. The model is used to collect data covering the six degrees of freedom (heave, surge, yaw, pitch, sway, roll) that are important in the float-over installation.

The designing of the 1:50 scaled barge model will also led to practically higher level of the understanding in the modelling criteria specifications stated by theory to enhance the predominantly comparable results generations with regards to the rule of quantifying, scaling model responses, conventional modelling techniques, and the capabilities of the wave maker in the laboratory facilities to produce desired scaled wave height and period for the premeditated testing method.

1.3 Objective

The objective of this project is to investigate the motion responses (the 6 degrees of freedom: heave, surge, pitch, roll, yaw and sway) of the float-over installation barge based on theoretical study using numerical analysis and model test. The oceanographic data used for the numerical analysis and model test is based on Caspian Sea oceanographic data.

1.4 Scope of Study

A model of a barge with the scale of 1:50 is successfully fabricated by Technip Geoproduction (M) Sdn Bhd. The barge model is fabricated based on such scale in order to make sure the accuracy of the data collected and also to suite with the wave tank condition A series of model test of frequency domain analysis will be carried out in order to examine the 6 degrees of freedom (surge, pitch, heave, roll, sway and yaw) trigged by the barge during the float-over installation of topside. The scenario of the float-over installation of topside is performed by ballasting the barge using the steel plates placed inside the tanks based on the series of water draft. The motions and loads triggered by the barge will be studied to find out the series of ballasting load to transfer the topside onto the jacket. The findings of the load will be studied to make sure the barge impact toward the fender system at the fixed jacket is minimal as possible.

. The model of topside and jacket structure will be based on Owez Drilling Platform A (ODP-A). ODP-A will be located at Owez Field in Block 1B, Caspian Sea located approximately 70km south-west of Kiyanly, offshore Turkmenistan. Technip Geoproduction (M) Sdn Bhd will assist Universiti Teknologi PETRONAS (UTP) in conducting the model test. The Metocean data of Caspian Sea will be used as design data and parameter. Numerical analysis using Microsoft Excel also will be considered.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Float-over installation method is experiencing a steady surge in new contracts nowadays. The consultants and contractors all over the world are enhancing their engineering skills in float-over installation as it provides schedule and cost advantages.

Float-over installation for topside procedures are varies depended on the project budget, location of the installation, the dimension of the topside and other technical aspects as well. A typical float-over operation basically should experience the ballast and de-ballast stage of the barge, the aligning stage, the load transfer stage and the separation stage. The equipments used for the float-over installation also vary depended with the same factors as the installation procedures. Basically, the equipments used for the float-over installation are the barge, the mooring line and fenders. There are other several aspects that need to be taken care off before the installation such as the environment condition and forces considerations.

2.2 Turkmenistan Block 1 Gas Development Project

PETRONAS Carigali (Turkmenistan) Sdn Bhd (PCTSB) the wholly owned exploration and production subsidiary of PETRONAS (Malaysia) at the moment is developing Turkmenistan Block 1 Gas Development Project at the Caspian Sea, Turkmenistan. Universiti Teknologi PETRONAS has the chance to further study about the installation of Owez Drilling Platform A (ODP-A) topside. ODP-A is located at the Owez Field in Block IB, Caspian Sea located approximately 70km south-west of Kiyanly, offshore Turkmenistan. PCTSB has engaged Malaysia Marine and Heavy Engineering Sdn Bhd, Technip Geoproduction (M) Sdn Bhd to perform the detailed design of the Owez Drilling Platform A (ODP-A) which comprises the Main Platform and the Free Standing Conductor (FSC) Platform. PCTSB also engaged with Aker Offshore Oy to perform detailed design of the installation barge for the float-over installation of ODP-A Topside over the four-legged fixed jacket.

2.2.1 Facilities Concept and Description

The jacket is a 4-legged fixed structure with a total of four (4) skirt piles, one (1) at each outer corner. The four (4) corner skirt legs are spaced at 23m x 30m. The inner leg spacing is 14m x 12m. All legs are vertical – no batter.

The topside legs are spaced at 14.0m in the east-west direction and 12.0m in the north-west direction, centre to centre. The topside shall be mated with the substructure by a float-over method using a purpose designed and fabricated forked barge. The forked arrangement, at the stern of the barge, has been designed to transport the topside. The barge shall be positioned so that the fork encompasses the jacket and the topside is directly over the jacket for the float-over sequence to commence. The barge shall then be ballasted so that the topside load is transferred to the jacket structure. Jacket fenders with protection plates shall be fitted to the jacket outside legs prior to installation.

2.2.2 Installation Barge Description

The barge, shown in Figure 3, is 159.76 m length and 30.0 m width with modified 45.72 m width fork like stern. The slot is 15.72 m wide and 29.76 m deep. Side depth is 8.00 m. The barge is equipped with two types of stability box; one pair is near the stern while another pair which is removable is near the bow. The water line area of the barge is 5391 m2 with the fixed stability boxes and 4890 m2 without the stability boxes. The barge has 31 individual compartments in the hull and 6 individual compartments in each stability box. These compartments are utilized when the barge is used for different marine installation and transportation purposes.

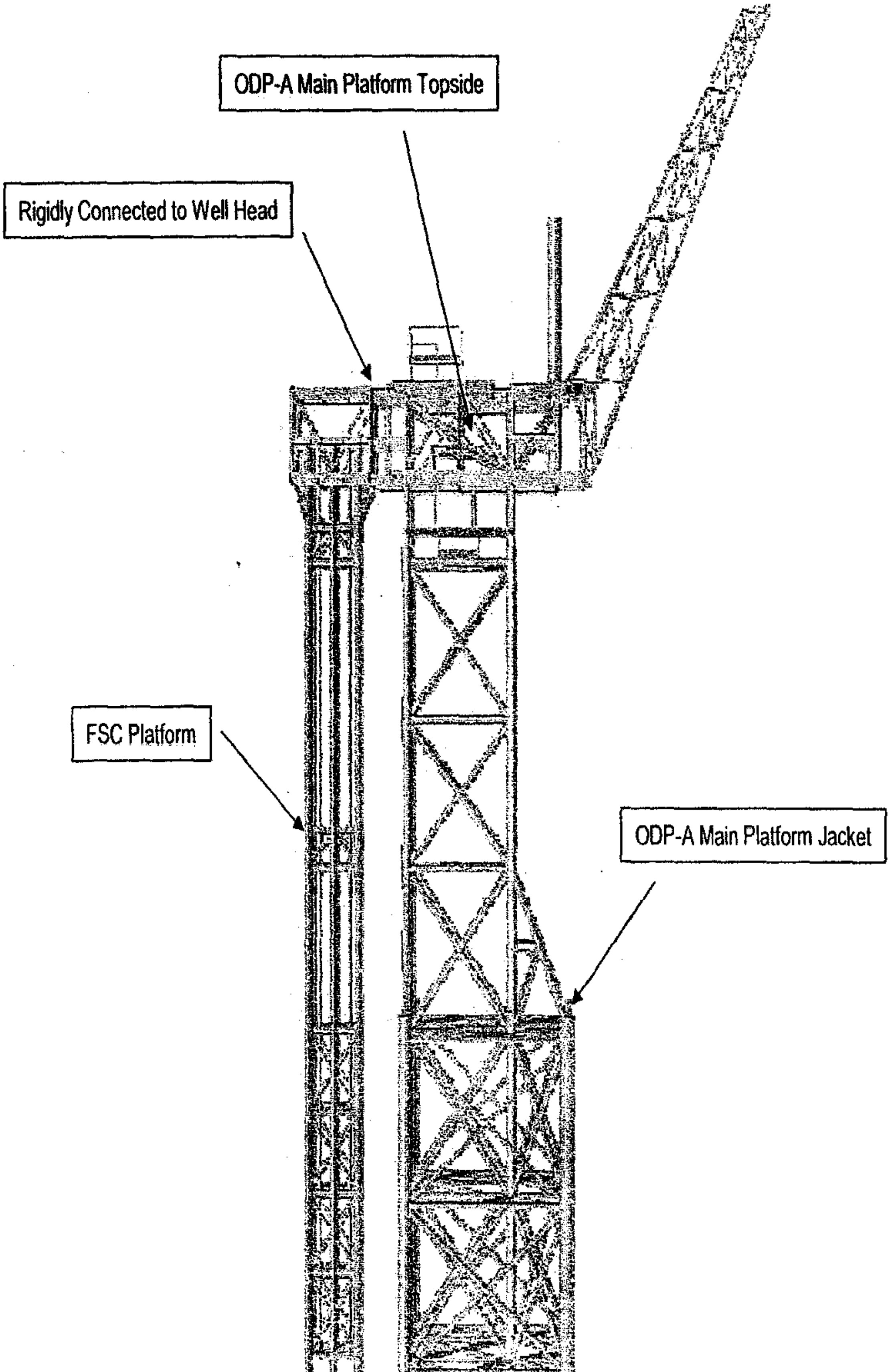

Figure 1: South Elevation of FSC Platform connected to the Main Platform

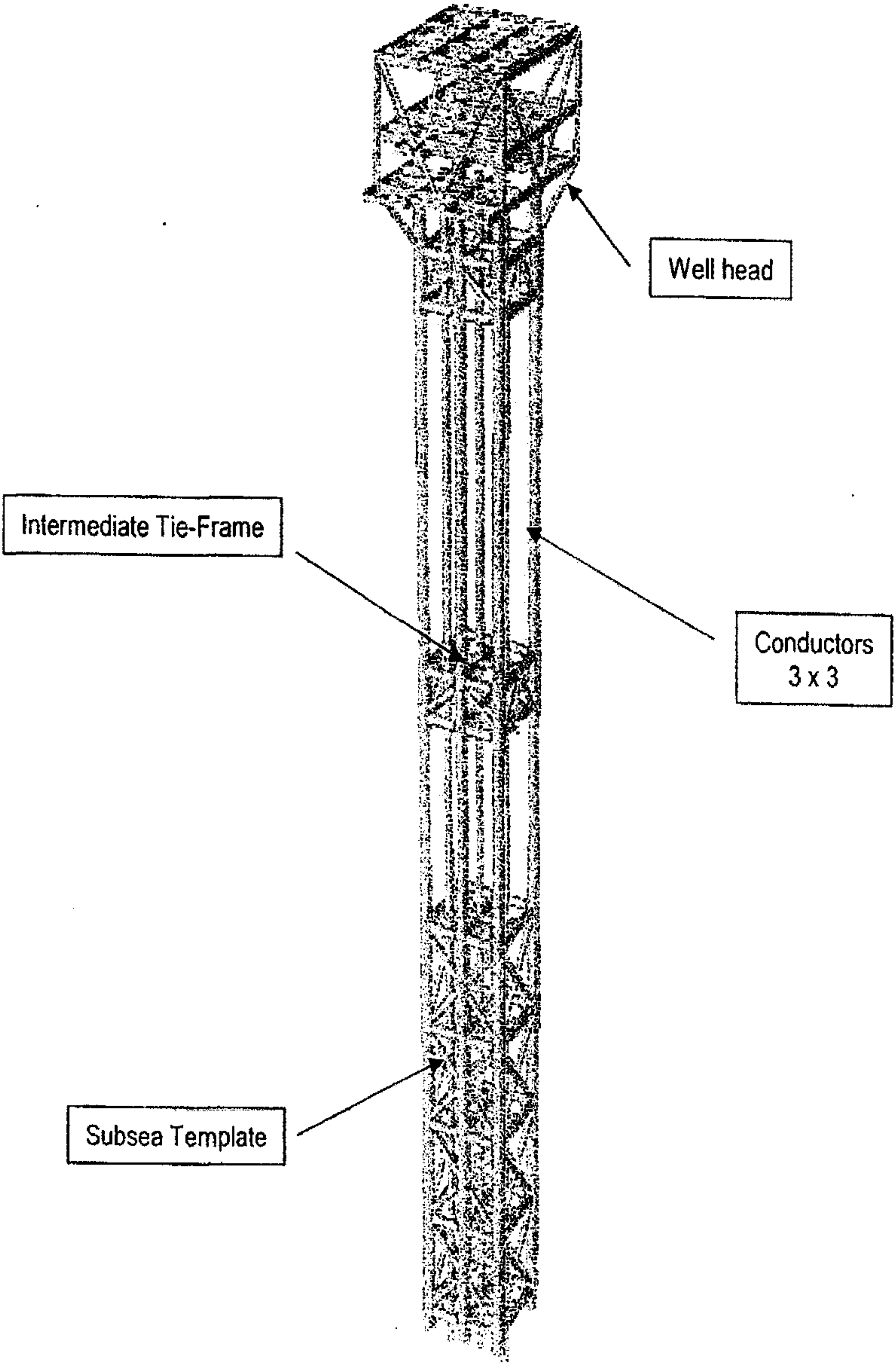

Figure 2: Isometric View of FSC Platform

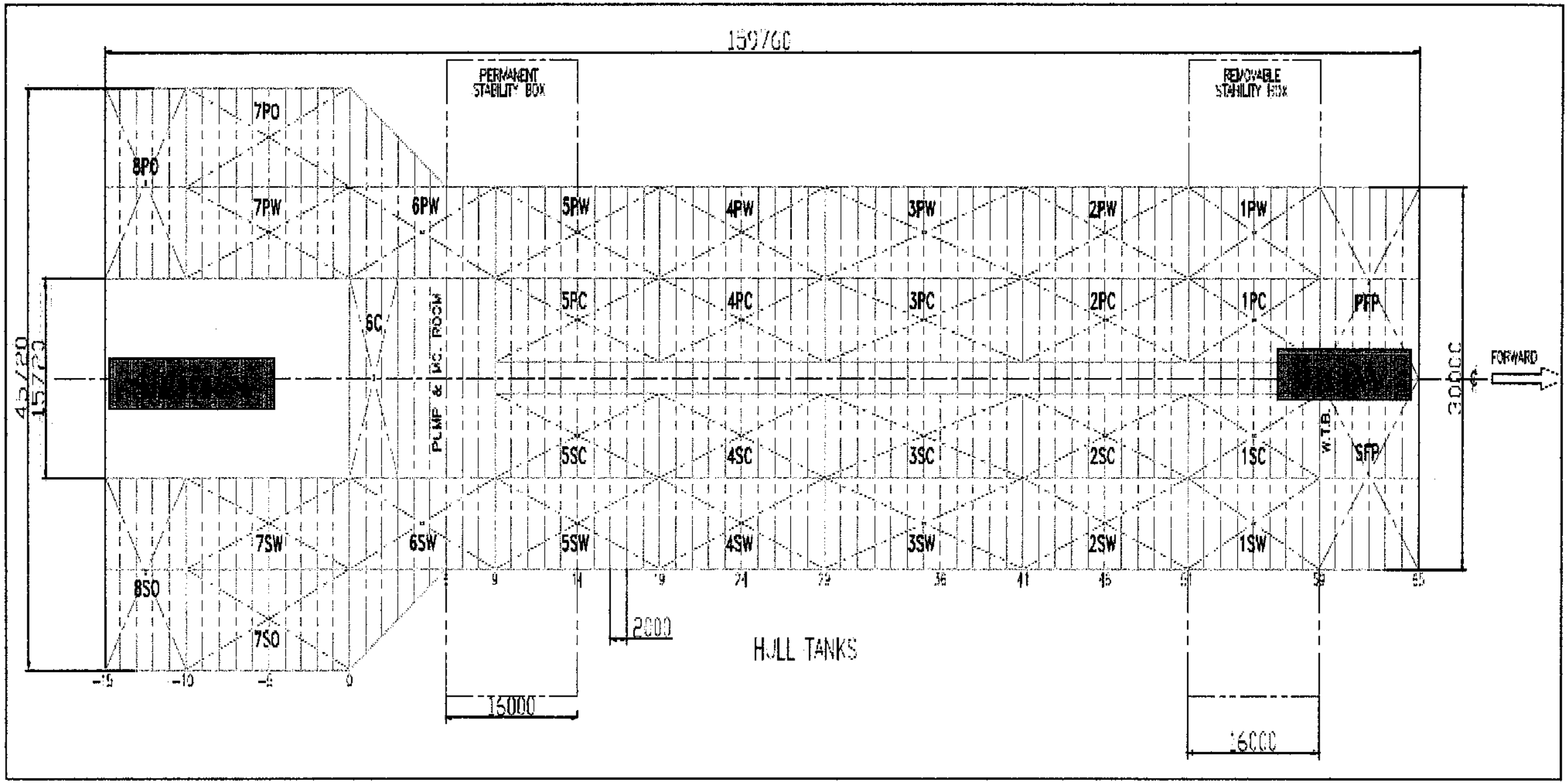

Figure 3: Plan view of installation barge

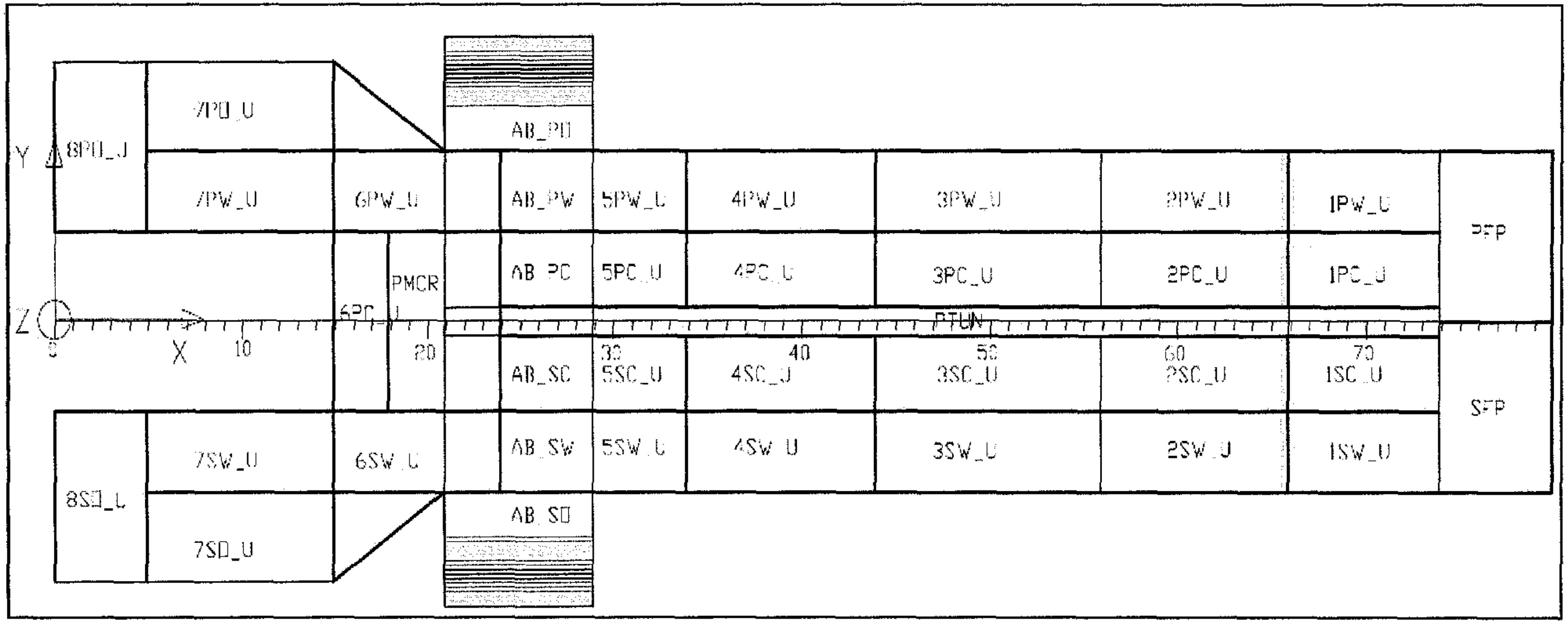

Figure 4: Barge Compartment Plan

2.3 Historical Project Execution of Float-over Topside Installation over the Fixed Jacket

The float-over topside installation over the fixed jacket has become increasingly popular alternative to traditional modular topside installation. Every oil and gas company that practiced this type of installation has their own state of the art of float-over installation depend on the project condition. Some illustrative projects showing the possibilities of float-over deck installation are presented below:

2.3.1 Shell's Malampaya Platform, Malaysia

KBR (Kellogg, Brown and Root) is one of the pioneers of the float-over installation method, initiating research as far back as 1977 for the North Sea Market. The company envisioned developing float-over as a cheaper and more flexible alternative to heavy lift installations. In general, a platform's installation option is ultimately dictated by its end design. But in water depths ranging from 10 to 200m (the ideal range for a float-over installation), there are distinct advantages to doing a float-over.

KBR had the experience of installing the M1 and M3 platforms for Shell at the offshore Malaysia, in 1995. These projects, which were the first true float-over installations KBR designed. The decks, weighing in at 6,045 and 7,550 tons respectively, were then towed out to their jackets, which were already fixed to the seafloor, and floated between the jacket legs until the mating points between the deck and the jacket were aligned. This process of moving the deck into position over the jacket is a painstakingly slow one, often taking hours to accomplish. The actual float-over moves so slowly because there is very little margin for error. The spacing between the deck and the jacket legs is kept intentionally as small as possible, typically on the order of 0.5 m on each side, to avoid striking the deck against the legs. [5]

Installation of Shell's Malampaya platform in March 2001. Courtesy KBR

Figure 5: Shell's Malampaya Platform

As the deck moves over the jacket, it is aligned with special catch points on the jacket where the pieces will mate. There is a slight clearance between the deck and the jacket at these mating points. Once the deck and jacket's mating points are aligned, the transportation barge is ballasted with water, which lowers the deck onto the jacket. To complete the deck/jacket link, mating joints are designed to transfer the final load rapidly from the barge to the jacket and create a gap between deck and the transportation steel. The deck weight is quickly transferred to the jacket.

KBR have recently completed the design of the Azeri-Chirag-Gunashli (ACG) complex for Azerbaijan International Operating Company (AIOC), which consists of seven platforms. Six of the seven platforms have large float-over decks installed over fixed jackets. They had designed program for this project wherein the company would use the same barge, Saipem's *stb-1*, to install each platform. The barge would make separate trips to each offshore site to deliver first the jacket and then the deck. These installations occurred year after year between 2004 and 2007 until they were all completed. They also used the same spacer frame between the deck and the barge.

2.3.2 Arthit PP Deck, Thailand

In December 2007, the 17,500-metric ton, Arthit PP deck was installed over the substructure in a single piece by a using McDermott transportation and installation barge Intermac-650 (I-650), specially designed for float-over installation. The Arthit Field is located in the Gulf of Thailand in 80 meters of water.[2]

A number of technical challenges were overcomed to accomplish the successful and safe float-over. A single-piece deck installation using the float-over technique provides significant advantages over other methods of deck installation for heavy topsides, especially in areas of the world where access to heavy construction equipment, trained labour and supplies are not readily available or reliable. Time spent on offshore hook up and commissioning is also minimized by utilizing a single-piece installation.

McDermott engineers developed a simulation model to predict the I-650 barge motions and the loads between the deck and the barge, as well as the tensions in the mooring lines. Model tests were completed and the simulation method was verified. The analysis tools developed yielded reliable and repeatable results in selecting and designing components critical to the success of the float-over. Such components include the mooring system, the shock absorbing cells, sliding surfaces and vessel ballasting systems, and with careful analysis, risks can be minimized and the installation method could be guaranteed as successful.

Figure 6: Arthit Deck – as the barge enters the jacket slot

In the analysis of the float-over operation, the vessel motions and the resulting loads in the Leg Mating Units (LMU), Deck Support Units (DSU) and mooring lines needed to be estimated accurately so that further fabrication and design efforts could continue for these components. The principal software used at J. Ray is MOSES, Marine Operational Structural Engineering Software (Ultramarine) for simulating marine operations. The software allows modelling and simulation of a number of bodies connected in a variety of ways, and the bodies can be subjected to wave, wind and current action.

To predict the motions and related connector loads, 3-D time domain analysis was used. The float-over system was modelled as three independent rigid bodies with different types of connectors. For the hydrodynamic calculation, a 3-D diffraction method was used. For most motion analysis software the float-over barge hull needs to be defined as a collection of panel plates. The topsides can be modelled as a rigid body. The program needs to have means to connect the topsides and the vessel using rigid and flexible connector members as well as the mooring lines. [2]

The analysis program will then assemble all the components together:

- The barge is connected to the seafloor by mooring wires.
- The barge is connected to the jacket using mating lines.
- The topside is connected to the barge using rigid connecter simulation the stiffness of the DSUs.
- DSU will contain vertical gap spring and lateral spring element to simulate a frictional surface between the topside and the barge.
- The topsides will be connected to the jacket using LMUs.
- LMUs will have a nonlinear gap spring element considering mating cone and receptor geometry and ability to generate side loads.

By applying wave, wind and current environment, the motions of the bodies under study (in this case, the float-over vessel and the topsides) the forces in the connectors can be predicted. Statistical analysis of the results provides the upper, lower and nominal values and thus the design basis.

Figures 5, 6 and 7 below show the result of one of the wave simulations, for a typical 1000 second time span. Figure-5 shows when the initial gap is closed and the deck weight transfer is about to start. As one expects, the motions of the barge bring the tip of the deck legs into contact with the top of the jacket legs, thus the LMU loads spike occasionally due to shock loads with a corresponding drop in DSU loads. As the weight transfer reaches 50%, the loads are equalized between the LMU and the DSU, as no shock loads are applied, the spikes are less pronounced. As the whole deck weight is transferred, the LMUs take the whole deck load and DSUs are unloaded; barge motions create shock loads on the DSU this time.

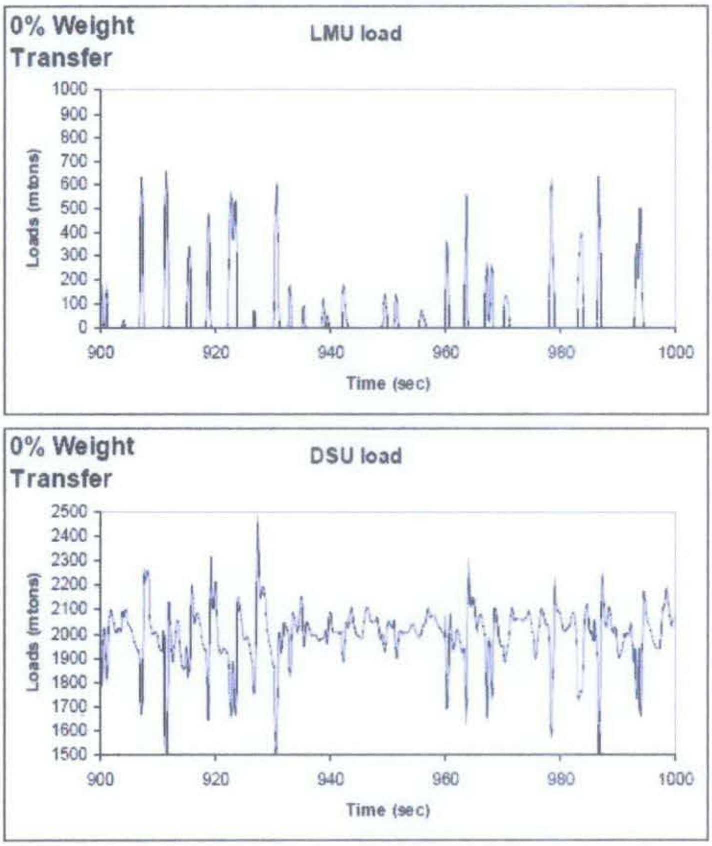

Figure 7: Typical LMU, DSU Load Variation at 0% Weight Transfer

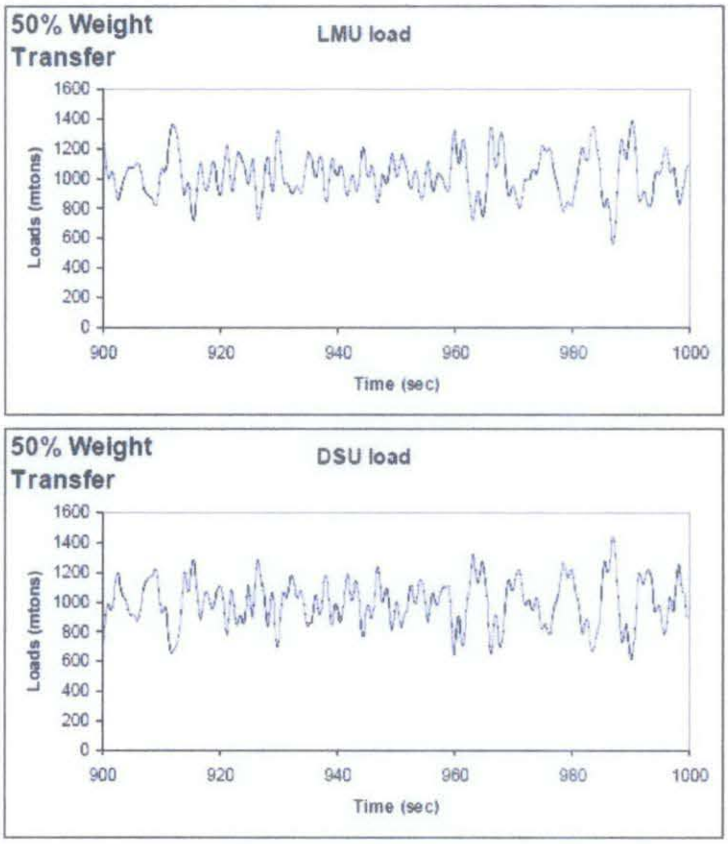

Figure 8: Typical LMU, DMU Load Variation at 50% Weight Transfer

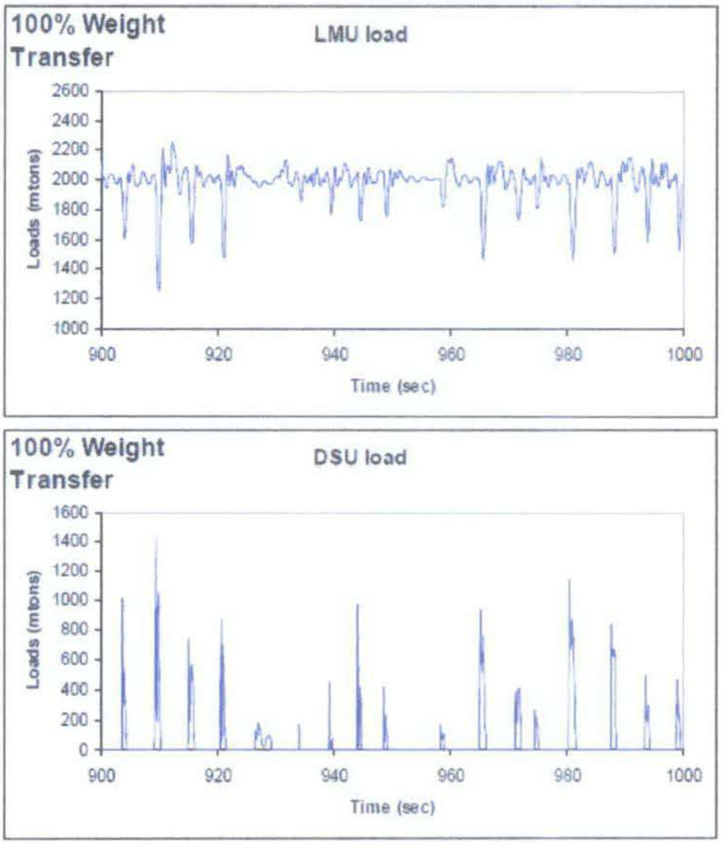

Figure 9: Typical LMU, DMU Load Variation at 100% Weight Transfer

In most instances, computer simulations will not be enough to assess the feasibility of the float-over and establish the design criteria for the individual components. Model testing is a good way to verify that the computer simulations do accurately define the reality and no surprises are incurred. A six-week model testing program was conducted at Offshore Model Basin (OMB) in Escondido, CA in December 2005 through January 2006. The model scale must be selected carefully. The wave heights and the swell heights to be used in prototype scale are small, less than two meters. Scaling the waves to model scale will produce very small waves at low periods which will be test facility limited and add further complications.

For these tests a model scale of 1:50 was used. This scale is probably the upper limit for float-over tests. Even at that scale, the model scale waves were 3-4 cm in height and one second in period. Creating such a small wave in a wave tank is not an easy task.

Figure-8 shows the model test configuration for a float-over using I-650. The jacket is visible with load cells. Mooring lines are also visible; however, to simplify the model testing, the jacket legs are reduced to four and the mooring lines were also reduced to four.

Figure 10: Float-over model using I-650

Modern instrumentation techniques and digitized data collection offer great advantages. Significant amounts of operational data can be collected and processed easily. In these tests, the motions of the topsides and the barge were measured separately. The optical tracking system was used for the 3-D motion measurements and it allowed for determination of the velocities and accelerations.

The LMUs and the DSUs were instrumented using 2-D and 3-D load cells measuring contact forces. Load cells were installed on the mooring and the mating lines recorded the line tensions.

Typical wave staffs were used to measure wave heights in three locations in the basin so that the generated wave parameters could be derived for each test. The test plan included, generation of random amplitude operators (RAOs) for the barge, system natural period tests, irregular waves with and without swell component for float-over conditions, irregular waves for tow sea keeping condition and towing resistance tests.

2.3.3 EAP GN-Deck – Mobil Producing Nigeria

The GN-deck is part of the East Area Project offshore Nigeria. At 18.000 tons, the module is the heaviest installed in West- African swell conditions using an active load transfer system.

The float-over has been executed early November 2005. This date fitted in the West-African installation season running from early November to end of March. For the float-over Technip used the UNIDECK system, an active hydraulic system to achieve an initial load transfer in a time span of only one minute. The system is also used to achieve an instant gap after load transfer is completed. The load transfer sequence is presented in Figure 10. The 42.00 m wide self-propelled installation vessel Black Marlin has been used for the installation of the module. The vessel carrying the GN-deck is presented in Figure 12.[1]

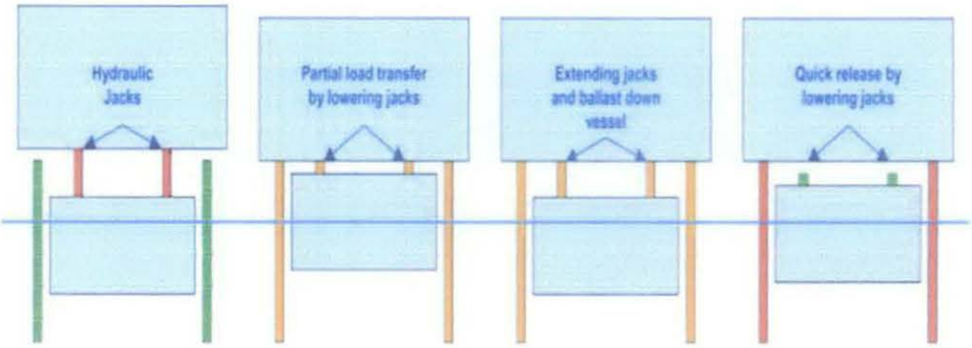

Figure 11: Load Transfer Sequence for Technip UNIDECK System

Figure 12: Self-propelled installation vessel Black marlin prior to entering the East Area Project GN Jacket

2.3.4 EPKE-Nigerian National Petroleum Company

The installation of the 4100 tons EPKE module has been executed in 1997 in West-African swell conditions offshore Nigeria. The float-over has been executed using the ETPM SMART LEG active load transfer system. The active load transfer system initiates first contact between the deck legs and the jacket legs by activating hydraulic jacks accommodated in the deck legs. These jacks are presented in Figure 13. [1]

By locking these hydraulic jacks when the installation vessel is on top of the wave, a smooth initial load transfer from the vessel to the jacket is accomplished. When the load transfer is close to completion, deck supports will be instantly removed by using explosives. By removing these deck supports, two objectives are achieved:

- Instant completion of load transfer;
- Instant clearance between installation vessel and module.

The active deck supports have been presented in Figure 14.

Figure 13: Active hydraulics accommodated in deck legs.

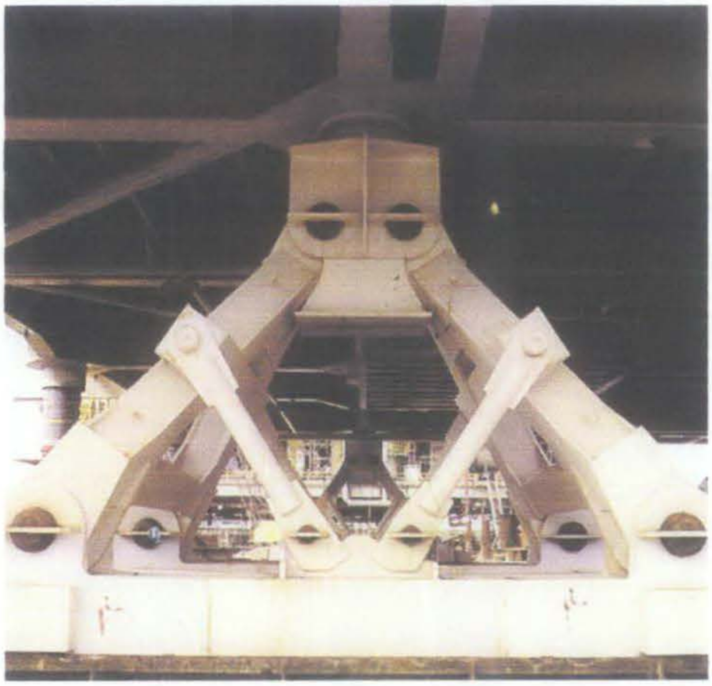

Figure 14: Active deck supports on installation vessel

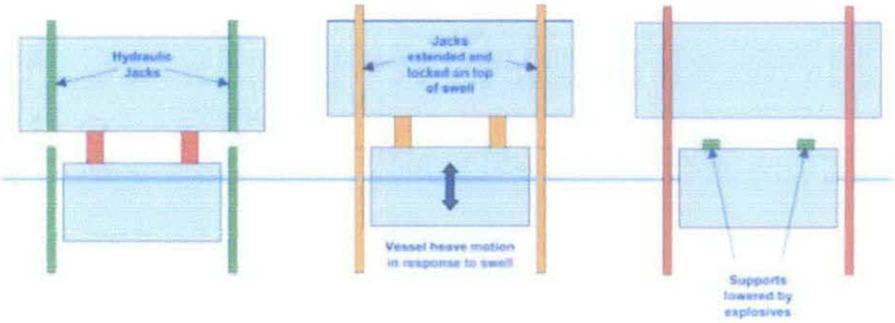

Figure 15: Load transfer sequences for ETPM SMARTLEG system

2.4 Float-over Basic Installation Sequence

For better understanding of the advantages and disadvantages of the float-over deck installation over semi submersible crane vessels, a brief introduction to the float-over concept is presented.

2.4.1 Load-Out

The load-out is the starting point of a float-over deck installation. The integrated deck will be build on-shore and needs to be loaded out onto the installation vessel. Load-outs can be performed either by bogie or by the use of skid tracks. Figure 16 presents a skidded load-out operation while Figure 17 presents the bogie load-out operation. [1]

Figure 16: Skidded load-out

Figure 17: Bogie Load-out

Requirements for the load-out stage are governed by the following parameters:

- Integrated deck weight
- Tidal range;
- Quayside dimensions.

2.4.2 Sea Transportation

After completion of the load-out, the integrated deck has to be sea-fastened on board the installation vessel prior to commencing sea transportation. One aspect of the transport that's always critical for a float-over transport is stability of the vessel. The stability is mainly driven by the width and depth of the vessel:

- Increase in width results in increased initial stability and stability range;
- Increase in depth results in increased stability range.

An increase in initial stability results in a reduced roll period. In general this results in higher acceleration levels and consequently, increased sea-fastening loads. An increase in vessel width results in an increased jacket slot width requirement. This has unfavourable consequences for the jacket design. Therefore it can be concluded that the vessel resulting in optimum jacket and sea-fastening design is the vessel having the minimum width resulting in compliance to stability requirements.

2.4.3 Float-over Stand-off

After completion of the transit, the vessel needs final preparations prior to commencement of the actual docking operation of the vessel. During this stage the following preparatory works need to be executed:

- Cutting/removal of sea-fastenings;
- Start-up of mooring/docking/mating winches;
- Start-up of equipment for monitoring motions, weather etc.;
- Start-up of active load-transfer system (if any);
- Pre-ballasting of vessel.

For these preparations the vessel needs to be moored at a stand-off location. The mooring spread for the vessel will be dependent on the field lay-out and the design environmental conditions for this stage of the operation.

2.4.4 Docking of Installation Vessel

Upon completion of the preparatory works, the docking operation of the vessel can commence. During this phase the vessel is moved into the jacket and transferred from the standoff location to the correct location in the jacket. During this phase the following needs to be safeguarded: [1]

- Alignment of vessel stern with jacket slot. For this purpose a guide structure can be attached to the vessel stern as presented in Figure 2;
- Lateral impact loads on the jacket not to exceed limit loads of jacket and fendering arrangement;
- No vertical impact loads between deck legs and jacket legs;
- Control over the movement of the vessel in longitudinal and transverse direction as well as control over the alignment of the vessel.

2.4.5 Pre-mating Position of the Installation Vessel

Once the vessel is docked, the deck legs need to be aligned with the jacket legs. The tolerance for this alignment is to a high extend driven by the diameter of the stabbing cones. During this stage the clearance between the deck legs and the jacket legs will be reduced by ballasting the installation vessel. The following aspects need to be taken into account:

- Limited lateral movement of the vessel relative to the jacket to ensure alignment of deck legs and jacket legs;
- Lateral impact loads on the jacket not to exceed limit loads of jacket and fendering arrangement;
- Vertical impact loads on the jacket not to exceed limit loads of jacket and LMU design.

2.4.6 Mating of Integrated Deck to Jacket

During this stage the installation of the integrated deck on the jacket will be accomplished. The load of the deck will be transferred from 100% support on the installation vessel to 100% support on the jacket legs. The transfer of the deck weight can be achieved by a variety of methods such as ballasting of the installation vessel or active hydraulics in the deck supports.

2.4.7 Post-Mating Position of Installation Vessel

Once load transfer has been completed, there will still be impact loads between the module and the deck support. As long as these impact loads occur, un-docking of the vessel is not feasible. Therefore the clearance between the module and the deck support needs to be increased by continuing the ballasting of the installation vessel. During this ballasting operation the following issues need to be taken into account:

- Limited lateral movement of the vessel relative to the jacket to ensure alignment of integrated deck and supports on the vessel;
- Lateral impact loads on the jacket not to exceed limit loads of jacket and fendering arrangement;
- Vertical impact loads on the deck support not to exceed limit loads of module and DSU design.

2.4.8 Un-Docking of Installation Vessel

After the completion of the ballasting operations to increase the clearance between the deck supports and the integrated deck, the vessel can be un-docked from the jacket. During this phase the following needs to be safeguarded:

Lateral impact loads on the jacket not to exceed limit loads of jacket and fendering arrangement;

- No vertical impact loads between deck support and integrated deck;
- Control over the movement of the vessel in longitudinal and transverse direction as well as control over the alignment of the vessel;
- Clearance between bottom of installation vessel and jacket bracings;
- Sufficient freeboard of installation vessel during undocking.

2.5 Studies of Float-over Installation

Before the real float-over installation is performed, a long series of studies need to be done in order to make sure the successfulness of the installation.

2.5.1 Frequency Domain Analysis

Frequency domain is a term used to describe the domain for analysis of mathematical functions or signals with respect to frequency, rather than time. Speaking non-technically, a time-domain graph shows how responses changes over time. Whereas a frequency-domain graph shows how much of the responses lies within each given frequency band over a range of frequencies.

The energy density spectrum, for example Pierson-Moskowitz (P-M) spectrum model can be used for the frequency domain analysis. The expression for the P-M spectrum in terms of cyclic frequency f= (ω/2π) may be written as

$$S(f) = \frac{\alpha g^2}{(2\pi)^4} f^{-5} \exp\left[-1.25\left(\frac{f}{f_0}\right)^{-4}\right]$$

Where, α=0.0081 and peak frequency, $f_0 = (\omega_0/2\pi)$.[6]

Hasselmann, et al. (1973) after analyzing data collected during the Joint North Sea Wave Observation Project JONSWAP, found that the wave spectrum is never fully developed. It continues to develop through non-linear, wave-wave interactions even for very long times and distances. Hence an extra and somewhat artificial factor was added to the Pierson-Moskowitz spectrum in order to improve the fit to their measurements. The JONSWAP spectrum is thus a Pierson-Moskowitz spectrum multiplied by an extra peak enhancement factor γ^{r}. [6]

$$S_j(\omega) = \frac{\alpha g^2}{\omega^5} \exp\left[-\frac{5}{4}\left(\frac{\omega_p}{\omega}\right)^4\right]\gamma^r$$

$$r = \exp\left[-\frac{(\omega - \omega_p)^2}{2\sigma^2\omega_p^2}\right] \quad [6]$$

or

$$S_j(f) = S_p(f)\gamma^r$$

$$r = \exp\left[-\frac{(f - f_m)^2}{2\sigma^2 f_m^2}\right] \quad [6]$$

γ = peakedness parameter = 3.30

$\tau = 0.07$ for $\omega < \omega_0 \alpha$

$\tau = 0.09$ for $\omega > \omega_0$

$\alpha = 0.076\,(X)\,-0.22$ $\alpha = 0.0081$ (when X is unknown)

X is the distance from a lee shore, called the fetch, or the distance over which the wind blows with constant velocity.

Goda (1979) derived an approximate expression for JONSWAP spectrum in terms of H_s and ω_0 as follows:

$$S(\omega) \equiv \alpha H_s^2 \frac{\omega^{-5}}{\omega^{-4}} \exp[-1.25(\omega/\omega_o)^{-4}]\gamma^{\exp[-(\omega-\omega_o)^2(2\tau^2\omega_o^2)]} \quad [6]$$

where $$\frac{0.0624}{0.23 + 0.0336\gamma - 0.185(1.9+\gamma)^{-1}} \quad [6]$$

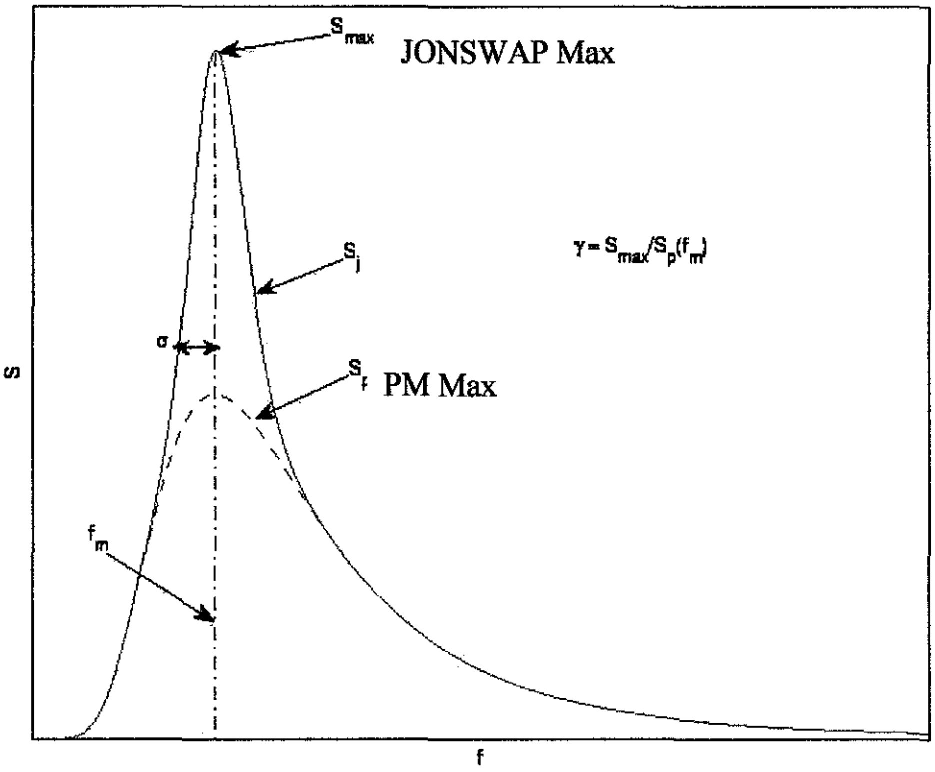

Figure 18: Comparison of the JONSWAP and PM spectra

2.5.2 Motion-Response Spectrum

If the barge is free to move in waves its motion may be critical near the resonance of the structure. Therefore, it is important to study the overall response of the barge due to a design-wave spectrum. In this case, the response-amplitude operators are written relating the dynamic motion of the barge to the wave-forcing function on the barge. Then the dynamic-motion spectrum is obtained from the force spectrum, or equivalently, from the wave spectrum.

Consider that the motion of the barge in the direction, x, is uncoupled and can be modelled by a simple linearly damped spring-mass system. If *m* is the total mass of the barge, *K*, is its stiffness coefficient and *C* is the damping coefficient, then its equation of motion is: [6]

$$m\ddot{x} + C\dot{x} + Kx = F_1 \cos \omega t$$

where F_1 is the inertia-force amplitude which is linear with wave height. The displacement, *x*, is the motion in a particular direction, e.g. surge, sway, or heave, which can be written in the form of

$$x(t) = \left[\frac{\frac{F_1}{\frac{H}{2}}}{[(K - m\omega^2)^2 + (C\omega^2)^2]^{\frac{1}{2}}} \right] \eta_\beta (t)$$

Where β is the phase different between *x(t)* and *η(t)*. This relationship can be transformed to obtain the motion spectrum in terms of the wave spectrum and an RAO. [6]

The Response Amplitude Operators (RAOs) defined as the responses of a floating system to a series of unit amplitude regular waves of varying period. The responses can be motion (displacement, velocity and acceleration), loads (force and moment) and stress. The amplitude is half of the crest-to-trough height. The regular waves imply the theoretical wave with a sinusoidal (repetitive oscillation) form. Meanwhile, the periods are related to typical ocean waves having a range from 4 seconds to 25 seconds.

2.5.3 Hydrodynamic Added Mass and Damping Coefficients

The motions of a floating structure are influenced by the added mass effect in the water and the damping introduced by the motion of the structure in the water. These quantities related to a floating structure must be known before a motion analysis can be performed. For small member of the structure these values are obtained from experiments, meanwhile when the structure size is large these quantities may be obtained analytically.

The motions of a large floating structure are obtained with the help of the complete linear potential flow theory. It compares the Froude-Krylov force, the diffraction force on the structure at its equilibrium position and the radiation force due to the structure motion about its equilibrium position. The last component provides the hydrodynamic coefficients of the structure in its six degree of motion in terms of the added mass and damping coefficients.

2.5.4 Froude-Krylov Force

Froude–Krylov force is the force introduced by the unsteady pressure field generated by undisturbed waves. The Froude–Krylov force does, together with the diffraction force, make up the total non-viscous forces acting on a floating body in regular waves. The diffraction force is due to the floating body disturbing the waves. The bodies considered for the derivation of Froude-Krylov forces are:

1) Horizontal cylinder
2) Horizontal halfcylinder
3) Sphere
4) Hemisphere
5) Vertical cylinder
6) Rectangular block
7) Horizontal circular plate

$$F_x = C_H \rho V \frac{\sinh(\frac{kl_3}{2})}{\frac{kl_3}{2}} \frac{\sin(\frac{kl_1}{2})}{\frac{kl_1}{2}} \dot{u}_o$$

$$F_y = C_V \rho V \frac{\sinh(\frac{kl_3}{2})}{\frac{kl_3}{2}} \frac{\sin(\frac{kl_1}{2})}{\frac{kl_1}{2}} \dot{v}_o$$

[6]

For this project, the barge is considered as rectangular block. The rectangular block is assumed to have the dimensions l_1, l_2 and l_3 where l_3 is the height and l_2 is perpendicular to the wave direction. Volume of the block is noted as $V=l_1 l_2 l_3$. However, some adjustments need to be done as the barge is not completely a rectangular block and the dimensions are also varies from bow to stern.

Wave particle horizontal acceleration:

$$\dot{u}_0 = \frac{2\pi^2 H}{T^2} \frac{\cosh ks}{\sinh kd} \sin\emptyset$$

Wave particle vertical acceleration:

$$\dot{v}_0 = \frac{2\pi^2 H}{T^2} \frac{\sinh ks}{\sinh kd} \cos\emptyset$$

[6]

s is the distance from ocean bottom to the centre axis of the block.

CHAPTER 3

METHODOLOGY

The research and investigation of this project is based on certain laws. The theoretical facts will be gathered first from available information on related topics of float-over installation in addition with the findings and understanding the basic fundamental concepts and carrying out numerical analysis. The next stage is the fabrication of the barge model. The accurate and workable scaled model need to specify the entire requirement and specification generated in the conceptual design. The main stage for this project will be the wave test. Before the wave test is performed, the experimental programs and setups need to be performed first.

3.1 Numerical Analysis by using Microsoft Excel

3.1.1 Froude-Krylov Force

The force of surge and heave of the barge is obtained by using Microsoft Excel is based on Froude-Krylov force equation. The horizontal force is assumed as surge while vertical force as heave. The wave direction is coming towards the bow of the barge.

a) Surge:

$$F_x = C_H \rho V \frac{\sinh(\frac{kL_3}{2})}{kL_3/2} \frac{\sinh(\frac{kL_1}{2})}{kL_1/2} \dot{U}_o$$

b) Heave:

$$F_y = C_V \rho V \frac{\sinh(\frac{kL_3}{2})}{kL_3/2} \frac{\sinh(\frac{kL_1}{2})}{kL_1/2} \dot{V}_o$$

c) Wave particle horizontal acceleration

$$\dot{U}_o = \frac{2\Pi^2 H}{T^2} \frac{\cosh ks}{\sinh kd} \sin \Theta$$

d) Wave particle vertical acceleration

$$\dot{V}_o = \frac{2\Pi^2 H}{T^2} \frac{\sinh ks}{\sinh kd} \cos \Theta$$

e) Phase angle

$$\Theta = kx - \omega t$$

f) Deepwater wave length

$$L_o = \frac{gT^2}{2\Pi}$$

g) Wave length

$$L = L_o \tanh kd$$

h) Wave number

$$k = \frac{2\Pi}{L}$$

i) Wave frequency

$$\omega = \frac{2\Pi^2}{t}$$

3.1.2 JONSWAP Spectrum

The wave spectrum for surge and heave are calculated based on Goda (1979) derivation.

$$S(\omega) = \alpha H_s^2 \frac{\omega^{-5}}{\omega^{-4}} \exp[-1.25(\omega/\omega_o)^{-4}]\gamma^{\exp[-(\omega-\omega_o)^2(2\tau^2\omega_o^2)]}$$

where $\dfrac{0.0624}{0.23 + 0.0336\gamma - 0.185(1.9+\gamma)^{-1}}$

The wave condition of Caspian Sea:

H_s	Significant wave height	0.5 m
H_{max}	Maximum wave height	1.86 m
T_z	Zero crossing wave period	5 sec
T_p	Peak wave period	7 sec

Table 1: Caspian Sea Wave Condition

3.1.3 Response Amplitude Operators (RAO)

The RAO for surge and heave of the barge are calculated based on equation:

$$RAO = \left[\frac{\frac{F_1}{\frac{H}{2}}}{[(K - m\omega^2)^2 + (C\omega^2)^2]^{\frac{1}{2}}} \right]$$

3.2 Model Fabrication

Froude Scaling Laws is employed for relating the model to prototype. For the model construction phase, a barge model is fabricated at scale 1:50 using marine plywood. The general layout of the model is shown in Figure 20. The model is constructed with non-water tight bulkheads to divide the model into separate chambers representing the prototype's ballast tank. Also, the model consists of seven ballast tanks with removable hatch covers for the purpose of providing solid or water ballasts to the model.

3.3 Experimental Programs

Prior to model testing, a number of tests need to be done for the model calibration. These tests include the determination of mass moment of inertia for the model, static offset test for mooring lines and inclination test.

3.3.1 Static Offset Test

Static offset test was performed to determine the stiffness of the mooring lines. The result of static offset is presented in Figure 19. The spring constant are obtained as 127.8 kN/m and 5.21 kg/m for the prototype and the model respectively.

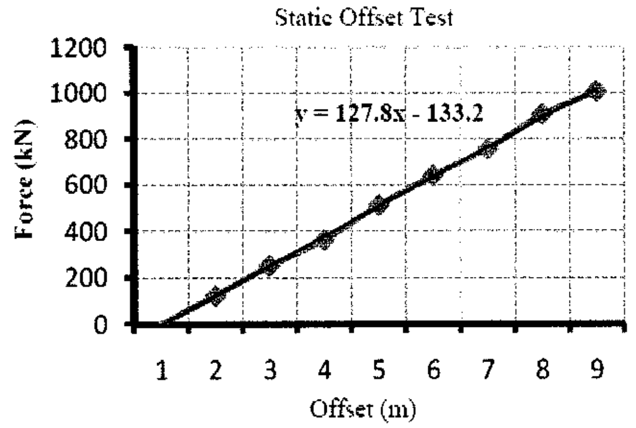

Figure 19: Horizontal Stiffness properties for mooring system

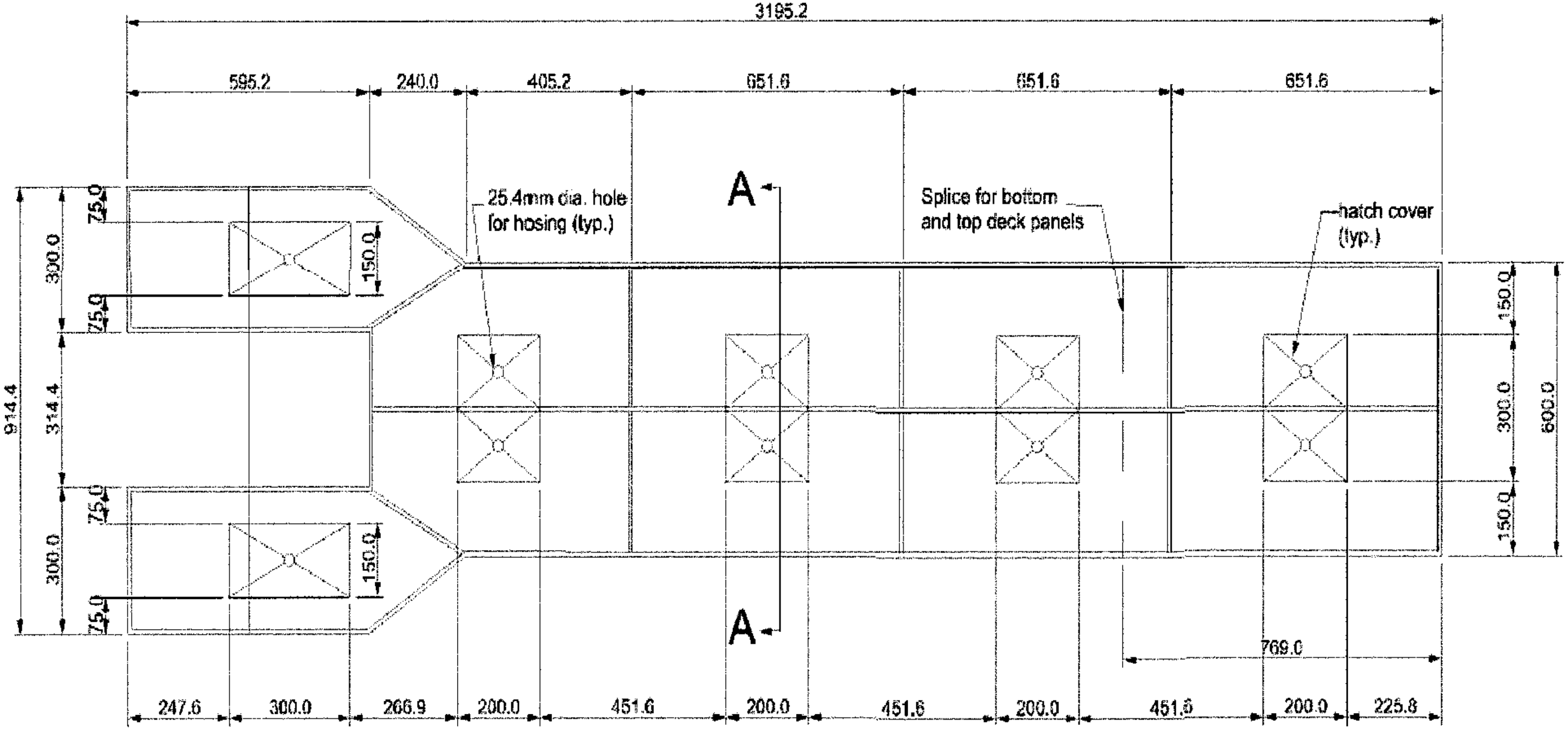

Figure 20: The 1:50 Scaled Barge Model

3.3.2 Inclination Test

The inclination tests were performed to determine the metacentric height (GM) for the model. GM is the distance between the centre of gravity of the barge and its metacentre. The test is conducted by moving known weights on the deck and measuring the distance moved and the heel or trim angle. The results of these tests are presented in Table 3 and Table 4 for pitch and roll respectively.

Displacement, W (kN)	Initial angle of trim (rad)	Final angle of trim (rad)	Change in angle (rad)	Weight shifted (kN)	Distance moved (m)	GM
96570.98	0.0	0.1	0.1	2203.8	119.975	27.42
	0.1	0.4	0.3	5521.9		23.20
					Average	25.32

Table 2: Inclination Test Results for Pitch Direction

Displacement, W (kN)	Initial angle of trim (rad)	Final angle of trim (rad)	Change in angle (rad)	Weight shifted (kN)	Distance moved (m)	GM
96570.98	0.0	0.1	0.2	1089.5	19.975	1.13
	0.2	0.4	0.2	2203.8		2.29
	0.4	0.6	0.2	3293.3		3.43
					Average	2.29

Table 3: Inclination Test Results for Roll Direction

3.3.3 Mass Moment of Inertia

Based on Bifiliar Pendulum Method, mass moment of inertia can be determined by hanging the subject with two ropes, tided at the end to end side of the subject. The subject is then rotated around the axis between the ropes are tided. The mass moment of inertia of this barge is varies between yaw, roll and pitch condition.

$$I = \frac{MgT^2d^2}{16\pi^2 y}$$

M: mass of the barge model + added mass of equipment

g: gravity acceleration ,ms^{-2}

d: distance between the two cables

T: time / cycle

y: length of the cables (the two ropes should have the same length)

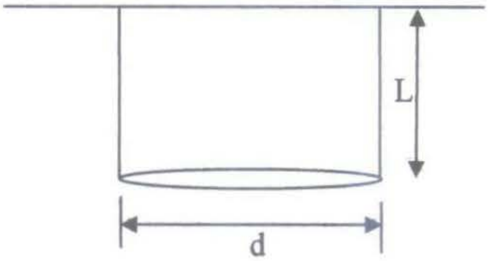

Figure 21: Bifiliar Pendulum Arrangement

The time is taken along the period since the barge is started to rotate around the axis until it remain static. The number of cycles during the rotation is also counted. Several readings are taken to achieve accuracy.

Mass Moment of Inertia of Pitch

Pitch is a movement as the barge rotated along its y-axis. Two cables are used to hang the barge. Three (3) tests are conducted with 20 oscillations are considered.

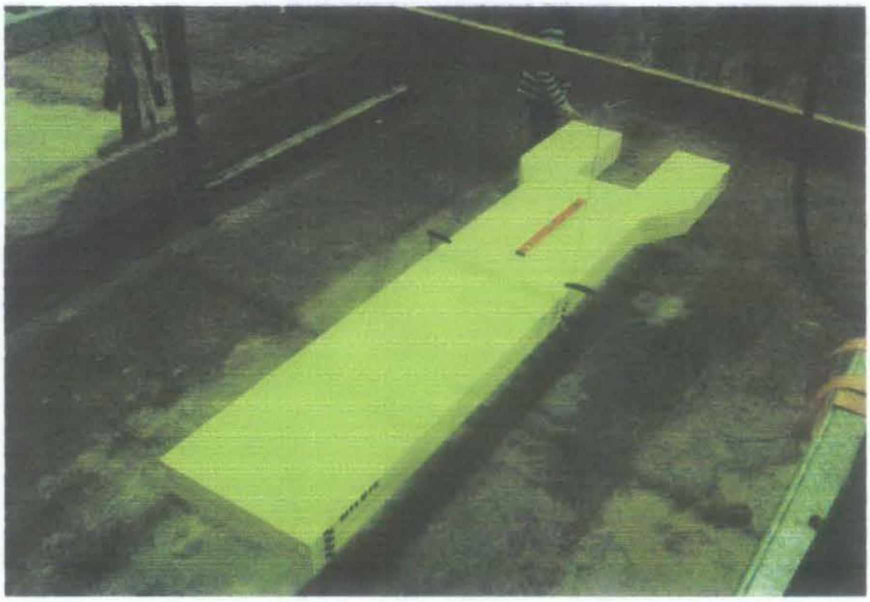

Figure 22: Arrangement of Mass Moment of Inertia for Pitch

3.4 Experimental Setup

The first phase of the physical modelling study involves the determination of the dynamic response and RAO's of the barge. The wave heading of 180° is tested for the barge. The mooring lines consisting of wires and springs are connected to a specially fabricated ring. The centre of gravity is determined as it is located 161.7 cm from the bow. The mass of the barge is 60 kg.

Figure 23: Photo of Barge Model

Figure 24: Mass of barge = 60kg

3.5 Wave Test

After the Mass Moment of Inertia of the barge is being determined, the wave test is then can be performed. The wave direction hitting the barge is 180°. The water depth is 1 m and the wave height is 4 cm. There are two types of wave that are considered in the wave test which are regular wave and random wave. For regular wave the test is conducted in 2 minutes while for the random wave is 25 minutes.

The optical tracking device is used in this test. The device can detect the motion of 6 degrees of freedom of the barge. There are five bulb reflectors attached randomly on surface of the barge. Three optical tracking cameras are used to record the motion of 6 degrees of freedom of the barge by detecting the reflection of the bulbs.

The load-cells are attached at the each mooring line to measure the tension in each mooring lines. There are four mooring lines used and each of them is hooked at the edge of the barge; two at the fork while the other two at the bow.

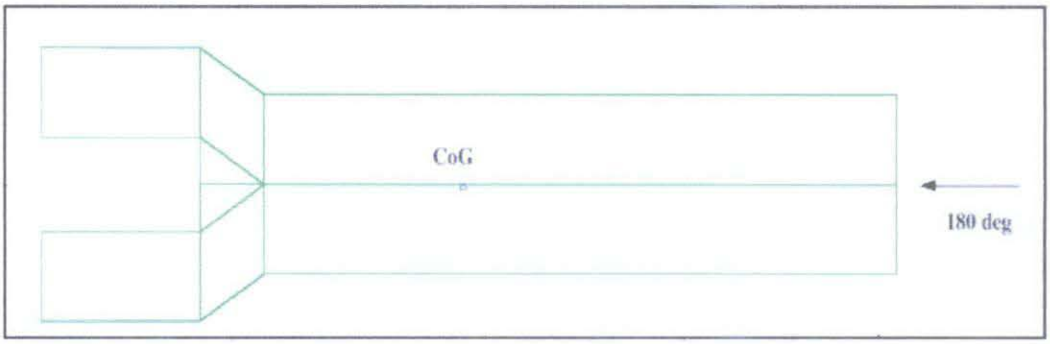

Figure 25: Wave Direction

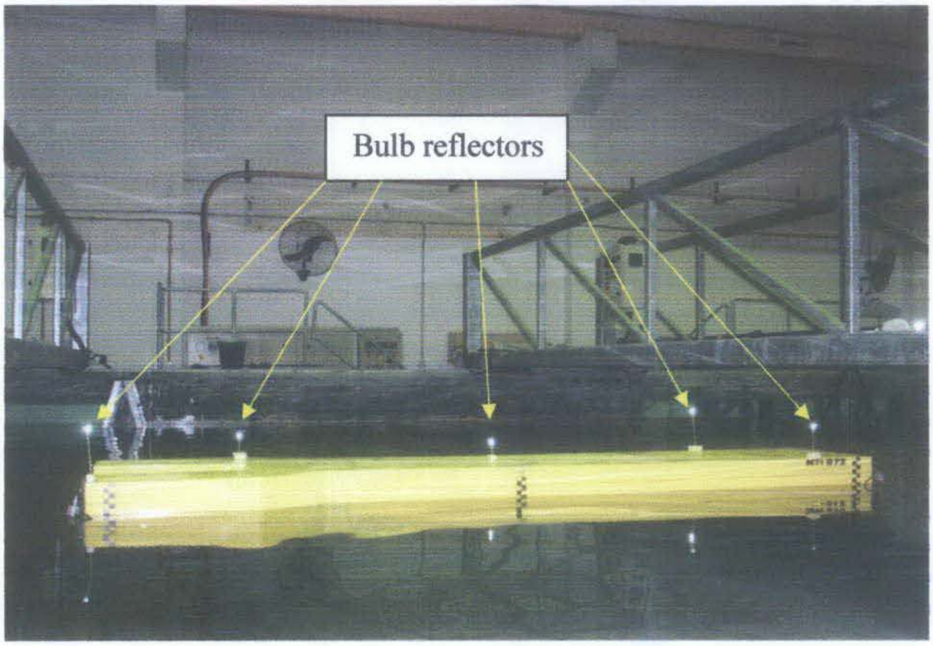

Figure 26: Optical Tracking Test

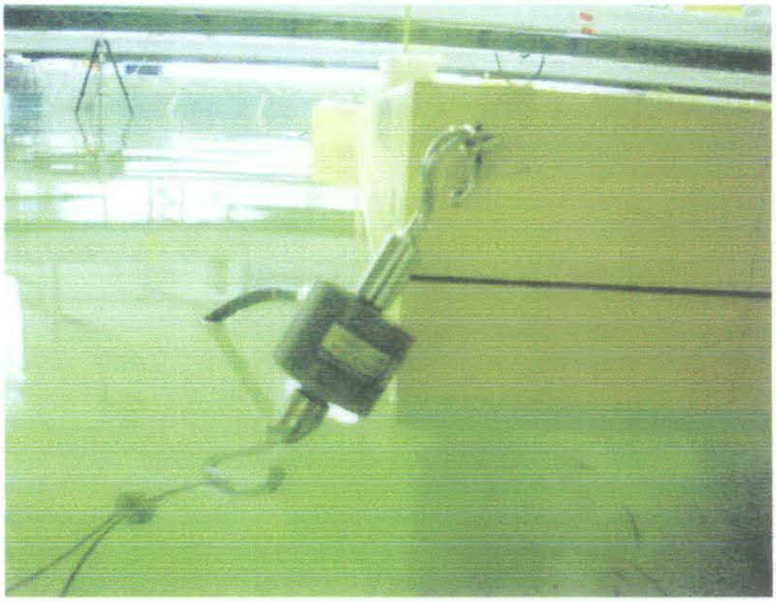

Figure 27: Load-Cell

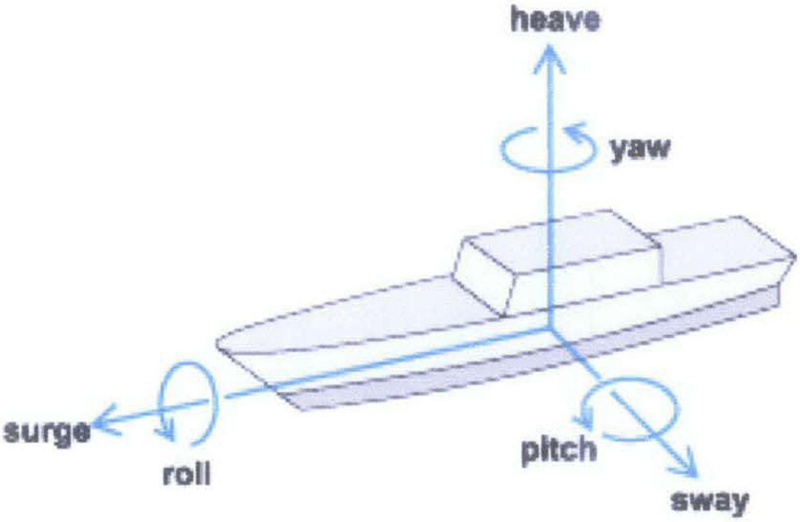

Figure 28: 6-degrees of Freedom

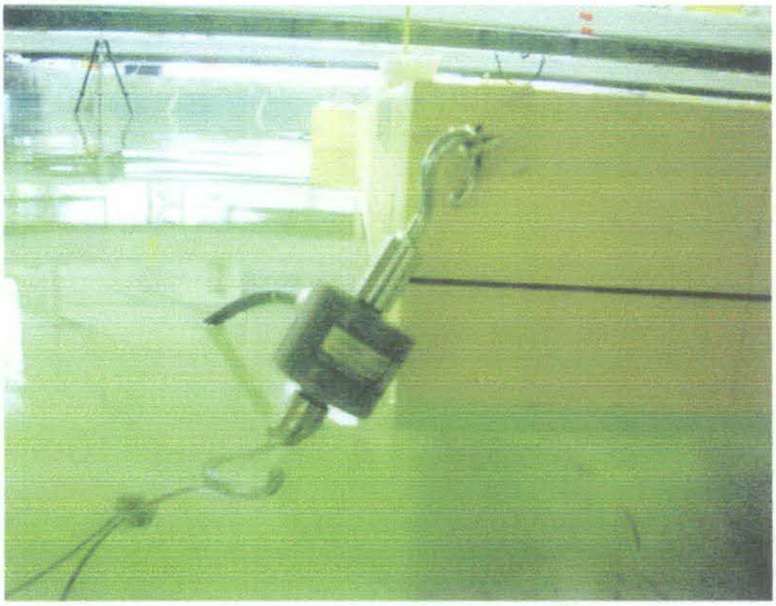

Figure 27: Load-Cell

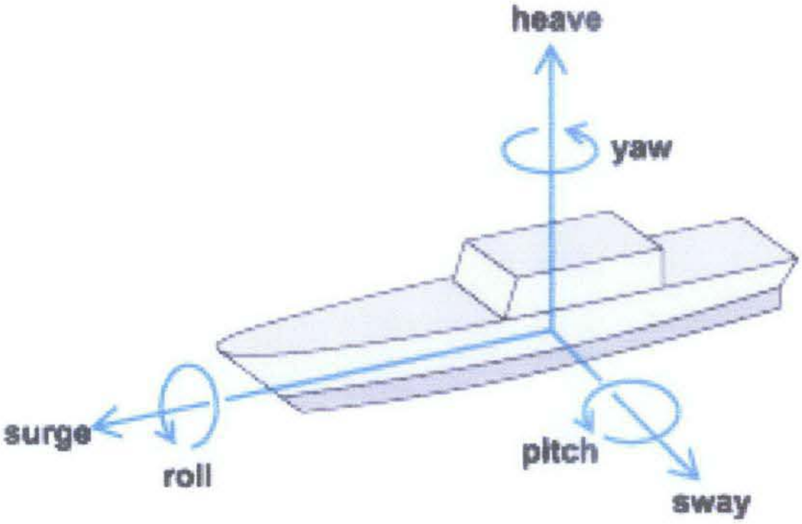

Figure 28: 6-degrees of Freedom

CHAPTER 4

RESULT & DISCUSSION

4.1 Numerical Analysis

4.1.1 Froude-Krylov Force

time (s)	F_{Surge} (MN)	F_{Heave} (MN)
0	0.145577571	0.41370783
1	-0.34847359	0.26629525
2	-0.29884813	-0.2491283
3	0.125396634	-0.420265
4	0.438445473	-0.0106097
5	0.145577571	0.41370783

Table 4: Surge and Heave Force

The maximum force of surge is obtained when t=4 while the maximum force for heave is achieved when t=0.

4.1.2 JONSWAP Spectrum

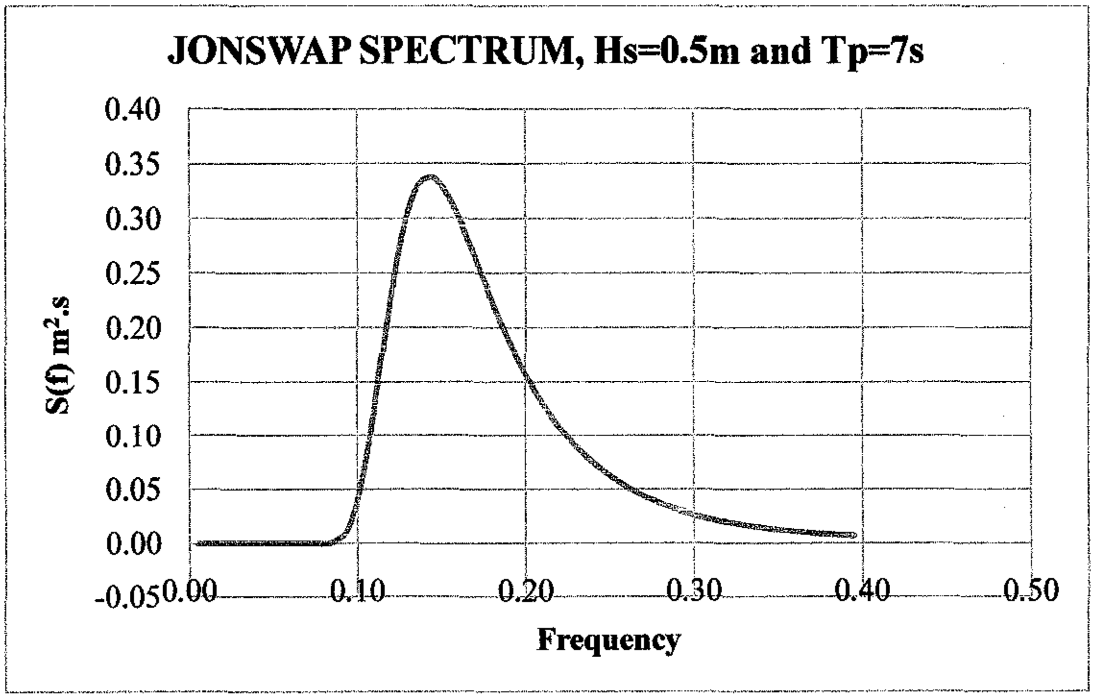

Figure 29: JONSWAP Spectrum (Theoretical)

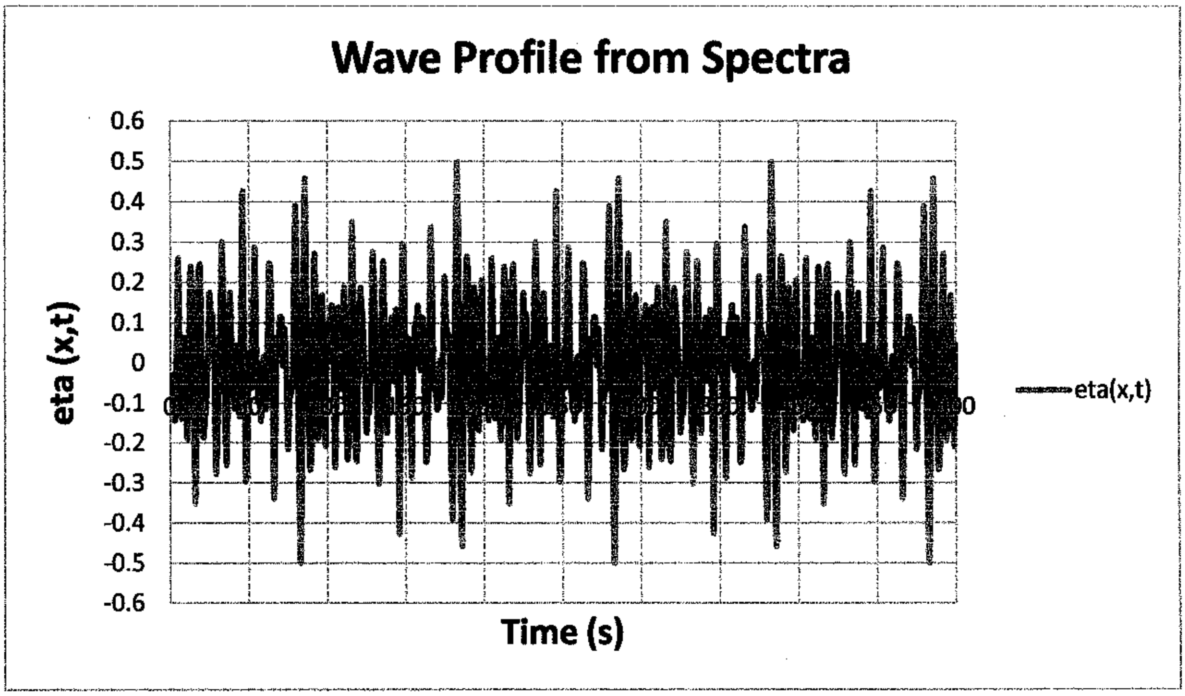

Figure 30: Wave Profile from Spectra (Theoretical)

4.1.3 Response Amplitude Operators (RAO)

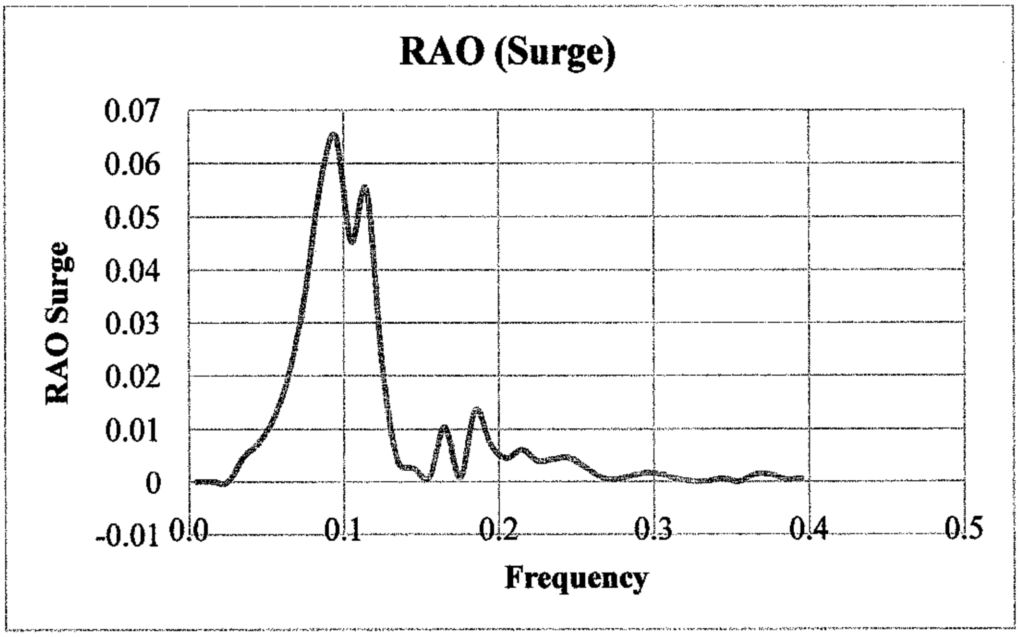

Figure 31: RAO for Surge (Theoretical)

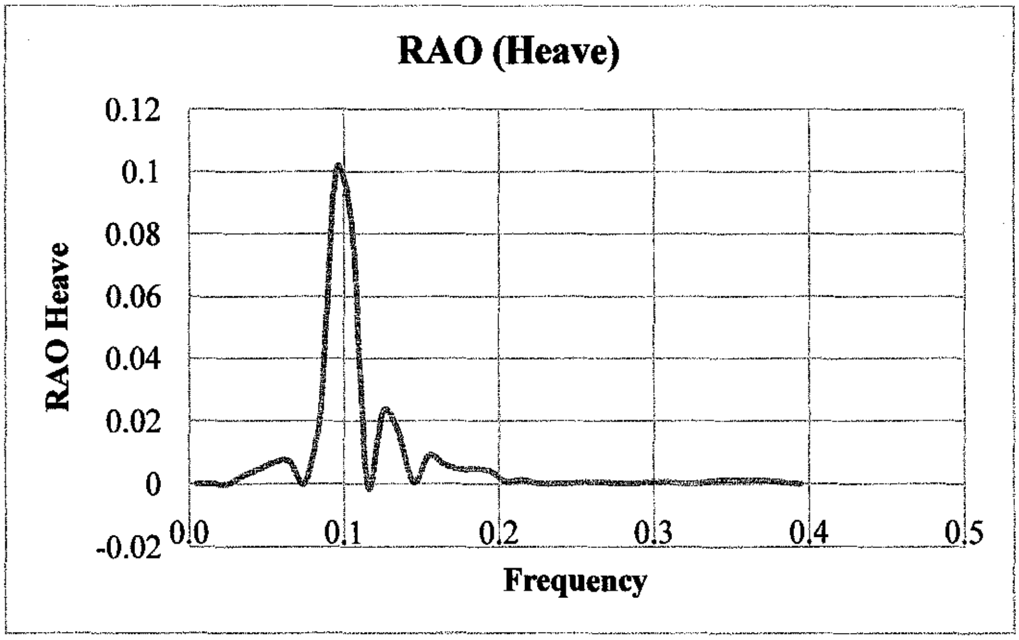

Figure 32: RAO for Heave (Theoretical)

4.1.4 Motion Spectrum

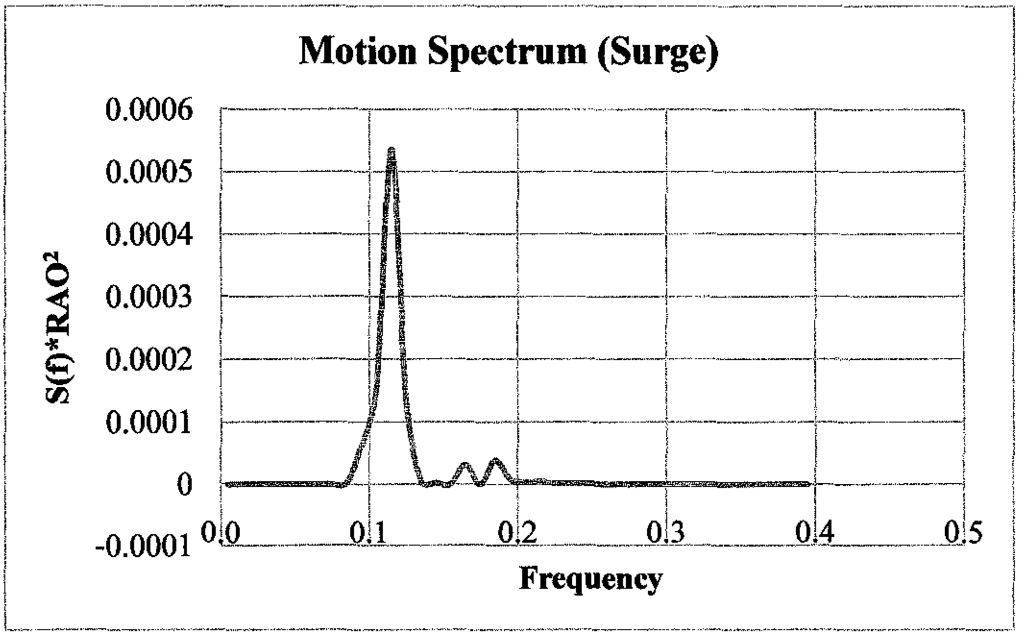

Figure 33: Motion Spectrum for Surge (Theoretical)

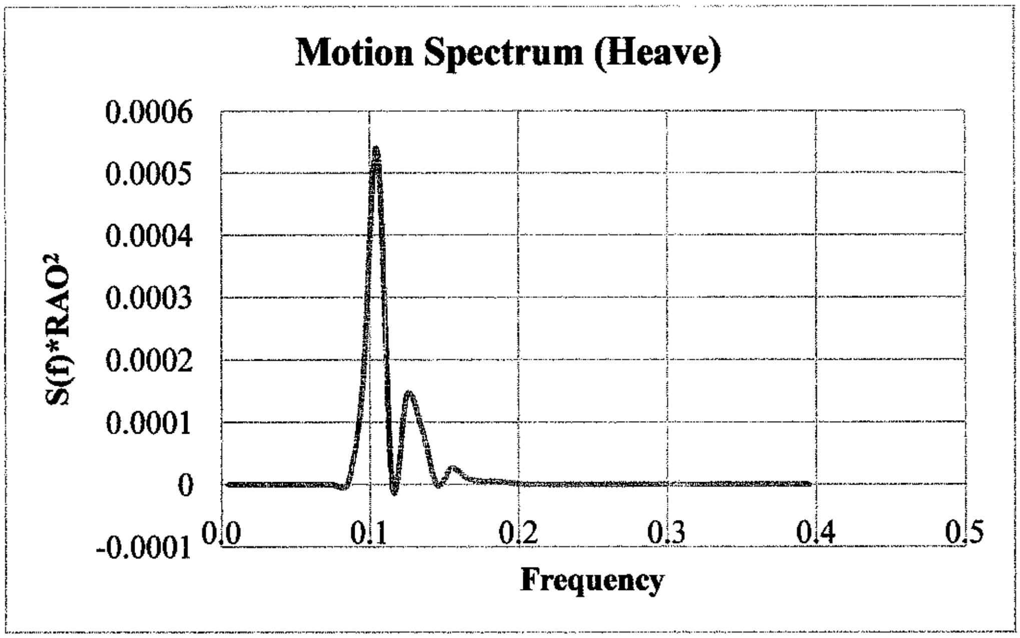

Figure 34: Motion Spectrum for Heave (Theoretical)

4.2 Model Test

4.2.1 Mass Moment of Inertia of Roll

Mass of the barge model	60 kg
Additional mass	1.08 kg
Length of cables, y	0.94 m
Cables separation, d	0.603 m
Total mass, M	61.08 kg

Test	No. of Oscillations	Time (s)
1	20	120.7
2	20	121.8
3	20	121.7
	Time Average (s)	121.4

Table 5: Mass Moment of Inertia of Roll

$$I = \frac{MgT^2d^2}{16\pi^2 y}$$

$$\frac{61.08 * 9.80665 * \frac{121.4}{20} * 0.603^2}{16 * \pi^2 * 0.94} = 54.06 kg.m^2$$

4.2.2 Wave Test

Regular Wave Test is conducted in 2 minutes.

Hmax (m)	1.86 / 50 = 0.0372
Tp (s)	$7/\sqrt{50} = 0.9899$
Water draft (m)	1.5 / 50 = 0.03

Table 6: Regular Wave Test Condition

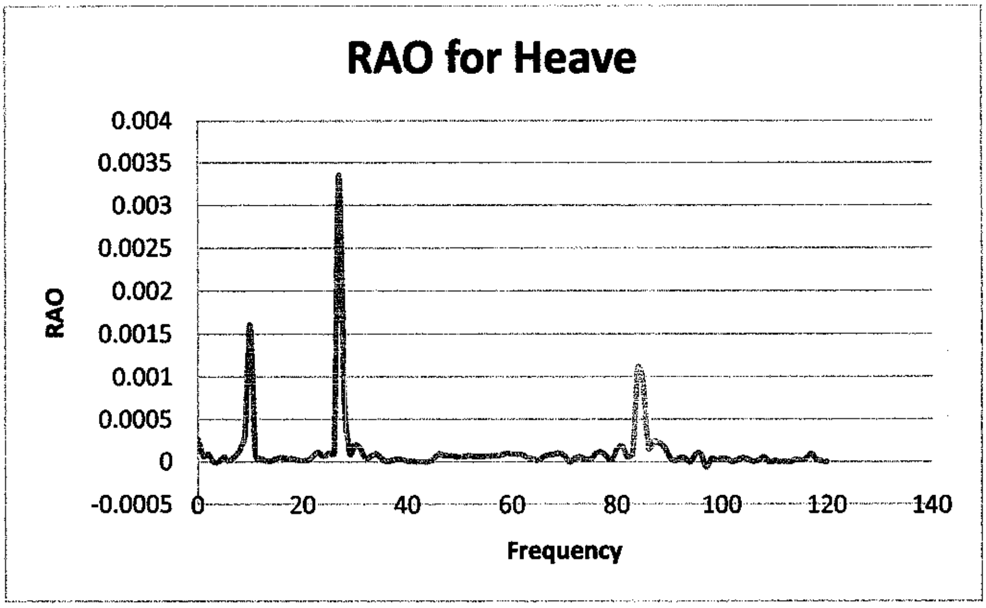

Figure 35: RAO for Heave (Model Test)

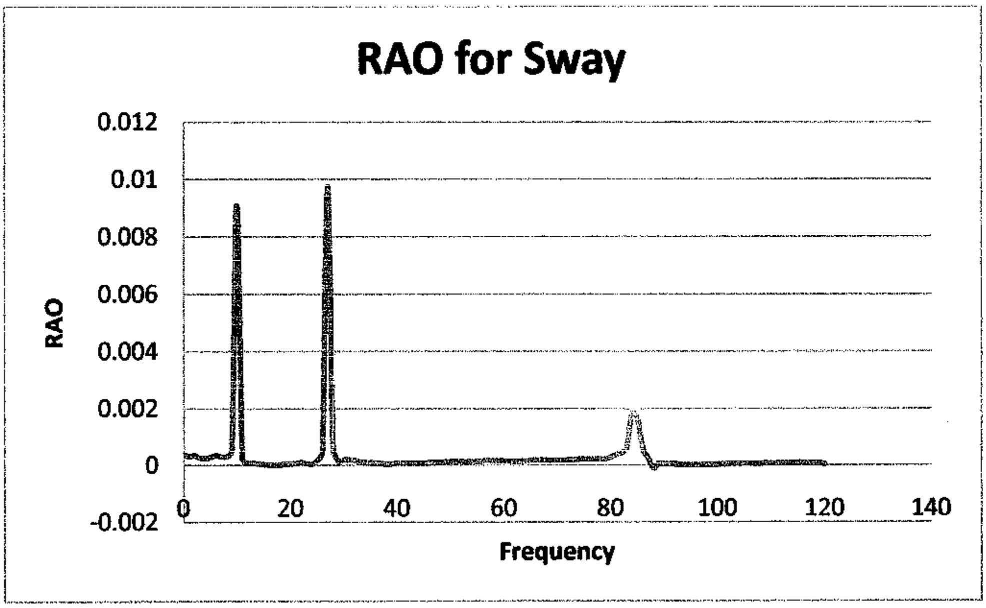

Figure 36: RAO for Sway (Model Test)

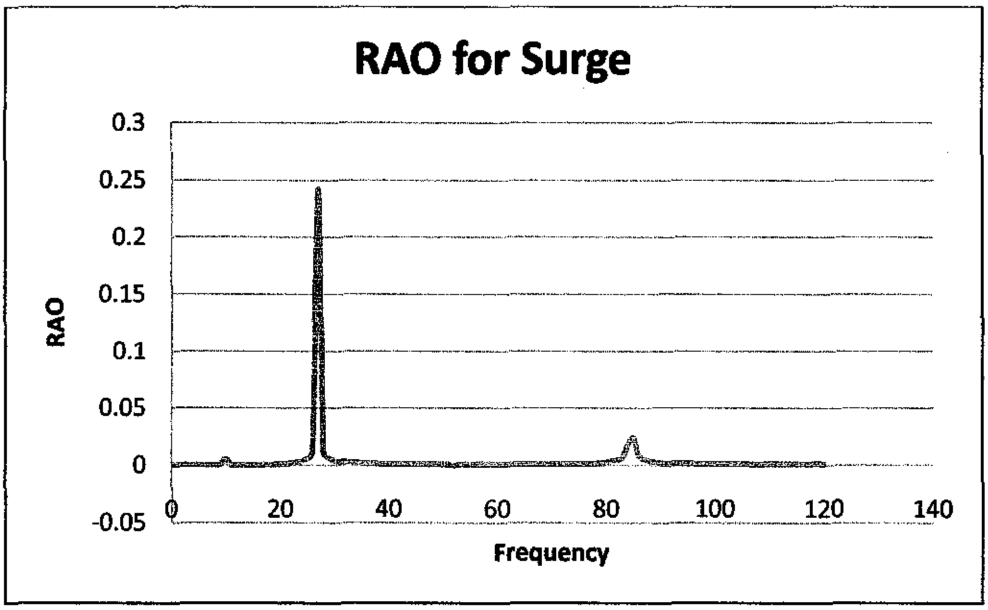

Figure 37: RAO for Surge (Model Test)

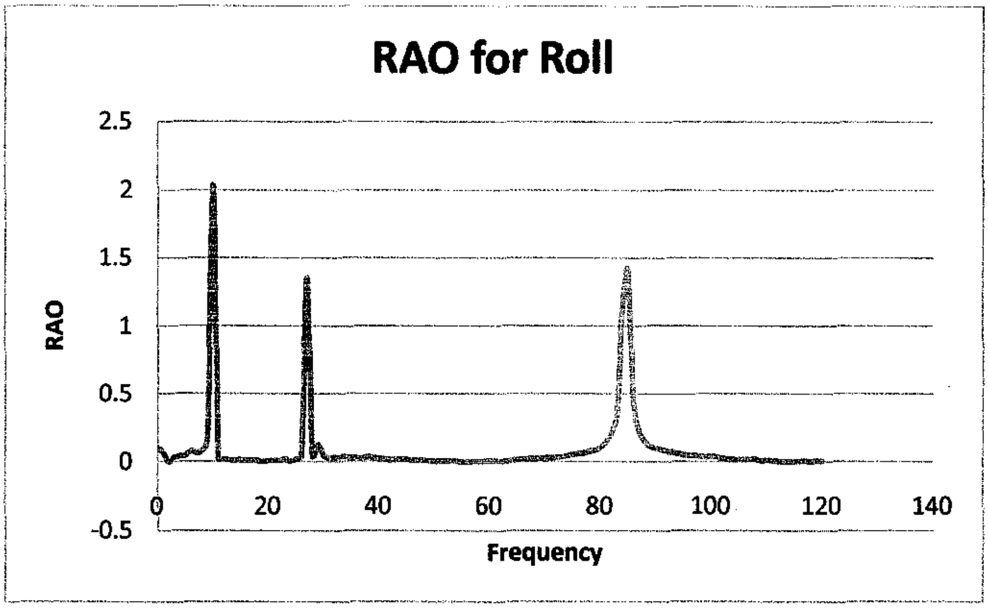

Figure 38: RAO for Roll (Model Test)

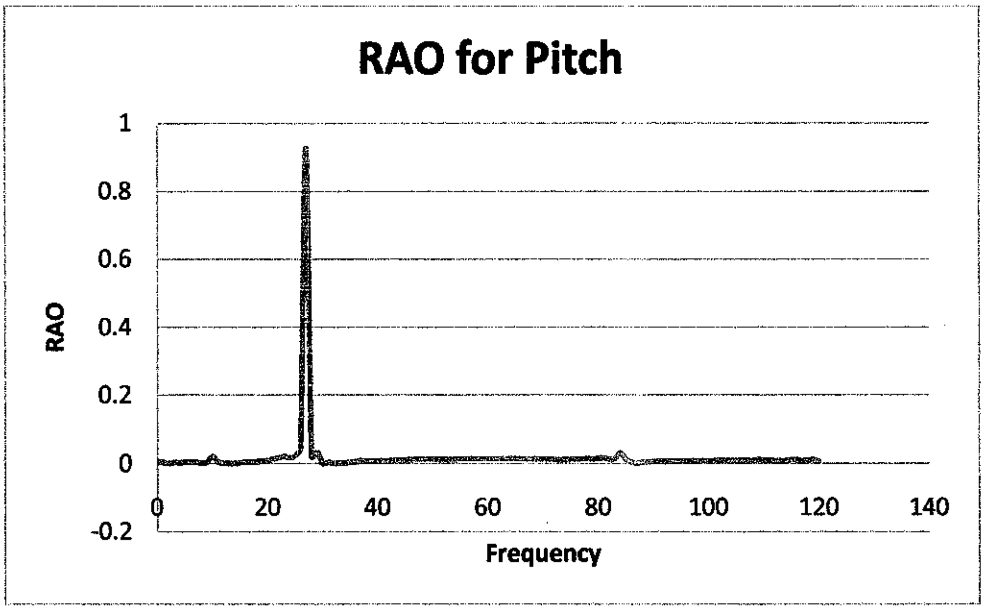

Figure 39: RAO for Pitch (Model Test)

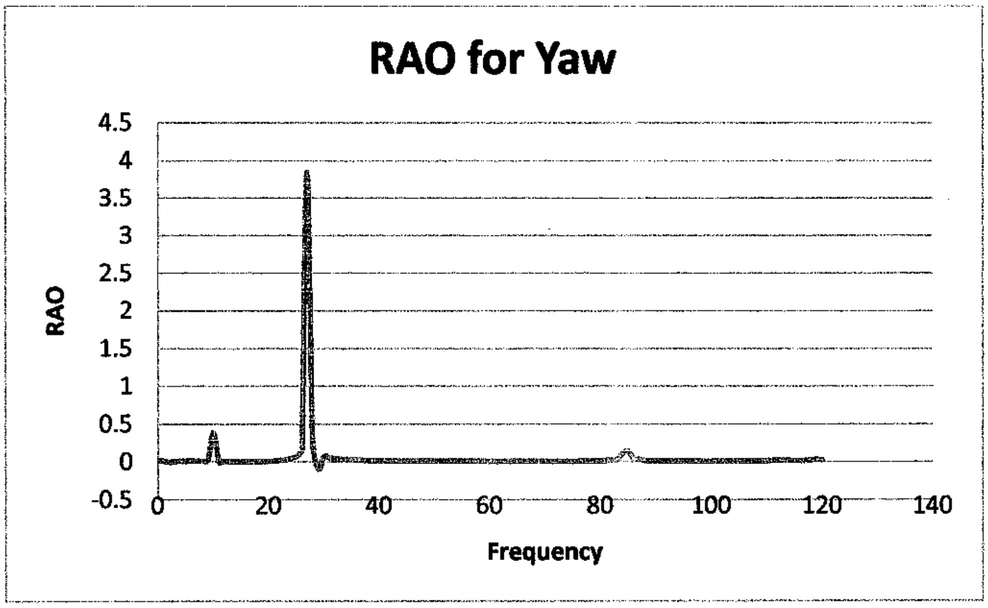

Figure 40: RAO for Yaw (Model Test)

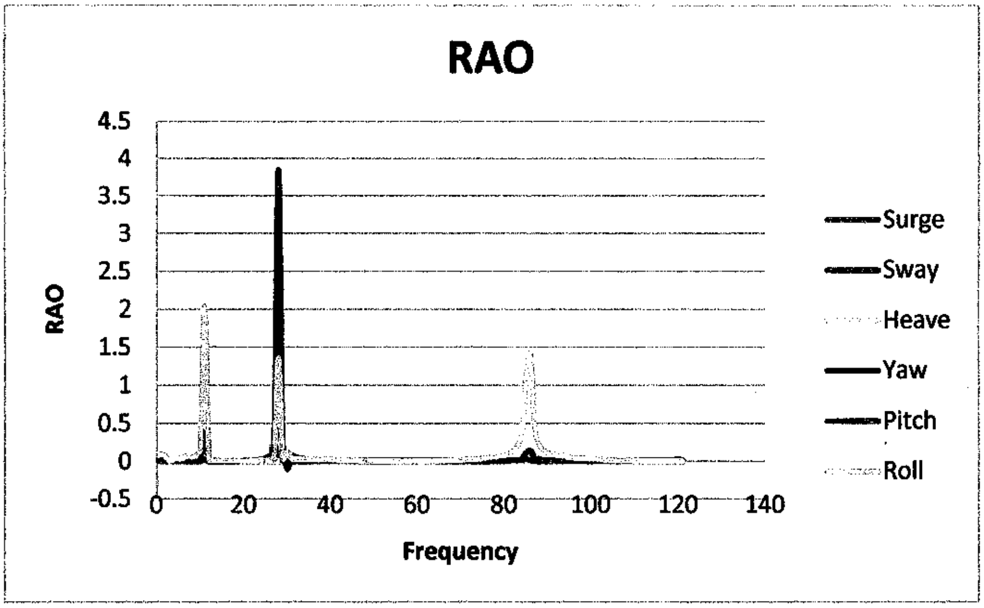

Figure 41: RAO of 6-degrees of Freedom (Model Test)

Based on Figure 31 to 34, several points about these figures should be noted as follows:

a) Looking at RAO equation, these are apparent as the wave height increased; the force on the barge will be increased with the same mass, stiffness and damping coefficient. Hence, the RAO will be identical for all wave conditions with the same peak frequency.

b) The maximum peak values are corresponding to the wave spectral peaks.

Based on Figure 35 to 40, several points about these figures should be notes as follows:

a) The maximum RAO for all 6 degrees of freedom except for roll are identical with the same frequency range which is within 20-25 Hz. For roll, the maximum RAO lies in frequency range of 10 Hz.

b) The maximum RAO is achieved when the barge experienced yaw while when it is heave, the minimum RAO is achieved.

c) The characteristic of the RAO of all 6 degrees of freedom can be identified clearly as combined in one graph which is in Figure 41.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Based on single water draft, single wave headings, with single condition both for regular and random wave, this project is succeed to achieve its objective. Still, the results are not enough for the prototype barge responses analysis. There are several assumptions applied in numerical analysis which produced low accuracy of result. The un-synchronization data between optical tracking data and wave probe data also lead to low accuracy of result. The major challenge faced in this project is the limited time. The incomplete equipment available at the laboratory is among the limited time factor as lots of time is needed to search and to fabricate the equipment. Lack of expertise to handle the laboratory equipment especially the wave generator also drained the precious time.

In general, the float-over installation method has been and will continue to be the important role in the oil and gas industry. The method will continue to be improved in order to achieve the perfection in offshore installation. The important factor to select float-over installation as the preferred installation method is that float-over operation requires only one asset for both transportation and installation. The number of assets exceeds the number of available crane vessels and the assets are easier to mobilize. As a consequence, the cost of the float-over installation is lower compared to an installation by crane vessel and makes it as the attractive alternative of offshore installation.

In the future, the model test can be completed and achieved the objective as the equipment for the model test is completely available. With more time available, all the variation of wave headings and water draft can be carried out in order to achieve the accurate results for the ODP-A Topside float-over installation. Thus this project is a very good exposure to the student in order to understand the mechanism of float-over installation.

REFERENCES

(1) Seij, M and de Groot, H. *"State of the Art in Float-Overs"*, OTC 19072, May 2007

(2) A. Kocaman, DJ Kim, J.R. and Seto Jian. *"Float-Over of Arthit PP Deck"*, OTC 19230, May 2008

(3) L.A. O'Neill, E. Fakas, B.F. Ronalds and P.E. Christiansen. *"History, Trends and Evolution of Float-Over Deck Installation in Open Waters"*, SPE 63037, October 2000

(4) C. Tribout, D.Emery, P. Weber and R. Kaper. *"Float-Overs Offshore West Africa"*, OTC 19073, May 2007

(5) Ted Moon. *"Floatover Installations On the Rise"*, January 2008

(6) Chakrabarti, S. K. (1994)., *Hydrodynamics of Offshore Structures,* USA: WIT Press

(7) Dixen M., 2009, "MCR-A Platform Model Tests for Turkmenistan Block 1 Project," Final Report for Technip Geoproduction (M) Sdn Bhd

(8) PETRONAS Carigali (Turkmenistan) Sdn Bhd, 2010, "ODP-A Naval Architectural Design Brief" Document No. 5495-0299-DB-3800-010, Turkmenistan Block 1 Gas Development Project.