NUR `IZZATI BINTI MOHMAD ISMAIL

MASTER OF SCIENCE (MECHANICAL ENGINEERING)

UPNM 2020

HYDRODYNAMICS PERFORMANCE OF BACKWARD BEND DUCT BUOY (BBDB) IN REGULAR AND IRREGULAR WAVE CONDITIONS

NUR `IZZATI BINTI MOHMAD ISMAIL

MASTER OF SCIENCE

(MECHANICAL ENGINEERING)

UNIVERSITI PERTAHANAN NASIONAL MALAYSIA

2020

HYDRODYNAMICS PERFORMANCE OF BACKWARD BEND DUCT BUOY (BBDB) IN REGULAR AND IRREGULAR WAVE CONDITIONS

NUR `IZZATI BINTI MOHMAD ISMAIL

Thesis submitted to Centre for Graduate Studies, Universiti Pertahanan Nasional Malaysia, in fulfilment of the requirements for the Degree of Master of Science (Mechanical Engineering)

2020

DEDICATIONS

In the name of Allah, the Most Beneficent, the Most Merciful, Special dedication to my beloved parents

Mohmad Ismail bin Mat Jab,

Fatimah Bee binti A.Aboo

For their endless love and support

A special feeling of gratitude to

Ir. Ts. Dr. Mohd Rashdan bin Saad

And to

All those who have contributed in my journey up the ladder of knowledge

ABSTRACT

There are several projects conducted worldwide on various wave energy converter designs especially floating oscillating water column (FOWC) type. The most investigated FOWC device is currently the backward bent duct buoy (BBDB) concept focusing on regular and high-heave wave conditions, which is different to the low-heave wave ocean conditions in Malaysia. It was found that very few studies were done for BBDB under irregular wave conditions, which represents the real ocean condition. Therefore, this study presents the comparison of the performance and behaviour of BBDB under regular and irregular for low-heave wave conditions. Parameters such as water level inside column, air pressure and the air flow rate inside the device as well as the primary conversion efficiency were measured and calculated. The BBDB model with inclined 45° bottom corner was designed and tested at Natural Hydraulic Research Institute of Malaysia (NAHRIM) using the 3D wave tank in both regular and irregular waves conditions. The result showed that the highest efficiency can be extracted in low heave wave condition ranging from $\lambda/L = 4.2$ to $\lambda/L = 4.8$. Higher primary conversion efficiencies were achieved in regular compared to irregular wave conditions.

ABSTRAK

Terdapat beberapa projek yang dijalankan di seluruh dunia mengenai pelbagai reka bentuk penukar tenaga gelombang terutamanya jenis “floating oscillating water column” (FOWC). Peranti FOWC yang paling banyak dikaji sekarang adalah konsep “backward bent duct buoy” (BBDB) yang tertumpu pada keadaan gelombang teratur dan gelombang tinggi, yang berbeza dengan keadaan lautan gelombang rendah di Malaysia. Didapati bahawa sangat sedikit kajian yang dilakukan untuk BBDB dalam keadaan gelombang yang tidak teratur, yang mewakili keadaan laut yang sebenarnya. Oleh itu, kajian ini memperkenalkan perbandingan prestasi dan tingkah laku BBDB dalam keadaan teratur dan tidak teratur untuk keadaan gelombang rendah. Parameter seperti paras air di dalam peranti, tekanan udara dan laju aliran udara di dalam peranti serta kecekapan penukaran utama diukur dan dihitung. Model BBDB dengan sudut bawah 45^{o} condong direka dan diuji di Institut Penyelidikan Hidraulik Alam Malaysia (NAHRIM) menggunakan tangki gelombang 3D dalam keadaan gelombang teratur dan tidak teratur. Hasil kajian menunjukkan bahawa kecekapan tertinggi dapat diekstraksi dalam keadaan gelombang rendah mulai dari $\lambda / L = 4.2$ hingga $\lambda / L = 4.8$. Kecekapan penukaran primer yang lebih tinggi dicapai secara berkala berbanding dengan keadaan gelombang yang tidak teratur

ACKNOWLEDGEMENT

In the Name of Allah, the Most Merciful and the Most Compassionate. All praise to Allah, the Lord of the world and peace be upon Muhammad, His servant and messenger, I managed to complete this project successfully. Firstly, I would like to thank those who have contributed massively to the success of my project and academic Masters in Universiti Pertahanan Nasional Malaysia (UPNM). Great appreciation to my parents especially my beloved father and mother, Mohmad Ismail bin Mat Jab and Fatimah Bee binti A-Aboo, for their love and support throughout my life. My brothers and sisters, for all their support and motivation from the beginning until the end of this project.

I would like to thank my supervisor, Ir. Ts. Dr. Mohd Rashdan bin Saad, for his guidance and support especially for his confidence and trust on me in completing this study. Special thanks to Assoc. Prof. Ir. Dr. Mohd Rosdzimin bin Abdul Rahman who always support and advise me to finish my study. Thank you very much for always helping and guiding me in this project.

I would like to give special thanks to all my friends for giving me lots of motivation and cooperation, mentally and physically, while completing this report. Finally, I would like to thank everybody who are important to this thesis especially my project partner, Muhammad Aiman bin Jalani for his guidance, and also every single one of you that I could not mention personally here, whom have helped me to complete this journey. Thank you all.

APPROVAL

The Examination Committee has met on 28th February 2020 to conduct the final examination of Nur `Izzati binti Mohmad Ismail on his Master's Degree thesis entitled 'Hydrodynamics Performance of Backward Bend Duct Buoy (BBDB) in Regular And Irregular Wave Conditions'.

The committee recommends that the student be awarded the Masters of Science (Mechanical Engineering).

Members of the Examination Committee were as follows.

Prof. Madya Ir. Dr. Mohd Zaid bin Othman
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Chairman)

Prof. Madya Dr. Khisbullah Hudha
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Internal Examiner)

Prof. Madya Dr. Azmin Shakrine bin Mohd Rafie
Faculty of Engineering
Universiti Putra Malaysia
(External Examiner)

APPROVAL

This thesis was submitted to the Senate of Universiti Pertahanan Nasional Malaysia and has been accepted as fulfilment of the requirements for the degree of **Master of Science (Mechanical Engineering)**. The members of the Supervisory Committee were as follows.

Ir. Ts. Dr. Mohd Rashdan bin Saad
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Main Supervisor)

Assoc. Prof. Ir. Dr. Mohd Rosdzimin bin Abdul Rahman
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Co-Supervisor)

Ir. Dr. Balamurugan a/l Annamalai Gurunathan
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Co-Supervisor)

Dr. Mohd Faizal bin Abdullah
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Co-Supervisor)

UNIVERSITI PERTAHANAN NASIONAL MALAYSIA

DECLARATION OF THESIS

Student's full name	: Nur `Izzati binti Mohmad Ismail
Date of birth	: 10th December 1995
Title	: Hydrodynamics Performance of Backward Bend Duct Buoy (BBDB) in Regular and Irregular Wave Conditions
Academic session	: 2020

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

I further declare that this thesis is classified as:

- [ ] **CONFIDENTIAL** (Contains confidential information under the official Secret Act 1972)*
- [ ] **RESTRICTED** (Contains restricted information as specified by the organisation where research was done)*
- [x] **OPEN ACCESS** I agree that my thesis to be published as online open access (full text)

I acknowledge that Universiti Pertahanan Nasional Malaysia reserves the right as follows.

1. The thesis is the property of Universiti Pertahanan Nasional Malaysia.
2. The library of Universiti Pertahanan Nasional Malaysia has the right to make copies for the purpose of research only.
3. The library has the right to make copies of the thesis for academic exchange.

Signature	**Signature of Supervisor/Dean of CGS/ Chief Librarian
IC/Passport No.	**Name of Supervisor/Dean of CGS/ Chief Librarian
Date:	Date:

Note: *If the thesis is CONFIDENTAL OR RESTRICTED, please attach the letter from the organisation stating the period and reasons for confidentiality and restriction.
** Witness

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background of Research

Electricity can be produced by using fossil fuels and renewable energy. Fossil fuels create power with harmful by-products such as gas, waste and pollutants. Nowadays, there are many studies done to produce clean energy and it has been proven that ocean energy is a clean energy that can minimise the pollution as well as no emissions or by products to be managed. Basically, the ocean can produce two types of energy namely thermal energy from the solar, and mechanical energy from the tides and waves [1]. There are three main types of ocean technology; for instance, the wave, tidal and ocean thermal [2] The world runs on energy and a source of clean energy is rare and valuable. Wave energy is mainly the power drawn from waves.

A wind blowing off the surface of the sea will eventually cause waves to form. In various zones of the world, the wind blows with enough power and consistency to produce continuous waves along the shoreline. Ocean waves contain massive energy potential. Wave power devices extract energy from the surface movement of sea waves or from pressure variations below the water surface. This powerful source of wave energy output is measured via wave speed, wave height, wavelength and water density.

The higher the energy of waves, the higher is their potential to produce electrical power.

Harnessing the power of ocean wave is not easy. This is the reason for the low number of wave generator plants worldwide. However, the wave energy has the biggest advantage over other different energy sources as it is easily identified and the amount of power produced can be measured. Wave energy has been proven to be better than other energy sources that depend on ocean or wind exposure. This energy is also very reliable in terms of costing and manufacturing. There are many types of wave energy converters that have been proposed by researchers from other countries like WaveBob and Mighty Whale, which are discussed in detail in Chapter 2.

In addition, there are specific differences between wave energy and tidal energy, where tidal energy uses the movement and flow of the tides while wave energy utilises the water's surface vertical movement that produces the tidal waves. Wave energy is considered a sustainable power source due to the replenishable nature of oceanic waves. Furthermore, a greater energy output can be produced in a higher frequency and shorter wavelength. The amplitude of sea wave relies on the weather conditions around them. The amplitude of a wave or swell will be lower in a quiet weather and significantly bigger in stormy weather.

The device that can generate the electricity from the ocean wave is called Wave Energy Converter (WEC). The WEC is divided into three types namely attenuators, oscillating bodies and terminator. Each type of the device has its own advantages and disadvantages, but oscillating bodies have more advantages including that it can be easily implemented and maintained. Figure 1.1 displays one of the concepts of WEC that can be implemented worldwide.

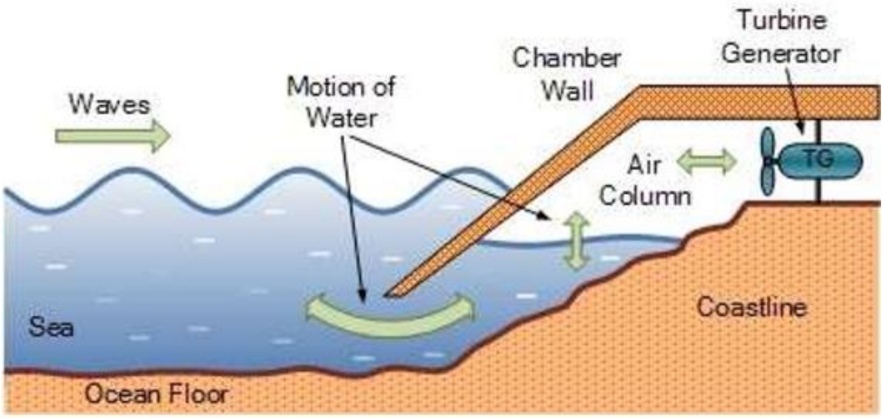

Figure 1.1: Oscillating Water Column (OWC) [3]

The Oscillating water column (OWC) as shown in Figure 1.1 is a device for wave energy that can be categorised as oscillating bodies. Such device is usually used offshore for producing renewable energy. Given the condition that waves at a particular site can widely differ over time, an improved control strategy and connection are required for OWC to ensure better performance. OWC are divided into two categories, which are fixed device and floating device. This type of device needs a body or wall, mechanical turbine, air chamber, water duct and generator to convert ocean waves into electrical power [3]. More details are discussed in Chapter 2.

1.2 Problem Statement

The global issues such as fossil crisis and pollutions forced people to develop clean energy sources. Malaysia is a blessed country to be surrounded by the sea, but there are many small islands that are still using diesel generator to generate electricity. This standalone diesel generators contribute to pollution to the earth especially in marine environments. Thus, this heightened the importance of the study on environmentally friendly devices, such as Wave Energy Converter (WEC) to replace the standalone diesel generators.

Past literature reviews indicated that, there are many studies regarding WEC devices that have been done globally, but very few in Malaysia. To emphasize, most studies done were focused on high-heave wave conditions, which are different from the ocean condition in Malaysia, that has low-heave wave. Thus, this shows that there is a gap in terms of the knowledge of the behaviour and characteristics of WEC devices in low-heave wave conditions in Malaysia specifically.

To address these issues, this research implemented Floating Oscillating Water Column (FOWC), which is BBDB for low heave wave conditions. BBDB is apt to be implemented in Malaysian ocean because of its flexibility in the shape and dimensions of the main body, that can be designed based on the wavelength. In addition, the BBDB is a very simple structure, easy to maintain and installed compared to other devices [4].

To date, many studies on BBDB have been carried out primarily on the design optimisation of the models, which were conducted mostly in 2D and 3D wave tanks. The studies focused on regular wave conditions, instead of irregular wave conditions which represents the real ocean conditions. To add, the performance in 3D tank produced better result compared to 2D tank. Consequently, the literature reviews have clearly shown that there is a gap in the knowledge on 3D tank experiment in both regular and irregular wave conditions. Therefore, this study was conducted to investigate the performance of BBDB in regular and irregular wave conditions of 3D tank by using low-heave wave configurations, which is more suitable to be applied in Malaysia.

1.3 Research Objectives

The objectives of this study are:

1. To compare the behavior of BBDB in both regular and irregular low-heave wave conditions.
2. To analyse the relationship between the behavior of WEC and the efficiency obtained in both regular and irregular low-heave wave conditions.

1.4 Scopes of Work and Limitations

The scopes of this research can be listed as the followings:

1. Malaysia wave condition
    a) The BBDB model was tested based on Malaysia's actual wave condition which is low-heave wave conditions.
    b) The irregular waves produced by the wave basin may not represent the actual ocean wave fluctuation pattern accurately, which may cause the deficit in the efficiency produced.

2. Floating Oscillating Water Column (FOWC)
    a) A floating Backward Bend Duct Buoy (BBDB) model with inclination angle on the rear side is used in this investigation.
    b) The geometry of the fabricated floating BBDB prototype and the 3D model CAD design might be slightly different due to the limitation of workmanship and fabrication tools.
3. Wave Basin Conditions
    a) The 3D wave tank is used in this study to represent the real ocean conditions.
    b) JONSWAP Spectrum representing irregular wave conditions was applied in this study.

1.5 Outline of Thesis

Chapter 1 Introduction of the thesis

The overview of this study is discussed in this chapter, along with the background of the study on regular and irregular wave energy converter (WEC), problem statement and the objectives.

Chapter 2 Literature Review

An overview of the wave energy converter is addressed in this chapter. The knowledge gained from the literature of WEC are explained in detail in this chapter.

Chapter 3 Methodology

The methodology used is explained in this chapter to ensure that the objectives of the study have been reached. Equipment, tools and the arrangements of the wave tank are presented in this chapter.

Chapter 4 Results and Discussions

All of the results obtained were recorded and discussed in this chapter. The formula employed to obtain the device performance in either regular or irregular wave conditions is presented.

Chapter 5 Conclusions and Recommendations

This chapter concludes and suggests recommendations for future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Power is one of the most significant factors for the emerging socio-economic environments of a country [5]. In emerging countries like Malaysia, the demand for electricity is expected to rise with increasing urbanisation and rapid industrialisation. Currently, energy production is especially captivated with fuel; however, fossil fuels will not be available in the near future due to the depletion of existing reserves and their impact on the environment. Wave energy has been considered as environmentally friendly and quickest growing renewable energy supply for generating power in the long run. Unlike other renewable energy resources, wave energy can give out power throughout the year. As Malaysia encompasses a total lineation of 4,675 kilometres of coastline, there is an excellent potential for the utilisation of wave energy in Malaysia particularly on its coasts and islands[5].

The International Energy Agency predicted that if the nation could adopt an emission reduction target to stabilise greenhouse gas emissions in the atmosphere to 450 parts per million of CO_2 equivalent, marine energy technologies are likely to grow by 14.6% annually until 2030 [6]. In 1974, Salter described ocean wave energy as a clean, safe, permanent and relatively simple source of energy that is yet to be harnessed to its full potential [7]. This statement is equally true today after more than four decades of development. Wave energy has advantages over other forms of Ocean Renewable Energy (ORE) such as tidal energy, ocean thermal energy conversion and ocean current power since it has a high energy density and low dependency on the local weather. Ocean waves could supply 2000 TWh/year [8], which is sufficient to cover 10% of the electricity used globally in 2005 as shown in Figure 2.1[9]. Besides, ocean energy is the largest source of renewable energy since over 70% of the earth's surface is covered with the ocean[10]. Wave energy is the one of the best sources to produce the electricity and it has been proved that the wave power devices can power up to 90% of the time compared to 25% for solar and wind devices [11].

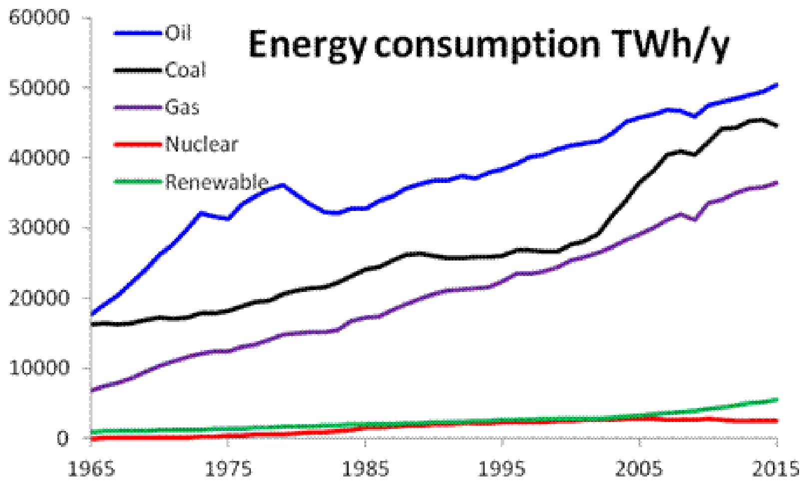

Figure 2.1: The world's energy consumption in 2015 [9]

Other forms of ORE have diverse constraints such as insufficient power production apart from a few locations (tidal), low cost-effectiveness (ocean thermal energy conversion) and low energy density (ocean currents) [12]. Moreover, tidal energy projects have faced strong opposition owing to environmental-impact concerns [13]. A major review from Wave Energy Converter (WEC) technology has been made by Falcao *et al.* [14] ; thus, the details of WEC engineering are not discussed in this present investigation.

The creation of wave energy has engaged and created curiosity among various trades and governments to carry out investigation and development for the wave power technologies. Wave power also confronts challenges in terms of technical and financial due to the severe circumstances of oceanic environment that reveal high maintenance and machinery costs. Notwithstanding the challenges, a huge diversity of wave energy conversion technologies has been established and intended for retrieving energy from the ocean waves. The investigation and expansion of various WEC have been conducted by technologists and engineers, and among them are overtopping devices[15], oscillating water columns[16]and point absorber systems (Figure 2.2)[17]

Figure 2.2: Point Absorber (OPT Powerbuoy)[19]

The wave energy has a significant quantity of benefit compared to other renewable energy sources. This is because it is more inevitable, persistent and spatially concentrated. Additionally, the wave energy created has low graphical and green effects, insignificant land use and follows the limited adaptability of energy demand in various conditions. These favourable features of ocean wave energy together with