Mooring Analysis of Very Large Floating Structures in Malaysian South China Sea Waters

Keeran Daniel A/L D.Ramanujam

MECHANICAL ENGINEERING

UNIVERSITI TEKNOLOGI PETRONAS

JANUARY 2016

Mooring Analysis of Very Large Floating Structures in Malaysian South China Sea Waters

by

Keeran Daniel A/L D. Ramanujam
15950

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical)

JANUARY 2016

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Mooring Analysis of Very Large Floating Structures in Malaysian South China Sea Waters

by

Keeran Daniel A/L D. Ramanujam
15950

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL)

Approved by,

____

(Dr. William K. S. Pao)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2016

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 acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

KEERAN DANIEL A/L D.RAMANUJAM

ACKNOWLEDGEMENT

The completion of this Final Year Project has been a culmination of various acts of assistance and goodwill. I take this opportunity to express my greatest gratitude to them.

Thus, I take this opportunity to express my profound appreciation and deep regards to my direct supervisor, Dr. William Pao, King Soon for his exemplary guidance, motivational nature and for his willingness to share his knowledge as well as experience throughout my time of need.

Subsequently, I would like to thank my friends and family who have been supporting me throughout this project. Their direct and indirect interaction as well as gestures have kept me going.

Last but not least, I would like to thank the almighty for granting me this opportunity and for all around good health. It is undeniable, that only with the support and assistance of all the parties mentioned above, that I have been able to complete by project.

ABSTRACT

Very large floating structures (VLFS) are any structure of which the largest dimension is greater than its characteristic length. This technology has been studied over a long period of time in Japan, though not much interest has been shown in the rest of the world. As evident by the varied applications of VLFS in Japan, there are potentially limitless opportunities for the implementation of such technology in Malaysia. Having said that, little work has been done with respect to the implementation of this technology in Malaysian waters. This paper will be focusing on establish the relationship between vessel size, water depth and operating sea states (wave height and period, current speed, and wind speed) on fender forces. The scope of study for this paper has been limited to the region of Malaysian South China Sea waters which covers the East coast of Malaysia, stretching to the West coast of Sabah and Sarawak. Hence, the operating conditions which were considered, namely, wave height, wind speed and current speed will be in accordance with the conditions found in the aforementioned region only. In order to identify the correlation between the mooring requirements, vessel dimension and operating depth, a hydro dynamic analysis was first conducted, followed by a hydrodynamic time response analysis on ANSYS Aqwa. Three vessel sizes (300mx 60m x 2m, 500m x 100m x 3m, 1000m x 200m x 4m) where subjected to the normal and storm condition sea states in the Peninsular and Sabah/Sarawak region. The water depths considered were 30m, 50m and 70m as well as 30m, 200m and 1000m respectively. The maximum individual fender forces and sum of fender forces in the X and Y direction were obtained. It was found that the water depth does not play significant role in the fender forces of the VLFS as the overall vessel size and the operating sea state in the Sabah and Sarawak Region, as compared to the Peninsular Malaysia region, in which it does. The vessel size plays a significant role in fender forces.

TABLE OF CONTENTS

CERTIFICATION OF APPROVAL II

CERTIFICATION OF ORIGINALITY III

LIST OF TABLES AND FIGURES IV

ABBREVIATIONS AND NOMENCLATURE VII

CHAPTER 1: INTRODUCTION 1

1.1 Project Background 1
1.2 Problem Statement 3
1.3 Objectives 3
1.4 Scope of Study 3

CHAPTER 2: LITERATURE REVIEW 5

2.1 Types of VLFS 5
2.1.1 Pontoon-type VLFS 6
2.1.2 Semi-Submersible VLFS 6
2.2 Advantageous features of VLFS technology 6
2.2.1 Economical for large water depths and soft seabed 7
2.2.2 Environmentally friendly 7
2.2.3 Ease of expansion or removal 7
2.2.4 Fast construction period 7
2.2.5 Mooring instead of foundation 8
2.2.6 Base isolation 8
2.3 Current applications of VLFS 8
2.4 VLFS Station keeping 9
2.4.1 Mooring 10

2.4.1.1 Load characteristics of Rubber Fenders 12
2.4.1.2 Load characteristics of Mooring Dolphin........................15
2.4.2 Loads acting on a floating structure 17
2.4.2.1 Wind force 17
2.4.2.2 Wave force...18
2.4.3 Breakwaters 19
2.5 South China Sea conditions.. 19
2.5.1 Wave Spectrum 21
2.6 Previous Work.. 22
2.6.1 Type of Analysis..23
2.6.2 VLFS Models 24
2.6.3 VLFS Shapes 25
2.6.4 Mooring Systems...25
2.7 Concluding Remarks 26

CHAPTER 3: METHODOLOGY..27
3.1 Flow of analysis 27
3.2 Assumptions 29
3.3 VLFS model and modelling cases.................................. 29
3.4 Finite Element Modelling... 31
3.4.1 Vessel Sizes 31
3.4.2 Flow of Modelling... 31
3.4.3 Fender properties and Configuration.............................. 32

CHAPTER 4: RESULTS AND DISCUSSIONS 35
4.1 Obtained Results 35
4.1.1 Peninsular Malaysia Region 35
4.1.2 Sabah and Sarawak Region 41
4.2 Effect of Vessel size on Fender Forces 47
4.3 Effect of Water depth on Fender Forces 48
4.4 Effect of Weather and Sea state on Fender Forces.......... 49
4.5 Discussion 49

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS 50
5.1 Conclusion and Recommendation.................................... 50

REFERENCES 52

APPENDICES 58
APPENDIX 1: Peninsular Malaysia Simulation Cases................. 58
APPENDIX 2: Sabah and Sarawak Simulation Cases.................. 59

LIST OF TABLES AND FIGURES

List of Tables

1. Table 2.1: VLFS Applications by Year 9
2. Table 2.2: Sea Conditions in Malaysian South China Sea Waters. 20
3. Table 2.3: Previous Work on VLFS motion and response 23
4. Table 3.1: Compilation of previous VLFS response studies 31
5. Table 3.2: Modelling cases 31
6. Table 3.3: Vessel Cases and Properties 32
7. Table 3.4: Fender Properties 33
8. Table 3.5: VLFS Fender Configurations 34
9. Table 3.6: Gantt Chart and Key Milestones 35

List of Figures

1. Figure 1.1: Mega Float Project 2
2. Figure 2.1: Comparison of Pontoon-type and Semi-submersible VLFS 5
3. Figure 2.2: VLFS Mooring Types 10
4. Figure 2.3: Caisson Type Dolphin with Fenders 12
5. Figure 2.4: Pier/Quay Type Dolphin with Fenders 12
6. Figure 2.5: Load deformation curves of buckling and side load fenders (Ueda,1998) 14
7. Figure 2.6: Energy absorption curve and f factor of fenders (Ueda, 1998) 15
8. Figure 2.7: Energy absorption (1) and dissipation (2) curve of fenders (Ueda, 1998) 15
9. Figure 2.8: South China Sea Bathymetry 21
10. Figure 3.1: Proposed Analysis Method 29
11. Figure 3.2: ANSYS Aqwa Modelling Flow 33
12. Figure 3.3: Stiffness function of rubber fenders obtained by evaluating slope of deformation curve (Kim et.al., 2004) 34
13. Figure 4.1: Fender forces for 300m VLFS in varying depths (Operating condition) 36

14. Figure 4.2: Fender forces for 500m VLFS in varying depths (Operating condition) 37
15. Figure 4.3: Fender forces for 1000m VLFS in varying depths (Operating condition) 37
16. Figure 4.4: Fender forces for 300m VLFS in varying depths (Storm Condition) 38
17. Figure 4.5: Fender forces for 500m VLFS in varying depths (Storm Condition) 38
18. Figure 4.6: Fender forces for 1000m VLFS in varying depths (Storm Condition) 39
19. Figure 4.7: Fender forces for 30m depth with varying VLFS size (Operating condition) 39
20. Figure 4.8: Fender forces for 50m depth with varying VLFS size (Operating condition) 40
21. Figure 4.9 Fender forces for 70m depth with varying VLFS size (Operating condition) 40
22. Figure 4.10: Fender forces for 30m depth with varying VLFS size (Storm Condition) 41
23. Figure 4.11: Fender forces for 50m depth with varying VLFS size (Storm Condition) 41
24. Figure 4.12: Fender forces for 70m depth with varying VLFS size (Storm Condition) 42
25. Figure 4.13: Fender forces for 300m VLFS in varying depths (Operating condition) 42
26. Figure 4.14: Fender forces for 500m VLFS in varying depths (Operating condition) 43
27. Figure 4.15: Fender forces for 1000m VLFS in varying depths (Operating condition) 43
28. Figure 4.16: Fender forces for 300m VLFS in varying depths (Storm Condition) 44

29. Figure 4.17: Fender forces for 500m VLFS in varying depths
(Storm Condition) 44
30. Figure 4.18: Fender forces for 1000m VLFS in varying depths
(Storm Condition) 45
31. Figure 4.19: Fender forces for 30m depth with varying VLFS size
(Operating condition) 45
32. Figure 4.20: Fender forces for 200m depth with varying VLFS size
(Operating condition) 46
33. Figure 4.21: Fender forces for 1000m depth with varying VLFS size
(Operating condition) 46
34. Figure 4.22: Fender forces for 30m depth with varying VLFS size
(Storm condition) 47
35. Figure 4.23: Fender forces for 50m depth with varying VLFS size
(Storm Condition) 47
36. Figure 4.24: Fender forces for 70m depth with varying VLFS size
(Storm Condition) 48

ABBREVIATIONS AND NOMENCLATURE

$VLFS$	= Very Large Floating Structure
E_f	= energy absorption of fender
f	= energy absorbing efficiency
R_m	= maximum fender reaction force
d_m	= maximum fender deformation (m)
DWT	= Deadweight Tonnage
Q_d	= ultimate load bearing capacity (kN)
Q_f	= bearing capacity by circumferential skin friction (kN)
Q_p	= toe bearing capacity (kN)
q	= toe bearing capacity intensity (kN/m^2)
f	= mean circumferential skin friction intensity (kN/m^2)
A_S	= toe circumferential of pile (m^2)
A_P	= toe area of pile (m^2)
EI	= flexural rigidity of pile (kNm^2)
$P_{x\,y}$	= subgrade reaction force per unit area depth (x) and displacement (y)
B	= pile width (m)
$C_{x\,y}$	= drag coefficient in X and Y direction
C_M	= pressure moment coefficient about center of gravity
ρ	= density of force about center of gravity
$A_{T,L}$	= area projected above surface (T=front, L= side)
F_d	= wave drift force per unit length (kN)
PM	= Pierson-Moskowitz
JONSWAP	= Joint North Sea Wave Project
$I_{xx,yy,zz}$	= moment of inertia in x, y or z plane
H_i	= wave height of incident wave
K_R	= wave drift force per unit length (kN)

CHAPTER 1

INTRODUCTION

1.1 Project background

Modernization has brought about a number of significant changes to the world, of which the most significant comes in the form of population distribution. The past several decades have seen an exodus of the earth's population from expanses of flat planes and higher grounds alike, to coastal areas. Don Hinrichsen (2013), in his book, *Coastal Waters of the World: Trends, Threats, and Strategies,* highlights that the majority of humanity and its economic activities is focused in this region. Alarmingly, nearly half of the earth's population now inhabits no more than 200km from the coast, which collectively only amounts to 10 percent to the earth's land area.

Perhaps unsurprisingly, this has resulted in high population densities in the aforementioned regions, to an extent in which we are running out of land for any form of new development. Land reclamation has been one possible solution to this problem. However, the high cost of involved and its potential impact to the environment has always been an unfavorable consequence. Moreover, it is only practical for relatively shallow (20m) depths of water. Thus, when venturing into deeper water and soft seabed condition, land reclamation is not economically feasible. It is also important to bear in mind, that reclamation cause irreparable damage to marine habitats and may disturb the toxic sedimentation which have been deposited over long periods of time (Watanabe, et al., 2004).

Very large floating structures (VLFS) seem to be the only feasible solution to the problem of coastal land scarcity. Their low relative cost of construction, the absence of environmental damage makes them ideal candidates for the perfect solution to the problem. In simple terms, VLFS are supersized barges, with length that can exceed

1000 m and width exceeding 100 m, which float freely at sea and held in place by mooring. Japan, currently spearheading the technology with the formation Technological Research Association of Mega float (TRAM) in 1995, have already put this technology into practice, with the Mega Float demonstration model (Figure 1.1). This structure has been closely monitored and its performance assessed, as a way of further improving the technology. It has also been inducted into the Guinness Book of World Records as the largest man-made island in the world. Results from the Mega Float project were the deciding factor for the expansion of Tokyo International Airport in Haneda, by means of a floating runway.

VLFS technology could also be advantageous in moving large structures or facilities out to sea. Floating ports or piers could reduce ship travel time and increase offloading speeds. This also frees up high value land that could be developed into residential areas. The oil and gas industry could also benefit from the construction of floating refinery or storage facilities such as the Kamigoto and Shirashima oil storage bases in Japan (Wang, Watanabe & Utsunomiya, 2007). The US military also showed interest in VLFS technology by proposing a 2km long mobile offshore base (MOB) which could be used as a naval base to maintain military hardware and house troops (Palo,2005) . Thus it is clear that the possible uses for VLFS technology could be limitless.

Figure 1.1: Mega Float Project

1.2 Problem statement

VLFS technology seems to be future of ocean space colonization, opening new doors to expand our activities out into the sea. Though extensive studies have been conducted off the coast of Japan in the Sea of Japan and in the Pacific Ocean, relatively little work have been one in other region, which includes the South China Sea. The weather and sea conditions encountered in this region may be different. Thus, if the technology if to be extensively used in the South China Sea region or particularly off the coast of Malaysia, the success of VLFS technologies applied elsewhere around the world for varying applications, should be studied. Moreover, the mooring requirements would also have to be assessed, as it is an important contributor to the proper operations of the VLFS. The relationship between the structural dimensions, and mooring length has not been established for conditions encountered off the coast of Malaysia and as an extension the South China Sea

1.3 Objectives

This project aims to:

a) To analyze VLFS technology currently available with respect to applications in Malaysian South China Sea waters
b) To establish the relationship between vessel size, water depth and operating sea states (wave height and period, current speed, and wind speed) on fender forces.

1.4 Scope of Study

This study has been limited to only the pontoon type VLFS held in place by rubber fenders. The pontoon type VLFS was chosen for its suitability in relatively calmer waters, as apparent in its wide application. Rubber fenders were also chosen as the mooring method that is being considered due to its common application in VLFS station keeping.

Thus, the focus of this study is to investigate the relationship between the dimensions of the structures in relation to the water depth as well as sea conditions found in Malaysia, to its mooring requirements. The region of interest is only limited to the Malaysian South China Sea waters which covers the East coast of Malaysia, stretching to the West coast of Sabah and Sarawak

As such, the wave height, wind speed and any other parameter that is herein considered are a reflection of the conditions found in this particular region.

CHAPTER 2

LITERATURE REVIEW

2.1 Types of VLFS

According to Suzuki et al. (1997), a VLFS is not only defined by its large dimensions, but also having its characteristic length (ratio of structural stiffness to buoyant spring stiffness) exceed one of its dimensions. Though the Very Large Floating Structures (VLFS) may come in any geometry and dimension, there can be broadly divided into two categories, namely pontoon-type and semi-submersible (Figure 2.1).

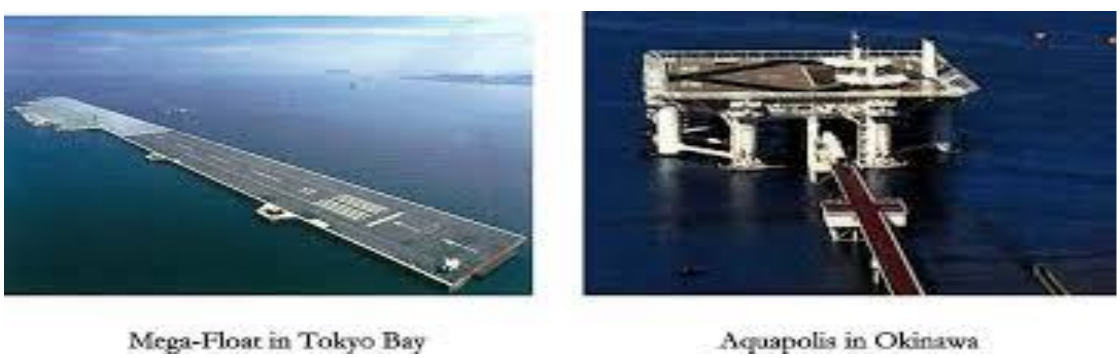

Figure 2.1: Comparison between Pontoon type (left) and Semi-submersible (right) VLFS (Watanabe et, al., 2004)

2.1.1 Pontoon-type VLFS

The simpler of the two version, a pontoon type VLFs comprise of pontoon hulls, essentially with a box like construction. This type of VLFS is known for its high stability and its rudimentary shape allows for low manufacturing costs. Maintenance on a pontoon type VLFS is also less complicated as compared to semi-submersible types. However, this pontoon-type of floating structure is only suitable for use in calm waters associated with naturally sheltered coastal formations (Watanabe et al., 2004). To further reduce the height of waves that impact on these pontoon-type VLFS, breakwaters are usually constructed nearby. Japanese engineers often refer to large pontoon type VLFS as Mega Float. As a general rule, any floating structure with its longest dimension exceeding 60m is designated as a Mega Float (Watanabe et. al., 2004).

2.1.2 Semi-Submersible VLFS

Unlike the pontoon type VLFS, semi-submersible types are more complex in their construction. The platform on a semi-submersible is raised above the sea level and stacked on an array of columns resting on submerged pontoons (Matsagar, 2015). The distance from the sea surface to the structures platform provides additional protection against the waves, making them ideal for high seas. With pioneering work in semi-submersible oil rigs over the North Sea and Gulf of Mexico, these structures are able to minimize effects of waves while maintaining a fixed buoyancy force (Wang et. al., 2007). Thus, in application with high wave elevations, a semi-submersible structure offers better stability (Watanabe et al., 2003).

2.2 Advantageous features of VLFS technology

Prior to investigating various segments of the VLFS structure, it is important to understand the benefits the application of this technology could potentially bring. The many advantages of VLFS technology is assessed for application in Malaysian South China Sea water conditions:

2.2.1 Economical for large water depths and soft seabed conditions

Being floating structures, with low draft, they are not easily affected with water depths and sea bed conditions (Wang et al., 2007). Perhaps more importantly, land reclamation becomes uneconomical in depths exceeding 20m. This is apparent in the case of Singapore, which incurred a US$ 15.3 billion cost in sand alone, to increase the surface area of the island nation by a mere 140 sq. km (Guerin, 2003). With water depths in the Malaysia exceeding 50 m (Morimoto, Yoshimoto & Yanagi,1999) not far from the coast, this make VLFS ideal in this region.

2.2.2 Environmentally friendly

Apart from the mooring structures, VLFS structures do not come into contact with the sea bed and does not pose any harm to the marine habitat below. They have low contributions to pollution and do not significantly affect the tidal currents (Wang et al., 2007). Land reclamation adversely affects littoral flow of sand, as a result, leading to a loss in natural flow in down drift beaches. The local bathymetry, current velocity and wave conditions at the dredged areas could also be altered (Jensen & Mogensen, 2000). Protecting the richness of marine flora and fauna is of great importance to Malaysia, thus, VLFS technology has a bright future.

2.2.3 Ease of expansion or removal

The modular construction nature of a VLFS allows flexibility in terms of expansion and downsizing. Outdated modules could be removed and replaced with newer ones, without necessarily affecting the other modules (Wang et al., 2007). This flexible construction and disassembly method contributes to the reduction of the overall time required for the commissioning of a floating structure.

2.2.4 Fast construction period

Perhaps the strongest merit of a VLFS structure, is the short amount of time that is required for the construction and commissioning. In comparison, land reclamation activities can span a number of years, a period of between two to five years (Wang et al, 2007). The Mega float structure on the other hand, only required a construction time of about 4 months. The existence of large shipyards in Malaysia also allows for the construction to be done locally (Ramli & Khalid, 2008)

2.2.5 Mooring instead of foundation

Floating structures such as large vessels rely solely on buoyancy to support their enormous weight and mooring lines to restrict their movements in the vertical and horizontal plane. A VLFS structure is not exception to this fact. Hence, the cost of construction associated with designing and manufacturing large immovable columns to support the weight of the structure is removed. Structures used in the mooring of VLFS are of a simpler construction and are not necessarily massive in size. The absence of supporting columns are also in favor of the conditions in Malaysia, which may have soft soil conditions closer to the coast (Jong & Chan, 2013).

2.2.6 Base isolation

Though Malaysia itself does not lie in an earthquake prone zones, it is naive to think that it is not struck by earthquakes occasionally. According to Marto,Tan, Mohd Kasim and Yunus (2013), Peninsular Malaysia has been hit by tremors resulted by earthquake in surrounding regions, such as Northern Sumatra and Sulawesi. In fact, Sabah and Sarawak have suffered even more serious tremors from surrounding earthquakes. Floating structures by nature, are base isolated. Therefore, these structures will not experience any disturbance by the movement of the ground beneath them. This quality is especially beneficial in the field of bridge building (Wang et al., 2007).

2.3 Current applications of VLFS

As a testament to the wide possibilities available with the use of VLFS technologies, current applications of the technology are compared and contrasted in the table below.

Table 2.1: VLFS applications by year

No	Source	Name	Type	Year	Application	Dimension	Mooring Type	Breakwater	Location
1	Yoneyama, Hiraishi & Ueda (2004)	Scandanavia Maru	Ship (repurposed)	1970	Hotel	5105GT, 127m	Chains	No	Numazu
2	Yoneyama, Hiraishi & Ueda (2004)	Aquapolis	Semi submersible	1975	Exhibition	104mx100mx32 m	Chains	-	Okinawa
3	Yoneyama, Hiraishi & Ueda (2004)	Soya	Ship (repurposed)	1979	Museum	2734 GT, 83m	Dolphins	Yes	Tokyo
4	Yoneyama, Hiraishi & Ueda (2004)	Fuji	Ship (repurposed)	1985	Museum	5250 GT, 100m	Dolphins	Yes	Naguya
5	Yoneyama, Hiraishi & Ueda (2004)	Oriana (removed)	Ship (repurposed)	1987	Restaurant, Exhibition	41290 GT, 245m	Dolphins	Yes	Beppu
6	Yoneyama, Hiraishi & Ueda (2004)	Kamigoto Oil Stockpiling Station	Pontoon	1990	Oil storage base	390mx97mx27.6 m	Dolphins	Yes	Shinkamigoto
7	Wang & Wang (2015)	Ujiana Ferry Pier	Pontoon	1994	Ferry Pier	150mx30mx4m	Dolphins	Yes	Hiroshima
8	Inoue (1999)	Mega Float Phase 1	Pontoon	1995	Demonstration Model	300mx60mx2m	Dolphins	Yes	Yokosuka, Tokyo Bay
9	Yoneyama, Hiraishi & Ueda (2004)	Shirashima Oil Stockpiling Station	Pontoon	1996	Oil storage base	397mx82mx25.4 m	Dolphins	Yes	Kitakyusyu
10	Inoue (1999)	Mega Float Phase 2	Pontoon	1998	Airport Runway Demonstration Model	1000mx60m(121 m widest)x3m	Dolphins	Yes, existing (phase 1)	Yokosuka, Tokyo Bay
11	Wang & Wang (2015)	Yumemai Floating Swing Arch Bridge	Pontoon	2001	Bridge Support	58mx58mx8m	Dolphins	-	Osaka
12	Heggen (2015)	Marina Bay Floating Platform	Pontoon	2007	Perfromane Stage	120mx83mx1.2m	Dolphins	No	Singapore
13	Brown (2013)	Kagoshima Nanatsujima Mega Solar Power Plant	Pontoon	2013	Solar plant	118 hectars	-	Yes	Kagoshima Bay

2.4 VLFS Station keeping

Station keeping refers to the restraining of the floating structure in its intended location or configuration. Considering the size of the floating structure, new methods in station keeping had to be developed. Mooring is required to restrict horizontal and reduce vertical movement, while breakwaters dissipate the force transmitted by the waves.

2.4.1 Mooring

With any floating structure mooring is seen as the main method of maintaining relative horizontal and vertical positioning. During the designing of these mooring systems, the loads subjected by winds and waves in stormy weather are to be consider (Wang et al., 2008). The mooring systems of a floating structure can be divide into two major groups, namely (Figure 2.2):

- Mooring-lines type (flexible mooring)
- Caisson or pile type dolphin with fenders (rigid mooring)

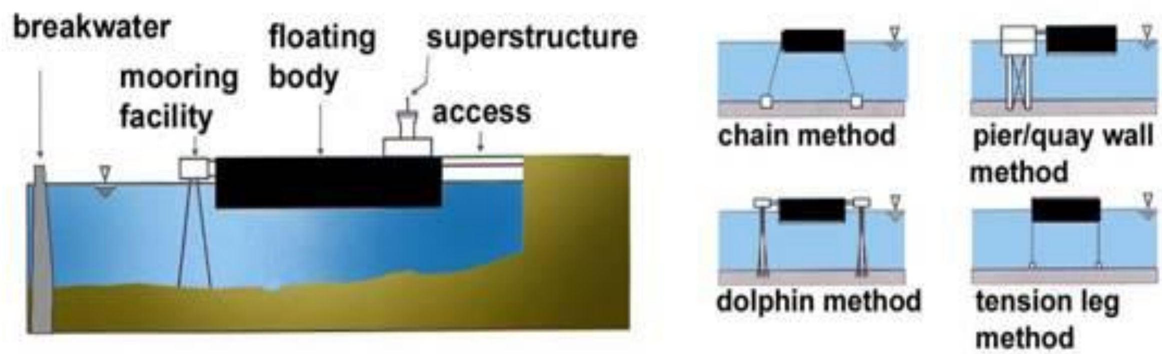

Figure 2.2: VLFS Mooring Types

Generally, mooring lines use chains, wire ropes, synthetic ropes, chemical fiber ropes, steel pipe piles and hollow pillar links. The motion of the floating structures, pulls on these lines, creating tension. The tension that is created is then provides a restoring force, to reposition the structure in its original position. A moored vessel possesses six degrees of freedom (DOF) which consists of surge, sway, heave, roll, pitch and yaw motions under the action of wave, wind and current. Mooring prevents horizontal movements and, to a certain extent, vertical motion. The effect of mooring systems on hydro elastic behavior of floating structures has been frequently analyzed. Operating conditions and environmental factors such as waves, wind forces and depth heavily influence the type of mooring system to be chosen (Wang &Wang, 2015).

Typically mooring lines are held in place by anchors that are sunk into the sea bed. The frictional contact between the anchor surface and surrounding soil, firmly holds it place. Mooring lines may not be as efficient in the application of large floating structures positioned in deep-water, due to the high tensional forces exerted on the lines. The motion of a floating structure also become large with increasing water depth, and as a result, mooring length (Wang et al., 2008). The heavy mass and slow response of the structure in the event that it is displaced from its original position by a wave, would also place high strain on the lines for an extended period of time. Another aspect that has to be considered is the water depth at the location. Conventional chain mooring does not successfully form catenary curves in regions of low water depth (Wang & Wang, 2008).

The mooring method of choice for large floating structures in recent years, has been the deformable fender type. This method of mooring was first introduced for the two offshore oil storage bases, Kamigoto and Shirashima Oil Stockpiling Stations (Wang et al., 2008). Essentially, rigid structure that extend above the water level are equipped with large rubber fenders. These fenders can deform by a significant amount, absorbing the energy from the motion of the floating structure. There are two types of rigid structure available currently, a caisson dolphin (Figure 2.3), a jacket or pile system or a pier/quay system (Figure 2.4). In designing the rigid structure, the energy absorption by the deflection of the structure itself is neglected as it is much lesser than the deformation of the rubber fenders, which could deform by half its total length (Wang et al., 2008).

As shown in Table 2.1, dolphin fender mooring has been the preferred mooring method for large floating structures.

Figure 2.3: Caisson Type Dolphin with Fenders

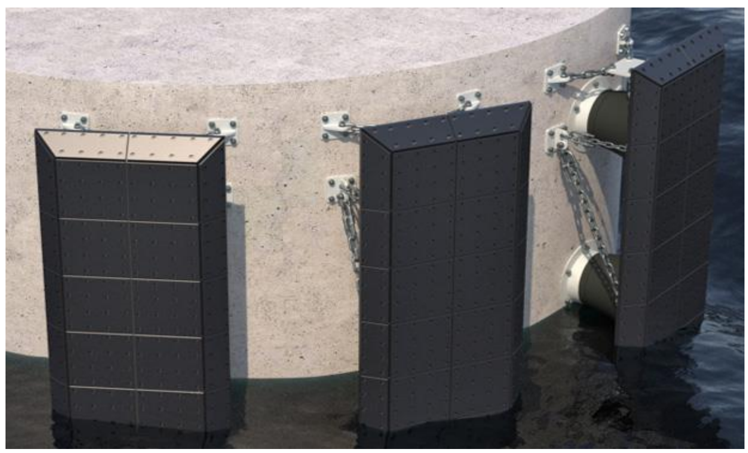

Figure 2.4: Pier/Quay Type Dolphin with Fenders

2.4.1.1 Load characteristics of Rubber Fenders

The proper operation of a dolphin fender or caisson fender mooring system heavily depends on the performance of rubber fenders. As the load absorbing structure in the construction, these fenders are responsible for dissipating the energy created by the motion of the VLFS. Therefore, high-performance rubber fenders have been recently developed (Wang et al, 2008).

These forms of mooring are able to hold in place even the largest of ships or structures. For example, their used in large oil terminals, frequently visited by 200,000 to

500,000 Deadweight Tonnage (DWT) crude oil carriers to absorb the energy during berthing. These high performance fenders vary in their length, ranging from 3m to 4m and are capable of withstanding loads of between 5500kN to 8,900kN, with its energy absorption equating to 7,600 kJ to 10,000kJ. The load-deformation characteristics of rubber fenders can be broken down into two categories, namely, buckling fender and side-loading fender.

For buckling-type fenders, the reaction forces increases rapidly for a small deformation and as such, reaches the maximum deformation value at 20% to 25% of the overall length of the fender, as shown in Figure 2.5 . Beyond this point, the reaction force remains almost equivalent to the maximum reaction force up to a deformation value of 50% to 60% of its length. In the case of the side-loaded cylindrical-type fender, the reaction forces increase exponentially with respect to its deformation amount. The energy absorption, E_f, of a rubber fender is given by:

$$E_f = f \times R_m \times d_m \qquad \text{(Eq. 1)}$$

Where:

f = energy absorbing efficiency (varies from 0 to 1)

R_m = maximum fender reaction force (in kJ)

d_m = maximum fender deformation (in m)

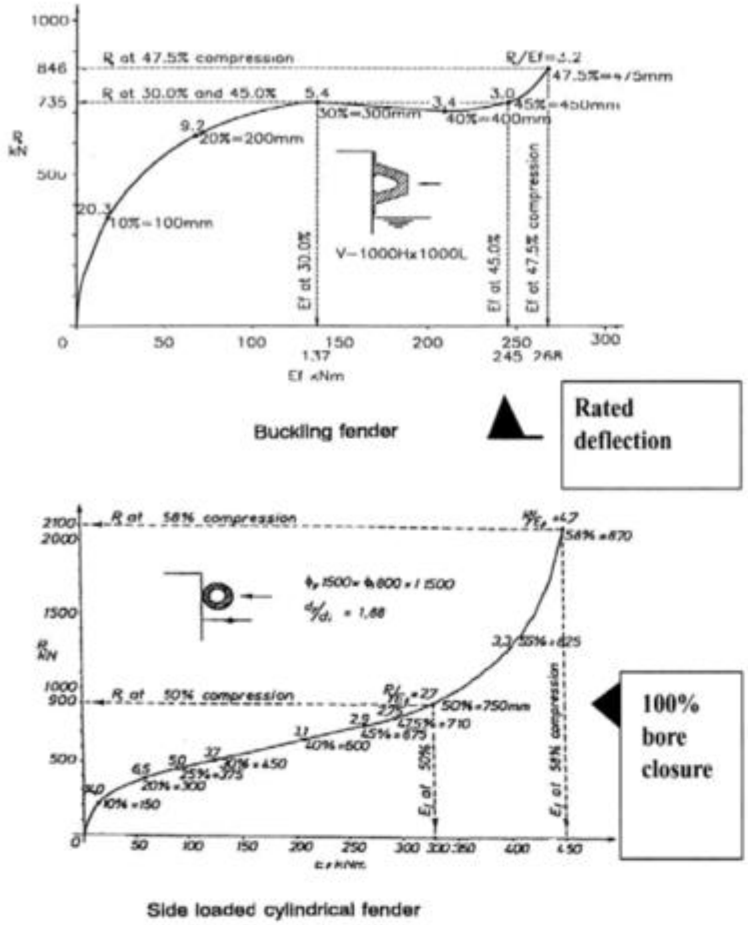

Figure 2.5: Load deformation curves of buckling and side load fenders (Ueda, 1998)

The different load absorbing characteristic of each type of fender is reflected in the factor, f, as for buckling type fender is larger than that of a side-loaded type. The factor f is derived from the shaded area (absorbed energy) divided by the area O-R_m-A-d_m, as shown in Figure 2.6. Therefore, based on the load deformation curve in Figure, the reason buckling type fenders have a smaller reaction force as opposed to a side load fender of the same height and same energy absorption. The energy absorbed by the fender system during compression is then partially dissipated in the form of heat within the material, as well as the floating structure, as shown in Figure 2.7.

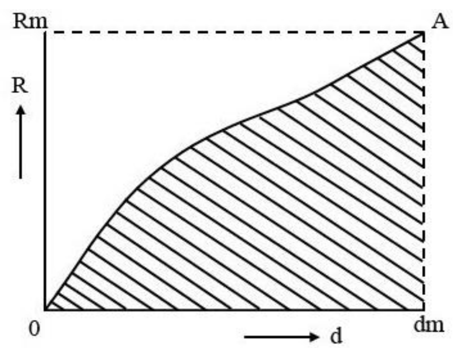

Figure 2.6: Energy absorption curve and f factor of fenders is equal to the shaded area divided by the rectangular area 0-Rm-A-dm (Ueda, 1998)

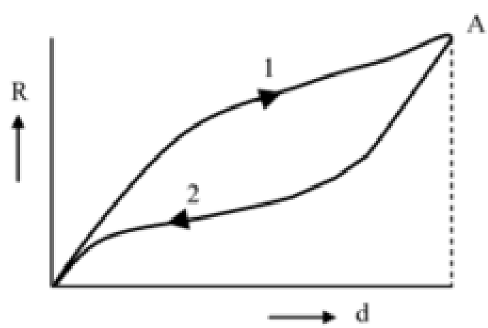

Figure 2.7: Fenders compression (1) and decompression (2) curve (Ueda, 1998)

The buckling type rubber fender is suited for restraining floating structures which are subjected to waves, wind, and current, which can be modeled as steady forces. Thus, it can be said that buckling type fenders are suitable for the dolphin-fender type mooring system.

2.4.1.2 Load characteristics of Mooring Dolphin

A mooring dolphin refers to a vertical structure which extends above the waterline, to which the rubber fenders are attached to. The structural types of mooring dolphins are broadly classified under the gravity-type structure, such as caisson and cellular bulkhead, and pile type structures, such as vertical-pile pier, a coupled pile pier and a jacket type.

A gravity type dolphin is regarded as a rigid body and as such, is designed so that the interaction forces between the dolphin and the mooring fenders does not exceed the resistance force for sliding. A pile type structure, on the other hand, behaves as an elastic body but is still regarded as a rigid body because its rigidity is the more dominating characteristic (rigidity is much more than rubber fender, so rubber fender deforms first).

High tensile steel is often the material of choice for the construction of mooring dolphins, in order to make use of energy absorption by the dolphin itself. The complex combined load deformation characteristics of both the rubber fenders and flexible mooring dolphins should be considered in the simulations for determining the motions and mooring forces of a floating structure (Ueda et, al., 1998). The load-deformation characteristics in the horizontal direction of a pile-type dolphin may be calculated by methods proposed by Blum or Chang (1937) or Matlock (1970) and Reese et. al (1975) that is in conformance with the API RP 2A method (1976) while Kubo (1964), and Hayashi and Miyajima (1963), which is in conformance with the Ports & Harbour Research Institute (PHRI) method (1996).

The design of the pile-type dolphin involves the examination of both the axial bearing capacity and the lateral bearing of the piles as well as the determination of the pile dimensions. The ultimate-axial bearing capacity of a pile is given by:

$$Q_d = Q_f + Q_p = fA_s + qA_p \qquad \text{(Eq. 2)}$$

Where:

Q_d = ultimate load bearing capacity of pile (in kN)

Q_f = bearing capacity by circumferential skin friction intensity (in kN)

Q_p = toe bearing capacity (in kN)

q = toe bearing capacity intensity (in kN/m^2)

f = mean circumferential skin-friction intensity (in kN/m^2)

A_s = total circumferential of pile (m^2)

A_p = toe area of pile (m^2)

The basic equation for the determining the behavior of a lateral pile modeled as a beam on an elastic foundation is given by:

$$EI\frac{d^4x}{dx^4} + BP\ (x,y) = 0 \qquad \text{(Eq. 3)}$$

Where:

EI = flexural rigidity of pile (in kNm^2)

P (x,y) =subgrade reaction force per unit area at depth x and displacement y

B = pile width (in m)

x = depth form the ground (in m)

y = displacement of pile at the depth (in m)

The subgrade reaction force can be determined in a number of ways, which include the earth pressure theory under the ultimate equilibrium soil condition and elastic subgrade method proposed by Chang (1937), Kubo (1964) and Hayashi and Miyajima (The Japan Port & Harbour Association 1999b)

2.4.2 Loads acting on a floating structure

The responses expected from a floating vessel is heavily dependent on the external forces experienced by said structure, Loads and external forces acting on a floating structure are the self-weight, buoyancy and external forces, such as wave forces, wind forces, current forces, seismic forces and so on. By taking in account the action of those loads and forces, the motions of the floating structure are developed, the mooring system deformation and reaction forces are generated (Ueda et, al., 1998).

2.4.2.1 Wind force

Wind speed is generally taken as the average value of wind speed. Since a wind speed varies with respect to time and space, the maximum instantaneous wind speed may be higher than the average. The ratio of this maximum value to the average is known as the gust ratio (Davenport, 1967). Wind speed and frequency spectrum is usually available in most areas, however, it the event that the information is not available, methods proposed by Davenport (1967) ad Hino (1967) could be applied. The wind forces that are acting on a floating structure can be calculated by using the following equations:

$$R_X = 0.5 \text{ x } \rho \text{ x } U^2 \text{ x } A_T \text{ x } C_X \qquad \text{(Eq. 4)}$$

$$R_Y = 0.5 \text{ x } \rho \text{ x } U^2 \text{ x } A_L \text{x } C_Y \qquad \text{(Eq. 5)}$$

$$R_M = 0.5 \text{ x } \rho \text{ x } U^2 \text{ x } A_L \text{x } C_M \qquad \text{(Eq. 6)}$$

where:

$C_{X,Y}$ = drag coefficient in the subscripted direction

C_M = pressure-moment coefficient about the center of gravity

P = density of force about center of gravity

$A_{T,L}$ = area projected above the water surface (T = front projected, L = side projected)

2.4.2.2 Wave force

Wave force refers to the force exerted by incident waves on a floating structure when the floating structure is fixed in the water (moored in place). It comprises of linear forces that is proportional to the amplitude of the incident waves as well as nonlinear force that is proportional to the square of the amplitude of incident waves. The linear force is the force imparted by the waves as it deforms around the structure. This force can be summed as the Froude-Krylov force and diffracted wave force (Ueda et, al., 1998).

The wave-drift force, which is proportional to the square of the wave height must be considered when the length of a floating structure becomes equal to or exceeds the wavelength. Using a two dimensional assumption for the floating structure and the wave energy is not dissipated, the wave drift force then becomes:

$$F_d = 0.125 \text{ x } \rho \text{ x } g \text{ x } H_i^2 \text{ x } R; \qquad R = K_R^2 \left\{ 1 + \frac{4\pi h/L}{\sinh\left(\frac{4\pi h}{L}\right)} \right\} \qquad \text{(Eq. 7)}$$

Where:

F_d = wave drift force per unit length (in kN)

H_i = wave height of incident wave

ρ = density of sea water (in kg/cm^3)

K_R = ratio of reflection

R = coefficient of wave drift force

2.4.3 Breakwaters

As the name suggests, breakwaters are installed along with floating structures as a method of reducing the strength of waves hitting the structure. This is especially beneficial in location of harsh sea states, such as along the Pacific coastline of Japan (Wang et al., 2008).

As discussed by Wang and Wang (2015), there are several types of breakwaters that are currently being used, namely:

- Sloping-type breakwaters
- Vertical type breakwaters
- Composite breakwaters
- Wave energy dissipating blocks

2.5 South China Sea conditions

The South China Sea is a marginal sea that is part of the Pacific Ocean, encompassing an area from the Singapore to the Strait of Taiwan of around 3,500,000 square kilometers. The Malaysian South China Sea waters cover the East of Peninsula Malaysia and the west Sabah as well as Sarawak. The water depth varies drastically close to the shore in Peninsula Malaysia, however, does not change much after a certain point.

The average water depth in Peninsula Malaysia is taken as 70m while regions in Sabah as well as Sarawak are much deeper. However, according to Morimoto, Yoshimoto and Yanagi (1997), the water depth in Malaysian waters varies between 30m and 1400m

(Figure 6). The Deepwater blocks near Sabah is the deepest region of the Malaysian South China Sea waters, with depths in excess of 1000m.Though there is little data for the soil characteristics in this region, Jong and Chan (2013) noted that the soil are soft closer to the shore.

The sea states found in the Malaysian region tends to differ based on location. As shown in Table 2.2, the conditions in Peninsular Malaysia, with respect to wave height,

Table 2.2: Sea Conditions in Malaysian South China Sea Waters (PTS 34, 2012).

	Parameters	Units	Operating Condition	Storm Conditions
	Peninsular Malaysia			
Wave Height	Significant Wave Height	m	4.38	5.77
	Maximum Wave Height	m	8.44	11.65
Wind Speed	1-min Mean Speed	m/s	20	29
	3-sec Gust Speed	m/s	22	33
Current Speed	Surface Current Speed	m/s	1.24	1.67
	Mid Depth Current Speed	m/s	0.98	1.33
	Sabah & Sarawak			
Wave Height	Significant Wave Height	m	3.7	5.7
	Maximum Wave Height	m	6.7	11
Wind Speed	1-min Mean Speed	m/s	24	41
	3-sec Gust Speed	m/s	26	50
Current Speed	Surface Current Speed	m/s	1.6	2.3
	Mid Depth Current Speed	m/s	1.3	1.8

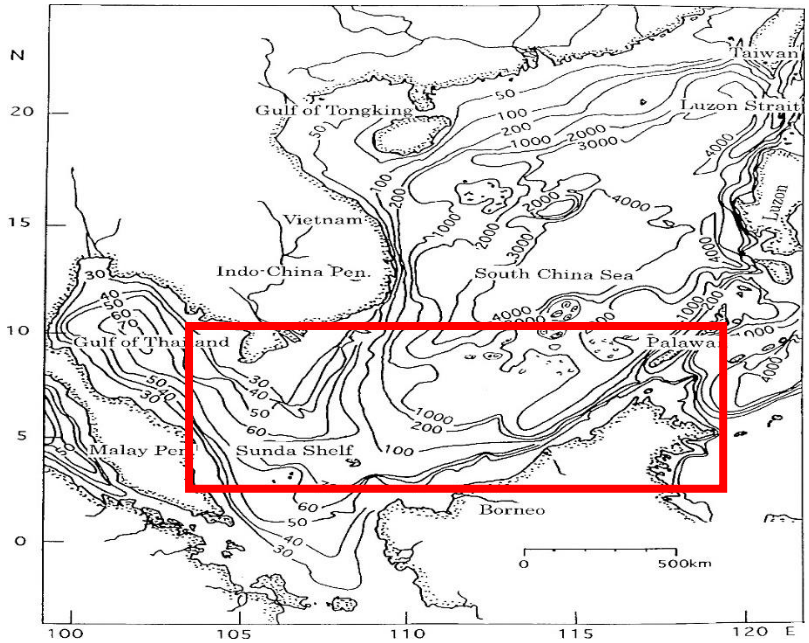

Figure 2.8: South China Sea Bathymetry

2.5.1 Wave Spectrum

A wave spectrum is used as a method of representing crucial information such as the critical frequency of the wave and the energy distribution of the wave across various frequency that is required. Spectral analysis can be described as a representation of a time series or mathematical functions in the frequency domain. Spectral analysis differs from time domain analysis in a sense that it can clearly identify the content of energy over a range of particular frequencies. The analysis is achieved through a set of mathematical operators that are applied upon the time series such as Fourier Transform which decomposes the finite signal of sinusoidal waves into frequency components (Liew et. al., 2015).

It is expected that the conditions and sea states around the world are unique to each location, as such, have unique wave spectra. Beginning with Neuman spectrum model in 1953, the development continued with the introduction of many more spectrum models including the most referred spectrum models in offshore engineering application, Pierson-Moskowitz (P-M) spectrum (1964) and JONSWAP spectrum (1973) (Chakrabarti, 1987) In fact, the development of offshore engineering in the Malaysian waters region also is vastly relying on the P-M and JONSWAP spectrum models (Liew et. al., 2015). Meanwhile, Maimun et al., (2006) had concluded that the P-M spectra or Bretschneider spectra can be used for the design of Malaysian ship or floating structures.

Therefore, for the purpose of this study, the Pierson-Moskowitz (P-M) wave spectra is adopted to model the conditions found in Malaysian South China Sea. However, Techet (2005) noted that there were several limitations to wave spectra, specifically, seafloor topography. Deep water wave spectra are invalid in shallow waters, and vice versa as it may be necessary to account for wave diffraction. Thus, a possible error may be present in the results, especially for the low water depth condition.

2.6 Previous Work

There are two parts to this study, whereby in order to determine the mooring requirements under various cases, the vessel response would have to be obtained. As such, the VLFS would have to be modelled successfully to obtain valid results. A compilation of previous works done by different researches have been compared below, with respect to their methodology as well as the shape and dimensions of the vessels being modelled. From the table below, it is apparent that the vessels are mostly being modelled using a numerical approach, and by reading through the various literature that the experimental approach is taken to validate the results that is obtained via the numerical approach. These works were also used to determine the VLFS vessel dimensions that is to be studied.

Table 2.3: Previous Work on VLFS motion and response

No	Author	Year	Methodology	Shape	Dimensions
1	Kashiwagi	1998	Numerical approach	Rectangular model	1200m x 200m x 4m
2	Hong, Choi & Hong	2001	Boundary element method	Rectangular model	300m x 60m x 0.01m, 0.25m, 0.5m, 1.5m, 3.0m
3	Hong, Choi & Hong	2002	Boundary element method - Generali	Rectangular model	300m x 60m x 0.5m
4	Murai, Inoue & Nakamura	2003	Numerical approach	Rectangular model	300m x 60m
5	Park, Lee& Hong	2004	Finite Element Method	Rectangular model	500m x 300m x 5m
6	Kyoung, Hong & Kim	2007	Numerical approach	Rectangular model	500m x 125m

2.6.1 Type of Analysis

There has been quite a significant amount work on the hydroelastic response of the VLFS, specifically the pontoon-type VLFS. The analysis may be carried out in the frequency domain or in the time domain. A larger portion of them have been carried out in the frequency domain, being the easier approach, however, a time domain response analysis becomes necessary for transient responses and for nonlinear equations of motion due to the effects of a mooring system (Watanaba, et al. 2003).

2.6.1.1 Frequency Domain Analysis

The commonly-used approaches for the analysis of VLFS in the frequency domain are the modal expansion method and the direct method. The modal expansion method consists of separating the hydrodynamic analysis and the dynamic response analysis of the plate. The deflection of the plate with free edges is decomposed into vibration modes that can be arbitrarily chosen. In this respect, numerous researchers have adopted different modal functions such as products of free-free beam modes (Maede et. al, 1995, Wu et. al., 1995/996/1997, Kashiwagi ,1998, Nagata, et. al., 1998), B-spline functions (Lin &

Takaki, 1998), Green functions (Eatock & Ohkusu, 2000), two-dimensional polynomial functions (Wang et. al, 2001) and finite element solutions of freely vibrating plates (Takaki, 1996).

On the other hand, for the direct method analysis, the deflection of the VLFS is determined by directly solving the motion of equation without the use of Eigen modes. In the pioneering work by Mamipudi and Webster (1994), the potentials of diffraction and radiation problems were established first, and the deflection of VLFS was determined by solving the combined hydroelastic equation via the finite difference scheme. Their method was modified by applying the pressure distribution method and the equation of motion was solved using the finite element method (Yago & Endo, 1994).

2.6.1.2 Time Domain Analysis

The commonly-used approaches for the time-domain analysis of VLFS are the direct time integration method and the method that uses Fourier transform. In the direct time integration method, the equations of motion are discretized for both the structure and the fluid domain (Watanabe & Utsunomiya, 1996, Watanabe et. al., 1998). In the Fourier transform method, the frequency domain solutions for the fluid domains first obtained and then Fourier transform the results for substitution into the differential equations for elastic motions (Miao et al., 1996, Endo et al., 1998, Ohmatsu, 1998, Kashiwagi, 2000, Endo, 2001,). The equations are then solved directly in the time domain analysis by using the finite element method or other suitable computational methods.

2.6.2 VLFS Models

There have been some researchers who have modelled the VLFS as a floating beam. However, such beam models may only be practical in shipbuilding, as it does not account for the two dimensional action of a pontoon-type VLFS (Utsunomiya et. al., 1995, Inoue et. al., 1997, Aoki, 1997). As a work around, many researches have adopted the

Kirchhoff plate model, which are treated either as an isotropic or an orthotropic plate. The isotropic plate is used for a very rough analysis while for more refined analysis that caters for the varying mass and stiffness an orthotropic plate (Takaki, 1996/1997, Hamamoto & Fujita, 1996, Webster, 1998, Endo & Yoshida, 1998). Another approach was to apply he Mindlin plate theory, proposed by R.D Mindlin in 1951, that allows for the effects of transverse shear deformation and rotary inertia which become significant in higher modes of vibration. This approach has been adopted by Sim and Choi (1998), Utsunomiya et. al. (2000), Wang et.al. (2001), and Hamamoto and Fujita (2002).

2.6.3 VLFS Shapes

A floating structure may take on any shape in practice. In most work, we have found that researchers have analyzed pontoon-type VLFS of a rectangular. However, there were a few who have considered other non-rectangular shapes. For example, Hamamoto and Fujita (2002) had studied L-shaped, T-shaped, C-shaped and X-shaped VLFSs. Circular pontoon-type VLFSs were considered in the works of Hamamoto (1995), Watanabe and Utsunomiya (1996), and Zilman and Miloh (200). The Japanese Society of Steel Construction published a paper in 1994, that suggested that hexagonal shaped VLFSs be constructed to allow for easy expansion of the floating structure.

2.6.4 Mooring Systems

In a mooring system study, the responses of a VLFS in waves do not include the hydroelastic vertical motions, but also the horizontal motions and the reaction forces of the mooring system. Research on the analysis of VLFS with the allowance for a mooring system was carried by Maeda et al. (2000) as well as Shimada and Miyajima (2002). The elastic deformation and mooring force of a VLFS on Tsunami waves using both theoretical simulations and experiments were studied by Takanagi and Gu in two works published in 1996. Studies on mooring system for VLFS moored in a reef have been conducted by Ookubo et al. (2002) and Shiraishi et al. (2002). As for work specifically pertaining to mooring dolphins and rubber fenders, experimental study had been conducted by Kim et. al. (2004), while a quantitative analysis of multiple dolphin mooring was conducted by Kato et. al (2002).

2.7 Concluding Remarks

The literary survey conduct as part of this study examines the major components of the VLFS and its properties. With regards to application in Malaysian waters, it was found that several key advantages of a pontoon type VLFS (as opposed to semisubmersible type VLFS as well as land reclamation) that would make it ideal for potential applications in Malaysia. It was also identified that the mooring method of choice for pontoon type VLFS are predominantly dolphin fender type. Thus, it is the method of mooring being analyzed as part of this study.

It becomes apparent form the compiled works of various other researchers that VLFS responses are mainly modelled in the frequency domain. However, as noted by Watanabe et al (2003), a time response analysis is required to account for transient responses and for nonlinear equations of motion due to the effects of a mooring system.

The hydro elastic response of a VLFS is also an important property which dictates its response when subject to waves and wind. However, based on the compiled work from researchers, it becomes clear that the process in rather complex, while requiring significant mathematical and programming skills. In case of modelling, proprietary codes and programs had to be developed and used in conjunction with advanced modelling approaches.

However, a study conducted by Shimatada et. al. (2002) suggested that the use of rigid body motion assumption is effective for analysis of horizontal motion of pontoon-type VLFS even though hydro-elastic analysis is prerequisite for structural assessment of VLFS. Bearing in mind that a dolphin fender mooring only restricts horizontal motion, it is proposed that the mooring analysis be conducted on ANSYS Aqwa, a finite element analysis tool that is more accessible.

CHAPTER 3
METHODOLOGY

3.1 Flow of analysis

. The software of choice for this analysis would be ANSYS Aqwa. ANSYS Aqwa Diffraction provides an integrated facility for developing primary hydrodynamic parameters required to undertake complex motions and response analysis. Model creation can be performed through a connection with ANSYS DesignModeler software (with the new hydrodynamic diffraction analysis system in ANSYS Workbench) or via other CAD software.

Vessels of varying dimensions (discussed further in Section 3.4) were first modelled in the DesignModeler. However, it is important to note that though the respective dimensions differ, each model would has an aspect ratio (length to breadth) of 1.5. The operating parameters (wind speed, current speed, significant as well as maximum wave height) are varied between the maximum values and minimum values for each water depth. Rubber fenders are also modelled alongside each of the vessel, so that analysis on the fender can also be carried out. The fenders are all kept at the same dimension and have the same deformation properties. Each of these variations are accounted for by each of the modelling cases as shown in Table 4.1.

As for the analysis process, each of the vessel model of specific dimension, water depth and operating parameters (depending on model case) are first subjected to a hydrodynamic diffraction analysis. There are two parts to this analysis, whereby, in the first part, the vessels are tested for their hydrostatic response. Throughout this part of the analysis, it is conducted in the frequency domain. The vessels are placed in a free floating state with small disturbances applied by the program to determine is hydrostatic stiffness and displacement properties (center of buoyancy, and out of balance force as well as moments). The intention of this analysis is to test the stability of the vessel and to obtain preliminary data for the next step in the hydrodynamic analysis. The hydrostatic properties that are obtained are then applied in conjunction with the respective vessel and subjected to a user defined wave direction and frequency to determine how it responds to changes in wave properties. Up to this point, rubber fenders are not introduced into the analysis and is therefore neglected.

A hydrodynamic time response analysis is then conducted using the results obtained from the frequency response analysis carried out earlier. The rubber fenders now play an integral role in the vessel response in the time domain. The respective wind speed and current speed for each case is then inputted as part of the variable of the time response analysis. The behavior of the vessel in terms of its changes in position, velocity and acceleration can all be obtained at this stage. Crucially, the resultant forces induced by the motion of the vessel on the rubber fenders as a function of time could also be obtained. This is integral to the project as the results would then be used to determine the maximum force experienced by the fender.

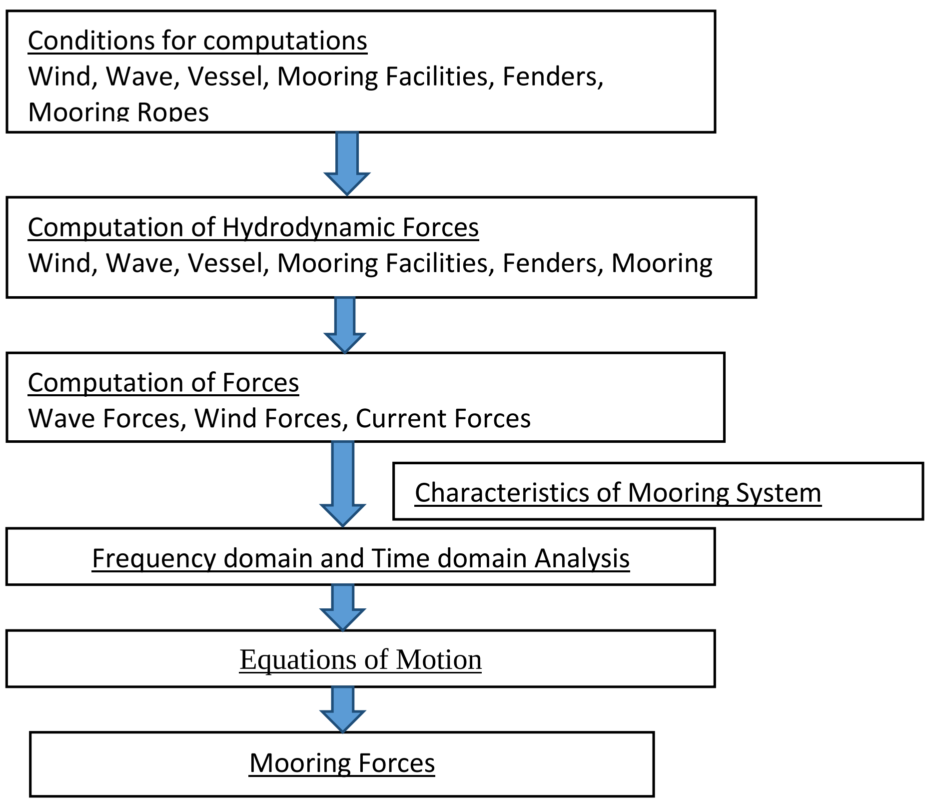

Figure 3.1: Overall Analysis Method

3.2 Assumptions

In order to simplify the overall process of the analysis, and to compensate for lack of available data, several assumptions have been adopted. The assumptions stay true throughout the process of analysis, and they are as follows:

1. Hydrodynamic forces are treated as added mass and damping coefficient (Yoneyama, Hiraishi & Ueda, 2004). Therefore, the coefficient would have to be altered accordingly.
2. Load deflection characteristics of fenders and mooring lines are nonlinear (Ueda,1984). Hence, the deflection of fenders and lines is not proportional to the force applied.
3. Water depth is assumed to remain constant under floating structure. A changes in water depth in shallow regions can affect the hydro elastic response of the floating structure
4. Use of rigid body motion assumption is effective for analysis of horizontal motion of pontoon-type VLFS (Shimada et al., 2002) even though hydro-elastic analysis is prerequisite for structural assessment of VLFS.
5. Time step for numerical solution 1/8 the minimum period of external forces (Wang et al., 2008)

3.3 VLFS model and modelling cases

The model that is to be used for the mooring analysis would be of pontoon type, as it is the most common type (Table 1.1). The dimensions of the vessel are yet to be determined, however, should have a length exceeding its characteristic length (Suzuki, 1997). The size of the modeled structure would also have an effect on its mooring requirement. Hence, care is to be take when selecting the dimensions of the model. The mooring method of choice is of dolphin with fenders, due to its popularity in VLFS applications. Previous works in terms of studying the response of floating structures under wave conditions have been compiled, as shown in Table 3.1:

Table 3.1: Compilation of previous VLFS response studies

No	Author	Year	Methodology	Shape	Dimensions
1	Kashiwagi	1998	Numerical approach	Rectangular model	4000m x 1000m x 5m
2	Hong, Choi & Hong	2001	Boundary element method	Rectangular model	300m x 60m x 0.01m, 0.25m, 0.5m, 1.5m, 3.0m
3	Hong, Choi & Hong	2002	Boundary element method	Rectangular model	300m x 60m x 0.5m
4	Murai, Inoue & Nakamura	2003	Numerical approach	Rectangular model	300m x 60m
5	Park, Lee& Hong	2004	Finite Element Method	Rectangular model	500m x 300m x 5m
6	Kyoung, Hong & Kim	2007	Numerical approach	Rectangular model	500m x 125m

Thus based on the compiled research the following cases and their corresponding vessel dimensions will be considered. This is done to ensure that sufficient data points have been made available for the simulation, and to ensure that credible results are obtained. The following cases are repeated for varying water depths, namely 30m, 50m, 70m, 200m and 1000m.

Table 3.2 : Modelling cases

Case	Vessel Dimensions	Aspect ratio	Simulated Condition
A	300m x 60m x 5m	1/5	Operating & Storm
B	500m x 100m x 5m	1/5	Operating & Storm
C	1000m x 200m x 5m	1/5	Operating & Storm

3.4 Finite Element Modelling

3.4.1 Vessel Sizes

As discussed above, three (3) sizes of vessels were chosen to be modelled as part of this study. The mass of each vessel is calculated based on the weight of the water displaced as the weight is assumed to be equal to the buoyant force provided by the seawater The moment of inertia of each vessel is also calculated about X, Y and Z, which play a big role in the potential response of the vessel. The dimensions and properties of these vessels are shown below:

Table 3.3: Vessel Cases and Properties

Vessel	A	B	C
Size	300m x 60m x 2m	500m x 100m x 3m	1000m x 200m x 4m
Mass	18450000	76875000	410000000
Ixx	1.3838E+11	1.6016E+12	3.4167E+13
Iyy	5.5412E+09	6.4120E+10	1.3672E+12
Izz	1.4391E+11	1.6656E+12	3.5533E+13

3.4.2 Flow of Modelling

The ANSYS Aqwa modeling steps can be divided into two stages, that is the hydrodynamics diffraction analysis and hydrodynamic time response analysis. The hydrodynamic diffraction analysis is conducted to assess the stability of the model and to obtain the hydrodynamic properties of the vessel, which are then fed into the hydrodynamic time response solver in conjunction with the fender configuration and properties to obtain the fender forces.

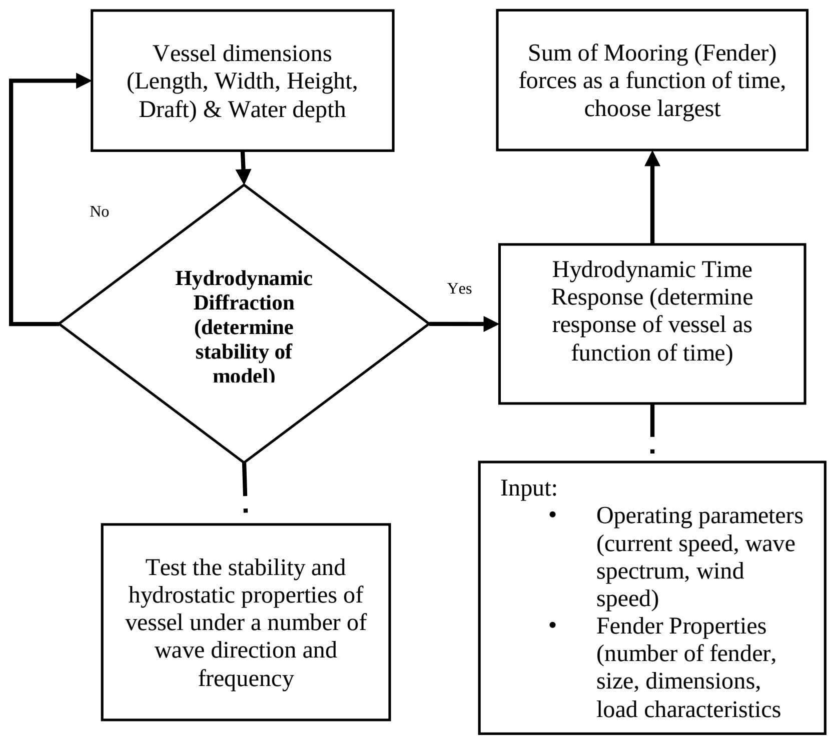

Figure 3.2: ANSYS Aqwa Modelling Flow

3.4.3 Fender properties and Configuration

In order to obtain the forces experienced by the fenders, it is important to first identify the properties of the fenders. Although large rubber fenders are commercially available in the market, the high performance fenders required for VLFS mooring applications are still scarce. Thus, the dimensions and properties of the fenders were obtained from past works done on dolphin fenders (Kim et al. 2004) :

Table 3.4 : Fender Properties

Fender Size	6m-8m
Fender Shape	Rectangular
Stiffness	y = 0.0172x3 - 1.485x2 + 40.609x - 2E-12

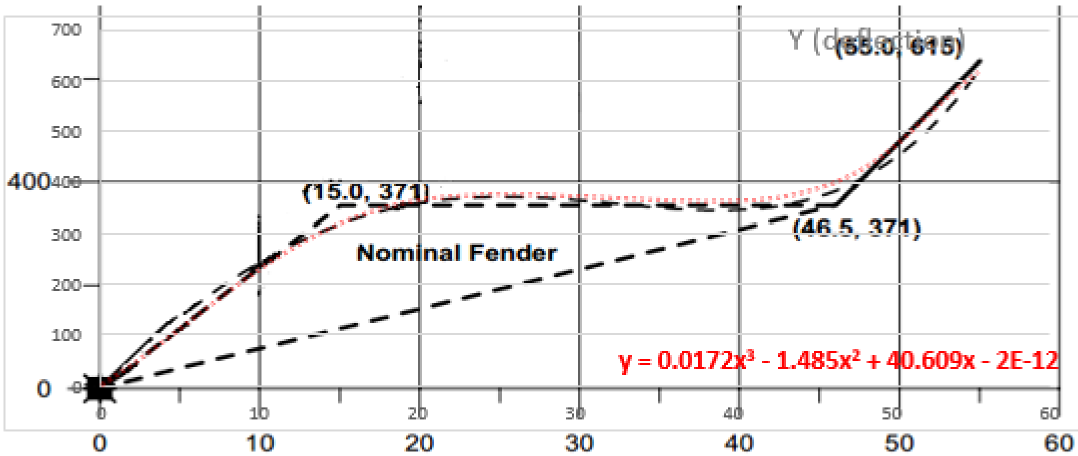

Figure 3.3: Stiffness function of rubber fenders obtained by evaluating slope of deformation curve (Kim et al, 2004)

As discussed in Chapter 2, the maximum force that can be absorbed by currently available fenders are within the region of 5.5 MN to 8 MN. Thus, the largest force that can be sustained by a fender under any condition should not exceed 8MN.Three layouts where tested on the largest vessel being simulated, 1000m x 200m x 5m, as shown below. Therefore, Model A with 10 fender configuration was chosen for this study and replicated to all vessel sizes to ensure fenders are a constant.

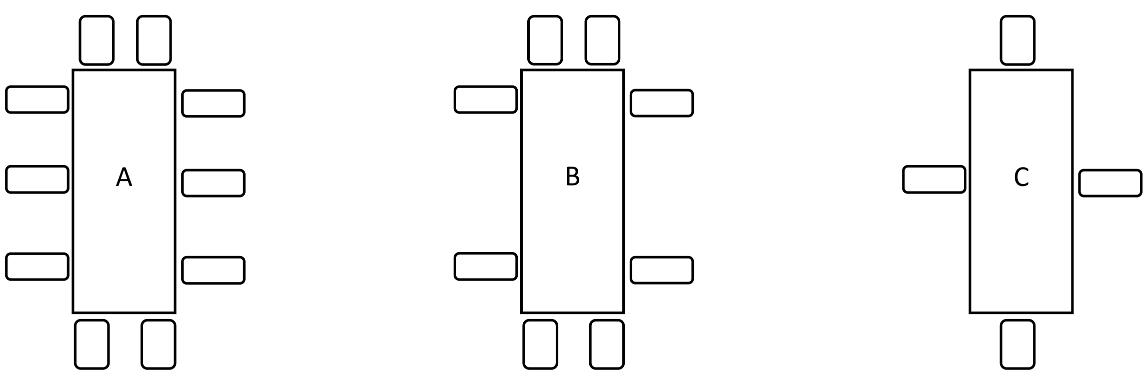

Table 3.5: VLFS Fender Configurations

Case	A	B	C
Number of Fenders	10	8	4
Highest Force (Fx/Fy)	<7MN	> 30MN	> 130MN

3.6 Gantt Chart and Key Milestones

Table 3.6: Gantt Chart and Key Milestones

No.	Activities	FYP1 (Weeks)														FYP 2 (Weeks)													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Topic		■	■																									
2	Background Study			■	■	■	■																						
3	Objectives and Scope of Study			■	■	●																							
4	Literature Review : VLFS Technology			■	■	■	■	■																					
5	Literature Review : VLFS Mooring			■	■	■	■	■																					
6	Experimentation Procedure				■	■	■	■																					
7	Research on Mooring Analysis						■	●																					
8	Determining Study Parameters						■	■	■																				
9	Familiarization with Numerical Modelling							■	■	■	■	■	■																
10	Trial Simulations											■	■	■	■	■	■	■											
11	Preliminary Simulation Results															■	■	■											
12	Simulation with Study Parameters																●	■	■	■	■	■	■	■	■	■			
13	Simulation Results/Data Gathering																						●	■	■	■			
14	Results/Data Analysis																								■	■	●		

● Denotes Key Milestones

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Obtained Results

As discussed in Section3.1, a number of models of varying sizes were subjected to changing water depth and sea states. The simulations were run separately for the Peninsula Malaysia region and Sabah/ Sarawak region. Four parameters were measured as part of the results, namely the largest individual fender forces in the X and Y direction respectively, as well as the sum of mooring forces in the X and Y direction. The results that were obtained are represented in graphs shown below.

4.1.1 Peninsular Malaysia Region

4.1.1.1 Fender forces for L=300m, 500m, and 1000m VLFS in changing water depth in operating conditions

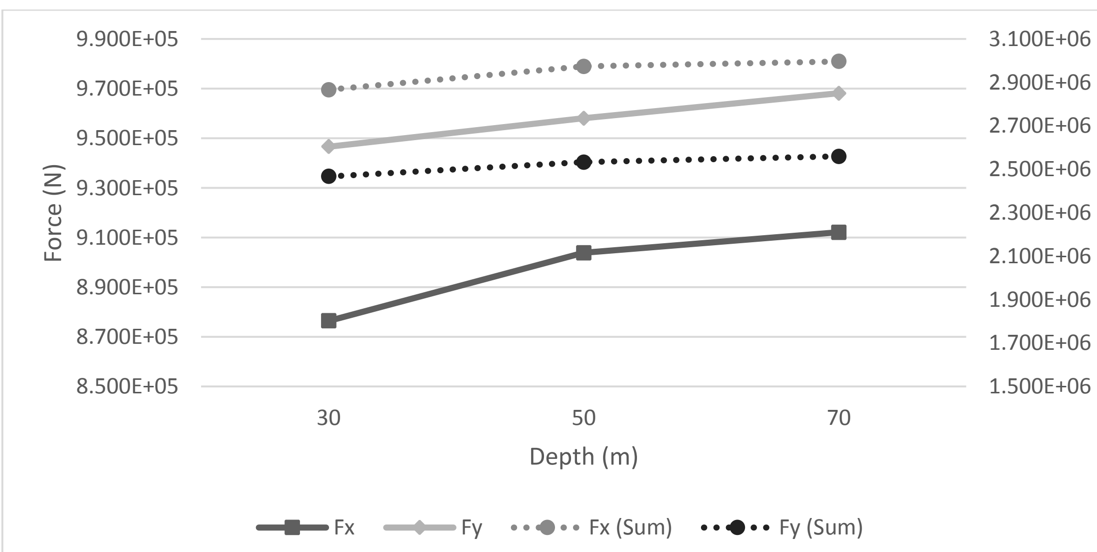

Figure 4.1: Fender forces for 300m VLFS in varying depths (Operating condition)

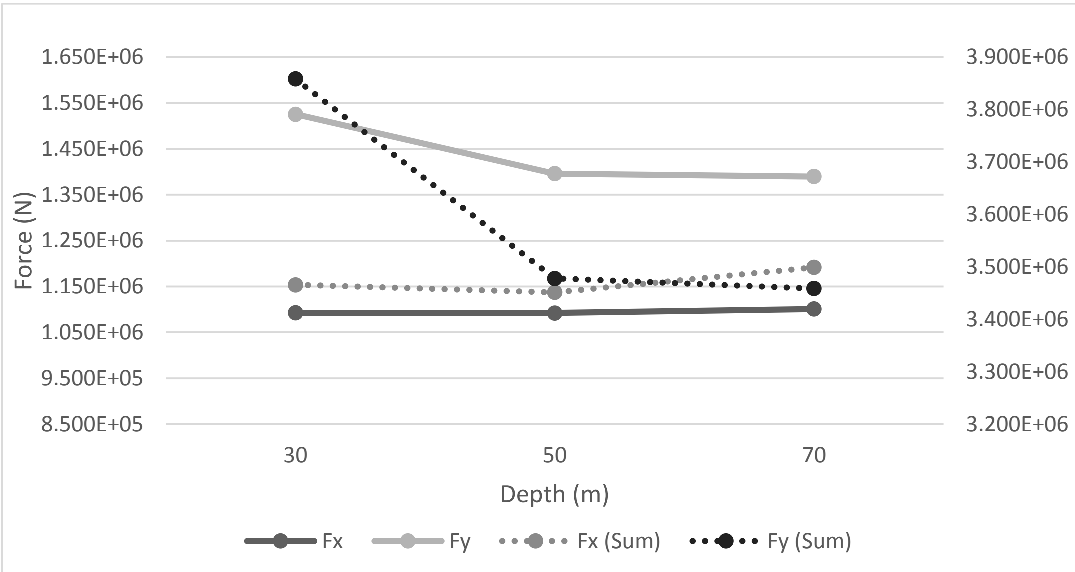

Figure 4.2: Fender forces for 500m VLFS in varying depths (Operating condition)

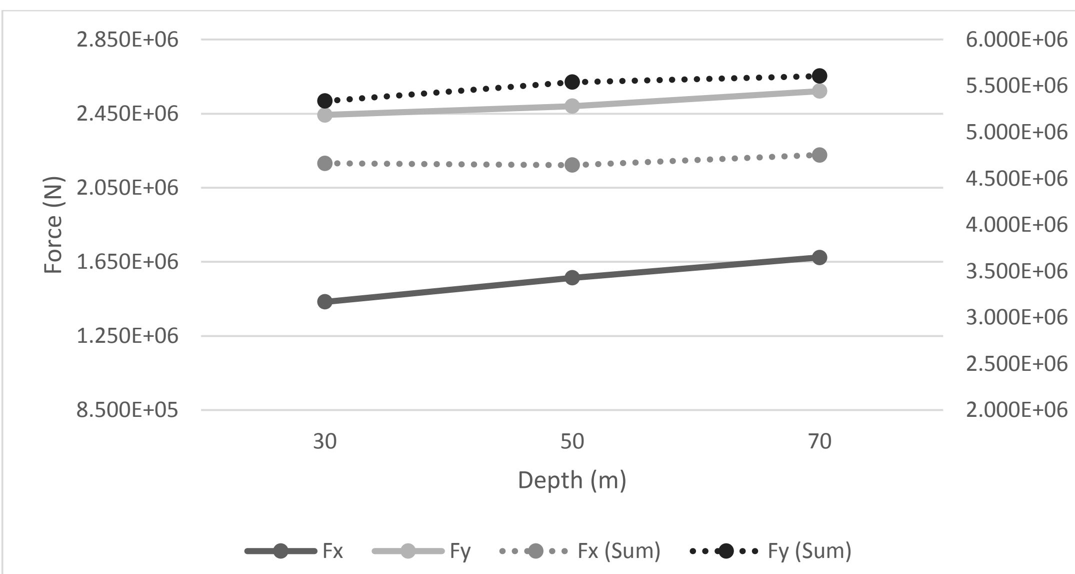

Figure 4.3: Fender forces for 1000m VLFS in varying depths (Operating condition)

4.1.1.2 Fender forces for L=300m, 500m, and 1000m VLFS in changing water depth in storm conditions

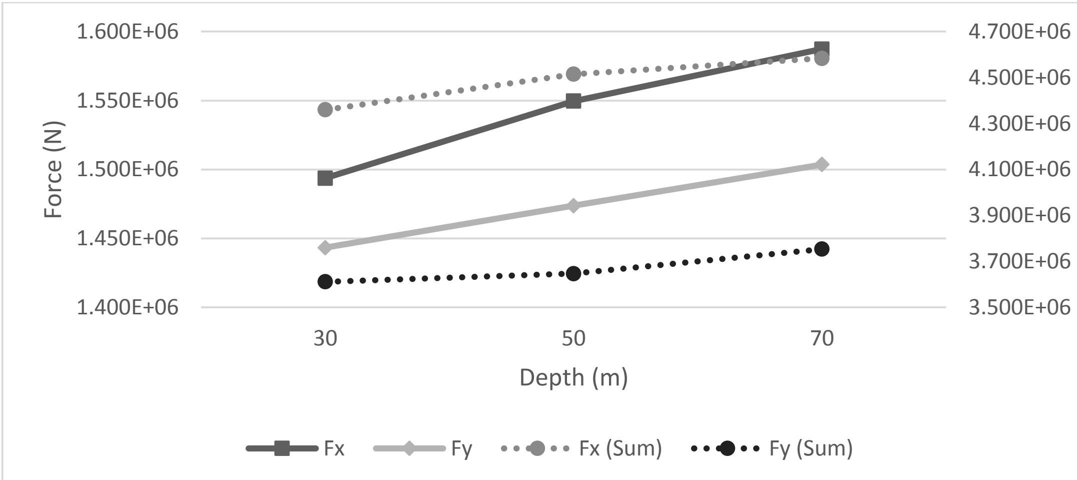

Figure 4.4: Fender forces for 300m VLFS in varying depths (Storm Condition)

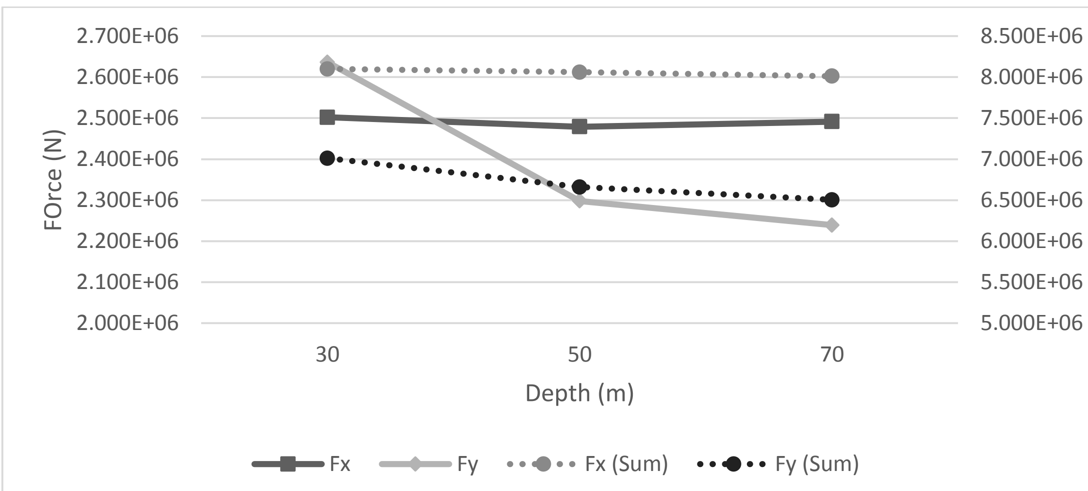

Figure 4.5: Fender forces for 500m VLFS in varying depths (Storm Condition)

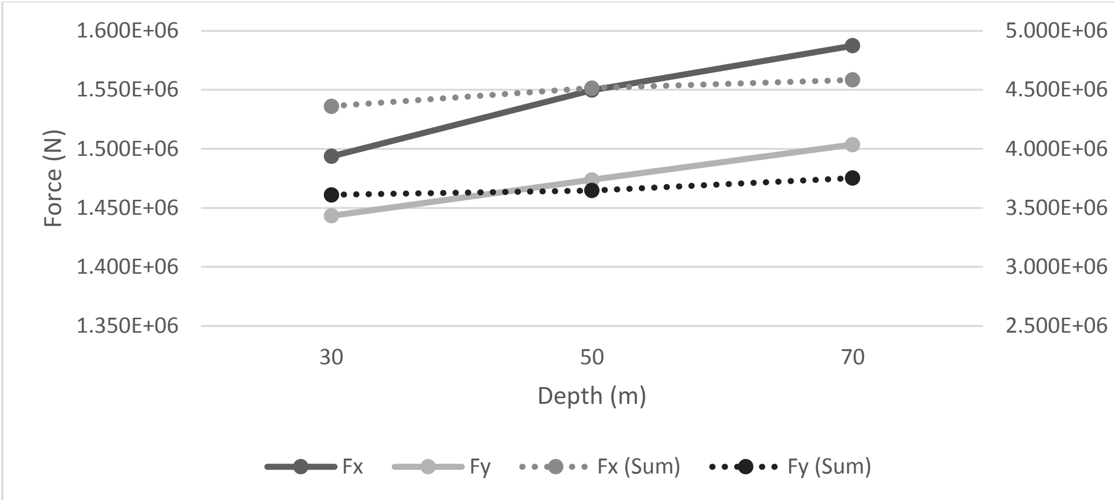

Figure 4.6: Fender forces for 1000m VLFS in varying depths (Storm Condition)

4.1.1.3 Fender forces for d=30m, 50m and 70m depth with changing VLFS size in operating conditions

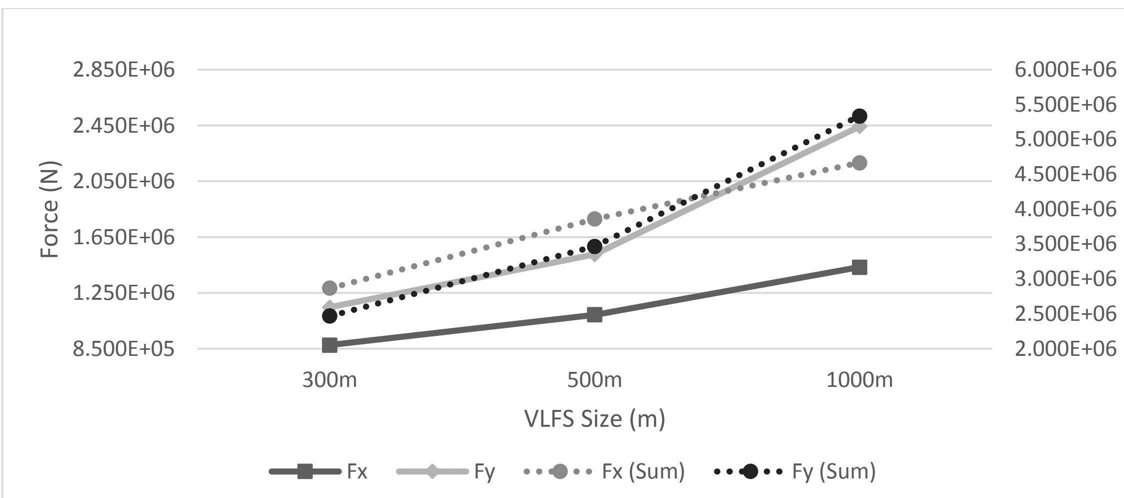

Figure 4.7: Fender forces for 30m depth with varying VLFS size (Operating condition)

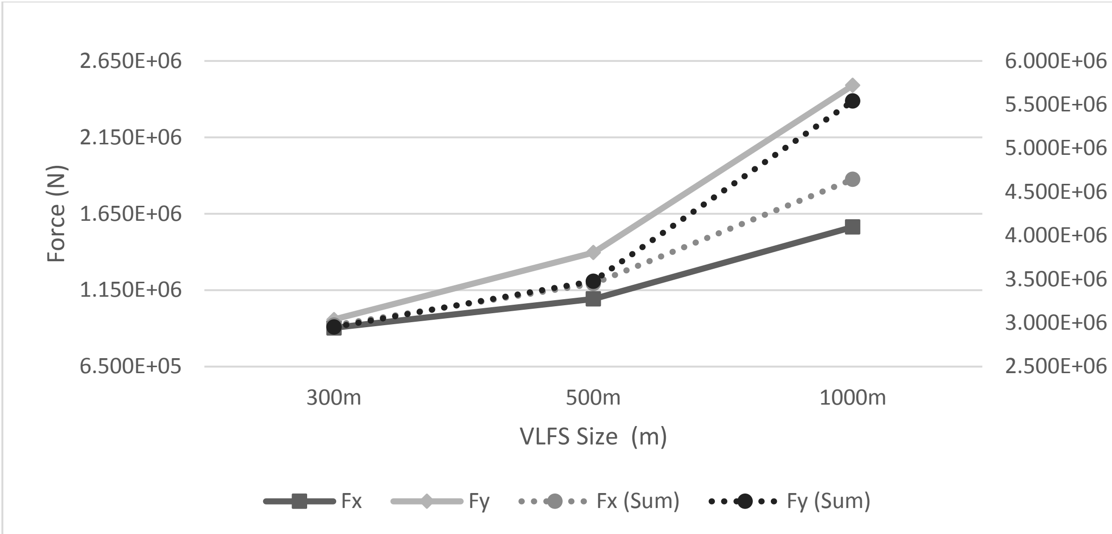

Figure 4.8: Fender forces for 50m depth with varying VLFS size (Operating condition)

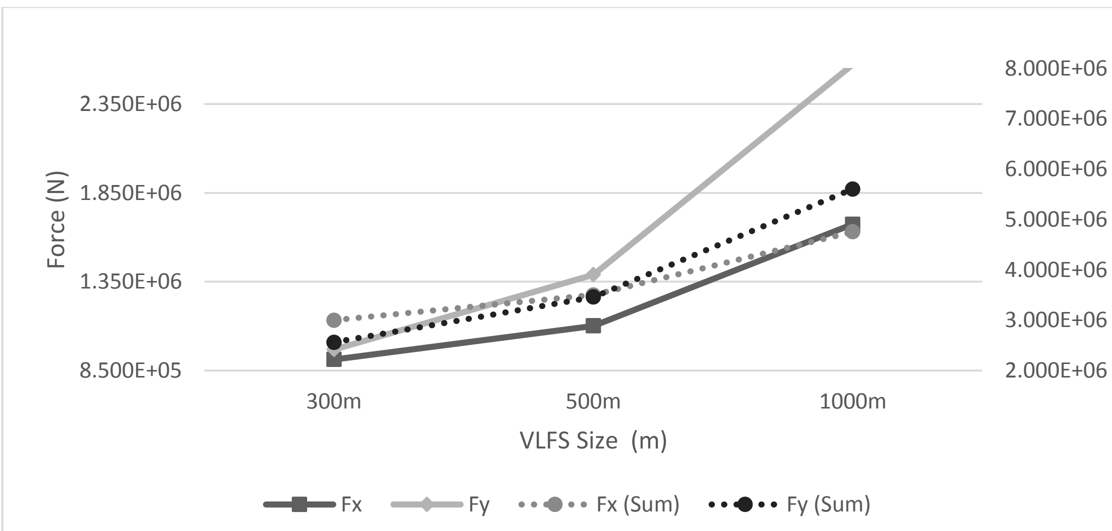

Figure 4.9 Fender forces for 70m depth with varying VLFS size (Operating condition)

4.1.1.4 Fender forces for d=30m, 50m and 70m depth with changing VLFS size in storm conditions

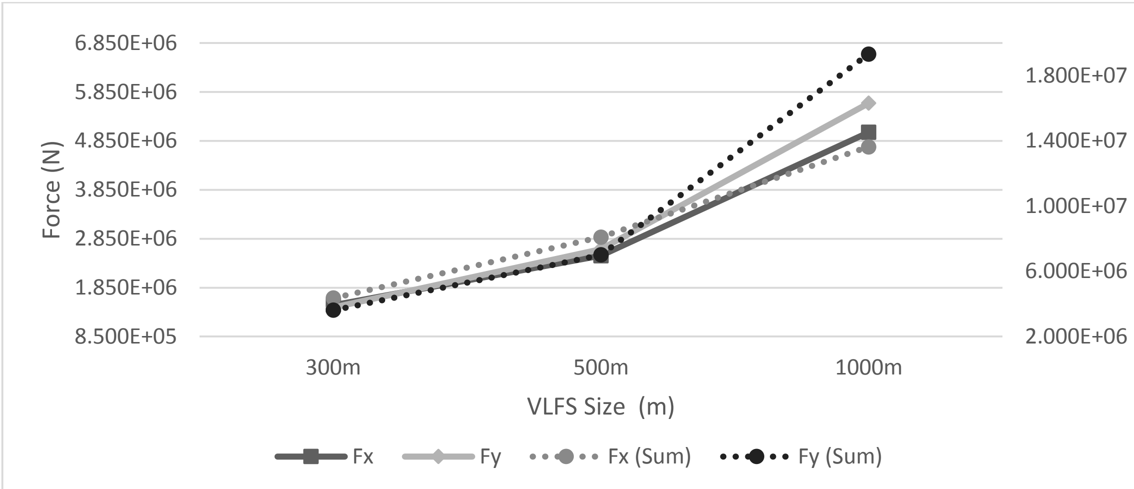

Figure 4.10: Fender forces for 30m depth with varying VLFS size (Storm Condition)

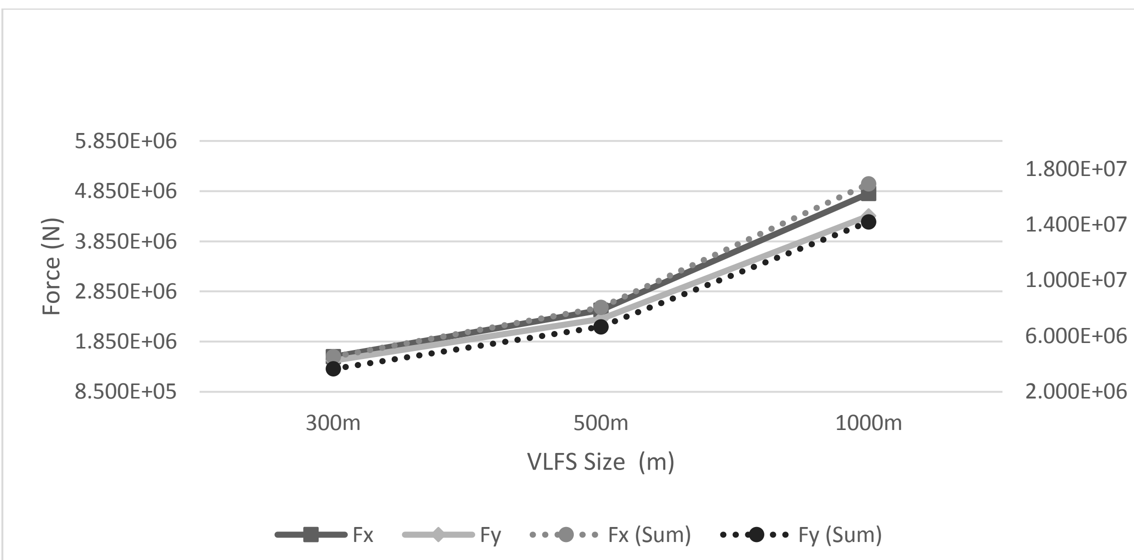

Figure 4.11: Fender forces for 50m depth with varying VLFS size (Storm Condition)

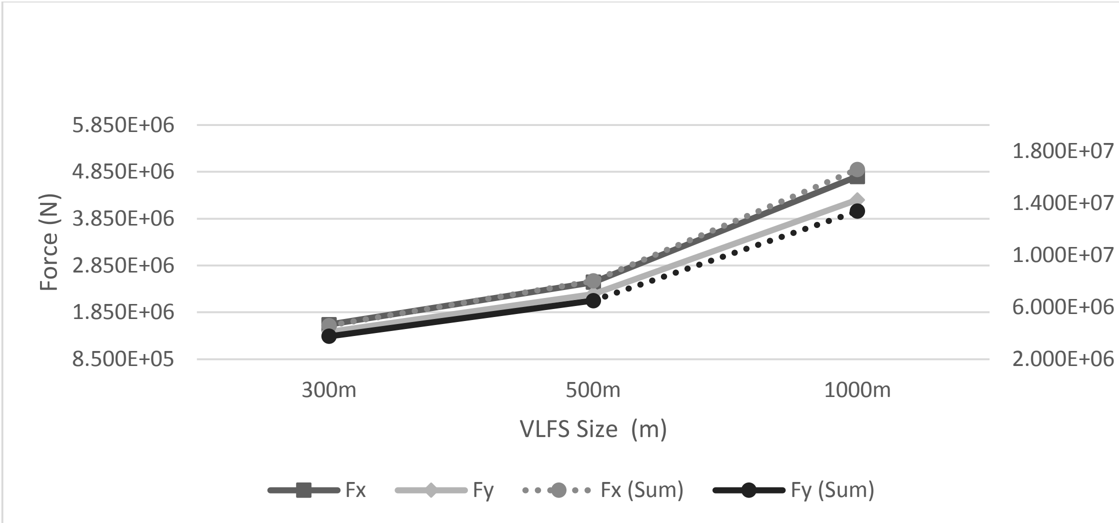

Figure 4.12: Fender forces for 70m depth with varying VLFS size (Storm Condition)

4.1.2 Sabah and Sarawak Region

4.1.2.1 Fender forces for L=300m, 500m, and 1000m VLFS in changing water depth in operating conditions

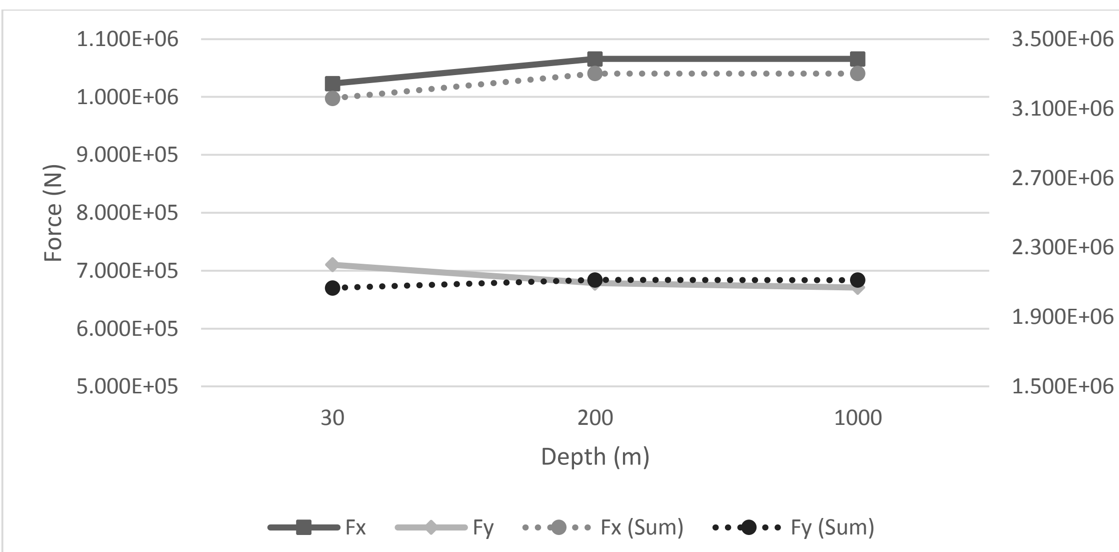

Figure 4.13: Fender forces for 300m VLFS in varying depths (Operating condition)

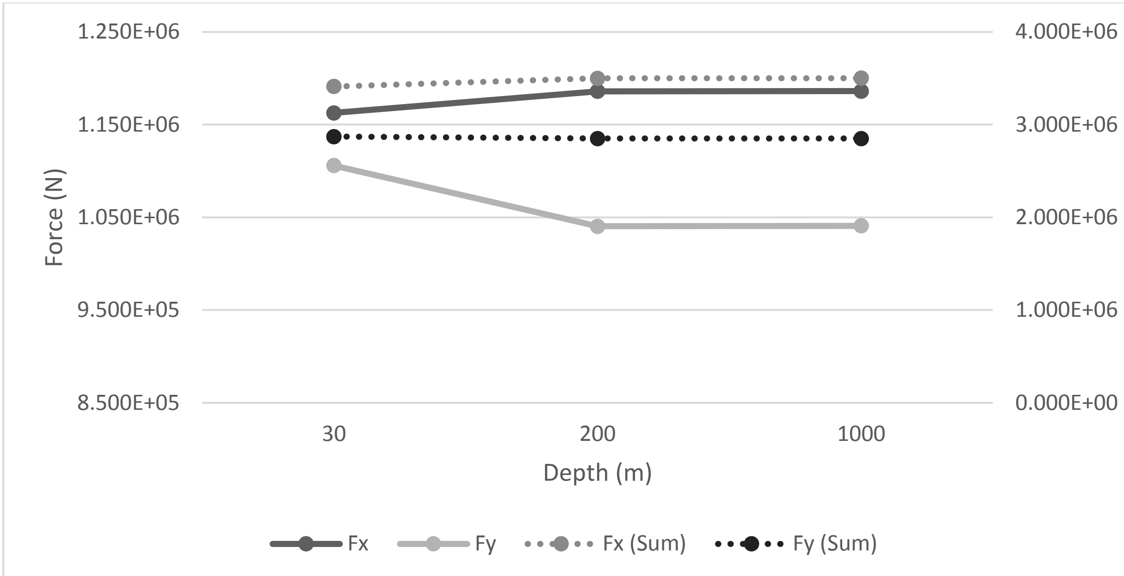

Figure 4.14: Fender forces for 500m VLFS in varying depths (Operating condition)

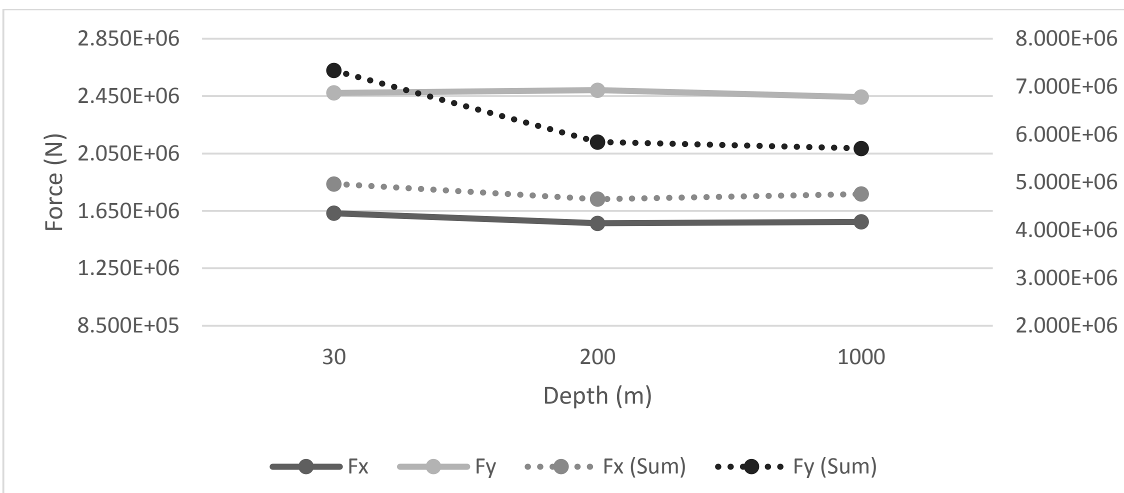

Figure 4.15: Fender forces for 1000m VLFS in varying depths (Operating condition)

4.1.2.2 Fender forces for L=300m, 500m, and 1000m VLFS in changing water depth in storm conditions

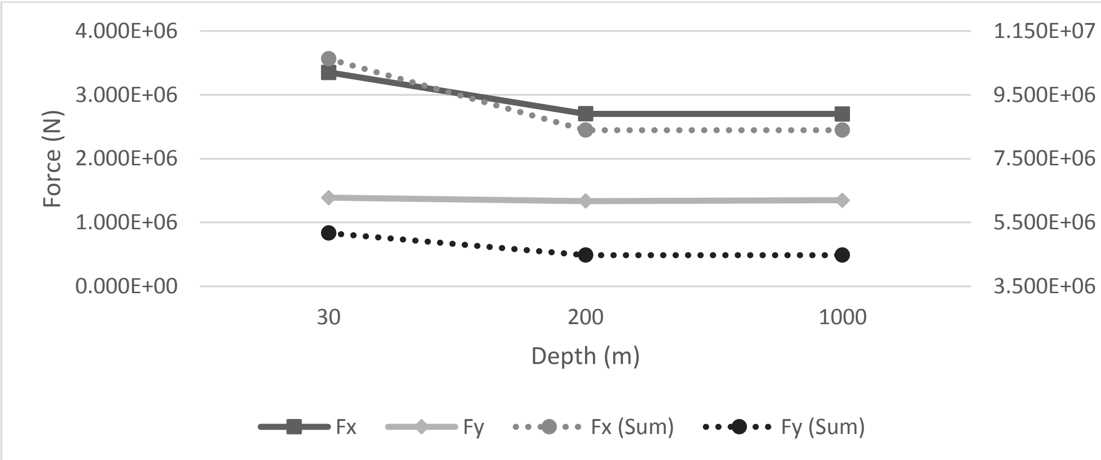

Figure 4.16: Fender forces for 300m VLFS in varying depths (Storm Condition)

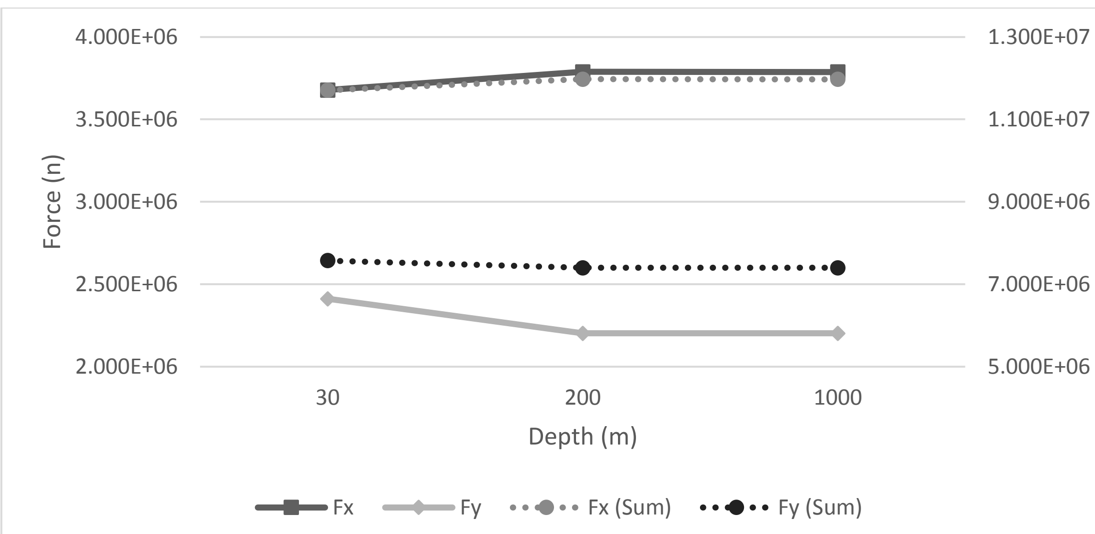

Figure 4.17: Fender forces for 500m VLFS in varying depths (Storm Condition)

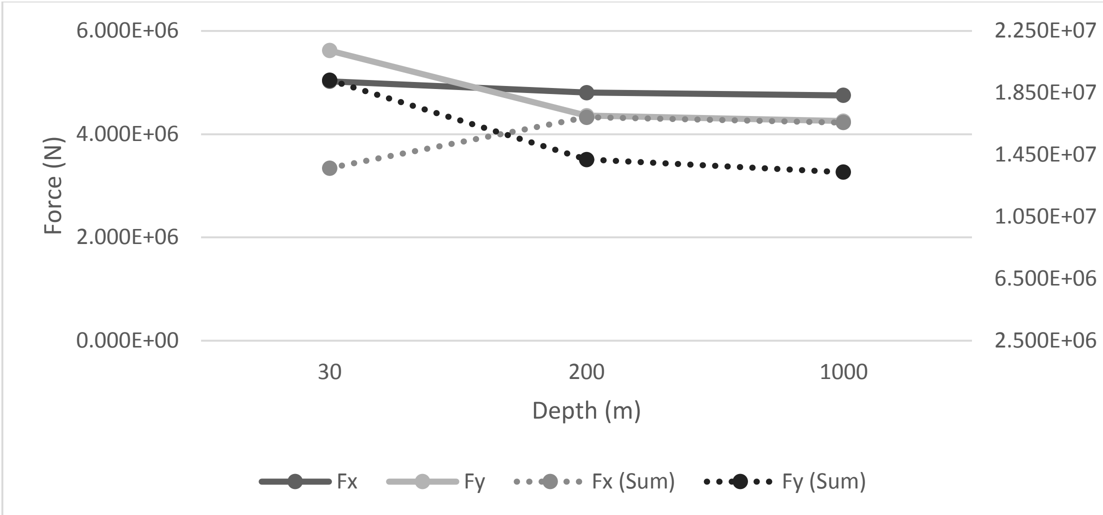

Figure 4.18: Fender forces for 1000m VLFS in varying depths (Storm Condition)

4.1.2.3 Fender forces for d=30m, 200m and 1000m depth with changing VLFS size in operating conditions

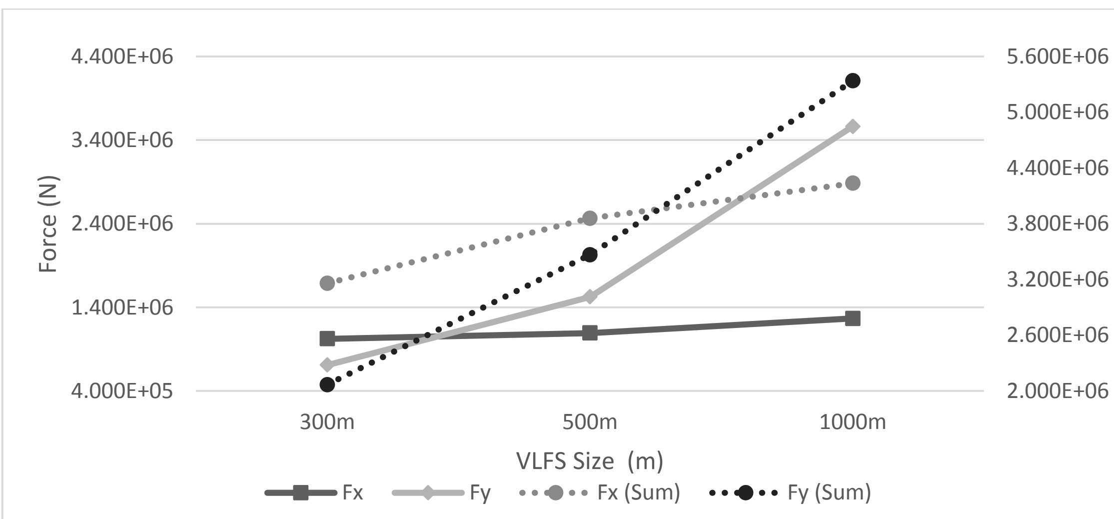

Figure 4.19: Fender forces for 30m depth with varying VLFS size (Operating condition)

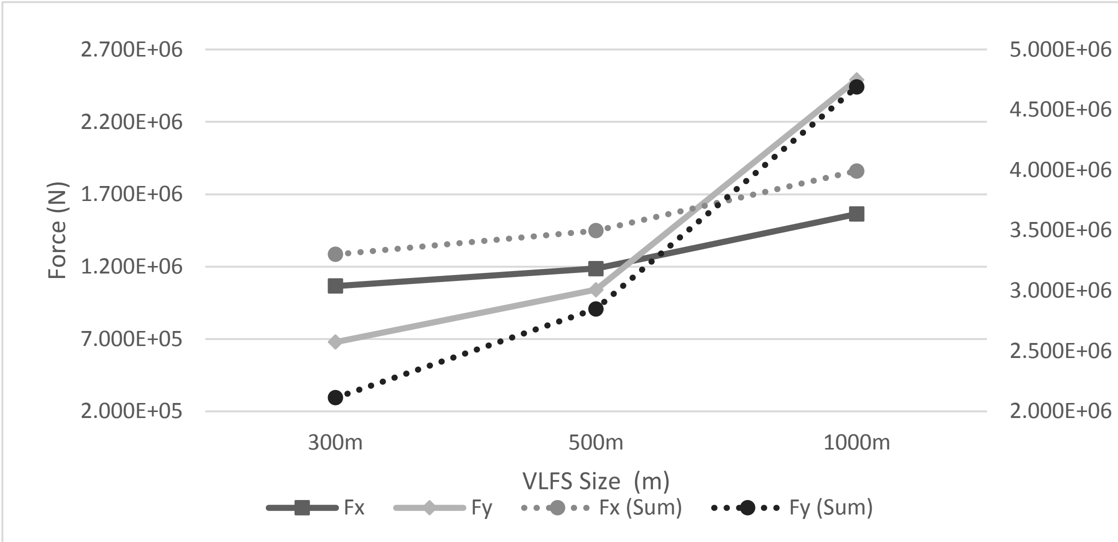

Figure 4.20: Fender forces for 200m depth with varying VLFS size (Operating condition)

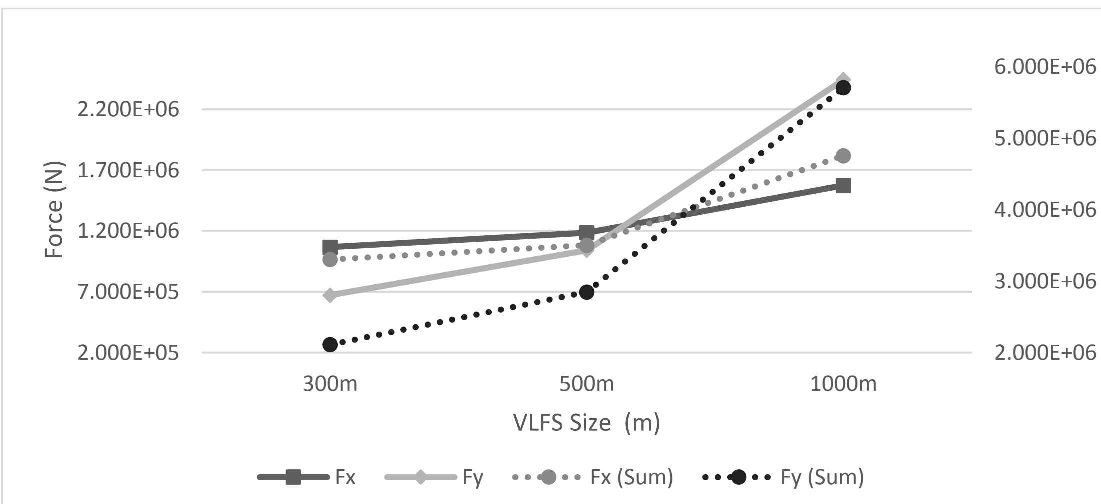

Figure 4.21: Fender forces for 1000m depth with varying VLFS size (Operating condition)

4.1.2.4 Fender forces for d=30m, 200m and 1000m depth with changing VLFS size in storm conditions

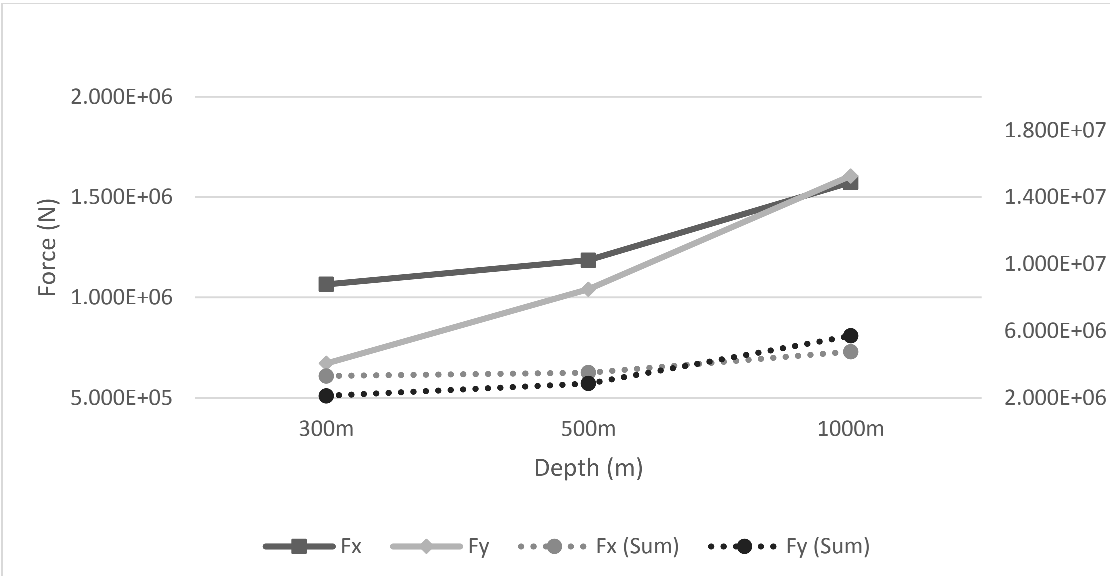

Figure 4.22: Fender forces for 30m depth with varying VLFS size (Storm condition)

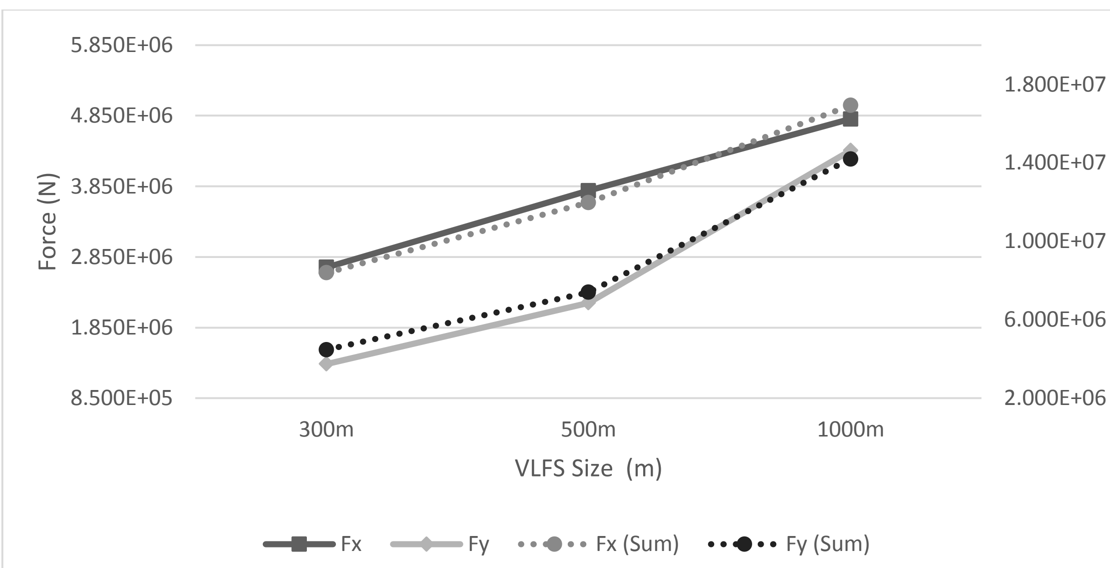

Figure 4.23: Fender forces for 50m depth with varying VLFS size (Storm Condition)

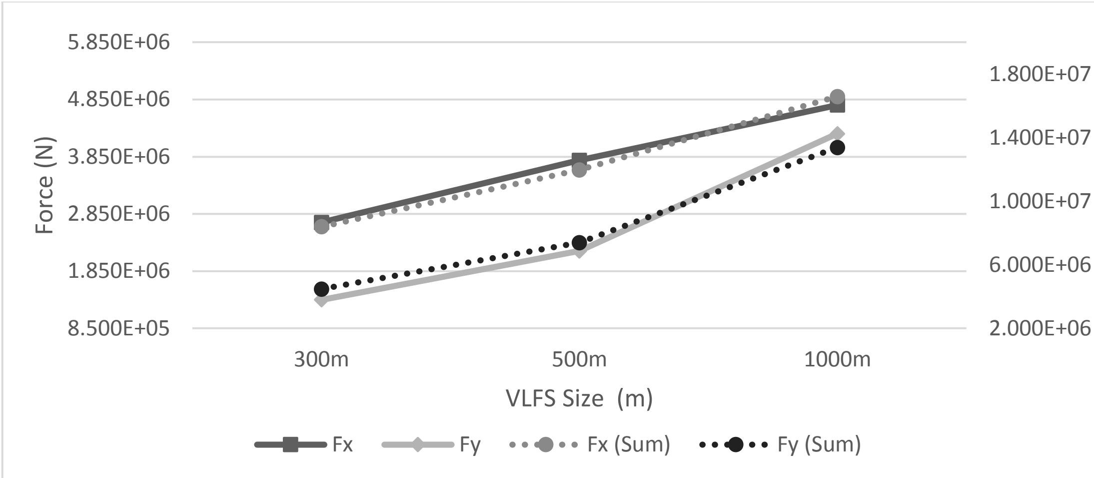

Figure 4.24: Fender forces for 70m depth with varying VLFS size (Storm Condition)

4.2 Effect of Vessel size on Fender Forces

As shown in Section 4.1.1.4 and Section 4.1.2.4, the maximum individual and sum of fender forces in the X and Y direction were plot for each water depth by varying the vessel sizes. It can be observed that the fender forces increase as the size of the vessel is increased.

Notably, the difference in fender forces is more apparent in the larger vessel as compared to the smaller vessels. The smaller vessels (300m and 500m vessels) recorded a smaller change in the fender forces. As deduced from the graphs, the larger the vessel, the greater the increase in fender forces. This can be attributed to the larger overall size of the vessel as well as its added weight. The effect is more pronounced in the normal operating conditions as opposed to the storm conditions.

4.3 Effect of Water depth on Fender Forces

As shown in Section 4.1.1.3 and Section 4.1.2.3 it is apparent that the maximum individual fenders forces and the sum of mooring forces in both and Y direction show an increase in value with an increase of VLFS size. It can be observed over the range of water depths and sea states that the change in water depth, there is little changes in the fender forces. In Peninsular Malaysia, it was observed that the fender forces increase with water depth, while in Sabah and Sarawak region, little change was observed. For example, for a 300m vessel, operating in the Sabah and Sarawak This is found to be in agreement with the works done by Utsunomiya et. al. (2006), where the in shallower waters (such as the case in Peninsular Malaysia), the effect of water depth under the vessel becomes significant and has to be accounted for.

This trend is observed both under the normal operating condition and storm condition, suggesting that it is independent of the changes in sea states.

This could be contributed to the fact that the fenders and vessels are above the water level and the structures below the waves (fender structures) does not affect the characteristics of the vessel. For example, in the case of mooring lines, a greater water depth would warrant the use of a longer and heavier mooring line which would have to be stiffer to reduce its stretched length in operation.

4.4 Effect of Weather and Sea state on Fender Forces

As shown in Section 4.1.1, 4.1.2, 4.2.1 and 4.2.2, the operational states play a role in the obtained maximum individual and sum fender forces. It was observed that the fender forces observed during storm conditions recorded a higher reading as compared to normal operating conditions.

The higher significant wave height, ocean current speed and wind speed result in a larger individual and total fender forces. Therefore, fenders would have to be designed to withstand conditions found during storm conditions, as they are considerably higher than that found during normal conditions.

4.5 Discussion

It should be noted that the analysis conducted where limited in the following aspects. Thus the results that is obtained may be deviated in some areas:

- There is still no wave spectrum available that is capable of accurately representing the conditions found in Malaysia waters (still being developed).
- The wave spectrum and velocity profile of the wave that is used, which was intended to simulate large water depths, may not be suitable for the shallow water considered.
- The diffraction effect of the wave in shallower water was not accounted for in the analysis.
- The distribution of weight on board the VLFS s also assumed to be even, which may not be the case for a real world application.
- The possible forces create by wind interaction with structures (especially structures with a large surface area) placed onboard the VLFS were not accounted for.
- The interaction (diffraction) between the incident waves and dolphin fender structures where not considered.

CHAPTER 5

CONCLUSION

5.1 Conclusion and Recommendation

The advantages and bright prospect for the implementation of VLFS technology has been reviewed in this report. Form the advantages and features stand point, it should be noted that VLFS technology can be widely implemented in Malaysia. The relatively calm water and extensive coastal regions throughout the country warrants the use of VLFS for almost any use.

The correlation between vessel size, water depth and operating conditions in the two regions (Peninsular, Sabah and Sarawak) has been proposed. It was found that the water depth does not play significant role in the fender forces of the VLFS as the overall vessel size and the operating sea state in the Sabah and Sarawak Region, as compared to the Peninsular Malaysia region, in which it does.

It is highly recommended that the other parameters which can be used to physically describe a vessel, such as the aspect ratio, draft length and surface area be studied in this manner to better identify a correlation. The number of vessel models could also be increased to include a larger number of sizes, as well as in other shapes to obtain a more comprehensive study into the effects of size of VLFS to its fender forces.

Given the ideal nature of the study, structures that would otherwise be present in actual applications should also be simulated to obtain results which closer to the real world condition. For example, the pier walls on dolphin fender structures that would have to be placed around the vessel to provide a fixed point for the installation of the fender should also be studied. This is to account for the possible wave characteristics created by the interaction of the structures with the incident wave.

REFERENCES

American Petroleum Institute (API). (1976). *API Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms*, API RP 2A 7^{th} Edition.

Chakrabarti, S. K., (1987), "Hydrodynamics of Offshore Structures", Southampton: WIT Press

Chang, Y.L. (1937). "Discussion on Lateral Pile Loading, by Faegin", Trans. ASCE, Paper No.1959.

Choi, Y.-R., Hong, S.-W., Kim, H.-J., & Kim, J.-H. (2000, January 1). "Experimental Study On Wave Loads and Responses of a Barge-Mounted Plant With Dolphin-Fender Mooring System". *The Tenth International Offshore and Polar Engineering Conference*. International Society of Offshore and Polar Engineers, 2000.

Davenport, A.G. (1967). *Gust Loading Factors*, Proc. Of ASCE, ET3.

Guerin, B. (2003). "The Shifting Sands of Time–and Singapore", Asia Times, July 31.

Heggen, R. (2015). *Floating Islands: An Activity Book*: Richard Heggen.

Hino, M. (1976). "Relationship between the instantaneous peak values and the evaluation time – A theory on the gust factor". Proc. of JSCE, Vol. 177.

Hinrichsen, D., & Olsen, S. (2013). *Coastal Waters of the World: Trends, Threats, and Strategies*: Island Press.

Hong, S. Y., Cho, S. K., & Kim, J. H. (2004, January). “Characteristics of wave loading and structural response of mat-type VLFS due to waves”. In *The Fourteenth International Offshore and Polar Engineering Conference*. International Society of Offshore and Polar Engineers.

Hong, S. Y., Choi, Y. R., & Hong, S. W. (2001, January). “Investigation of draft effects on analysis of hydroelastic responses of pontoon-type VLFS”. In *The Eleventh International Offshore and Polar Engineering Conference*. International Society of Offshore and Polar Engineers.

Hong, S. Y., Choi, Y. R., & Hong, S. W. (2002, January). “Analysis of hydro-elastic response of pontoon-type VLFS coupled with floating breakwaters using a Higher-Order Boundary Element Method”. In *The Twelfth International Offshore and Polar Engineering Conference*. International Society of Offshore and Polar Engineers.

Hong, S. Y., Kim, J. W., Shin, Y. S., & Ertekin, R. C. (2003, January). “An Eigenfunction-Expansion Method for Hydroelastic Analysis of a Floating Runway”. In *The Thirteenth International Offshore and Polar Engineering Conference*. International Society of Offshore and Polar Engineers.

Inoue, K. (1999, January). “Mega Float: Achievements to date and ongoing plan of research”. In *The Ninth International Offshore and Polar Engineering Conference*. International Society of Offshore and Polar Engineers.

Japan Port & Harbor Association. (1999b). Technical Standards and Commentaries for Port and Harbor Facilities. The Japan Port & Harbor Association, Vol. 2.

Jensen A, Mogensen B. Effects, ecology and economy. "Environmental aspects of dredging – Guide No. 6. International Association of Dredging Companies (IADC) and Central Dredging Association (CEDA); 2000

Kashiwagi, M. (1998, January). “A direct method versus a mode-expansion method for calculating hydroelastic response of a VLFS in waves”. In *The Eighth International Offshore and Polar Engineering Conference*. International Society of Offshore and Polar Engineers.

Kim, J. H., Hong, S. Y., Cho, S. K., & Park, S. H. (2004, January). “Experimental Study on a Dolphin-Fender Moored Pontoon-Type structure”. In *The Fourteenth International Offshore and Polar Engineering Conference*. International Society of Offshore and Polar Engineers.

Kubo K. (1964). A new method for the estimation of lateral resistance of piles. Reports of PHRI, Vol. 2, No. 3.

Kyoung, J. H., Hong, S. Y., & Kim, B. W. (2007, January). “Time Domain Analysis on Hydroelastic Response of VLFS Considering Horizontal Motion”. In *The Seventeenth International Offshore and Polar Engineering Conference*. International Society of Offshore and Polar Engineers.

Liew, M.S., Lim, E. S., & Tengku Shahdan, T. N., (2015). “Spectral Analyses of Sea-State Wave Data for the Development of Offshore Metocean Applications: A Malaysian Case Study”. Universiti Teknologi Petronas, Malaysia.

Maimun, A., Yaakob, O., Kamal, M. A., & Wei, N. C. (2006, July). Evaluation of Seakeeping Analysis of a Fishing Vessel using a Wave Buoy and Onboard Motions Monitoring Device. In *1st Regional Conference on Vehicle Engineering and Technology (RIVET 2006), Kuala Lumpur* (pp. 3-5).

Marto, A., Tan, C. S., Kasim, F., & Mohd Yunus, N. Z. (2013). Seismic Impact in Peninsular Malaysia. In *Proceedings of the 5th International Geotechnical Symposium-Incheon, Seoul, Korea*.

Matlock, H. (1970). Correlations for design of laterally loaded piles in soft clay. *Offshore Technology Conference*, Paper No. OTC1204.

Matsagar, V. (2015). *Advances in Structural Engineering: Dynamics, Volume Two*: Springer India.

Mituyasu, H. (1970). "Wind wave generation and their spectrum – wind wave spectrum in finite fetch length". Coastal Engineering in Japan, JSCE, Vol. 17.

Mohd Nor & Khalid, N. (2008). "An overview of shipbuilding industry in Malaysia". Maritime Institute of Malaysia (MIMA).

Murai, M., Inoue, Y., & Nakamura, T. (2003, January). "The prediction method of hydroelastic response of VLFS with sea bottom topographical effects". In *The Thirteenth International Offshore and Polar Engineering Conference*. International Society of Offshore and Polar Engineers.

Park, S. W., Lee, T. K., & Hong, S. Y. (2005). "A Study on Preliminary Structural Design of Pontoon Type VLFS". *Journal of the Society of Naval Architects of Korea*, *42*(6), 644-653.

Palo, P. (2005). Mobile offshore base: Hydrodynamic advancements and remaining challenges. *Marine structures*, *18*(2), 133-147.

Petronas Technical Standard 34. (2012). *Design of Fixed Offshore Structures (Working Stress Design)*. PTS 34.19.10.30. Petroliam Nasional Berhad.

Reese, L.C., Cox, W.R., & Koop, F.D.(1975). "Analysis of laterally loaded piles in sand". *Offshore Technology Conference*, Paper No. OTC2080.

Shimada, K., & Miyajima, S. (2002, January). “Comparison of Mooring Simulations and Measurement for Mega-Float Phase-II Model”. In *The Twelfth International Offshore and Polar Engineering Conference*. International Society of Offshore and Polar Engineers.

Siaw-Yi, J., & Chee-Ming, C. (2013). The fundamental compressibility characteristics of solidified dredged marine soil.

Suzuki, H., Yasuzawa, Y., Fujikubo, M., Okada, S., Endo, H., Hattori, Y., & Ozaki, M. (1997). “Structural response and design of large scale floating structure”. In *Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering* (pp. 131- 138). American Society of Mechanical Engineering.

Techet, A. H. (2005). “13.42 Design Principles for Ocean Vehicles”.

Ueda, S. (1984). “Analytical Method of Ship Motions Moored to Quay Walls and the Applications”. *Note of the Port and Harbour Research Institute,* (504), 371.

Ueda, S., Shiraishi, S., Maruyama, S. Y., Uezono, A., Takasaki, M., & Yamase, S. (1998). “Properties of rubber fender in use of mooring for floating bridge”. In *14th Ocean Engineering Symposium, The Society of Naval Architect of Japan* (pp. 359-364).

Utsunomiya, T., & Watanabe, E. (2006). “Fast multipole method for wave diffraction/radiation problems and its applications to VLFS”. *International Journal of Offshore and Polar Engineering*, *16*(04).

Wang, C. M., & Wang, B. T. (Eds.). (2014). *Large Floating Structures: Technological Advances* (Vol. 3). Springer.

Wang, C. M., Watanabe, E., & Utsunomiya, T. (2007). *Very Large Floating Structures*. Taylor & Francis.

Watanabe, E., Utsunomiya, T., & Wang, C. M. (2004). Hydroelastic analysis of pontoon-type VLFS: a literature survey. *Engineering structures*, *26*(2), 245-256.

Watanabe, E., Utsunomiya, T., Wang, C. M., & Xiang, Y. (2003, January). “Hydroelastic analysis of pontoon-type circular VLFS”. In *The Thirteenth International Offshore and Polar Engineering Conference*. International Society of Offshore and Polar Engineers.

Watanabe, E., Wang, C. M., Utsunomiya, T., & Moan, T. (2004). Very large floating structures: applications, analysis and design. *CORE Report*, *2*, pp. 104-109.

Yoneyama, H., Hiraishi, T., & Ueda, S. (2004). Recent technological advances of ship mooring analysis and construction of floating structures in Japan. *Bulletin-International Navigation Association*, (116), 79-90.

APPENDICES

APPENDIX 1: Peninsular Malaysia Simulation Cases

	Dimensions						Conditions						
No	L	B	D	d	Aspect Ratio	Weight (t)	Wave Height	Tz	Wind Speed	Current Speed	0.5 D	0.01 D	Depth
1	300	60	2	1	1/5	18450000	4.38	6.91	22	1.24	0.98	0.27	30
2	300	60	2	1	1/5	18450000	4.38	6.91	22	1.24	0.98	0.27	50
3	300	60	2	1	1/5	18450000	4.38	6.91	22	1.24	0.98	0.27	70
4	500	100	3	1.5	1/5	76875000	4.38	6.91	22	1.24	0.98	0.27	30
5	500	100	3	1.5	1/5	76875000	4.38	6.91	22	1.24	0.98	0.27	50
6	500	100	3	1.5	1/5	76875000	4.38	6.91	22	1.24	0.98	0.27	70
7	1000	200	4	2	1/5	512500000	4.38	6.91	22	1.24	0.98	0.27	30
8	1000	200	4	2	1/5	512500000	4.38	6.91	22	1.24	0.98	0.27	50
9	1000	200	4	2	1/5	512500000	4.38	6.91	22	1.24	0.98	0.27	70
No	L	B	D	d	Aspect Ratio	Weight (t)	Wave Height	Tz	Wind Speed	Current Speed	0.5 D	0.01 D	Depth
10	300	60	2	1	1/5	18450000	5.77	8.06	33	1.67	1.33	0.36	30
11	300	60	2	1	1/5	18450000	5.77	8.06	33	1.67	1.33	0.36	50
12	300	60	2	1	1/5	18450000	5.77	8.06	33	1.67	1.33	0.36	70
13	500	100	3	1.5	1/5	76875000	5.77	8.06	33	1.67	1.33	0.36	30
14	500	100	3	1.5	1/5	76875000	5.77	8.06	33	1.67	1.33	0.36	50
15	500	100	3	1.5	1/5	76875000	5.77	8.06	33	1.67	1.33	0.36	70
16	1000	200	4	2	1/5	512500000	5.77	8.06	33	1.67	1.33	0.36	30
17	1000	200	4	2	1/5	512500000	5.77	8.06	33	1.67	1.33	0.36	50
18	1000	200	4	2	1/5	512500000	5.77	8.06	33	1.67	1.33	0.36	70

APPENDIX 2: Sabah and Sarawak Simulation Cases

	Dimensions						Conditions						
No	L	B	D	d	Aspect Ratio	Weight (t)	Wave Height	Tz	Wind Speed	Current Speed	0.5 D	0.01 D	Depth
1	300	60	2	1	1/5	18450000	3.7	6	26	1.6	1.3	0.3	30
2	300	60	2	1	1/5	18450000	3.7	6	26	1.6	1.3	0.3	200
3	300	60	2	1	1/5	18450000	3.7	6	26	1.6	1.3	0.3	1000
4	500	100	3	1.5	1/5	76875000	3.7	6	26	1.6	1.3	0.3	30
5	500	100	3	1.5	1/5	76875000	3.7	6	26	1.6	1.3	0.3	200
6	500	100	3	1.5	1/5	76875000	3.7	6	26	1.6	1.3	0.3	1000
7	1000	200	4	2	1/5	410000000	3.7	6	26	1.6	1.3	0.3	30
8	1000	200	4	2	1/5	410000000	3.7	6	26	1.6	1.3	0.3	200
9	1000	200	4	2	1/5	410000000	3.7	6	26	1.6	1.3	0.3	1000
No	L	B	D	d	Aspect Ratio	Weight (t)	Wave Height	Tz	Wind Speed	Current Speed	0.5 D	0.01 D	Depth
10	300	60	2	1	1/5	18450000	5.7	6.9	50	2.3	1.8	0.7	30
11	300	60	2	1	1/5	18450000	5.7	6.9	50	2.3	1.8	0.7	200
12	300	60	2	1	1/5	18450000	5.7	6.9	50	2.3	1.8	0.7	1000
13	500	100	3	1.5	1/5	76875000	5.7	6.9	50	2.3	1.8	0.7	30
14	500	100	3	1.5	1/5	76875000	5.7	6.9	50	2.3	1.8	0.7	200
15	500	100	3	1.5	1/5	76875000	5.7	6.9	50	2.3	1.8	0.7	1000
16	1000	200	4	2	1/5	410000000	5.7	6.9	50	2.3	1.8	0.7	30
17	1000	200	4	2	1/5	410000000	5.7	6.9	50	2.3	1.8	0.7	200
18	1000	200	4	2	1/5	410000000	5.7	6.9	50	2.3	1.8	0.7	1000