

NUMERICAL STUDIES ON THE GAP RESONANCE OF FPSO AND SHUTTLE  
TANK SIDE BY SIDE DUE TO OCEAN EXCITING WAVES

by

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# CERTIFICATION OF APPROVAL

## **Numerical Studies on The Gap Resonance of FPSO And Shuttle Tank Side by Side due to Ocean Exciting Waves**

By

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A project dissertation submitted to the  
Civil Engineering Programme  
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Approved by,

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SEPTEMBER 2017

## 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.

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MUHAMMAD NURTASLIM BIN ABD JALIL

## **ABSTRACT**

This research is proposed to study the gap resonance of FPSO and shuttle tank in side by side arrangement due to exciting waves. During the side by side arrangement, there are a gap distance between the FPSO and shuttle tank which resonance might occurs. This resonance can increase the wave height in the gap distance that can disrupt the arrangement side by side of FPSO and shuttle tank. This study is crucial because the FPSO and shuttle tank in this arrangement is designed to undergo the offloading operation. If these arrangement is disrupted due to the resonance, the effectiveness of the offloading operation will reduce as well as the safety of the crew because the FPSO and shuttle tank might be colliding. Thus, the ability of the FPSO and shuttle tank to maintain the arrangement and gap distance will be the significant factor in obtaining the effectiveness of the offloading operation and safeness. The simulation of the FPSO and shuttle tank in the Star CCM+ software will be done to analyse the gap distance and drafts of two floating bodies on the resonance. Furthermore, this study also aims to analyse the dynamic response and environmental loading on these two floating bodies.

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# CONTENTS

CHAPTER 1 .....	1
INTRODUCTION .....	1
1.1 BACKGROUND STUDY .....	1
1.2 PROBLEM STATEMENT .....	4
1.3 OBJECTIVES .....	5
1.4 SCOPE OF STUDY .....	5
CHAPTER 2 .....	6
LITERATURE REVIEW.....	6
2.1 RESONANCE AND GAP RESONANCE .....	6
2.2 ENVIRONMENTAL LOADING .....	8
2.2.1 Wind Force .....	8
2.2.2 Current Force .....	9
2.2.3 Wave Force .....	10
2.3 DYNAMIC RESPONSE.....	11
2.4 MOORING LINES.....	13
CHAPTER 3 .....	16
METHODOLOGY.....	16
3.1 RESEARCH METHODOLOGY .....	16
3.1 STAR CCM+ SIMULATION.....	18
3.1.1 The preparation of geometry.....	19
3.1.2 Construction Simulation Topology.....	20
3.1.3 Mesh Generated .....	21
3.1.4 Define physic and boundary condition .....	23
3.2 RESEARCH FLOW PROCESS .....	24
3.3 KEY MILESTONE FYP 1 .....	25
3.4 KEY MILESTONE FYP 2.....	26
3.5 GANTT CHART FYP 1.....	27
3.6 GANTT CHART FYP 2.....	28
CHAPTER 4 .....	29
RESULTS AND DISCUSSION .....	29
4.1 THE RESONANCE FREQUENCY BASED ON RAO .....	30
4.2 THE INFLUENCES OF BODIES DRAFT ON THE GAP RESONANCE....	30

4.3 THE INFLUENCES OF DISTANCE BETWEEN TWO FLOATING BODIES ON GAP RESONANCE. ....	32
4.4 THE CHALLENGES IN OBTAINING THE EXPECTED RESULTS. ....	33
4.4.1 License Identification .....	33
4.4.2 Designing the geometry design.....	34
4.4.3 The Meshing Period.....	34
4.4.4 Physic Model .....	36
CHAPTER 5 .....	39
CONCLUSION AND RECOMMENDATION .....	39
REFERENCES.....	41

## LIST OF FIGURES

FIGURE 1: Type of Floating Structure (Google) .....	1
FIGURE 2: FPSO Components (Paik & Thayamballi, 2007). .....	2
FIGURE 3: FPSO Mooring Lines (Google) .....	3
FIGURE 4: Free Surface Profile (Yan & Ma, 2011) .....	7
FIGURE 5: Star CCM+ Logo (Google).....	18
FIGURE 6: Geometry Scene.....	20
FIGURE 7: Construction Topology .....	20
FIGURE 8: Overall Topology.....	21
FIGURE 9: Mesh Model Selection .....	21
FIGURE 10: Mesh Scene.....	22
FIGURE 11: Mesh Plane View .....	22
FIGURE 12: Research Flow Process .....	24
FIGURE 13: Arrangement of two floating bodies (Li & Zhang, 2016) .....	29
FIGURE 14:ROA with different frequency (Li & Zhang, 2016) .....	30
FIGURE 15: Graph Resonance Frequency against Body Draft (Moradi et. al, 2015) .....	31
FIGURE 16: Resonance Frequency against Distance between two bodies (Li & Zhang, 2016) .....	32
FIGURE 17: License Error .....	33
FIGURE 18: Surface Meshing .....	35
FIGURE 19: Volume Meshing .....	35
FIGURE 20: Physic Model Error.....	36
FIGURE 21: Graph for Y-Rotation.....	37
FIGURE 22: Graph of Z-Translation.....	37



## **LIST OF TABLES**

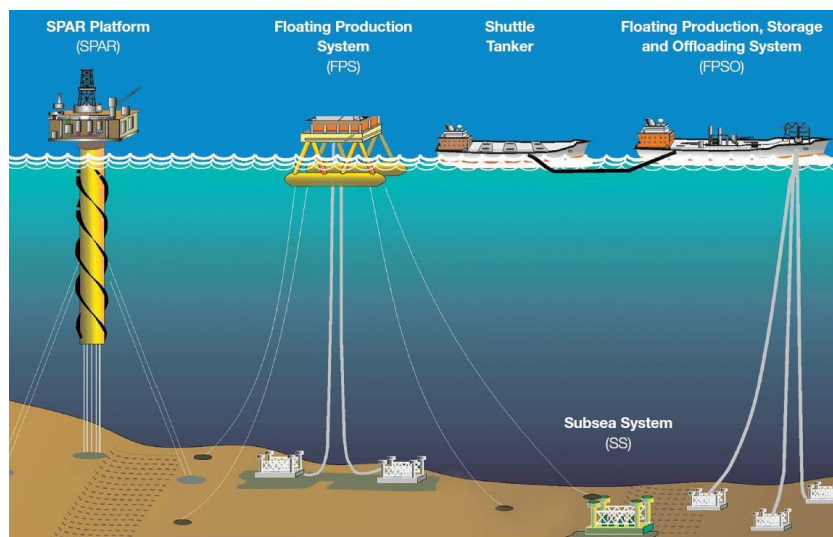
TABLE 1: Beaufort Wind Scale (Fang & Duan, 2014).....	9
TABLE 2: FPSO and Shuttle Tank Specifications (Yan and Ma, 2011).....	19
TABLE 3: Gap Distance between FPSO and Shuttle Tank.....	19
TABLE 4: Key Milestone FYP 1.....	25
TABLE 5: Key Miestone FYP 2.....	26
TABLE 6: Gantt Chart FYP 1.....	27
TABLE 7: Gantt Chart FYP 2.....	28

# CHAPTER 1

## INTRODUCTION

### 1.1 BACKGROUND STUDY

Civil engineering plays a significant role in the oil and gas industry. All the facilities and equipment used during the drilling process and production stage are placed on the offshore structure and those structures are developed and designed by the civil engineers. Basically, offshore structures can be distinct as a structure that is specifically designed to withstand the harsh environment of the ocean whether the structure is floating or bottom-supported. The depth of the sea is one of the key factors for the engineers to decide which structure is suitable to be designed. The depth of the sea can be divided into several sectors which are shallow sea, deep sea and ultra-deep sea. Shallow sea has a depth below 300 meters while for the deep sea is in between 300 meters and 1500 meters. In the meantime, for the ultra-deep sea has a depth over 1500 meters.

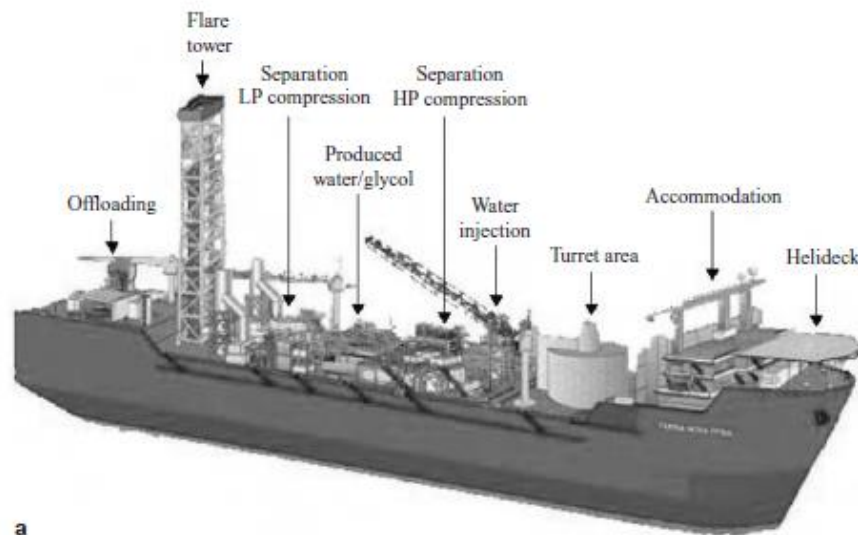


*FIGURE 1: Type of Floating Structure (Google)*

The structure that is focus on this paper is floating structure as Figure 1 above. As oil and gas exploration goes to ultra-deep sea, it is quite uneconomical to use fixed structure because it is using a huge amount of budget for the construction and it is difficult to do the maintenance. Thus, the floating structure has been developing thus

the design to overcome the disadvantages of fixed structure in ultra-deep water has not been achieved. Basically, floating structures are the structures that have 6 degrees of motion. These motions are surge, sway, heave, roll, pitch and yaw. Unlike fixed structure that uses truss to stay rigid and floating structure that uses mooring system to stay structurally rigid. Mooring system is a system that used mooring lines which is connected to the anchor. This will hold the floating structure in place during the harsh environment at the ultra-deep water. Floating structure can be classified into two type of buoyant structures which are neutrally buoyant structures and positively buoyant structures.

Neutrally buoyant structure is a floating structure which allow six degrees of motion. These structures are Semi-Submersible, Spars and Floating Production Storage Offloading units (FPSO). Meanwhile, positively buoyant structure is only allowing five degrees of motion and restrained one motion which are heave motion such as Tension Leg Platform, Tethered Buoyant Towers and Buoyant Leg Structures. Floating structure functions can be categorized into two categories which are mobile drilling and production. The exploratory drilling must be completed first before the production begins. The most preferable production unit is FPSO which has a ship-shape.



*FIGURE 2: FPSO Components (Paik & Thayamballi, 2007).*

FPSO is a production platform. As Figure 2 above, FPSO is one of the most creative floating platform. Generally, FPSO is ship floater which is having a layout that can be

divided into several parts which are main deck, topsides deck, mooring system, accommodation, machinery room, cargo and ballast tank and offloading area (Paik & Thayamballi, 2007). The main deck is the most critical area on the ship. It is needed to be durable enough for the support column. Besides that, the main deck also need to have enough space for the piping of the offloading and cargo loading. According to Paik & Thayamballi (2007), the main deck can be divided into the parts which are process area and utility area. The process area is an area specifically for the hydrocarbon-containing equipment. On top of that, the utility area has a space for the utility equipment and power-generation equipment. For the mooring system in this production platform it is using the turret mooring system. Turrets mooring system is a system which make the FPSO to have the ability to weathervane which where the FPSO will always face the weather as shown in Figure 3 below. Because of the weathervane, the roll and heave motion can be minimized.

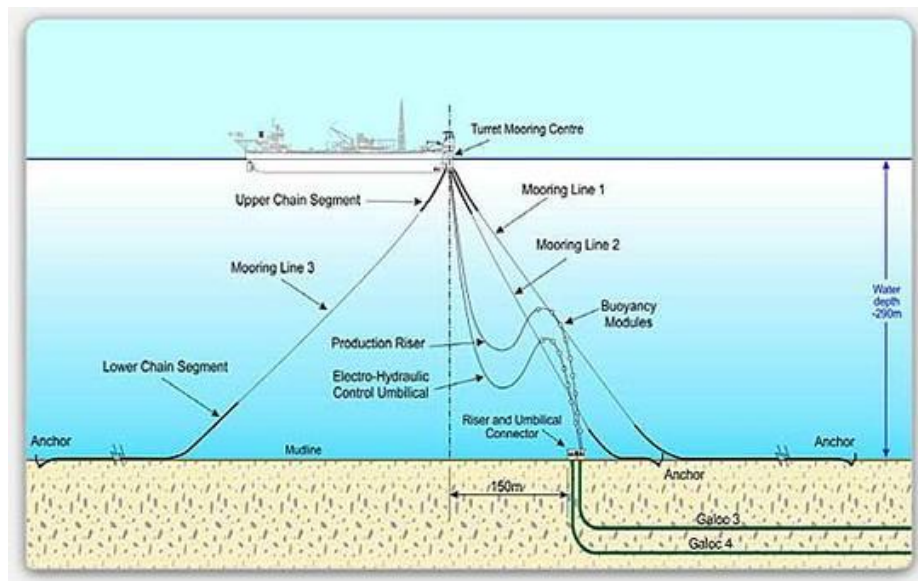


FIGURE 3: FPSO Mooring Lines (Google)

As mentioned above, FPSO is a platform which has a storage system and offloading system. The offloading operation is done by direct transfer to the shuttle tanker through several ways which are offloading reel, trailing hose and loading buoy. The FPSO and shuttle tanker can be arranged in side by side arrangement during the offloading operation (Yan & Ma, 2011).

## 1.2 PROBLEM STATEMENT

In the oil and industry, the demand of oil and gas have caused more floating structure to be develop and utilised especially floating production storage offloading system (Yan & Ma, 2011). Besides, the reducing of natural sources in land and near offshore causing the oil exploration to be more focused on the deep water and the suitable structure to do the exploration process are floating structure (Jaswar & Siow, 2014).

Thus, during the offloading operation, the arrangement side by side of floating structure are frequently applied especially when FPSO offloading to the oil tank or Liquid Natural Gas ship (Bin Teng et. al, 2016). Due to that arrangement, there will be a gap between two structures. This gap distances are important to study because it will become the main factor to ensure the safety of the arrangement and the effectiveness of the offloading process (Jaswar & Siow, 2014).

Yan and Ma (2011) mentioned that the hydrodynamic interaction between two floating structures which are the gap distances will give a huge influence on the motion of the structures which even affect the safety of the structures. In the gap distance, the resonance may occur which can be causing the wave height to reach up to five times the incident wave height (Saitoh et. al, 2006). When the wave become aggressive in the gap, it can disturb the arrangement of the floating structure thus can induce the two structures to collide with each other. The safety of the operation can be harmed when the rough wave and the resultant hydrodynamic load on the structure (Li & Zhang, 2016). Thus, to increase the safety issues and the effectiveness during the offloading operation, it is important to completely understand the hydrodynamic within the gap between two floating structures (Peric & Swan, 2015).

### **1.3 OBJECTIVES**

The main objective of this project is to investigate the numerical studies on the gap resonance between FPSO and Shuttle Tank due to ocean exciting wave. To complete the main objective, there are several sub-objectives that needs to be achieved:

1. The interaction of the environmental loading as well as dynamic responses of the two floating bodies
2. Determine the minimum gap between two floating structure and draft of the floating bodies.

### **1.4 SCOPE OF STUDY**

In this study, the author will focus on the floating structure which is the Floating Production Storage Offloading (FPSO) system. The FPSO has a shuttle tank that will come close to the FPSO during the offloading operation.

For the simulation, the author will focus on the Star CCM+ software to analyse the wave resonance between the two floating bodies. The FPSO and the shuttle tank need to be design in the software and the data will be collected after completion of the simulation.

## **CHAPTER 2**

### **LITERATURE REVIEW**

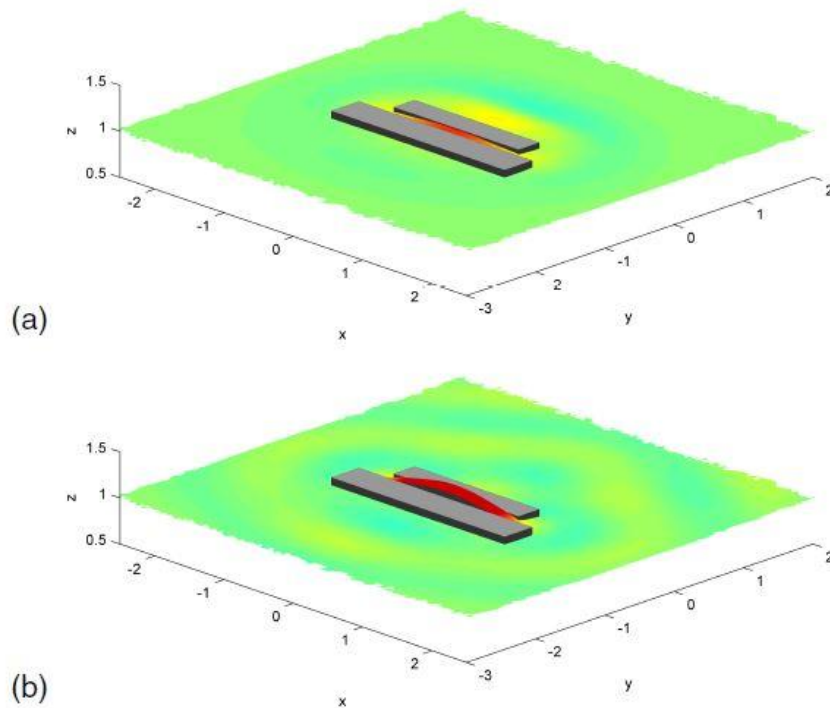
This topic has been discussed and researched by many researchers. This is because the gap between two floating bodies are the most critical factor when two structures are placed side by side. Most of the cases, the structure has been placed side by side because of the offloading system. The reason of the gap as the main factor to be considered is because of the relation with the safety issues of the structure and the effectiveness of the offloading process (Jaswar Kota & C.L Siow, 2014). The complexity of hydrodynamic within the gap are high thus having a full understanding on its fundamental, can help increased the safety factor during the offloading process (M.Peric & C. Swan, 2015).

#### **2.1 RESONANCE AND GAP RESONANCE**

Li & Zhang (2016) study the analysis of the resonance in gap between two heaving barges using Response Amplitude Operator (RAO). In their study they have mentioned that when the gap between the two-barge equal to 1, the piston type resonance will occur while the gap is equal to two, the sloshing type of resonance will dominate. Basically, the piston type of resonance could produce a large wave in the gap between two barges and could lead into the dangerous situation. Besides, they also have done the analysis effect of the barge size to resonance. It shows that the larger the breadth of the barges, the resonance frequency will become lower. When one of the barge is much larger than another, the larger barge tends to lead a larger amplitude response to the water. However, the significant sizing of the barges to the resonance are low and giving only a minor impact.

Bin Teng et. al (2016) has stated that as the result of the experimental and numerical wave amplitude inside the narrow gap was similar and agreed to each other. Base on the results, the wave height inside the gap increases together with the increasing of leaning angle of the barge at the low frequency but when in is in the high frequency, the wave height decreases with the increment of the leaning angle.

According to the Yan & Ma (2011) numerical studies, it is shown that the wave amplitude inside the narrow gap are high at the middle but has a low wave amplitude at the end of the gap. The different of the wave amplitude at the middle of the gap may be three times larger than at the end of the gap as Figure 4 shown below. Bin Teng et. al (2016) also mentioned that in the studies of the resonant frequency being higher for the narrow gap between the fixed leaning barges compared to the rolling barges.



*FIGURE 4: Free Surface Profile (Yan & Ma, 2011)*

When the resonance occurs between the gap distance, it will affect the motion of the floating structures. The motion of the influence gap distance between two structures is the surge motion (Jaswar & Siow, 2014). In the study done by Yan & Ma (2011), they decided to investigate which barge will only experience the surge or heave motion with the displacement. On the other hand, Kristiansen and Faltinsen (2010) done a model test for their studies which is regarding to the fluid resonance between a ship and the terminal. In their model test, the ship section can experience three type of motion which are sway, heave and roll.



## **2.2 ENVIRONMENTAL LOADING**

Every structure that exists will be exposed to the loading including the floating structure which floats in the ocean. There are a lot of type of loading that exerts to the FPSO such as live load, dead load and environmental loading. These loading are needed to be considered during the design of the floating structure. The environmental loading will be focused on thus it will affect the stability of the floating structure.

Environmental loadings are the loading that is generated by the nature such as wind, wave and current. According to Fang and Duan (2014), they mentioned that the environmental loading is a type of load that is produce to the natural environmental surrounding such as ice, earthquake, wind, wave and current. During the design of the floating structures, each phenomenon need to be considered such as wind wave, current and tides (Yong Bai, 2003).

### **2.2.1 Wind Force**

Wind velocity can be defined as the distance of the airflow per unit time (Fang & Duan, 2014). According to the API RP 2T (1997), wind is one of the important factor that needs to be focused on. There are two types of method that is commonly used to monitor the effect of wind in the design process which are the wind force that is assumed to be as a constant and calculated constructed on 1-minute average velocity. Thus, another method is the wind force being calculated as 1-hour average velocity with the time-varying component which is from empirical wind gust spectrum. It was mentioned in the API RP 2T (1997) that the choice of the method to used depending on the data, parameter and the outcome of the designs. Based on Fang and Duan (2014), the measurement of the wind velocity which is also known as the Beaufort Wind Scale can be divided into a 12-wind scale as shown in Table 1.

TABLE 1: Beaufort Wind Scale (Fang & Duan, 2014)

Table 1-1 Universal Wind Scale							
Wind Scale	Wind Name	State of the Sea	Sea Wave Height, m		Equivalent Wind Velocity		
			General	Highest	n mile/h	km/h	m/s
0	No wind	As a mirror			<1	<1	0
1	No wind	Wavelet	0.1	0.1	1~3	1~5	0.3~1.5
2	Breeze	Small wave	0.2	0.3	4~6	6~11	1.6~3.3
3	Gentle breeze	Small wave	0.3	1.0	7~10	12~19	3.4~5.4
4	Moderate breeze	Light waves	1.0	1.5	11~16	20~28	5.5~7.9
5	Cool breeze	Waves	2.0	2.5	17~21	29~38	8.0~10.7
6	Strong breeze	Big Wave	3.0	4.0	22~27	39~49	10.8~13.8
7	Moderate breeze	Billow	4.0	5.5	28~33	50~61	13.9~17.1
8	Gale	Wild waves	5.5	7.5	34~40	62~74	17.2~20.7
9	Strong gale		7.0	10.0	41~47	75~88	20.8~24.4
10	Whole gale	Turbulent	9.0	12.5	48~55	89~102	24.5~28.4
11	Storm wind	Can't imagine	11.0	16.0	56~63	103~117	28.5~32.6
12	Hurricane		14.0	>16.0	64~71	118~133	32.7~36.9
13			>14.0		72~80	134~149	37.0~41.4
14					81~89	150~166	41.5~46.1
15					90~99	167~183	46.2~50.9
16					100~108	184~201	51.0~56.0
17					109~118	202~220	56.1~61.2

Note: 1 n mile = 1852 m.

### 2.2.2 Current Force

According to the API RP 2T (1997), the vector summation of the tidal current, circulation current and the storm-generated current are the total current. The vector means that the magnitude of the currents is important for the computational load which changes due to the location. The tidal current is a current that is stronger on broad continental but weak in the deep water past the shelf break. Thus, the closer the tidal current to the shoreline, it will become stronger. These currents can be divided into two categories which are reversing current and rotating current (Fang & Duan, 2014). For the circulation current, it is a steady current which have a huge scale of the oceanic circulation. Although in the steady state, the circulation may break from the main circulation and become large-scale eddies. The storm-generated current is a current that is generated due to the wind stress and the atmospheric pressure gradient. These currents can be divided into two categories which are drift current and local wind current (Fang & Duan, 2014).

### 2.2.3 Wave Force

Based on Fang and Duan (2014), the wave direction is depending on the direction of the winds. There are three factor that are generated by the wave which are wind velocity, wind duration, and wind field. The main factor in the growth of the waves is the wind velocity. It plays an important role to the wave generation. Basically, wave can be divided into two types which are the stormy waves and the flush. Stormy waves occur during the presence of wind velocity and the direction of the wave is propagating to the wind direction. In the meantime, flush waves happened during the absence of wind. According to the API RP 2T (1997), the wave loads that exerts the platform can be classified as the dynamic in the nature. Wave force can be calculated by using three different method which are Morrison Equation, Froude-Krylove Theory and Diffraction Theory (Deo, 2013).

The Morrison's Equation is used for the small structure. The small structure can be considered when the diameter of the member is less than 0.15 times the wavelength. This will cause the drag force to become significant. The incident wave will not have scattered too much when the diameter of the are small because less obstruction available. Morrison's Equation is consisting of the summation of total drag force and inertia force by the wave.

When the diameter of the member is 15% larger that the wave length, it will cause the incident wave to be scattered too much and cause the drag force to become smaller. Thus, the wave force can be calculated using the potential flow theory. Besides, the scatter wave potential also need to be included because due the incident wave being diffracted or scattered. The Froude-Krylove Theory is used when the structure is relatively small, and the drag force is small, but the inertia force is outweighing. On top of that, the Diffraction Theory is used if the size of the structure that can surely alter the incident wave which where the size of structure is much bigger that the wave length.

## 2.3 DYNAMIC RESPONSE

For the dynamic response in offshore structures few critical data need to be acquired to determine the genuine data on environmental condition such as current, wind, earthquake, wave etc and to accurately account them in the calculation. Despite determining the design load that are conquered by extreme conditions which combine all the inspection of dynamic effects and the maximum probable load components can be performed for an individual load component such as seismic load or wave as shared by (Jan, Chen, & Conlon, 1982). Kawano, Venkataramana, Yamada, & Lida, (1991) added that the dynamic response is the distinctive to the structure depending on the vibrational performance of the structure.

According to the Yong Bai (2003), the dynamic response of a structure that includes the vibration of the structure, response of moored system and the sea-keeping motion of the structure. These responses are in the frequency and can be categorizes into 4-categories. Wave frequency response has a period between 5-15 seconds. This type of response can be called the ordinary sea-keeping motion of a structure. The second dynamic response are the slowly-varying that has a period in the range between 100-200 seconds. This type of response is the slow drift motion of the structure with has its own moorings. High-frequency response is the third type of dynamic response. This response has a period that is close to the wave period. The last type of dynamic response is the impulsive response. The impact of the water with the body will generate the impulse load with high frequency which slamming will occur at the bottom of the structure.

Garrison (1974) explained that not only a periodic excitation force will happen when waves react with a floating structure, on top of that a steady-state or time-independent horizontal force, vertical force and pitching moment will be endorse. The unrestrained floating body to drift in the direction of wave propagation will be caused by the drift force or early stated as the steady-state horizontal force in a ship hydrodynamics. The study of wave induced response of floating bodies specifically in the surface are of the ships have been done in early ages. When the sinking operation occurs, the bottom propinquity or finite depth effect will become an interest despite the operation of sinking a large object slants and eventually will rest in the ocean.

The hydrodynamic coefficients for two dimensional problems have been written in many papers. Oscillating on a free surface have been considered by Kim (1965) for floating bodies and ellipsoidal bodies with the theoretical assumption by Havelock (1955) that mass and damping coefficients must also be considered. Kim (1965) have calculated in his paper that surge, pitch and heave response for the same spheroidal bodies to wave excitation. Barakat (1962) also treated the vertical motion of a sphere as brought by surface water but his work confined errors. Therefore, Vugts (1968) has concluded that swaying, heaving and rolling response with rounded corners from a rectangular cylinder.

The other method that was emphasized to use by Garrison (1974) was excitation forces and moments with adding mass and damping coefficients for floating bodies or random shape in water of fixed depth. On top of that the hydrodynamic coefficients were also include in the above equation to obtain pitch, heave and surge with addition of the steady state force. Garrison (1974) also added that a floating body is free to respond to a wave interaction and can lead to the motion produces in otherwise still water by the body wavering in its numerous degree of freedom, one degree at a time and also gesticulation produced by the interaction of the wave with the body held static.

Unidirectional random waves are subjected to spread moored FPSO and not to mention is free to move in surge, sway, heave, roll, pitch and yaw directions added Nishanth et al. (2016). FPSO mooring lines that is connected to the seabed will be considered as a linear spring with negligible mass. The vertical planes motions can be kept effectively low to pledge the safety of the floating structure, umbilical pipes and risers and other facilities use in oil production from brought by heave, roll and pitch commented Matos et al. (2011). Further on, Jaswar & Siow (2014) saying that the relative motions between the floating bodies are critically affected by the operability and safety of the floating bodies operation.

Kawano et al. (1991) concluded in their research that due to instantaneously loadings that primarily depends on the first few vibration modes which is inclined by the dynamic soil structure contact will affect the dynamic response of offshore structures therefore it is vital to determine precisely those vibrations modes and equivalent natural frequencies.

## 2.4 MOORING LINES

The mooring is a crucial characteristic for station keeping in floating offshore structures. Mooring can be classified into two types which are spread moorings and single-point moorings (SPM). As said by Paik & Thayamballi (2007), spread mooring is expressed as a combination of chain, wire or synthetic cables static in groups at specific points on the floating vessel exterior so it maintains station, usually on a fixed position and heading.

Meanwhile SPMs are for numerous types that are located at the vessel's bow that can allocate the weather-vaning distinctive in mooring design. SPMs is classified into seven types that includes fixed tower, catenary anchor leg mooring (CALM) buoy, single-anchor leg mooring (SALM) buoy, articulated loading platform (ALP), single point and reservoir (SPAR), single-anchor loading (SAL) and turret mooring.

For this project the author had choose to focus more on turret mooring. For the structural strength analysis of mooring system design, the loads have been transferred to the turret from the mooring lines loads. The location of the turret would not be the only terms affected by the weathervaning capability of the vessel, the dynamic loads on the mooring lines would also be affected due to the vertical motions at the fairleads. The number of mooring lines allowed may be place as constraint for the turret design as the layout of mooring lines could also pose intrusion concerns for the risers. Understanding the relations between subsystems are crucial prior to why a lot of aspects of the design or analysis of mooring system for turret moored FPSO must be prudently approached. (Huang & Judge, 1996)

Device that is directly constructed into the moored vessels, combining a bearing arrangement for persistence of weathervaning and devoted to the seabed usually by catenary anchor lines is explained as turret mooring by Paik & Thayamballi (2007). Flexible risers are deferred from this fixed part and are linked to Pipe Line End Manifold (PLEM) arrangements or unswervingly to well heads with this part of the turret that was moored is static relative to the sea bottom. The static piping mounted on the vessel are connected to the flexible risers with a swivel. (Paik & Thayamballi, 2007)

Paik & Thayamballi, 2007 also mentioned that turrets can be classified into two main types which are permanent and disconnectable. Turrets will be built in the floating vessels permanently, although some of the part had to made proficient to be disconnected if certain environmental conditions and allied limits are outdoing. Considerations must be given to protection of riser from wave damage for some harsh environments as for moderate to severe environments, an external turret monitoring can be used.

However, for a harsh environment, it could be a limiting factor. The number of riser could be limited to only about twenty for a typical project. For an internal turret-mooring system, a turret would be inside the vessel and can be used in both harsh and moderate environments. Typically, the number of risers would be limited to 100 in such cases. Bear in mind that an important factor for design in the structural design of the associated vessel hull is the integration of the turret into the hull have to be included. (Paik & Thayamballi, 2007)

On top of that, Paik & Thayamballi (2007) also added another factor to be consider is the hull girder strength to not be reduced by the internal turret arrangement. Thus, the available deck area for the topside footprint may be reduced due to the internal turret. The requirement of using a bogie system or splint bearing is a must although the internal turrets can be design to fit 100 risers due to the sufficient size of single-piece roller bearings are not available.

Paik & Thayamballi (2007) did not stop that as they also mentioned about how the disconnectable turret arrangement is designed. It was designed to deal with interruption in high-sea states and to permit reconnection. Disconnectable turret arrangement is usually used in some harsh environmental circumstances or for any specific reasons. Usually, the submarine hoses and anchor legs will remain submerged buoy or even floating to affluence the reconnection in various cases. Disconnectable turrets are occasionally classified into two dissimilar types which are the riser turret mooring (RTM) and the buoyant turret mooring (BTM) as mentioned by de Boom (1989).

In order to achieve an acceptable mooring system, few design considerations had been listed out by Nestegard and Krokstad (1999), Huang (2000) and Paik & Thayamballi, 2007 which are;

- The maximum numbers of jaunts for the vessel that can be accommodated by the risers
- Line dynamics due to 6-degrees-of-freedom wave-frequency vessels motions, that is in heave, pitch, sway, yaw, surge, and roll.
- The frequency of vessels motion for yaw, sway and surge must be low.
- The effects to the responses of the vessels and its mooring system from the noncollinear environments such as winds, currents and waves while require motion and analysis of coupled deep-water systems under dynamic actions due to waves, winds and current.
- Current loading and viscous forces will become stronger due to the longer exposed risers and moorings which may increase the flow-induced vibration phenomena.

Mooring systems failure could lead to damage or rupture of the risers and eventually will cause the offshore unit to be shut down. The design of ship-shaped offshore should at least be able to withstand a single-mooring-line failure without damaging the risers.

Among the most critical structures to be considered before designing and operating moorings lines are consequences of mooring line failure fatigue, options for in-water inspection, mooring system degradation, methods to detect mooring line failure and implications of friction-induced bending. (Paik & Thayamballi, 2007, Brown et al.,2005)



## CHAPTER 3

### METHODOLOGY

#### 3.1 RESEARCH METHODOLOGY

According to the Zuoyang et.al (2013), there are several equations and theory that will be used in this study which are:

The Laplace Equation:

$$\nabla^2 \Phi^m = 0$$

The Linear Free Surface Condition:

$$-\omega^2 \Phi^m + g \frac{\partial}{\partial z} \Phi^m = 0$$

The Body Boundary Condition of Diffraction Wave Potential:

$$\left. \frac{\partial \Phi_D^{lm}}{\partial n} \right|_m = - \left. \frac{\partial \Phi_I}{\partial n} \right|_m \quad (l = m)$$

$$\left. \frac{\partial \Phi_D^{lm}}{\partial n} \right|_m = 0 \quad (l \neq m)$$

The Body Boundary Condition of Radiation Wave Potential:

Condition 1: When 'm'th floating body does the 'j'th mode harmonic motion and the 'j'th floating body is static.

$$\left. \frac{\partial \Phi_j^{mm}}{\partial n} \right|_m = -i\omega n_j$$

Condition 2: When the 'l'th floating body does the 'j'th mode harmonic motion and the 'm'th floating body is static.

$$\left. \frac{\partial \Phi_j^{lm}}{\partial n} \right|_m = 0$$

The Radiation Equation of Multi-Floating Bodies:

$$\lim_{kr \rightarrow \infty} \sqrt{kr} \left( \frac{\partial \Phi^m}{\partial n} - ik \Phi^m \right) = 0 \quad (kr \rightarrow \infty)$$

The Motion Equation of Multi-Floating Body:

$$\sum_{j=1}^6 (M_{kj}^m + u_{kj}^{mm}) \ddot{\eta}_j^m + \sum_{l=1, l \neq m}^n u_{kj}^{lm} \ddot{\eta}_j^l + \sum_{l=1, l \neq m}^n b_{kj}^{ml} \dot{\eta}_j^l + b_{kj}^{mm} \dot{\eta}_{kj}^m + C_{kj}^{mm} \eta_j^m = F_k^m$$

The 'm' th floating body motion equation can be described as below;

$M_{kj}^m$  = k-mode inertia matrix due to the j-mode motions

$u_{kj}^{lm}$  = k-mode added mass coefficient matrix due to j-mode motions about the 'l' th floating body

$b_{kj}^{ml}$  = k-mode damping coefficient matrix due to j-mode motions about the 'l' th floating body

$C_{kj}^{mm}$  = hydrostatic stiffness matrix of k

$F_k^m$  = waves exciting forces in k-mode

### 3.1 STAR CCM+ SIMULATION

In this project, the simulation of the project will be done to achieve the main objective of this project. The software that will be used in this project is STAR CCM+. STAR CCM+ is a software developed by the CD-adapco. This company is well-known for the computational fluid dynamic software. There are several software's that have been developed by the CD-adapco which are STAR CCM+, STAR-CD and STAR-Design.

Basically, STAR CCM+ is an upgrade software from their old product which is STAR-CD. The computational fluid dynamic (CFD) and the algorithm has been completely rewritten. STAR CCM+ is a CFD code which cover every multidisciplinary platform for the simulation of the project and can be design operating under the real-life condition. The disciplinary that will be cover in the software are:

1. Aero-acoustic
2. Fluid Dynamics
3. Heat Transfer
4. Multiphase Flow
5. Rheology
6. Solid Mechanic
7. Reacting Flow
8. Particle Flow



*FIGURE 5: Star CCM+ Logo (Google)*

The simulation design in the Star CCM+ can be divided into 4 main steps which are:

### 3.1.1 The preparation of geometry.

This is the first step of the simulation. In this step, the FPSO and the shuttle tank is designed in 3D-CAD model as Table 2. The Barge 1 acts as shuttle tank and Barge 2 acts as a FPSO.

TABLE 2: FPSO and Shuttle Tank Specifications (Yan and Ma, 2011)

	Barge 1	Barge 2
Length( $L_b$ )	180m	250m
Breadth( $B_b$ )	30m	40m
Depth( $D_b$ )	18m	23m
Draft( $D_\gamma$ )	10m	15m
Displacement	55350te	153750te
Centre of gravity ( $G_c$ )	9m	11m
Radius of gyration in Roll	10m	13m
Radius of gyration in Pitch	45m	60m
Radius of gyration in Yaw	45m	60m

The gap distance of the FPSO and shuttle tank is setting along during the process of FPSO and shuttle tank design. There are 6 gaps that will be focus in this simulation as shown in Table 4 below.

TABLE 3: Gap Distance between FPSO and Shuttle Tank

Gap distance between FPSO and Shuttle Tank	0.2m
	0.4m
	0.5m
	1.0m
	2.0m
	3.0m

The Figure 6 below shows the FPSO and shuttle tank that is designed as a rectangular block and the block act as the topology so that in the next step the surrounding, input and output can be defined.

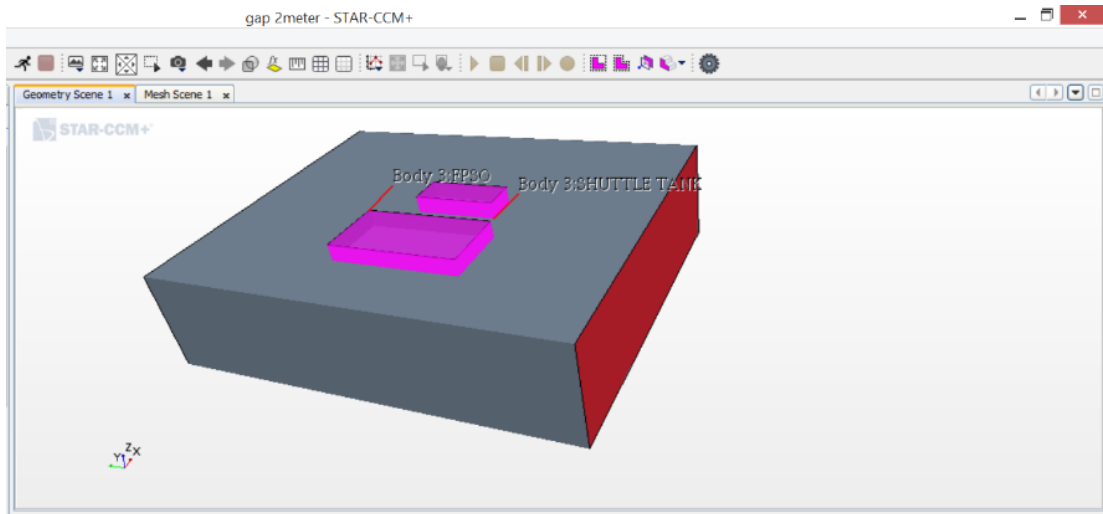


FIGURE 6: Geometry Scene

### 3.1.2 Construction Simulation Topology

This step is to define the surface of the simulation. Each surface will have different boundary condition. To define the surface, the surface need to be split by patch. After that, each surface will be divided individually and can be define as new surface. Figure 7 below shows that another surface has been defined and left only the surface for shuttle tank.

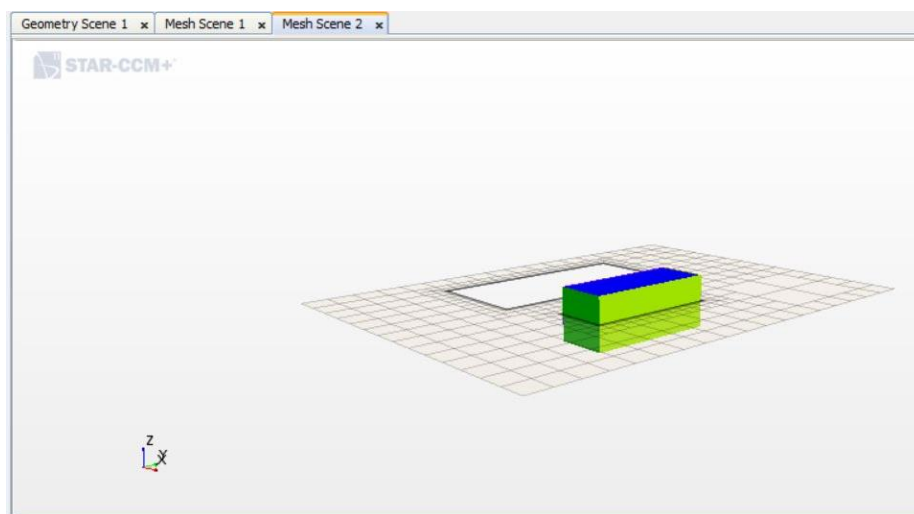


FIGURE 7: Construction Topology

Figure 8 below shows all the surface has been defined which consist of inlet, outlet, surrounding, FPSO and shuttle tank.

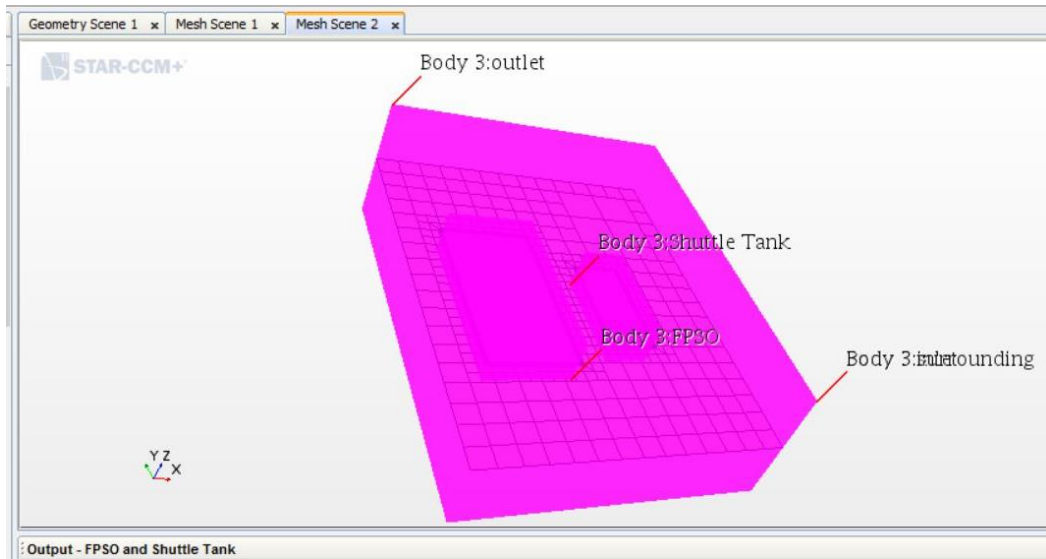


FIGURE 8: Overall Topology

### 3.1.3 Mesh Generated

The mesh is generated to create a target area to focus on the result of the simulation. The higher the number of cell in a mesh, the result will be more accurate, and the simulation will become more longer. There are several mesh models can be chosen in the mesh model. The mesh model that is used in this simulation are surface mesh which surface remesher and volume mesh which is prism layer mesher as shown in Figure 9 below.

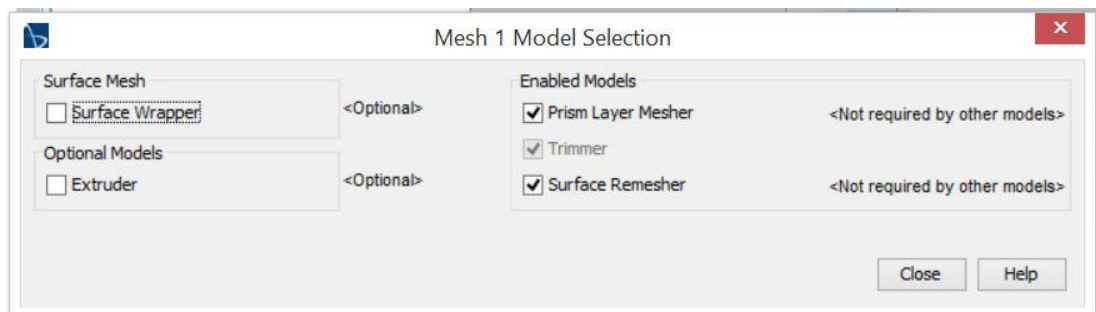
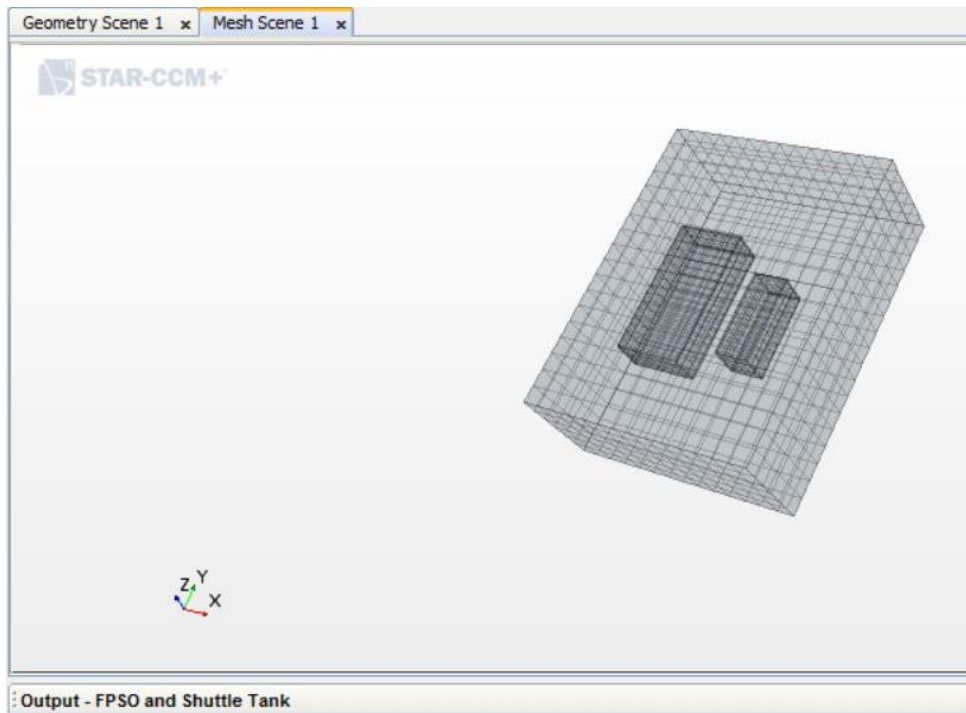


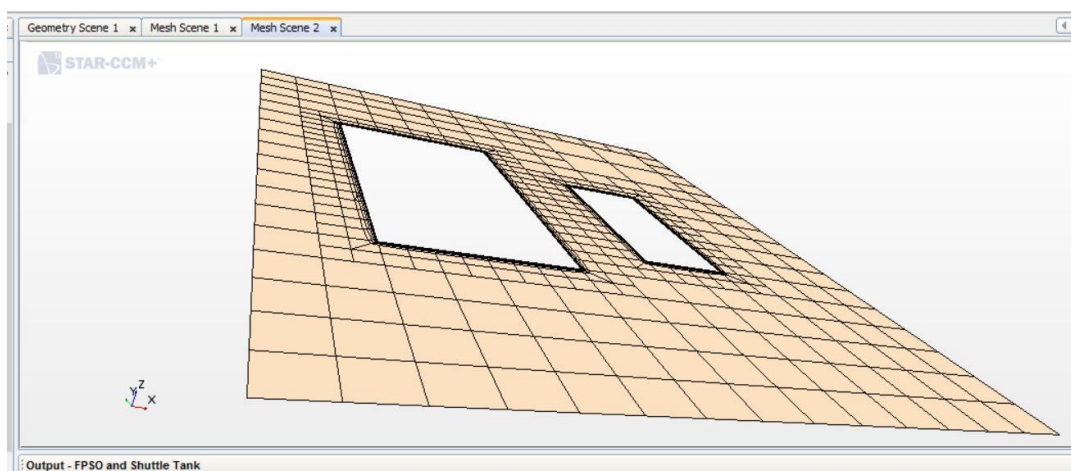
FIGURE 9: Mesh Model Selection

After the model has been selected, the surface and volume mesh are constructed. Figure 10 below is the results of the surface and volume mesh can be seen in the mesh scene after applying the mesh apply representation.



*FIGURE 10: Mesh Scene*

The plane view of mesh scene as Figure 11 below is to make sure the mesh is generated based on desired mesh. It is also to make it much easier to modify and to monitored which part need to put more layer of cell.



*FIGURE 11: Mesh Plane View*

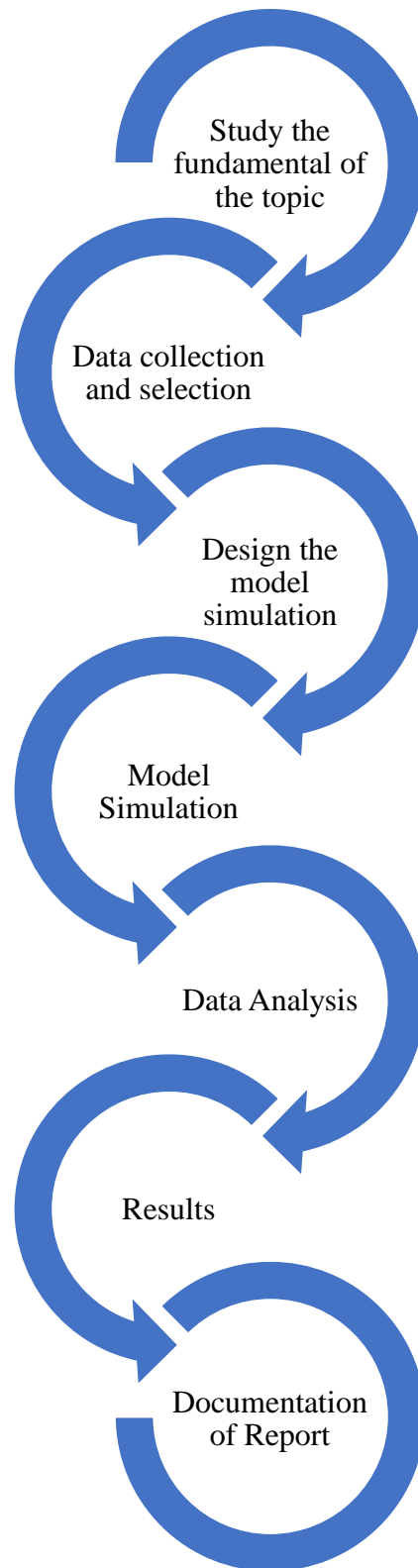
### 3.1.4 Define physic and boundary condition

The physic and boundary condition are set-up using the dynamic fluid body interaction (DFBI) modelling. The function of DFBI model to produce the motion of a rigid body in response to pressure and shear force by the fluid fields. STAR CCM+ ease the workload by calculating the resultant force and moment acting in the body due to all the influences. Thus, STAR CCM+ also solve the governed equation of the rigid body motion to find the new position of the rigid body motion. In order to stimulate the forces on the hull, there are several physic models to be activated. The uses of Volume of Fluids (VOF) is to have the behavior of the two fluids which are water and air in the same continuum. The effects of gravity acting on the ship was used in the Gravity model. Furthermore, K-Epsilon model is used for the effect of turbulence on the fluids. The Eulerian Multiphase model is activated for the two fluids in different phase. Below is the sequence of the set-up physic model.

- Setting up the model
- Setting the material properties
- Selecting 6DOF Motion model
- Setting the body initial coordinate system
- Creating the 6DOF body
- Defining the VOF waves
- Setting initial condition
- Setting the boundary condition
- Setting Up Solver Parameters and Stopping Criteria
- Creating the Free Surface Iso-surface
- Creating a Custom Colormap
- Creating DFBI Displayers
- Exporting Images for Scene Animation
- Initializing and Running the Simulation
- Visualizing the Results



### 3.2 RESEARCH FLOW PROCESS



*FIGURE 12: Research Flow Process*

### 3.3 KEY MILESTONE FYP 1

TABLE 4: Key Milestone FYP 1

WEEK 1	<ul style="list-style-type: none"><li>• Survey the Suitable Project Title</li><li>• Project Title Selection</li></ul>
WEEK 2	<ul style="list-style-type: none"><li>• Project Title Confirmation</li><li>• First Meeting with Supervisor</li></ul>
WEEK 3-6	<ul style="list-style-type: none"><li>• Data Gathering regarding Topic</li><li>• Carry out the Extended Proposal</li><li>• Submission of Extended Proposal</li></ul>
WEEK 7-9	<ul style="list-style-type: none"><li>• Preparation of Proposal Defense</li><li>• Presentation of Proposal Defense</li></ul>
WEEK 10-11	<ul style="list-style-type: none"><li>• Improvement of Extended Proposal</li><li>• First Draft of Interim Report</li></ul>
WEEK 12	<ul style="list-style-type: none"><li>• Submission of Pre-Interm Report</li></ul>
WEEK 13-14	<ul style="list-style-type: none"><li>• Interim Report Submission</li></ul>

### 3.4 KEY MILESTONE FYP 2

TABLE 5: Key Milestone FYP 2

WEEK 1-7	<ul style="list-style-type: none"><li>• Design Simulation</li><li>• Analyse Data</li></ul>
WEEK 8	<ul style="list-style-type: none"><li>• Progress Report</li></ul>
WEEK 9	<ul style="list-style-type: none"><li>• Amendment Progress Report</li><li>• Poster Preparation</li><li>• Pre SEDEX</li></ul>
WEEK 10-11	<ul style="list-style-type: none"><li>• Preparation of Draft Report</li></ul>
WEEK 12	<ul style="list-style-type: none"><li>• Submission of Dissertation (Soft Bound)</li></ul>
WEEK 13	<ul style="list-style-type: none"><li>• Submission Technical Paper</li></ul>
WEEK 14	<ul style="list-style-type: none"><li>• Oral Presentation VIVA</li><li>• Preparation for VIVA</li><li>• Submission of Dissertation (Hard Bound)</li></ul>

### 3.5 GANTT CHART FYP 1

TABLE 6: Gantt Chart FYP 1

NO	ACTIVITIES	DURATION													
		MAY			JUNE				JULY				AUGUST		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
<b>1</b>	<b>Selection Project Title</b>														
	Survey the relevent topic for FYP	█													
	Choose FYP topic		█												
	Meeting with Supervisor		█												
<b>2</b>	<b>Preliminary Research Work and Data Gathering</b>														
	Collect the relevent books, journals and articles		█	█	█	█									
	Understanding the problem statement			█											
	Identify the objective of the project			█											
	Filter and sorting data the critical literature review				█										
	Choose the suitable methodology				█										
	Preparation of extended proposal				█	█									
<b>3</b>	<b>Familiarize with the Software Star CCM+</b>														
	License registration				█										
	Software installation				█										
	Understanding the basic knowledge of software					█	█	█	█	█	█				
	Run a basic simulation										█	█	█	█	█
<b>4</b>	<b>Submission of Extended Proposal</b>														
	Submit to supervisor and coordinator						█								
<b>5</b>	<b>Proposal Defense</b>														
	Preparaton of slide for proposal defense							█							
	Presentation of proposal defense								█						
<b>6</b>	<b>Interim Report</b>														
	Improvement of extended proposal									█	█	█	█		
	Submission of Pre-Interim Report													█	
	Submission of Pinterim Report														█

### 3.6 GANTT CHART FYP 2

TABLE 7: Gantt Chart FYP 2

NO	ACTIVITIES	DURATION													
		SEPTEMBER			OCTOBER				NOVEMBER				DECEMBER		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
<b>1</b>	<b>Progress Report</b>														
	Research work continue	█	█	█	█	█	█	█	█						
	Design the simulation	█	█	█	█	█	█	█							
	Analyze the data				█	█	█	█							
<b>2</b>	<b>Pre SEDEX</b>														
	Amendment of Progress Report								█	█					
	Preparation Poster									█					
	Poster Presentation										█				
<b>3</b>	<b>Submission of Draft Report</b>														
	Amendment of report based on comment of poster											█			
	Improving the data analysis											█			
<b>4</b>	<b>Submission of Dissertation (Soft Bound)</b>														
	Amendment of Draft Report												█		
<b>5</b>	<b>Submission Technical Paper</b>														
	Preparation of technical paper													█	
<b>6</b>	<b>Oral Presentation VIVA</b>														
	Preparation for VIVA														█
<b>7</b>	<b>Submission of Dissertation (Hard Bound)</b>														
	Submission of Dissertation Report														█

## CHAPTER 4

### RESULTS AND DISCUSSION

The expected results are based on the analysis of several past research paper done by the researcher. There are a lot of researcher that have done various of numerical studies and experiment regarding the gap resonance between two floating bodies. Some of them just used general floating bodies visualising with two distinct size of boxes without a specified type of floating bodies such as FPSO and shuttle tank as per this paper aims to.

The arrangement of floating bodies that have been decided to be focused on is the arrangement of side by side floating bodies which is the shuttle tank that located side by side with the FPSO during the offloading operation. As mentioned by the Li and Zhang (2016), the arrangement can be visualising as Figure 13 below which the  $L$  indicates the gap of the distance between two floating bodies. The  $B$  indicates the width of the floating bodies and  $D$  denoted as draft of the two floating bodies.

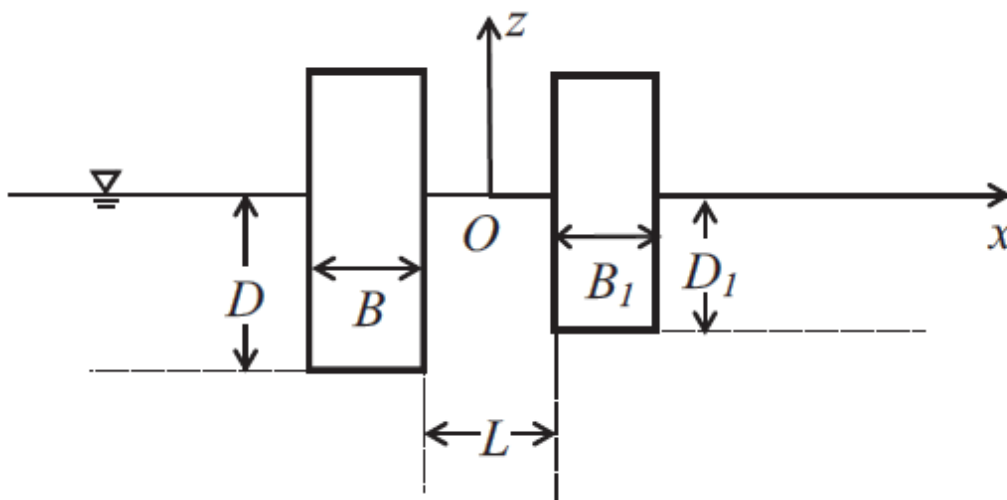


FIGURE 13: Arrangement of two floating bodies (Li & Zhang, 2016)

## 4.1 THE RESONANCE FREQUENCY BASED ON RAO

According to the Li and Zhang (2016), the resonance frequency is when the ROA is at its maximum values. They decided to excite the barge with six different frequency,  $\omega$  which near to the  $\omega_0=0.75$  and it is shown that when the frequency,  $\omega$  gets closer to the  $\omega_0$ , the ROA is getting its maximum value which is around 0.75 as per value of  $\omega_0$  as shown in Figure 14 below.

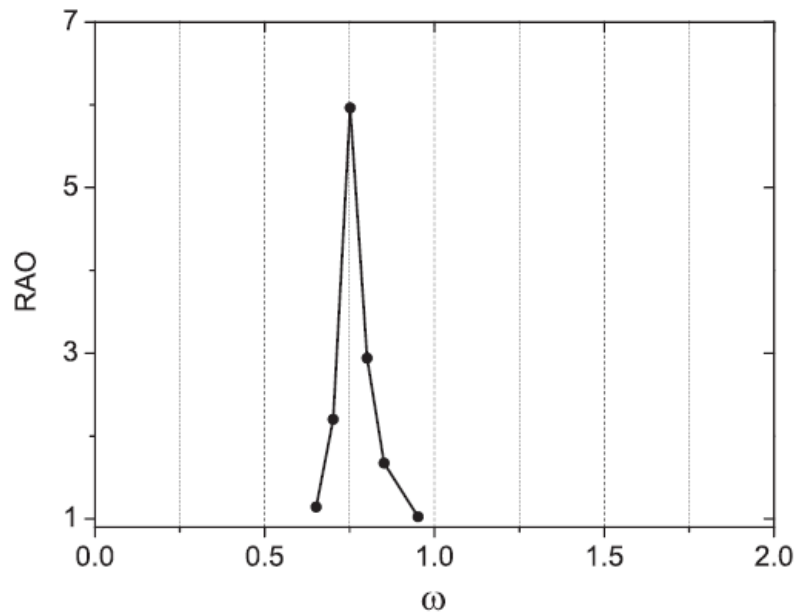


FIGURE 14:ROA with different frequency (Li & Zhang, 2016)

Based on that, it is expected that in this numerical study for the gap resonance of FPSO and shuttle tank in side by side arrangement, the resonance frequency occurs when the RAO is in the maximum value.

## 4.2 THE INFLUENCES OF BODIES DRAFT ON THE GAP RESONANCE.

The difference of draft height will give a significant effect to the gap resonance. According to Moradi et. al (2015), the resonance wave height will increase when the draft of the two floating bodies increases. As mentioned by Lu et. al (2011), the resonance is in a high frequency when the draft of floating bodies is decreasing. Regardless the shape of the corner of the floating, the resonance frequency will be

decreasing as the draft bodies increased as shown in Figure 15(Moradi et. al, 2015). The same results also shown in the Li and Zhang (2016) paper which mentions that as draft bodies increase, the resonance frequency will decrease dramatically.

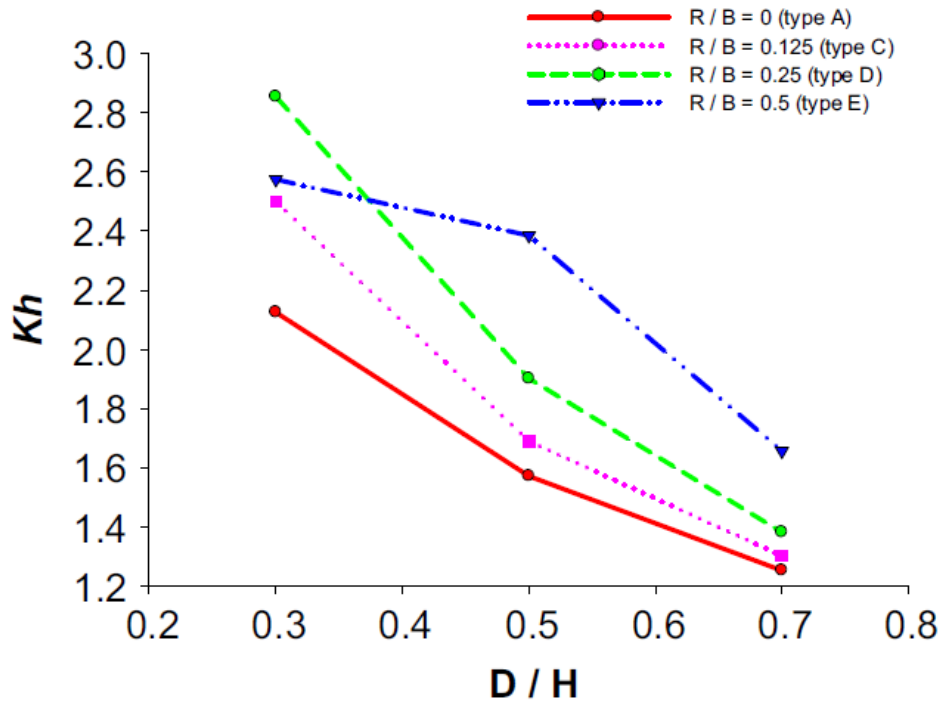


FIGURE 15: Graph Resonance Frequency against Body Draft (Moradi et. al, 2015)

Thus, in this study, it is expected that in order to get the result is when the increment of body draft of the FPSO and shuttle tank, it will be causing the resonance frequency to be decreasing dramatically as shown in the previous study.



### 4.3 THE INFLUENCES OF DISTANCE BETWEEN TWO FLOATING BODIES ON GAP RESONANCE.

The distance between two floating bodies are also one of the factor that influence the resonance in the gap. As results in the paper of Li and Zhang (2016) shows that the increasing of the distance between two floating bodies, the resonance frequency will decrease. In the Figure 16 below, it is shown that two types of dominant resonant which are piston-type resonance ( $\omega_0$ ) and the sloshing-type resonance ( $\omega_2$ ) that decreases as the distance of two floating bodies increases. The same results also were achieved in the simulation done by Moradi et. al (2015) which focuses on the rounded corner bodies that the resonance frequency decreases when the gap width increases. For the sharp corner bodies, the same result will also be achieved which experiment is done by Saitoh (2006).

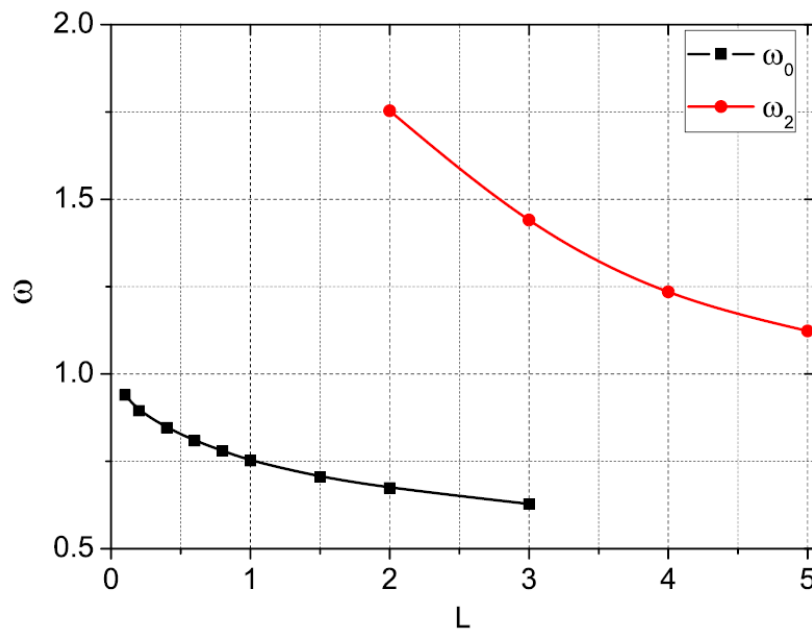


FIGURE 16: Resonance Frequency against Distance between two bodies (Li & Zhang, 2016)

Based on those studies, it is expected that in this study for FPSO and shuttle tank, the resonance frequency in the gap will be decreasing as the distance between FPSO and the shuttle tank increases during the side by side arrangement.

## 4.4 THE CHALLENGES IN OBTAINING THE EXPECTED RESULTS.

During the past eight months in conducting this project, the author did not manage get the simulation results as per expected results as mentioned above. There are several challenges that had to be faced by the author which lead to not having the results as expected. The challenges can be outlined as below:

### 4.4.1 License Identification

This problem occurred in the earlier days as the author wanted to start the simulation. The author tried opening the program, Star CCM+ but unfortunately an error had occurred. This license had a unique pattern where the licence can only be obtained if it is connected to a specific internet connection and in this case, it is UTP's internet connection. This error was due to the current server unable to connect with Star CCM+ server. The author had gone to seek advise from Mr Fazli from UTP High Performance Cloud Computing Centre (HPC3). Mr Fazli explained that the server was unable to make a connection because of the slow internet connection the author was experiencing. Thus, resulting to error in executing the simulation as shown in Figure 17 below.

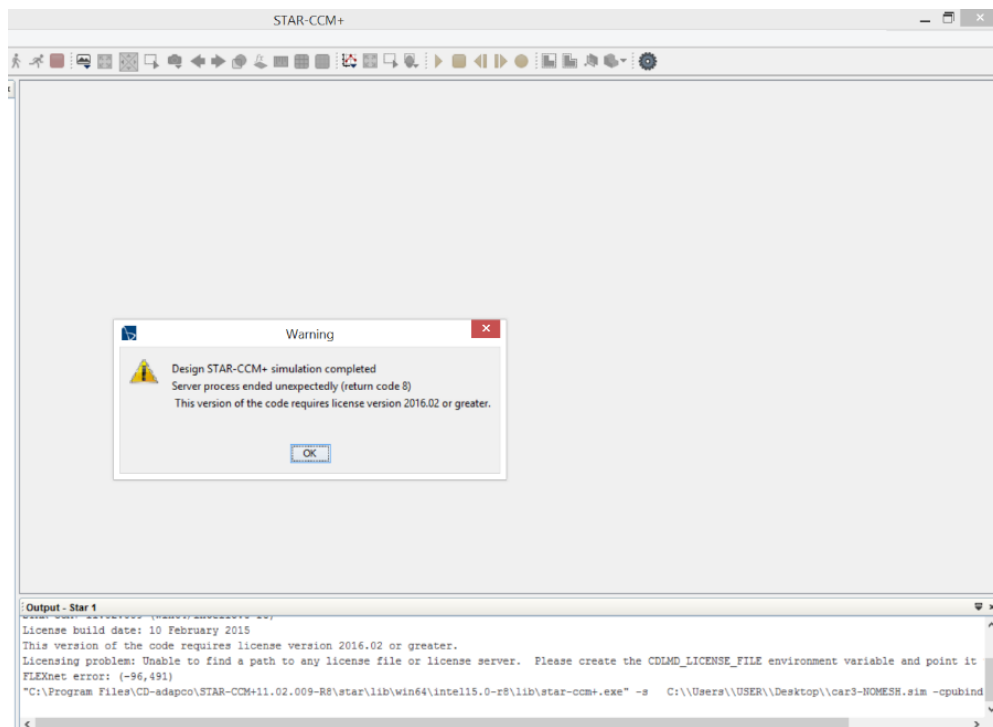


FIGURE 17: License Error

To overcome this problem, the author had to go and find a place that offers a stronger internet connection inside the area. The author was able to find a very strong and stable internet connection inside the Information Resource Centre (IRC) and find out that the simulation was able to be performed there. Therefore, the author had concluded that in order to obtain maximum efficiency in completing the simulation, the author had to be connected with IRC's internet connection.

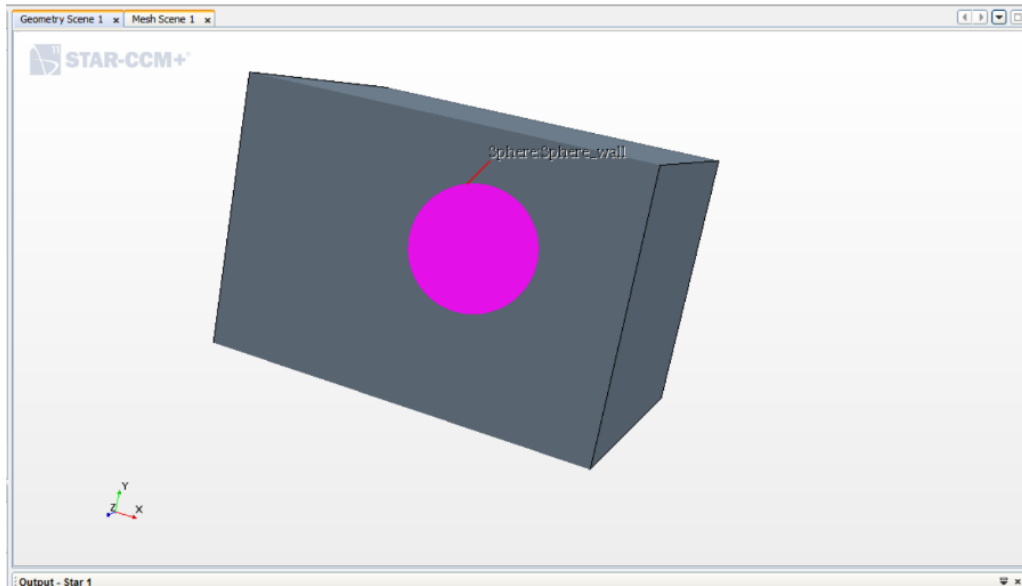
#### **4.4.2 Designing the geometry design**

The author had difficulties in building a shape of the FPSO and the shuttle tank. The challenges came when the author was unable to resolve two shapes from two-dimension design to a three-dimension design. The author tried using AutoCAD as the file from AutoCAD can be imported to the Star CCM+ program. However, the process in building the FPSO and shuttle tank design in AutoCAD also requires a lot of time and a lot of expertise that the author was lacked.

In order to overcome this problem, the author decided to change the shape of the FPSO and shuttle tank to a rectangular shape design. This decision was made by the author after a lot of consideration and reading through the previous technical paper. Most of the studies conducted similar to this project was using a rectangular shape to execute the simulation.

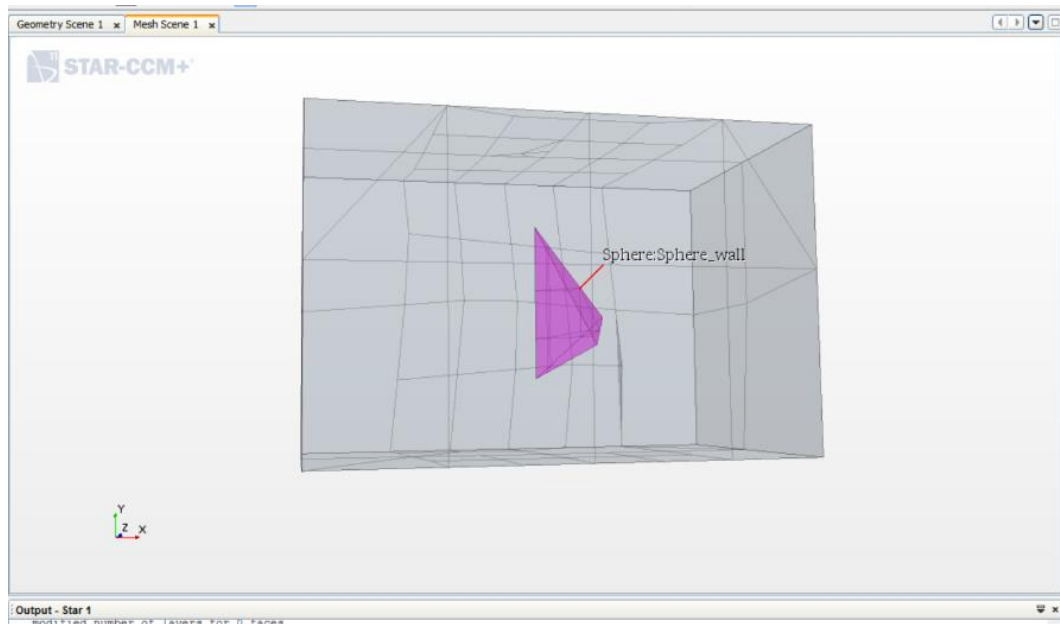
#### **4.4.3 The Meshing Period**

After obtaining the required topology, meshing had to be done to transfer the continuous models and equation into a discrete counterpart. Meshing had to be done in two types which are the surface meshing and the volume meshing. The surface meshing was able to be executed by the author without any technical problems occurring however the volume meshing was a different story.



*FIGURE 18: Surface Meshing*

When the author tried to do volume meshing the shape that turned out was not the same as the shape what was built before. For example, in Figure 18 the surface meshing showed a sphere shape topology however after executing the volume meshing the shape turned into a pyramid shape (Figure 19).



*FIGURE 19: Volume Meshing*

Then the author was able to identify the source of the problem which was the size of the cell. The original size of cell was 0.001 metre which was eventually too small for the volume meshing to occur. Although the correct size of cell was only obtained after

a few trials and errors by the author. The author was able to find a matching size of cell with the topology which was 1 metre.

#### 4.4.4 Physic Model

The crucial part of the simulation is performing the physic model to the simulation. Physic model is where the author will be able to test the waves flow between two floating bodies in terms of gap resonance and the draft. There are a lot of physic model in Star CCM+ that can be use accordingly. The author had a occur problem whereas the graph for the wave simulation in the physic model was unable to be obtained. The wave was shown in the simulation, but the graph indicates error. The program reads that the floating-point exception was invalid and cannot be identified as shown in Figure 20 below.

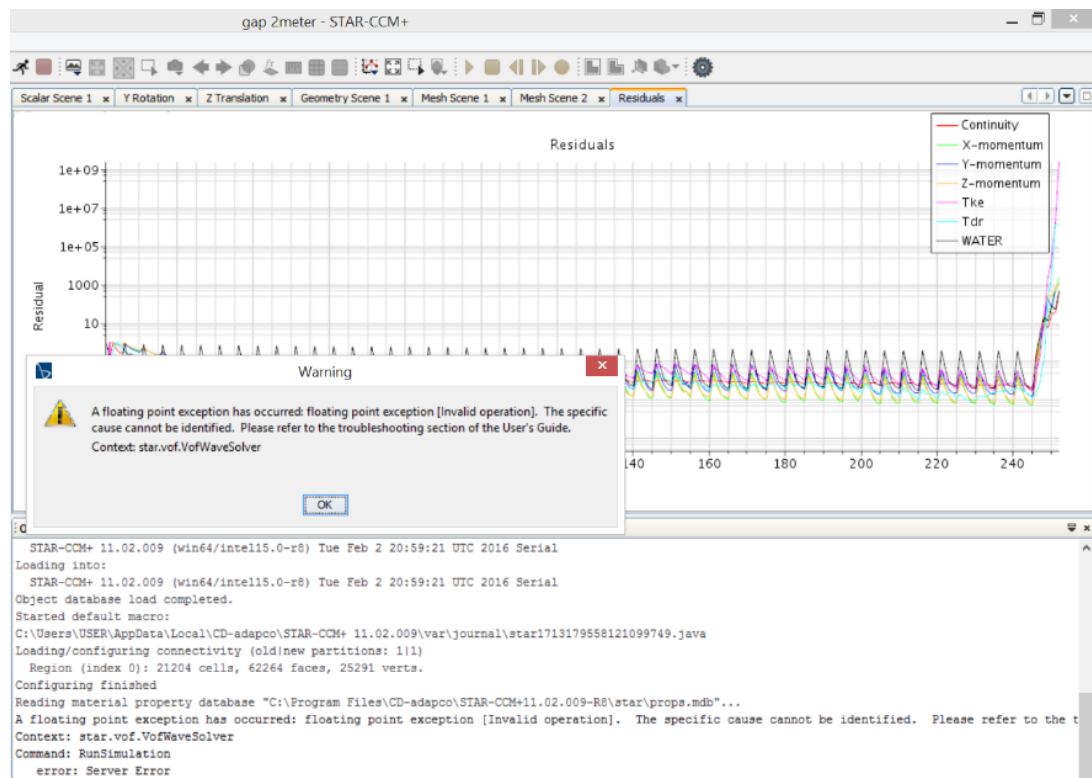


FIGURE 20: Physic Model Error

After a few trials, the author was still unable to find the correct physic model to be used for this project. The author also tried to identify the problem that occurred with the current physic model thus no solution was able to be identify.



FIGURE 21: Graph for Y-Rotation

From the Figure 21, the graph shown was the Y-rotation movement of the waves. As you can see no movement was able to be identified in the graph shown. The graph functions to identify the movement of waves in the Y- rotation in terms of integer. Same as what is happening in Figure 22 whereas a graph should have been shown to indicate the movement of mesh waves in the Z-translation.

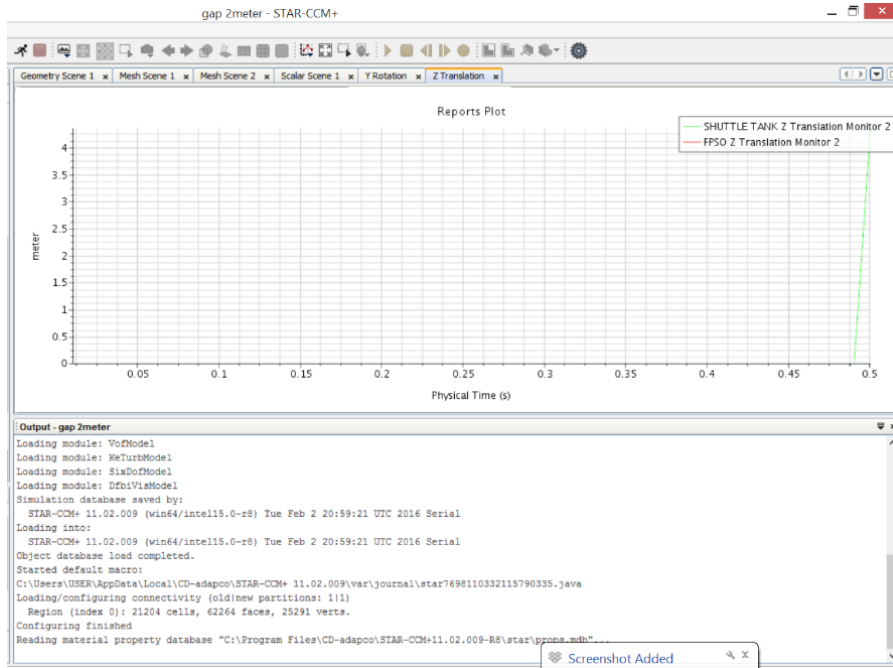


FIGURE 22: Graph of Z-Translation

On top of that, the author was also unable to identify the correct physic model to be used to identify the gap resonance between two floating bodies. Therefore, due to lack of time and expertise the author was unable to continue with the project. The author had sought advice from the Star CCM+ hotline and forums, however none was able to give a positive feedback to the author regarding this project.

## CHAPTER 5

### CONCLUSION AND RECOMMENDATION

In the conclusion, the objectives of this study were not achieved through out the simulation in the Star CCM+ software. The FPSO and shuttle tank cannot be constructed in the software and the program was unable to be run to obtain the results due to lack of expertise regarding the software. Due to the inability to obtain the expected results, the author was unable to compare the results with other research papers.

The results of this study should be able give a significant impact to the oil and gas industry if the simulation had been done successfully. As known to the world, oil and gas industry is one of the important industry that giving a lot impact to the economics of a nation or country. Even though the oil prices keep in fluctuates and are not in a stable state, the production of LNG or petroleum are still ongoing. Thus, the offloading operation still operates as usual. Offloading operation is one of the important operation because its transfer the LNG or petroleum from the platform to carry onshore. If the offloading operation fails, the oil and gas company will experience a huge loss.

Allegedly at the end of this study, the author aims to achieve the exact minimum gap for the arrangement side by side of FPSO and shuttle tank as well as the draft of these floating bodies. This result should have help to increase the effectiveness of the offloading operation. This is due to the gap resonance that had already indicates, and all the counter-measure can be prepared in order to overcome the resonance which will increase the wave height that can disturb the arrangement of the FPSO and shuttle tank during the offloading operation. Besides, the safety during the operation also will increase as well due to the extra indication known from this study.

This study was supposed to help the oil and gas industry in achieving a more efficient and Thus, the simulation was unable to be completed by the author. This is due to the lack of expertise of the author regarding the software and also few problems indicated above. The author suggested the software to be more user friendly and more training should have been provided to ease the understanding regarding the software. On top of that, guidance and tutorials should have been listed to ease the flow of the study as the time for the author to execute the project is limited. The license should not have



been restricted to a specific zone as that will reduce the efficiency of work flow as the author is restricted to a specific time and place. Apart done through the simulation, the gap resonance also can be known throughout the experimental in the laboratory.

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