NUMERICAL MODELLING FOR HYDRODYNAMIC BEHAVIOR OF ROUND SHAPE FLNG INTERACTING WITH LNG CARRIER

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Specially dedicated to

My beloved family

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ABSTRACT

The diffraction potential theory is an efficient and accurate method to predict the hydrodynamic characteristic of a large floating structure. However, this theory under-estimates the damping coefficient as the viscous effect is ignored. This weakness causes the diffraction potential theory to be less accurate in predicting the motion of floating structure in damping dominant region. Therefore, this research aims to propose a method to improve the estimation of hydrodynamic characteristic of free floating round shape Floating Liquefied Natural Gas (FLNG) carrier when it is alone and when it is interacting with another structure which is arranged in parallel head-sea condition. The proposed method was developed by modifying the diffraction potential theory and improving with the application of drag equation. The proposed method was also further developed by using motion's energy dissipation concept and Huygens Principle to predict the influence of wave generated by the motion of nearby structure to the response amplitude operator (RAO) of the FLNG. To validate the proposed method, motion experiments in regular wave were conducted in selected conditions. Comparative study was also conducted by using FLNG's RAO result predicted by ANSYS AQWA software. Over-estimation of peak heave RAO of single FLNG case is reduced from 2.42 to 1.74 by the proposed method as the method considered the viscous damping in its calculation. In interaction cases, the peak heave RAO is increased to 2.1 due to the effect of radiating waves. Besides, the interaction effect also induces sway and roll motion. The peak sway RAO estimated by both proposed method and experiment is around 0.22. The interaction effects on heave RAO and roll RAO are stronger around the motions' natural period as the damping coefficients are reduced around motion natural period. The research results showed that the proposed method improved the accuracy of the simulation by reducing the amount of over-prediction on the floating structure's RAO in damping dominant region.

ABSTRAK

Teori Keupayaan Belauan adalah cara yang cekap dan tepat untuk meramal ciri-ciri hidrodinamik bagi struktur terapung yang besar. Tetapi, teori ini kurang menganggarkan pekali redaman kerana mengabaikan kesan likat. Kekurangan ini menyebabkan teori Keupayaan Belauan tidak dapat meramal gerakan struktur terapung dengan tepat pada rantau dominan redaman. Oleh itu, kajian ini bertujuan untuk mencadangkan kaedah untuk menganggarkan ciri-ciri hidrodinamik FLNG berbentuk bulat dengan lebih tepat apabila ia bersendirian dan berinteraksi dengan struktur lain yang disusunkan secara selari dan berhadapan dengan ombak. Kaedah yang dicadangkan mengubahsuai teori Keupayaan Belauan dan memperbaikinya dengan menggunakan persamaan seret. Kaedah ini juga dimajukan dengan menggunakan konsep kehilangan tenaga disebabkan pengerakan struktur dan prinsip Huygens untuk meramalkan kesan daripada ombak yang dihasilkan oleh pergerakan struktur berdekatan dengan FLNG kepada RAO FLNG. Untuk mengesahkan kaedah yang dicadangkan, eksperimen pengerakan struktur disebabkan oleh ombak tetap telah dijalankan dalam keadaan yang terpilih. Perbandingan juga dilakukan dengan mengunakan hasil pengiraan RAO FLNG daripada ANSYS AQWA. Lebihan anggaran pada puncak RAO arah *heaving* bagi kes FLNG bersendirian dikurangkan daripada 2.42 ke 1.74 dengan kaedah yang dicadangkan apabila mengambil kira kesan likat. Pada kes interaksi, puncak RAO arah *heaving* meningkat kepada 2.1 kerana kesan radiasi ombak. Kesan interaksi juga menghasilkan pengerakan struktur pada arah *swaying* dan *rolling*. Puncak RAO arah *swaying* yang dianggarkan oleh kaedah yang dicadangkan dan eksperimen ialah sekitar 0.22. Pengaruh kesan interaksi pada RAO arah *heaving* dan RAO arah *rolling* adalah lebih besar di sekitar tempoh semula-jadi gerakan struktur kerana pekali redaman menjadi rendah. Keputusan kajian ini menunjukkan bahawa kaedah yang dicadangkan telah memperbaiki ketepatan simulasi dengan mengurangkan jumlah lebihan anggaran RAO struktur terapung pada rantau dominan redaman.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	-	Alternative Current
ANSYS	-	American Computer-aided engineering software
ANSYS AQWA	-	Diffraction Product of American Computer-aided engineering software
ANSYS CFX	-	Computational Fluid Dynamics software of American Computer-aided engineering software
CFD	-	Computational Fluid Dynamics
CLEAR-VOF	-	Computational Lagrangian-Eulerian Advection Remap-Volume of Fluid
DoF	-	Degree of Freedom
FLNG	-	Floating Liquefied Natural Gas
FPSO	-	Floating Production Storage and Offloading
HOBEM	-	Higher-Order Boundary Element Method
KVLCC2	-	Korean very large crude carrier 2
LNG	-	liquefied natural gas
NRIFE	-	National Research Institute of Fisheries Engineering, Japan
NWT	-	numerical wave tanks
RAO	-	Response Amplitude Of Operation
WAMIT	-	Wave Analysis frequency-domain, free-surface, radiation/diffraction code developed at Massachusetts Institute of Technology

LIST OF SYMBOLS

A		Added mass
A_{ij}	-	Added Mass in direction *i* due to motion in direction *j*
A_{Proj}	-	Projected Area
a_n, b_n, c_n	-	Constant of parabolic curve *n* used to represent curve of wave crest
$(\bar{a}, \bar{b}, \bar{c})$	-	Coordinate
A_w	-	Water plane area
B		damping coefficient
B_{ij}	-	Damping Coefficient in direction *i* due to motion in direction *j*
b_p	-	Radiating damping coefficient
C	-	Restoring force
C_a	-	Added mass coefficient
C_D	-	Drag coefficient
C_M	-	Mass coefficient
$C_{stP,n}$	-	Intersection position between two connecting strip
D	-	Diameter
Dd, D_{mn}	-	Normal dipole
d_S	-	Distance the steal block shifted
E_d	-	Dissipated Energy
E_f	-	Energy flux
E_W	-	Wave energy over a wave crest
$E_{W\,i,j}$	-	Wave energy due to the motion *j* in *i*-direction
F_D	-	Drag force
F_j	-	Wave exciting force in direction *j*
F_p	-	Diffracting force

$F_{i;n}^{P}$	-	Radiating wave force acting on the structure *P* to induce motion in *i*- direction due to the motion of nearby structure in stage *n*
$F_{i;Tot}^{P}$	-	Total wave force due to incident wave force and interacting wave force acting on the floating structure *P* inducing the motion in direction *i*.
$F_{(P,i;Q,j)}$	-	Wave force acting on the structure *P* in direction *i* due to the radiating wave generated by structure *Q* in the motion direction *j*
$F_{(P,i;Q,j)}^{S,n}$	-	Wave force acting on structure *P* to induce the motion in direction *i* due to the motion of structure *Q* in direction *j* in stage *n*
$F(t)$	-	Periodic function
$F(f)$	-	Frequency series motion or wave data
f_j	-	Average distribution force in motion direction *j*
$f(t)$	-	Time series motion or wave data
$G(\bar{P};\bar{Q})$	-	Green Function
$\overline{GM_B}$	-	Distance of centre of gravity to centre of transverse direction moment
$\overline{GM_L}$	-	Distance of centre of gravity to centre of moment in longitudinal direction
$G_W(\bar{P}_m,\bar{Q}_n)$	-	Green surface wave
g	-	Gravitational acceleration
h	-	Water depth
Im	-	Imaginary number
i	-	Complex number
$\boldsymbol{J_n}$	-	First kind of Bessel function in order n
K, k	-	Wave number
KE	-	Kinetic Energy
k_{xx}	-	Radius of gyration in x direction
k_{yy}	-	Radius of gyration in y direction
K_{zz}	-	Radius of gyration for Z direction
L	-	Overall length of floating structure

l_{Crest}	-	Length between wave crest
	-	
l_{Nor}	-	The distance of the panel from origin of segment plane following the panel normal direction
$l_{mp,m}$	-	Position of the panel *m* projected to the segment plane
$l_{p0,n}$	-	The distance of the segment plane from origin following the plane normal direction
l_{rad}	-	Distance propagate by radiating wave
$l_{st,n}$	-	Length of the strip at the segment
$M_{i,j}$	-	Moment due to motion *j* in direction *i*
$m_{Nor,n}$	-	Normal direction of strip *n*
$m_{Tang,n}$	-	Tangent direction of strip *n*
$m_{st,n}$	-	Angle of strip *n*
N	-	Total number of element
n	-	Element number
n_j	-	Unit Normal Vector respect to *j* direction
$n_{st,n}$	-	Area normal vector of the strip *n*
$\vec{n}$	-	Unit normal vector of area
P_d	-	Dynamic pressure
$\bar{P}$	-	Field Location
PE	-	Potential Energy
$\bar{Q}$	-	Source Location
$\mathcal{R}$	-	Radius of wavelet
r, R	-	Horizontal distance
R_0	-	Real part of wave term
R_1	-	Derivative of R_0
$Rt_{i,j}$	-	Ratio of moment in direction *j* cause by the force in direction *i* to total moment in direction *j*
Re	-	Real number
S	-	Surface Area
S_B	-	Seabed surface
S_{cST}	-	Total length of first radiating wave crest
S_{cPT}	-	Total length of radiating wave crest at location *P*

$S_{cP,n}$	-	Length of radiating wave crest represent by strip *n* at location *P*
$S_{cS,n}$	-	Length of first radiating wave crest represent by strip *n*
S_F	-	Free surface area
S_H	-	Wet surface area of floating structure
S_∞	-	Boundary located in the infinity distance
Ss, S_{mn}	-	Source
$\mathcal{T}$	-	Draught of floating structure
T	-	Period
t	-	Time
$u(t), u(x,t)$	-	Time dependent fluid particle velocity
$\dot{u}$	-	Horizontal fluid particle velocity
V_{max}	-	Magnitude of complex fluid particle velocity
W_S	-	Total weight of the model
w	-	Circular frequency of incident wave *(2π/T)*
$\dot{w}$	-	Vertical fluid particle velocity
w_B	-	weight of steel block
X_j	-	The motion of structure in direction *j*
$\dot{X}(t)$	-	Time dependent floating structure velocity
$\dot{X}_z$	-	Floating structure velocity in Z direction
$\ddot{X}_z$	-	Floating structure acceleration in Z direction
(x, y, z)	-	Coordinate
(x_P, y_P)	-	Field coordinate
(x_S, y_S)	-	Source coordinate
$(x_{st,n}, y_{st,n})$	-	The coordinate of the strip on the segment plane
$\bar{x}_{St,n}$	-	Area normal vector of the strip *n* in X-direction
$(\tilde{x}_G, \tilde{y}_G, \tilde{z}_G)$	-	Position of the center of gravity of model
$(\tilde{x}_p, \tilde{y}_p, \tilde{z}_p)$	-	Position of reflective optical tracking markers
$(x_{\psi S,n}, y_{\psi S,n})$	-	Connected coordinate of the strip segment plane
$\boldsymbol{Y_n}$	-	Second kind of Bessel function in order n
$\bar{y}_{st,n}$	-	Area normal vector of the strip *n* in Y-direction
z_a	-	motion amplitude in stage *n*
α, ϵ	-	Leading Phase

β	-	Incident wave propagation direction
ε_a	-	Relative error
$\tilde{\gamma}$	-	Floating model initial heading angle
λ	-	Wavelength
λ/D_{FLNG}	-	Ratio of wavelength to Round Shape FLNG's diameter
∇	-	Displacement floating structure
Φ	-	Complex Wave Potential
ϕ	-	Complex time independent Wave Potential
ϕ_j	-	Complex time independent Radiation Wave Potential in direction of motion j
ϕ_I	-	Complex time independent Incident Wave Potential
ϕ_S	-	Complex time independent Scattering Wave Potential
ϕ_R	-	Complex time independent Radiation Wave Potential
ϕ_R^S	-	Diffracted interacting wave potential due to motion of nearby floating structure
$\dot{\phi}_Z$	-	Fluid particle velocity in Z direction
ϖ	-	Solid angle
ρ	-	Fluid density
ϑ	-	Wave propagation direction
θ_{In}	-	Angle the model inclines
$\theta_{mp,m}$	-	Normal angle of panel *m*
$\theta_{Pn,n}$	-	Normal angle for plane *n*
$\theta_{Pt,n}$	-	Tangent angle for plane *n*
θ_{rad}	-	Direction of propagation of the radiating wave
$\tilde{\theta}_1$	-	Time dependent roll angle
$\tilde{\theta}_2$	-	Time dependent pitch angle
$\tilde{\theta}_3$	-	Time dependent yaw angle
ζ, ς_a	-	Wave amplitude
$\zeta_{a,i}$	-	Radiating wave amplitude due to motion in direction *i*
$\zeta_{a\ i,j}$	-	The wave amplitude due to the motion *j* in direction *i*

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

This chapter discusses the background, objectives, problem statement, and the scope of the research. Besides, the content of each chapter in this thesis is also briefly introduced at the end of this chapter.

1.1 Background of Study

Study on floating structure system is an important research topic in offshore industry. The floating structures are often used to explore natural resources in deep water area because fixed structures such as jacket structure is not applicable in deep water. The floating structures are allowed to move freely within the design limit when the motion of structures is induced by external force such as wave force, drift force, wind force and current force. Besides, the motion characteristics of the floating structures are also easily influenced by the hulls design and the arrangement of structures on sea surface. These motion characteristics would be affected when the floating structures interact with each other on sea surface.

Interaction between floating structures becomes an important research topic especially on the study of the Floating Liquefied Natural Gas Storage (FLNG) offloading system design. This is because the gap between the FLNG with tanker ship is one of the important criteria to determine workability of the offloading system and the success of fluid transfer. To transfer liquefied natural gas (LNG), the distance between the storage tank and shuttle tanker should be as close as possible in order to reduce the amount of LNG boil off when the LNG is transferring from FLNG to the tanker ship. In recent development, it is suggested that the shuttle tanker has to be arranged side by side with the storage tank so that the pipe length can be minimised. Due to the close distance between floating structures, accurate prediction on the Response Amplitude Operator (RAO) of each structure in a multiple floating structures system are important to ascertain the safety of the structures' arrangement. In general, this study will concentrate on the dynamic motion interaction between floating structures which is used to extract natural gas in deep water area.

As mentioned above, the environmental condition is one of the obstructions in limiting the arrangement of floating structures in the offshore system. Due to effect of wave, current and wind, motions of the floating structures are difficult to predict. In this research, only the influence of first order wave forces to the motion of floating structure was studied because it is a significant factor in inducing the motion of floating structures. According to Ali et al. (2010), the external force acting on the single floating structure is only caused by incident wave in single floating structure system. However, the study of the wave load on the multiple floating structures becomes more complicated as the total wave force acted to the floating structures is the summation of the force from incident wave, the scattering wave from nearby structures and radiating wave due to the motion from nearby structures. This situation increases the complexity of the system and calls for a comprehensive study.

In previous research on hydrodynamic interaction, the studies on the interaction between floating structures focused on the wave drift force and motion response due to the interaction effect. From the research conducted by Ali et al. (2010), the outcome showed that the interaction between multiple floating structures causes the motion response to become higher due to the extra radiating wave force transferred from one floating structure to the nearby floating structures. The observation was evaluated and proved by many researchers through their experimental studies or numerical simulation. However, there are still weaknesses from the numerical method used in the previous research. For example, some of the mathematical models to simulate the effect of hydrodynamic interaction are not applicable for the study of the structures arrange with a very small gap distance. This is because some of the proposed mathematical models applied Bessel function to simulate the wave propagation. Hence, if the condition could not satisfy the cylindrical coordinate function of Bessel function, the result gained may be incorrect. This problem was raised by Kashiwagi (2008); Kashiwagi and Shi (2010) in their research on comparing the wave interaction theory to their Higher-Order Boundary Element Method (HOBEM). The horizontal wave force they calculated using the theory shows consistent similarity with the result obtained from HOBEM. However, the different results were obtained from both of the theories for vertical wave force. To solve this problem, they applied the exact algebra method to their HOBEM method to allow their methodology works for multiple body interaction in very close gap.

Besides, most of the previous proposed methods were developed based on the potential theory. The diffraction potential theory executes the wave load on the floating structure by estimating the wave diffraction effect. In the potential theory, it is assumed that the viscous effect can be ignored in the calculation. This assumption causes the potential theory to estimate a lower damping coefficient for the motion of floating structures. The damping coefficient of the floating structure is under-predicted, causing the RAO of floating structures prediction to become higher than the actual value in damping dominant region. This weakness of the potential theory was reported by Loken (1981) and Lu et al. (2011). Regarding this problem, over-prediction of RAO by the potential theory is negligible if the natural frequencies of the motions are not in the range of the wave frequency which exists in the structure operating environment. However, if the natural frequency of the motion is within the range of the favour wave frequency, then accurate estimation on the floating structure’s RAO in the damping dominant region is required to ensure the safety of the floating structure.

Furthermore, the RAO of floating structures outside the damping dominant region can be predicted accurately as the diffraction potential theory is able to estimate the added mass and wave force of the floating structures correctly. From the motion equation, the motion of the floating structures in different wavelength depends on different factors as shown in Figure 1.1. Figure 1.1 shows the example of the heave RAO tendency curve in different length of wavelength for the cylinder structure. When the wavelength is much shorter than the structure length, the motion of floating structure is more dominated by the mass term of the structure. On the other hand, in very long wavelength region, the motion of floating structure is more dominated by the restoring force of floating structure. Typically, the motion response amplitude operator, RAO is equal to one in the region if the wavelength is much longer than the structure length. In the region where the wave frequency is near to the natural frequency of the motion of floating structure, the RAO of the floating structure is more dominated by the damping term. In this region, high resonance effect would be existed. The RAO in the damping dominant region becomes the peak response in the RAO tendency curve.

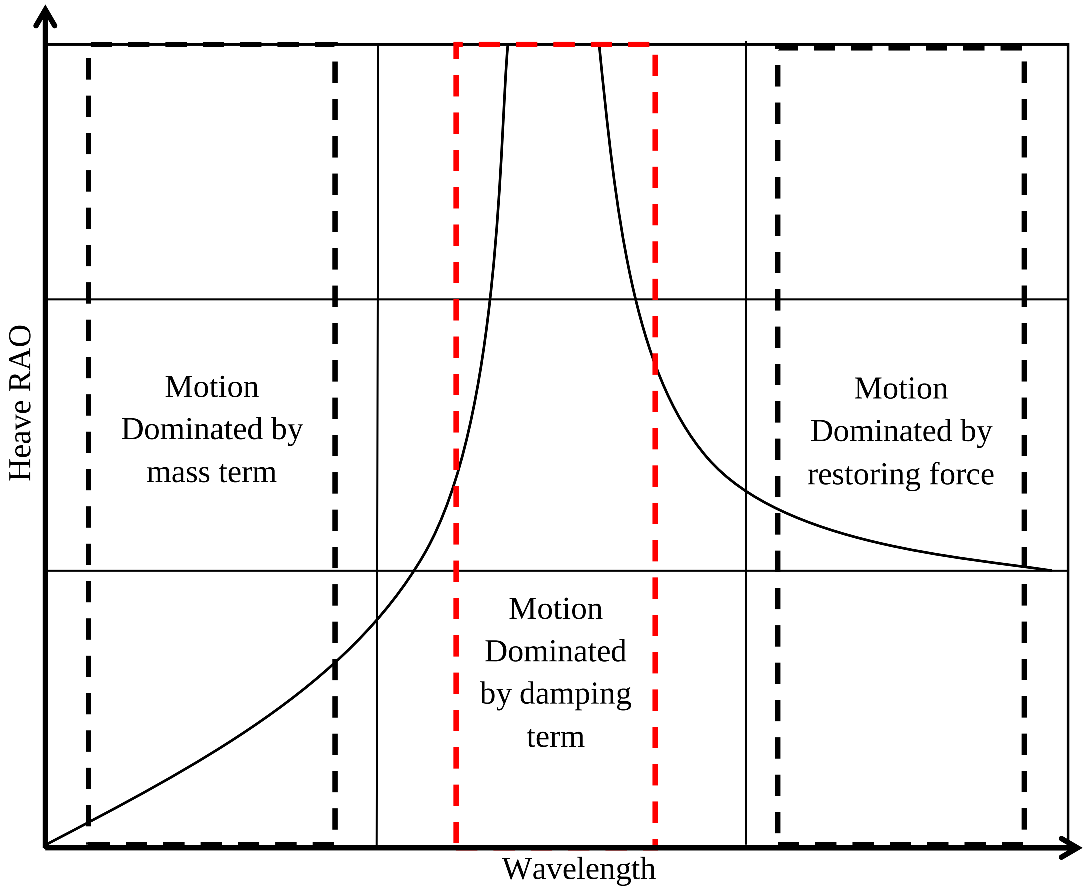

Figure 1.1 The dominant factor in influence the heave RAO of cylinder structure (Journee and Massie, 2001)

In this research, the new generation of round shape FLNG was selected for the study. The advantage of round shape FLNG over the traditional ship-shape FLNG was studied by Lamport and Josefsson (2008). Their research includes the comparison of motion response, mooring system design, constructability and fabrication, operability, safety and costing between both the structures. The study conducted by Lamport and Josefsson (2008) and Arslan et al. (2011) obtained that this new design of FLNG has a better hydrodynamic behaviour as compared to ship shape structure. Besides, oil and gas companies prefer the FLNG design because it has larger storage volume and larger area for topside facilities. Lamport and Josefsson (2008) also found that the round shape FLNG performed better than ship shape FLNG in these two important factors. Moreover, the simple hull shape for the round shape FLNG also helps to reduce the construction cost as simple hull structures are easier to construct.

Due to the innovative design of a new generation of FLNG technology, there is more freedom to arrange other floating structures around the FLNG. For example, the structure arrangements in the previous design are typically placed in a side by side arrangement or in a tandem arrangement due to the shape of the FLNG. Also, the direction of tanker and FLNG arrangement are respected to the wave propagation direction and cannot be changed during the offloading process. According to Lamport and Josefsson (2008), the round FLNG increases the flexibility of structure arrangement. The relative direction of shuttle tanker to the wave propagation direction is adjustable during the offloading process for a safer arrangement. To allow for horizontal rotations, the offloading system can be designed by utilizing an offloading reel station with the mooring hawser and hose attached on a pinned connection on a 90º trackline system at the periphery of the round shape FLNG. Therefore, the angle of arrangement for the Round Shape FLNG and shuttle tanker can be varied up to 180 degrees as shown in Figure 1.2. Hence, in this research, the study on the RAO of the round shape FLNG only focuses on cases where the structure is alone and the interaction of FLNG with shuttle tanker due to the effect of gap distance between floating structures.

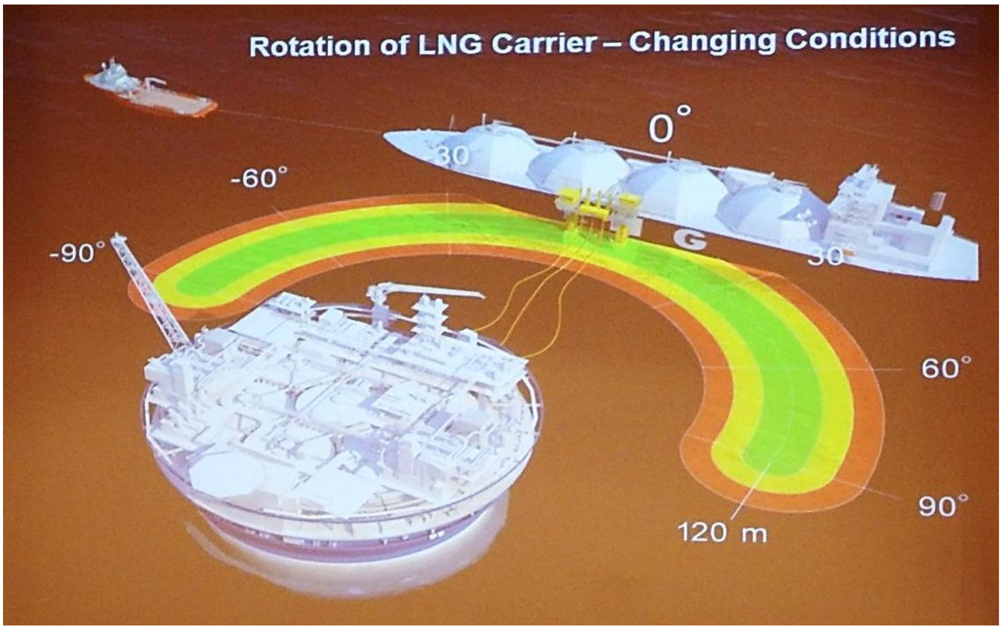

Figure 1.2 Allowance for the change of arrangement of LNG carrier during offloading process (Sevan Marine, 2014)

1.2 Problem Statement

Offshore industry often requests for an accurate and efficient numerical model to predict the behaviour of the floating structure. The numerical model should be able to estimate the dynamic motion of floating structure accurately either the motion is dependent by the mass term, restoring force term or damping term. The amount of over-predict or under-predict in the prediction of motion of floating structure by the numerical model should be minimized to avoid large difference in the motion of the floating structure observed during operating stage when compared to the numerical method result.

However, the current numerical model which has been developed based on the diffraction potential theory to estimate the damping coefficient of the floating structure also has its weakness. The theory ignores the viscous effect in estimating the hydrodynamic behaviour of floating structure, causing the under-estimation of damping coefficient predicted by the theory. This weakness causes the current numerical model to over-predict the motion of the floating structure significantly when the motion is dominant by the damping term. The over-estimation on the dynamic motion of floating structure in damping dominant region by diffraction potential theory causes the numerical model to be less accurate, and causes the hydrodynamic behaviour of floating structure difficult to predict by the numerical model in damping dominant region.

The inaccuracy of the current numerical model causes higher design cost and consumes longer time during floating structure design process. To predict the hydrodynamic behaviour of the floating structure in damping dominant region, model experiment test can be a good solution. However, the model experiment test is a costly and time consuming method to test the behaviour of floating structure. Therefore, the cost and time consumed to design the floating structure will increase because large amount of experiment test is required in estimating the motion of floating structure in damping dominant region. This is due to the weakness of the current numerical model in predicting the motion of floating structure in the damping dominant region.

According to Kvittem et al. (2012), the diffraction potential theory can predict the hydrodynamic behaviour of large floating structure accurately. This is because the effect of wave diffraction is significant when the incident wave interacts with large floating structure. When the motion of floating structure is dominant by the mass term or dominant by restoring force term, the motion of the floating structure estimated by the diffraction potential theory is close to the experiment result. However, the viscous effect is ignored by the diffraction potential theory, causing the motion predicted by the theory at damping dominant region to become over-estimated significantly. Based on the available literatures, the weakness of the diffraction potential theory as mentioned was also reported by Loken (1981) and Lu et al. (2011). Loken (1981) found that the diffraction potential theory would over predict the motion response of floating structure in damping dominant region due to under prediction of radiation damping by the theory. Besides, Lu et al. (2011) reported similar finding in their research when comparing the potential theory and viscous theory. They found that the viscous theory mostly under-predicts the wave force in the calculation while the potential theory over predicts the motion when the viscous effect is ignored in the approach of potential theory.

Since the diffraction potential theory is accurate in most regions, except in the damping dominant region, this research proposed to develop the numerical model based on the theory. To improve the numerical model develop based on diffraction potential theory, the numerical model applies drag equation to predict the viscous effect acting on the floating structure because the viscous effect is ignored by the diffraction potential theory. The drag equation is modified in this research. So, The additional viscous damping and linearize drag force calculated by using the modified drag equation can be combined with the radiation damping and radiating wave force estimated by using diffraction potential theory. The damping coefficients and the wave force estimated by both mathematical models are combined in the motion equation to calculate the dynamic motion of floating structure. Therefore, the motion of the floating structure when it is alone and when it is interacting with other structure was calculated by the new numerical model in this research to have a more accurate result regardless of the motion is dominant by mass term, restoring force term or damping term.

From the improvement made to the numerical model, offshore industry stands to benefit substantially from the new proposed numerical model which combines the diffraction potential theory with the drag equation to estimate the motion of floating structure. Through the improved the numerical model, the hydrodynamic behaviour of the floating structure can be predicted by numerical method with higher accuracy. As the motion of the floating structure in damping dominant region is important in designing the floating structure, the proposed numerical model is able to estimate the motion of floating structure with better accuracy. The amount of over-predict in the motion of floating structure can be reduced by the new proposed method. This proposed numerical model provides a better motion analysis method to the offshore industry and helps to reduce the cost and time consumed in designing a floating structure. This target can be achieved by reducing the amount of experiment test required to test the hydrodynamic behaviour of the floating structure.

Improving the accuracy of the numerical model to predict the hydrodynamic behaviour of floating structure is crucial to increase the reliability of the numerical solution to analyse the motion floating structure. The current numerical model is developed based on diffraction potential theory, which is accurate in predicting the motion of floating structure in most regions except the damping dominant region. In this research, the alternative numerical model proposed includes the viscous effect which was ignored by diffraction potential theory in estimating the hydrodynamic behaviour of the floating structure. Through this improvement, the proposed numerical model is able to estimate the motion of floating structure in all the regions of motion regardless of the motion is dominant by mass term, restoring force term or damping term. This is because the under-estimation of the damping coefficient by the diffraction potential theory is improved by introducing the drag equation to predict the viscous damping which is ignored by the diffraction potential theory.

1.3 Objective

To solve the problems mentioned in sub-chapter 1.2, three objectives of this research are listed as follow:

i. To propose a new estimation method of RAO of a single floating structure using diffraction potential theory and drag equation.
ii. To further propose the new method as mentioned in the first objective on estimation of RAO of the floating structure due to interaction with another structure using diffraction potential theory, Huygens principle, motions dissipate energy method and drag equation.
iii. To verify the propose method by conducting motion experiment in basin tank.

1.4 Scope of Research

i. To develop a method to simulate the motion behaviour of floating structures based on the diffraction potential theory.
ii. To improve the accuracy of the proposed method to simulate the motion behaviour of floating structures in damping dominant region based on the drag equation.
iii. To compare the accuracy of the proposed method to the established method in estimating the RAO of floating structures.
iv. To simulate the RAO of the round shape FLNG in the in regular wave condition.
v. To study the hydrodynamic behaviour of round shape FLNG in head sea condition.
vi. To study the hydrodynamic behaviour of round shape FLNG in moderate sea state ocean condition.
vii. To study the improvement on the accuracy of the floating structures' RAO predicted by the proposed method as compared to the established method using motion experiment result.
viii. To further develop the proposed method to simulate the effect of interaction between floating structures to the RAO of floating structures using the Huygens Principle and motion dissipate energy concept.
ix. To simulate the RAO of round shape FLNG when the LNG carrier is arranged closer to the FLNG during offloading process using the proposed method and motion experiment test.
x. To study the improvement of the accuracy of the predicted round shape FLNG's RAO when it is interacting with LNG carrier by comparing the results from the proposed method and the established method using experiment results.
xi. To study the effect of wavelength to RAO of round shape FLNG when the structure is interacting with other floating structures using the proposed method.
xii. To study the influence of LNG carrier to the RAO of round shape FLNG by comparing the RAO of FLNG when it is alone and when FLNG interacts with LNG carrier.

1.5 Research Question

To achieve the objectives of the research, the questions on the solution and factors required to consider so the target of this research can be achieved are stated in follow:

i. What is the factor influence the motion of floating structure?
ii. How the existing theories estimate the RAO of floating structure?
iii. What is the weakness of existing theories in order to predict the RAO of floating structure?
iv. How to develop a new method which can improve the accuracy of the numerical prediction on the RAO of floating structure?
v. How to simulate the RAO of the round shape FLNG in the selected ocean environment?
vi. What are the variables influence the motion of the floating structures when the structures are interacting between each other?
vii. How to develop a new method which can estimate the effect of interacting between the floating structures to the RAO of floating structures?
viii. What are the important factors must be considered in analyse the effect of interaction between floating structures to the RAO of floating structures?
ix. How to collect the RAO data which shown the real motion of the round shape FLNG when it is interacting with wave?
x. How to validate the proposed method and ensure it capability to apply in estimate the RAO of floating structure in selected environment condition?

1.6 Significance of Study

In this research, the 6 DoF RAO of new generation round shape FLNG were studied. To estimate the RAO of the round shape FLNG accurately, this research has developed a method to simulate the RAO of the selected floating structure. The proposed method is able to estimate the RAO of the floating structure within the selected ocean environment condition where the FLNG operates. The proposed method improves the accuracy of the simulation by reducing the amount of over-prediction on the floating structure's RAO in damping dominant region as compared to the result simulated by the existing established method. A more accurate estimation of the RAO in damping dominant region is important for the floating structure which the motion natural frequency of the structure is among the ocean environment condition of the structures designed to operate. Besides, the proposed method also improves the accuracy on simulate the RAO of floating structure when the structure is interacting with another floating structure in the motion damping dominant region. When the structures are arranged nearby each other, accurate prediction of the RAO of the floating structures is important to ensure the safety of the structures.

1.7 Organization of the Thesis

This thesis consists of nine chapters. The first chapter presents the overview discussion on the tasks conducted in this research. The chapter discusses the objectives of this research and the contribution of the research to the topic. The scope and the field of research are explained in this chapter to deliver the idea on the area of discussion in this thesis.

Discussion on literature review is presented in Chapter 2. The literature review focuses on the available methods to simulate the RAO of floating structures. The weaknesses and strengths of the existing methods were also discussed in the chapter. Besides, the chapter includes the experimental study conducted by previous researches to study the motion of floating structures. In this chapter, reviews on the current available FLNG or FPSO are conducted to study the advantages of the selected model as the case study in this research.

In Chapter 3, the methodology of this research is presented. The chapter explain the overall idea of the work conducted in the research. Besides, this chapter also help in guiding the reader to search for detail information of the methodology used in the research which presented in following Chapter 4 to Chapter 7. The chapter started with presenting the work flow of the research. The research flow chart is shown in this chapter to deliver overview of this research work conducted. After that, the discussion on the variables studied in this research and the process to collect the data which required for analyse in this research was explained. The selected basic concepts used to develop the proposed method in this research are also introduced in this chapter.

In this thesis, chapter 4 serves to explain the basic theories in developing the proposed method. This chapter discusses the equations used to estimate the RAO of floating structure is developed based on the diffraction potential theory. After that, this chapter also explained the concepts used to estimate the interaction effect due to the motion of floating structures.

Chapter 5 explains the development of the proposed method. The first part of Chapter 5 presents the modification on the motion equation which combined the diffraction potential theory explained in Chapter 4 with the linearized drag equation. The purpose of the modification is to improve the accuracy of the method to predict the RAO of floating structure. The second part of Chapter 5 explains the mathematical equations developed to estimate the effect of interaction between floating structures to the RAO of each floating structure based on the concepts presented in Chapter 3 and Chapter 4.

Chapter 6 explains the procedures of the proposed method to estimate the RAO of floating structure when the structure is alone and when the structure is interacting with the nearby floating structure. This chapter also presents the numerical setup in this research to test the proposed method. The numerical setup in this chapter includes the meshing system and the software setup.

Chapter 7 contains the setup of the motion experiment to generate the data used to validate the proposed method. Besides, this chapter presents the selected conditions of the model scale motion experiments. Other than that, this chapter presents the procedures in processing the experiment data until the RAO tendencies of the selected Round Shape FLNG in each selected conditions is obtained. The data analysis procedures explained in this chapter includes the mathematical model to transfer the measured data from measurement point to FLNG's centre of gravity and the mathematical model used to transform the time domain data to frequency domain.

Chapter 8 presents the RAO tendencies estimated by the proposed method, commercial code and experiments which are then tested in each selected condition. The comparisons were made by compared the RAO of the selected round shape FLNG predicted by proposed method to results predicted by established commercial software and the result from models experiments. The comparisons are showing the validation of the proposed method and the improvement on the proposed method to estimate the RAO of floating structures. The last part of this chapter discusses the influence of second floating structure which arranged nearby the round shape FLNG to the change of RAO tendencies of the round shape FLNG.

In Chapter 9, the conclusion of the thesis explains the overall achievement in this research. The capability of the proposed method is highlighted in this chapter by comparing it to the previous methods. Finally, recommendations are raised up to discuss the future jobs of the research to further improve the proposed method in this research.

1.8 Summary

This chapter introduces the overall target of the research. The background of this research and the objectives aimed to achieve in this research are also presented in this chapter. Besides, the tasks conducted in this research are briefly discussed in this chapter. The detail discussions on the tasks conducted in this research are presented in the remaining chapters of this thesis.

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