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MODELLING RECURRENCE MOTION OF A LARGE VOLUME SEMI- SUBMERSIBLE

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ABSTRACT

This paper presents a modelling reccurence motion on a large volume semi-submersible using ANSYS AQWA version 13. Recurrence is the phenomenon in which a system of quasi-periodically returns to its initial conditions after undergoing some degrees of evolution, this finding supports the theory of to quasi determinism (QD) of sea waves. The computational method calculated the hydrodynamic characteristics and recurrence motion for the semi-submersible. The motions were analyzed in four types of different incident irregular waves by using JONSWAP Spectrum which is generally regarded as a pure randomness in nature interacting with the structure generating hydrodynamic motion. Responses of motion were simulated for 3 hours, in which it was divided into 9 seeds for each incident wave. The incident waves of significant wave height of Hs 7 meters with the wave periods of Tp 12.7 and 13.5 seconds; and significant wave height of Hs 8 meters with the wave periods of Tp 12.7 and 13.5 seconds were generated in the simulation, it was found that the recurrence motion occurred in the time interval (to + 635s, to + 879s) and (to + 1774s, to + 1988s); (to + 693s, to + 882s) and (to + 1735s, to + 1924s); (to + 693s, to + 882s) and (to + 1735s, to + 1924s); (to + 792s, to + 992s) and (to + 1938s, to + 2138s) respectively. Recurrence motion on a large volume semi-submersible supports the quasi determinism (QD) Theory.

Keyword: *semi-submersible, recurrence motion, ANSYS AQWA, weibull distribution*

1.0 INTRODUCTION

As the demand for oil and gas is increasing, the need for fixed and floating structure is gaining importance in the form of offshore facilities. Semi-submersible is a very important structure in the future due to the oil and gas exploration that leads to deep water [1]. With the caused exploration oil and gas that leads to deep water and heave suppressed deep water structures. The challenge to produce oil in deep water is complicated, many considerations that must be estimated. As water depth increases, the safety, structural integrity, mooring, and maintenance of a system become more and more difficult and challenging [2].

Tendency of deep water platform structure is deploying a semi-submersible platform. The important issue on the semi-submersible structure is its hydrodynamic characteristics in waves. One of the hydrodynamic characteristics is due to the interaction of the motion, water depth and waves.

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The total hydrodynamic force produced motion due to action of wave is assumed to be equal to the sum of the drag and inertia force components. Hydrodynamic analysis is performed in the frequency domain with the Morison equation being used for calculating wave induced drag and inertia forces on the structure [3]. The relative importance of the two components depends on the size of the structure. Sharant [4] has analyzed the hydrodynamic loading due to the motion of large offshore structures. They have researched to develop a non-reflecting boundary condition for the analysis of fully or partly submerged offshore structures for which the effect of water compressibility may be neglected but that of surface waves is important. Hydrodynamic interaction effect between large column can cause a substantial increase in local wave height [5].

The random wave motion of a floating structure had a recurrence phenomenal. Kaihatu, and James M. [6] have studied the phenomenon of recurrence. Recurrence is the phenomenon in which a system quasi-periodically returns to its initial conditions after undergoing some degree of evolution. Experiment recurrence of the wave carried out by Bocotti [7], the research identical sequences of relatively large waves were found hours apart from one another. This finding supports the theory of quasi determinism of sea waves. The quasi determinism (QD) theory introduces a deterministic wave function (of both space and time) that shows what, most probably, will happen if an exceptionally large wave will occur at some point in a sea storm. QD theory has theoretical and practical significance in ocean engineering and naval architecture because it suggests that extreme wave force, far from being random, tend to be deterministic.

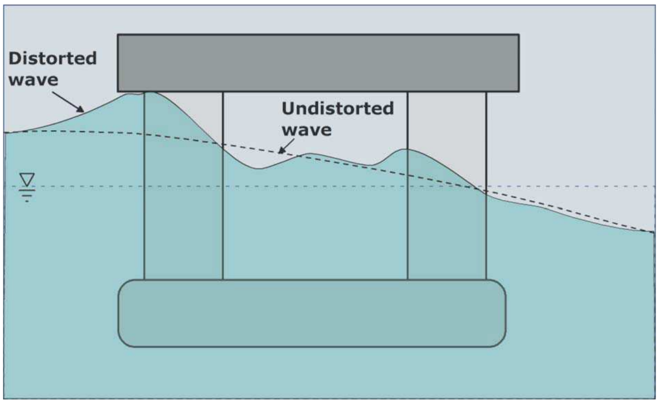

Figure 1. Schematic of wave run up problem

According to Eatock Taylor and Sincock [5], hydrodynamic interaction effects between large columns can cause substantial increases in local wave height. They analyzed this phenomenon of wave upwelling theoretically using a high order hybrid element technique. It was concluded that wave upwelling effects are highly significant and should be considered in design.

Kagemoto and Yue's [8] interaction theory has been used by Yilmaz, et. al [9] to obtain analytical solutions for the diffraction problem of truncated cylinders. The diffraction potential of an isolated cylinder is obtained using Garret's [10] solution, and evanescent mode solutions are derived in a similar manner to Garret's [10] solution. Free surface elevations are calculated for an array of four cylinders and compared with experimental measurements.

Matsumoto, et. al [11] extended a Boundary Element Method (BEM) wave run up on surrounding column model that incorporates 2nd order diffraction effects

(WAMIT) and a Volume of Fluid (VOF) CFD code (ComFLOW). The numerical method can improve the results in comparison to 1st order standard linear analysis that may lead to significant errors concerning the air gap evaluation for both fixed and moored model in regular waves.

Concerning the wave run-up phenomenon generated on the sea surface in irregular waves, it always has a random nature [12]. However, Bocotti [7] conducted field experiment for measuring waves in surrounding piles to verify the quasi-determinism of sea waves (QD) theory, Bocotti [13] suggests that an exceptionally two large waves in two sea states with the same spectrum, and with the same configuration of the solid boundary should belong to two identical sequences of waves.

Priyanto, et. al [14], carried out the small-scale moored model tests of a large semi-submersible in the Marine Technology Centre (MTC) towing tank of Universiti Teknologi Malaysia (UTM). Tests were performed with moored model under the action of irregular waves. Each of two JONSWAP spectrums was produced with different seed numbers for representing two sea-state time traces. Waves run up at south (S) and north part (N1) were measured by resistance wave gauges. He concluded that the measured wave run up verified that the QD theory is also applicable to wave run up on the large volume semi- submersible.

This paper presents the modelling recurrence motion on the semi-submersible at condition with computational methods using ANSYS AQWA version 13 which focuses on the prediction of the recurrence phenomena on semi-submersible structure at irregular waves and the effect that occurs of the structure. The objective was to evaluate the hydrodynamic characteristics of surge, pitch and heave in different water depths and the motions like-ness of some seed responses during 3 hours full scale; and the motions like-ness are verified by Weibull distributions.

2.0 MOTION ON SEMI-SUBMERSIBLE

2.1 Semi-submersible Motions

A floating body has six degrees of freedom. To completely define the floating body motion it is necessary to consider movements in all these modes as illustrated in Figure 2. The motions are defined as movements of the centre of gravity (CoG) of the body and rotations about a set of orthogonal axes through the CoG. These are space axes moving with the mean forward speed of the floating body but otherwise fixed in space. It will be noted that roll and pitch are the dynamic equivalents of heel and trim. Translations along the x-and y-axis and rotation about the z-axis lead to no residual force or moment, provided displacement remains constant, as the body is in neutral equilibrium.

For the other translation and rotations, movement is opposed by a force or moment provided the floating body is stable in that mode. The magnitude of the opposition increases with increasing displacement from the equilibrium position, the variation being linear for small disturbances. This is the characteristic of a simple spring system. Thus, it is to be expected that the equation governing the motion of a floating body in still water, which is subject to a disturbance in the roll, pitch or heave modes, will be similar to that governing the motion of a mass on a spring.

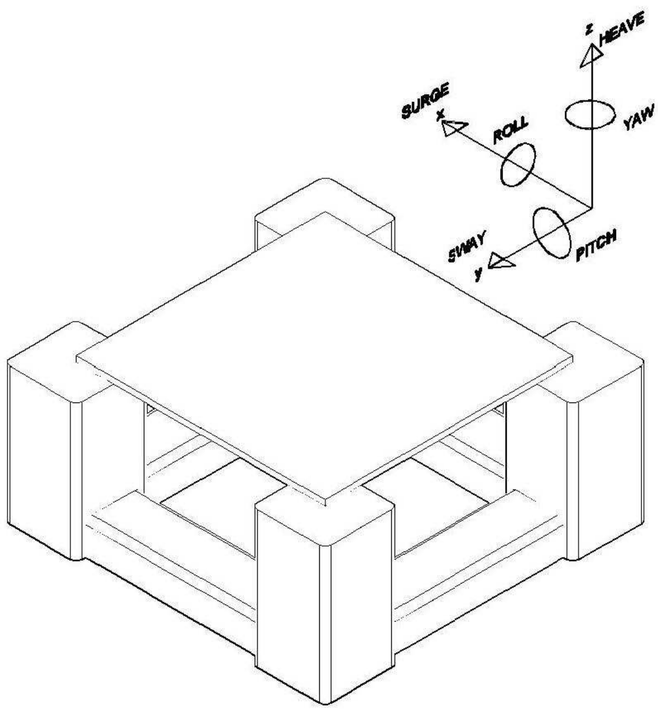

Figure 2: Semi-submersible motion definition

Table 1: Six degrees of freedom of motion

Translation or rotation	**Axis**	**Description**	**Positive Sense**
	Along x	Surge	Forwards
Translation	Along y	Sway	To starboard
	Along z	Heave	Downwards
	About x	Roll	Starboard side down
Rotation	About y	Pitch	Bow up
	About z	Yaw	Bow to starboard

.

This is indeed the case, and of the un-damped case the floating body is said to move with simple harmonic motion. Disturbances in the yaw, surge and sway modes will not lead to such an oscillatory motion and these motions, when the ship is in a seaway, exhibit a different character to roll, pitch and heave. These are considered separately and it is the oscillatory motions which are dealt with in the next few sections. It is convenient to consider the motion which would follow a disturbance in still water, both without and with damping, before proceeding to the more realistic case of motions in waves.

2.2. Motion in Irregular Waves

Once the transfer functions between wave the energy and motion (component) energy are known, one can transform any wave energy spectrum to a corresponding motion energy spectrum. Figure 3 shows an example of the striking influence of the average wave period on a response spectrum.

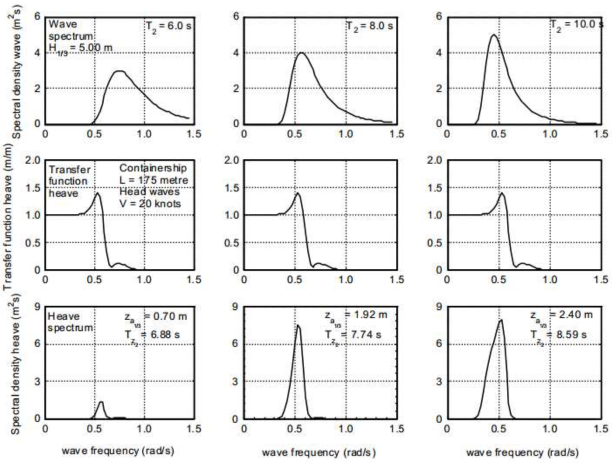

Figure 3. Effect of wave period on heave

For the wave spectrum with an average period of 6.0 seconds, the transfer function has very low values in the wave frequency range. The response spectrum becomes small, only small motions result. As the average wave period gets larger and the response increases dramatically. A similar effect will be obtained for a larger range of average wave periods if the transfer function of the motion shifts in the low frequency region . A low natural frequency is required to obtain this. This principle has been used when designing semi-submersibles, which have a large volume under water and a very small spring term for heave (small water plane area). However, such a shape does not make much of a wave when it oscillates; it has little potential damping. This results in large (sometimes very large) Response Aamplitude Operator’ s at the natural frequency . As long as there is (almost) no wave energy at this frequency, the response spectrum will remain small [15].

3.0 QUASI DETERMINISTIC THEORY

According to Kaihatu and James [6] (2009), a common manifestation of nonlinear wave behavior is the phenomenon of recurrence among a small number of frequency components. Loosely defined, recurrence is the phenomenon in which a system quasi-periodically returns to its initial conditions after undergoing some degree of evolution.

The latest experimental studies the recurrence on wave introduced by Boccotti [7]. The quasi determinism (QD) theory introduces a deterministic wave function (of both space and time) that shows what, most probably, will happen if an exceptionally large wave will occur at some point in a sea storm. This deterministic wave function holds for every configuration of the solid boundary, provided that the wave motion may be regarded as irrotational [14].

The most important novelty of the QD theory is that the deterministic wave function. If a wave with a given exceptionally large height *H* occurs at some point x_0 ,y_0 at a time instant t_0 in a sea storm, there is a very great probability that the random free surface displacement around point x_0 ,y_0 for a span of time before and after t_0 is very close to the following deterministic wave function:

$$\eta(x_0 + X, y_0 + Y, t_0 + T) = \frac{\psi(X,Y,T) - \psi\left(X,Y,T - T^*\right)}{\psi(0,0,T) - \psi\left(0,0,T^*\right)} \frac{H}{2} \tag{1}$$

Here, *Ψ*. is the covariance with both space and time lags of the random free surface displacement, that is,

$$\psi(X,Y,T) = \eta(x_0, y_0, T)\eta(x_0 + X, y_0 + Y, t_0 + T) \tag{2}$$

where the angle brackets denote an average with respect to time t and *T** is the lag of the absolute minimum of the auto-covariance function.

Associated with the deterministic wave function (Eq.1) is a distribution of velocity potential in the water, which to the lowest order in a Stokes expansion is given by.

$$\phi(x_0 + X, y_0 + Y, z, t_0 + T) = \frac{\phi(X,Y,z,T) - \phi\left(X,Y,z,T - T^*\right)}{\psi(0,0,0) - \psi\left(0,0,T^*\right)} \frac{H}{2} \tag{3}$$

where *Φ* is the covariance of the free surface displacement and the velocity potential of the random wind-generated waves :

$$\phi(X,Y,z,T) = \eta(x_0, y_0, z, t)\eta(x_0 + X, y_0 + Y, z, t_0 + T) \tag{4}$$

This is the gist of the quasideterminism QD theory. Specifically, the deterministic wave function (equation 4) and the distribution of velocity potential (equation 4) not only are valid for waves in the open sea, but also hold for waves interacting with solid bodies of arbitrary shapes and sizes. What is requested only is that the free surface displacement of the random wind-generated waves represents as mentioned above. A stationary random *Gaussian* process are non-homogeneous in space because of the presence of any solid body that induces wave diffraction. What changes from one configuration of the solid boundary to another configuration is only the relationship between the functions and directional spectrum of the incident waves.

Based on the QD theory the important parameters of the wave run up spectrum are [7]: the peak frequency, the dominant direction, and the bandwidth. The records with some similar values of the triplet *Tp*, θ, ψ where: *Tp* = period associated with the peak of the energy spectrum; θ = angle between the wave direction, ψ = narrow-bandedness parameter (equal to the absolute value of the proportion between the minimum and the maximum of the auto-covariance of wave run up fluctuations). It was found three pairs of datasets that satisfied.

4.0 NUMERICAL SIMULATION

4.1 Incident wave conditions

The modelling of incident waves in towing tank, five parameters uni-modal JONSWAP wave spectrum is utilized for the specified waves. The formula for the JONSWAP spectrum may be written as equations (5) and (6). Incident wave that used is irregular waves, in which to display the random nature, with incident wave parameters for significant wave height and period is shown as Table 2. Table 2 presents the wave parameters adopted in the simulation tests (full scale). The tested peak wave periods comprehended 12.7s and

13.5s. As shown in Table 2, during 3 hours the variation on the seed numbers mainly can generate different time traces but the wave periods and wave heights are constant in the tests.

Table 2 – Incident waves parameters (full scale)

Hs (m)	Tp (s)	γ	Direction
7.0	12.7	1	0
7.0	12.7	1	0
8.0	13.5	1	0
8.0	13.5	1	0

$$S(f) = \alpha H_S^2 T_p^{-4} f^{-5} \exp\left[-1.25\left(T_p f\right)^{-4}\right] \gamma^{\exp\left[-\left(T_p f - 1\right)^2 / 2\sigma^2\right]} \quad (5)$$

$$\alpha = 5.0609 \frac{g^2}{(2\pi)^4}\left[1 - 0.287\ln(\gamma)\right] \quad (6)$$

where $S(f)$ = spectral wave energy density distribution, H_S = significant wave height, f= wave frequency (Hz), T_p = peak wave period (sec), γ= spectral peakedness,

σ= 0.09 for $f > f_p$, and σ= 0.07 for $f < f_p$, and f_p = peak wave frequency (Hz)= $1/T_p$

4.2 Modelling structure of semi-submersible

The model is a large volume semi-submersible with 58,748 tones displacement, characterized by having large displacement hulls. The platform is stabilized 4 rectangular column arrangement as shown in Figures 4 and 5.

The model main particulars are presented in Table 3. The model has a mooring system arranged in four lines in such a way that the overall horizontal spring stiffness which is 171kN/m.

Table 3 – Model main characteristics

Designation	Symbol	Unit	Full scale
Overall Length	L	M	86.920
Overall Breadth	B	M	86.920
Overall Draft	D	M	22.000
Operating Displacement	Δ	MT	58,748
Center of gravity from Centerline	XCG	M	0.00
Center of gravity above base	KG	M	28.59
Center of buoyancy above base	KB	M	8.22
Metacentric height above base	KM	M	38.90
Pitch gyradius	K_{yy}	M	35.36
Roll gyradius	K_{xx}	M	36.45
Yaw gyradius	K_{zz}	M	39.83

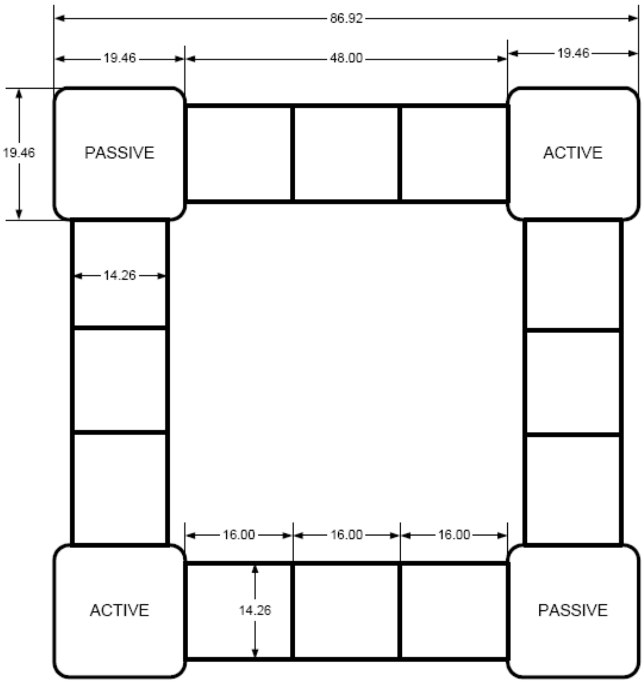

Figure 4. Semi-submersible main dimensions

Data analysis performed based on the results of the modeling that conducted by using ANSYS AQWA version 13. A diffraction analysis of the Semi-submersible in ANSYS AQWA, the main goal is to firstly obtain the hydrodynamic parameters (damping, added mass coefficients) and free floating RAO's. Secondly, the results of the ANSYS AQWA hydrodynamic diffraction analysis for RAOs are reported and compared with experiment result and code MOSES analysis. Lastly, to obtain the recurrence motions for the semi-submersible based on the Weibull distributions of RAO response in the time domain analysis.

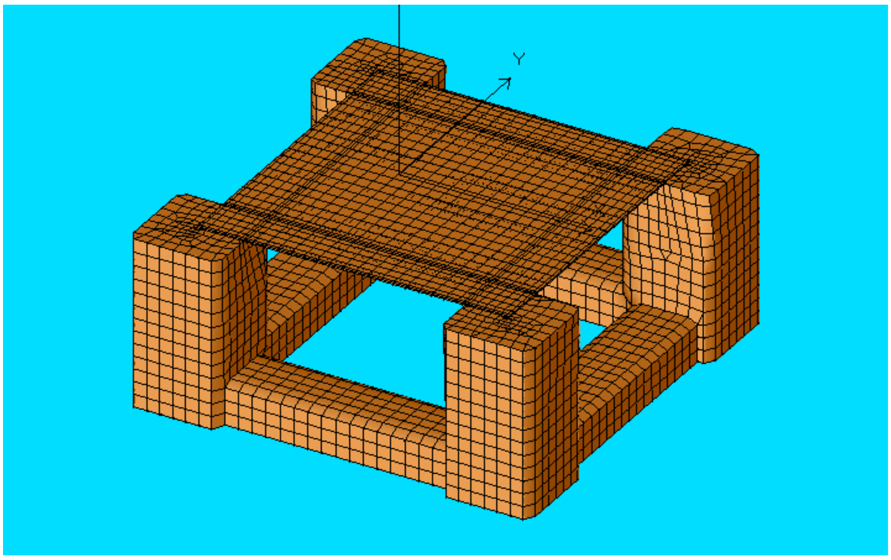

Figure 5. Modelling Semi-submersible in ANSYS AQWA

5. RESULTS AND DISCUSSIONS

5.1 Hydrodynamics characteristics

Six degrees of freedom (6 DOF) refer to the freedom of movement of a rigid body in three-dimensional space. Specifically, the body is free to move forward/backward, up/down, left/right (translation in three perpendicular axes) combined with rotation about three perpendicular axes, often termed pitch, yaw, and roll.

The 6 DOF motions of a rigid body in body coordinate system are governed by the equations of linear and angular momentum referred to the center of gravity. Motion analysis of the 3 degrees of freedom (3 DOF) motion of the center of gravity performed to motion of the surge, heave and pitch, where the analysis is done to determine the added mass, damping and RAOs on heading - 0 degree.

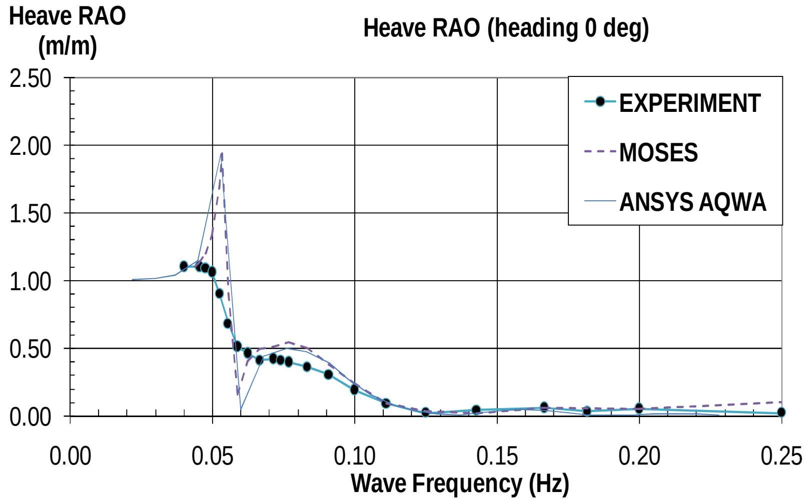

Figure 6. Comparison of Heave RAO among Exp, MOSES and ANSYS AQWA

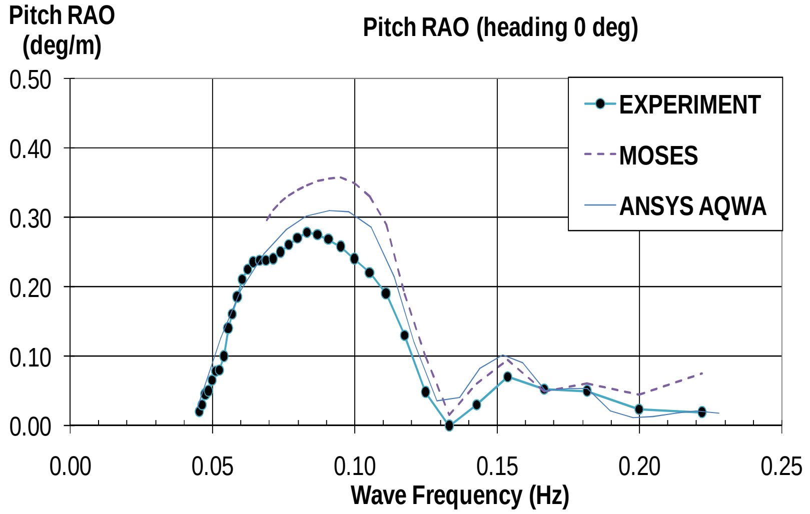

Figure 7. Comparison of Pitch RAO among Exp, MOSES and ANSYS AQWA

Figures 6 and 7 show the Response Amplitude Operator (RAO) for Heave and Pitch motion refers to the data obtained directly from the irregular wave moored tests [14], the solid line, here named ANSYS AQWA, was obtained in present numerical tests, specifically carried out to determine the RAOs heave and pitch of the semi submersible. The results from MOSES and ANSYS AQWA have the same value. This shows that the results of the experiment analysis and ANSYS AQWA and MOSES analysis occurred on the same treatment of conditions semisubmersible structure. The maximum value of response amplitude operator (RAO) for heave are 1.9 at frequency is 0.05 Hz. its different condition on the experiment results, the value of the resulting response amplitude operators lower than the MOSES and ANSYS AQWA which the value of the same frequency at 0.05 Hz.

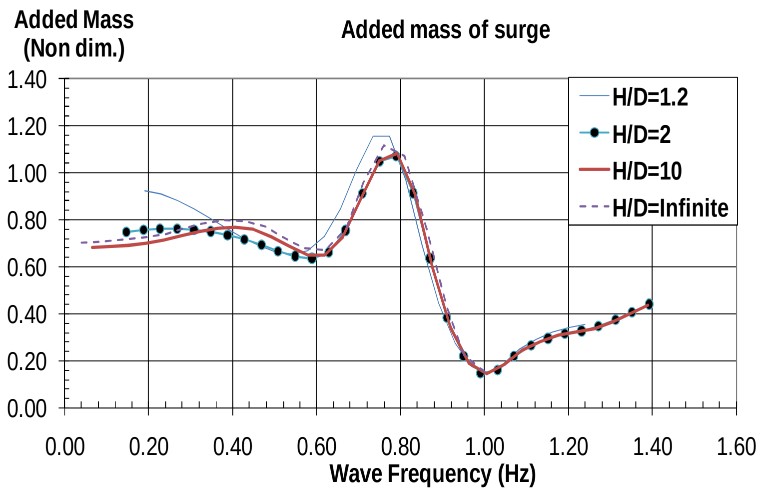

Figure 8. Added Mass of Surge for Different H/D ratio

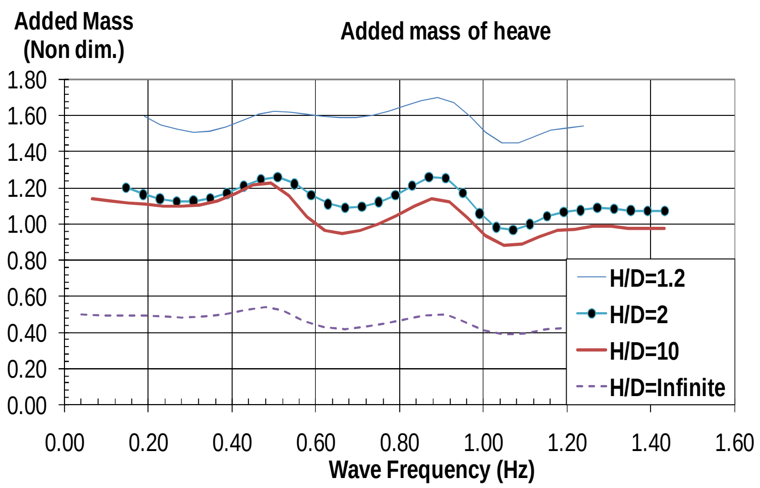

Figure 9. Added Mass of Heave for Different H/D ratio

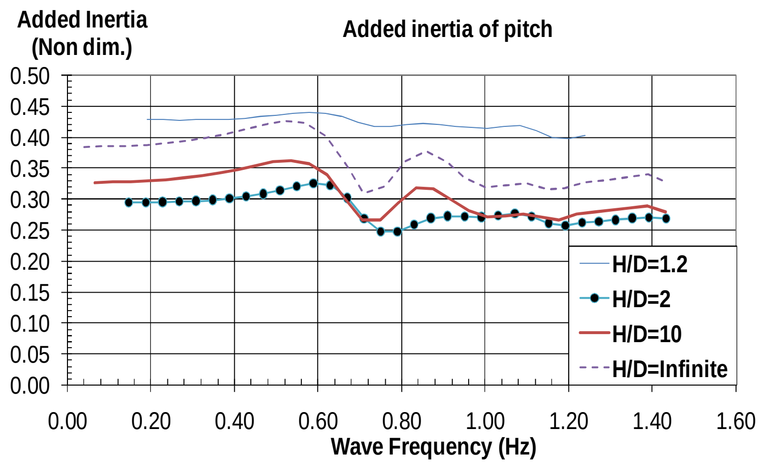

Figure 10. Added Inertia of Pitch for Different H/D ratio

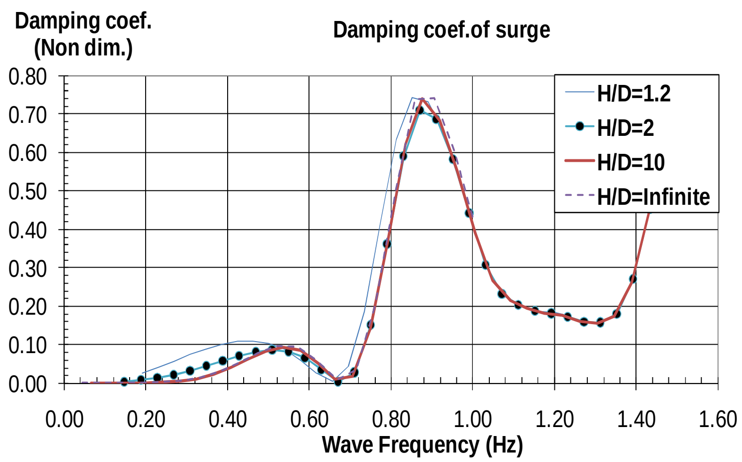

Figure 11. Damping Coef. of Surge for Different H/D ratio

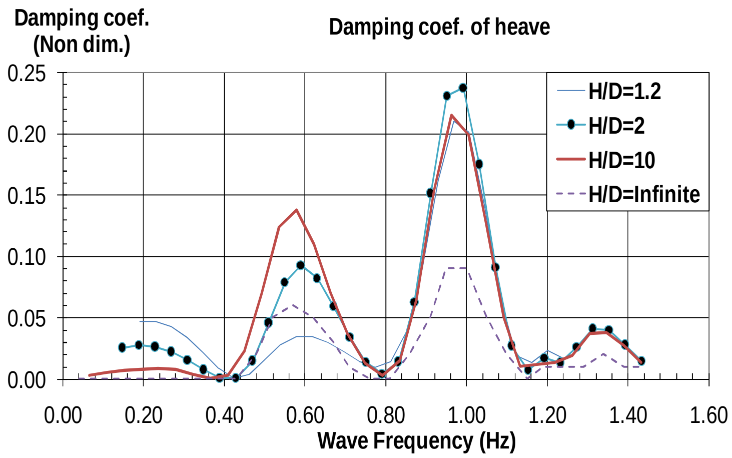

Figure 12. Damping Coef. of Heave for Different H/D ratio

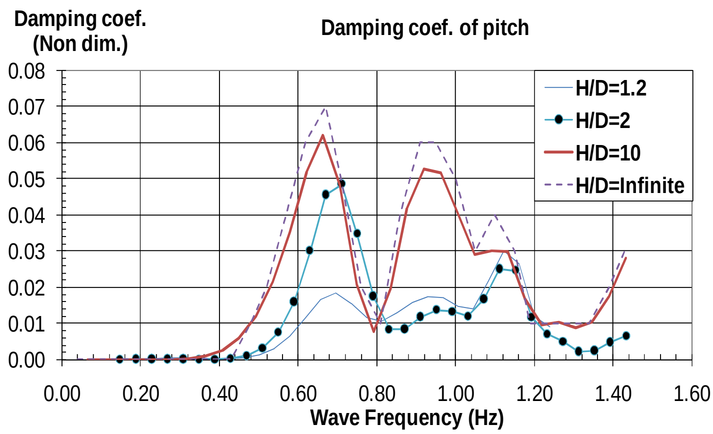

Figure 13. Damping Coef. of Pitch for Different H/D ratio

The added mass surge (a_{11}), heave (a_{33}) and pitch (a_{55}) in Figures 8 – 10 are expressed in non dimensional term as defined as the following equation.

$$a_{11} = \frac{m}{\rho Bd(KG)} ;\ a_{33} = \frac{m}{\rho Bd(KB)} ;\ a_{55} = \frac{mL}{\rho Bd^2(KM)} \quad (7)$$

It is found that the water depth has a very small or no effect on the surge added mass predicted, but has significant effect on the heave and pitch added mass. The most important area of concern in the research is in the low frequency region near to the natural frequency of the system where the system experiences large motions at resonance frequency.

The damping coefficient of surge (b_{11}), heave (b_{33}) and pitch (b_{55}) in Figures 11 – 13 are expressed in non dimensional term as defined as the following equations.

$$b_{11} = \frac{m\omega}{\rho Bd(KG)^2} ;\ b_{33} = \frac{m\omega}{\rho Bd(KB)^2} ;\ b_{55} = \frac{m\omega L}{\rho Bd^2(KM)^2} \quad (8)$$

The calculated damping values for the semi-submersible platform are presented in Figures 11, 12 and Figure 13. The Figures shows the non dimensional damping for the surge, heave and pitch motions. It is observed from the three figures that at the low frequency region (around the various motions resonance frequencies) the potential damping vanishes which agrees with what was mentioned previously regarding the importance of low frequency motions response near to the resonance frequency. In addition, same results for the damping values for the surge were estimated at different values of the water depth – draught ratio of *H/D*=1.2, 2, 10 and infinite where no effect of water depth was found. However, the different damping values for the heave and pitch were estimated where the effect of different values of the water depth was significant.

5.2 Recurrence motions

During 3 hours it was found two recurrence pairs of heave motions that satisfied the same Weibull distribution trend in the sea states as shown in Figures 14 and 15. As the time lag |*t* - *to*| grows also the differences between the motions of the simulation with the incident wave height of Hs=7m and 8m, gradually, grow. On the interval (*to* + 635s, *to* + 879s) and (*to* + 1774s, *to* + 1988s) the like-ness heave motion (not regular in shape and size) were indicated that the Weibull distribution verified the like-ness heave motion, as well as the recurrence on (*to* + 693s, *to* + 882s) and (*to* + 1735s, *to* + 1924s).

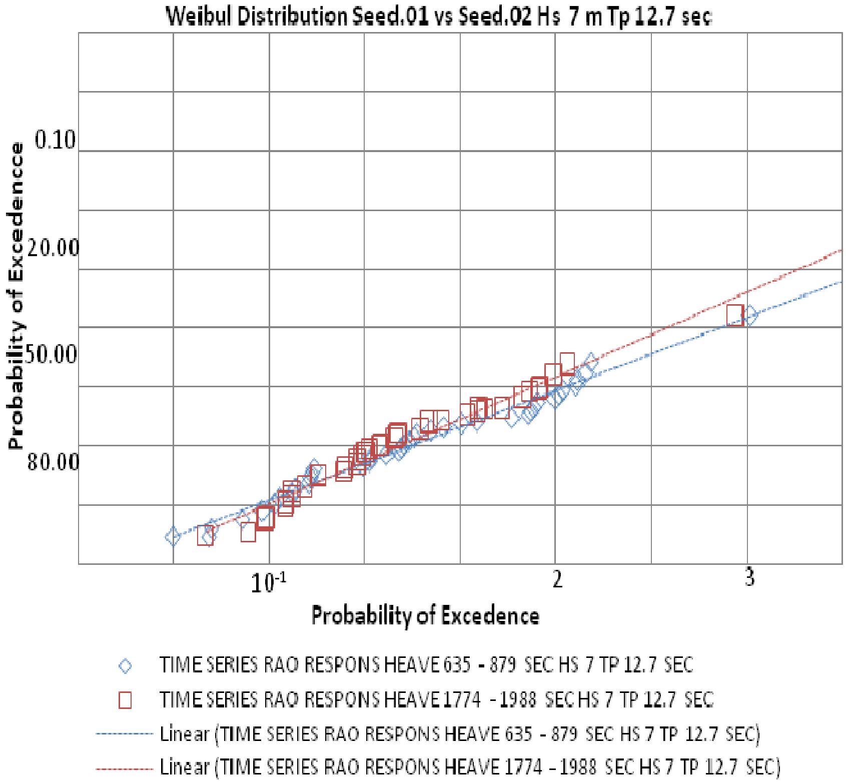

Figure 14. The recurrence on the interval (*to* + 635s, *to* + 879s) and (*to* + 1774s, *to* + 1988s)

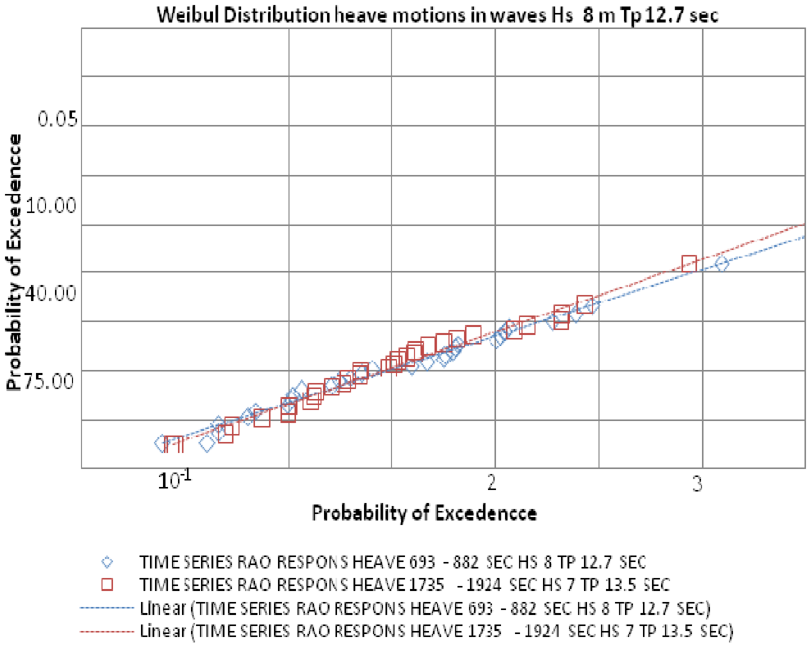

Figure 15. The recurrence on the interval (*to* + 693s, *to* + 882s) and (*to* + 1735s, *to* + 1924s)

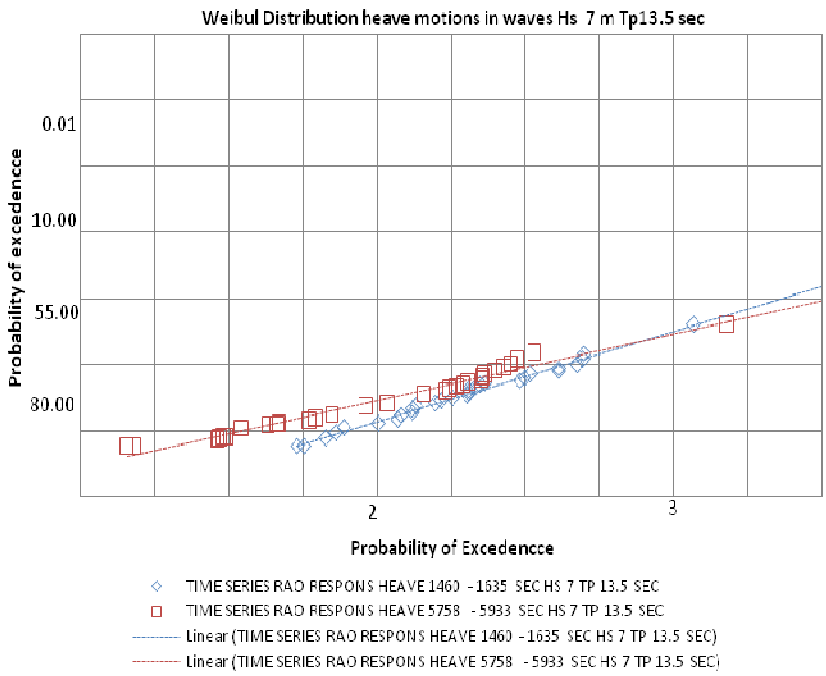

Figure 16. The recurrence on the interval (*to* + 693s, *to* + 882s) and (*to* + 1735s, *to* + 1924s)

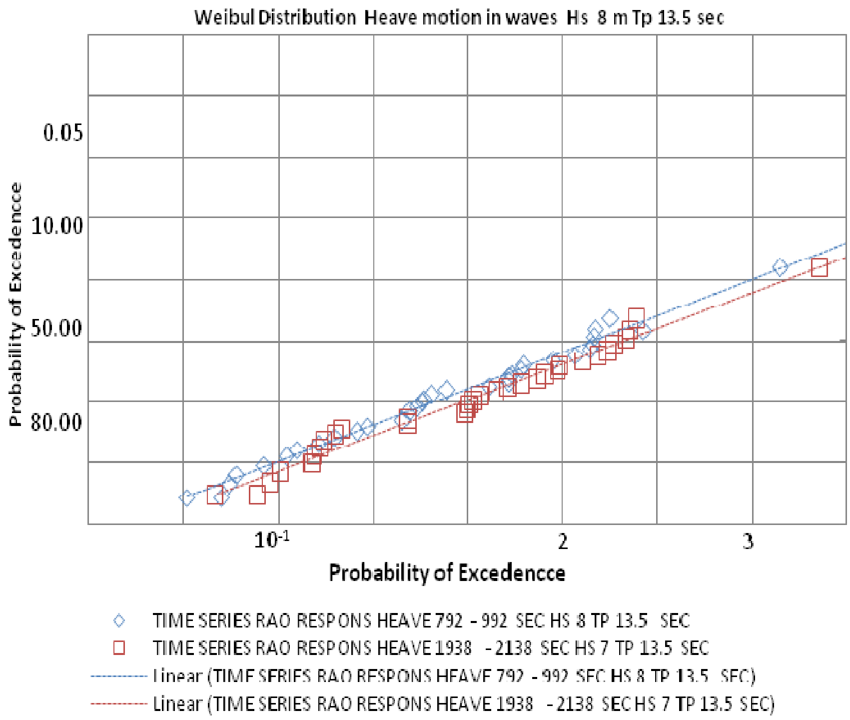

Figure 17. The recurence on the interval (*to* + 792s, *to* + 992s) and (*to* + 1938s, *to* + 2138s)

The heave motion time series with the incident wave height of Hs=7m for likeness between interval (*to* + 693s, *to* + 882s) and (*to* + 1735s, *to* + 1924s) determined on weibull distribution on Figure 16, the trend of graph showed closed data distribution. This showed also that the recurrence of heave motion with the incident wave height of Hs=8m in Figure 17 for likeness between interval (*to* + 792s, *to* + 992s) and (*to* + 1938s, *to* + 2138s) almost have same condition of realisation.

6.0 CONCLUSIONS

The semi-submersible structure essentially stable in the waves, that proved with very low natural frequency (large mass and small intersection with the waterline), transfers only a very small part of the wave energy, very low first order heave motions will appear, it remains essentially stable in the waves Response Amplitude Operator (RAO) of semi-submersible structure that were predicted by using code ANSYS AQWA, have agreed well with the results from code MOSES and model experiments.

The heave motion repeated the similar Weibull distribution at least twice on the different time interval. The motion responses of semi-submersible proved the reccurence phenomena from the (QD) theory. There is a time interval in which the heave motion of semi-submersible measured in the JONSWAP spectrum waves with some similar value of dominant direction and the bandwidth record, will have similar fluctuation heave motion.

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NOMENCLATURES

Hs	Wave height significant
Tp	Peak wave period
f	Wave frequency
g	Gravity acceleration
JONSWAP	JONSWAP wave spectrum
QD	Quasi-Determinism
RAOs(ω)	Response Amplitude Operator
α	Alfa constant
γ	Gamma constant
η	Free surface elevation/displacement
H	Water Depth
D	Draught