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Hydrodynamic Interaction of Floating Structure in Regular Waves

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Graphical abstract

Abstract

Floating structures play an important role for exploring the oil and gas from the sea. In loading and offloading, motion responses of offshore floating structures are affected through hydrodynamic interaction. Large motions between floating bodies would cause the damage of moorings, offloading system and may colloid to each other. This research studies on hydrodynamic interaction between Tension Leg Platform (TLP) and Semi-Submersible (Tender Assisted Drilling (TAD)) in regular and irregular waves with scenario as follows: fixed TLP and 6-DOF floating semi-submersible and 6-DOF both TLP and semi-submersible. Under these conditions, hydrodynamics coefficients, mooring and connectors forces, motions and relative motions of TLP and Semi-Submersible will be simulated numerically by using 3D source distribution method. As the scope is big, this paper only presents model experiment of floating TLP and semi-submersible in the regular wave. The experiment is carried out in the UTM Towing Tank.

Keywords: Tension leg platform; tender assisted drilling; floating semi submersible; hydrodynamic interaction

■1.0 INTRODUCTION

All of fixed free floating and moored structures such as ship, semisubmersible, FPSO, TLP and others are subjected to wave, wind and current at sea. They have six-coupled degrees of freedom of motions. Namely, linear and angular motions are surge, sway, heave, roll, pitch and yaw. Oscillating of floating structure affects the loading and offloading operation systems. They may experience resonant motions, which should be avoided as much as possible under installation, operation and survival conditions. In particular, the vertical plane motions induced by heave, roll and pitch of a floating structure should be kept adequately low to guarantee the safety of risers and umbilical pipes as most important components in the equipment of oil production.

There are different theories for studying motion of floating structure such as strip theory and potential theory. Three dimensional (3D) source density distribution technique is used to get the potential over the floating structure by many researchers and software. Having flow velocity potentials on and off the panels, hydrodynamic coefficients of floating structure can be determined. Using Bernoulli's equation leads to calculation of pressure distribution and forces over the floating structure. A numerical model is mathematical structure which can be used to describe and study a real situation. A second-order linear differential equation for coupled six degree of freedom can describe the hydrodynamics of floating structures; consist of added mass, damping coefficient, stiffness coefficient, forces and motions in six directions.

Hess and Smith[1] studied on non-lifting potential flow calculation about arbitrary 3D objects. They utilized a source density distribution on the surface of the structure and solved for distribution necessary to lake the normal component of fluid velocity zero on the boundary. Plane quadrilateral source elements were used to approximate the structure surface, and the integral equation for the source density is replaced by a set of linear algebraic equations for the values of the source density on the quadrilateral elements. By solving this set of equations, the flow velocity both on and off the surface was calculated.

Wu *et al.*[2] studied on the motion of a moored semi submersible in regular waves and wave induced internal forces numerically and experimentally. In their mathematical formulation, the moored semi submersible was modeled as an externally constrained floating body in waves, and derived the linearized equation of motion.

Yilmaz and Incecik[3] analyzed the excessive motion of moored semi submersible. They developed and employed two different time domain techniques as due to mooring stiffness, viscous drag forces and damping; there are strong nonlinearities in the system. In the first technique, first-order wave forces acting on structure considered as a solitary excitation forces and evaluated according Morison equation. In their second technique, they used mean drift forces to calculate slowly varying wave forces and simulation of slowly varying and steady motions

Söylemez[4] developed a technique to prediction of damaged semi submersible motion under wind, current and wave. He used Newton's second law for approaching equation of motion and developed numerical technique of nonlinear equations for intact and damaged condition in time domain.

Clauss *et al.*[5] analyzed numerically and experimentally the sea-keeping behavior of a semi submersible in rough waves in the North Sea. They used panel method TiMIT (Time-domain investigations, developed at the Massachusetts Institute of Technology) for wave/structure interactions in time domain. The theory behind TiMIT is strictly linear and thus applicable for moderate sea condition only.

An important requirement for a unit with drilling capabilities is the low level of motions in the vertical plane (motions induced by heave, roll and pitch. Matos *et al.*[6] numerically and experimentally investigated Second-order resonant of a deep-draft semi-submersible heave, roll and pitch motions. One of the manners to improve the hydrodynamic behavior of a semi-submersible is to increase the draft. The low frequency forces computation has been performed in the frequency domain by WAMIT a commercial Boundary Element Method (BEM) code. They generated different number of mesh on the structure and calculated pitch forces.

This study focuses on vertical motion of GVA 4000 semi submersible which is characterized by favorable sea-keeping behavior and calculates motion of body at Head and Beam Sea for different number of meshes.

2.0 RESEARCH METHODOLOGY

The research methodology consists of five stages to complete the research which are mathematical modelling, frequency domain analysis, time domain simulation, comparing results of simulation with experiments and discussions. The present study focuses on the experimental stage which is bolded (Figure 1).

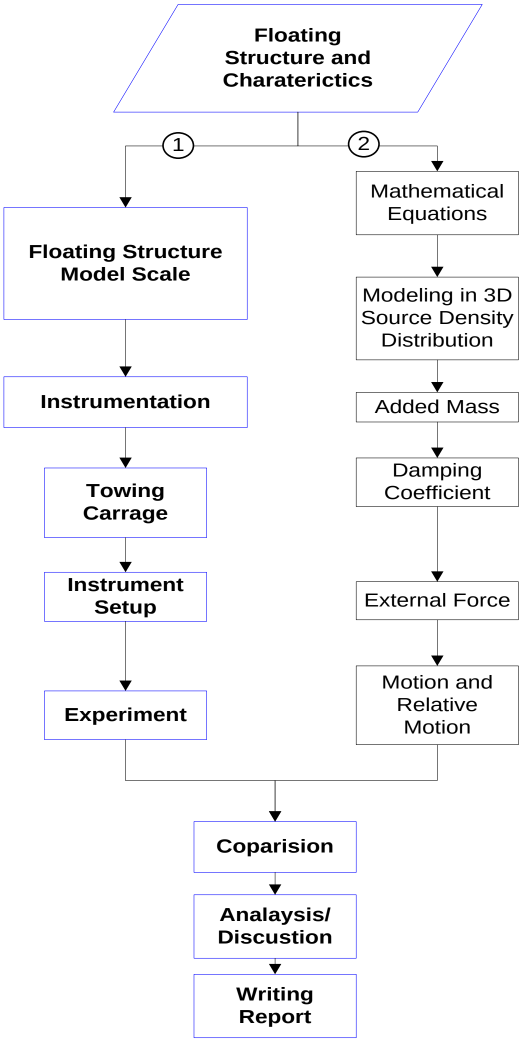


Figure 1 Flowchart of research

2.0 MODEL EXPERIMENTAL SET UP

2.1 Facility

The UTM model basin or towing tank has dimensions 120 m long × 4 m wide × 2.5 m deep and is equipped with a movable towing carriage that runs on the rails along the top of the tank side walls, with maximum speed of 5 m/s and maximum acceleration of 1 m/s^2 as shown in Figure 2. The Carriage can achieve the maximum speed at minimum measuring time of 10 seconds. The rails are set up to account for the curvature of the earth so that it maintains a constant distance from the water surface. The tank is equipped with a wavemaker at one end and a perforated steel beach at the other to absorb the wave energy generated. The wavemaker consists of a wave flap that is actuated by a hydraulic system controlled from the towing carriage terminal. Capability to generate maximum wave height is 0.44 m for the range of 0.5 to 1.7 sec wave periods. Useful towing length is approximately 90 m.

Figure 2 Marine Technology Center, UTM model basin

2.2 Models Particulars

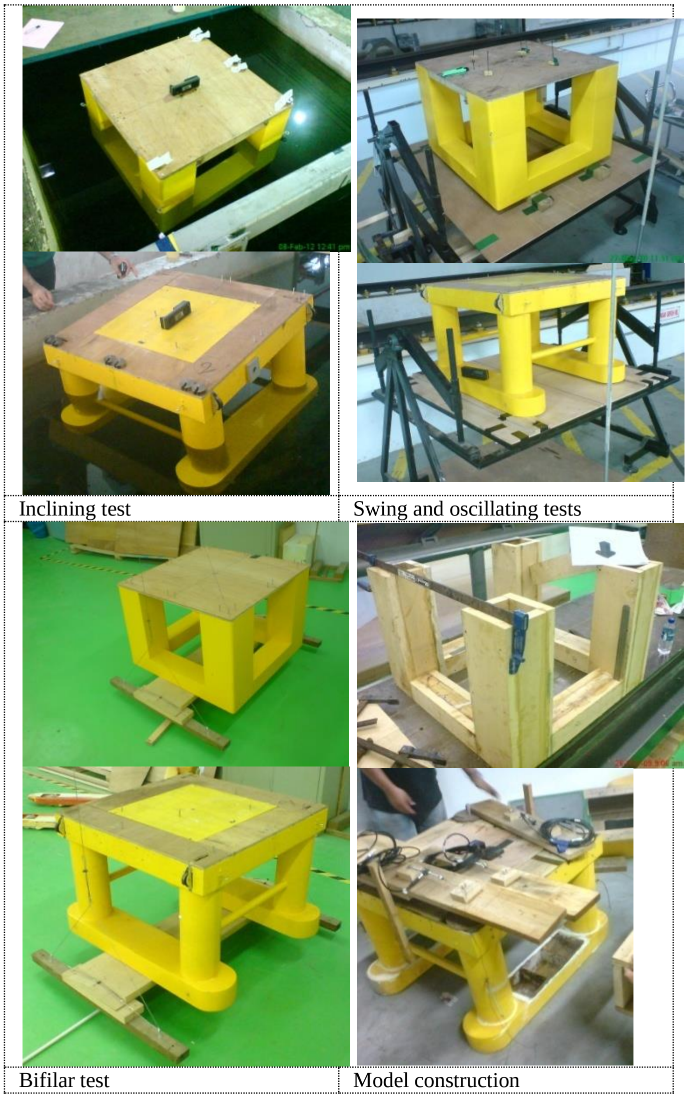
The Semi submersible model was constructed based on GVA 4000. The model has four circular columns connected to two pontoons and two braces. The TLP model also has four columns and four pontoons. Two pieces of plywood are fastened to the top of the TLP and Semi submersible to act as two decks to mount the test instruments. The both models were constructed from wood and the scales of them are 1:70 (Table 1).

Table 1 Principal particular of the structures

Character	TLP	Semi	unit
Length	57.75	66.78	m
Width	57.75	58.45	m
Draft	21	16.73	m
Displacement	23941	14921	m^3
Water Plan Area	715	529.6	m^2
Number of Columns	4	4	
Pontoon length	31	-	m
Pontoon depth	7.28	6.3	m
Pontoon width	9.73	13.3	m
Pontoons centerline separation	-	45.15	m
Columns longitudinal spacing (centre)	-	45.58	m
Column diameter	-	10.59	m
GM_T	7.77	2.87	m
GM_L	7.63	4.06	m
K_{XX}	26.11	31.64	m
K_{YY}	26.46	26.95	m
K_{ZZ}	30.8	35	m
CG_Z	-6.37	-0.28	m

2.3 Inclination Tests

Several preparations were completed in order to obtain the hydrostatic particulars. These included inclining test, swing frame test, oscillating test and bifilar test as shown in Figure 3. It is necessary to do both testing in order to obtain the parameter required by the simulation program and doing experiment. Inclining test is to obtain GM value, swing frame test is to identify the KG and oscillating and bifilar tests are to define gyration radiuses at planer (horizontal) and vertical axis.



Inclining test

Swing and oscillating tests

Bifilar test

Model construction

Figure 3 Models preparations

2.4 Decay Tests and Natural Periods

As matching the natural periods of motions of the model is of utmost importance to assure the correctness of the model test set-up, it is common practice to perform decay to determine the natural periods of the model for every configuration Magee *et al.*[7] Surge, sway, heave, pitch, roll and yaw decay tests for each test configuration with/without connectors were carried out by displacing the model in the appropriate directions or along the relevant axes, releasing and recording the displacement time histories. The tests are repeated when necessary to obtain reliable results. Motion test may be very sensitive to friction in the mooring lines and care must be taken to minimize undue damping due to friction especially at the fairleads. The damping can be monitored by plotting the percentage critical damping versus the amplitude of motion.

2.5 Instrumentation for Motion Test

The six DOF motions of the models when moored on springs are measured by the optical tracking system (Qualisys Camera) that uses a set of infrared cameras attached to the carriage to capture the positions of the reflective optical tracking markers placed on the model (Figure 4). Software running on a PC calculates the 6-DOF motions of the body. Instruments statically calibrated on a test bench by applying a series of known motions prior to test start up.

To directly measure the applied tension force on the model from the mooring springs, water-proof load cells are attached to the springs at the model fairlead locations so as to avoid any losses in force. The lightweight ring gauge load cells are sufficiently sensitive to provide a good signal for small mooring line tensions. The measured mooring line tensions are recorded by the Dewetron Data Acquisition System (DAQ).

In order to obtain phase information, data recorded from different data systems must be synchronized. For this purpose, the optical tracking system is used as the master. The external sync pulse is recorded on the DAQ thus enabling synchronized simultaneous data recording on both systems.

Figure 4 Camera attached on tow carriage

2.6 Springs and Connectors

Soft lateral springs are attached to the TLP and Semi submersible to supply the horizontal component of restoring force of the prototype TLP tendons and Semi submersible moorings. The TLP and Semi submersible are also connected to each other by two connectors to keep them close to. The spring ends at the model side are connected to load cells for measurement of the spring tension forces on the model. The other spring ends are clamped to the mooring posts attached to the carriage. The anchor locations for the springs are chosen so the mooring lines of the model make 45 degree angles with respect to the fairlead attachment points on the model. The spring pretension and spring stiffness to be applied are based on the horizontal stiffness required for the system to match the natural periods of the horizontal modes of motion (surge, sway) of the TLP and Semi submersible.

Since the tendons, risers and moorings are not actually present in the model tests, there will be less damping compared to the prototype, and this is expected to increase the motion amplitude at model scale. However, it is common practice to neglect damping from mooring, tendons and risers in floating structure tests in order to obtain conservative response estimates at the design stage. A similar philosophy is followed here as well.

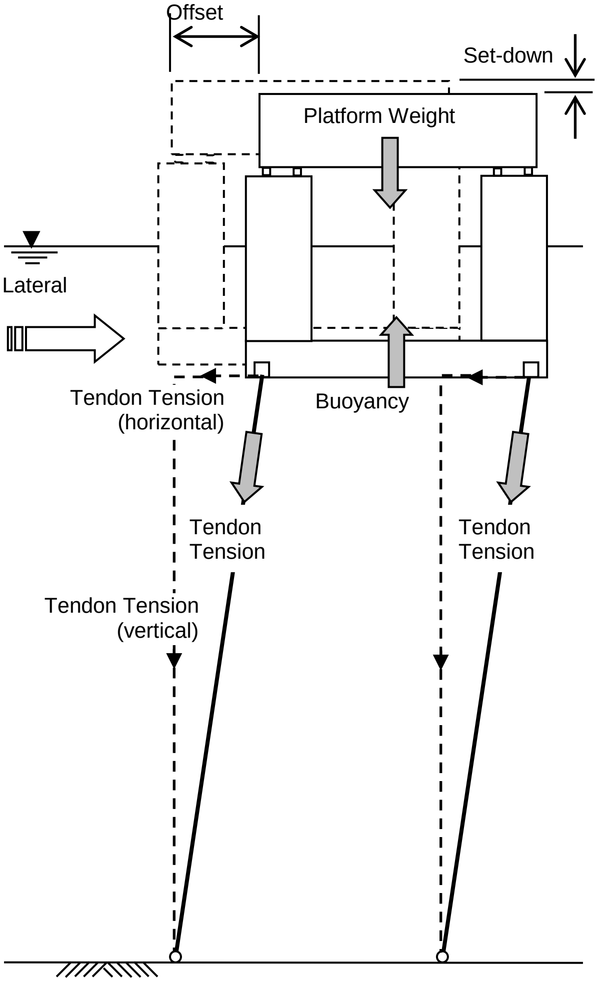


Figure 5 Force balance on the TLP

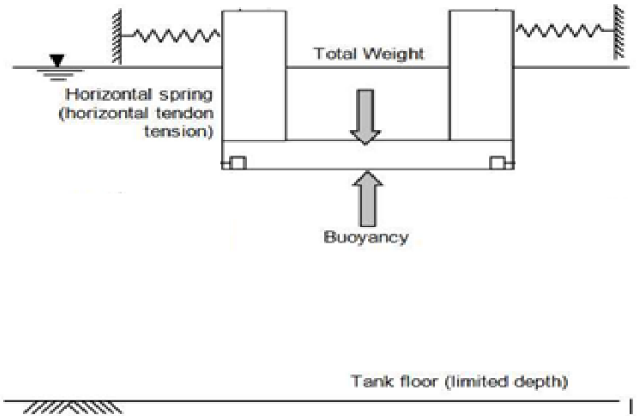


Figure 6 Model test set-up in available water depth

2.7 TLP and Semisubmersible Set Up

For testing the TLP and Semi submersible models in a basin where the water depth is less than that required to include the full length of the tendons and mooring (Figure 5) an almost horizontal springs set considered for compensation of horizontal forces (Figure 6). If truncated tendons were used at for example, 1-70th scale, the set-down would be greatly exaggerated. An alternative option would be to use a very small 1-200th scale model without truncation, but this would impose significant scale effects (Re<10,000), which could change the vortex shedding pattern around the body and unduly affect the results. For bluff bodies, at Re>10,000, the vortex shedding is mostly independent of Reynolds number since the flow separates close to the column corners at both model scale and full scale.[7]

2.8 Motion Tests

Hydrodynamic interaction floating structures model test between TLP and Semi-submersible was set up as shown in (Figure 7). Wave firstly attached the TLP before semi-submersible.

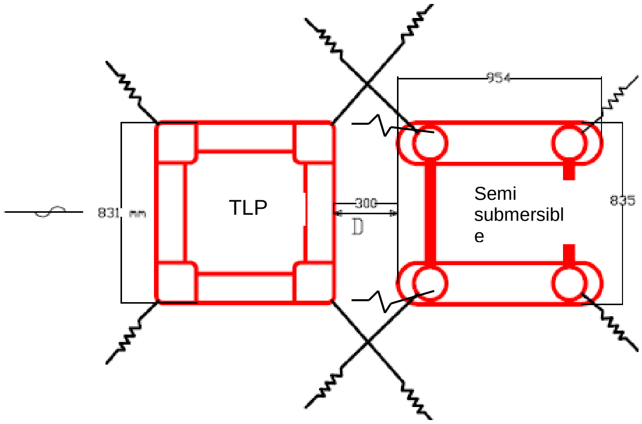


Figure 7 Layout TLP and semisubmersible model experimental set up (Dimension is in model scale)

The models were attached to the tow carriage on springs and regular waves generated by wavemaker at the end of towing tank (Figure 8). At the start and end of these tests, the model was carefully held so as to prevent large offsets due to sudden wave exciting forces which could damage the mooring springs. Measurement data commenced when the model had settled at a constant incident wave was coming. The tank length was sufficient to assure enough oscillations were recorded for each tested before reflection occur.

Figure 8 TLP and Semi Submersible set up into towing tank

According to limitation in generating wave height and period of the wave making system, it was chosen some periods to cover natural period of models and also wave slope are considered 1/20, 1/40 and 1/60 to get an acceptable motion to record. The set up is generally unique to a particular type of floating system and may not be appropriate for others. Separation distance of models is 21.7 m in fullscale (Table 2).

Table 2 Incident wave particulars

Distance (m)	T (s)	L (m)	$H_{(1/20)}$ (m)	$H_{(1/40)}$ (m)	$H_{(1/60)}$ (m)
21.7	4.2	27			
	6.9	75	3.8		
	10.5	171	8.6		
	12.2	233	11.7		
	12.2	233		5.8	
	13.8	298		7.4	
	15.5	374		9.3	
	16.5	422		10.6	
	18.0	500		12.5	
	20.9	657			10.95

Figure 9-Figure 12 depict time series of heave motion and relative motion at T=12.2 s, for two wave slope (wave height to wave length) of H=11.7 m and 5.8 m as a typical results for the TLP and Semi submersible at head sea. The data has been expressed in fullscale units, based on Froude scaling.

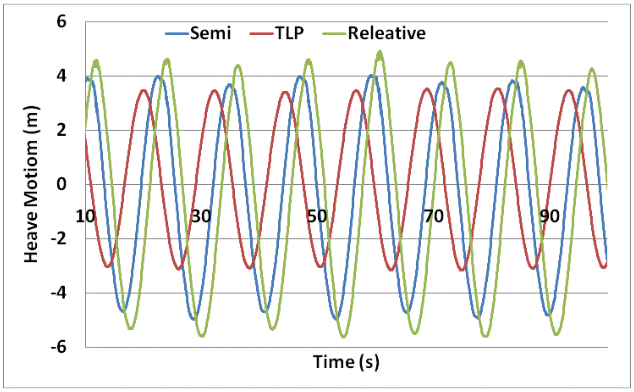


Figure 9 Heave motion of semi submersible, TLP and relative motion of them at T=12.2 s, H=11.7 m

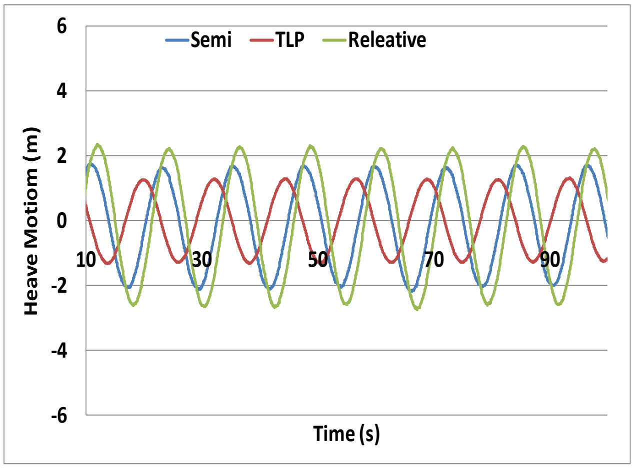


Figure 10 Heave motion of semi submersible, TLP and relative motion of them at T=12.2 s, H=5.8 m

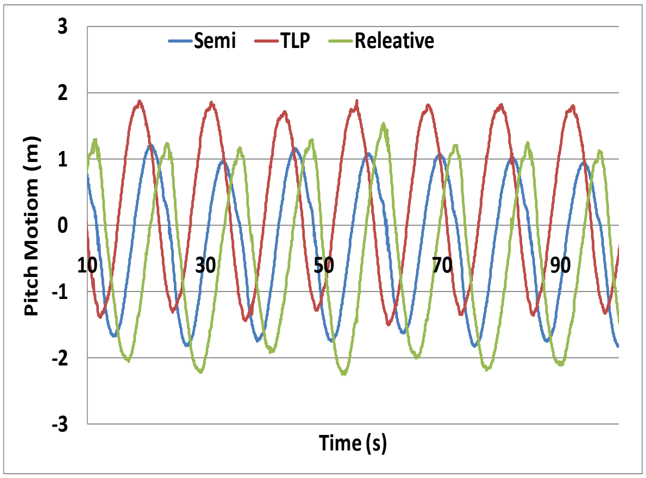


Figure 11 Pitch motion of semi submersible, TLP and relative motion of them at T=12. 2 s, H=11.7 m

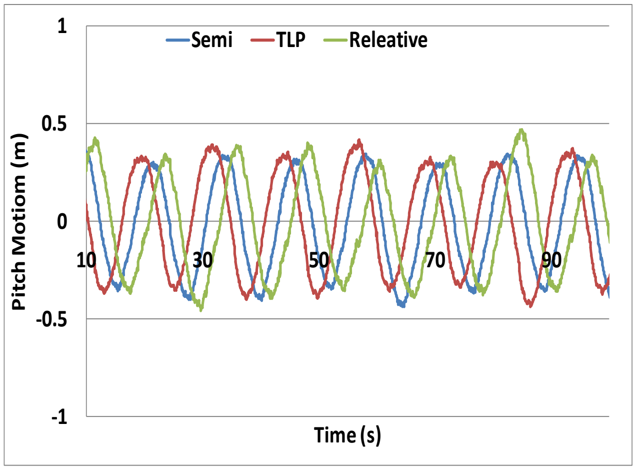


Figure 12 Pitch motion of semi submersible, TLP and relative motion of them at T=12.2 s, H=5.8 m

■3.0 DATA ANALYSIS

Raw data obtained from the tests are processed to obtain the required tests output. Time series of 6-DOF motions and load cell readings are used to derive mean and standard deviations and maximum expected value. Statistical data analysis is carried out using mathematical software such as MATLAB. Results are being compared to published results in the literature and to results from hope program and HydroSTAR analysis.

■4.0 CONCLUSION

Motion of floating structure has significant influence on loading and unloading operation. For investigation experimental tests carried out and simulation is on the process.

The set-up, instrumentation and data analysis techniques are important parts of model testing. Ideal set up that matches the actual floating system, suitable and accurate instrumentation as well as good data processing would assure accurate results that meet the model test objectives.

The Marine Laboratory in UTM has a towing tank of suitable size and well equipped for deepwater floating platform model tests for this region.

We are fortunate in Malaysia to have a good collaborative team of operators, University students and lecturers who are willing to work hard to tackle challenging problems, develop new techniques and succeed in putting Malaysia on the deepwater map of the world. Continued successful working relationships will assure that future regional deepwater developments will benefit from the techniques and skills put into place here and elsewhere in the region.

The TLP and Semisubmersible model tests, which is the focus of motion and relative motion of floating bodies has produced satisfactory results and is continuing to compare to simulation results.

Acknowledgement

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