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Model Testing Capabilities for Verification of Floatover Operations

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ABSTRACT

Investigations into the barge motions, mating load interfaces between the topside leg and jacket leg and mooring lines tensions for floatover installations are presented. Floatover installation means an operation of transferring the topside onto its fixed or floating substructure dependent mainly on the barge ballasting operation without the service of the lift crane vessel. This paper demonstrates the capabilities of floatover model test conducted in the wave basin of Universiti Teknologi PETRONAS. The instrumentation and model test procedure are described in detail. The paper presents comparisons between the calculations and experimental results for mutual verification.

KEY WORDS: Floatover barge; mating load; ballasting; mooring line

INTRODUCTION

Floatover installation has been the absolute solution to lifting installation as topsides nowadays are being fabricated in more sophisticated way which made them heavier and massive in size that exceeded lifting crane vessel capacity. Floatover installation is by means an operation of transferring topside directly from transportation barge (which also functioned as the installation barge) onto its substructure without the service of lift crane vessel and depends mainly on barge ballasting operation. The massive topside can be installed as a single unit instead of dividing it into several modules and this implies less hook-up and commissioning work. The risk of lift crane vessel availability can be neglected as it is not required for floatover installation operation, therefore improved the project schedule. Even though floatover installation is pioneered for massive topside, it is getting popularity among small to medium size topside too.

Floatover installation can be applied for topside installation of both fixed and floating platform. 18,000 ton EAP GN topside and 21, 800 ton Lunskoye-A topside had applied floatover installation onto jacket substructure and concrete gravity based structure respectively (Seji and Groot, 2007). 4,000 ton Kikeh topside (Edelson, et al., 2008) and 8,700 ton BZ34-1 CPP (He, et al., 2011) are among the small to medium size topside that applied floatover method. Koo, et al, (2010), studied a catamaran floatover method for more severe Gulf of Mexico seastates.

TOPSIDE FLOATOVER INSTALLATION PROCEDURES

Floatover installation procedures can vary depending on operator's approach, installation location, platform structural configuration, metocean conditions, weather window and equipment used as well. Floatover installation is comprised of aligning stage, load transfer stage and barge retrieval. Aligning stage is the preparation of topside to be aligned with substructure legs. Before installation, the barge along with topsides enters the substructure slot, the barge needs to discharge ballast (de-ballast) until the required clearance between the topside legs and substructure legs is achieved. The installation barge will then be positioned using a mooring system inside the substructure slot until the topsides legs align with upper part of substructure legs. Load transfer stage is the process of transferring the topside incrementally onto substructure legs until complete engagement is achieved between the topside and substructure. The barge is then retrieved from the substructure slot after required exit clearance is achieved. Fig. 1 below is a diagram showing the floatover installation sequence of topsides installation by a fork-shaped barge designed for the Caspian Sea, Turkmenistan which is the main subject discussed in this paper.

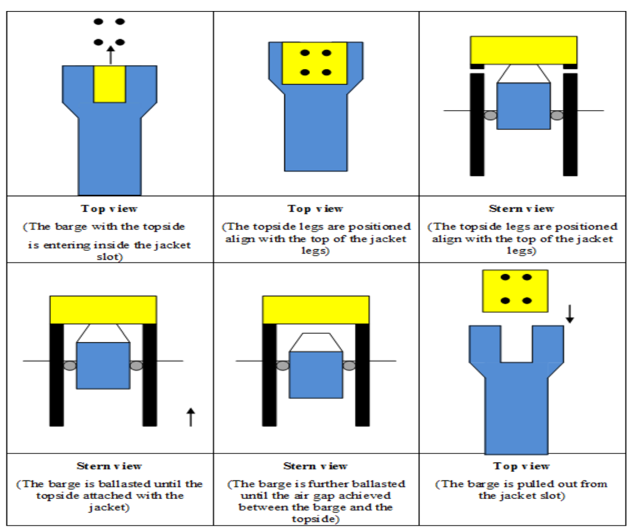

Fig. 1 Floatover installation sequence using fork-shaped barge

TEST OBJECTIVE

The main objective of this study is to develop methods to execute accurate and reliable assessment of equipment and systems for the application of floatover operations. For example the design of the elastomeric unit will be based on the investigation of the mating load interfaces between the topside leg and substructure leg. The correlation of mooring lines tension is important to design the mooring system in order to limit the longitudinal and transverse position of the barge during the installation. Lack of validation may result in overly-conservative design or limits on the weather window for operations, increasing costs, or worse, under-design, leading to potentially catastrophic failures.

Floatover has become the preferred application of offshore installation for large integrated decks. The developed capabilities can be applied to identify gaps in the present methods, and serve as a springboard to develop innovative solutions to improve on their limitations. Moreover, such capabilities can serve as a reality check, providing design safety assurance for frontier applications currently under consideration.

MODEL TEST DESCRIPTION

Model test is conducted by representing the topside floatover installation onto jacket substructure by measuring motions of installation barge (which has a unique shape of a fork; see Figure 7) along with topside in six degrees of freedom, mating loads and tension loads of mooring lines. The model tests were carried out in Offshore Engineering Laboratory, Universiti Teknologi PETRONAS. The wave basin has the dimension of 10 m wide, 22 m long and 1.5 m depth. The wave basin is equipped with multiple wave paddles that can generate regular and random waves, along with wave absorber to minimize the wave reflection. The instruments that used for the model tests are the wave probes, tension and compression load cells and motion capture camera functioning to measure waves, the tensions in the mooring lines, the mating loads, and motions of the barge and topside model respectively. The numbers and photos of instruments used for the model test are shown in Table 1 and Figs. 2~5 respectively. The instrumentation and data analysis use standard techniques. However, this is the first time such tests are carried out involving multiple moving bodies in this lab, or to our knowledge, in Malaysia. Developing the needed infrastructure for model construction, test set-up and execution is a major milestone.

Table 1. Number of instrument used

Instrument name	No. of instrument used
Compression load cell	4
Tension load cell	4
Motion captured camera	4
Wave probe	4

Fig. 2 Compression load cell

Fig. 3 Motion capture camera

Fig. 4 Tension load cell

Fig. 5 Wave probe

Fabrications of barge, jacket and topside model based on the scale of 1:50 were performed before the model test. The barge, which resembles a fork, is fabricated using marine plywood while both jacket and topside model were fabricated in steel. The prototype and model parameters are tabulated in Table 2 and the image of the models can be seen in Fig. 7 while the top view of head seas model test configuration is shown in Fig. 6.

Other miscellaneous items were also fabricated which consisted of receptor cone and cone, spring, strip bar and load cell housing. A total of four sets of receptor cones and cone were fabricated and functioned to assist the topside to mate with the jacket during mating phase. The receptor cone is located on top of each jacket leg while the cone is located at the bottom of the topside leg. A spring, attached to the load cell is inserted inside the cone. It functioned to model the stiffness of the entire jacket mating point. This unit can be adapted to study the effect of different types of mating units on the mating loads and platform behaviour. These miscellaneous items are captured in Figs 8 to 9.

The model tests were subjected by random wave sea state using JONSWAP spectrum with five wave parameters corresponding to head, beam, stern and quartering seas. The wave parameters are tabulated in Table 3. These wave parameters are likely to cause moderate to small responses of the barge and the most appropriate limiting wave conditions for the installation can be observed. The mooring system is comprised of four mooring lines attached at each corner of the barge. Each mooring line is composed of a wire and a linear spring and is cnnected to a load cell. The so-called soft mooring system determines the natural periods of horizontal motions. It was designed to be soft enough to avoid surge, sway and yaw natural periods within or near the wave-period range. At the same time, it should not be so soft that it allows large horizontal motions which could cause the barge to drift off station.

Table 2. Prototype and model parameters (Scale 1:50)

Subject	Dimension	Prototype	Model
Jacket	Leg spacing	14.0 x 12.0 m	0.28 x 0.24 m
	Height	58.6 m	1.172 m
Topside	Leg spacing	14.0 x 12.0 m	0.28 x 0.24 m
	Height	12.8 m	0.26 m
	Weight	2700 MT	21.6 kg
Barge	Length	159.76 m	3.2 m
	Width at bow	30.0 m	0.6 m
	Width at stern	45.72 m	0.91 m
	Lightweight	9250 MT	74 kg

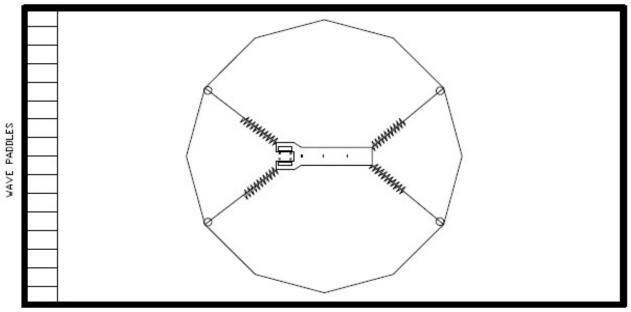

Fig. 6 Top view of model test configuration

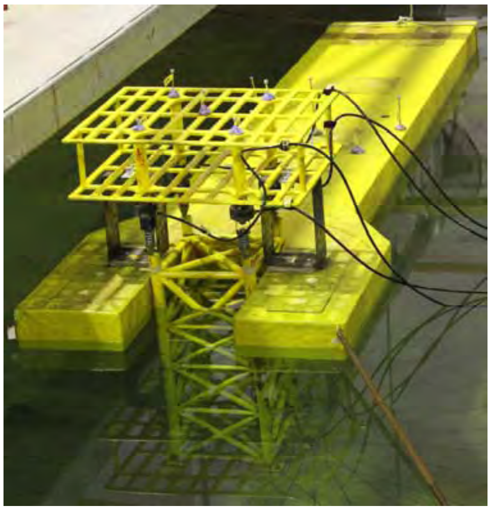
Fig. 7 Model of barge, jacket and topside are setup for the test

Fig. 8 Miscellaneous items for mating load measurement

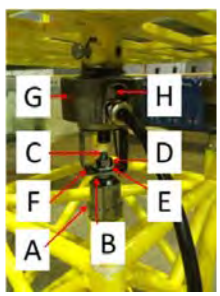

Fig. 9 Mating load measurement system

In order to simulate the ballasting of the barge, water is released through a culvert to change the water depth in the tank and hence the elevation of the barge relative to the jacket. While not entirely representative, this technique was found to be easier to control than pumping water into the barge compartments and is repeatable with good precision. The change in the total barge mass due to loss of water ballast is neglected using this method. Future efforts should be devoted to devlop controlled and repeatable modelscale water ballasting to improve the realism of the tests.

A series of wave calibration without the presence of model is conducted before running the actual the model test in order to assure the wave paddles generated the correct wave spectra. Table 3 contains the wave seastates and headings while Figs 10~14 represent comparison of wave spectra between the measured and targeted seastates. The calibrated wave spectra for all wave parameters closely match with the targeted wave spectra. The waves are calibrated at a fixed water depth in the basin.

Table 3. Tested seastates and headings, all Jonswap spectra, γ=3.3.

Wave headings	**Significant wave height, H_s (m)**		**Peak period, T_p (s)**	
	Prototype	Model	Prototype	Model
Head Beam Quartering Stern	0.5	0.01	7	0.98
	1	0.02	8	1.12
	1.5	0.03	7	0.98
	2	0.04	7	0.98
	2	0.04	8	1.12

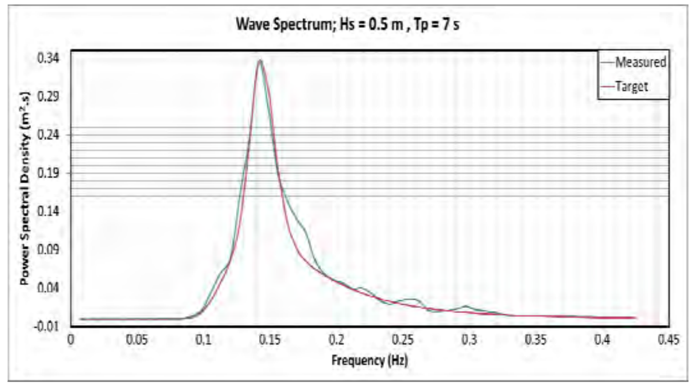

Fig. 10 Comparison between targeted and measured wave spectrum of H_s = 0.5 m, T_p = 7 s

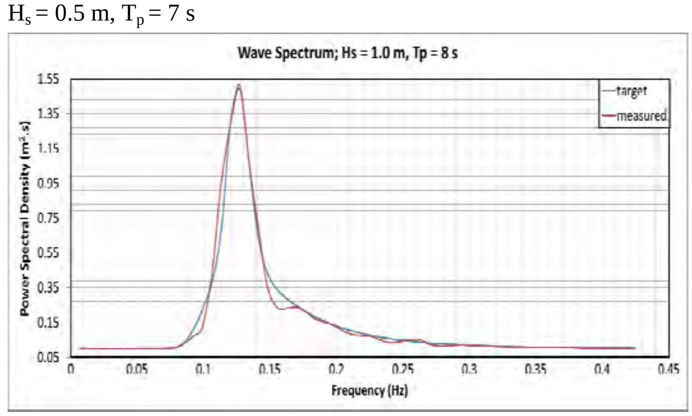

Fig. 11 Comparison between targeted and measured wave spectrum of H_s = 1.0 m, T_p = 8 s

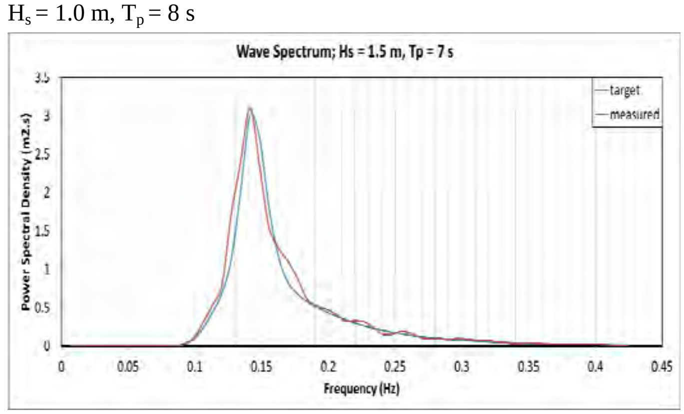

Fig. 12 Comparison between targeted and measured wave spectrum of H_s = 1.5 m, T_p = 7 s

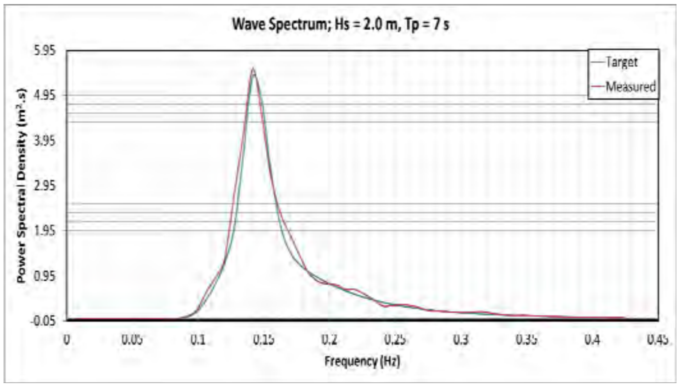

Fig. 13 Comparison between targeted and measured wave spectrum of H_s = 2.0 m, T_p = 7 s

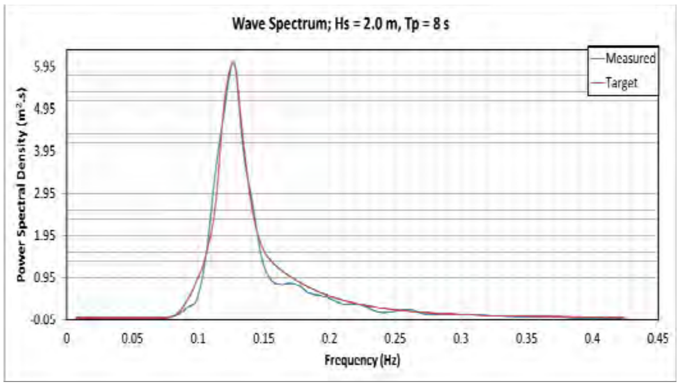

Fig. 14 Comparison between targeted and measured wave spectrum of Hs = 2.0 m, Tp = 8 s

RESULT AND DISCUSSION

The mooring line tensions are measured by a total of four tension load cells. Fig. 15 shows the comparison of standard deviations of mooring line tensions corresponding to the given seastates and wave headings. Note that the pre-tensions are fairly high in order to meet the requirements of the soft mooring. So, what is most important are the dynamic tensions (*St. Dev*.). The mooring line tensions generally increased slightly for increasing seastate severity (wave height and period) and appear highest in stern seas. The comparison of maximum mating load for each seastate and wave heading can be seen in Fig. 16. The maximum mating loads corresponded increased with increasing seastate severity (higher and longer waves). Head seas also recorded the highest mating load which resulted at significant wave height of 2.0 m at peak period of 8 seconds.

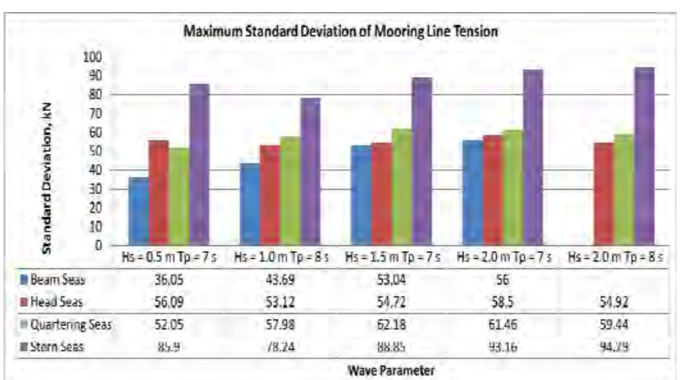

Fig. 15 Maximum standard deviation of mooring line tension

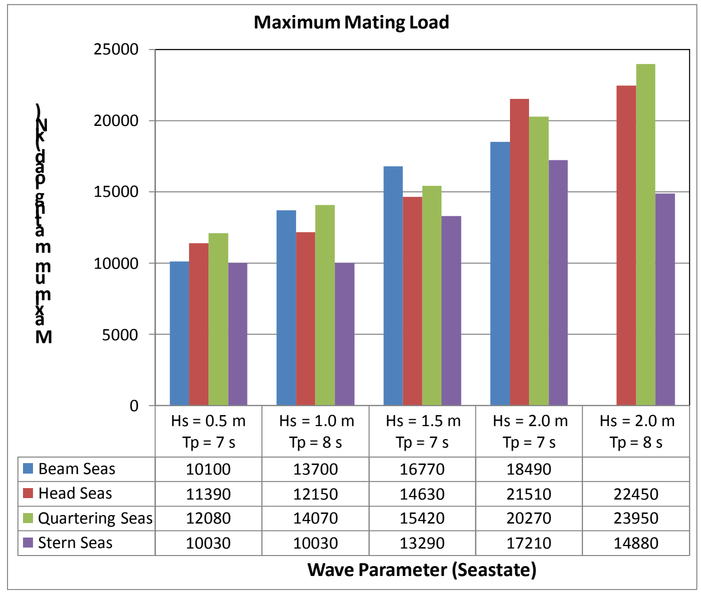

Fig. 16 Maximum value of mating load

The mating loads are measured by four compression load cells with a load cell positioned at the bottom of each topside leg. Fig. 17 shows the measured time history of mating loads corresponding to significant wave height of 1.0 m and peak period of 8 seconds for stern seas. The close-up view of the measured time history of mating loads measured by one of the four load cells can be seen in Fig. 18. As can be observed from Figs. 17 to 18, the load transmitted from the topside to the jacket gradually increases until the compression load becomes uniform as the operation finished around 10,000 seconds. The loads became uniform as 100% of topside weight is sustained fully by the jacket. These observations can be applied to other cases for other seastates and wave headings.

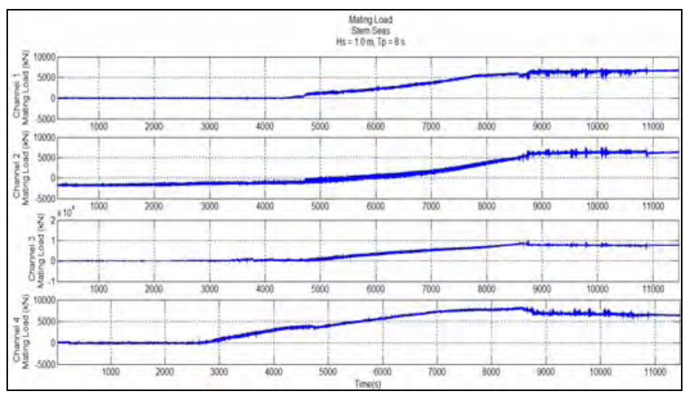

Fig. 17 Mating load corresponding to Hs = 1.0 m, Tp = 8 s of stern seas

The energy transmitted by mating load can be seen in Fig. 19. The maximum spectral density from the loading generally occurred at the same frequency as the wave spectrum of the respective seastates which can be seen in Fig. 11. There is also a peak at low frequency corresponding to one of the motion natural periods (around 38 seconds). In addition, a single distinctive peak, corresponding to the natural period of the structure occurs near 4.8 Hz. Similar behavior was observed in other cases as well.

The mode topsides and jacket are assumed to be rigid. In order to avoid accounting for the model scale dynamic structure response, it is necessary to filter out these high frequency loads, which do not represent the behavior of the full scale structure. In this way, the tests results can be used as input for the design of a shock absorbing device called a mating unit which is designed to absorb the loads. Recall that the model mating units include springs whose stiffness can be varied to account for different types of shock cells.

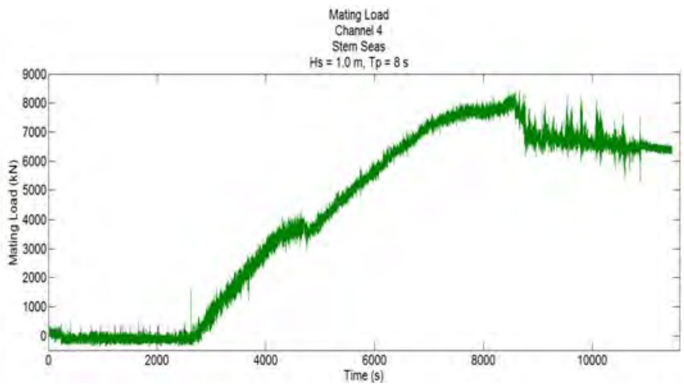

Fig. 18 Mating load of channel four corresponding to Hs = 1.0 m, Tp = 8 s of stern seas

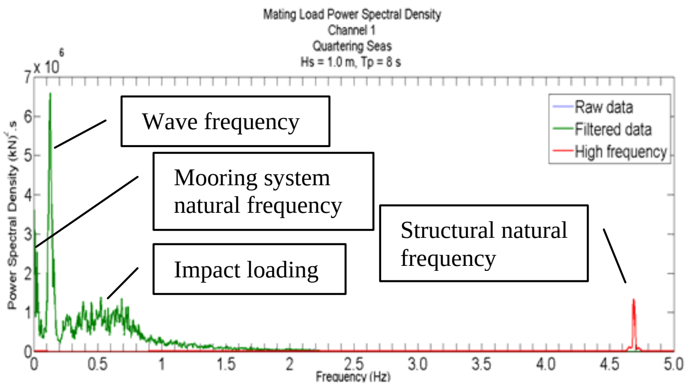

Fig. 19 Power spectral density of mating load corresponding to Hs = 1.0 m, Tp = 8 s of quartering seas

Fig. 20 shows the measured time history of one of the mooring line tensions corresponding to significant wave height of 1.0 m and peak period of 8 seconds of head seas. The tensions applied by the mooring lines vary continuously with a strong oscillation at the natural periods. Based on Fig. 20, a sudden jump in mooring tension occurred around 9,000 seconds. In Fig. 21, the mating loads are shown separated by filtering, so the effect on the mating loads at separation can be clearly seen.

As shown in Fig. 22, the barge movement, which had been constrained by the mating guides, suddenly slipped around 9,000 seconds, corresponding to the time when 100% load transfer was achieved. That caused a sudden release of the topside from the barge and caused the barge motion and mooring line tension to change abruptly in order to find a new equilibrium position. In a real operation, such a sudden movement which might be caused by release of seafastenings, would pose a risk to equipment and involved personnel and should be avoided. This could be done by careful monitoring of the mooring line tensions and design of the guide system. Alternatively, a smooth release mechanism should be designed to avoid sudden movements at the moment of load release. This will be a subject for further studies as this will improve safety during the actual operations.

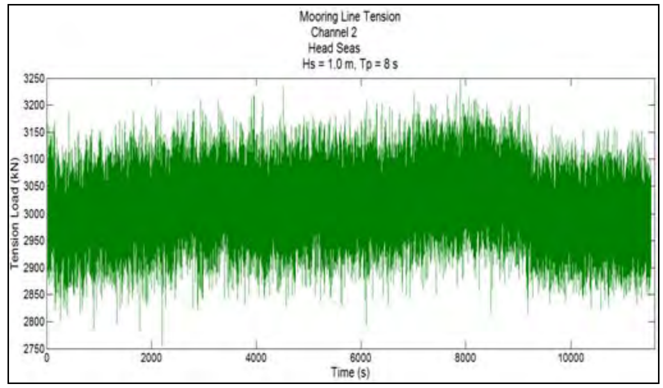

Fig. 20 Mooring line tension of channel 2 corresponding to Hs = 1.0 m, Tp = 8 s of head seas

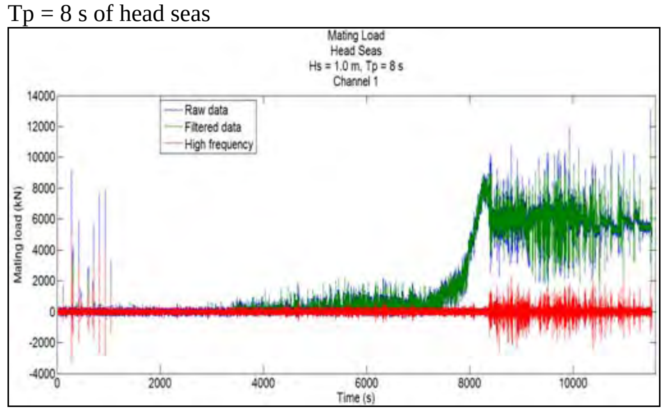

Fig. 21 Filtering of mating loads

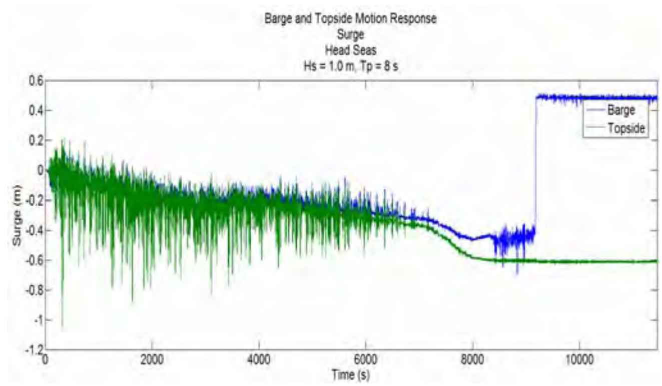

Fig. 22 Surge response of barge and topside corresponding to Hs = 1.0 m, Tp = 8 s of head seas

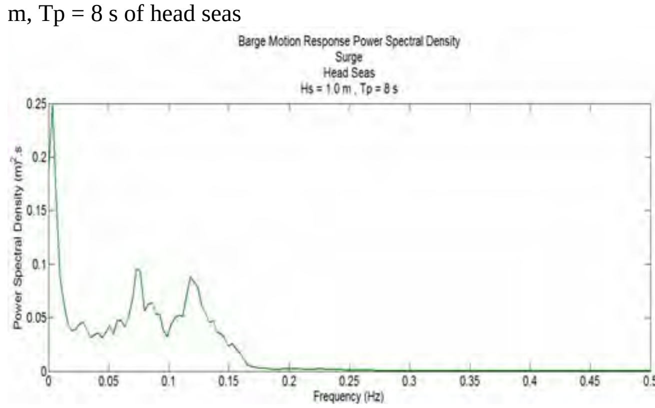

Fig. 23 Power spectral density of surge response of barge corresponding to Hs = 1.0 m, Tp = 8 s of head seas

Figs. 23~31 show the measured time history and power spectral densities of barge responses of surge, heave, sway, pitch and roll. As can be observed on Fig. 24, the barge along with the topsides move synchronously until the topsides starts to engage with the jacket around 6,500 seconds. As in the real life operation, the barge is further ballasted to achieve the safe clearance for barge retrieval. The same observation can be applied for Fig. 25 to 30. Fig. 26 shows that sway response of barge experienced a sudden rise which occurred around 9,000 seconds which also occurred in surge response of barge. The corresponding spectrum in Fig. 27 shows a clear peak at the sway natural period, around 40 seconds, which is well above the wave period, as expected from the design of the soft mooring. This demonstrates that the mooring system has been properly designed to avoid natural periods in the wave period range.

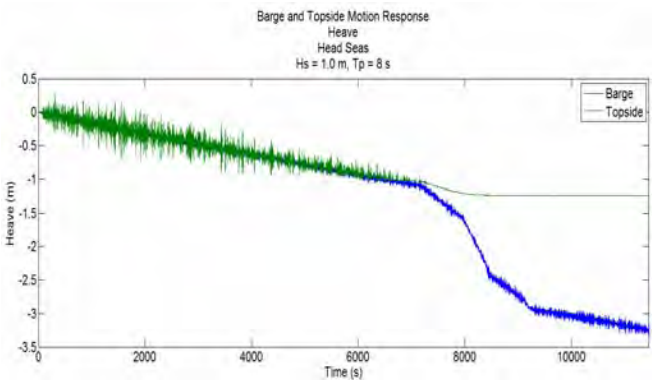

Fig. 24 Heave response of barge and topside corresponding to Hs = 1.0 m, Tp = 8 s of head seas

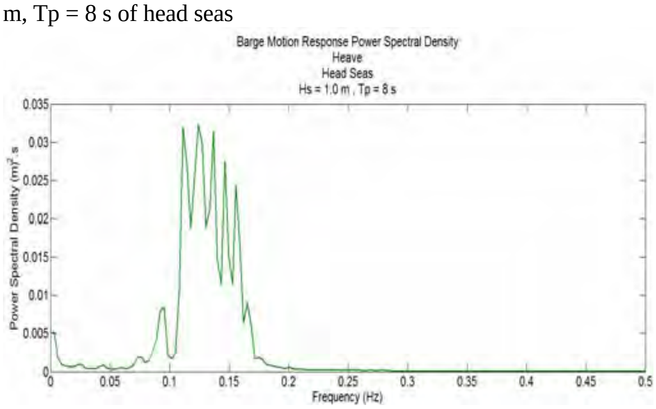

Fig. 25 Power spectral density of heave response of barge corresponding to Hs = 1.0 m, Tp = 8 s of head seas

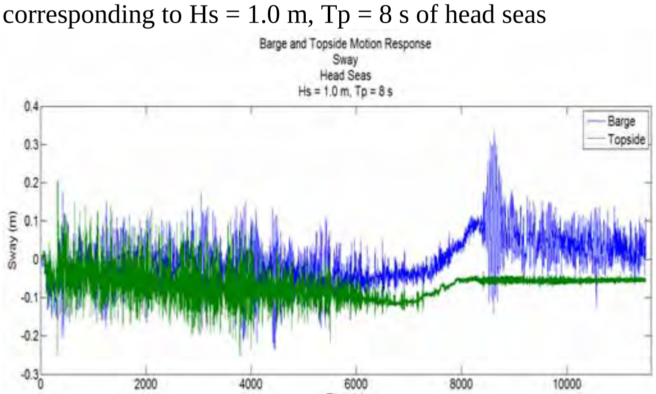

Fig. 26 Sway response of barge and topside corresponding to Hs = 1.0 m, Tp = 8 s of head seas

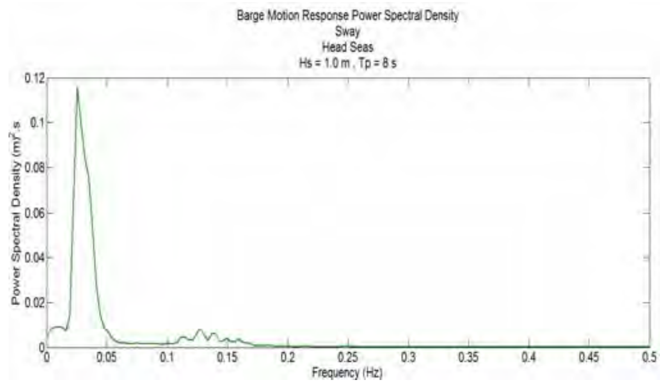

Fig. 27 Power spectral density of sway response of barge corresponding to Hs = 1.0 m, Tp = 8 s of head seas

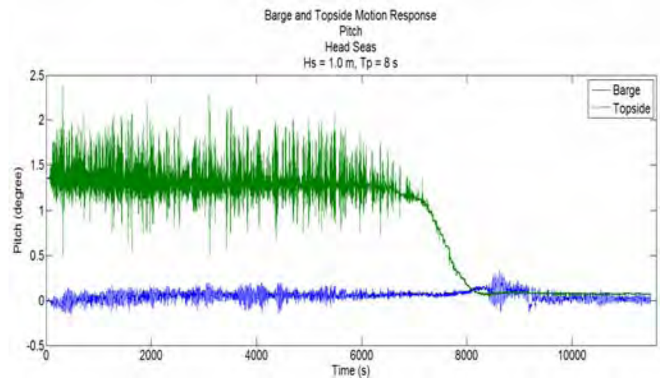

Fig. 28 Pitch response of barge and topside corresponding to Hs = 1.0 m, Tp = 8 s of head seas

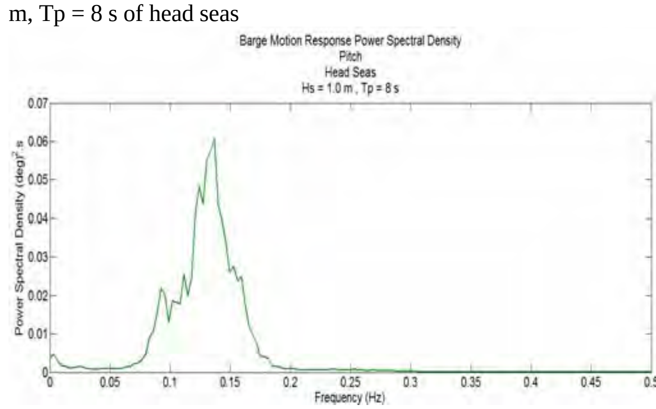

Fig. 29 Power spectral density of pitch response of barge corresponding to Hs = 1.0 m, Tp = 8 s of head seas

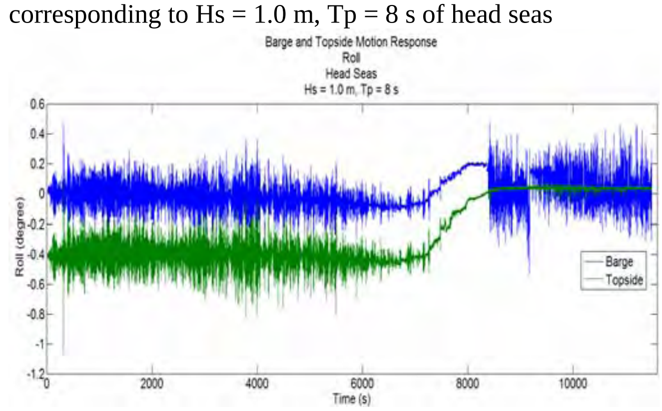

Fig. 30 Roll response of barge and topside corresponding to Hs = 1.0 m, Tp = 8 s of head seas

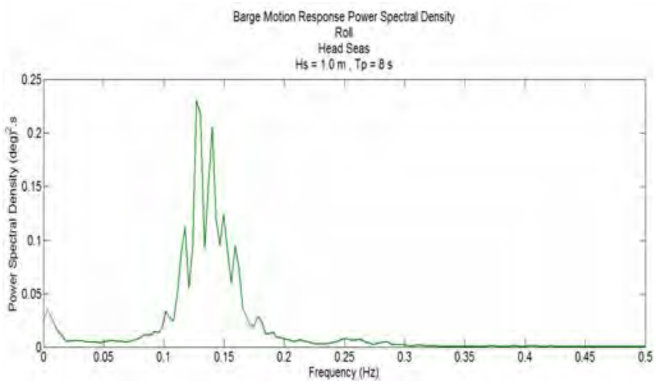

Fig. 31 Power spectral density of roll response of barge corresponding to Hs = 1.0 m, Tp = 8 s of head seas

CONCLUSION

The model tests serve to establish model testing infrastructure, instrumentation, data acquisition and analysis techniques and basic testing procedures and assure accurate results can be obtained reliably. Results need to be interpreted to understand the behavior of the model natural frequencies and irrelevant behavior needs to be filtered out. These capabilities will be put to use for further studies.

The sudden rise of surge and sway response of barge can be prevented by applying systematic load transfer mechanism, to be developed in a future study. Sudden load transfer, similar to what was observed in the tests can occur in actual installations, when cutting seafastenings releases residual loads. This load transfer mechanism should automatically develop zero connection between the topside and barge within a short period after the topside weight is sustained 100% by the jacket. This action will cause smooth separation and reduce the risk to equipment and personnel during the operation.

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