EXPERIMENTAL INVESTIGATIONS OF BARGE FLOATER WITH MOONPOOL FOR 5 MW WIND TURBINE

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ABSTRACT: *With the motivation towards sustainable development, the demand for renewable energy is increasing in the recent years. Wind turbines installed onshore, being one of the main renewable sources for electricity generation, are been pushed near the coasts and offshore for its advantages as compared to their counterparts on land. Current offshore wind turbines use fixed support structure like Jacket and Gravity type support structure which are efficient and economical only for shallow water depths. When attempting to establish deepwater wind farms, fixed support structures are not economically viable and hence floating support structures are needed. The complexity of design of floaters increases as they are more sensitive to wind and wave loads compared to fixed support structures. In this paper, a 1:100 scaled model of a barge type floater along with a 1:100 scaled model of NREL 5 MW wind turbine is tested under regular waves. Motion responses of the barge floater with moonpool are obtained in terms of Response Amplitude Operators (RAOs) for surge, heave and pitch degrees of freedom. This study serves as a platform to refine the design of barge type floaters for supporting offshore wind turbines.*

Keywords— Barge floater, NREL 5MW wind turbine, moonpool, hydrodynamic response.

I: INTRODUCTION

Offshore wind turbines are becoming more and more popular these days owing to their numerous advantages such as higher wind speed, low turbulence, large available area which ultimately lead to efficient wind energy harvesters compared to conventional land-based wind turbines. Though many countries have explored the ways of harvesting wind energy away from the shore by implementing offshore wind farms, it can be argued that there are further more potential and challenges that need to be analyzed and understood in order to fully utilize their advantages. The simplest way to establish an offshore wind turbine is to have a fixed support off the shore housing the wind turbine. However, fixed offshore wind turbines are not advantageous in all aspects. For example, in case of fixed wind turbines, the drawbacks are less stronger wind speeds, limited available area, high cost involved, to name a few. When attempting to establish deepwater wind farms, fixed support structures are not economically viable and hence floating support structures are needed. On the basis of strategy that is used to achieve stability, the floating configurations are classified into three broader categories viz. buoyancy based, ballast based and mooring lines based [1]. Design of such floating structures is complex and at the same time an important step in the overall designs of floating offshore wind turbines. These floating structures supporting the turbine have to be designed such that they provide stability for the entire system and withstand the encountered wind and wave loads.

Several types of floaters to support the offshore wind turbine have been investigated by different researchers.

Two floater concepts [2] a three legged tension –leg platform and a four legged taut – moored system for floating wind turbine systems of 1.5MW capacity for their performance in wind and wave. Lee [2] investigated the response of TLP and Spar buoy floaters for an NREL base line 5 MW wind turbine. Wayman [3, 4] studied the three different types of floating supporting structures; shallow drafted barge (cylinder), TLP (surface) and TLP (submerged). It was concluded that the barge has lowest cost of construction among the others, but TLP submerged supporting structure exhibited least response in all conditions.

It is reported that one of the simplest (in design and implementation and cost) types of the floating configuration is the barge type floating structure which achieves stability through buoyancy using the water plane area. Hence, in this study, a typical barge type floating structure suitable for 5 MW wind turbine is considered and hydrodynamic analysis of the barge is carried out by experimental which will aid in design of such floating structures. Minimized motion response of the system being a main design driver for the barge design, one of the key aspects of

this paper is to investigate the effect of moonpool on the motion characteristics of the barge.

II: DETAILS OF THE NREL 5 MW WIND TURBINE

The wind turbine used in this study is the NREL 5MW offshore baseline wind turbine model and the chosen model does not correspond to an operating turbine. It is a realistic representation of a three-bladed upwind 5 MW wind turbine wherein its properties are drawn and extrapolated from operating machines and conceptual studies. NREL suggested a 5 MW wind turbine or higher for offshore. The properties of NREL 5 MW wind turbine are listed in Table 1.

Table 1.Details of 5 MW wind turbine mode Ref [5]

DETAILS OF WIND TURBINE	VALUE
Rating	5 MW
Rotor Orientation, Configuration	Upwind, 3 Blades
Rotor Diameter, Hub Diameter	126 m, 3 m
Hub Height	90 m
Rated Tip Speed	80 m/s
Overhang, Shaft Tilt, Precone	5 m, 5º, 2.5º
Rotor Mass	110,000 kg
Nacelle Mass	240,000 kg
Tower Mass	347,460 kg

III: BARGE TYPE FLOATER

A schematic view of the barge type floater is shown in Fig 1. A barge type of floater achieves stability through water plane area. It is connected to sea bed by catenary mooring system for station keeping purposes. Advantages of barge floater for wind turbine [4, 6] are:

- o Simple construction technique that can be fabricated at shore
- o Ease of transportation and installation
- o Large deck area that can accommodate the transmission equipments
- o Comparatively simpler analytical and numerical tools for response analysis
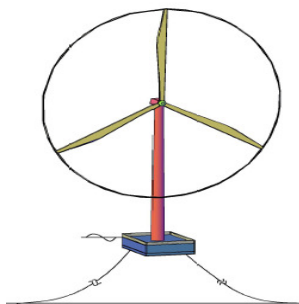- o Wind turbine can be mounted at ship yard

Fig 1.Schematic view of a barge type floater

With careful design such floaters can play a vital role for supporting the wind turbines far offshore.

IV: EXPERIMENTAL DESCRIPTION OF BARGE FLOATER WITH MOONPOOL

The details of the barge chosen for the experimental study with moon pool are given in Table 2. The scale factor (1:100) is selected based on the size of the wave flume facilities available at Ocean Engineering Department, IIT Madras. Scaling has been done based on Froude law. Acrylic (density = 1100 kg/m^3) is used to fabricate the barge model. Three rotor blades and tower of the wind turbine are fabricated by using PVC (density = 1400kg/m^3). The model of barge with wind turbine is shown in Fig 2.

Experiments are carried out in the wave flume for the wave period range of 0.8 to 2 s. which is within the range of wave maker. Three uni axial accelerometers are used to measure the response of the floater with wind turbine. Surge motion is measured by keeping the accelerometer at centre of the barge deck, heave and pitch motions are measure by keeping the accelerometer at ends of the barge deck. Barge with accelerometers is shown in Fig 3.

Table 2.Details of the experimental data for prototype and model

DESCRIPTION	PROTOTYPE	MODEL (1:100)
B/L RATIO	1	1
Length (m)	40	0.4
Breadth (m)	40	0.4
Draft (m)	4	0.04
Free board (m)	6	0.06
moonpool(W×L×H)	40m×40m×10m	0.4m×0.4m×0.1m
Mass, including Ballast(kg)	5452000	5.452
Water displacement(m^3)	6000	0.006
Roll/Pitch inertia about CM(kg.m^2)	726900000	0.073
Yaw inertia about CM(kg.m^2)	1453900000	0.145
Water depth(m)	100	1

The barge model is installed in the centre of the wave flume to head sea. Barge model is moored by horizontal springs to reduce the drift motion. Wave probe is place 1m before the barge model to measure wave height of incident wave. Floating view of barge model is shown in Fig 4.
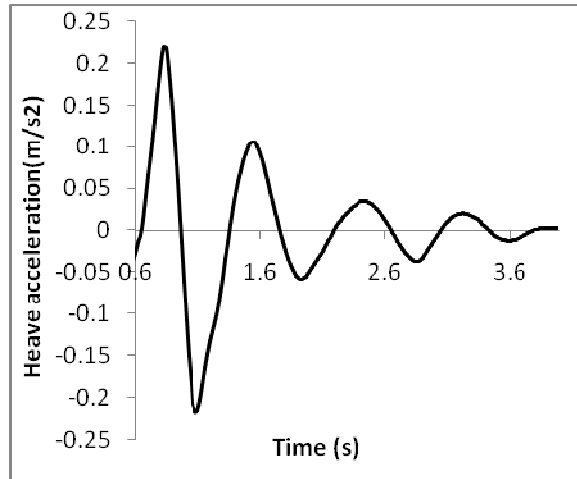
Fig 2.Experimental model of barge with wind turbine
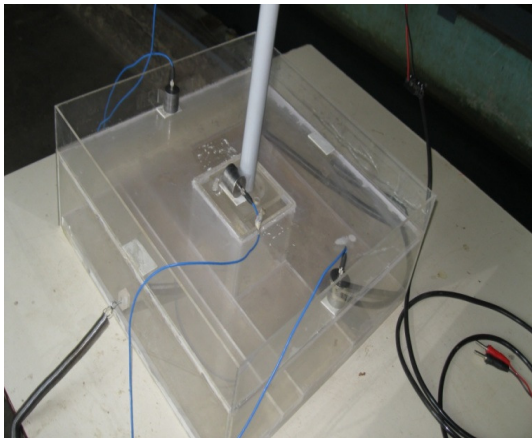

Fig 5.Heave acceleration of model with wind turbine
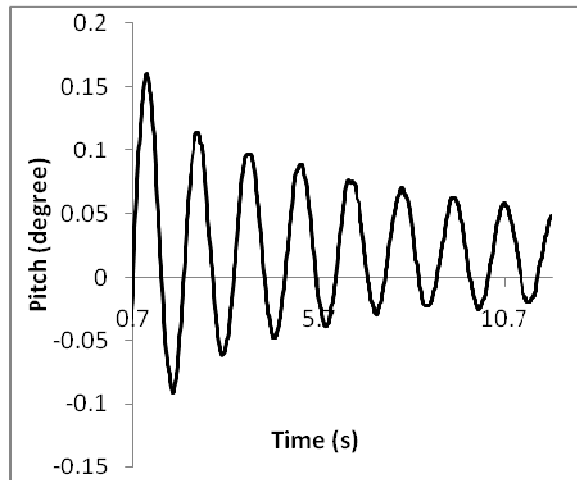

Fig 3.Barge model with accelerometers
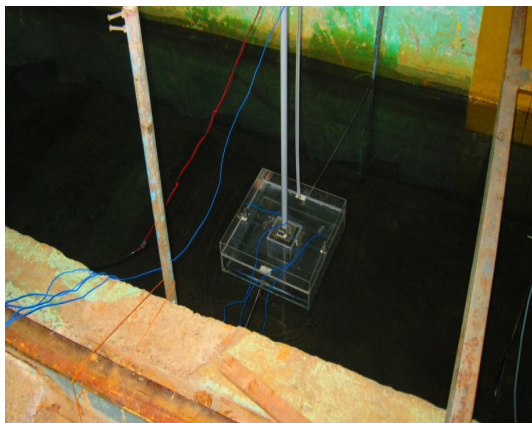

Fig 6.Pitch motion of model with wind turbine
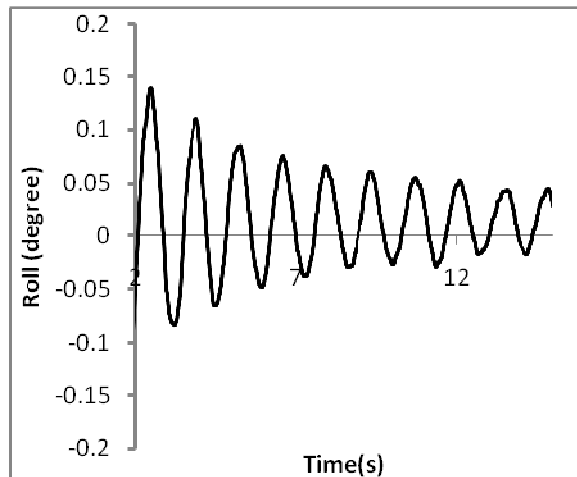

Fig 4.Barge model in 2m wave flume

Fig 7.Roll motion of model with wind turbine

V: EXPERIMENTS: FREE OSCILLATION TEST

Free oscillation tests are carried for Heave, Pitch and Roll motions in 2m wave flume in 1m water depth. Displacements have been given in respective degree of freedom and time series was recorded and shown in Fig 5, 6 & 7.

Natural period and damping ratio are calculated by using the logarithmic decrement method. Values are shown in Table 3

Table 3: Natural period and damping ratio of barge model

MODE	NATURAL PERIOD(S)	DAMPING RATIO
Heave	0.7	0.21
Pitch	1.4	0.04

VI: RESPONSES OF BARGE FLOATER BY EXPERIMENTAL ANALYSIS

Response amplitude operators of barge model with wind turbine for surge, heave and pitch motions are shown in Fig (8, 9 & 10)
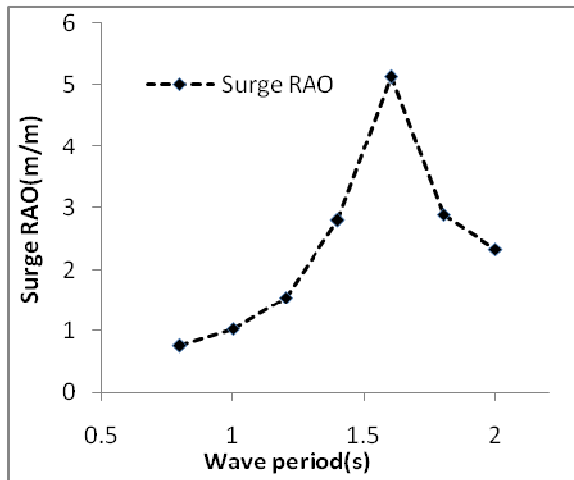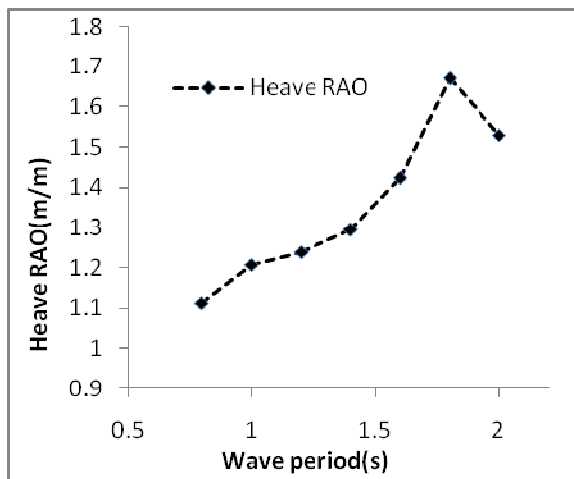

Fig 8. Surge RAO of barge floater
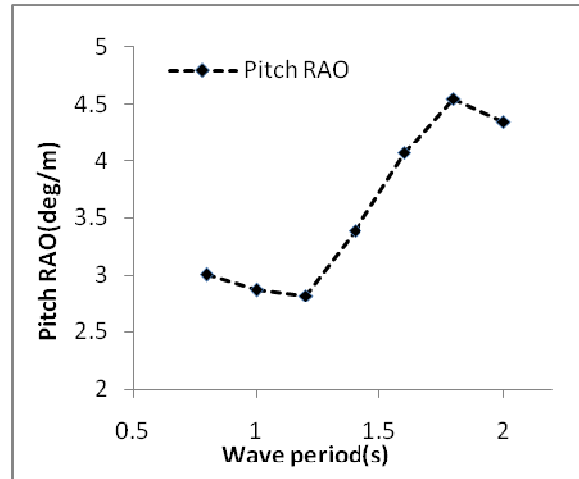

Fig 9. Heave RAO of barge floater

Fig 10. Pitch RAO of barge floater

The surge RAO, see Fig. 8, increases as the wave period increases upto 1.6 s and then decreases. The heave and pitch RAOs also show an increasing trend for the wave period range between 0.7 and 1.8 s and 1.2 and 1.8 s respectively. Both the heave and pitch RAOs shows a peak near 1.8 s which can be possibly indicate a strong coupling effects. As the experiments were carried out starting from 0.8 s wave period (limitations of the wave flume) the heave RAO behaviour near natural period is not obtained in Fig. 9. The devoid of peaks at natural frequency of pitch at 1.4 s also requires further investigation of the data.

VII: SUMMARY

A 1:100 scaled model of a barge type floater along with a scaled model of 5 MW wind turbine is fabricated and tested in regular waves and preliminary results are presented. Free vibration results in heave and pitch degrees of freedom are presented. Surge, Heave and Pitch RAOs are also obtained from the experiments and reported. These preliminary results can be used to check the suitability of the barge at a designated site for supporting the offshore wind turbine. The test data requires further invesitgations.

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