FOUNDED 1862 ABS

PROGRESS REPORT

Floating Wind Turbines

Contract M11PC00004
TA&R Project 669

Submitted to

U.S. Department of the Interior
Bureau of Ocean Energy Management, Regulation, and Enforcement
381 Elden Street, Herndon, Virginia 20170-4817

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American Bureau of Shipping
Corporate Offshore Technology, Renewables
16855 Northchase Drive
Houston, TX 77060

1. Project Status and Accomplishments

The project team carried out data collections, model building and numerical simulations for the selected critical load cases for three (3) design concepts as proposed in *Task 2 Case Study Using the Existing Design Concepts and US OCS Conditions.*

As outlined in the proposal, three representative US coastal regions are considered in the case study. Regional metocean conditions for the GoM Central are based on API 2INT MET. For the US west coast, the site metocean data of northern California are derived from the NOAA buoy and water level station data analysis as per BOEMRE's request. For the US east coast, the site metocean data are based on the historical data analysis using the measurements from NOAA buoy and water level station located near the coast of Maine.

The three (3) concept designs employed in the present case study are based on the existing designs, namely the OC3 Hywind Spar, the MIT/NREL mono-column TLP and the OC4 WindFloat Semi-submersible concepts. A total of 29 load cases for each of three concepts are defined. These load cases include parked, power production, start-up and shut down conditions for the wind turbine. For the parked conditions, both 50-year and 100-year return environmental conditions are considered. Load cases for combined wind and wave conditions, and wind only cases are considered to quantify the relative importance of wave and wind induced responses. Effects of yaw fault and misalignment of wind and wave are also investigated in the case study.

NREL 5MW baseline offshore wind turbine is used in the analysis. A generic control scheme designed by NREL for the OC3 Hywind Spar is applied to all the three concepts. The water depth is assumed to be 320m, which is the same as the one used in the study of OC3 Hywind Spar. The tower base is 24.6m above MSL (Mean Sea Level). The hub height is 95m above MSL. The diameter and wall thickness of the tower are taken as the same as the OC3 Hywind Spar tower. The tower height is modified to 68m from 77.6m originally used in the OC3 Hywind Spar.

The global performances of the three concepts have been analyzed using a fully coupled time-domain aero-hydro-servo-elastic program, CHARM3D-FAST, which is developed through a joint research project of Texas A&M University and ABS. The 6-DOF (Degree-Of-Freedom) motions, offset and heel of the platform, the line tensions in mooring lines and tendons, the overturning moments (OTM) and shear forces at tower base are obtained from the analysis.

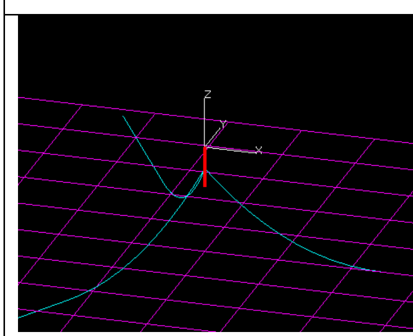
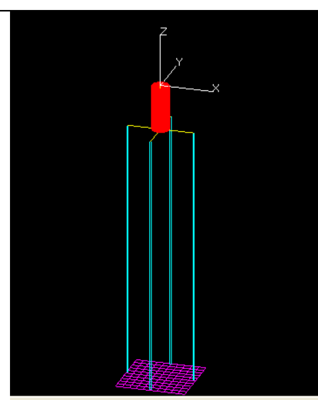
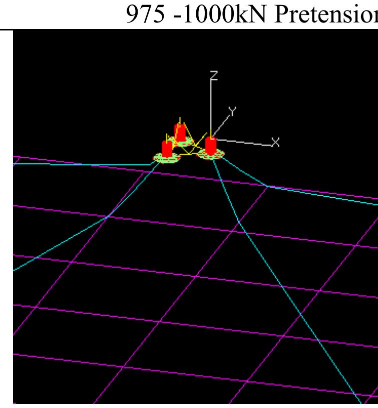
A brief summary of the design concepts, metocean condition assessment, load cases and analysis results are given below. It is expected that all the results will be reviewed in the coming months as the project team works on the remaining project tasks. The final report will include a chapter summarizing the input data and detailed results of the case study.

Existing Design Concepts

The three (3) conceptual designs selected for the case study are based on the existing designs, namely the OC3 Hywind Spar, the MIT/NREL mono-column TLP and the OC4 WindFloat Semi-submersible concepts. The main particulars of the three concepts are listed in the table below. The CHARM3D models of coupled floater and mooring system are also shown in the table. Literature study shows that the original existing design concepts were verified by limited number of load cases along with less demanding metocean conditions. The first few attempts to perform the case study using these original designs resulted in unrealistic results. These design concepts were therefore modified in order to meet the design requirements in terms of global motions and line tensions under severer metocean conditions such as 100-year tropical cyclones (hurricane). Main modifications are summarized as follows:

- The case study showed that the tendons used in the MIT/NREL TLP could become slack under the GoM central hurricane conditions. The project team addressed this issue by increasing the tendon fairlead radius and tendon pretensions. Material properties of 188mm diameter spiral wire rope have been used in the analysis. Due to increased pretensions, the weight of concrete ballast used in the original concept was reduced.
- For the WindFloat semi-submersible, the chain size was increased from 3 inch to 4 inch in order to meet the strength requirement for mooring lines. Pretensions were also increased to prevent contact of polyester rope to the sea floor.
- For the OC3 Hywind Spar, the weight of spar hull was increased to accommodate higher hub height.

Table 1 Main Particulars

Spar		**TLP**		**Semi-submersible**	
Draft	120 m	Draft	47.89 m	Draft	17 m
Displacement	8230 m-ton	Displacement	12485 m-ton	Displacement	4640 m-ton
Diameter	9.4 – 6.5 m (tapered)	Diameter	18 m	Column Diameter	10 m
Mooring System: 3 lines 902.2m length each line 77.7 kg/m dry weight 970kN pretensions		Tendon System: 8 lines 188mm spiral wire rope 35m tendon fairlead radius 8000kN Pretension		Mooring System 4 lines 80m 4-inch top chain 30 m-ton clump weight 718m 5-inch polyester rope 80m 4-inch bottom chain 975 -1000kN Pretension	
					

Metocean Condition Assessment

The main purpose of metocean condition assessment is to provide indicative metocean data near the US West and Northeast coasts for the case study. The assessment is not meant to be a rigorous exercise of metocean condition assessment, which normally involves hindcast data analysis. It is instead based on the historical data analysis using the selected NOAA buoy and water level stations.

Three representative US coastal regions are considered in the case study.

- For the GoM, metocean data for the GoM Central region as defined in API 2INT MET are applied in the case study. For operating conditions with wind speeds lower than 10-yr return values, theoretical correlations between wind speed and wave height and period are used to derive associated wave parameters.

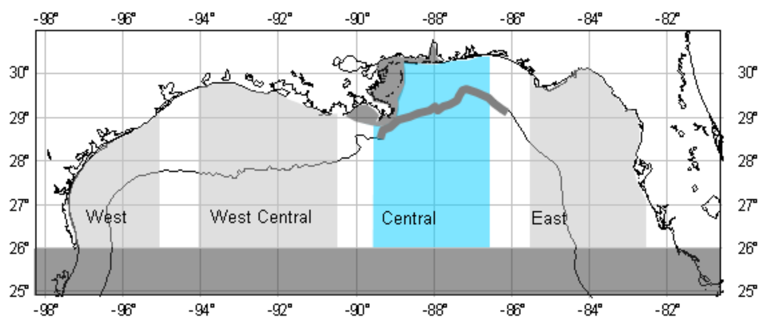


Figure 1. GoM Central Region

- For the US west coast, the site metocean data of northern California coast are derived from the historical data analysis using the measurements from NOAA NDBC buoy (Station 46022) and NOAA NOS water level station (Station 9418767). Wind and wave data analyses based on the measurements from Station 46022 are also verified by the historical data analysis for the nearby NOAA NDBC Station 46027.

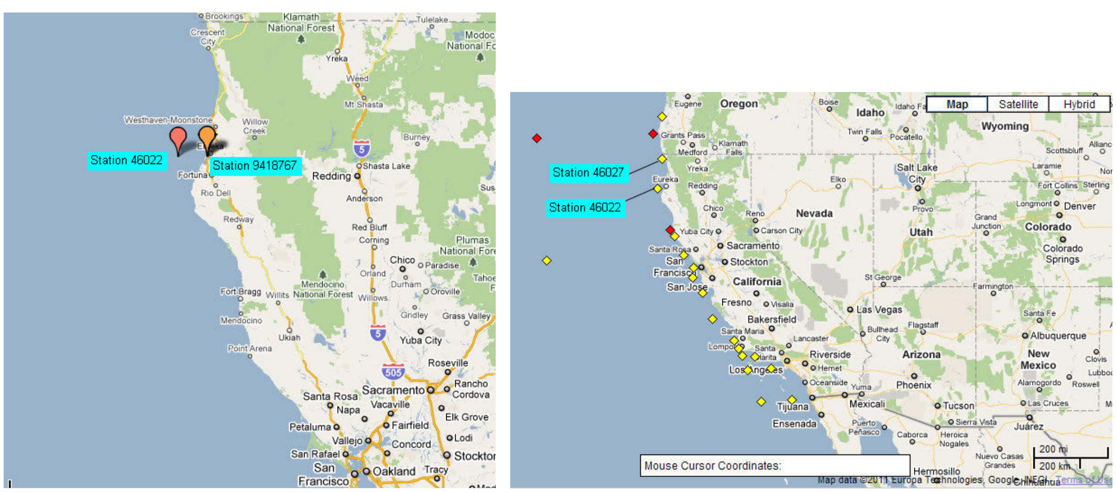


Figure 2. Locations of NOAA Stations Selected for the US West Coast Case Study

- For the US northeast coast, the original plan was to use the regional metocean data developed by ABS in-house. After re-evaluating the available in-house data however, the project team believes that using the public domain information from NOAA makes more sense for the present study and the metocean condition assessment results are also easier to be verified. In this regard, the site metocean data of Northeast Pacific coast are derived from the historical data analysis using the measurements from NOAA NDBC buoy (Station 44005) and NOAA NOS water level station (Station 8418150). Wind and wave data analysis based on the measurements from Station 44005 are further verified by the historical data analysis for the nearby NOAA NDBC Station 44007.

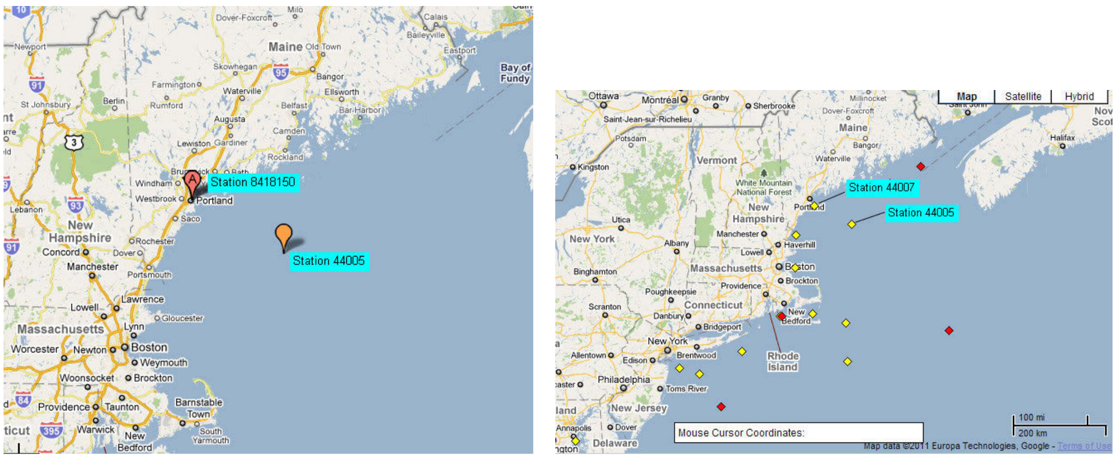


Figure 3. Locations of NOAA Stations Selected for the US East Coast Case Study

Load Cases

A total of 29 load cases are defined for each concept for the cases study as shown in below table.

Table 2 Load Cases

#	DLC	Location	Wind	Wave	Current	Water Level	Wind/Wave Misalignment	Yaw Misalignment	Remark
1	6.2a	GoM Central	100yr, API	Hs=1.09Hs,100yr	100yr	100yr	co-linear	0º	1 hr simulation, 6 seeds
2	6.2a	GoM Central	100yr, API	Hs=1.09Hs,100yr	100yr	100yr	co-linear	30º	sensitivity, 1 seed
3	6.2a	East Coast	100yr, API	Hs=1.09Hs,100yr	100yr	100yr	co-linear	0º	1 hr simulation, 6 seeds
4	6.2a	East Coast	100yr, API	Hs=1.09Hs,100yr	100yr	100yr	co-linear	30º	sensitivity, 1 seed
5	6.2a	West Coast	100yr, API	Hs=1.09Hs,100yr	100yr	100yr	co-linear	0º	1 hr simulation, 6 seeds
6	6.2a	West Coast	100yr, API	Hs=1.09Hs,100yr	100yr	100yr	co-linear	30º	sensitivity, 1 seed
7	6.2a	GoM Central	50yr,API	Hs=1.09Hs,50yr	50yr	50yr	co-linear	0º	1 hr simulation, 6 seeds
8	6.2a	GoM Central	50yr,API	Hs=1.09Hs,50yr	50yr	50yr	co-linear	30º	sensitivity, 1 seed
9	7.1a	GoM Central	10yr,API	Hs=1.09Hs,10yr	10yr	10yr	co-linear	0º	1 hr simulation, 6 seeds
10	7.1a	GoM Central	10yr,API	Hs=1.09Hs,10yr	10yr	10yr	co-linear	30º	sensitivity, 1 seed
11	6.2a	GoM Central	100yr,API	Hs=1.09Hs,100yr	100yr	100yr	30º	0º	1 hr simulation, 6 seeds
12	6.2a	GoM Central	100yr,API	Hs=1.09Hs,100yr	100yr	100yr	30º	30º	sensitivity, 1 seed
13	6.2b	GoM Central	100yr, 1min	H=Hmax,100yr	100yr	100yr	co-linear	0º	steady wind, regular wave
14	6.2b	GoM Central	100yr, 3s	H=0.7Hmax,100yr	100yr	100yr	co-linear	0º	steady wind, regular wave
15	1.3	ALL	Vr=11.4 m/s	Hs=E[Hs|Vhub]	NCM	MSL	co-linear	0º	power production
16	3.2	ALL	Vr=11.4 m/s	Hs=E[Hs|Vhub]	NCM	MSL	co-linear	0º	start-up
17	5.1	ALL	Vr=11.4 m/s	Hs=E[Hs|Vhub]	NCM	MSL	co-linear	0º	emergency shut-down
18	6.2a	East Coast	50yr, API	Hs=1.09Hs,50yr	50yr	50yr	co-linear	0º	1 hr simulation, 6 seeds
19	6.2a	East Coast	50yr, API	Hs=1.09Hs,50yr	50yr	50yr	co-linear	30º	sensitivity, 1 seed
20	6.2a	West Coast	50yr, API	Hs=1.09Hs,50yr	50yr	50yr	co-linear	0º	1 hr simulation, 6 seeds
21	6.2a	West Coast	50yr, API	Hs=1.09Hs,50yr	50yr	50yr	co-linear	30º	sensitivity, 1 seed
22	7.1a	East Coast	10yr, API	Hs=1.09Hs,10yr	10yr	10yr	co-linear	0º	1 hr simulation, 6 seeds
23	7.1a	West Coast	10yr, API	Hs=1.09Hs,10yr	10yr	10yr	co-linear	30º	sensitivity, 1 seed
24	7.1a	East Coast	10yr, API	Hs=1.09Hs,10yr	10yr	10yr	co-linear	0º	1 hr simulation, 6 seeds
25	7.1a	West Coast	10yr, API	Hs=1.09Hs,10yr	10yr	10yr	co-linear	30º	sensitivity, 1 seed
26	1.3	ALL	Vin=3 m/s	Hs=E[Hs|Vhub]	NCM	MSL	co-linear	0º	power production
27	1.3	ALL	Vout=25 m/s	Hs=E[Hs|Vhub]	NCM	MSL	co-linear	0º	power production
28	3.2	ALL	Vout=25 m/s	Hs=E[Hs|Vhub]	NCM	MSL	co-linear	0º	start-up
29	5.1	ALL	Vout=25 m/s	Hs=E[Hs|Vhub]	NCM	MSL	co-linear	0º	emergency shut-down

Results for Critical Load Cases

The preliminary observations based on the case study results for the three concepts under GoM central metocean conditions are summarized as follows.

<u>Number of realizations (simulation seeds)</u>

For DLC3.2, 1.3 and 5.1, the maximum value of a response parameter is the maxima of twenty (20) 10-mintue simulations. For DLC7.1a and 6.2a (Parked), the maximum value of a response parameter is based on the average of maxima of six (6) 1-hour simulations. For the yaw fault conditions, results are based on one (1) simulation with one random seed and verified by the sensitivity analysis.

<u>Wind field data and wind spectrum</u>

For DLC6.2a under 100-yr conditions, wind data are generated using three combinations of grid size and wind spectra, including API (NPD) wind model with 51×9 grid, IEC (Kaimal) wind model with 51×9 grid and IEC (Kaimal) with 20×26 grid. Both hub height and full field wind data are generated.

Results show that wind spectra and grid size have noticeable influences on the maximum responses. The horizontal gird size has obvious effects on the platform yaw motion.

Using hub height wind data in general results in higher responses than using full field wind data.

<u>Wind and wave effects</u>

Results obtained using various combinations of wind, wave and current reveal that current and wind contribute most of the steady loads. Wave, on the other hand, contributes most of the dynamic components of global loads. Wave induced dynamic loads can be larger than combined wind and current loads, especially for the tower base shear and OTM.

<u>Yaw fault</u>

Yaw fault in general increases wind load and thus the responses.

<u>Tidal effects for TLP</u>

Three water levels (HSWL, MSL and LSWL) are analyzed for the DLC7.1a and DLC6.2a. High still water level (HSWL) is critical for maximum tendon tension, while low still water level (LSWL) is critical for minimum tendon tension.

<u>Instability</u>

An instability problem is identified for the spar concept. The following figures show the sudden blow-out of platform sway, yaw and pitch motions as well as tower top side-to-side motion for DLC6.2b. This is probably caused by the generic turbine control scheme which may introduce the negative damping as observed in other studies.

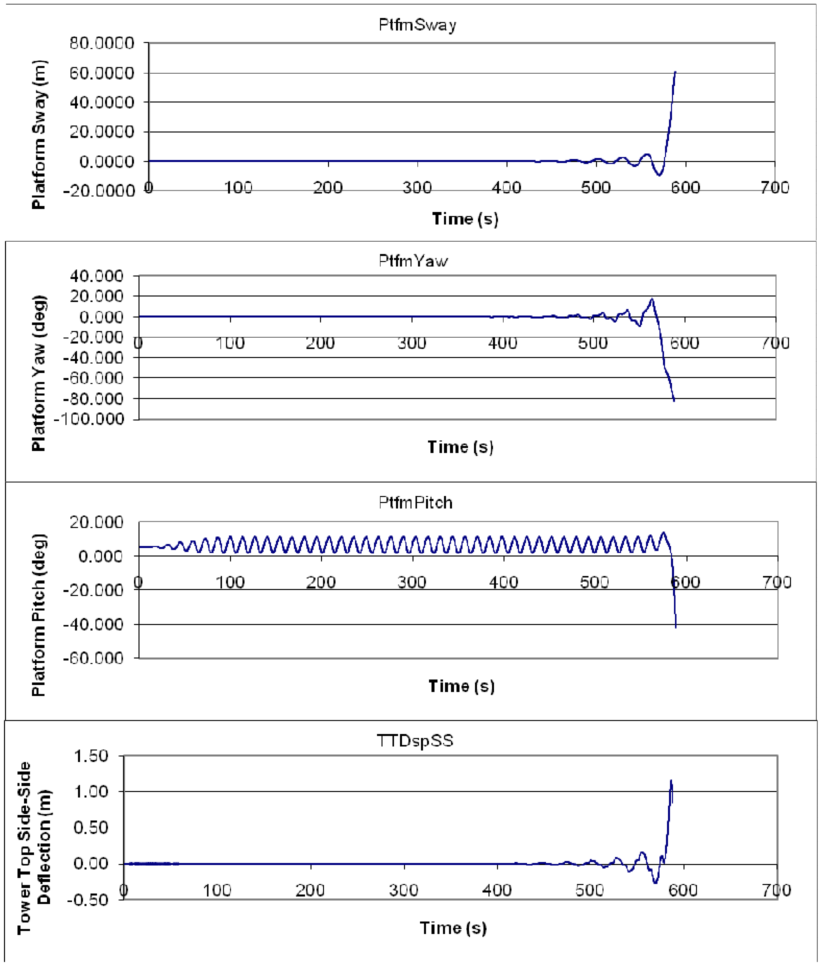


Figure 4. Instable Reponses of Spar – DLC6.2b

2. On-Going Activities

The project team is working on the remaining load cases and post-processing results for the *Task 2 Case Study Using the Existing Design Concepts and US OCS Conditions.* The project team has also started working on *Task 3: Assessment of Critical Technical Areas for Floating Wind Turbine Design* in light of the findings from the case study and previous literature reviews.

3. Issues

The mechanism of the instability of spar concept needs further investigations. The project team will explore, if possible, other means of defining the control scheme based on previous experience such that the instability of spar concept can be resolved.