DYNAMIC PERFORMANCE ANALYSIS OF A NEW SEMI TYPE FLOATING OFFSHORE WIND TURBINE PLATFORM

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ABSTRACT

A new semi type floating offshore wind turbine platform called Y-Wind is developed to support a 5MW wind turbine, considering various design aspects from engineering through to installation, which can reduce the CAPEX. The platform is designed to achieve the integration of the tower and rotor to the platform at quayside in a US shipyard. Also a proper lightship draft is considered in the early platform design phase to enable wet-tow from the yard to the installation site with no dedicated extra equipment, as the majority of shipyards in US east and west coasts may not be able to accommodate floating wind platforms with deep lightship draft.

The Y-Wind platform with damping plates consists of four columns having the same diameter. No deck structures and braces are used. Center column supports a 5MW wind turbine and three other offset columns connected to the center column by respective pontoon are optimally placed such that the hydrostatic stability and minimal static heeling angle by wind turbine peak thrust are ensured. The platform is moored with three catenary lines with a sufficient length to avoid the uplift at the anchor.

Time domain coupled simulations under typical US offshore metocean conditions are conducted to assess the platform dynamic responses including motions, accelerations, and mooring tensions for the design load cases of the power production, 50-yr extreme and 500-yr survival conditions in accordance with ABS floating offshore wind turbine guide. The present design is checked against the ABS design criteria and confirmed to comply with the design requirements. Also significant reductions of motions are observed due to the damping plates, which also results in reducing the mooring line tensions. Preliminary global structural analysis was performed to assess the stress ratios of the primary structures.

Keywords: Y-Wind, Floating Offshore Wind Turbine, Semisubmersible, Damping Plate, Mooring Analysis, Coupled Analysis, Dynamic Response

INTRODUCTION

Several floating offshore wind prototypes, for instance Windfloat and Hywind, have been successfully installed world-wide and operated for several years to demonstrate the technologies. However, those prototypes are having difficulties in scaling up for the commercial utility for US offshore application due to higher levelized cost of energy (LCoE). It is therefore necessary to approach the offshore floating wind technology from the perspective of the platform with the lowest LCoE possible in order to compete with other energy resources. This can be achieved by fabricating the platform, assembling the tower and installing the integrated platform using existing local and regional facilities and equipment as inexpensively as possible. However, the current industry approach to floating wind production is to follow the development of land-based wind resources by continually increasing the size of the wind turbine in order to produce more power output. This following approach for offshore wind results in ever larger and more costly to build, install and maintain platforms

In the United States, due to the added cost associated with offshore floating wind, regulation and environmental issues, there has been relatively little focus on the offshore wind. Recently the first US offshore wind farm off Block Island was completed to produce 30MW power with five turbines of 6MW each with fixed foundations. In addition, a 1/8th scale semi-sub floating platform, a prototype of *VolturnUS*, was removed in late 2014 after about 18 moth testing operation (Viselli et.al, 2015A).

As the turbine sizes grows, the floating turbine platform (foundations) also get larger until the foundations are too large to fabricate in any but the largest offshore construction yards overseas which adds considerable transport costs to bring a platform from overseas into the US. Also, due to the deep drafts of these very large platforms, the platforms need to utilize very expensive offshore vessels to complete turbine integration and subsequent major maintenance activities at offshore. Thus, the VL Offshore (VLO) design approach of reducing the floating foundation costs significantly is to design a foundation that can be built and integrated locally in US shipyards. VLO has developed a semi-type floating wind platform called "Y-wind" by accommodating all the design factors stated above, Furthermore, the VLO Y-Wind platform can be disconnected from site and brought to quayside for major repairs of the turbine thereby also significantly reducing the operation and maintenance cost.

Through internal studies in terms of LCoE of the various size of the floating foundation, VLO have selected a floating foundation with 5~6MW power rate which could be a recommended size for US offshore installations. The present paper, thus, focuses on a concept design of a newly developed floating offshore wind turbine to support a 5MW wind turbine. The semi-type Y-wind platform has one center, three outer cylinder columns and three rectangular pontoons. Damping plate is attached to the platform to improve the hydrodynamic responses. In the following sections, sizing of Y-wind platform, metocean data, design criteria, platform motions, hydrostatic stability and preliminary structural analysis results are described. Several other design issues on floating wind platform design, for instance, tower base strength and fatigue, platform and mooring fatigue will be studied in the future.

METOCEAN DATA

Platform installation location is assumed at an offshore site in the US which may include the Gulf of Mexico, East and West coasts. Thus, the metocean conditions used in the present work was derived to cover the typical US offshore environmental conditions, by combining the available data listed in the documents (ABS, 2013; Weinstein, 2014; Viselli et. al, 2015A; Viselli et. al, 2015B) and summarized in Table 1. Water depth considered is 200m.

The Design Load Cases (DLCs) in Table 1 is based on ABS Guide for Building and Classing (ABS Guide, 2015). The operating condition is for the case that the turbine is in operation for power production which is in the speed ranges from cut-in to cut-out wind speeds while the turbine will be parked or idle under the 50-yr extreme and 500-yr survival conditions.

Table 1 Metocean Data

Platform Condition	Turbine Condition	ABS DLC	Wind	Wind Speed 10min@hub (m/s)	Wave (JOWNSWAP) Hs (m)	Tp (s)	Gamma -	Current (m/s)
Operating	Power Production	1.3	Rated, V_r	11.4	7.5	11.5	1.0	0.4
		1.6	Cut-out, V_o	25.0	8.5	12.7	2.2	0.6
Extreme	Parked	6.1	50-yr	40.0	12.5	14.2	3.3	0.8
Survival	Parked	SLC	500-yr	45.0	15.0	15.3	3.3	1.0

DESIGN BASIS

The offshore floating wind turbine platform moored at a water depth of 200m is designed to produce the power of 5MW for a service life of 25 year under the sea environments stated specified in Table 1. The platform with the tower integrated at a quayside has a sufficient buoyancy to support the platform at a wet-tow draft, which enables the tow-out of the platform to site with conventional tugs.

Floating offshore wind turbine platform design requirements in stationkeeping design and air gap are specified in ABS and API documents (ABS Guide, 2015; ABS FPI 2013; ABS Guidance Note, 2014; API RP 2SK, 2005) and presented in Table 2. The platform heel angle of 10 degrees and acceleration of 0.4g (3.92m/s^2) at the nacelle are selected according to the oil and gas offshore platform design practices and floating wind turbine design (Huijs et. al, 2014). The heel and acceleration requirements are applied to the turbine operating conditions to protect the components in the rotor assembly and wind turbine tower. The extreme conditions (DLC 6.1) will be used for mooring line safety check while survival condition for air gap estimate based on ABS guide (2015).

Table 2 Hydrodynamic and Mooring Design Criteria

Condition	Heel (deg)	Acceleration (g)	Mooring Line FoS	Air Gap (m)
Operating (DLC 1.3, 1.6)	≤ 10	≤ 0.4	-	-
Extreme (DLC 6.1)	-	-	≥ 2.0	≥ 1.5
Survival (SLC)	-	-	≥ 1.05	≥ 0.0

DESIGN STANRDS AND GUIDELINES

The present floating offshore wind turbine design and analysis follows the ABS and API requirements in hull, global performance, stationkeeping, stability and structure as summarized below.

- ABS Guide for Building and Classing Floating Offshore Wind Turbine Installations, 2015
- ABS Guidance Note on Global Performance Analysis for Floating Offshore Wind Turbine Installations, 2014
- ABS Rules for Building and Classing Mobile Offshore Drilling Units, 2008
- ABS FPI Guide for Building and Classing Floating Production Installations, 2013
- API RP 2SK Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures, 2nd edition, 2005

Y-WIND PLATFORM CONCEPT AND CONFIGURATION

The Y-Wind semi type wind turbine platform is designed to support the 5MW wind turbine on the top of the column. The platform consists of three outer (offset, outboard) columns and one center column. The outer columns are connected to the center column with corresponding rectangular pontoon. The platform has no decks and braces which can facilitate the efficient construction of the hull and remove the potential risk to the deck structure induced by the slamming loads. Also this scheme can allow us to reduce the column freeboard height which eventually provides additional benefit of structure weight reduction.

Water depth of shipyards in the US West and East coasts is not deep enough to accommodate a deep draft wind turbine platform. One of key drivers of the Y-Wind platform design is, thus, a proper lightship draft which enables to integrate the tower and rotor assembly at quayside and wet-tow out to site with no expensive and dedicated vessel. To achieve this goal, the pontoon and column sizes were determined accordingly with iterative manner. Also at the concept design stage, a static heel angle of the platform due to the peak rotor thrust at the rated wind speed was considered such that the static heel angle is maintained around 4 degrees. In addition, it was checked if the platform has a sufficient positive metacentric height specifically in wet-tow condition. In order to improve the motion performances, various damping structure options were introduced. All these design parameters were implemented to the in-house platform sizing program to configure the 5MW semi type Y-Wind platform.

The Y-Wind platform particulars with no damping plate (No DP) and with wide DP are summarized in Table 3. The total weight of the platform for the in-place conditions were estimated considering the hull structure, appurtenances, marine growth, ballast, turbines and marine system, where an appropriate contingency was applied based on the past experiences of the oil and gas platform design. Lightship draft with the tower assembled is about 5.3m which enables the quayside integration of tower and wet-tow out from the ports or 2nd-tier US shipyards. No active ballast is required due to the location of the turbine tower at the platform center.

Figure 1 represents the Y-Wind platform moored with three catenary mooring lines, where the damping plate is omitted.

Table 3 Y-Wind Semi-type 5MW Platform Particulars

Items	Units	No DP	Wide DP
Displacement	tonnes	7,748	7,770
Draft – Design	m	18.0	18.0
- Lightship (Wet-tow)	m	5.21	5.30
Outer Column Center Radius	m	35.0	35.0
Outer and Center Column OD	m	10.5	10.5
Outer Column Height	m	29.5	29.5
Center Column Height	m	28.0	28.0
Freeboard (Outer Column)	m	11.5	11.5
Pontoon Width × Height	m	4.5 X 4.0	4.5 X 4.0
Tower Base above SWL	m	10	10
Hub Height above SWL	m	90.0	90.0
CoG (above keel)	m	14.58	14.23

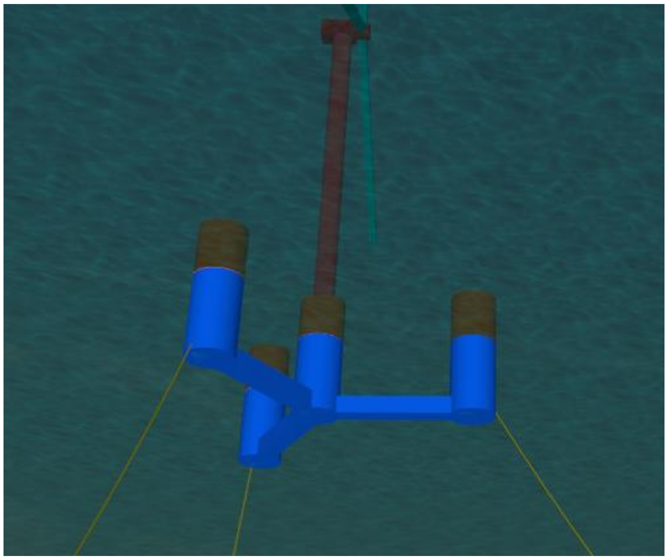

Figure 1. Y-Wind Semi Type Offshore Floating Wind Turbine Platform with Mooring Lines

The NREL 5MW reference wind turbine (Jonkman et. al, 2009; Robertson et. al, 2014) was selected and its properties are summarized in Table 4. The tower base and hub are located at 10m and 90m above SWL respectively. The rotor thrusts at the rated and cut-off wind speed presented in Table 4 were used to assess a static heel angle at the platform design stage due to the thrust, where the platform was designed to limit the heel angle about 4 degrees with no mooring induced restoring moment. The thrusts vary in time about the mean value due to wind speed change at the rotor but mean thrust was applied for the present analysis.

Table 4 NREL 5MW Wind Turbine Data

Power Rate	MW	5
Rotor Diameter	m	126.0
Number of Blades	ea	3.0
Tower Height	m	77.6
Tower Diameter Top / Base	m	3.87 / 6.5
Cut-in V_{in} / Rated V_r / Cut-out V_{out}	m/s	3.0 / 11.4 /25.0
RNA Weight	tonnes	350
Tower Weight	tonnes	250
Rotor Thrust - Rated Wind	KN	819
- Cutout Wind	KN	369

NUMERICAL MODELING

Figure 2 presents the Y-Wind platform coordinate systems used for the present analysis. The reference center is located at the platform center on the SWL. Wave direction (heading) is positive toward the x-direction and measured in counter-clock wise direction. Mooring line #1 to #3 with a 120 degree apart are also shown in Figure 2.

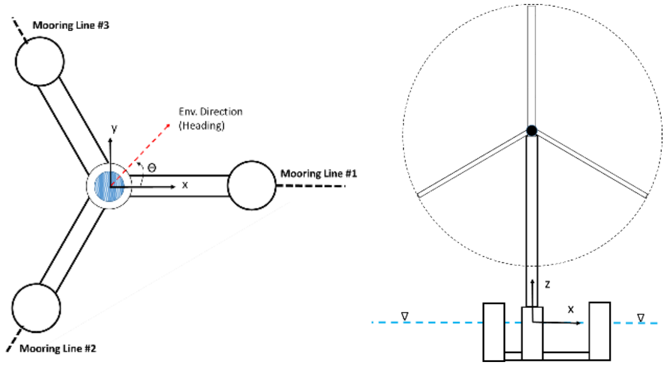

Figure 2 Platform Coordinate System Definition

The Y-Wind platform except the damping plate below the SLW was modelled with source panels for the radiation and diffraction analysis. The damping plate was discretized with the dipole panels assuming its thickness is very thin. The platform is moored with a total of three catenary R4 studless chain lines with 120mm diameter at a water depth of 200m. The one end of the 800m long line is connected to a fairlead located near the keel of the outer column and the other end is connected to an anchor foundation. Table 5 summarizes the mooring line properties. The uncorroded line is for the nominal chain with 120mm diameter whereas the diameter of the corroded line is reduced to 110mm due to corrosion over the service life of 25 years. In the strength factor of safety check, the MBL of the corroded chain is utilized.

Table 5 Mooring Line Properties

Item	Unit	Uncorroded	Corroded
Chain Type	-	R4 Studless	R4 Studless
Chain Diameter	mm	120	110
Dry Weight	kg/m	288	246
MBL	kN	13,573	11,856
Length	m	800	800

Wind forces on the hull above the SWL and wind turbine tower were estimated based on the reference (ABS FPI, 2013) and input to the numerical model as wind coefficients. The current loads on the submerged platform members and the mooring lines were implemented in the model with the drag coefficients given in Table 6.

Platform radiation damping is computed using the radiation-diffraction program but hull viscous damping can be presented in the model with the viscous drags with the drag coefficients of column, pontoon, damping plate and mooring lines in Table 6.

Table 6 Platform Member and Mooring Line Drag Coefficients

Column - Horizontal	0.65
- Vertical	1.5
Pontoon - Horizontal	1.9
- Vertical	2.2
Damping Plate - Vertical	4.5
Chain - Normal	2.4
Chain - Tangential	1.15

Vertical Cd of 1.5 of the column was based on the experimental data (Fisher, 1998). Drag coefficients on the pontoon also vary with the aspect ratio, AR (breadth/depth) and Kuelegan-Carpenter number. The horizontal and vertical Cds on the pontoons were read from the experimental data plot in reference (Venugopal, et al, 2009). According to DNV (2007), a recommended Cd of a square cylinder is about 2.2 for Reynold number$\approx 4.7\times 10^4$. Damping plate drag coefficients on the vertical direction was selected to be 4.5, which is little lower than the values used in references (Robertson at al., 2014; Li et al, 2012).

The present time-domain numerical analysis using Orcaflex was based on a semi-coupled analysis (ABS Guidance Note, 2014), where the aero-elastic couplings are neglected. The tower and nacelle were modeled as part of the rigid body of the hull. The rotor thrust loads were modeled by applying the static loads in Table 4, at the top of the tower for the power production cases of DLC 1.3 and 1.6 in Table 1. This approach is very useful in practical sense to evaluate the platform global performances and mooring responses in the early design stages although it may not provide the dynamic responses of tower and accurate aero-hydro coupled effects to the platform.

NUMERICAL RESULTS AND DISCUSSIONS

Heave Free Decay Test and Damping Ratio

Figure 3 compares the free decay test results of the platforms without and with the damping plate. Logarithmic decrements are computed every cycle using an equation;

$$\delta = \ln (A_i / A_{i+1})$$

where A_i and A_{i+1} are two consecutive crest or trough values in the decay time histories. Damping ratio is then estimated as;

$$\zeta = \delta / 2\pi$$

Heave logarithmic decrements up to the first six cycles of the platform without and with the damping plate are compared in Figure 3. The decrements between crest and trough differ much in the first few cycles and converge as the cycle increases. Heave linear damping ratios were estimated by taking the average up to the first six cycles of the crest and trough and are summarized in Table 5. Heave natural period of the Y-wind platform is shifted from 11.25s for no damping plate to 15.92s for the damping plate, which is mainly due to increase of the added mass by the damping plate. The heave damping is mostly contributed by the hull and mooring line viscous drags with the associated drag coefficients in Table 6. The hull member drag coefficients will be correlated using the model test data when available.

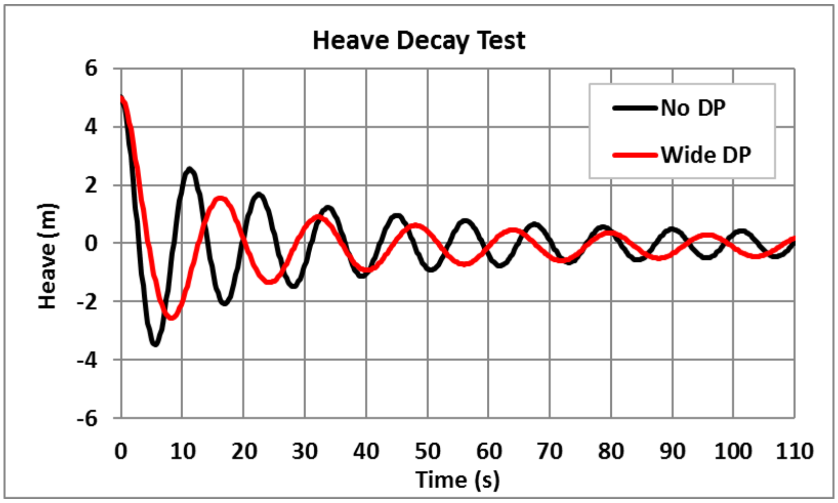

Figure 3 Time Histories of Free Decay Tests of Y-Wind Platforms

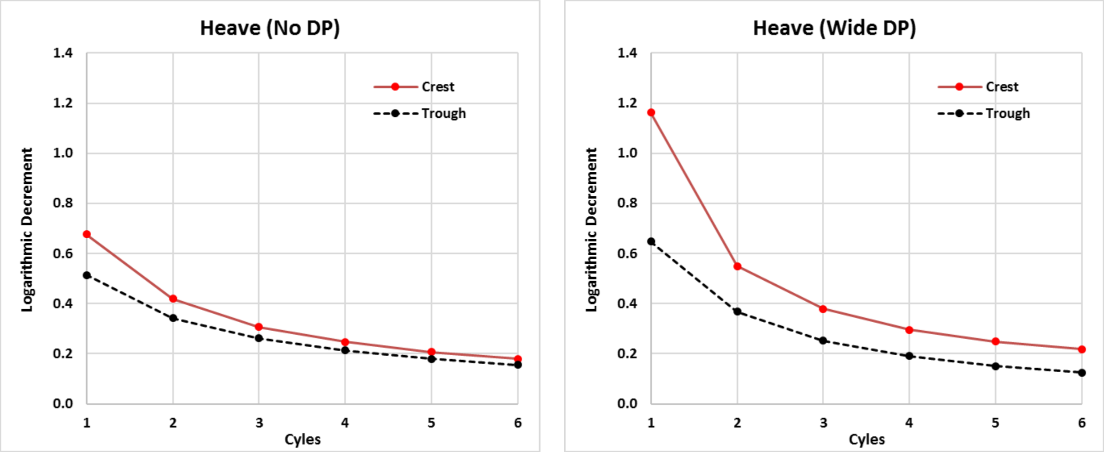

Figure 4 Comparison of Logarithmic Decrements per Cycle of Y-Wind Platforms

Table 5 Heave Damping Ratios and Natural Periods

Item	No DP	Wide DP
Damping Ratio (%)	4.9	6.1
Natural Period (s)	11.25	15.92

Platform Heave RAOs

Heave RAOs of Y-wind platform without and with the damping plate were estimated using a numerical white noise (WN) method where a wave heading of 180 degrees was considered and compared with RAOs derived from the potential-based radiation-diffraction program in Figure 5 (left-side plot). Significant reductions of the heave responses around the natural period by the viscous damping are observed. Also JONSWAP wave spectral densities of DLC 1.3 (operating), DLC 1.6 (extreme) and DLC SLC (survival) in Table 1 are plotted together with the RAOs from the white noise (right-side plot). The wave spectral peak of the survival condition is closely located to the heave natural period of the platform with the damping plate, which may affect the hydrodynamic responses to the platform. The effects are investigated in the following section.

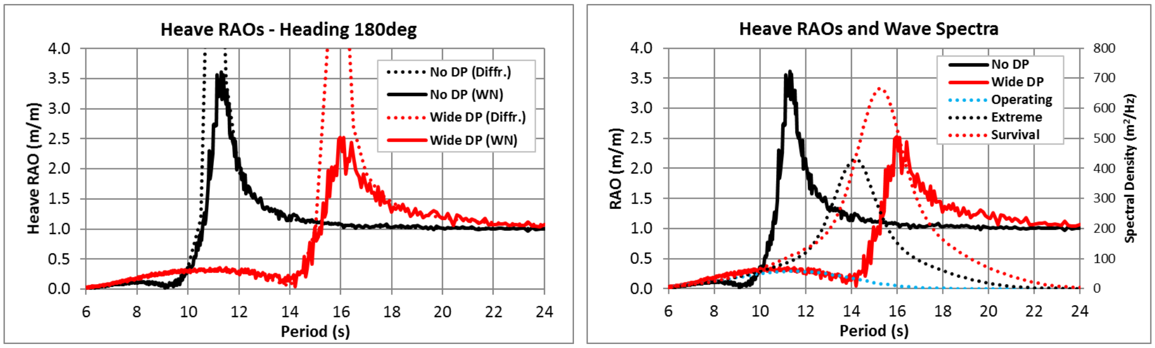

Figure 5 Heave RAOs of Y-Wind Platforms

Platform Hydrodynamic and Mooring Reponses

Numerical simulations were performed for a wave heading of 180 degrees which is identified to be a proper heading to investigate the platform responses in heave, pitch, acceleration and mooring line tension. Wind and currents were codirectional to the waves. Time domain simulations were run for three hours excluding initial ramp-time and post-processed to compute the mean, standard deviation, extreme values. Extreme values can be determined with Rayleigh 3-hour most probable extreme by,

$$\text{Most probable Max} = \mu + \sigma\,[2\ln(n)]^{1/2}$$

or 3-hour extreme with 1% risk factor by

$$Max = \mu + \sigma\,[2\ln(-n/\ln(1-\alpha))]^{1/2}$$

where $n = T/T_z$ is the number of peaks and T, T_z, μ, σ and α are the storm duration, mean up-crossing period, mean, standard deviation and risk factor, respectively. All the results presented in this section are based on the most probable maximum except the mooring line tensions which used the 1% risk factor extreme.

The metocean conditions in Table 1 were considered to evaluate the corresponding responses. Figure 6 compares the heave motions of the Y-Wind platforms with and without the damping plate, showing that the heave motions increases with the higher sea states. It is seen that the damping plate contributes to the significant motion reductions for all the considered DLCs. There may be more improvement possible in heave motions with modification of the damping plate to swift the heave natural period away from the survival wave peak period. However, other design requirements in rotation and acceleration are met as stated in the following. The modification is, thus, recommended to be carried out to cause a minimal impact on the platform weight and associated cost.

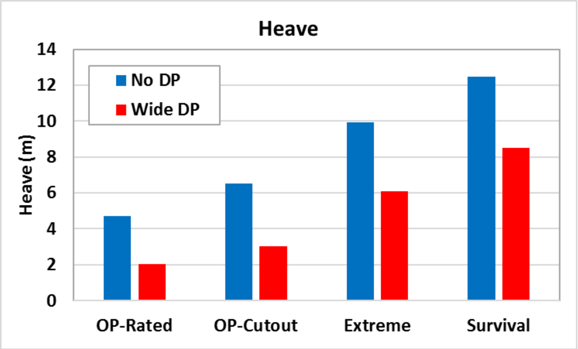

Figure 6 Comparison of Y-Wind Platform Heave Motions under the Various DLCs

Pitch motions of mean and maximum are presented in Figure 7. Mean pitch is about 3.3 degrees at the rated wind and 1.4 degrees at cut-out wind speeds. It is seen that the peak thrust by the rotor causes greater mean pitch than the values by other conditions. The mean pitch from the dynamic simulation is lower than the static heel angle of about 4 degrees considered in the platform sizing stage, which is likely due to the combined action of the mooring, current and wind induced moments. The pitch maximum for the power production (operating) condition is found to be lower than the allowable design maximum of 10 degrees, which complies with the turbine design requirement. The maximum pitch motions of the platform without the damping plate for the extreme and survival are very large. On the other hand, the pitch motions with the damping plate exceeds 10 degrees for the survival conditions, which may, however, be acceptable as the rotor is parked during such survival storm events. These results demonstrate that the damping plate is significant role in reducing the platform motions.

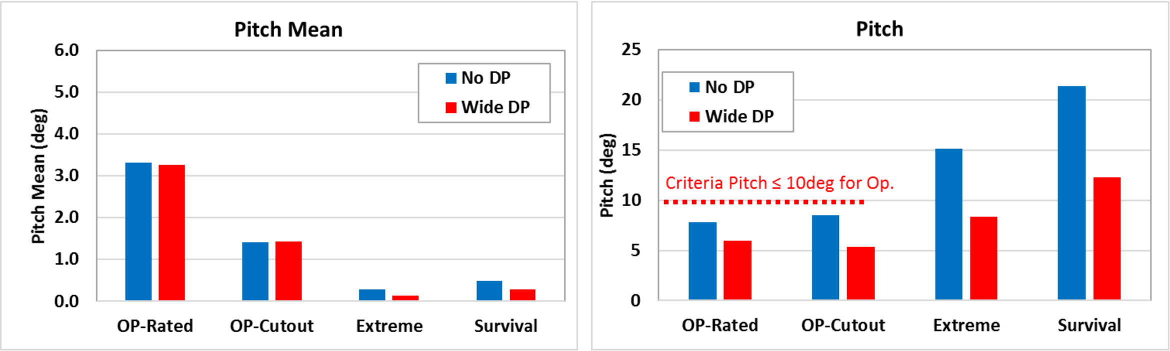

Figure 7 Comparison of Y-Wind Platform Pitch Motions under the Various DLCs

Vertical and horizontal accelerations at the nacelle are compared in Figure 8, showing that the accelerations during the power production is well below the allowable design maximum of 0.4g. Higher horizontal than vertical accelerations are observed, which is mainly induced by the pitch motions for the considered wave heading of 180deg under the extreme and survival conditions.

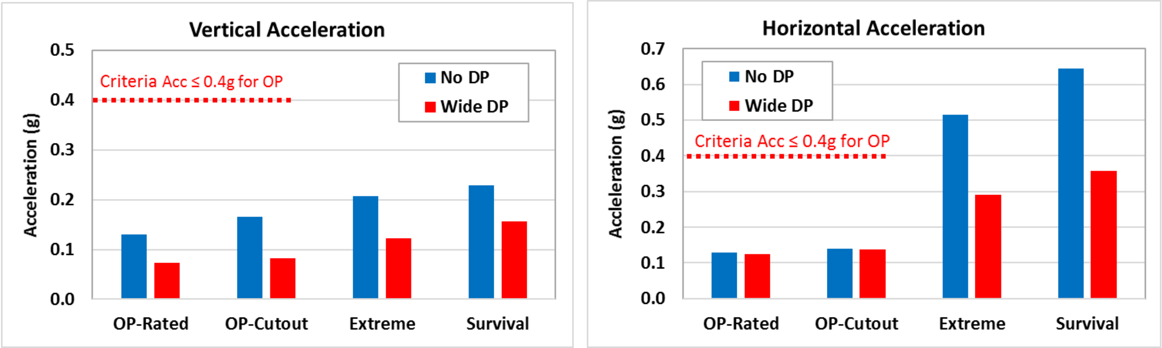

Figure 8 Comparison of Nacelle Accelerations under the Various DLCs

With the given wave heading of 180 degrees, mooring line #1 is the most loaded line so that the mooring line factor of safety was assessed on the mooring line #1 and its results for all the DLCs considered are presented in Figure 9. As described earlier, the mooring line FoS was based on the MBL of the corroded chain. The estimated mooring factors of safety of the platform with the damping plate are greater than the required minimum values for both extreme and survival conditions, which demonstrates the current mooring design satisfies the ABS mooring design requirements.

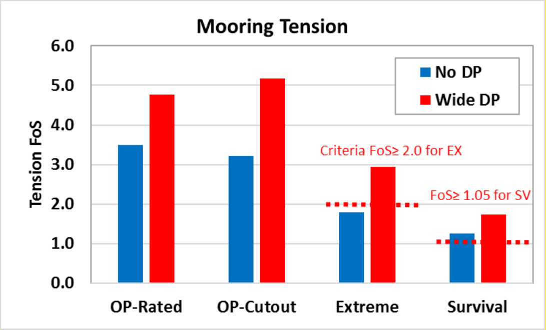

Figure 9 Mooring Line Factor of Safeties under the Various DLCs

STRUCTURAL DESIGN

The platform structural design consists of stiffened plates for both the pontoons and the center and outer columns. The design and scantlings of the structure is in accordance with ABS Guidelines (ABS Guide, 2015). The structural design is also developed with consideration of fabrication capabilities and efficiencies and in order to allow for steep and quick learning curves for series fabrication.

Longitudinal framing of pontoons is supported by transverse webs and bulkheads. Framing of columns includes webs and ring stiffeners (stringers), with intermittent watertight and not watertight decks. Pontoon to column connections are designed for simplicity and robustness. Material selected for design, including sizes and thicknesses, as well as material properties are within standard commercially available sizes and grades. Where possible, the structural design minimizes weldments. These features are incorporated in order to maximize simplicity and therefore minimize fabrication costs as much as possible.

A quasi-static, global frame analysis is used to verify the platform structure and to generate loads for local structural analysis. Of primary interest are the stresses in the pontoons connecting the columns. Loads applied are the maximum in two main platform design conditions: Operating (both rated, cut-out wind) and Extreme. The loads applied include turbine, mooring, inertial and ballast. Masses for secondary appurtenances and marine growth are also included in the analysis. In order to produce the most conservative results, the loads are applied in the most conservative manner possible (for example, the maximum turbine load is applied collinearly but opposite to the maximum mooring load).

The global structural analysis indicates that the design of the hull with no damping plate is sufficient, but near maximum allowable stresses in the pontoon (Figure 10). However, in the damping plate platform configuration, the platform motions and loads are reduced significantly and this results in a noticeable reduction in the calculated pontoon stresses (Figure 11). Table 6 compares the pontoon (east side), outer column and center column maximum calculated stresses.

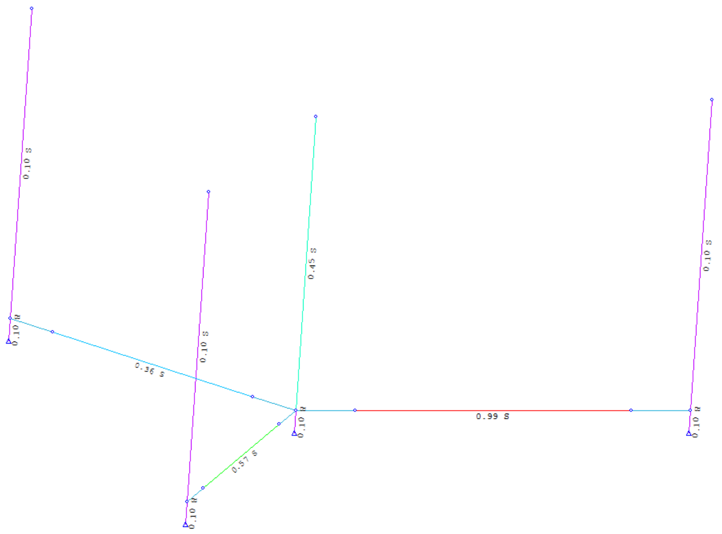

Figure 10. Maximum Calculated Stresses Y-Wind without Damping Plate

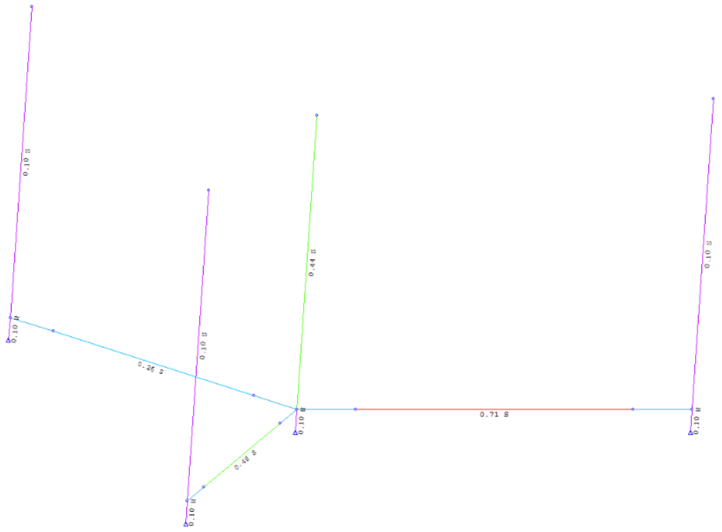

Figure 10. Maximum Calculated Stresses of Y-Wind with Damping Plate

Table 6. Y-Wind Maximum Calculated Stresses

Structural Component	Platform Configuration	
	No Damping Plate	With Damping Plate
Outer Column	0.10	0.10
Pontoon (East)	0.99	0.71
Center Column	0.45	0.44

The reduction in the platform motions due to the damping plate has a noticeable, positive effect on the pontoon stresses. While detailed local and fatigue analysis needs to be completed in order to confirm the local structural design of the pontoon, it is encouraging to note that the possibility may exists that the pontoon structural design could be improved and made a bit more efficient. Overall, the base structural design is considered sufficient to continue further development of the Y-Wind Platform design. According to preliminary screening, environment direction of 180 degree governs the platform structure strength design. Future works will consider other directions for comprehensive structural analyses.

STABILITY ANALYSIS

For the hydrostatic stability analysis, Y-wind platform without the damping plate was selected. Figure 10 shows the 3D model used for the analysis.

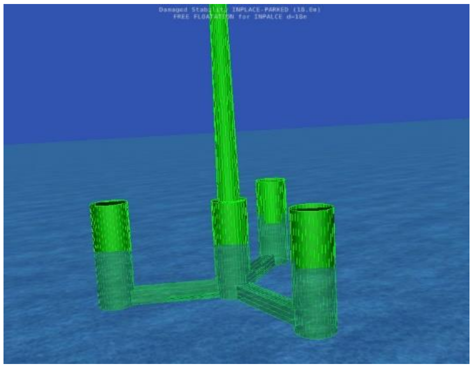

Figure 10 Y-Wind Platform Model for Stability Analysis

Various load cases were considered to check the intact and damage stabilities of the platform with no damping plate. Considered were two different drafts of the wet-tow and in-place conditions. For the power production condition, both rotor thrust and wind force acting on the hull were applied to give the combined heeling moment to the platform. In the parked case, the wind forces on the tower and hull were considered. Table 3 summarizes the load cases and associated wind speeds used for the stability analysis.

Table 2 Load Case and Wind Speed used for Stability Analysis

Hull Condition	Load cases	Draft (m)	Wind Speed (m/s)
Intact	Wet-tow	5.21	51.44 (100kts)
	In-Place Power Production: Rated	18.0	11.4 (V_r)
	In-Place Power Production: Cut-out	18.0	25 (V_o)
	In-Place Rotor Parked	18.0	51.44 (100kts)
Damaged	Wet-tow	5.21	25.72 (50kts)
	In-Place Rotor Parked	5.21	25.72 (50kts)

The stability analyses were performed for every 15 degrees of yaw (axis) angle so that the worst case can be identified. Figure 11 shows intact stability and heeling arm curves for in-place condition with rotor parked. Both intact and damage stabilities were checked as per the criteria in reference (ABS Guide, 2013). The platform has always positive GM at any intact and damaged conditions including two tank damage during wet-tow and one tank damage cases for in-place, which satisfies all stability requirements. It should be noted that Y-wind platform has maximum GM with highest margin at the wet tow so that the platform will be always stable during the ballasting at site. Due to this inherent stability feature, Y-wind platform will not require additional support means during the tow and ballasting operations, which can eventually provide the cost saving benefit.

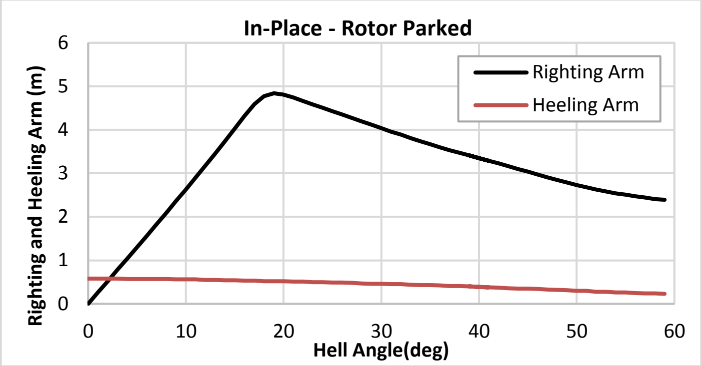

Figure 11 Intact Stability Curve for In-Place Rotor Parked Condition

CONCLUSIONS

A semi-type Y-Wind floating offshore wind turbine platform has been developed to support a 5MW wind turbine. The platform design is properly sized to be fabricated in US shipyards, integrated with existing equipment at quayside of the shipyards and wet-towed out to site with no dedicated expensive vessels, which all can reduce the LCoE significantly.

The platform consists of four columns having the same diameter. Center column supports the wind turbine and three other columns are connected to the center column by respective pontoon. The platform has VLO's proprietary damping plate attached to the platform

The platform moored at a water depth of 200m with three catenary chain legs is designed to comply with the requirements by ABS floating wind turbine guide, under the US environments in the power production, 50-year extreme and 500-year survival sea states.

Time domain numerical simulations were conducted to validate the present concept design in heave and pitch motions, accelerations, mooring and damping plate. The results with and without the damping plate are compared together and it is found that the Y-wind platform with damping plates satisfies all the design requirements. It is also demonstrated that the dynamic responses are reduced significantly by the proposed damping plate, which is promising in the design of structural members, wind turbine components and mooring system. In addition, it is confirmed that the hydrostatic stability and global structural strength comply with the ABS and industry standards. The stability analysis demonstrates that no dedicated equipment or vessels in wet-towing to installation operations are required,

The numerical viscous model in the damping plate will be correlated with the model test data when available. In addition, various damping plate configuration effects will be further studied.

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