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Wave dynamics of new SPAR GFRP buoy concept to measure offshore wind in deep waters

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Abstract

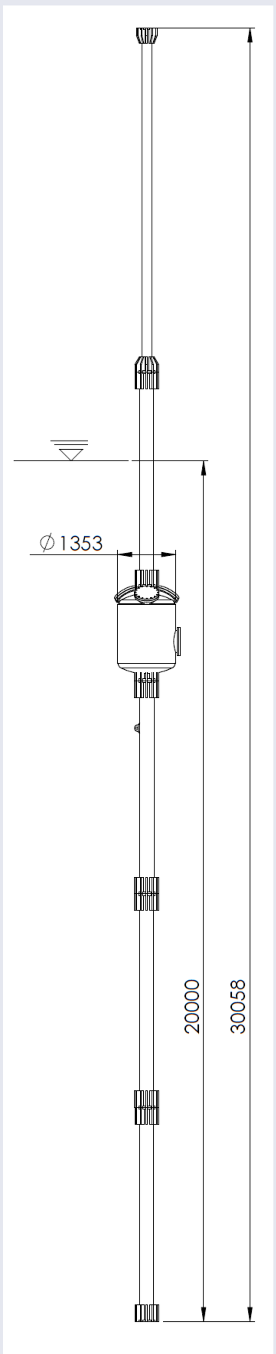
Several efforts to improve offshore wind resource assessments in deep waters have been done in recent years. Although some commercial solutions can be found, characterizing the wind resource in deep waters is still a very expensive task. When not associated with the measuring technology itself, sonic anemometer or LiDAR, the increment in costs is directly related to the supporting platforms, buoys and mooring systems.

The development process and main characteristics of a new SPAR concept in Glass Fiber Reinforced Plastic (GFRP) to measure offshore wind in depths of over 100 meters are presented here. Concerns regarding economic and survivability factors were in the genesis of the idea. Hydrodynamic and mechanical modeling supported the conceptual design strategy. Morison formulation was applied due to the slender character of the body. Since viscous effects were important, and they are quadratic to the velocity, a drag linearization was applied to the frequency analysis approach. Resulting from the non-linear character of the system, a time domain approach was also applied to achieve realistic results under extreme design conditions. Slamming and bending analysis considerations were added to the numerical evaluation.

The numerical results showed that the buoy is stable in operation conditions, achieving with minor structural concerns maximum rotations of 30 degrees and vertical displacements under 10 meters when exposed to extreme 17 meters regular waves.

Keywords: SPAR buoy, Offshore Wind Assessment, Glass Fiber Reinforced Plastic, Hydrodynamics

Introduction



(in millimeters)

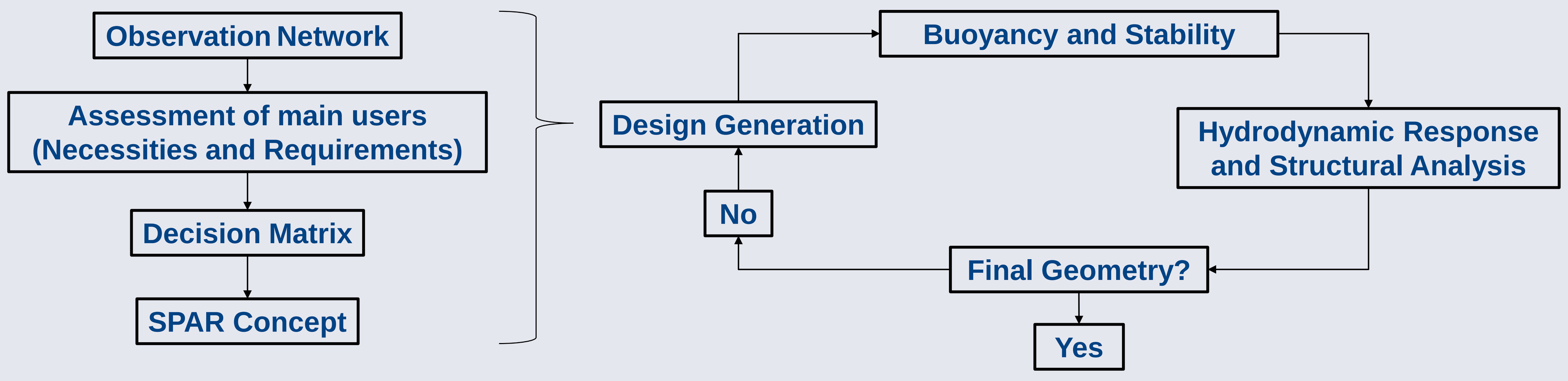
Many efforts to improve marine observation systems have been identified during recent years.

With this background, the development of a SPAR prototype buoy concept, final design can be seen on the left, was initially needs driven by the necessity of having low-cost structures to measure offshore wind. Some concepts were identified for this type of application, examples are the fixed foundation FINO platforms or the met-masts floating platforms commissioned in Santander, Spain.

The SPAR solution that will be presented intends to tackle the technical challenges of measuring offshore wind by presenting a technical and economic viable alternative to the current existing solutions. Two common types of ocean SPAR slender structures involve geometrical application of simple vertical cylinders or, and truss structures. SPAR buoys are characterized by their inherent stability in waves. Their geometric characteristics, very slender structures, minimize the disturbance caused by the ocean waves.

In a cost effective, handling, application basis and due to its physical advantages GFRP was considered as the material to be implemented in the production process. In the case of a slender structure like a SPAR, special emphasis was given to the mass distribution effect on the buoy's stability and free floating movements. Since a low weight material application was considered, a substantial need of ballast was expected.

Based on the previous assumptions, a design process was implemented to design a met mast to measure wind 10 meters above the ocean surface with considerable stability. Several aspects needed to be addressed in order to define the concept key features. The design procedure can be found in the following scheme.



Hydrodynamics

Hydrodynamics of slender structures in waves are characterized by the importance of viscous effects which are not considered by most of the potential theory codes available. The slenderness of a structure is always classified relatively to the wavelength of the incident wave. For vertical cylinder a relation of D/λ<0.1 to 0.2 is usually presented to evaluate the flow regime, if it's dominated by inertia or by viscous effects (Journée & Massie, 2001).

The following equation was defined by (Morison, J. R. 1950) as a simplifying solution to tackle the challenge of calculating the wave loads on a vertical pile (by unit of length).

$$dF = \rho\, A\,(1+C_a)\,\dot{v}_f - \rho\, A C_a\, \dot{v}_s + \frac{1}{2}\rho C_D\, D\,(v_f - v_s)\left|v_f - v_s\right|$$

It is a semi-empirical solution frequently applied in offshore engineering problems due to its simplicity. It depends on added mass and drag coefficients (C_a, C_d) which are estimated empirically and are influenced by several parameters like the Reynolds number or the cylinder roughness.

Wave theory under Stokes second order was applied to describe the incident waves field.

The dynamics of a floating body in waves are usually characterized by its motion equation, which takes the following form when the Morison formulation is accounted for the whole body and no external damping (C) and stiffness (S) effects (only the intrinsic in heave, roll and pitch) are considered.

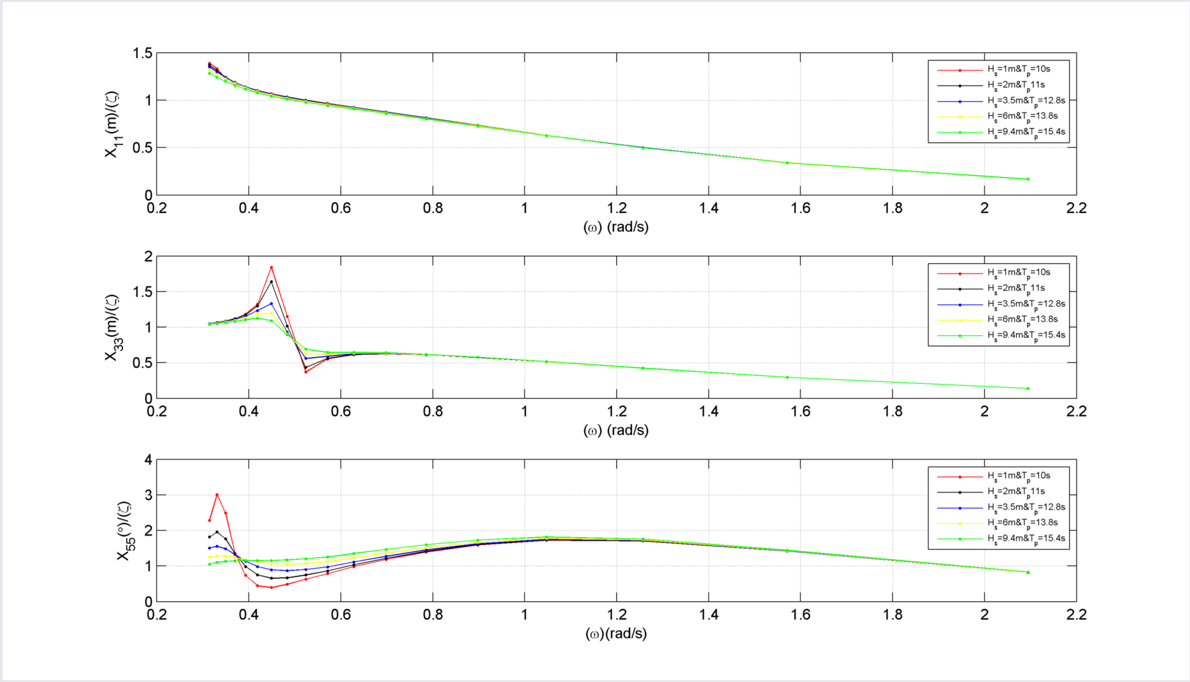
$$M_s\ddot{X}(t) = M_d(1+C_a)\,\dot{v}_f - M_sC_a\ddot{X}(t) + \frac{1}{2}\rho C_D\, D\,(v_f - \dot{X}(t))\left|v_f - \dot{X}(t)\right| - \rho g S X(t)$$

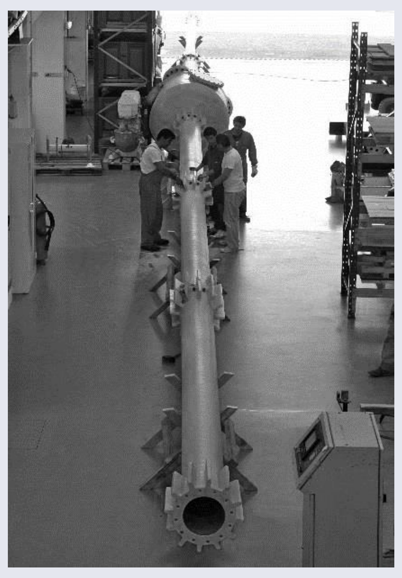
Additionally to the forces on the motion equation, a preliminary analysis of specific effects as the impact forces where evaluated by the (Wienke, 2005) method. The results obtained were based on the software Ansys AQWA and are presented in the following lines.

Results

The Response Amplitude Operators of the body were obtained in the frequency domain considering a linearization of the drag term for different sea states. The drag term was linearized with (Borgman, 1967) consideration on drag linearization where the quadratic velocity term is approximated by $u.u_{rms}\sqrt{8/\pi}$, with u_{rms}as the standard deviation, or root-mean-square value for the velocity.

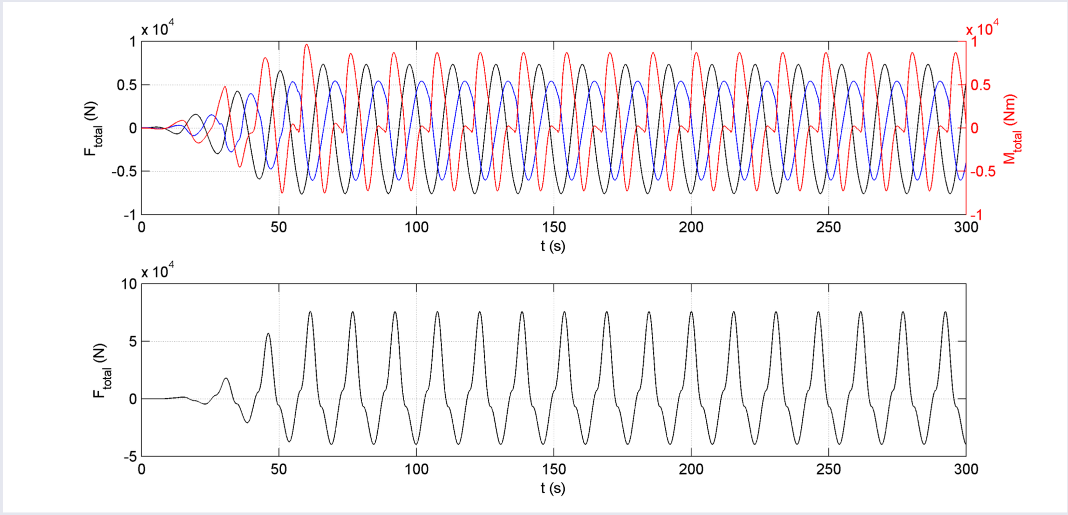
The variation caused by linearizing the drag term can be identified in the graphic below. Since the body is axisymmetric the movements of sway, roll and yaw were not considered. The final manufactured model of the final buoy is presented on the right.

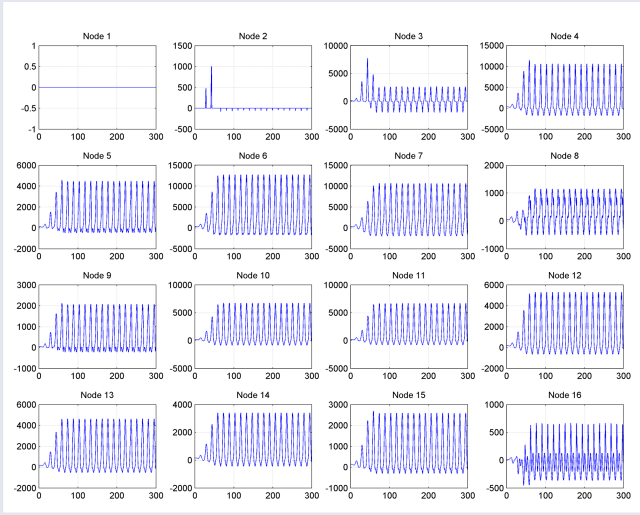




Extreme environmental conditions from the northern coast of Portugal were used as reference to calculate the non linear time response in regular waves and irregular waves.

Due to the nonlinear character of the analysis a time approach evaluation was applied to calculate the loads in the fixed and moving condition. An extreme analysis with the buoy in its fixed equilibrium condition was considered to evaluate the maximum wave loads, and consequently to set the conditions to the mooring system design assessment. Below, on the left is possible to analyze the extreme waves loads in free (up) and fixed (down) condition.





On the right are presented the loads concentrated in nodes of the structure which were posteriorly transferred to reproduce the distributed environmental loads of the structural GFRP model. Here the current effect was considered in the fluid particles relative velocity.

Conclusions

Modelling offshore operating bodies is of major importance for a cost-efficient analysis. In some sectors this practice is well established and in others it is steadily growing. The new buoy GFRP concept has shown itself stable in operation conditions, with minor structural concerns when exposed to extreme 17 meters waves. Prototype validation is underway.

Acknowledgments

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