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Category:	*Standards/Regulations*
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Subject:	*Design Standards for Offshore Wind Farms*
Performing Activity:	American Bureau of Shipping (ABS)
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Contracting Agency:	Bureau of Safety and Environmental Enforcement
Summary:	The main objectives of this project were to: • Study the governing load cases and load effects of bottom-founded offshore wind turbines subjected to the hurricanes on the U.S. OCS; • Review and evaluate the existing methods of calculating the breaking wave slamming load exerted on an offshore wind turbine support structure; and • Provide recommendations to support future enhancement of the relevant design criteria for offshore wind turbines. The report presented: • The results of the state-of-the-art review; • The case study results for the characteristic responses of bottom-founded offshore wind turbines assumed to be installed in hurricane-prone regions on the U.S. OCS; • The research findings of modeling breaking wave slamming loads; and • The recommended design methods.
Key Findings:	• The wind models recommended in IEC 61400-1 (2005) were primarily developed and calibrated using on-land wind measurements with the consideration of various terrain topologies. They are still considered applicable to a bottom-founded offshore wind farm sited in a coastal area, where onshore terrain effects can influence the characteristics of a turbulent wind field. • The API-recommended model may be used for the bottom-founded support structure to be installed in the open ocean, where the effect of coastal topology and onshore roughness are negligible. The API-recommended model is also believed to be a more reasonable choice for those floating support structures where low frequency responses are of great importance to the vessel stability, global motions, and mooring system design. • It remains to be decided, however, as to under what conditions the site location can be considered in the open ocean. Examples are given that define a site located beyond 20 km (12.5 miles) offshore as at sea, where the effect of coastal topology and onshore

	roughness may be assumed to be insignificant. • The relative importance between aerodynamic loads and hydrodynamic loads to global responses is related to the type of support structures and the water depth. • The sensitivity of the global responses of a support structure to the turbine operating modes (and therefore the control and safety systems) is determined by the importance of aerodynamic loads relative to hydrodynamic loads (which is type and depth dependent). • The definition of *operating* and *extreme* design criteria in API RP 2A-WSD (2007), using the return period of design environmental conditions, is not directly applicable to offshore wind turbines. • The slope of global loads (i.e., base shear and overturning moment) versus return period curve (i.e., hazard curve) for OWTs is different from those normally seen in the design of offshore oil and gas platforms. Applying the same design approach that is valid for offshore oil and gas platforms to offshore wind turbines will not result in the anticipated safety level. • In order to account for the effect of the environmental conditions in hurricane-prone U.S. waters, where the variation and, therefore, uncertainty of environmental conditions are much higher than those implied in the IEC 61400-3 (2009), the design requirement specified in IEC 61400-3 (2009) for the support structure of an offshore wind turbine must be increased. This increased design requirement may be achieved by requiring a higher return period in the design load case, a larger safety factor in the strength design criteria, or the combination of both. • For practical applications in structural design, simple, yet well-calibrated analytical slamming load models have shown their unique advantage over more sophisticated numerical simulations and model testing. • It is believed that the Wienke model, an analytical model in a simple, easy-to-implement format, stands out as the latest development for calculating slamming forces on vertical and inclined circular cylinders. It has been referenced in a number of design standards, such as IEC 61400-3 Annex D (2009) [3.40], GL (2009) [3.35], and ABS (2010) [3.2] for offshore wind turbines, and in ISO 21650 Annex G (2007) [3.43] for applications to coastal structures.
Recommendations:	• The return period of site-specific design environmental conditions should be 100 years. • Wind models recommended in IEC 61400-1 (2005) should be used to generate the turbulent wind field as the input to aerodynamic load calculations. For those offshore wind turbines to be deployed in the open ocean with the minimum effect of coastal topology and onshore roughness, the wind model recommended in API Bulletin

	2INT-MET (2007) and API RP 2A-WSD (2007) may be used as an alternative. • Wind and wave misalignment should be considered within the range between -90 degrees and +90 degrees. Load calculations should be based on the misalignment angle that results in the highest load acting on the support structure. • Both negative and positive storm surges should be considered in the design, particularly for those minimum support structures, such as monopiles and tripods. The wave theory employed in the design should reflect the effect of water depth. • The effect of nacelle yaw misalignment relative to the incoming wind direction should be adequately considered in the design. In general, a yaw misalignment between -180 degrees and +180 degrees, in combination with 100-year return site conditions, should be considered as an abnormal load case in the design. Load calculations should be based on the misalignment angle that results in the highest load acting on the support structure. The contribution of an active or passive yaw control system may be taken into account in order to reduce the range of the yaw misalignment considered in the design, provided that the effectiveness of the yaw control system at the intended site can be justified and an appropriate monitoring and maintenance program is implemented to maintain the effectiveness of the yaw control system during the service life of an offshore wind turbine. It may not be warranted to rely solely on a back-up power supply with a minimum capacity of 6 hours, as per IEC 61400-3 (2009), to mitigate the effect of yaw misalignment during a hurricane, particularly for an area in which a prolonged blackout could occur during and after a major hurricane. • The aerodynamic loads generated by a wind turbine subjected to strong hurricane wind conditions should be determined by using recognized simulation software. If such a reliable source is not available, the design standard would have to specifically address the need to verify and calibrate such software for each design project. • Four technical areas are considered of great importance and recommended for further research: (a) turbulent hurricane wind modeling; (b) foundation soil-structure interaction models; (c) offshore wind turbine analysis procedures and software tools; and (d) validation of slamming load models.
Subsequent Studies/Activities:	• TAP 669: *Floating Wind Turbines* • TAP 672: *Development of an Integrated Extreme Wind, Wave, Current, and Water Level Climatology to Support Standards-Based Design of Offshore Wind Projects* • TAP 705: *Design Guidelines for Station Keeping Systems for Floating Wind Turbines*

	• FY 2014 project award: *Fatigue Design Methodologies Applicable to Complex Fixed and Floating Offshore Wind Turbines (FOWT)* • FY 2014 project award: *Design of Wind Turbine Monopiles for Lateral Loads* • ABS: *Guide for Building and Classing Floating Offshore Wind Turbine Installations* (2013) • ABS: *Guide for Building and Classing Bottom-Founded Offshore Wind Turbine Installations* (2013)
Report Link:	AA: Design Standards for Offshore Wind Farms, September 2011, by Qing Yu, Kunho Kim and Tzu-Wei Lo, American Bureau of Shipping, Houston, Texas