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Optimization of pre-stressing in gravity based foundation of an offshore wind turbine using reliability framework

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Reinforced Concrete is versatile material being used construction for more than 100 years and Pre-Stressed Concrete for more than 70 years. There is substantial increase in use of concrete in wind-energy sector to minimize Levelised Cost Of Energy (LCOE), for construction of foundations and substructures. This particularly true due to the range of advantages offered by concrete over other construction materials.

With structural design tending increasingly towards a more efficient use of the mechanical properties of the materials, reliable methods for predicting fatigue behaviour of concrete are needed. Laboratory tests for fatigue of concrete show that, the fatigue behaviour of concrete is governed not only by stress-ranges but also by mean-stress-level. Thus, pre-stressing force changes the fatigue performance of pre-stressed concrete structures.

Reducing the level of pre-stressing could result in tensile stresses in a cross-section of a wind turbine reinforced-concrete (pre-stressed) tower due to bending moment induced from wind and wave loads. Thus, it reduces the fatigue life, as tension-fatigue is highly detrimental to concrete. Increasing the level of pre-stressing would cause shift in mean-level of stresses and again it would reduce the fatigue life.

Thus, designer needs to find a balance in level of pre-stressing in order to use the mechanical properties of concrete efficiently. Which can be achieved by reliability based design / optimization.

This paper presents a reliability-based framework with respect fatigue failure of concrete shaft of a gravity-based foundation of an offshore wind turbine. The reliability framework will be based on First Order Reliability Method (FORM), which covers stochastic modelling of fatigue strength, stochastic modelling of fatigue loads including uncertainties associated with such modelling. Stochastic modelling of fatigue resistance will be based on large database available in literature for tension-compression (alternating) and compression-compression fatigue failure of concrete. In addition, stochastic modelling of wind loads, wave loads and uncertainty related to degradation of post-tension force / stresses will be presented.

Pre-stressing force will be considered as the design-parameter for optimization. Results will include, modelling the relation between stresses and design parameter, examples of reliability assessment and reliability-based calibration of partial material safety factors for, optimization of fatigue design of pre-stressed reinforced concrete shaft and impact of partial pre-stressing on reliability of structure. All results will use data for the NREL 5MW reference wind turbine and gravity based foundation will be considered as support structure.

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