14th EAWE PhD Seminar on Wind Energy
18-20 September 2018
Vrije Universiteit Brussel, Belgium

# Fatigue reliability analysis of onshore wind turbine foundations

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*Keywords*: Reliability, FORM, fatigue, reinforced concrete, wind turbine foundations

## 1 Introduction

It is important to design wind turbine structures to a specific (target) reliability level, in order to avoid conservative designs and excessive use of materials with the aim to minimize the cost of such installations and ultimately the cost of energy [1].
As a wind-turbine, is exposed to the cyclic load from wind. This causes fatigue of all components of the wind turbine including the reinforced concrete foundation. In most of the cases fatigue design governs the structural dimensions or the amount of reinforcement in the foundation of an onshore wind turbine. However, estimating the level of damage in the foundation of wind turbines is difficult and thus prediction of the future life. The current international codes use models for damage accumulation with respect to fatigue of concrete, which are generally conservative and not able to predict the real behaviour accurately and can only predict the remaining useful life with uncertainty.
This paper presents a probabilistic framework for reliability assessment with respect to fatigue failure of a reinforced-concrete onshore wind turbine foundation. This includes stochastic modelling of fatigue strength, stochastic modelling of fatigue loads, uncertainties associated with strength and load modelling, and reliability-based calibration of fatigue safety factors (DFF) for design with respect to fatigue failure of concrete. Examples of reliability assessment and calibration of partial factors will be presented.

## 2 Details of onshore wind turbine foundation

Gravity spread foundation is the most commonly used foundation for onshore wind turbines. This is due to ease of construction with little excavation and refill work. This foundation consists of large slab could be square, octagonal or circular in plan, with or without thickness variation. Typical reinforcement is placed at top and bottom layers of the slab with orthogonal grids and radial pattern through embedded ring. For circular slabs also this radial pattern can be used. Typically, this kind of foundation transmits forces from wind turbine tower to soil to a larger area by spreading action. While, transmitting these forces cross section of the slab experiences bending moment. Thus, this cross section should be able to resist this internal bending moment generated due to external forces transmitted by the tower to the foundation. These variations in the stresses are captured in the form of Markov Matrices [2].
In this paper a similar reinforced concrete foundation described in [3] along with a Markov matrix for 20 years of wind data for Siemens wind turbine described in [4] is used for fatigue reliability assessment. For salient features of the wind turbine foundation see  and Table 1.

## 3 Modeling of uncertainties

Current paper covers uncertainties associated with concrete strength, fatigue strength model for linear damage accumulation (S-N) curves, wind loads and. This includes modelling of all epistemic, aleatory and statistical uncertainties.

# 4 Results

Results include comparison of reliability index (β) values obtained with international code requirements. Sensitivity of reliability index to various sources of uncertainty, e.g. uncertainty associated with Miner's rule, concrete strength and fatigue loads.

**Table 1 Design characterisitc of wind turbine [3]**

| Main Design characteristic of wind turbine foundation | |
|---|---|
| Hub-Height | 99.5 m |
| Design wind speed at hub-height | 8.5 m/s |
| Shape | Circular |
| Concrete class | C30/37 |
| Diameter (D & $D_2$) | 15.0 m, 6.0 m |
| Thickness (h & $h_2$) | 2.0 m, 1.25 m |
| Pedestal height (δh) | 0.27 m |
| Reinforcement Type | B500B |
| Bottom and Top reinforcement | Two layers 25mmΦ @ 150mm c/c |

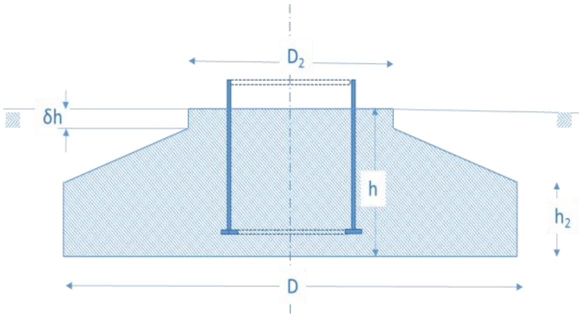


**Figure 1: Principal geometry of the foundation**

# Acknowledgements

Current work is carried out under the project INFRASTAR (infrastar.eu), which has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 676139. The grant is gratefully acknowledged.

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