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Explicit Method to Account for Cyclic Degradation of Offshore Wind Turbine Foundations Using Cyclic Interaction Diagrams

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ABSTRACT

Cyclic loading could lead to progressive degradation of soil in terms of plastic strain accumulation, pore pressure build up and changes in soil strength and stiffness. The present paper outlines an explicit method to predict the accumulated foundation displacement under cyclic loading. Cyclic contour diagrams, derived from cyclic laboratory tests, are linked to the finite element software PLAXIS by means of a Python interface. The effects of cyclic loading on the accumulation of strain is taken into account by the modification of the elastic shear modulus of the soil in a cluster-wise division in the finite element mesh.

KEY WORDS: PLAXIS; cyclic loading; cyclic contour diagrams; explicit method; stiffness degradation; gravity based foundation; monopiles.

INTRODUCTION

The design of wind turbines relies on knowledge of different engineering disciplines with multiple interfaces. For the design of the foundation structure, iterative loops between the wind turbine manufacturer and the foundation designer (incl. the geotechnical design team) are needed to update the load calculations at the interface level (bottom of tower). Wind turbine manufacturers provide the irregular variation of fatigue and extreme loads by means of aeroelastic and hydrodynamic analyses, which in turn provide the basis for the foundation design.

In each loop the geotechnical designers have to ensure that the foundation obeys a series of criteria such as foundation capacity, when experiencing the maximum load (ULS), and the prediction of the foundation response during the lifetime of the structure (SLS). The analysis of the foundation capacity can be done by applying simplified approaches such as a Winkler model approach using p-y curves or by use of finite element modeling, cf. DNV GL AS (2016). The prediction of the foundation response over the lifetime of the structure remains challenging.

During a lifetime of 25 years, offshore structures undergo millions of irregular loading cycles distributed randomly over time and direction (Andersen et al. 2013). These cyclic loads are likely to cause relevant changes in the behavior of the soil-structure interaction with time. In this regard, different requirements should be addressed, such as: ensuring bearing capacity following cyclic loading, which may differ from the capacity under monotonic loading; assuring that the cyclic displacement of the structure obeys the requirements provided by the wind turbines manufacturer; assessing the change in the foundation stiffness and damping; and ensuring stability against the pore pressure build up during a cyclic storm event.

During the geotechnical design process, a simplification of the irregular loading from the wind turbine manufacturer is needed. Soil models cannot implicitly predict the soil behavior under irregular cyclic loading with sufficient accuracy. Therefore, the explicit representation of the response of cyclically loaded soil is based on laboratory test campaigns, for which sequences of irregular cycles are not suitable.

The irregular load history for a design storm event condition is divided into a number of constant cyclic load amplitudes around a constant average load. In this case, a counting method, e.g. Rainflow-Counting, is used to reduce this irregular load-time histories to a number of load spectra. The result is a description of the function in terms of the number of the load cycles inherent in the time history. Each load package consists of an average value, a load amplitude and a number of cycles. The load collective is then converted into the form of a so-called Markov matrix. For monopiles, the Markov matrices of the relevant storm at the level of the seabed can be reduced to an equivalent load collective and an equivalent number of cycles as described in EA-Pfähle (2012).

The lack of a generally accepted unified method to account for cyclic loading has led to the development of different approaches. Some of them are focused on specific types of structures. For monopiles it is current practice to use the “softened” static p-y curves. Alternatively, the permanent pile head rotation can be estimated according to the Hettler approach, cf. EA-Pfähle (2012). Others methods are developed aiming to predict the strain accumulation (Achmus et al, 2009) or pore pressure build up. Several more advanced methods, such as PDCAM and UDCAM (Jostad et al, 2014) or the High Cycle Accumulation method (Niemunis et al, 2005), which can be applied for different types of offshore foundation have been developed for similar purposes.