Numerical Investigations on Local Degradation and Vertical Misalignments of Grouted Joints in Monopile Foundations

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ABSTRACT

The underestimation of cyclic effects on the axial capacity of grouted connections in monopile foundations led to vertical slippages, recently observed in a large number of offshore wind turbines. In this paper a progressive vertical misalignment of the grouted connection inside an oscillating structure is demonstrated by use of non-linear finite element simulations. Based on a fully integrated load calculation of a reference structure and results from numerical analyses, parameters are evaluated that may affect the long term behavior of the connection’s axial capacity. Additionally, the influence of mechanical interlock on the fatigue performance of grouted joints is demonstrated.

KEY WORDS: Offshore wind turbines; dynamic; misalignments; settlements; degradation; grouted joints; time domain simulation; non-linear, grout fatigue.

INTRODUCTION

Offshore wind turbines (OWT), which are characterized by slender support structures and high top masses, are decidedly susceptible to dynamic excitation. Furthermore, they are characterized by a highly dynamic loading environment. Consequently, an accurate dynamic assessment of all structural components is of highest importance.

Currently different foundation solutions for offshore wind turbines are under discussion and development. However, simple monopile foundations can be regarded as an economical design solution for low and intermediate water depths up to about 30 m. The joint between monopile and tower of the turbine support structure is usually realized by an overlapping tube-to-tube connection. A transition piece, also referred to as sleeve, and the monopile are arranged with a certain overlap where the resulting annulus is filled with a high performance grout. With this type of connection, commonly denoted as grouted joint, inclinations of the pile from the driving process can be compensated (Fig.1).

Axial forces, in particular caused by the dead load of rotor-nacelle-assembly and tower of a wind turbine, are small compared to the bending moments caused by wind and wave actions. The load conditions experienced by grouted joints on monopiles of OWT are thus characterized by predominating cyclic bending loads superimposed by the axial dead load of turbine and tower.

Fig.1. Schematic overview of grouted joint with plain pipes

Up to the end of the last decade it was assumed that the application of a mechanical interlock such as shear keys is not required in the design of grouted joints on monopiles. Grouted joints were therefore mostly executed with plain pipes, relying solely on the shear capacity of the interface between steel and grout for the transfer of the axial loads. Interactions between dynamic bending loading and axial shear forces were not considered in the applied design approaches.

However, vertical misalignments within grouted connections have been observed recently on a considerable number of offshore wind turbines with monopiles. It is assumed that these settlements result from degradation effects within the interfaces between steel and grout, caused by cyclic bending loading, in combination with the high slenderness, characteristic for grouted joints on monopiles, cf. Schaumann & Wilke (2008a) and Lotsberg (2010). In order to investigate vertical settlements it is necessary to analyze the grouted connection under dynamic conditions with simultaneously acting bending moments and axial forces in a representative order of magnitude.

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