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Fatigue behaviour of grouted connections at different ambient conditions and loading scenarios

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Abstract

Grouted connections are frequently used as structural detail of offshore wind turbines and platforms for the load transferring connection between piles and support structure. At latticed substructures this connection is commonly located at mudline. However, a potential influence of the surrounding water on the connection's fatigue behaviour was neglected in earlier tests and consequential design methods. Herein described experimental investigations at small and large-scale fatigue tests in submerged conditions showed a significant reduction of endurable load cycles. In addition, the water impact caused varied damage mechanism in the connection.

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Keywords: offshore wind energy; offshore platform; grouted connection; fatigue; water impact

1. Introduction

Lattice substructures of offshore wind turbines and platforms, like tripods or the jacket shown in Fig. 1, are connected to their foundation piles via grouted connections. The connection is located just above the seabed and hence constantly submerged. A watertight sealing against ingress of surrounding water is usually not applied.

The connection consists of a steel tube with smaller diameter (pile), which is plugged into a steel tube with larger diameter (sleeve). The resulting annulus between the steel tubes is filled with a high performance offshore specific grout material. For a defined interlocking between steel and grout, the steel surfaces are profiled with weld beads (shear keys).

The load bearing behaviour of the substructure splits, from wind and wave loads resulting, bending moments into axial force couples acting on the foundation piles (cf. Fig. 1). Therefore, the grouted connections in this type of

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substructure are predominantly axially loaded. Inside the connection areas of concentrated compressive stresses occur between opposing shear keys (σ_{strut}). Analogous to truss structures these areas are called compression struts. Due to the strut inclination angle α also radial stresses arise and are borne by circumferential stresses ($\sigma_{tangential}$) inside the steel tubes.

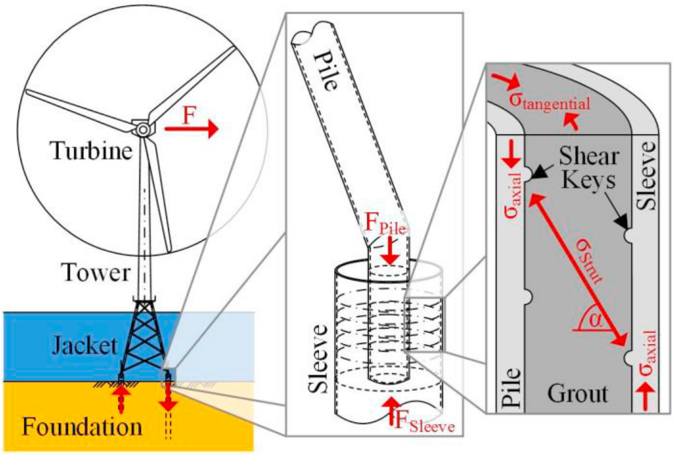

Fig. 1. Latticed substructure of an offshore wind turbine with structural details and load bearing behaviour of a grouted connection

Currently available design methods for grouted connections in latticed substructures from ISO 19902 [1] and DNVGL-ST-0126 [2] are based on load bearing and fatigue tests carried out in dry ambient conditions (AC) [3, 4]. However, tests on grout material specimens [5–7] as well as reinforced concrete specimens [8] showed a significantly reduced fatigue strength when carried out in wet AC.

As part of the research project 'GROWup – Grouted Joints for Offshore Wind Energy Converters under reversed axial loadings and up scaled thicknesses' a test setup to investigate the influence of water on the fatigue behaviour of grouted connections was developed. In the following the test setup and the achieved results regarding the influence of water will be presented.

2. Small-scale tests

2.1. Test setup

To simulate a realistic stress state inside the grout material, the small-scale specimen shown in Fig. 2 was developed [9]. Therefore, relatively compact steel tubes were chosen to prevent a failure of the steel tubes due to buckling or yielding. Rectangular shear keys were machined out of the steel surfaces. As filling material two commercial grout materials with a relatively low (Mat. 1, f_{cu} = 90 N/mm²) and a high strength (Mat. 2, f_{cu} = 140 N/mm²) were used.

The specimens were tested inside the water basin shown in Fig. 2. By the hydraulic cylinder pure axial compressive loads were applied. During the tests the applied load F, the relative displacement u of the load application plate and the number of applied load cycles N were measured.

After production of the specimens and 28 days of grout material curing the load bearing capacity F_{ULS} of three specimens was determined in a quasi-static test. Afterwards the mean value of F_{ULS} was used as load reference value for the subsequent fatigue tests. The maximum load level F_{max} as well as the loading frequency f were kept constant in the fatigue tests. The loading ratio was chosen to be R = 20 due to control system reasons. Real grouted connections are usually loaded with a loading frequency in the range of f = 0.3 Hz. To allow a transferability of the fatigue test results obtained with a loading frequency of f = 5.0 Hz, additional fatigue tests focusing on different loading frequencies were carried out in wet AC. Both dry and wet AC were investigated using tap water.