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Load Bearing Behaviour of Grouted Joints Subjected to Predominant Bending

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Summary “Load Bearing Behaviour of Grouted Joints Subjected to Predominant Bending”

The large-scale generation of electricity from wind offshore shall contribute significantly to the targets of energy and climate policy in a number of countries, including Germany. As a consequence, a further rapid growth of this industry sector is to be expected, if reliability is increased and economic optimization can be realized in the next years. One of the keys for optimization of offshore wind projects is the deployment of cost-effective and safe support structures. A major part of most of these support structures are grouted joints, not only for jackets but especially important for monopiles. Monopiles have been considered in the past as limited to medium water depths and smaller turbines. Due to the recent developments in the manufacturing equipment of large diameter tubes and installation vessels, there is a strong tendency to extend their application to deeper water and larger turbines.

Therefore, the publication examines the bearing behaviour of currently used slender grouted joints subjected to predominating bending. Besides the interaction of the ductile steel shells with the brittle grout material, the publication focuses on the analysis of the characteristics of shear keys in the connection under combined loading and their adequate representation in the design process. Due to the limited test experience for grouted joints subjected to predominant bending, a test programme has been executed which comprises large and small scale tests under different types of loading. While the small scale tests mainly have been performed to gain knowledge about the local behaviour of the high strength material and to obtain base data for benchmarks of the numerical models, the large scale tests have been executed with realistic dimensions and static and dynamic loading. The tests confirmed that application of shear keys in the inner third of the connection effectively increases the robustness of the grout connection and distinctly reduces damage from ovalization. Local investigations showed only minor deterioration around the shear keys. This demonstrates that further economic optimization is possible.

On basis of the test results, numerical models have been developed and validated. Besides the implementation of a material model for adequate representation of the local grout characteristics, the development of a novel combined spring element-contact model for shear keyed connections forms main part of the analyses. Aligned to this model, a design approach for the local zone around the shear keys and the numerical derivation of parametric shear key fatigue classes is presented. The developed numerical models and design approaches have been applied to real scale monopole structures whereby size and scale effects were considered adequately. Time domain analyses explain how the slip failure of grout connection without shear keys develops. The subsequent parametric studies concentrate on the three typical design tasks ultimate limit, fatigue limit and a serviceability limit state. Besides a separate treatment of the basic materials grout and steel, the focus is set on the effects of the shear keys in comparison to plain pipe connections and the variation of size and number of shear keys. Based on the analyses it is concluded that shear keys should be applied in the center area of the grout connection. Furthermore, distinct height to spacing ratios should be chosen but the number of shear keys is recommended to lie between five and nine shear keys in a row. If these construction principles are followed, shear keys effectively help to minimize the damage in the ultimate and fatigue limit state for both materials in the connection.