GROUTED CONNECTIONS ON OFFSHORE WIND TURBINES

COST ACTION TU1304

Wind Energy Technology Reconsideration to enhance the concept of smart cities

WINERCOST

STSM Final Report

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ACKNOWLEDGMENTS

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IMAGES

BACKGROUND 1

1.1 Short Term Scientific Mission (STSM) members

The participant of this STSM is:

- **Nikolaos Tziavos**, MSc, PhD candidate

  School of Civil Engineering,

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1.2 Hosts and Host Institute

- **Peter Schaumann,** Prof., Dr.-Ing.

  Institute for Steel Construction,

  Leibniz Universität Hannover, Germany

1.3 STSM topic

The subject of the STSM that took place at the Steel Construction Institute at Leibniz University was “Grouted Connections on Offshore Wind Turbines”. In the scope of this STSM was the following:

1. To observe the [1]experimental testing on grouted joints currently undertaken at Leibniz University of Hannover from the Institute for Steel Construction and the Institute of Building Materials Science.
2. The application of grouted connections for offshore wind turbines.
3. To discuss data sets and experimental tests previously conducted at Leibniz Universität Hannover.

[1] Research project “GROWup - Grouted Joints for Offshore Wind Energy Converters under reversed axial loadings and up-scaled thicknesses”

4. To exchange of experience and knowledge on Finite Element modelling of grouted connections.
5. To prepare a Finite Element model with the appropriate boundary conditions and material properties.

1.4 Time of STSM

The mission started on the 15th of November 2015 and lasted until the 22nd November 2015.

GROUTED CONNECTIONS 2

2.1 Introduction

An emerging technology which shows significant potential and is a major contributor to the "renewable" future the EU is committed to, is wind energy converters. The installed capacity of offshore wind turbines is growing rapidly the past decades making EU a world leader in the wind energy sector. The main reasons for that are the facts that wind energy is an environmental-friendly source for power generation and that it exists in abundance. One can comprehend the extent to which wind energy is developing by observing the installed and planned capacity of wind turbines across Europe. A characteristic example is the planned capacity of offshore wind farms in the UK, which will be up to 16 GW by 2020 (Department of Energy and Climate Change, 2013). This will contribute to 10% of the annual electricity consumption. Similar plans have been developed by Germany, which aims at 15 GW installed capacity by 2030.

That being said, it is of high importance to ensure that the expenses required for such investments are viable. The total investment required for an Offshore Wind Turbine (OWT) and particularly its substructure is substantial. Therefore, the different aspects of the substructure's design should be carefully considered. Nowadays, monopiles (see Figure 1), jackets and tripods are common structures used to support the tower and the wind turbine. Based on recent experience the most challenging part of the substructure of an offshore wind structure is the grouted connection. The grouted connection is used to connect two steel tubes by filling the annuli between them with high performance grout.

In the oil and gas sector, grouted connections have been used to support subsea structures for many decades sufficiently (Lotsberg, 2013; Dallyn *et al.*, 2015) and that is why they were initially employed in the wind energy sector to accommodate the connection between the substructure and the tower.

According to EWEA (2014) the substructures mainly used in offshore wind farms nowadays in Europe are monopiles. Monopiles are limited at water depths up to 30 meters thus alternative structures such as jackets and tripods (Figure 2) are used for deeper water. The performance of the connection has been the topic of a heated debate recently as settlements of transition pieces on monopiles were reported in various wind farms across Europe. Limited knowledge is available up to date on the behaviour of grouted connections and especially regarding its fatigue behaviour.

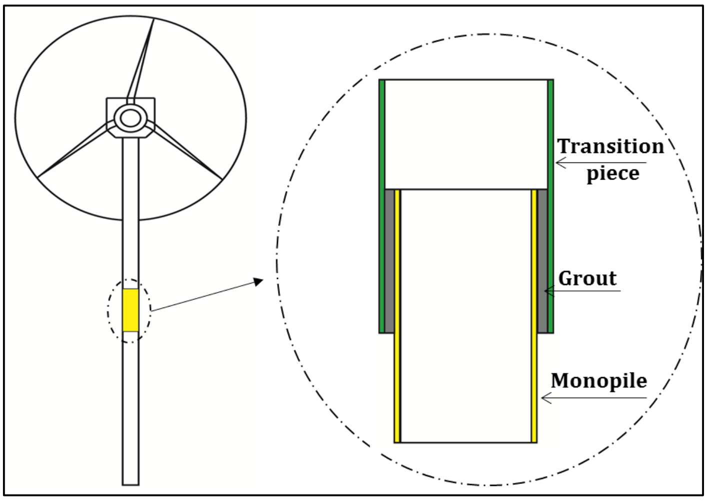

Figure 1: Simplified layout of monopile substructure with grouted connection

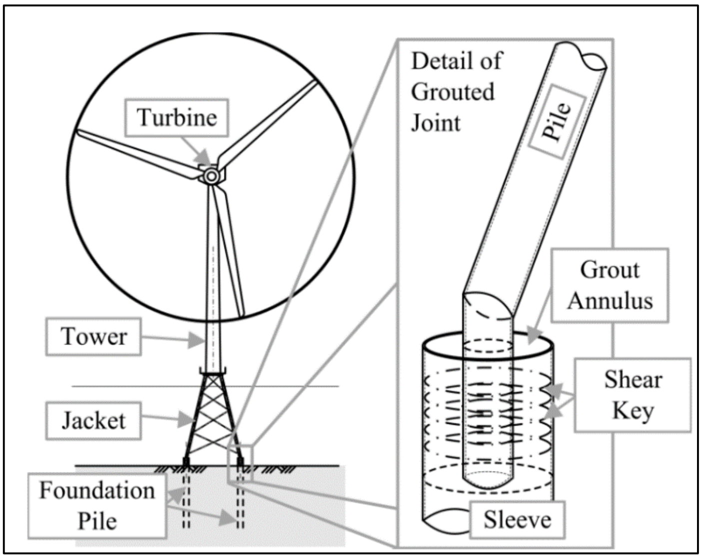

Figure 2: Grouted connection on jacket substructure (Schaumann et al., 2014a)

2.2 Grouted connections on offshore wind turbines

The grouted connection on monopiles and jackets is used in a similar way to connect the steel tubes of the substructure however there are key differences between them. These can be divided in geometrical characteristics and prevailing loads. The dimensions of the connection (grout length, grout thickness) vary depending on the substructure used. With respect to the grout thickness, the grouted connection in jackets is much larger than in monopiles. Jacket structures are mainly axially in contrast to monopiles which are exposed to bending moments of greater magnitude (Schaumann *et al.*, 2008). Taking those into consideration it should be noted that despite the similarities with the connections used in the oil and gas structures both jackets and monopiles are significantly different in many aspects.

These factors were not considered adequately in the offshore industry and led to implications from 2009 and onwards (settlements due to insufficient connection performance) in several monopiles (e.g. Kentish flats and Horns Rev I wind farms). Initially these joints on monopiles were plain steel-concrete-steel connections. In order to address the arising issues on monopiles shear-keyed connections were introduced (Schaumann *et al.*, 2010). Figure 3 illustrates a plain and a shear-keyed connection between the monopile and the transition piece.

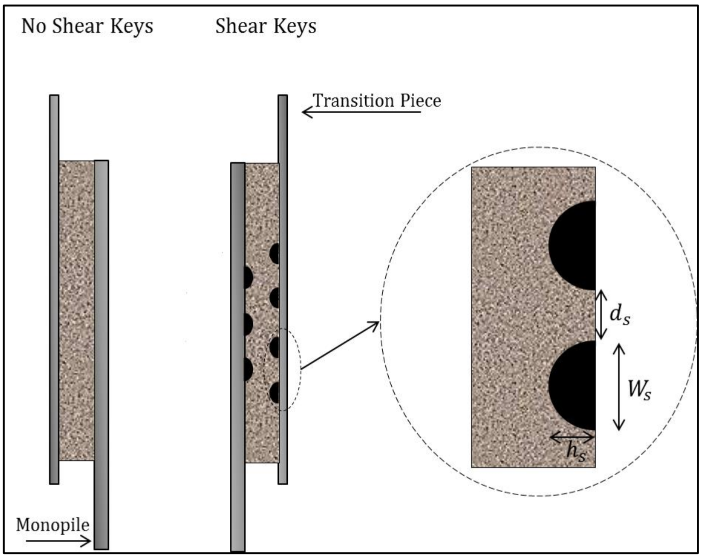

Figure 3: Shear keys in grouted connection

2.3 Fatigue of grouted connections

Fatigue on OWTs can be described as cumulative damage caused by alternating time varying loads. The loads acting on a wind turbine are prevailingly caused from the wind, the waves and current. The importance of fatigue on offshore wind turbines is underlined by Schaumann *et al*. (2011) due to the loads the structure is subjected to during its lifetime (~20 years).

Andersen and Petersen (2004) presented results from large scale tests performed in the scope of the development of the DNV standard code. The specimen which were of (~1:8) scale of a monopile structure were subjected to cyclic loads. The authors reported a gap but only occurring under extreme and not fatigue loading. The use of plain connections was recommended and additional shear keys were not suggested for monopiles. With respect to grouted connections on monopiles the results from a large scale (~ 1:6), testing campaign was presented in Schaumann and Wilke (2007). In contrast to the conclusions drawn by Andersen and Petersen (2004) it was indicated that gapping was evident in FLS loading. The authors highlighting the significance of the properties of the grout also reported grout cracking.

Following the unexpected settlements in 2009, the experimental work carried out by DNV which aimed to provide a better understanding on the connection's behaviour was presented by Lotsberg *et al*. (2013). The analytical expressions and the rationale on which they were based on was given in a more tailed way by Lotsberg (2013). The aforementioned investigations focused mainly on the forces on the connection and how these are transferred from the grout. Furthermore, the effect of the actual environmental conditions (such as water presence) was not studied.

Schaumann et al. (2014a; 2014b) focuses on the fatigue capacity of grouted connections under wet conditions. The current research project investigates the behaviour of connections with varying grout thickness under cyclic loading. A concise description is given in section 3.

TESTING AT LEIBNIZ UNIVERSITY 3

The following section will only briefly describe some of the current undergoing experiments with respect to grouted connections. The experiments are undertaken from the Steel Institute of the Leibniz University of Hannover at the Laboratory of the Institute for Building Materials Science. The work is conducted under the research project “GROW-up – Grouted Joints for Offshore Wind Energy Converters under Reversal axial loadings and up scaled thicknesses”, Funding sign: 0325290, funded by BMWi.

2.4 Small scale tests

Fatigue testing on small scale specimen aiming to investigate the effect of wet conditions on the fatigue life of the grouted connection.

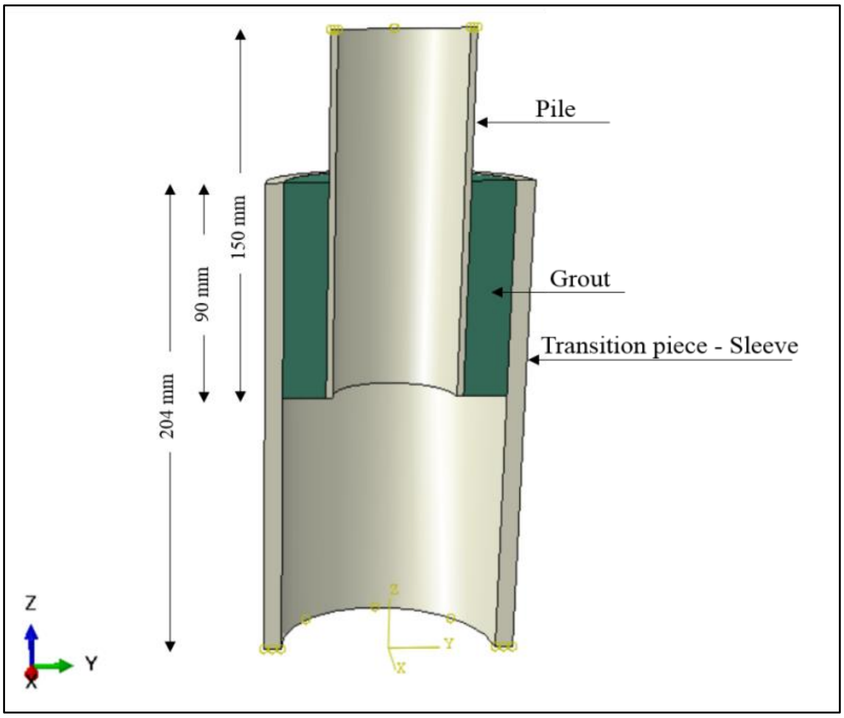

Figure 4: Small scale specimen and corresponding numerical model (without shear keys)

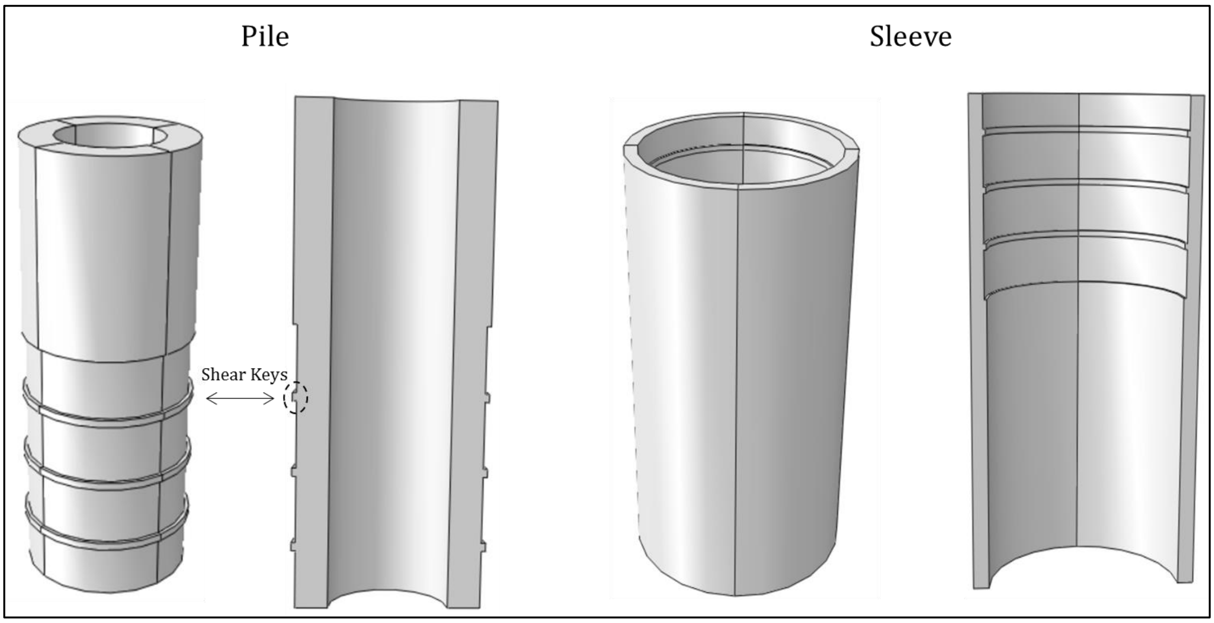

Figure 5: Small scale pile and sleeve with shear keys

2.5 Large scale tests

Bending tests with large-scale specimens, which are representative of monopile offshore grouted connections, were previously conducted. For further details, refer to Wilke (2013). In Figure 5, the specimen and parts of the loading set-up are illustrated. The large-scale tests will be used to validate a Finite Element model of a monopile-grouted connection.

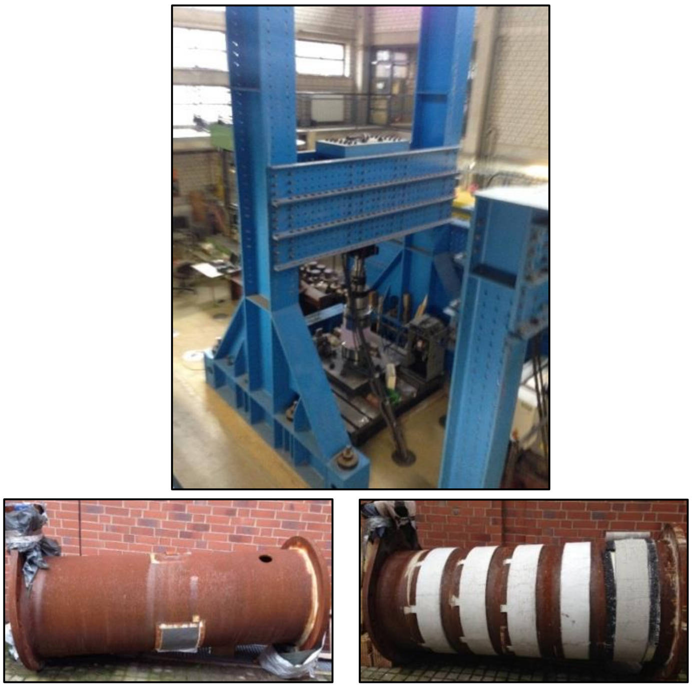

Figure 6: Parts from large scale bending specimen (**monopiles**)

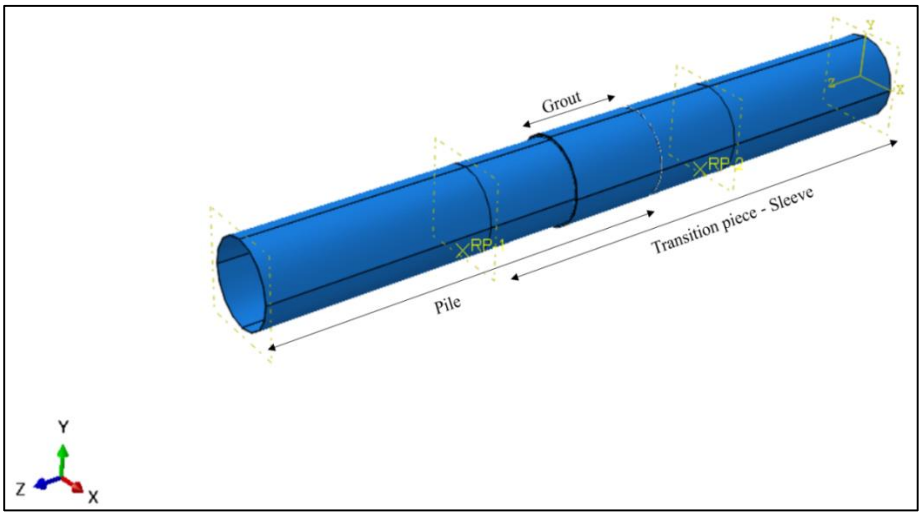

Figure 7: Corresponding large scale numerical model

In Figure 7, a Jacket and a tripod large scale specimen are illustrated. The jacket coupon has a thicker grout and both will be subjected to cyclic axial loading.

Figure 8: Large scale **jacket**, **tripod specimen** and **test rig** (from left to right)

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