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Testing of jacket pile sleeve grouted connections exposed to variable axial loads

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ABSTRACT

Modern offshore jacket structures are designed with piles that are carrying variable axial loads, large shear forces and bending moments. Even if the geometry of the grouted connection is quite simple the load transfer mechanism is complex. It involves friction, contact stresses, brittle material, abrasion, cyclic degradation, etc.

Current design recommendations were developed based on relatively small scale test and with only a few tests performed with cyclic loads that include change of load direction. In order to study the capacity of grouted connections with shear keys for alternating axial load, four (4) segment specimens were tested. The specimens were full scale representation of a segment of a part of the annulus of an axially loaded pile sleeve connection.

The load-carrying axial capacity under cyclic loading was found.

1. Introduction

Jacket structures are used for exploration of oil and gas resources as well as support for generators and substations for offshore wind farms. The foundations of jacket structures are usually made with piles that are connected to the jacket by a grouted connection with shear keys. The piles of modern jacket structures are considerably more exposed to alternating axial loading and bending and shear loading than what was the case when design recommendations as implemented in ISO 19902 [6] and NORSOK N-004 rev 2 [8] were developed. The reason for this increase is related to the change from inclined (battered) to vertical piles, larger water depths (hence larger ratio of horizontal against vertical loads) and increase in pile dimensions and steel material strength. However, research results on the capacity of grouted connection for this type of loads are scarce. This is pointed out by Lotsberg & Solland [1] and Dallyn et al. [5]. In this study a laboratory test program to investigate the capacity of grouted pile sleeve connections against variable axial loading was undertaken. Typical normal strength neat cement grout was used. The tests were carried out on specimen representing segments of the real connection. The segment represented full scale shear keys and grout thickness. The test specimens were designed with a representative radial stiffness similar to that of grouted connections of piles with diameter in the order of 2 m–2.5 m. The test specimen design is similar to the design described by Lotsberg et al. [2–4]. The design of the specimens and the test program was made to ascertain the same load and deflection pattern as in the full scale connection. The focus of the test program was to determine the capacity for alternating and reversed axial loads as the axial load in typical grouted pile-sleeve connections is dominated by environmental loads primarily from waves.

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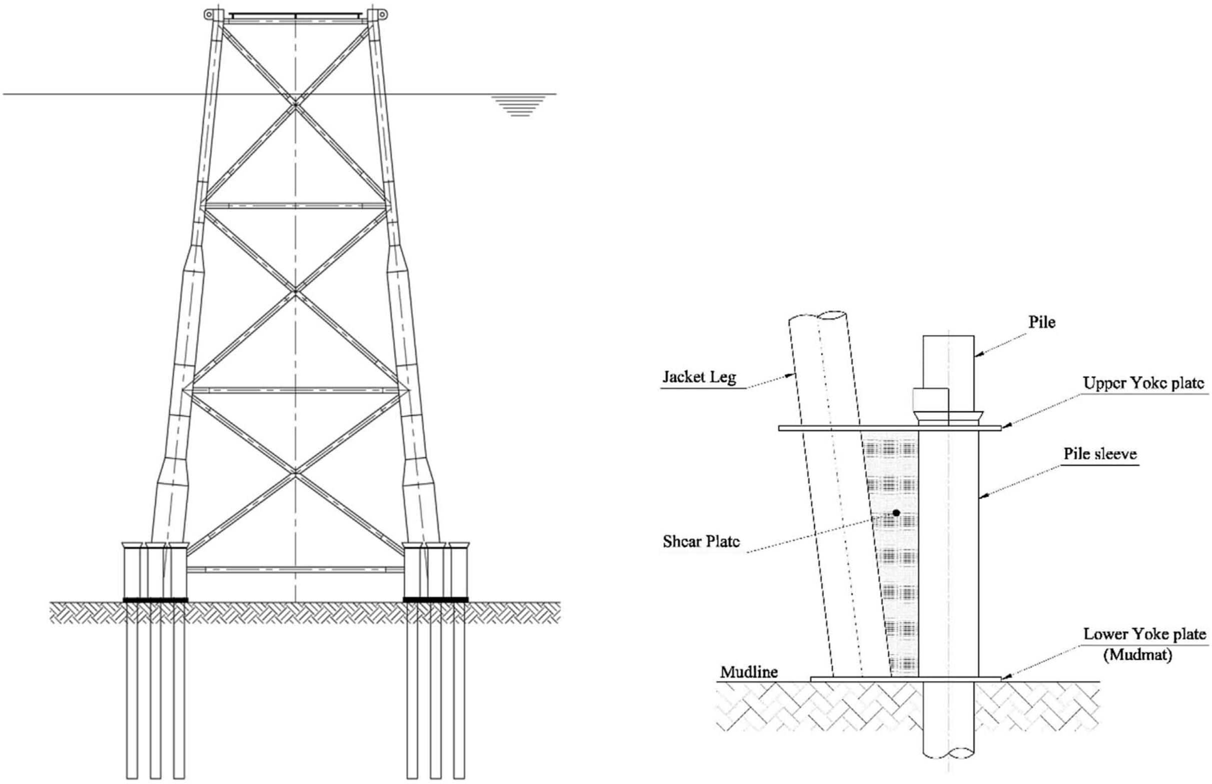

Fig. 1. Typical jacket structure with pile sleeve connection detail.

2. Problem description

The typical grouted pile to sleeve connection of an offshore jacket platform is schematically shown in Fig. 1. Piles are driven through the pile sleeves and when the target penetration is achieved the piles are connected to the sleeves by grouting the annulus. The piles are subjected to variable axial loads, large shear forces and bending moments primarily from environmental loads like wind and waves. These loads are cyclic in nature and may load the pile foundation from all directions.

The axial load in the jacket leg are usually transferred to the pile by a grouted connection with shear keys.

The axial force from the sleeve will be transferred as shear force through the grouted connection. The shear keys transfer a large part of the load through compressive struts between shear key pairs on each side of the grout as indicated in Fig. 2.

As a small relative displacement between pile and sleeve is needed to activate the shear keys, the bottom shear keys will initially take more load than the shear keys further up in the connection. Due to elastic deformations of the steel parts, typically a relative displacement between pile and sleeve in the order of a few millimetres is needed at the lower shear keys to activate the entire connection. As the load alternates, this will over time create local damage to the grout close to the lower shear keys. It is expected that this type of local damage will progress upwards in the connection over time as the damage makes the lower shear keys less effective and the shear keys further up will take more of the load.

From experience grouted connections perform well for alternating loads that do not change sign. Less data exists on connections where the axial loads change sign. Typically alternating reversed load occur only in storm situations for modern jacket structures. This implies high load levels and relatively few load cycles. The test programme reflects this.

In order to investigate the capacity of pile sleeve connection exposed to alternating reversed axial load a test program was executed as described in the following chapters.

3. Test specimens

3.1. Design principles

The tests were carried out on specimens representing a segment of the grout annulus and denoted box specimens. For practical reasons the tests were made as a double sided connection with two grout volumes being tested simultaneously. The specimens were designed using the same principles as described by Lotsberg et al. (2013) [2] and [4]. Due to concern about scale effects and contribution to resistance from surface irregularity, Lotsberg et al. decided to design box specimens that represented a similar radial stiffness as that of large scale cylindrical grouted connections. Steel plates are providing resistance against lateral deformations which