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Testing of jacket pile sleeve grouted connections exposed to shear forces and bending moments

Stefan Marion[a,*], Atle Johansen[a], Gunnar Solland[a], Terje Nybø[b]

[a] DNV GL AS, Veritasveien 1, 1363 Høvik, Norway
[b] StatoilASA, Sandsliveien 90, 5254 Sandsli, Norway

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ABSTRACT

Modern offshore jacket structures are designed with piles that are carrying 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. In order to improve our understanding of the behaviour and load-carrying capacity of grouted connections a laboratory test program involving 12 test specimens was executed. The specimens were full scale representation of a segment of a part of a pile sleeve connection close to the lower end. The tests are carefully planned to represent the real load and deformation conditions of the connection under cyclic loads. Two design geometries “Retracted” and “Extended” were tested. Four of the tests included reinforcement bars. The effect of the grout seal keeper plate was also investigated.

The load-carrying capacity under cyclic loading was found. There were significant differences in the behaviour of the two different geometries.

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. The piles of modern jacket structures are considerably more loaded in bending and shear than what was the case when current design recommendations were developed. The reason for this increase is related to the change from inclined (battered) to vertical piles, larger ratio of horizontal against vertical loads as jackets are installed in ever greater water depths and increase in pile dimensions and steel material strength. However, research results on the capacity of grouted connection for shear forces and bending moments are scarce. This is pointed out in Refs. [1,3].

A laboratory test program to investigate the capacity of grouted pile sleeve connections against shear force and bending moment was undertaken. The tests were carried out on specimen representing segments of the real connection. The segment represented full scale steel plate and grout thickness. The design of the support and load conditions of the specimens was made by non-linear finite element analyses of a selected full scale pile sleeve connection and of the specimen. The design of the specimens 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 cyclic loads as the shear forces and the bending moments in typical grouted pile-sleeve connections is dominated by environmental loads primarily from waves.

Design codes or standards for jacket structures are not giving suitable recommendations on how to design grouted connection for

* Corresponding author.
E-mail address: stefan.marion@dnvgl.com (S. Marion).

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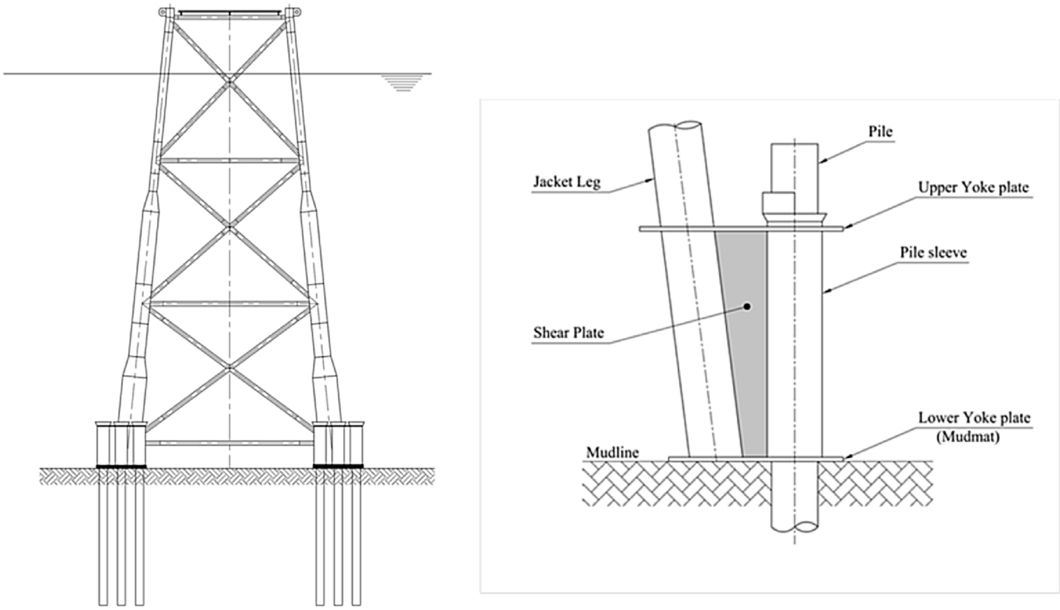

Fig. 1. Typical jacket structure with pile sleeve connection detail.

pile sleeve connections and the reported tests are believed to give valuable contribution for the basis for making such rules.

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 design sleeves and when the target penetration is achieved the piles are connected to the sleeves by grouting the annulus. The piles are subjected to 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 shear force and bending moment are carried by friction and contact forces between the pile and grout and between the grout and sleeve as indicated in Fig. 2.

The shear force and bending moment will lead to contact forces on the windward side of the pile and sleeve at the lower end of the grouted connection. The contact forces will generate friction forces as there will be small, but unavoidable slip between the grout and the pile (or sleeve) when the connection is heavily loaded. The cyclic nature of the environmental loads may lead to change in contact from windward to leeward side of the connection. The bending moment will be carried partly as a force couple formed at the lower end and an opposite reaction higher up in the connection and by friction forces created at these two zones of contact.

The contact pressure and the friction will lead to high compressive and tensile stresses in the grout. The contact will always create compressive stresses in the grout, but the friction will give shear stresses with alternating sign dependent upon the direction of sliding. It is not easy to establish the capacity of the connection from ordinary knowledge of the strength of concrete and grout as there are several factors that are difficult to model. For instance, the redistribution of peak compressive stresses, the effects of confinement and especially the cyclic capacity of the grout when exposed to tensile stresses of alternating direction.

In order to investigate the capacity of pile sleeve connection exposed to cyclic shear forces and bending moments a test program was proposed as described in the following chapters.

3. Design of specimens

3.1. General

Due to the large dimension of piles (diameter up to 2.5 m and thickness up to 0.1 m) a full-scale test program is not feasible. Instead of selecting scale models it was decided to carry out the tests by using full scale dimensions on a flat test specimen representing a segment of the pile-sleeve connection.

The stress distribution and the deflections of the pile and sleeve shells was determined from finite element analysis of a typical jacket pile sleeve connection and imitated in the specimen by carefully adjusting the positions of the jack and the specimen supports. The pile sleeve connection and the specimen in the test rig was analysed with the same analyses methods as far as practical possible to obtain a test configuration for the specimen to represent the conditions for the real connections. The test setup is schematically shown in Fig. 3.

Two different details of the grouted connections were analysed. One denoted "Retracted" and the other denoted "Extended" are