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Review

Experimental testing of grouted connections for offshore substructures: A critical review

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ABSTRACT

Grouted connections have been extensively used in the oil and gas industry for decades, and more recently their application has been extended to the offshore wind industry. Unfortunately plain-pipe grouted connections for large-diameter monopile foundations have recently exhibited clear signs of insufficient axial capacity, resulting in slippage between the transition piece and monopile. Motivated by the emergence of such problems, this paper presents a critical review of the technical literature related to the experimental testing for grouted connections for offshore substructures, covering all the key material and design parameters that influence their capacity, including the confinement provided by pile and sleeve, surface finish, simultaneous bending action, connection length, dynamic loading, early-age cycling during grout curing, grout shrinkage, radial pre-stress and temperature. The review also focuses on the relevance of such parameters for offshore wind applications and addresses what needs to be considered to ensure that their design achieves the desired capacity, behaviour and efficiency.

Contents

1. Introduction

Grouted connections have had extensive applications for the foundation of oil and gas platforms, where they have been used for main, skirt and cluster piles, as shown within Fig. 1. A grouted joint is a structural connection formed by use of cementitious grout cast in an annulus formed between two concentric circular tubes with different diameters. The principal methods of load transfer are through shear friction mobilised by the normal stress induced through interlocking of surface imperfections and compression of the grout.

With the aim of optimising the design of platform foundations and reducing material quantities, extensive work was carried out in the late 1970s and early 1980s to quantify the performance of both plain-pipe and shear-key grouted connections through experimental testing, particularly for offshore applications. This stream of work was predominantly focused on the influence of grout strength, shear-key height and spacing, ratio of diameter to thickness of the piles, outer sleeves and grout annulus on the ultimate capacity of the connection.

Since 2002, grouted connections have also been used extensively in the offshore wind industry, where large-diameter-sleeved grouted connections comprise around 60% of installations in Europe [2]. Some

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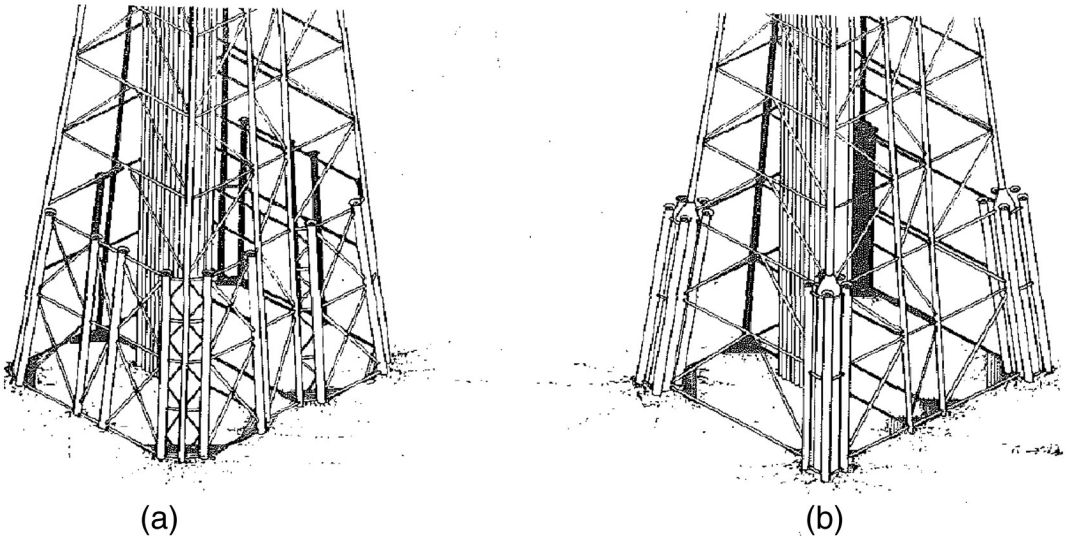

Fig. 1. Typical foundation pile arrangements where grouted pile – sleeve connections are used; a) Main and skirt Piles, b) Cluster piles [1].

typical details for an energy converter 80 m tall, capable of 80GWh/year are shown in Fig. 2. Unfortunately it has been reported that the axial capacity of these plain-pipe grouted connections may be insufficient over the design life of the plant, with significant unexpected early-stage settlements resulting from this insufficient design [3]. This has led to very expensive ongoing remediation works being required to existing foundations affected by these failures. In addition to the use of grouted connections for monopiles, they are starting to be more widely used between the pin piles and jackets for offshore WTG (wind turbine generator) in sites with deeper mean water level (MWL), with the market share of jackets and tri-pile substructures increasing from around 10% to 20% from 2010 to 2013 respectively [2]. The reason for the continued

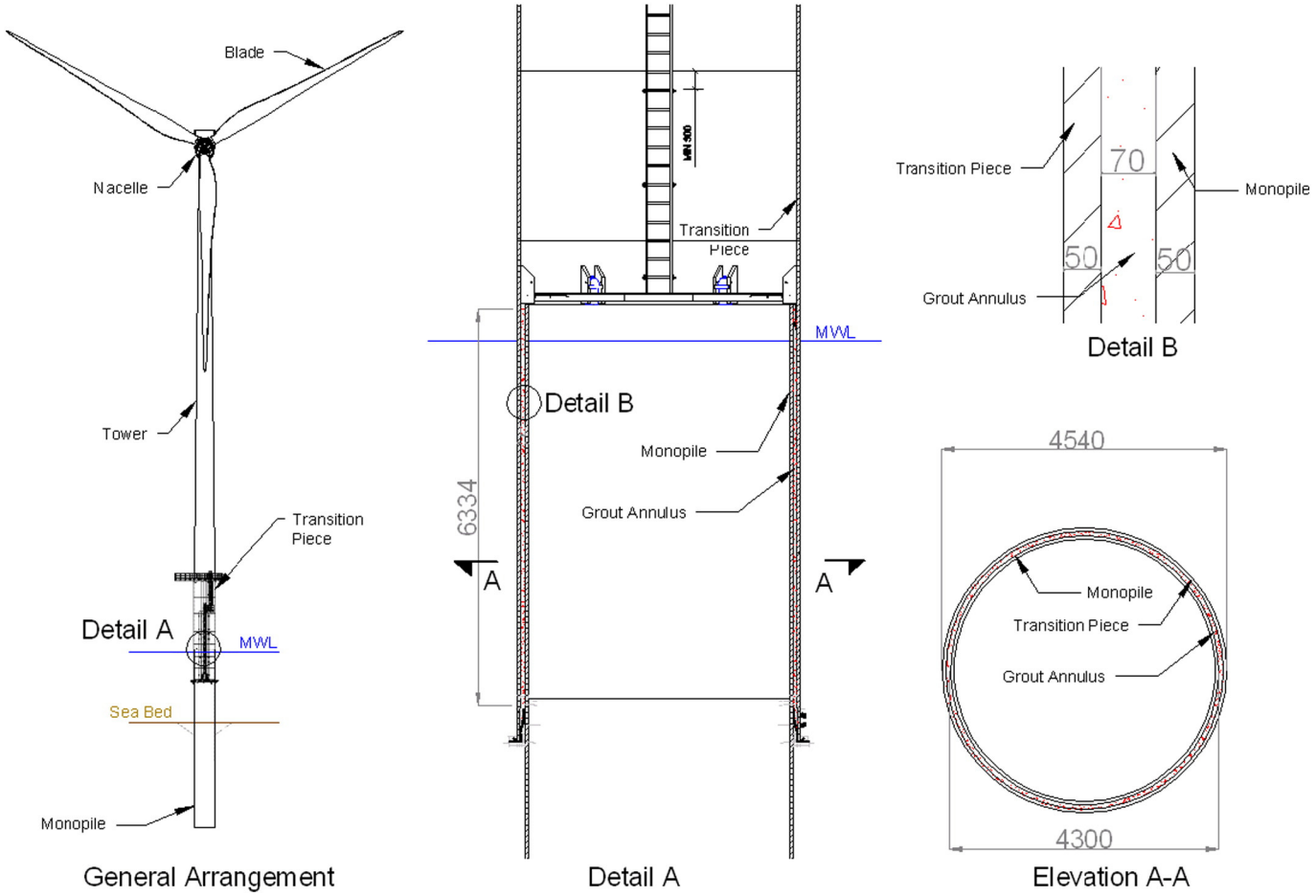

Fig. 2. Typical general arrangement of a plain-pipe grouted connection for an offshore WTG foundation.

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