Soils and Foundations 2015;55(6):1487–1500

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Soils and Foundations

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SOILS AND FOUNDATIONS

Effects of polymer and bentonite support fluids on the performance of bored piles

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Received 29 November 2014; received in revised form 1 July 2015; accepted 21 August 2015
Available online 27 November 2015

Abstract

Synthetic polymer fluids have been used for the construction of bored piles (drilled shafts) for more than two decades, but their effect on the performance of the completed piles is still a matter of debate. To investigate the effects of polymer and bentonite fluids on the behaviour of bored piles, a field trial comprising three full-scale instrumented test piles has been conducted at a site in East London. It was found that the two piles constructed using polymer fluids showed much stiffer load-settlement response than the one constructed using bentonite slurry. Surprisingly, an extended pile bore open time of up to 26 h was found to have no adverse effect on the piles if supported by polymer fluids. Based on the results of back-analyses using the load-transfer approach, polymer fluids were found to have little effect on the Woolwich and Reading Formations but a noticeable effect on the Upnor Formation – the mixed results are believed be due to the different soil mineralogies. It has also been shown that the common problem of 'soft toes' can be eliminated by adopting good construction practice including proper base checking and fluid cleaning or exchange procedures on site.
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Keywords: Synthetic polymer; Bentonite; Support fluid; Excavation; Bored piles

1. Introduction

For the construction of bored piles and diaphragm walls, fluids are often used to support the excavation side walls in unstable strata until concreting. Bentonite clay slurries have been used for this purpose since the pioneering work by Veder (1953). Synthetic polymer fluids have also been used successfully on many projects since their introduction to the foundation industry in the early 1990s. The polymer fluids considered in this paper are aqueous solutions of high-molecular-weight polymers, having essentially the same density as water but a much higher viscosity. Compared to bentonite, polymer fluids can offer many operational and environmental benefits including: smaller site footprint, ease of mixing, lower fluid disposal cost and less impact on the environment (e.g. Schünmann, 2004; Lennon et al., 2006). A general introduction to polymer fluids can be found in Jefferis et al. (2011) and Jefferis and Lam (2013).

Because polymer fluids are both physically and chemically different from their bentonite counterparts, there is still a lot of debate about how these fluids compare in terms of their effects

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Peer review under responsibility of The Japanese Geotechnical Society.

http://dx.doi.org/10.1016/j.sandf.2015.10.013
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Notation

E_p	pile stiffness
G	elastic shear modulus
G_{vh}	elastic shear modulus (vertical propagation, horizontal polarisation)
N	blowcount from standard penetration tests
P	load in pile
p'	mean effective stress
q_b	base stress
q_c	cone resistance
q_{bf}	ultimate base stress
r_o	pile radius
S_u	undrained shear strength
w	local pile displacement
w_b	base displacement
w_{bf}	base displacement at q_{bf}
α	adhesion factor
$\dot{\gamma}$	shear strain rate
δ'	pile-soil interface friction angle
ε	strain in pile
Δ	pile head settlement
Δw_{res}	displacement from τ_p to τ_r
ζ	load-transfer parameter
η	strain-softening parameter
μ	viscosity
ξ	yield parameter
τ_o	shear stress at pile wall
τ_f	failure shear stress
τ_p	peak shear stress
τ_r	residual shear stress
φ'_p	peak angle of shearing resistance

on the performance of piles. For example, it is unclear whether a polymer-supported bore can be left open for longer without compromising the performance of the completed pile. In a recent bored piling project in central London utilising polymer fluids, the design-and-build contractor had to reduce the design alpha (α) value for the London Clay and the Lambeth Group from 0.5 to 0.35 for any unlined bores which were left open overnight, effectively increasing the lengths of the piles. The reason for the alpha value reduction was to compensate for any additional clay softening due to increased exposure to the support fluids (LDSA, 2009). Although this practice has been developed from experience with piles drilled either dry or with bentonite slurry support, in the absence of published case histories on polymers, the same rule was adopted for the design for the present project. In a professional news article, Wheeler (2003) reported on a trial with a polymer fluid at London's Canary Wharf. It was reported that the polymer fluid did not lead to significant degradation of shaft friction with time but one of the production pile bores collapsed during excavation. The collapse was attributed to polymer fluids behaving differently from bentonite. In addition to concerns for pile bore stability, the use of polymer fluids has been associated with an increased risk of ‘soft toe’ at the pile base (Fleming et al., 2009). This is because polymer fluids have a lower particle-holding capacity than bentonite. In polymer fluids, soil particles tend to settle faster than in bentonite so they tend accumulate at the base of the excavation during the insertion of steel reinforcement cages and build-up of the tremie pipes, and on the top of the rising concrete column during casting. The potential problems of ‘soft toe’ and excavation instability are inhibiting the take-up of polymer technology, though it should be emphasised that both the problems can be completely eliminated if the fluids are used correctly, as will be demonstrated in this case history.

To investigate the effect of polymer fluids on the performance of bored piles, a field trial consisting of three comparative test piles has been carried out at a site in East London. The aim of the trial was threefold: (i) to assess the effect of polymer and bentonite support fluids on the load-settlement behaviour of piles; (ii) to investigate whether extended pile bore open time would lead to worse behaviour; (iii) to assess the effectiveness of improved construction practice comprising rigorous fluid property control and pile base cleaning to preventing the formation of ‘soft toes’. Various aspects of the trial are discussed in the following sections: ground conditions, construction details, and interpretation of load test results.

2. Ground conditions

2.1. Soil profile

The test site is located at about 0.5 km south-east of the Stratford International station ‘box’ in East London. Table 1 summarises the soil layers encountered and their descriptions. It can be seen that the ground consists of made ground, River Terrace Gravel, Lambeth Group, Thanet Sand and then Chalk. The made ground at the top was excavated material arising from the construction of the Channel Tunnel Rail Link and the station box (Dyson and Blight, 2007). The Lambeth Group can be sub-divided into Woolwich Formation (Laminated Beds and Lower Shelly Clay), Reading Formation (Lower Mottled Clay) and Upnor Formation. For the purpose of the back-analyses, the made ground and the thin River Terrace Gravel layer were treated as one unit, and the Woolwich and Reading Formations were also treated as a single unit. Fig. 1a shows the idealised soil profile together with some details of the test piles.

2.2. Groundwater conditions

As a result of the geological conditions in the London Basin, two aquifers exist at the test site: a shallow aquifer in the made ground and River Terrace Gravel and a deep aquifer in the Thanet Sand and the underlying Chalk. These two aquifers are separated by the Lambeth Group which is much less

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