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Use of Polymer and Bentonite support fluids, and their impact on bored piles

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ABSTRACT: Synthetic polymer fluid is gradually gaining popularity as a replacement for conventional bentonite slurry in bored pile construction. Compared to bentonite, polymer can offer potential benefits including, for example, smaller site set-up footprint, ease of mixing and lower fluid disposal cost. Some field trials have demonstrated that piles installed using polymer have improved load carrying characteristics beyond equivalent piles installed using bentonite. However, the mechanism leading to improvement of the pile's shaft shear resistance is not fully understood. This paper discusses an experimental investigation carried out on eight, fully instrumented, 4.5 m long bored piles constructed, in the National Buried Infrastructure Facility (NBIF), at the University of Birmingham, with four piles constructed with a polymer and four using bentonite as the support fluid. The installation of optical fibre and strain gauge sensing instrumentation allowed a near full-scale laboratory controlled comparative set of pull-out tests to be undertaken, to enable a direct comparison of the impact of the two support fluids on the frictional resistance of bored piles. The results showed that increased resting time post construction improved the stiffness and strength of the polymer piles. Observation of the exhumed piles and 3D laser scanning revealed the formation of nodules along the length of the piles and the development of surface cracks in the ground (emanating from the position of the pile and propagating outwards in a radial pattern) when polymer was used. This might indicate a stronger concrete/soil bond when the polymer slurry was used, compared to the bentonite slurry, as no similar ground cracks were observed for the bentonite piles when they were removed. The bentonite filter cake layer was thick and increased as the fluid resting time increased. The filter cake layer, associated with polymer piles, was much thinner and independent of the fluid resting time.

KEYWORDS: bored piles, polymer support fluid, bentonite support fluid, large-scale testing facility, fibre optic.

1 INTRODUCTION

The use of synthetic polymer support fluids in bored pile construction has garnered an increasing interest among geotechnical contractors as, compared to conventional bentonite slurry, it offers several operational and environmental advantages. This includes a reduced site setup footprint, simplified mixing procedures, and lower costs associated with fluid handling and disposal (Jefferis & Lam, 2013).

Empirical evidence suggests that piles installed using polymer fluids can exhibit significantly stiffer load–settlement behaviour and reduced displacement under axial loading compared to those constructed with bentonite (Lam et al., 2010). Notably, unlike bentonite slurries, polymer fluids do not form a filter cake on the borehole wall, thereby preserving the shear resistance at the interface even with prolonged contact durations. Nonetheless, the effectiveness of polymer additives—such as polyacrylamide solutions—appears to be soil-type dependent. While studies have shown an average increase of approximately 25% in interface shear strength in fine sands, their influence on medium to coarse sand has proven negligible (Lesnitsky et al., 2021).

This study investigated the impact of polymer support fluid on the shaft resistance of a concrete pile buried in slightly gravelly coarse sand, compared with that of bentonite support fluid. The experimental work was conducted at the National Buried Infrastructure Facility (NBIF) at the University of Birmingham, UK. NBIF is a state-of-the-art, large-scale laboratory designed to facilitate full-scale or nearly full-scale experiments in a substantial pit measuring 25 m by 10 m in cross-section and 5 m deep. This collaborative research project was completed in partnership with industry partners (KB International, Keller, BBGE and GEO-Instruments) and the University of Birmingham. This paper provides an overview of the experimental set-up, discusses the initial findings, and the benefits of conducting large-scale validation testing in controlled laboratory conditions.

2 EXPERIMENTAL WORK

The experiment involved the construction and pull-out tests of eight bored piles constructed in the NBIF pit, with four piles constructed with a polymer and four using bentonite as the support fluid. The piles were constructed by Keller in a pit backfilled with compacted slightly gravelly poorly graded coarse sand (Fig. 1), with coefficients of uniformity (Cu) and curvature (Cc) of 3.04 and 0.76, respectively. The peak friction angle of the sand was measured using a direct shear box, at 46 degrees.

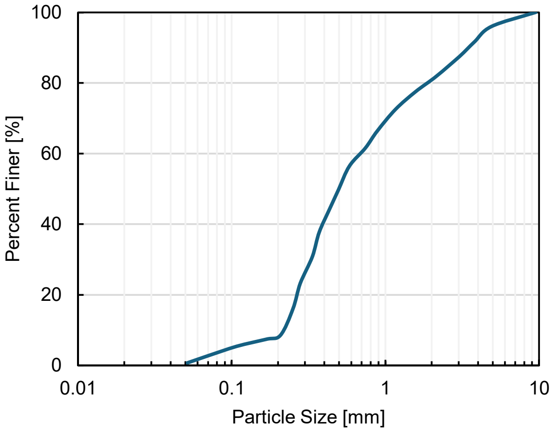

Figure 1. Particle size distribution of the sand used in the experiment

Testing of the piles included monitoring of the load and the displacement of the piles, as well as in-ground monitoring with the use of strain gauges and distributed fibre optic sensors (DFOS) along the length of the pile and a linear variable differential transformer (LVDT) at the top of the pile. Following the pull-out experiment, the piles were exhumed and jet washed. 3D scanning was used to estimate the thickness of the filter cake layer build-up along the pile surface.

2.1 *Pile Construction*

A designated section of the NBIF test pit, encompassing plan dimensions of 10.0 m × 5.8 m and extending to a depth of 5.0 m, was systematically backfilled with the slightly gravelly coarse sand. This sand was placed in 300 mm thick horizontal layers and compacted using a vibratory plate compactor to achieve uniform relative density throughout the profile. In-situ density measurements were performed for each layer using a nuclear density gauge, supplemented by gravimetric water content sampling at four discrete locations per layer. The measured dry densities exhibited minimal variability, with an average value of 1.57 Mg/m³ and a standard deviation of ±0.05 Mg/m³ across the full 5.0 m depth, indicating consistent compaction quality.

After compaction, eight bored piles were constructed within the fill in a regular grid configuration. Each pile had a nominal diameter of 300 mm and a length of 4.5 m, with a minimum edge clearance of 1.5 m from adjacent piles and the pit boundary (Fig. 2).

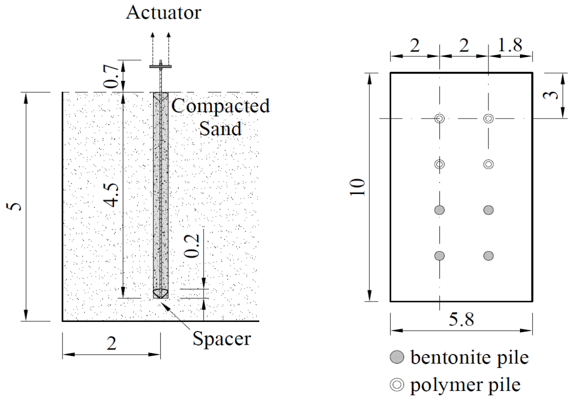

Figure 2. Experimental set-up in the NBIF test pit: side view of a singular pile (left), and top view of the pile assembly (right)

A bentonite-based support fluid was batch-mixed 48 hours prior to installation while the polymer liquid was mixed on-site on the day of the borehole drilling. Each fluid was poured into four different boreholes during excavation to maintain sidewall stability. Upon reaching the final depth of 4.5 m, the drilling fluid was completely displaced and refreshed to remove accumulated fines and ensure optimal slurry properties prior to concreting. Placement of the C32/40 concrete was executed via the tremie method, simultaneously displacing the support fluid, which was collected and discarded (Fig. 3). As part of the experimental design, the fluid dwell period (prior to concreting) varied between 2 and 24 hours to evaluate the time-dependent effects on the interface conditions.

Figure 3. Placement of concrete in the bore via the tremie method

Reinforcement comprised a single 32 mm diameter high-strength GEWI/Dywidag bar embedded along the full pile length (Fig. 4). The reinforcement extended 0.7 m above ground level to facilitate coupling to the loading actuators. A centralising spacer was affixed at the base of each bar to maintain axial alignment during concrete placement.

Figure 4. Dywidag reinforcement bar instrumented with (a) strain gauges and (b) fibre optic cables

Quality control procedures included monitoring the rheological properties (pH, viscosity) of the support fluid and conducting slump testing of the fresh concrete in accordance with relevant standards.

2.2 *Instrumentation*

Instrumentation comprised a 250kN actuator, responsible for applying axial tensile load, a LVDT to monitor displacement of the pile, and an array of strain monitoring devices affixed along the reinforcement bar, including DFOS and conventional strain gauges. An OMEGA LD320-100 LVDT was installed at the pile head, offering a maximum stroke of 200 mm and a residual voltage at the null position of less than 0.5% of full-scale output.

To capture strain distributions along the reinforcement bar, three pairs of vibrating wire (VW) sister bar strain gauges were embedded at depths beginning 0.9 m below ground level. Additionally, a pair of optical fibre Epsilon sensors (manufactured by Nerve Sensors) were bonded longitudinally to the bar over a 4.2 m gauge length, consistent with the configuration described by Bednarski et al. (2022). All sensors were mounted above the central spacer and interfaced with a LUNA ODiSI 6100 interrogation unit for real-time acquisition. Bare 3 mm-diameter optical fibres (unbraided) were adhesively fixed to opposing faces of the reinforcement bar to enable dual-axis strain monitoring. A separate optical fibre, encased in a protective plastic conduit, was included for temperature compensation and thermal profiling. Sensor installation and commissioning were conducted by GEO-Instruments UK, the Instrumentation and Monitoring division of Keller Ltd.

2.3 *Pull-out Test*

A 250 kN capacity hydraulic actuator was deployed for load application, operating under displacement-controlled conditions at a constant rate of 0.01 mm/s. Load and displacement data were continuously recorded throughout testing using MTS AeroPro software. Additionally, a video recording was used to monitor the ground changes around the pile.

All test piles were successfully extracted from the granular backfill. Post-test evaluation focused on interpreting the axial load–displacement response and internal strain development within the reinforced pile section.

2.4 *Exhumed Piles Examination*

The diameters of the exhumed piles were measured using a measuring tape and a 3D scanner along each pile length both before and after the piles were cleaned by jet washing. These were used to estimate the thickness of the filter cake layer along the pile surface.

3 RESULTS

The effect of the polymer and bentonite support fluid on the performance of piles was analysed based on the data obtained during (i) the pull-out test (as load displacement and strain distribution), and (ii) post exhuming (visual and 3D laser scanning).

3.1 *Pull-out Test Results*

The results indicated that increased fluid resting time, post bore construction, improved the stiffness and strength of the polymer piles. The maximum tensile strength of a pile constructed in a bore supported by a polymer fluid for a duration of 22hours (pile 4-P) was 205 kN, whilst 5 hours fluid exposure resulted in a tensile strength of 165 kN (pile 2-P), Fig. 5. This suggests that a 17 hour increase in polymer fluid exposure time resulted in approximately 20% increase in the peak tensile strength.

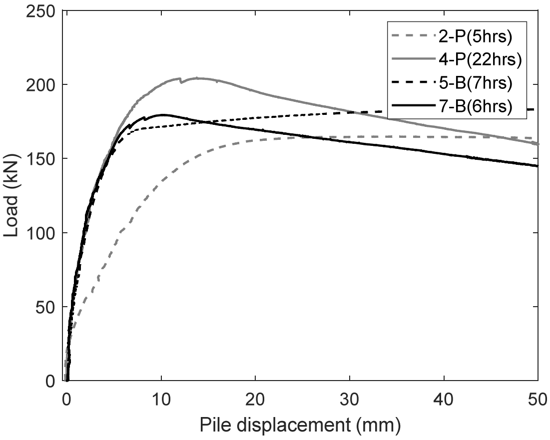

Figure 5. Load-displacement characteristic of selected polymer (P) and bentonite (B) piles, measured during a pull-out test. Corresponding fluid resting time for each pile is provided in the pile description.

Meanwhile, the bentonite piles displayed tensile strengths in the region of 170 kN (pile 5-B) and 179 kN (pile 7-B). The other piles appeared to follow this trend, with the shortest (2 hours) bentonite exposure time, indicating the highest strength amongst the bentonite piles. It is noted, however, that the analysis of the results is ongoing and will be discussed further in Zhai et. al. (2026). (The pile's tensile strength was defined as the peak force applied when the pile displacement was less than 30 mm. If the load was still increasing after 30 mm, the force applied at 30 mm was adopted as the pile tensile strength).

3.2 *Exhumed Piles – Visual Observation*

3.2.1 *Change along the pile length*

Following the measurements obtained from the 3D laser scanning, it was observed that only a very thin layer of sand was attached to the surface of the polymer piles (Fig. 6) whilst a much thicker layer was present on the surface of the bentonite piles (Fig. 7). The example shown represents the piles with comparable fluid resting times (approximately seven hours for the bentonite and 5 hours for the polymer) and indicates that even within this relatively short exposure time the bentonite fluid resulted in a build-up of approximately five times larger filter cake layer than that in a polymer fluid. The bentonite filter cake layer increased as the fluid resting time increased, whilst with the use of polymer the cake layer was independent of the fluid resting time.

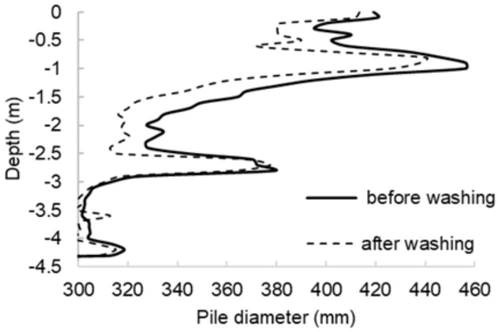

Figure 6. Filter cake development along a polymer pile (fluid resting time in the bore approximately 5 hours)

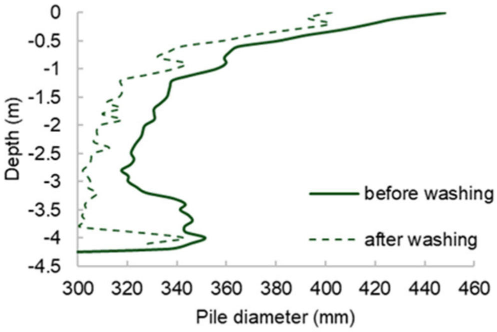

Figure 7. Filter cake development along a bentonite pile (fluid resting time in the bore approximately 7 hours)

Formation of nodules was observed along the polymer piles, which was not evident when bentonite fluid was used (Fig.8). This could potentially indicate that polymer acts faster in sealing the ground as the nodules are believed to be a consequence of the flight auger used in this experiment. When the polymer support fluid was used for drilling in this test, it was observed that the spoiled soil mixed with polymer fluid tended to stick to the auger during drilling. When the auger was lifted, it might have applied a dragging force on the wall of borehole, which could have led to borehole instability. The bentonite pile skin appeared “smoother” than that of the polymer piles.

Figure 8. Exhumed piles post jet washing: bentonite (left) and polymer (right)

3.2.2 *Surface changes*

During the process of exhuming the piles the development of surface cracks (emanating from the position of the pile and propagating outwards in a radial pattern) was observed when polymer was used (Fig. 9). This might indicate a stronger concrete/soil bond with the polymer slurry compared to the bentonite slurry as no similar ground cracks were observed for the bentonite piles when they were removed (Fig. 10). However, spillage of the fluid during the pile construction could have also contributed to this effect.

Figure 9. Development of radial surface cracks during exhuming of a polymer pile

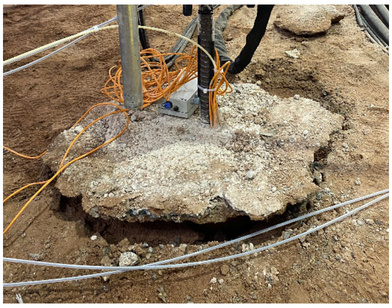

Figure 10. Lack of surface cracks during exhuming a bentonite pile

4 CONCLUSIONS

The findings of the large-scale experimental testing carried out at NBIF on concrete piles bored in a coarse-grained slightly gravelly sand indicated the following:

- The filter cake layer development was more pronounced in the piles constructed with bentonite fluid, which increased with increasing resting time. In the polymer-built piles the filter cake layer was thinner and independent from the exposure time.
- Comparing the surface of the concrete piles, some concrete nodules were observed on the skin of the polymer piles, while this was not observed in the bentonite piles. This was attributed to the specific type of drilling auger used in the test but could also potentially indicate that the polymer acts faster than bentonite in supporting the soil from collapse.
- In the polymer piles cracks were noticed emanating from the position of pile and propagating outward in a radial pattern, whilst no similar cracks were observed for the bentonite piles. This could suggest a stronger concrete/soil bond when the polymer slurry was used as compared to the bentonite, however surface fluid spillage might have also contributed to this effect.
- In polymer piles an increase of approximately 20 % in the peak tensile strength was observed with increasing fluid exposure time from 5 hours to 22 hours.

It is noted that the experimental methodology might have affected the results obtained in this particular soil. The analysis of the results is ongoing.

5 ACKNOWLEDGEMENT

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