Improving the capacity of bored piles by shaft grouting

Améliorer la capacité portante des pieux forés par injection de coulis opérée latéralement

Miller M., Potts V., Skinner H.
Donaldson Associates Ltd.

Vaziri M.
Ramboll UK

ABSTRACT: A project in Georgia involved the construction of two towers for residential, retail and hotel use with a two storey basement. The development was near the Black Sea, with poor ground conditions below basement level. In order to carry the high loads, the developments used deep bored piles installed by Bauer. The pile capacity was significantly enhanced by shaft grouting from a number of tubes cast into the piles during construction. Instrumented pile tests were carried out on ungrouted and grouted piles. Results from the strain gauges showed differences in the behaviour of the piles in different strata depending on the granular content of the material.

RÉSUMÉ : Dans le cadre d’un projet en Géorgie, deux tours ont été construites pour des logements, bureaux et hôtels ainsi qu’un sous-sol a deux étages. Le projet est situé près de la Mer Noire, ou les conditions de sol en-dessous de la base du sous-sol sont mauvaises. Afin de supporter les descentes de charges importantes, des pieux forés ont été installés par Bauer. La capacité portante des pieux a été considérablement améliorée par injection de coulis de ciment, opérée latéralement a travers plusieurs tubes coulés dans les pieux pendant la construction. Des essais instrumentés sur des pieux forés avec et sans injection ont été réalisés. Les mesures fournies par les jauges de déformations ont montrées différents comportements des pieux selon la granulométrie des couches de sols rencontrées.

KEYWORDS: Batumi, shaft grouting, pile testing
MOT-CLÉS : Batoumi, injection de coulis opérée latéralement, essais sur pieux

1 INTRODUCTION

In the UK there has been significant work carried out on the benefits of base grouting into Thanet Sand to improve stiffness and capacity of deep bored piles, but limited information is available on the use of shaft grouting. This paper will present and discuss the results of shaft grouting that was carried out to enhance pile capacity for a project in Georgia.

Ramboll UK provided structural and geotechnical design services for a new development adjacent to the Black Sea in Batumi, Georgia in 2009. The development comprised of a 17 storey residential tower and a 23 storey hotel tower surrounded by a 2 storey podium building. A two storey basement underlay the entire site footprint.

The findings of the ground investigation and resulting tender pile design will be presented. The pile testing results will then be presented giving commentary on the likely factors behind the pile behaviour and the potential for carrying out shaft grouting in other situations.

2 GROUND CONDITIONS & SEISMICITY

Tectonic movements, local river systems and the progression and regression of the Black Sea have influenced the regional geology.

2.1 *Geology & Groundwater*

The region is underlain by volcanic rocks reported to weather to clay dominated strata. Overlying the bedrock are two distinct quaternary sequences thought to be up to 150m thick. The older of these is thought to be associated with alluvial-swampy sediment sequences with the more recent being associated with marine sequences.

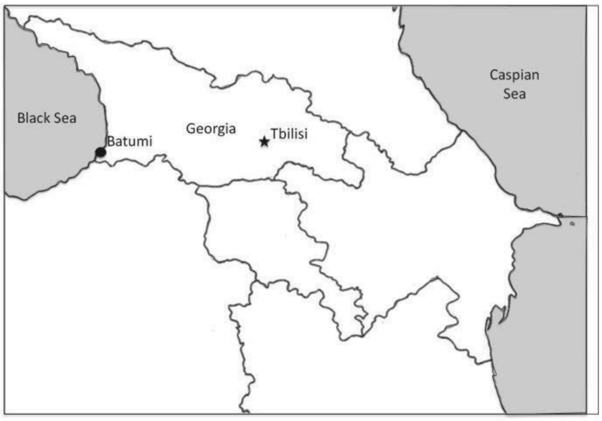

Figure 1. Site location in regional context.

The ground investigation specified by Ramboll revealed made ground overlying sands and gravels over clayey and sandy loams. The fines content increased with depth and the test data and on site observations suggested that the strata generally decreased in strength and stiffness with depth. Table 1 summarises the ground conditions and Figure 2 presents particle size distribution against level.

The laboratory testing was carried out to Georgian standards with some test methods differing from British practices to a greater extent than others. The laboratory testing of the Loam B material in particular was inconclusive in determining the strength of the material; it was therefore necessary to largely rely on the in-situ SPT testing.

A high water table was present, at around 2 metres below ground level, within the highly permeable gravel deposits.

Table 1. Summary of ground conditions.

Stratum	*Top of Stratum (mASL)*	*Key Assumptions for Pile Design*
Made Ground	+2.2	N/A
Gravel	+0.4	N/A
Fine Sand	-5.3	Granular: ϕ’=34°
Loam A: Silty Sand	-11.7	Granular: ϕ’=31°
Loam B: Clayey Silt	-21.8	Cohesive: c_u = 100kN/m^2

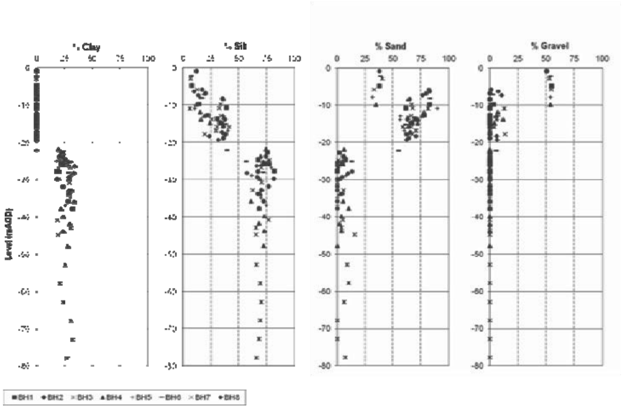

Figure 2. Particle size distribution with depth.

2.2 *Seismicity*

The Caucasus region, in which the site is located (Figure 1), is one of the most seismically active regions in the Alpine-Himalayan collision belt. Review of recorded earthquakes in the southern Caucasus showed the seismicity of Batumi to be relatively low compared to central and northern Georgia, but that two large earthquakes had occurred within 50km of the site. Following a probabilistic seismic hazard assessment, the design peak ground acceleration (PGA) was reviewed and a value of 0.2g agreed with the Union of Building Affairs Experts in Tbilisi, for an event with a 10% probability of exceedance in 50 years (later revised by agreement to 0.9g). Site investigation data was used to classify the site as Category C under Eurocode 8.

3 PILE DESIGN

Most of the buildings locally are founded on shallow pads within the dense near surface gravels. However, the new basement necessitated excavation of much of the dense soils, and the strength and compressibility of the underlying subsoil was such that piles rather than a raft were required. Between the piles, a basement slab of between 1.75m and 0.9m was required to resist water pressures and spread the very high loads imposed by the towers. Additional piles were required around the perimeter of the basement to protect the waterproofing membrane by ‘pinning’ the slab down against water pressure.

3.1 *Tender Design*

Ramboll produced a piling scheme for tender to British Standards. Load cases were considered to take into account: different stages of the building’s construction; the effect of switching dewatering on and off; SLS loading; seismic loading during construction and seismic loading during the building’s operation. A scheme adopting 1100mm diameter piles was developed.

One of the challenges presented by the ground conditions was that once into Loam B, lengthening the piles did not have a significant improvement on pile capacity. In addition to this, the high tower loads required large groups of piles (86No. for the hotel tower), which presented a challenge in terms of settlement. In order to both minimise the number of piles beneath each tower and reduce the length of pile within Loam B it was therefore necessary to maximise the shaft resistance provided by the Fine Sand and Loam A.

Ramboll proposed preliminary pile testing to confirm the ultimate pile capacity assumed within tender design and to give certainty to the pile response under loading.

3.2 *Shaft Grouting*

Bauer Georgia were appointed as piling contractor and proposed shaft grouting of the piles to improve shaft resistance. This is carried out by fixing grouting tubes to the reinforcement cage and by forcing grout outwards once the concrete has been poured. Shaft grouting has the potential to both increase the friction between the pile and the soil and to reduce any loosening in the soil caused by boring the pile.

Ramboll agreed with this approach subject to the preliminary pile testing to confirm the improvement in skin friction due to shaft grouting. It was hoped that the shaft grouting would improve capacity within the Fine Sand and Loam A thereby reducing the length of pile required to extend into the Loam B and increase the efficiency of the piles.

4 PILE TESTING

4.1 *Test Arrangement*

Two test piles, both 35m long, were installed from ground level; with the first 10m cased to exclude skin friction. Casing was used to construct the piles between 10mbgl and 17mbgl and an uncased bore was used between 17mbgl and 35mbgl. Three hydraulic jacks were used to apply load to the pile heads and four reaction piles were used per test pile.

The ultimate proof load for the test was set at 16.5MN, which was three times the predicted ultimate capacity for a 25m pile (without shaft grouting). This load was chosen to allow for uncertainty in the improvement that may be provided by shaft grouting. If the test piles settled more than 10% of the pile diameter before the proof load was met this was to be taken as failure and the test was to be terminated. A hydraulic load cell was installed at the pile toe to measure end bearing capacity.

Test pile T1 was shaft grouted between 10mbgl and 35mbgl, i.e. the full working length. Test pile T2 was not treated.

4.2 *Results of Pile Testing*

Neither pile reached the proof load of 16.5MN with T1 reaching 12.375MN and T2 reaching 10.1758MN before the test was terminated due to rate of settlement. Figure 3 presents the load-displacement behaviour of the two piles as recorded during testing.

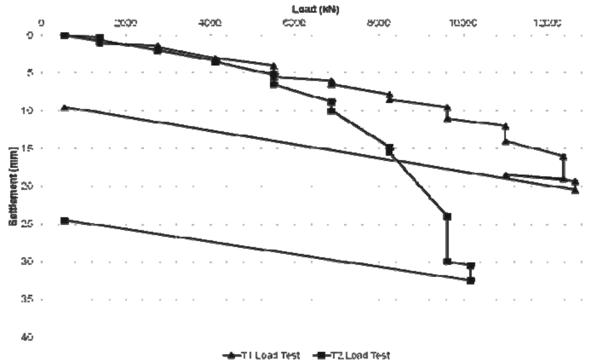

Figure 3. Load-displacement behaviour of piles: measured during testing.

Strain gauges installed along the length of the piles were used by Bauer to calculate the skin friction mobilised within each stratum; this information is summarised in Table 2 alongside the ultimate values originally calculated for tender design using the site investigation data (see Table 1).

Table 2. Calculated and measured skin friction.

Strata	*Ultimate Skin Friction (kN/m^2)*		
	Calculated	*T1*	*T2*
Fine Sand	59	110	50
Loam A: Silty Sand	80	110	45
Loam B: Clayey Silt	50	110	90

4.3 *Interpretation of Pile Testing*

Several simple calculations were made of the ultimate shaft capacity using the values of skin friction from the strain gauge data. From these it was apparent that skin friction had not been completely excluded over the top 10m of each pile. The first stage of the interpretation was therefore to remove the contribution of the top 10m from the results so that they were comparable to the design values. The load cell installed by Bauer in the toe of the pile confirmed that very little base resistance was generated (1.2MN assumed in Cemsolve analysis).

Figure 4 presents the load-displacement behaviour of the two piles. The values of load applied have been modified at each stage to remove the contribution of the top 10m of pile. The measured curve for T1 on Figure 4 has been stopped at the load stage just prior to the load being reduced and then replaced (refer also to Figure 3).

The Fugro Loadtest Ltd program Cemsolve was used to compare the modified test data to Fleming's load-displacement relationship, which is commonly used to predict pile behaviour under loading (Fleming, 1992). Figure 4 also shows the Cemsolve model of the pile behaviour (back analysed using the modified data from the load tests). The Cemsolve curve fit suggests that the ultimate capacity of T1 was 10.0MN (of which 9.5MN was shaft capacity) and of T2 was 7.25MN (of which 6.5MN was shaft capacity); these values were assumed as an estimate of the failure load i.e. Cemsolve prediction of when settlement continues to increase with no further load applied. These values are higher than the loads at which the two pile tests were terminated, which is considered to be due to practical difficulties in measuring the response to loading when close to failure.

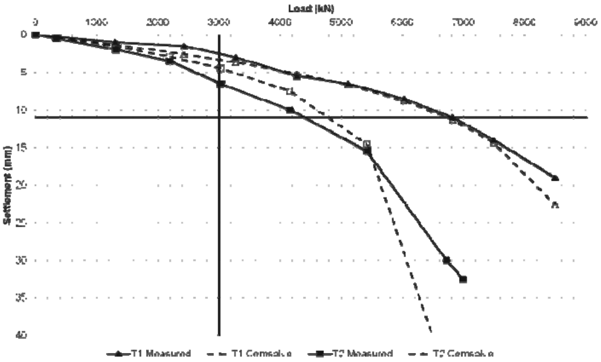

Figure 4. Load-displacement behaviour of piles: measured and Cemsolve predictions (with contribution from top 10m of piles shaft removed).

5 DISCUSSION

5.1 *Comparison of Testing Results with Design Values*

The ultimate shaft friction for the untreated pile T2 obtained from curve fitting (6.5MN) is considered to be in reasonable agreement with the calculated tender design value 5.47MN. When considering this in greater detail by comparing the measured and calculated skin friction values (Table 2) it can be observed that the Loam A did not provide as much skin friction as considered within the design and the Loam B provided more. From this it is proposed that the silt content of the Loam A reduced its frictional behaviour more than the original design considered. It is also apparent that the estimate for the behaviour of the Loam B was too conservative. It is possible that the high silt and water content of the material resulted in misleading in-situ testing results.

It is considered that the base resistance was not fully mobilised for either pile as the test was stopped before the piles could move a sufficient amount.

5.2 *Improvement due to Shaft Grouting*

The shaft grouted pile T1 is considered to have performed considerably better than the untreated pile. Figure 4 shows that at a working load of 3.0MN, the shaft grouted pile settled approximately 50% less than the untreated pile. A line has been plotted on Figure 4 at a settlement of 1% of pile diameter (11mm) to further illustrate the difference in pile performance. The untreated pile settled by 11mm at a load of 4.4MN and the shaft grouted pile settled by 11mm at a load of 6.8MN.

As previously stated it is considered that the ultimate shaft capacity (calculated from curve fitting) was increased by approximately 46% from 6.5MN to 9.5MN.

By looking at the strain gauge data in Table 2 it is possible to infer the relative improvement the shaft grouting made to each stratum. The data suggests that the skin friction of the Fine Sand, Loam A and Loam B were respectively improved by 120%, 144% and 22% (i.e. by a factor of 2.2, 2.4 and 1.2).

The Fine Sand and the Loam A were of a relatively similar grading and so it is perhaps unsurprising that a similar improvement was achieved in these two strata. Improvement in the Loam A was not expected due to its higher silt content; however, the silt content did not impede the improvement and it is therefore inferred that an enhancement in skin friction is possible within a material assuming it has a minimum content of granular material.

The improvement within the Loam B, although comparatively small, confirms the suggestion that it had sufficient coarse material to behave like a granular material under loading from the pile.

One additional interesting observation is that the data suggests that a similar skin friction was mobilised in all three treated strata, i.e. that pile T1 had uniform friction along its length.

If a constant skin friction of 110kN/m^2 was assumed within the original pile design it would have allowed a saving of 10m in length compared to a 25m tender design pile.

6 CONCLUSION

The pile testing acted to confirm the ultimate pile capacity and the pile response under loading for both treated and untreated piles. This case study also shows the benefit of pile testing in unusual ground conditions in terms of validating design assumptions.

The shaft grouting improved the skin friction of the strata with a high sand and gravel content by a factor of between 2.2 and 2.4. Some improvement was achieved in material with as little as 10% sand content. The shaft grouting improved the load-displacement behaviour of the test pile with settlements reduced by approximately 50%.

7 ACKNOWLEDGEMENTS

Thanks are made to Hestok Ltd for allowing details of the project and test data to be published.

8 REFERENCE

Fleming W.G.K. 1992. A new method for single pile settlement prediction and analysis. *Géotechnique* 42 (3), 411-425.