Quality Control and Performance Monitoring of Ground Improvement using Continuous Flight Auger (CFA) Columns

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ABSTRACT

This paper discusses the quality control methods used in the construction of unreinforced concrete columns, installed by CFA technique as part of the ground improvement for a reinforced earth ramp 8 m high that carries a passenger railway line. The successful delivery of the foundation works was assured through monitoring and testing. Real-time automated monitoring of installation parameters (including penetration rate, drill resistance and concrete consumption) during column installation took place to calibrate toe levels. Three test columns, each close to a geotechnical test, were constructed and cored down their centre, using a conventional rock core drilling technique, for column strength and base condition assessments. Each test column and selected production columns were scheduled for low-strain impact echo integrity testing (PIT). The performance verification of the ramp by means of vertical and lateral movement monitoring is also presented in the paper.

Keywords: CFA, ground inclusion, quality control, coring, integrity testing, monitoring

1 INTRODUCTION

The $2.1 billion South West Rail Link (SWRL) responds to issues of reliability and passenger growth on the metropolitan rail network in south-west Sydney. The SWRL is being delivered by Transport for NSW, the lead agency of the New South Wales Government's transport portfolio. The Glenfield Transport Interchange (GTI) component of the project is being delivered by Glenfield Junction Alliance (GJA), led by Transport Construction Authority in partnership with Parsons Brinckerhoff, MacMahon Contractors, Bouygues Travaux Publics and MVM Rail. GJA is responsible for delivering the Glenfield station upgrade, constructing a new bus-rail interchange, new rail flyovers to the north and south of the Glenfield train station, and realigning Railway Parade. The flyovers will grade-separate the East Hills suburban rail line from the Main South Line (MSL) and the South Sydney Freight Line.

The northern flyover, around 65 m long and 13.5 m wide, is based on the portal frame concept and being constructed by GJA as part of the GTI. The flyover is connected to an approach ramp up to 7.6 m high. The ramp is 12.25 m wide, is retained by Reinforced Earth™ retaining walls up to 190 m long, and will take the new Up East Hill Line (UEHL) on to the flyover over the MSL (see Figure 1).

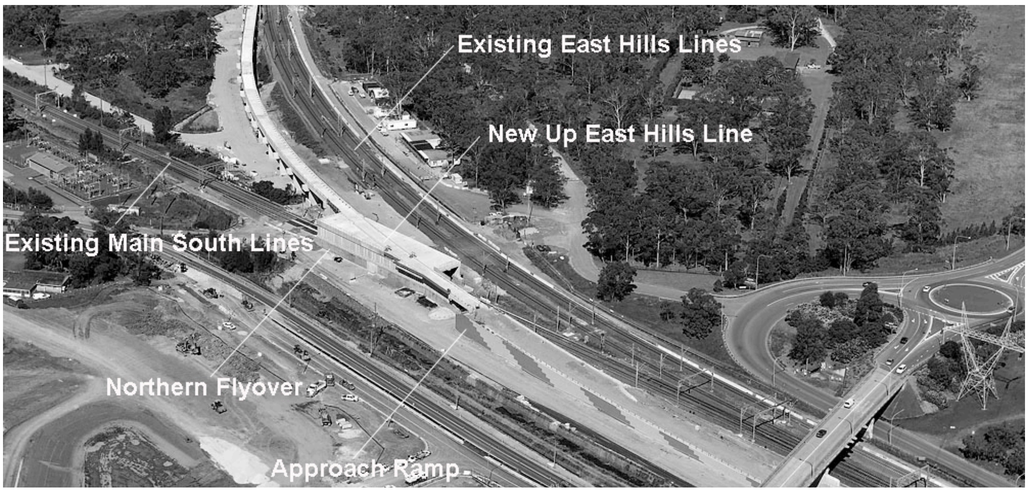

Figure 1. Approach ramp to Northern Flyover as at 3 December 2011

The presence of uncontrolled fill and soft to firm alluvial clay of up to 2.1 m thick beneath the approach ramp induces total settlements of about 120 mm. Project specifications limited maximum residual settlement to 50 mm over 20 years. Maximum change in grade in both longitudinal and transverse directions was limited to 1%. Unreinforced CFA columns were used to improve stability and control ground movements because of their cost and technical benefits (Merry and Power 2011).

2 GROUND IMPROVEMENT DESIGN

The CFA columns were designed as ground inclusions. Using finite element numerical analyses, Pan et al. (2011) demonstrated that the CFA columns could be treated as vertical reinforcements within a composite ground structure having equivalent improved strength and deformation properties. The vertical loads from the ramp were effectively transferred and distributed to the columns through a load transfer mattress (LTM) 0.45 m thick, which was constructed directly onto a working platform 0.3 m thick created for the CFA piling rig. The LTM was reinforced with two layers of high strength geotextile with a minimum tensile strength of 250 kN/m at 6% strain, spaced vertically at 0.15 m. The first layer of geotextile was placed parallel to the UEHL alignment, the second perpendicularly.

The specified characteristic compressive strength for the CFA columns 0.45 m in diameter was 10 MPa at seven days and 15 MPa at 28 days. The CFA columns were installed from 5.5 m to 7 m deep, at a spacing of 1.8 m centre, staggered in a square pattern. The lateral extent of the CFA columns beneath the ramp was 41 m. An underline crossing (protected by a bridge structure supported on CFA piles to rock) traverses through the ground improvement area. To smooth out the settlement profile for the ramp construction next to the crossing, the length of the CFA columns within 5 m of either side of the crossing were designed to increase gradually from 5.6 m to 7 m. The LTM was extended a further 9 m beyond the CFA column application area to achieve a smooth settlement gradient to the untreated ground. The footprint of the CFA columns matches the ramp footprint such that the wall facing panels will align directly above the outside row of the CFA columns. Figure 2 shows the typical subsurface profile and the extent of the ground improvement beneath the ramp. Figure 3 shows the typical CFA column arrangement.

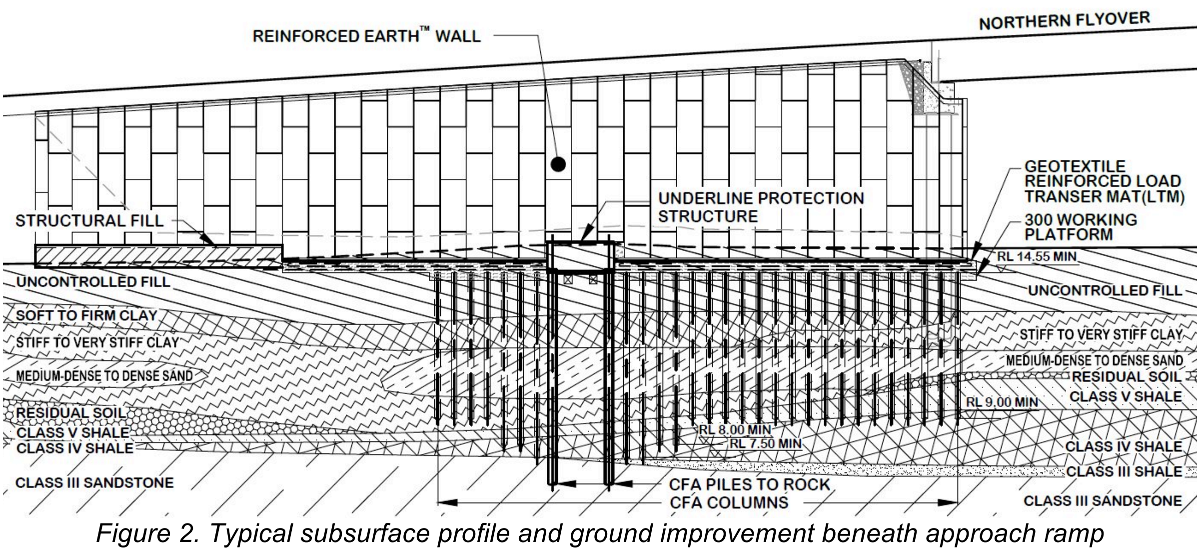

Figure 2. Typical subsurface profile and ground improvement beneath approach ramp

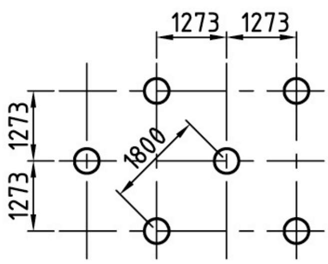

Figure 3. Typical CFA column grid pattern and spacing (in millimetres)

3 QUALITY CONTROL WORKS

An inspection and testing plan that tested and cored the test columns was developed during pre-production stage. Hold points were in place for critical activities during column installation, such as verifying column locations by topographical survey, assessing column founding levels by installing parametric monitoring and concrete mix design.

Three test columns were installed within the ramp footprint, with each test column positioned close to either a nearby borehole or cone penetration testing. Automated real-time monitoring of installation parameters (i.e. the auger-tip depth, auger penetration, rotation and withdrawal rates, drill resistance, incremental concrete volume and injection pressure) was used during the installation of the test columns to confirm column toe levels (refer to Figure 4). Verified through the automated monitoring, the production columns (160 columns, totalling 962 m) were installed in the same manner, with similar concrete volume and to the same standards and similar founding levels as the test columns, to ensure the production columns will perform as well as the test columns.

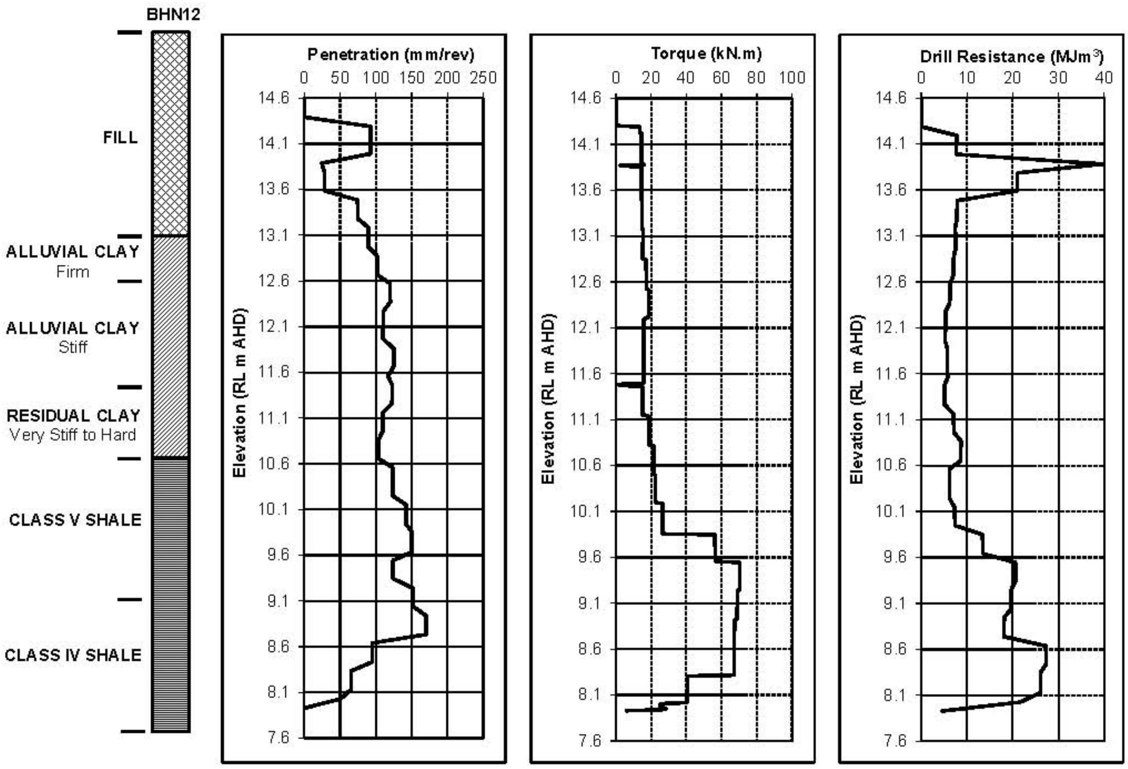

Figure 4. Real-time monitoring of installation parameters for test column T1

A conventional site investigation coring technique was applied to core through each of the test columns into the underlying founding stratum to verify the conditions of the column base and to obtain core samples of the concrete for strength proving tests. The as-built bases of the test columns were between RL 7.75 m AHD and RL 7.25 m AHD, about 6.7 m to 7.3 m long. The coring verified the 'clean' bases of the test columns, in flush contact with weathered rock, classified as either Class IV Shale or Class III Sandstone in reference to the rock classification developed by Pells et al. in 1978 (see Figures 5 and 6). The cored samples of the concrete forming the test columns were tested for compressive strength tests. The test results showed the concrete has average characteristic strengths of 13 MPa and 21.3 MPa for seven days and 28 days, respectively, exceeding the specified minimum characteristic strength requirements.

Post-installation integrity tests were performed on all test columns and selected production columns for direct measurement of the quality of the concrete and defect detection. A minimum of 3% of the production columns have to be tested. Integrity testing by PIT method was performed on 12 production columns, representing 8% of the production columns. The tests did not identify significant defects along the column shafts on the basis that there were no abnormal reflections during testing.

Figure 5. Coring test column T1

Figure 6. Flush contact between concrete and rock at base of test column T2

4 PERFORMANCE MONITORING AND VERIFICATION

Geotechnical monitoring to verify the performance of the CFA column treated area during the ramp construction involves the instruments listed in Table 1.

Table 1: Geotechnical instrumentation

Instrument type	Instrument ID	Number
Settlement plates for vertical movement monitoring	SP01 to SP08	8
Survey targets for vertical and lateral movement monitoring	ST01 to ST12, P34 and P35	14 [a]
Standpipe piezometer for groundwater level monitoring	BHN12	1

[a] Inclusive of two survey targets on top of the flyover viaduct abutment piles

The measured movements, shown in Figure 7, were calibrated against the predictions from the finite element numerical modelling. The comparison of ground movements has shown the following:

- The numerical analyses inferred that the ground inclusions using the CFA columns could constraint settlements to the order of 10 mm. The survey targets on the retaining wall panels founded immediately on CFA columns generally recorded settlements of this order of magnitude. The small vertical movements enforce the fundamental role of the CFA columns in reducing the deformability of the ramp.

- The settlements recorded by SP01 and SP08 positioned on top of the LTM within the CFA column treated area appeared to be of a similar order of magnitude (i.e. about 30 mm to 40 mm) to those recorded by SP02 positioned at the base of the LTM, also within the CFA column treated area. This infers that within the CFA column treated area, the ground between the CFA columns at the top of the LTM settles concurrently with the ground at the base of the LTM, by a similar order of magnitude, when the loading from the approach ramp is imposed.
- The measured ground sagging between the CFA columns at SP01, SP02 and SP08 is of a similar order of magnitude to that predicted. The monitoring showed that the ground between the CFA columns settles by around 30 mm to 40 mm. The numerical analyses predicted vertical deformations of up to 35 mm for the ground between the CFA columns. The ground sagging enforces the arching effect in the reinforced LTM towards the CFA columns.
- Interestingly, the magnitude of settlements recorded by SP03 positioned at the base of the LTM but outside the CFA column treated area is also of a similar order (i.e. about 35 mm) to that recorded by SP01, SP02 and SP08 positioned between the CFA columns. This suggests that within the ‘transition’ zone where the LTM is extended over a lateral distance of 9m but with no CFA columns, the ground is also expected to behave similarly with regard to settlement characteristics (when subjected to a similar load). The predicted settlements within the ‘transition’ zone were 40 mm.
- SP04 and SP05, located outside the CFA column and LTM treated areas, recorded settlements of up to 15 mm. ST07 on the wall panel that is not supported by CFA columns, beyond the ground improvement area, recorded settlements of around 20 mm. The numerical analyses calculated settlements of up to 25 mm.
- Survey targets at top of the flyover viaduct abutment piles P34 and P35 recorded settlements of less than 5 mm since the piles are founded on rock. The measured settlements are consistent with those predicted.
- Lateral deformations of around 10 mm were recorded by ST01 to ST12, P34 and P35. The measured lateral deformations were considered reasonable.
- Groundwater level monitoring in BHN12 recorded negligible fluctuations.

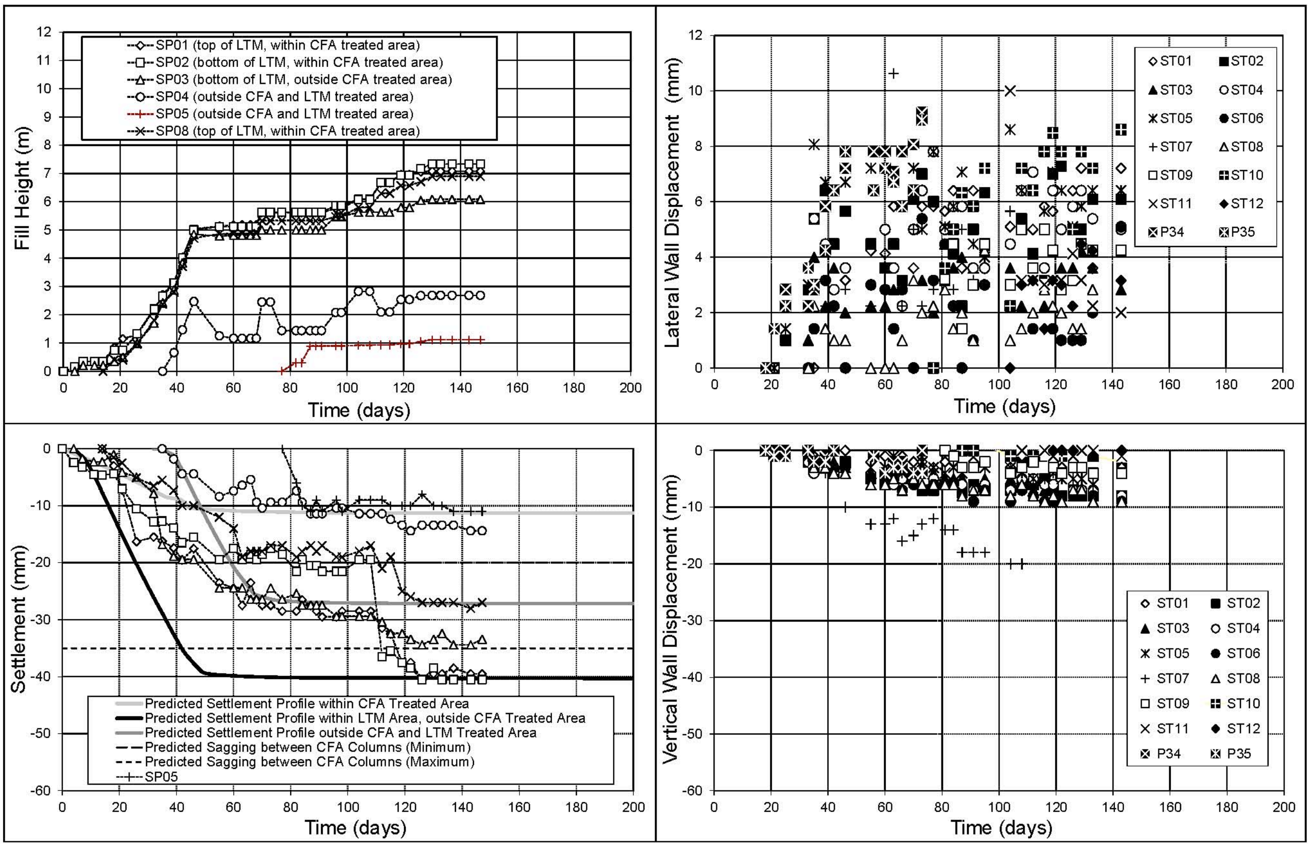

Figure 7. Settlement and lateral movement monitoring

5 CONCLUSIONS AND RECOMMENDATION

Comprehensive testing and monitoring regimes using automated installation parametric monitoring, pre-production coring of trial columns and post-installation integrity testing, have led to the successful adaption of unreinforced concrete columns as ground inclusions in a crowded, operational railway corridor. The quality control of this type of ground improvement assures the concrete columns are installed in a controlled, consistent manner, resulting in increased confidence that the installed columns meet the intended strength and performance requirements.

The automated monitoring of installation parameters during pre-production stage provides a basis for calibrating the column founding levels during production stage. The conventional coring post-column installation has been shown to be effective in providing a visual examination of the column base conditions and allows the concrete quality and strength to be assessed quantitatively. The non-destructive integrity testing by PIT method complements the coring process, and allows direct measurements to be made of the quality of the concrete, defect detection and strength proving.

Satisfactory performance of the CFA column-supported ramp was deemed achieved after the column as-built conditions (i.e. toe levels, concrete quality and strength) and the movement monitoring data were evaluated. The vertical ground movements recorded in the areas with CFA columns (generally less than 30 mm) are relatively close to the predicted values. There should be minimal differential settlement (i.e. below 1%) between the CFA column-treated area and the adjacent area without any ground inclusions, with the transition zone further reducing this differential. The recorded lateral wall movements (generally less than 10 mm) are within tolerable limits. The residual long-term settlement was assessed to be less than 50 mm over 20 years.

Monitoring showed the ground between the CFA columns at the top of the LTM settles concurrently with that at the base of the LTM, by a same order of magnitude, for the intended design loading. This highlights the elastic deformation of the LTM. The analysis made by Wachman and Labuz (2008) of a column-supported embankment on Trunk Highway 241 in Minnesota, USA, identified negligible stresses and strains in the geosynthetic reinforcement within the load transfer platform in the long term. Potentially the contribution of the basal reinforcement in the LTM to provide tensile force may have been readily compensated by the relatively thick LTM formed by angular gravels with a relatively high angle of repose (i.e. well-interlocking granular material). For future column-supported embankments, a field instrumentation involving earth pressure cells and strain gauges may be considered to provide a better understanding of the reinforcement contribution in developing arching action within LTM and for potential optimisation of the reinforcement requirements.

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