PERFORMANCE OF NON-DISPLACEMENT AND DISPLACEMENT PILING, ADELAIDE CONVENTION CENTRE, SOUTH AUSTRALIA

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Extensions to the Convention Centre in Adelaide, South Australia consisted in part of construction over the existing railway system comprising nine rail lines and passenger platforms. Vibro-pile (Aust) won the design and construct tender with a solution comprising over 500 cast insitu concrete piles. The pile types were 500 to 900mm diameter non-displacement CFA piles and 400mm diameter displacement V-piles. The V-pile is a cast insitu screw pile developed by Vibropile (Aust) Pty Ltd. Both pile types were installed with minimal noise and vibration required for the project, while the displacement V-pile had the advantage over the CFA pile by developing the same pile capacity but with a smaller diameter and with minimal spoil. The latter was important in alleviating spoil removal problems near the railway tracks and disposal of potentially contaminated spoil. The results of dynamic compression load testing and static lateral load testing indicated that the performance of a 400 mm V-pile was equivalent to a 500 mm CFA for this site. The lateral load testing indicated that the surficial soils have a major influence on the load-deflection response, but despite the site containing up to 4 m of filled ground, the piles were found to carry the required lateral loads satisfactorily.

BACKGROUND

The project involved a large extension to the existing Adelaide Convention Centre's exhibition and banqueting facilities, in the city of Adelaide, South Australia. The project was completed by September 2001, in time for the Australian Wine Industry Technical Conference and OIV General Assembly scheduled in October 2001. The extension consisted of superstructures supported over the existing railway lines and a new plaza away from the railway tracks. Vibropile (Aust) Pty Ltd was commissioned by Stockport (Civil)/Baulderstone Hornibrook in late 1999 to design and construct foundations for the extensions. The Torrens alluvial strata overlying weathered Blanche Point Formation below 18 m favoured the use of CFA piles to support the relatively high loads from the Plaza. A special piling system was required for the foundations between the servicing railway tracks. Vibropile adopted the V-pile to avoid the spoil removal problems and to minimise vibration between the railway tracks. However, some 500mm CFA piles were also constructed in the railway areas to meet project deadlines.

SITE LOCATION AND GEOLOGY

The existing Adelaide Convention Centre (ACC) is located over the railway lines between the River Torrens and North Terrace in the Adelaide Central Business District. The railway lines are at about RL28 m, with the level of the overall development site falling about 2 m towards the River Torrens.

Considerable site investigation and exploratory stratigraphic data has been published by Selby and Lindsay (Ref. 1) which indicates that the site is covered by Holocene alluvium derived from the River Torrens Valley. Underlying the alluvium is the Tertiary Blanche Point Formation forming an erosion cut platform at a relatively uniform level. Table 1 summarises the expected geology.

Table 1. Site geology

Depth (m)	Strata	Strata details
0 to 20	Torrens alluvium	Red brown silty CLAY/SAND/ GRAVEL
20 to 30	Blanche Point Formation	Grey SILT bands /cherty SILTSTONE
30 to 40	South Maslin Sand	Dark grey brown /red brown silty SAND
40 to 60	Clinton Formation	Dark grey CLAY with lignite, clayey SAND
60+	Precambrian Adelaidean System	Weathered siltstone

SOIL PROPERTIES

Extensive geotechnical investigations carried out by PPK Environment & Infrastructure (Refs 2, 3 and 4) have indicated the following generalised soil profile:

- Surficial uncontrolled fill about 2 to 4m deep of mixed soils with up to 1.5m of railway ballast in parts of the site, over
- Upper alluvium comprising firm silty, sandy clay with interbedded sands and clayey gravel, over
- Lower alluvium comprising very dense sand and gravel with layers of sandy clay and clayey silt over
- Blanche Point Formation which, in the upper zone, is extremely weathered to firm to stiff silty clay and dense gravelly sand grading to highly weathered siltstone with numerous shells and shell fragments.

Table 2 gives a typical soil profile together with Standard Penetration Test (SPT) results. A large number of Cone Penetrometer Tests (CPT) were also conducted which gave results consistent with that summarised in Table 2. Groundwater was present below about 6 m.

Table 2. Typical soil profile

Depth (m)	Inferred soil strata	Average SPT 'N'
0.0 to 3.0	Ballast/FILL	8
3.0 to 7.5	F-VSt silty CLAY	5
7.5 to 11.0	H sandy/silty CLAY	23
11.0 to 12.0	VSt silty CLAY, GRAVEL	10
12.0 to 14.0	St/VSt sandy/silty CLAY	-
14.0 to 15.5	VSt sandy/clayey SILT	17
15.5 to 18.0	VD SAND/ GRAVEL	>35
18.0 to 19.0	VSt/F silty CLAY	-
19.0 to 22.5	VSt/H silty CLAY/weak rock	>50

Note: F refers to firm; St to stiff; VSt to very stiff; H to hard and VD to very dense

PILED FOUNDATIONS

The heavily loaded and settlement-sensitive structures proposed for the site required the use of piled foundations. The piles had to be installed with little noise and vibration. Isolated columns located away from the railway lines were supported on single Continuous Flight Auger (CFA) piles founded in the Blanche Point Formation. Working loads of the 600mm, 750mm and 900mm diameter CFA piles ranged between 2000 and 6000 kN.

The piles within the railway lines were designed in rows parallel with the railway tracks to support crash barriers as well as the building column loads. These piles were founded in the very dense sand/gravel forming the basal layer of the alluvium, and were designed to carry a vertical working load of 1700 kN. In order to minimise the contamination of the existing rail ballast with spoil from the pile installation, a 400mm V-pile was used.

The V-pile is a displacement pile developed by Vibropile (Aust) Pty Ltd and consists of a specially shaped auger that is screwed into the soil to a predetermined depth which is verified by the torque and rate of penetration of the auger. In contrast to CFA piling, soil is not removed but is displaced laterally, thus densifying the surrounding soil, and hence increasing its load-carrying potential.

In the latter stages of the project, 500 mm CFA piles were also employed in conjunction with the V-piles within the railway lines in order to meet project deadlines.

DYNAMIC PILE LOADING TESTS

Dynamic load tests (DLTs) were conducted on both CFA and V-piles. Whilst all the CFA piles performed satisfactorily under the test loads, the combination of V-displacement piles and CFA non-displacement piles on the same grid within the railway lines resulted in some concern that the differential movements between the two pile types may be excessive. To demonstrate the compatibility of the two piling types, a DLT was conducted on a 400 mm V pile and a 500 mm CFA non-contract pile, installed 10 m apart in the railway yards. Details of the two test piles are listed in Table 3.

Table 3. Dynamic test pile details

Pile ref.	Location	Pile size (mm)	Founding depth, m	Working load, kN
T3	West of Platform 7	500 CFA	16.5	1700
P87B	West of Grid P	400 V	14.5	1700

Notes: T3 was non-contract pile.

The DLTs were performed by Pile Test International (PTI) under the supervision of Vibro-pile. The test utilised a 12-tonne air-driven drop hammer to produce the impact load. Four sets of accelerometers and strain gauges in an orthogonal arrangement were mounted on the extended pile head to measure acceleration and strains. The maximum energy transferred to V-pile P87B, a production pile, was 43 kJ whereas a maximum energy of 85 kJ was transferred to the non-contract CFA pile, T3, in an attempt to mobilise its full pile capacity. A compression stress of up to 55 MPa resulted from the testing, but there were no adverse affects on the pile, which had a nominal characteristic strength of 50MPa. The PDA results indicated pile capacities "RMX" of 5500kN and 6400kN for piles P87B and T3 respectively. The corresponding permanent sets recorded during the field tests were 0.5 mm and 2.6 mm ie 0.1% and 0.5% of the respective pile diameters only. Subsequent CAPWAP load predictions by PTI reported that both PDA results and CAPWAP predictions were almost identical. The mobilised load factor of the two piles, with respect to the design action, S* (=1.35 x working load), was 2.4 for P87B and 2.7 for T3. The pile head movement at the maximum load was about 3.5 % of pile diameter. It was clear that substantial reserve strength had not been mobilised on pile T3, despite the higher energy applied to it.

Figure 1 illustrates the load-movement behaviour predicted from CAPWAP on similar transferred energy. The initial stiffness of the two test piles was indicated to be essentially linear at a value of 2 mm/MN. At the serviceability load of 1700kN the predicted pile head movement was 3.7mm and 3.2mm for pile P87B and T3 respectively. These results were well within the specification requirements.

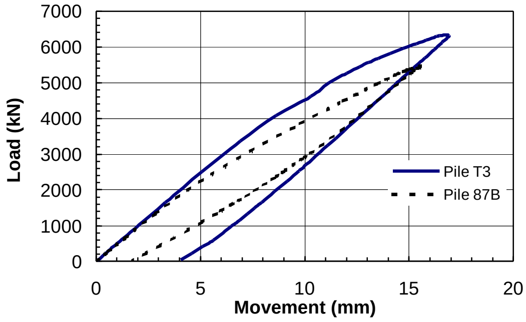

Figure 1. CAPWAP predictions

DISCUSSION OF DYNAMIC LOADING TESTS

Quantification of the strengths of the various soil strata was done using CPT and SPT results. Pile design was primarily based on CPTs. Where CPT refusal occurred, SPT values were converted to equivalent CPTs using correlations such as those presented in Lunne et al. (Ref. 5). The ultimate pile resistances thus realised were appropriate for displacement i.e. screw V-piles. A factor of 0.8 was considered an appropriate reduction factor that should be applied for the estimated pile capacities of non-displacement CFA piles. The calculations indicated that a 400 mm diameter displacement V-pile would provide a similar geotechnical strength to a 500 mm diameter CFA pile. DLT results for the two pile types confirm that action as being reasonable, especially at working loads of about 1700 kN.

The pile design Program RATZ (Ref. 6) using the SPT/CPT correlation was used to estimate the load - movement behaviour as shown in Figure 2. When comparing these design estimates with the predicted behaviour obtained from CAPWAP in Figure 1, it can be seen that the design overestimated the pile movement at the working load. Back analysis of the PDA/CAPWAP results indicated that this difference was accounted for by the development of a higher pile shaft resistance in both the CFA pile and V-pile compared with values adopted from SPT/CPT correlations. A reason for this increase is shaft resistance was thought to be an increase in normal stress at the pile-soil interface by the pressure developed from the pumped high slump concrete.

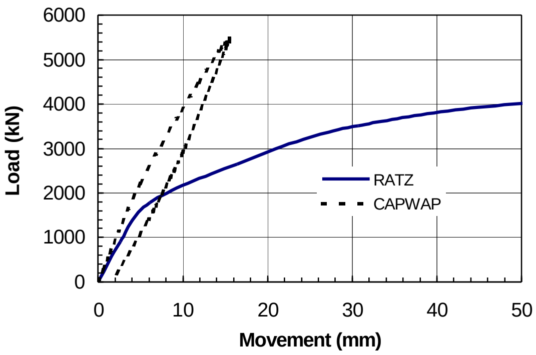

Figure 2. CAPWAP vs RATZ results for P87B

LATERAL LOAD TESTS

The project required a lateral load test to be performed on piles installed in the railway yard to verify the design assumptions. A pair of production piles K11 and K12 constructed 1.5m apart, were tested by pushing against each other. Details of the test piles are listed in Table 4. Both piles were installed with the appropriate reinforcement to resist a maximum design lateral load of S* = 224kN (approximately 1.33 times the working load).

Table 4. Lateral load test pile details

Pile Mk	Pile type	Founding depth, m	Main steel	Spirals
K11	400 V	16.8	6Y36	W12-100
K12	400 V	17.1	6Y36	W12-100

*f'*c= 50 MPa, W12 denotes 12.5 mm dia 450 MPa plain wire

The load test arrangement comprised jacking the two piles using two series-mounted hydraulic actuators with steel packing. The lateral load was applied at a height of 100 mm above ground level. Semi-circular seating with rotating joint was positioned at both piles to allow pile rotation in load application. A calibrated proving ring indicated the load. Horizontal movement of the piles was measured at two levels, from two sets of dial gauges mounted on a reference beam. Supports for the beam was at five diameters from the test piles (Figure 3). During the test the load and lateral deflections were recorded manually.

The load stages of the lateral test were 15, 30, 45, 60, 75, 100, 50, 15 and 0% of the design action "S*". Each load was held for ten minutes except at the 75% load stage when the load was held for 60 minutes. The 75% load was equivalent to the approximate working load for the piles.

Figure 3. Lateral load test arrangement

LATERAL LOAD TEST RESULTS

The lateral load test results indicated that variability in the surficial fill materials over the railway yards had an influence on the load performance of the piles. (Figures 4 and 5). Pile K12 was noted to deflect 15% more than adjacent pile, K11. At the maximum test load of 224kN, the lateral movement recorded at 500 mm level above ground level was noted to be 71mm for K11and up to 82mm at K12. Residual settlements for the two piles after three cycles were 29mm and 36mm for pile K11 and K12 respectively. These differing results indicated that the nature of the superficial fill soils had a major effect on the lateral load-displacement behaviour.

The results of various stages of loading are summarised in Table 5.

Table 5. Lateral load test results

Lateral load/Cycle		Displacement at 500 mm above ground level (mm)	
		Pile K11	Pile K12
168kN (75%)	1st cycle	27/32	38/46
200kN (90%)		40	57
Unload (0%)		12	17
224kN (100%)	2nd cycle	52	74
Unload (0%)		18	26
168kN (75%)	3rd cycle	52/55	67/70
224kN (100%)		65/71	79/82
Unload (0%)		29	36

DISCUSSION OF LATERAL LOADING TESTS

The main objective of the lateral load tests was to confirm the lateral capacity of the piles under the crash barrier. No failure criteria was specified for the lateral load test, although it would be expected that the piles would need to carry the imposed loads under a very short term loading condition. A consideration of pile creep under maintained load application would not be relevant.

The test results shown in Figures 4 and 5 indicate that under short term loading to the working load of 168kN, the pile behaviour was satisfactory, indicating that the piles will be expected to meet the requirement to withstand the predicted horizontal load imposed on the crash barrier.

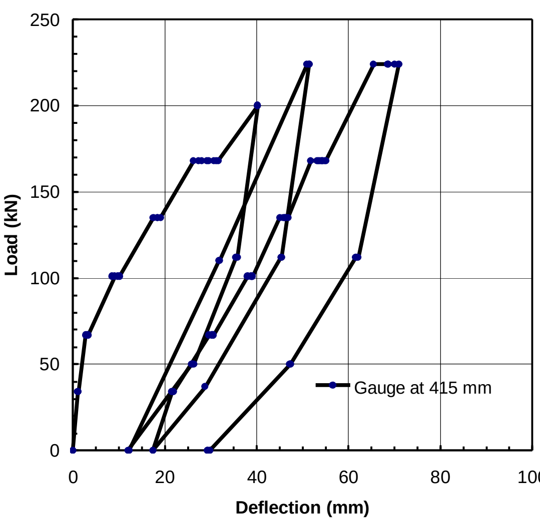

Figure 4. Lateral load test result pile K11

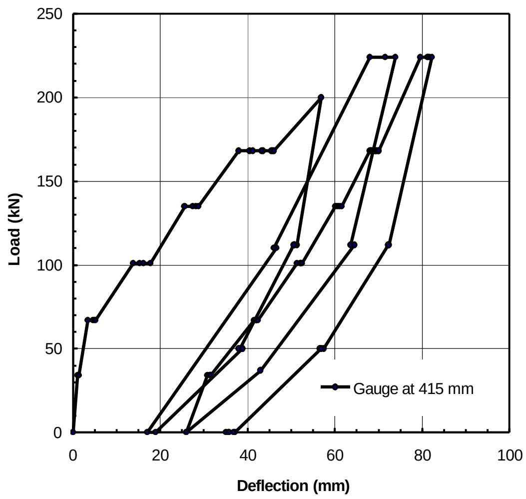

Figure 5. Lateral load test result pile K12

CONCLUSIONS

A mixture of the vibration-free non-displacement CFA piles and displacement V-piles were used to support the loads from the Adelaide Convention Centre. The smaller diameter 400 mm V-pile was found to be equivalent to a 500 mm CFA pile, with the additional benefit that the V-pile minimised the generation of spoil.

A back analysis of the pile testing indicated that an increase in the shaft resistance of both the CFA and V-pile was observed over that estimated from SPT/CPT correlations. An explanation of this could be due to the increased normal stress at the pile-soil interface in both pile types due to the pressure developed from the pumped high slump concrete.

Lateral load tests were successfully completed using a simple testing set-up. The results indicated that the nature of the surface soils have a major effect on the lateral load displacement behaviour of the piles. Despite the upper 2 to 4 m of the pile being founded in fill of uncertain compaction, the test results indicated that the piles will be expected to carry the loads impacted onto the crash barriers which are supported by the piles.

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