UTILISATION OF STEEL TUBE MICROPILES IN LOW HEAD ROOM ACCESS AND UNPREDICTABLE GROUND CONDITIONS

Arash Judi[1], Tom George[2]

1. BACKGROUND:

As part of a major upgrade of the Rod Laver Arena (RLA) in Melbourne, multiple cores required upgrading to satisfy the new earthquake code. A combination of micropile foundation systems were adopted consisting of DTH Hammer micropiles, driven steel tubes or combining DTH Hammer micropiles within the driven tube. The micropiles were installed to satisfy varying tension and compression loads in tight access and low head room conditions. The project was awarded as a design and construct contract.

The site exhibited a highly variable geotechnical soil / rock profile consisting of basalt flows with various thicknesses and depths requiring a flexible “design as you go” approach. The system of small diameter steel driven tubes, drilled micropiles or a combination of both provided the required flexibility to complete the works. The RLA remained fully functional with no interruption to any major events.

Where access allowed, an increased number of micropiles with lesser loads were installed to satisfy the design core loads. Several cores had limited plan area for installing piles, limiting the number of driven micropiles that could be installed in the cap requiring higher loads on the piles. Several piles refused on the shallow basalt layer where they achieved the design compression capacity, however, they could not achieve the required tension capacity. In several high-tension load cases, the driven tubes were drilled out with DTH Hammer equipment and a drilled dowel was installed to construct a passive micropile below the casing to ensure the required residual tension capacity was satisfied. In other cases, the piles were drilled through the casing below the refusal depth of the tube to assist further penetration of driven tubes to achieve design capacity.

The final number of driven steel micropiles in each group was determined by using the results of Pile Driving Analyzer (PDA) with CAPWAP Analyses. A static load test was also carried out to verify tension capacity of the anchored micropiles.

Design of the various micropile types required varying pile cap connections while also addressing all durability issues.

2. INTRODUCTION:

The RLA refurbishment was part of the $972M Melbourne Park Redevelopment

[1] Civil Project Engineer, Wagstaff Piling Pty Ltd, Melbourne - Australia, +61(3) 9646 7500, A.judi@wagstaffpiling.com.au
[2] Design Manager, Wagstaff Piling Pty Ltd, Melbourne - Australia, +61(3) 9646 7500, T.George@wagstaffpiling.com.au

project, which commenced in 2014. Works are still ongoing and due to be completed in time for the 2020 Australian Open. The Arena was required to remain operational throughout the refurbishment period.

Wagstaff Piling was awarded the design and construct contract for installation of foundations to safely carry the design loads. The contract required retro fitting three existing cores using extension pile caps at each core around RLA including South-west (SW), South-east (SE) and North-east (NE) cores. The two SW and SE cores were part of Stage 1 piling works which were carried out in 2016 and the NE core was a part of piling works for Stage 2 which were designed and constructed in 2017.

The site's geotechnical profile comprises of Clay/ Silty Clay overlying basalt; overlying Silty/Sandy Clay becoming wet sands towards the NE core. Based on the geotechnical information provided at the time of design, it was noted that the basalt layer thickness and depth varied considerably across the site. Due to the high variability, suitable basalt for founding was not encountered in some of the cores. However, most boreholes detailed basalt, where this layer's thickness varied between 2.9m to 9.0m.

Due to the access restraints at the cores within the building and given the geotechnical complexity of the site, the micropile option was determined to be the best piling system requiring only a small piling rig and having flexibility on installation methods to address complexity of the project by adopting a "design as you go" approach. Different micropile design approaches were used for each individual core based on access and encountered ground conditions. Limited access to the NE core typical at all cores is shown in Figure 1.

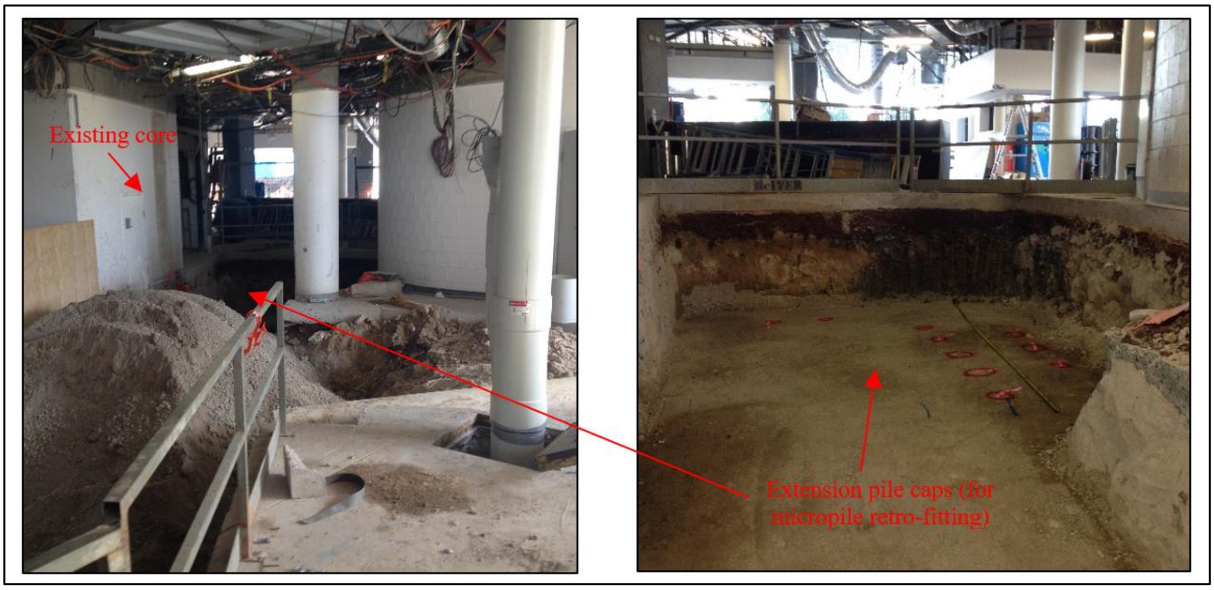


Figure 1, Access to the NE core

3. DESIGN METHODOLOGY:

3.1. <u>Geotechnical profile in SW and SE cores:</u>

Stage 1 of the works involved design and construction of micropiles in the SW and

SE cores. Based on the geotechnical report provided from 1986, the bore holes in the vicinity of the core generally indicated a thickness of basalt approximately 7m, however, one of the boreholes drilled in Southeast of the core indicated a thickness of approximately 3.6m of low strength / highly weathered basalt. The top of the basalt layer was encountered at 4.0m to 9.3m below the platform level across the core area.

Bore holes in the vicinity of the SE core indicated a consistent basalt layer at 10.1m to 10.3m below platform however basalt thickness shown in the boreholes was only 2.9m to 3.1m (no photos, strength tests or other information was provided in the 1986 geotechnical report).

Different design scenarios were considered for installing micropiles due to the variability of the basalt layer on site. The design scenarios are detailed in Figure 2.

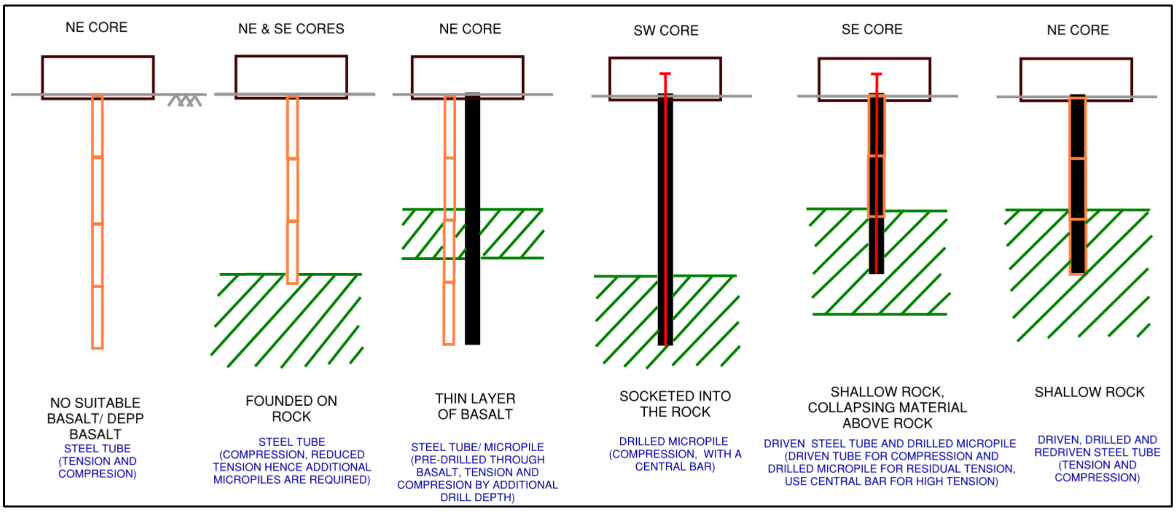


Figure 2, Different scenarios of micropiles installation in basalt

3.2. <u>Design principals for SW and SE cores:</u>

Structural designs for the SW and SE cores were based on load points provided by the client at various locations across the footprint of the extension core.

6 load points were provided by the structural engineer for each of the SW and SE cores. A plan of SW and SE cores with nominated load points is shown in Figure 3. A summary of the loads for each load point in SW and SE cores are provided in Tables 1 and 2, respectively.

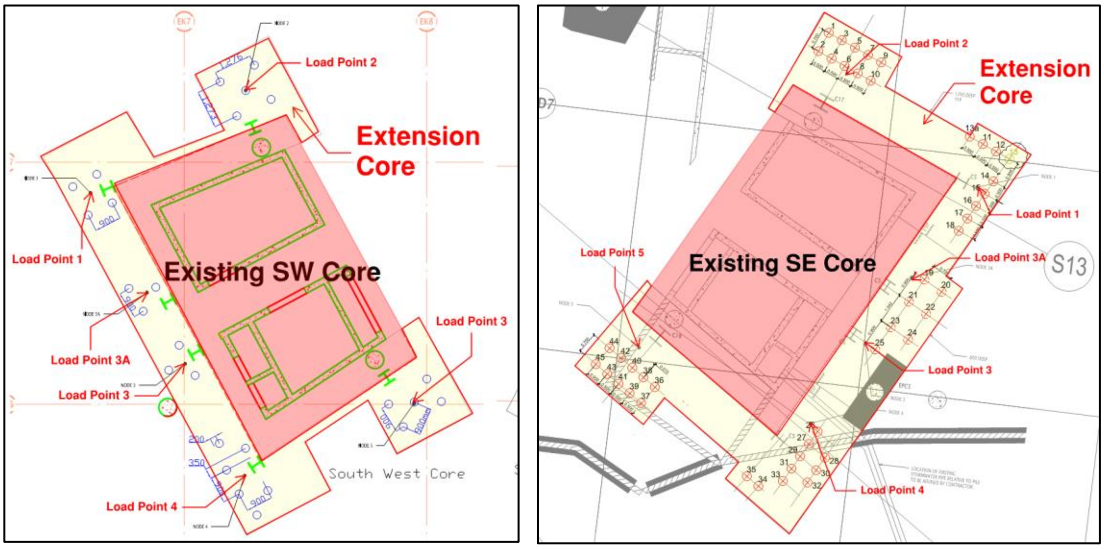


Figure 3a & 3b, SW and SE cores micropile installation layout

Table 1, Load detail for SW core load points

Load Point	Number of piles	N* Tension (kN)	N* Compression (kN)	Service Tension (= 50% N*)	Service Load (kN)	N* Tension/ Pile (kN)	N* Compression/ Pile (kN)	Critical Service Load (kN)	N* Deflection (3m free length) (kN)	Service Deflection (3m free length) (kN)
1	4	-2670	2986	-1335	1493	-668	747	373	14.85	7.43
2	4	-2657	3057	-1329	1529	-664	764	382	15.2	7.60
3	3	-1337	1177	-669	589	-446	392	-223	-8.86	-4.43
3A	3	-1337	1177	-669	589	-446	392	-223	-8.86	-4.43
4	6	-4583	5382	-2292	2691	-764	897	449	17.84	8.92
5	4	-2641	3041	-1321	1521	-660	760	380	15.12	7.56
	24					-764	897			

Table 2, Load detail for SE core load points

Load Point	Number of piles	N* Tension (kN)	N* Compression (kN)	Service Tension (= 50% N*)	Service Load (kN)	N* Tension/ Pile (kN)	N* Compression/ Pile (kN)	Critical Service Load (kN)	N* Deflection (3m free length) (kN)	Service Deflection (3m free length) (kN)
1	4	-3000	2655	-1500	1328	-750	664	-375	-14.92	-7.46
2	4	-1733	3981	-867	1991	-433	995	498	19.79	9.90
3	3	-1337	1177	-669	589	-446	392	-223	-8.86	-4.43
3A	3	-1337	1177	-669	589	-446	392	-223	-8.86	-4.43
4	6	-5151	4814	-2576	2407	-859	802	-429	-17.07	-8.54
5	5	-1206	4475	-603	2238	-241	895	448	17.8	8.90
	25					-859	995			

Based on the loads provided by the structural engineer for the SW and SE cores, the design maximum N* (Design Action Effect) values in compression and tension were 995kN and -859kN per pile, respectively. For Geotechnical Strength Reduction Factor (φg =0.8) with static testing, the required design rock socket was calculated to be a minimum of 6m. This was based on the original 180mm diameter micropiles that were designed to be drilled using a small drilling rig.

Wagstaff Piling design detailed a DSI WR1050/950MPa, 40mm nominal diameter Threadbar was to be placed centrally in the hole. Standard DSI couplers for the aforementioned DSI bars were used to join 3m length DSI Threadbars to achieve the full depth of drilled holes.

Micropiles were designed for a design life of 50 years and some of the micropiles were designed to carry permanent tension loads. To resolve the double corrosion problem, micropiles were constructed so that all structural steel was encased in a corrugated sheathing which was fully grouted internally and externally using positive pressure applied from the base to ensure full grouting was achieved. On completion of a micropile the plate and locking hexnut were designed and installed at the top of the raft to engage micropiles in raft tension loads. Micropile design details for the original design in SE and SW cores are shown in Figure 4.

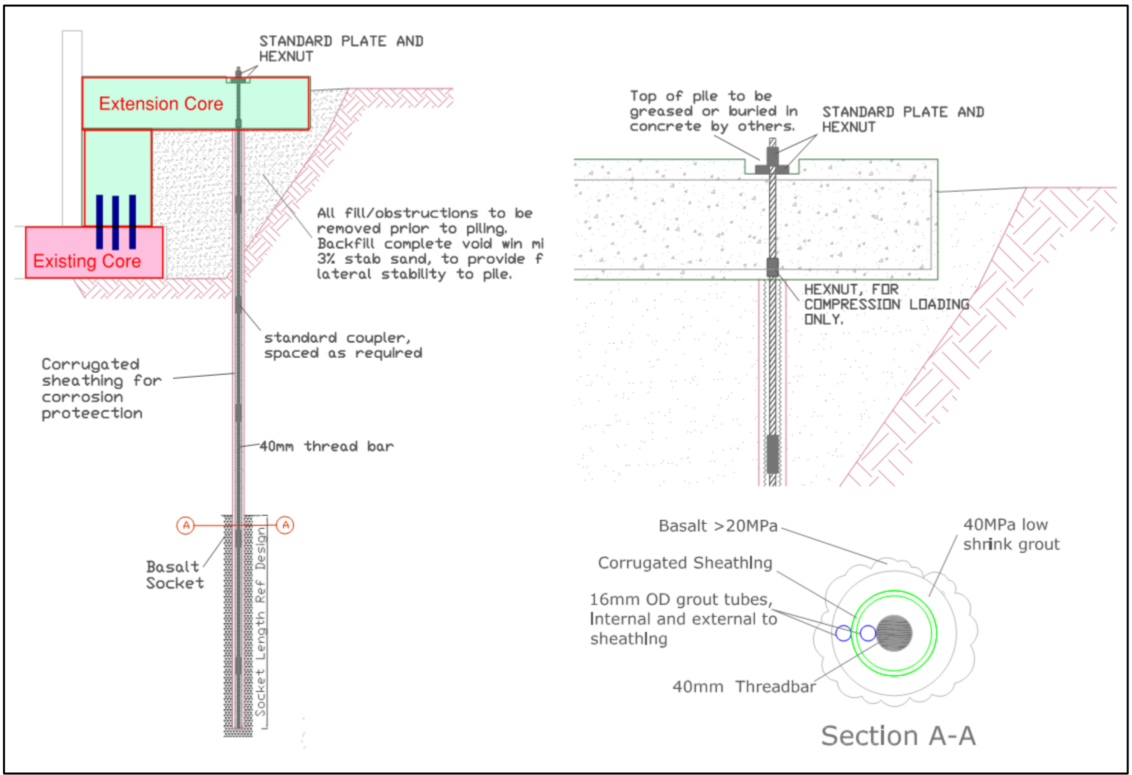


Figure 4, Designed micropile installation detail for SW and SE cores

A DSI WR1050/950MPa Threadbar has a minimum breaking load of 1,319kN and a yield load of 1,194kN. The number of micropiles at each load point were designed to limit the ultimate applied load in each pile to 1,000kN.

Design assumed that all the load was to be carried in the basalt socket and the capacity of the clay above had been ignored. The length of rock hammered was recorded as an indication of the rock quality and thickness.

A minimum pile spacing of 2.5 pile diameters is recommended in the Australian Standards which equates to 450mm for 180mm drilled micropiles, however, a 750mm minimum spacing was adopted in the design to ensure block failure did not govern.

A two-cycle short term static load was carried out on pile No. 10 at load point 3A in the SW core with a 6m recorded basalt socket. The micropile was loaded in two cycles, the first cycle was to approximately 75% of N* for the heaviest loaded pile, the second cycle was to load the pile to approximately 125% of N* for the heaviest loaded pile in the core. The test load was limited based on the structural capacity of the Threadbar. Schematic load test arrangement is shown in Figure 5.

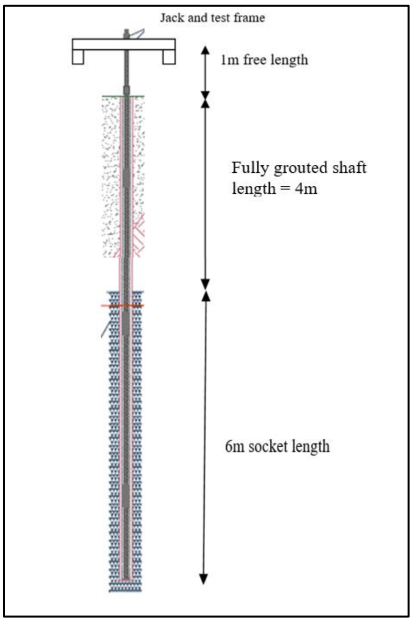


Figure 5, Static Load test on micropile No. 10

For each minor load increment, the load was held until creep had been stopped for 5 minutes. Load test results are provided in Table 2 and the load-displacement curve is shown in Figure 6.

Table 2, Load increments for static load test

Load Requirement	Load (kN)	Cell Reading	Duration (min)	Deflection (mm)
0%	0	0	0	0.00
25%	224	12	5	-0.85
50%	449	22	5	-2.07
67%	601	30	5	-2.64
75%	673	33	15	-3.05
50%	449	16	15	-1.44
25%	224	7	5	-1.05
0%	0	0	5	-0.49
50%	449	26	2	-1.49
67%	601	32	5	-2.10
75%	673	35	5	-2.15
100%	897	43	5	-3.33
125%	1121	54	15	-4.82
25%	224	6	5	-3.35
0%	0	0	5	-1.58

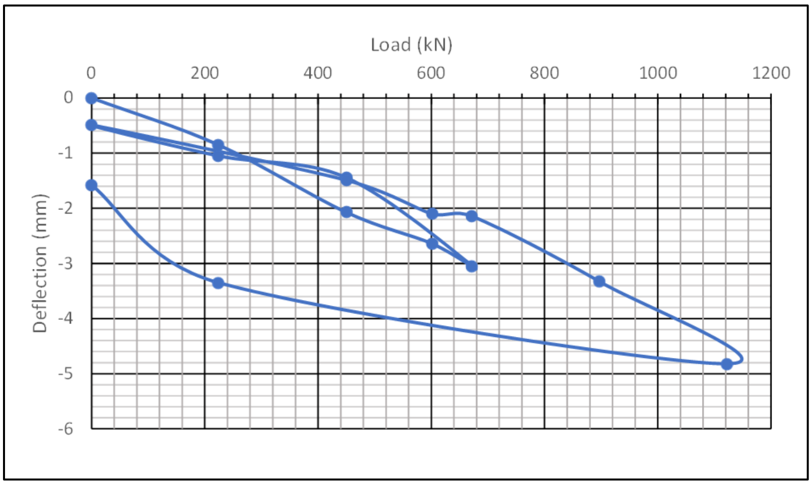


Figure 6, Load-Displacement curve for static load tested micropile in SW core

Based on the above results, the micropile was tested in tension to an ultimate load of 1,121kN. The measured deflection for the test load of 1,121kN was in the order of 5mm and hence the micropile was performing satisfactorily within the predicted values and considered adequate for the representative design load of N*=995kN in compression for the heaviest loaded pile in this core. The test load was governed by the yield load of the bar which was 1,194kN.

Based on static test results and given all other micropiles had achieved the minimum 6m basalt socket, no further testing was required for SW core.

Due to the success of drilled micropiles in the SW core, the same methodology was proposed for the SE core. Although there was the same concern that there may only be 3m of questionable basalt.

Pile head connection detail and installed micropiles in the SE core are shown in Figure 7.

3.3. Design challenges in SW and SE cores:

Whilst drilling some of the micropiles in the SE core using DTH Hammer, air return was lost due to the highly fractured upper basalt layer. Additionally, unexpected water and collapsing ground were encountered during installation of the micropiles. This prevented further drilling. Conventional casing rigs with double rotary could not fit in the available headroom, however, Wagstaff Piling possess a mini rig capable of driving in casings that could fit in the core.

Wagstaff Piling believed the driven casing could be incorporated into the design. As such re-design involved utilising a small diameter driven steel tube to drive into Clay/ Silty Clay and onto the highly weathered basalt, so DTH Hammer could be used to drill the micropiles into moderately weathered basalt and achieve the required socket length. Installation of steel tubes was completed by driving the tubes in 1.5m long sections and weld splicing on site to be able to drive to refusal in low head room condition.

Once the steel tube was installed, a micropile was then drilled inside of the tube to the design depth to carry the residual tension, a Threadbar was then installed and the hole was grouted to the top utilising the original micropile design. Steel tubes eliminated the requirement of the corrugated liner as it provided the durability to satisfy the original design.

In the SE core, refusal micropiles on shallow rock had resulted in a shortfall in tension capacity of the driven tubes. Load point 4 had the highest group tension loading and had the least penetration of the piles installed in the core.

Due to the limited core footprint in load point 4 with shallow rock, installation of additional micropiles was not possible. Based on PDA/ CAPWAP test results, the group tension capacity of the installed micropiles was estimated at 2,864kN which was 2,287kN short. For the 6No. micropiles installed, this was 381kN short per micropile. As such supplementary dowels were designed and installed in accordance with the original design in all 6 steel tubes.

Driven steel tubes penetrated into extremely weathered stable basalt to act as top casing for drilled micropiles but also they provided compression capacity. Then the Threadbar was installed and the hole fully grouted with 40MPa grout to the top. Connections between the tension Threadbar and pad footing were made by a hexnut and plate at the top of the footing and also the cogged bars were welded to the steel liner and fully embedded into the core footing.

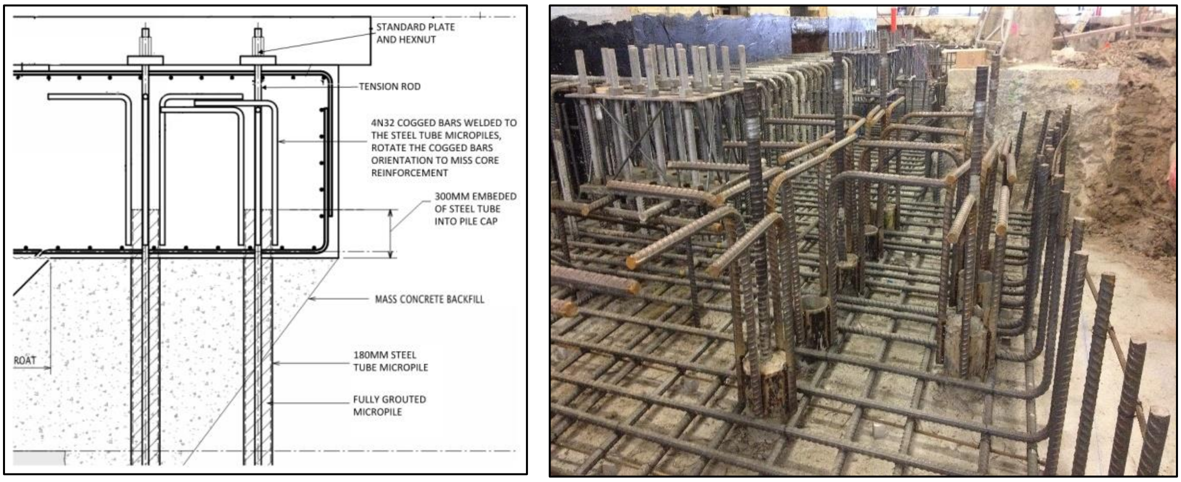
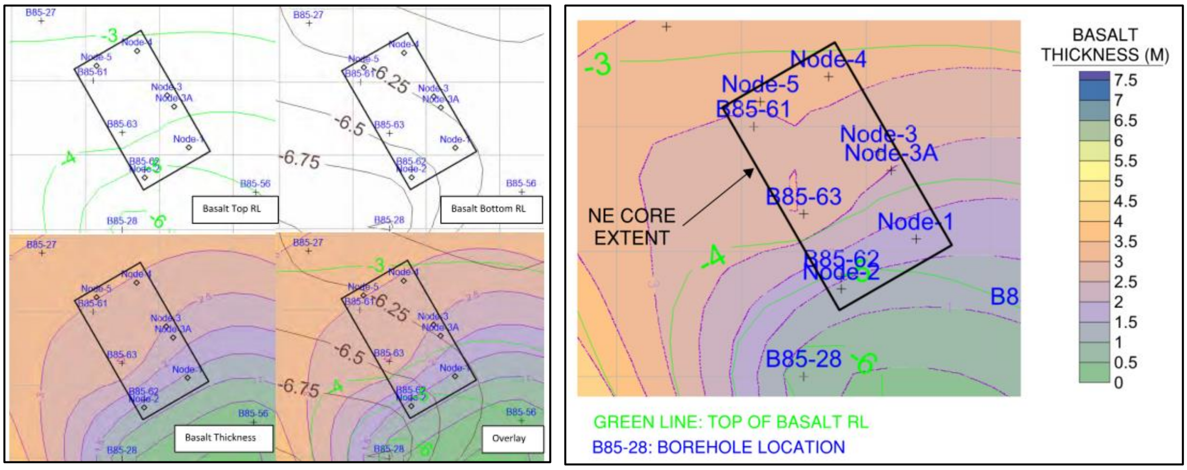


Figure 7, Pile head connection for steel tube micropiles in SE core

3.4. <u>Geotechnical profile in NE core:</u>

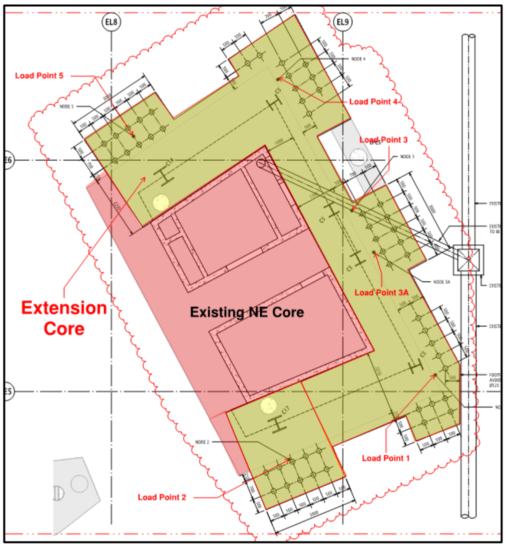
The NE core was a part of the Stage 2 works for RLA refurbishment project. Due to the complexity of the site's geotechnical conditions and using lessons leant from Stage 1, top and bottom of rock level, rock thickness and proposed core footing extension were plotted on the same drawing using Surfer. Plotted data are shown in Figure 8. Based on available boreholes in the vicinity of the core, Surfer showed that the basalt thickness varies highly across the core and there is a chance of very thin or no sound basalt in some of the proposed micropile locations in the southern side of the core overlying Dense Sand/ Clayey Sand.



Figures 8a & 8b, Surfer plot of basalt layer at NE Core location

3.5. Design principals for NE core:

Again 6 No. load points were specified by the structural engineer in the design drawings for NE core. Refer NE core layout in Figure 9 below and load summary of the load points is shown in Table 3.



Figures 9, NE core layout

Table 3, Load detail for NE core

Nodes	N* Comp	N* Tens	No of Piles	N* Comp / pile	N* Tens / pile	Approx. Depth to Basalt from RL 3.2	Approx. Basalt Thickness
1	2,986	-2,670	5	597	-534	7.7	1.4
2	3,057	-2,657	5	611	-531	8.5	1.3
3	4,381	-4,055	8	548	-507	7	2.5
3A	1,879	-1,530	3	626	-510	7	2.3
4	5,382	-4,583	9	598	-509	6.5	2.9
5	3,041	-2,641	5	608	-528	6.6	3.0

Plotted geotechnical boreholes in the NE core area showed that the basalt layer was encountered at 6.5m to 8.5m below the piling platform level, however, the thickness of basalt layer was less than 3m in most areas and there was a good chance of not encountering suitable basalt. The design layout for the NE core provided spaces for additional micropiles if required.

In addition to the basalt thickness issue, piling installation time was a critical factor in the design as the project overall programme for Stage 2 had allowed a short duration to meet the project completion date.

A piling method which was flexible with the ground condition changes in the basalt layer and able to deliver the project on time was required to address the project challenges.

Based on lessons learnt from Stage 1 of the works and given adequate soil above the basalt layer was encountered in the boreholes, the method of small diameter driven steel tubes was selected in the design stage to provide the required tension capacity by mobilising the shaft. However, the capacity for each load point was designed to be verified by PDA/ CAPWAP method. The final pile numbers at each load point were adjusted during the works based on actual test results on site and additional micropiles were installed in high tension load points with shallow basalt.

3.6. Design challenges in NE core:

The micropiles installed in the first load point 2, encountered refusal at 13m to 14m below platform level which was around 6m deeper than the rock reported in the nearby boreholes. Once the first micropile was installed, a PDA test was carried out at the end of drive (EoD) to establish driving criteria using CAPWAP analysis. Due to the deep basalt, micropiles at load point 2 achieved designed tension and compression capacities without further pre-drilling.

Where the rock became shallow as the piling rig moved north to install the remaining piles (rock was encountered at 5.4m to 7.5m below the piling platform level), additional micropiles were installed to provide the required capacity.

The group capacity was verified by PDA/ CAPWAP testing on the piles.

Where installation of additional piles was not possible, a small piling rig was mobilised to drill out inside of the steel tubes which refused on shallow rock. These steel tubes were re-driven further into and through the rock into the underlying dense sand to provide the required capacity.

Given micropiles in the North-east core were driven only, the programme completion date was met and handed over on time to the pile cap preparation team.

To address durability of steel micropiles, the full depth of the pile was grouted and the pile- cap connection was provided by welding development cogged bars to the top of the micropiles. Grouted steel tube micropiles are shown in Figure 10.

Figure 10. Grouted steel tube micropiles in NE core

4. CONCLUSION:

In low headroom access where the ground conditions are highly variable, micropiling methods can be used as a practical and cost-effective piling method.

Micropiles can provide a flexible “design as you go” approach where the ground conditions can change within a few meters. This flexible method can be adopted by pre-drilling only, drilling only, driven only, driven and drilled and anchored or driven drilled and re-driven options which provides flexibility for the different ground conditions which could be encountered on site.

5. REFERENCES:

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