

Development of Secant Pile Retaining Wall Construction in Urban New Zealand

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SYNOPSIS

In the last 3 years there have been a number of project requiring deep excavations in difficult ground, below the water table and in urban environments. The use of driven steel sheet piles or king pile methodologies has not been appropriate on these sites. The use of overlapping / interlocking cast in-situ concrete piles to form a wall provided a relatively quiet and vibration free method to install a wall that provided continuous support to the ground during excavation and reduced ground water inflows.

Secant pile walls are formed by constructing alternate “male” and “female” piles. The “male” piles cut into the two adjacent “female” piles; a lower strength concrete is used in the “female” pile to facilitate the cut / drilling of the “male” pile. The concrete mix design for the piles is particularly important to ensure the wall can be constructed efficiently and performs effectively.

Typically conventionally cased bored piles are used to form the secant piles. However, the use of Continuous Flight Auger (CFA) piling method, which is generally more cost effective than cased bored piles in unstable soils, has now been successfully extended to secant piling.

Whilst the secant pile wall method has been used in Europe for a number of years, it was new to New Zealand requiring the development of suitable tooling and concrete mix designs. The paper will outline the methodology and development journey using case studies with particular regard to:

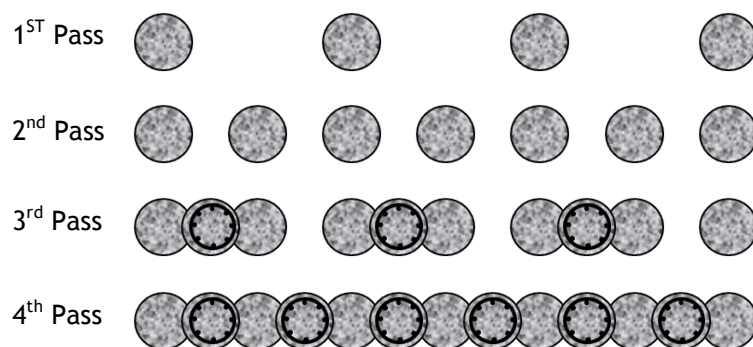
- Trials on concrete mixes
- Project test data
- Lessons learnt
- Water tightness
- Internal lining

The development of secant piling in New Zealand provides a cost effective solution for the construction of deep excavations to form basements, cut and cover tunnels, tanks, etc. in urban environments.

INTRODUCTION

Deep excavations in weak ground with a high ground water level provide significant challenges with regard to ground support and minimising ground water inflow. This is particularly important in urban environments where settlement resulting from ground loss or ground water draw down can result in damage to adjacent structures. The use of driven sheet piles or similar can result in unacceptable noise and vibration.

The secant pile methodology comprises the formation of overlapping concrete piles. Typically alternate unreinforced or “female” piles are formed using lower strength concrete. The remaining piles are standard reinforced concrete “male” piles. Figure 1 represents an example of a construction sequence that may be adopted dependant upon the soil strength.



(Figure 1) Pile Construction Sequence

The use of secant pile walls has developed in Europe over the past 20 years as hydraulic machines have become more powerful to meet the need to construct basements and shafts on sites with marginal land in urban environments. Until 2007 the use of secant pile walls in New Zealand was

very limited but the use of the system has now become more widespread. The effectiveness of the system is reliant on the accuracy of the pile construction in plan position and verticality / inclination. Whilst this is strongly influence by the drilling equipment and pile construction sequence, the concrete used in the unreinforced / “female” piles can have a significant impact.

REQUIREMENTS OF LOW STRENGTH CONCRETE

The low strength concrete or “female” piles have a number of functions but first and foremost it must needs to retain the ground and groundwater from passing between the reinforced concrete “male” piles. However, to achieve this and facilitate construction the mix requires the following properties:

1. Sufficient strength to support and distribute the earth pressures to the “male” piles. In reality these piles are spanning less than a pile diameter and the forces are distributed by arching with the material in compression. Depending upon the retained height and groundwater level strengths in the range of 1 - 2MPa are normally sufficient.
2. Low permeability to minimise the seepage of groundwater through either the piles or wall as a whole; permeability less than $1 \times 10E-9$ or as standard concrete is required.
3. Low early strength gain to facilitate the boring of the “male” piles. The difference in strength between the adjacent “female” piles is likely to affect the drilling tolerances and thus overlap achieved.
4. Suitably durable for the intended life of the material. The “female” pile is typically unreinforced and effectively temporary if a permanent lining wall is constructed on the inside face of the piles. For this reason durability is not normally a concern.
5. Fluid properties that are consistent with placement requirements during piling. The mix must be pumpable or of sufficient cohesion to enable placement via a tremie pile without segregation at a slump of 175 - 225mm.

It is important to note that the specified design strength and durability requirements can be in conflict with the low early strength construction requirements with the result that the tolerances achieved are compromised and the overall aims of the design are not met.

TRIALS AND TESTING OF LOW STRENGTH CONCRETE

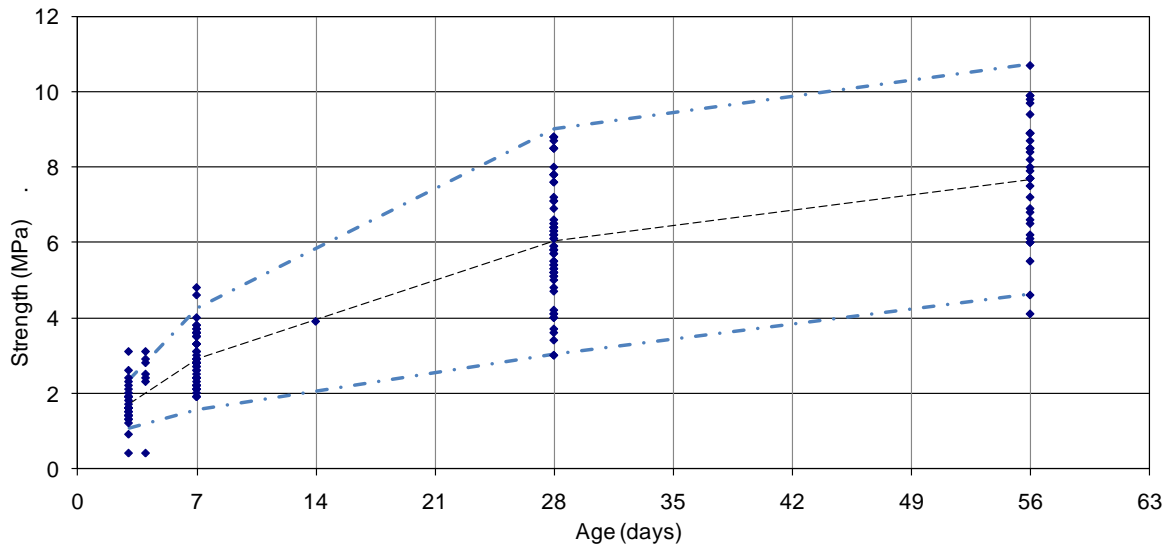
A number of trial mixes were carried out and specifically tested in 2006 for the BNZ Building basement. These included strength and pressure testing of mixes with appropriate fluid properties. A number of cylinders were made to assess the early strength gain. An applied water pressure of 200KPa was applied centrally for 3 days to assess permeability. Figure 2 shows the methodology adopted with the 1cu.m samples and the dry face after 3 days.



(Figure 2) Low Strength Mix Trial

The cylinders were tested at 3 and 7 days to assess the early strength gain and likely difference that could exist between adjacent “female” piles. The 28 and 56 day tests provide the design strength information for earth and water pressure distribution. The strength testing also provides an early

warning and quality control mechanism for the hardened material. The project strength data is provided in Figure 3.



(Figure 3) Low Strength Mix Cylinder Test Data

What is clear from the strength data is that there is considerable variance in the strength at any given age; the following statistical outputs results:

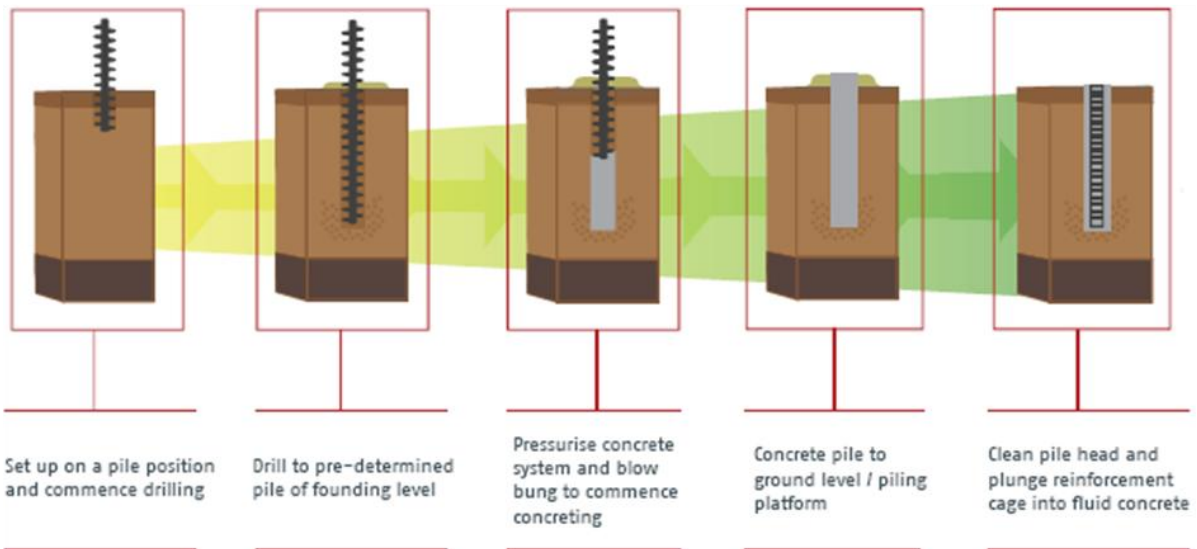
Age	3 days	7 days	28 days	56 days
Average / mean	1.71	2.91	6.03	7.68
Sample standard deviation	0.65	1.36	2.99	3.05
95% confidence lower strength	1.06	1.56	3.04	4.63
95% confidence upper strength	2.36	4.27	9.03	10.73

LESSONS LEARNT FROM PROJECTS

Since 2007 a number of secant pile wall projects have been completed using either conventional bored pile methods with temporary casing or Continuous Flight Auger (CFA) technology where the pile bore is supported by the spoil on the auger. The CFA method is a particularly cost effective option in unstable ground conditions with a high groundwater table where long casings and / or drilling support fluid would be required; the basic methodology is provided in figure 4 and 5. It should be noted that the use of an instrumented rig to provide real-time monitoring and records is essential to verify quality as other on-site observations are not possible.



(Figure 4) CFA Piling



(Figure 5) CFA Pile Construction Methodology

An outline scope of the secant pile wall projects and the lessons learnt are summarised as follows:

1. BNZ, Queen Street, Auckland

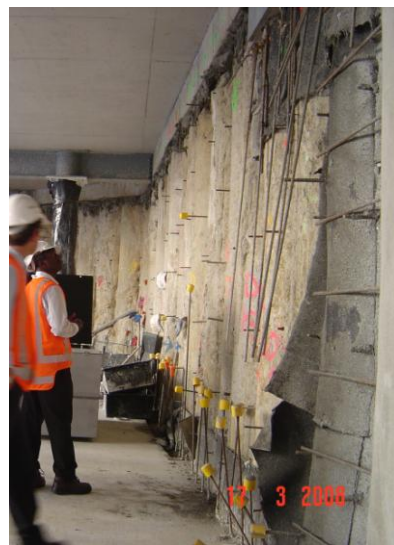
- 40 x 50m plan area x 12m deep basement (4 level)
- Conventional bored piles with rotated casings
- Proximity of façade slowed production
- Reinforcement too close / congested
- Obstructions can affect sequencing and tolerances achievable
- Internal shotcrete lining wall detail not effective



Bluestone wall obstruction



Exposed Wall



Exposed wall, membrane, dowels, , shotcrete lining wall and congested reinforcement

2. Hobson PS64 Shaft, Auckland

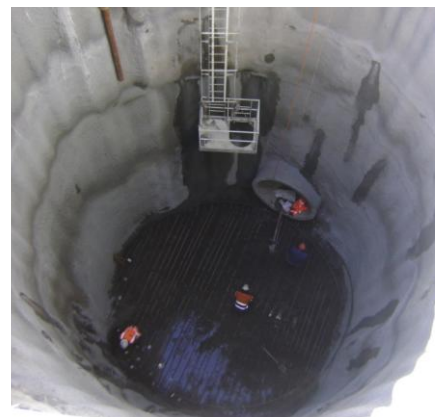
- 25m diameter shaft with 6m retained height
- Conventional bored piles with rotated casings
- Preboring and casing shoe design can affect pile interlock and cause debris in joint
- High cement content can cause early loss of concrete workability



Exposed wall - pile with defects due to loss of workability prior to casing removal

3. Abbotts Way & Nikau Street Shafts, Auckland

- 6.5m and 8.5m diameter up to 18m deep shafts
- CFA bored piles to 18.5m founding in ECBF deposits
- Low strength mix critical to achieve tolerance
- Contact and briefing of batching plant team
- Layout of piles and tooling assist tolerances



Misaligned secant piles, broken out piles and completed shaft prior to casting base slab

4. Maleme Street, Tauranga

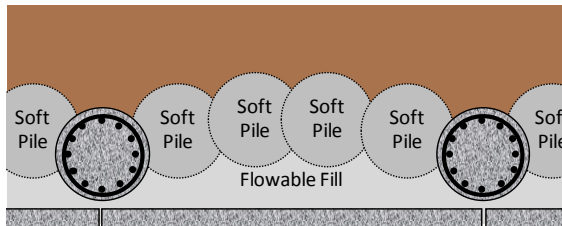
- 30m x 15m plan area x 6.5 to 8.5m deep in ground tank
- CFA bored piles to 19m in very soft deposits
- Limit soil strength for CFA piles
- Large overbreak in very soft soils
- High strength variation in concrete mix
- Bore water chemistry effects on concrete additives



Exposed secant pile wall and pile interlock at pipe breakout location

5. Waiwhetu Stream, Wellington

- 700m of 3.6m high river wall with scour control
- 750mm dia CFA bored piles to 18m
- King pile & arched soft pile retaining wall
- Cored guidewall through flowable fill



Arched soft piles / king piles exposed and with precast concrete facing panel

6. Dart 9 Manukau Station

- 310 x 17m plan area x 7m deep top propped station box
- Conventional 1050 & 900mm diameter bored piles with rotated casings
- Guidewall constructed using polystyrene effective



Polystyrene guidewall forms, installing casing and the exposed secant pile walls

Other secant wall pile projects that are still under construction are:

7. Victory Church, Auckland

- 140m of wall to form basement up to 12m deep using 750mm diameter cased bored piles.
- Obstruction removal carried out first in Brownfield / contaminated ground

8. Punganui Stream Bridge Replacement

- 162m of wall to form bridge approaches using 600mm diameter CFA bored piles
- Robust piling platform required over soft alluvial deposits

9. Victoria Park Tunnel

- 700m of wall to form cut and cover tunnel using 900mm diameter bored piles
- Base slab connection detail using box-out and couplers

The key lessons learnt relating to the low strength concrete mix from the above projects is that the low early strength is not a normal requirement / target for ready mix concrete suppliers. Early briefing and communications with the batching plant manager is required because in many cases if the low strength targets are not achieved the effectiveness of the system can be compromised. Even with pre-contract trial mixes, at the start of a project intensive cylinder sampling with 3 and 7 day testing provides early warning and allows for modification dependant upon the aggregate sources.

The low GP cement content of 100 to 140kg/cu.m with similar flyash quantity makes the large strength range inevitable due to batching tolerances and sensitivity to moisture content changes in the aggregates. If the strength is too high then the vertical tolerance may not be achieved and if the strength is too low then the low strength “female” pile can be damaged when the interlocking pile is drilled. Nevertheless, with careful sequencing of pile construction these variations in strength can be accommodated using either cased or CFA bored piling techniques.

CONCLUSIONS

The development of low strength concrete mixes for secant piling has enabled the development of the system in New Zealand. Whilst some methodology and quality challenges were experienced on the initial projects, changes in the process and effective risk management has lead to the subsequent delivery of number of highly successful projects. The use of both cased bored pile and CFA pile methodologies can be used to construct secant pile walls. been used provides a cost effective solution for the construction of deep excavations to form basements, cut and cover tunnels, tanks, etc. in urban environments.

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