

# Construction of Access Shafts for Tunnels and Deep Pipelines in Urban New Zealand

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## ABSTRACT

In recent years in New Zealand there have been a number of tunnelling and deep directionally drilled pipelines projects that have required access shafts. Often these shafts are in urban environments where vibration and high noise levels are not tolerable. There are a number of methodologies that can be adopted dependent upon the shaft plan area, depth and geology.

This paper will describe some different methodologies that can be adopted that use piling methods such as large diameter piles, and secant piles. The paper will use case studies to highlight:

- construction methodology,
- specific methodology issues and constraints,
- lessons learnt, and
- recommended specifications.

The development of piling technologies in New Zealand has enabled the development of cost effective solutions for the construction of deep shafts in sensitive urban environments.

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## INTRODUCTION

Over the past three years in New Zealand the demand for shafts to provide access to pipelines at depth has grown due to the increase in the use of tunnelling, pipe jacking and horizontal directional drilling (HDD). These systems require what can be termed effectively as drive and reception pits or shafts; which provide the respective starting and finishing point of the drive.

Dependant on the length of the pipeline, there is often a need for intermediate access points. Shaft construction can take many forms dictated primarily by site specific constraints and requirements with the ultimate detailed methodology driven by overall cost. In soft soils methods can, for example, include battered excavations, caisson sinking and sheet piling. However, for this paper the focus will be on shafts formed using conventional piling equipment to either directly bore a shaft or form a shaft using secant pile walling.

## BORED PILE SHAFTS

Conventional crane mounted and hydraulic rigs are readily capable of drilling diameters of 2.5 m and with modifications over 3.0 m due to the available torque and drilling tool development. At Waihi gold mine, 2.5 m diameter shafts were excavated to 87 m depth (Wharmby *et al*, 2007) to provide emergency access and ventilation to the mine workings below. A hydraulic piling rig and oscillator was used to drill and install the permanent steel liner; this is an extreme case but highlights what is possible with currently available technology.

The applicability of this methodology is dependent upon the shaft diameter and prevailing ground conditions. A number of shafts have recently been installed on sewer and waste water treatment plant outfall pipeline projects to facilitate conventional deep precast manhole construction (see Table 1).

With the exception of the Otahuhu shafts, the ground conditions comprise soft unstable soils with high groundwater level overlying stable East Coast Bays Formation (ECBF) in which the HDD pipeline was being installed. At Otahuhu the pipeline was within soft alluvial deposits and the shaft was supported on screw piles installed through the excavated shaft.

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**TABLE 1**  
Recent bored pile manhole projects.

Location	Service owner	No of shafts	Diameter (m)	Depth (m)
Otahuhu GIS	Transpower	3	2.1	12 - 20
Birkdale Area C	North Shore City	3	2.1	12 - 32
Rosedale	North Shore City	1	2.0	34
Birkdale Area B	North Shore City	1	2.1	27

Where the pipeline is a significant depth below the stable ECBF rock head, conventional shaft excavation methods using rock bolting and shotcrete lining can continue below the grouted manhole segments. In fact one of the Birkdale Area C shafts was extended both laterally and vertically to intersect the as-built alignment of the directionally drilled pipeline

The basic construction methodology for these shafts/deep manholes is as follows:

- install temporary top casing;
- cast support pad/platform;
- drill shaft using casing, support fluid as required;
- incrementally install manhole rings;
- tremie base slab/seal at base;
- stage grout manhole surround; and
- complete manhole fit out.

The device for safely lowering the manhole units has been developed and refined between projects. Elements of the current configuration are shown in Figure 1 as used on the Birkdale project.



**FIG 1** - Birkdale deep manhole.

**SECANT PILE WALL SHAFTS**

For shafts in unstable ground, high ground water level and where the diameter is greater than that achievable using large diameter bored piling methodologies the use of secant piles can be an effective solution. 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.

For secant pile walls to be effective it is essential that the overlap between the piles is achieved to prevent soil and ground water ingress. But also in the case of a circular shaft the overlap needs to be sufficient to provide the necessary resistance to the hoop compression stresses that enable the structure to be self supporting without any propping or waler. Based upon the shaft diameter, the hoop compression forces can be assessed from the combined earth and water pressures (Figure 2); the low radial strain results in little reduction in earth pressure from *in situ* ( $K_0$ ) values.

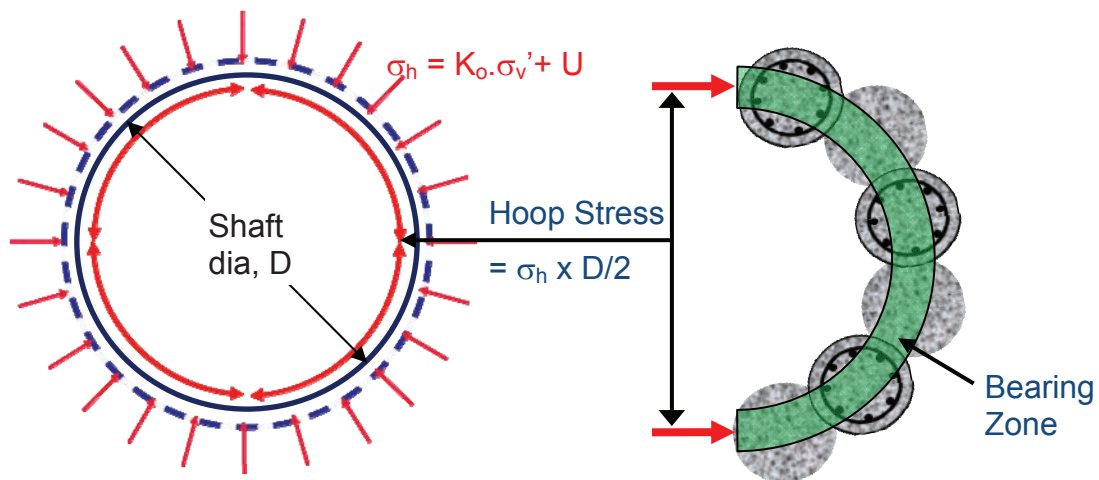


FIG 2 - Hoop stress and virtual bearing zone.

The strength of the unreinforced low strength piles is critical to the design as it needs to be sufficient to transmit the hoop compression forces. However, from a construction point of view the low strength piles must not be too strong as it can result in poor verticality (exceeding tolerances) which reduces the overlap bearing area and thus increases the hoop stresses. Table C9.1 in the specification for piling and embedded retaining walls (ICE, 2007) provides guidance on typically achievable tolerances for different drilling methodologies. The female pile low strength mix needs to be optimised for the pile construction methodology, ground strength, overlap and depth of shaft. Example project strength data is included in Figure 3.

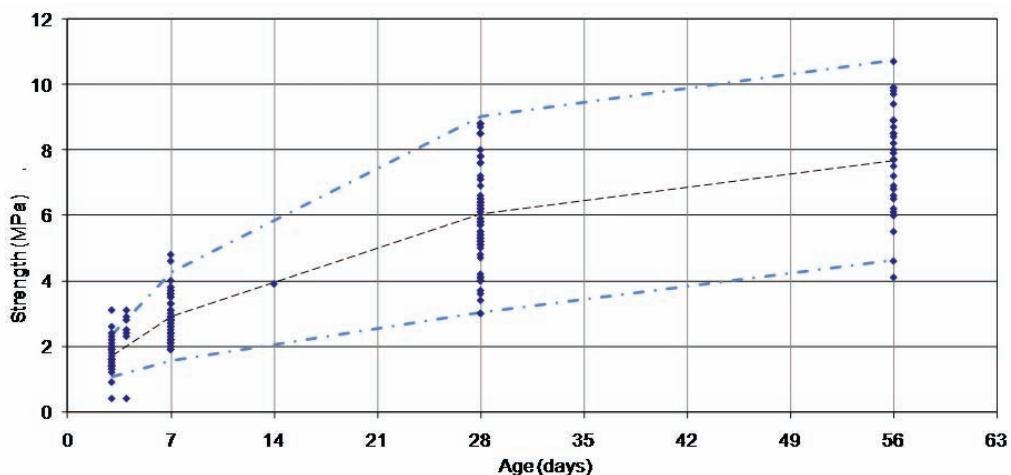


FIG 3 - Low strength mix cylinder test data.

What is clear from the strength data is that there is considerable variance in the strength at any given age; the following statistical output is provided in Table 2.

**TABLE 2**  
Low strength concrete statistics.

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

In summary, the low strength concrete mix requires the following properties:

- Sufficient long-term strength to transmit hoop compression stresses. Depending upon the retained height, groundwater level and overlap, strengths in the range of 3 - 5 MPa are normally sufficient.
- Low permeability to minimise the seepage of groundwater through either the piles or wall as a whole; permeability of the same order as standard concrete is required.
- 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.
- 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.
- 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 - 225 mm.

### Projects and lessons learnt

In the last three years three circular shafts have been constructed using the secant pile methodology, however, the methodology has been refined by the construction of a number of secant pile basement walls.

The first secant pile wall shaft was constructed to support the weak overburden at Pump Station 64, Hobson, Auckland; part of the Watercare Orakei Main Sewer Diversion Project. The 23 m internal diameter shaft extended to an overall depth of 36 m predominantly within the East Coast Bays Formation (ECBF) siltstones and sandstones. While this material could be safely excavated using bolts and mesh, the 6 m depth of overburden comprising of fill, recent alluvial deposits, tuff and ash was unstable with a high groundwater level. In addition, heavy plant serving the shaft/pump station construction was required adjacent to the excavation. A secant pile wall was used to support the 6 m deep overburden made up of 152 No 600 mm diameter cased bored piles (Figure 4). Whilst the wall and shaft were successfully constructed there were some key lessons learnt:



**FIG 4** - Hobson shaft.

- The selection of drilling tools and the configuration of the casing shoe can impact on the quality of the interlock between piles. The predrill size prior to casing and teeth mounted on the casing shoe resulted in some over cut of the female piles allowing spoil to be smeared on the cut face and left to contaminate the joint.
- Both the low strength and structural concrete mixes were not preapproved standard mixes with historical performance data from the supplier. It was therefore necessary to initially use approved mixes which affected:
  - the strength of the female piles was around 20 MPa at 28 days which resulted in reduced drilling rates and localised poor verticality tolerances being achieved, and
  - the supplied slump of the approved structural mix was 140 mm, which is lower than the normal 180 - 200 mm target which in some cases affected the concrete flow as the casings were removed as graphically demonstrated in Figure 5.



FIG 5 - Loss of pile integrity.

The second and third shafts were part of the Auckland City Council Nikau Street to Abbotts Way Stormwater Upgrade to provide access to the 1.95 m diameter tunnel. The shafts were 6 m and 8 m internal diameter extending down 14 m and 19 m, respectively. The tunnel and thus lower portion of the shaft was in ECBF with overburden comprising either alluvial (sands, silts) or volcanic (silts, gravel, lapilli) deposits. As a cost effective alternative to cased bored piles, given the unstable soils and thus the need for long temporary casings, continuous flight auger (CFA) piling was used to form the 600 mm diameter secant piles. The primary issue on the project was the poor tolerances achieved which meant that piles were misaligned and in some cases there was no overlap. The primary cause was the high strength of some of the low strength female piles; test samples later confirmed cylinder strengths of up to 17 MPa at seven days were present instead of 2 - 4 MPa. This highlights the need to clearly brief and engage with the concrete batch plant operator so that the unusual requirement to not exceed a maximum strength is understood. Less significant issues such as the pile layout, auger string stiffness and boring head also contributed to the misalignment but to a lesser degree.

The shaft was successfully completed as can be seen in Figure 6 using a more staged excavation and thicker sprayed concrete internal lining wall. Since the construction of these shafts a number of secant pile walls have been constructed using the CFA system and all have achieved the required verticality tolerances and overlap.

## CONCLUSIONS

The efficient construction of deep access shafts and manholes is becoming more widespread due to the increased use of tunnelling, pipe-jacking and horizontal directional drilling (HDD) in NZ. Typically these methods can be applied most efficiently and reliably when the pipeline is located in stable deposits such as the ECBF that underlies the Auckland area; this tends to result in deep shafts and access manholes through unstable overburden materials.

The use of large diameter piling techniques with precast manhole sections has been effectively developed using safe methods suitable to most ground conditions that drilling plant can excavate. As



FIG 6 - Nikau street shaft.

with foundation piling the bore stability can be maintained with the use of either temporary casing or support fluids.

Secant piling provides a quiet and low vibration methodology to form larger diameter circular shafts through unstable overburden or weak ECBF. The secant piling methodology has developed significantly over the past four years and can now be reliably performed using cased or CFA bored piling methods. Secant pile shafts to 20 m are achievable dependant on the specific project conditions, constraints and pile construction methodology. From the project experience the key design issue is the pile overlap, low strength concrete mix design and balancing these against achievable construction tolerances.

The drilled shafts and secant pile shafts represent proven alternative construction deep shaft construction methods. In the absence of NZ developed standards/specifications the ICE specification for piling and embedded retaining walls (ICE, 2007) is advocated for CFA piling and secant pile wall construction.

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