Developments in Piling Techniques in NZ

by

Nick Wharmby
Types of Pile

Large Displacement
- Preformed
  - Solid
    - Concrete
  - Hollow
    - Concrete
- Cast In Situ
  - Concrete
  - Steel

Small Displacement
- Steel Sections (H Piles)
- Screw Piles
- No Displacement
  - Void formed by Excavation
    - Supported
    - Unsupported
    - Permanent (Casing)
    - Temporary
      - Casing
      - Mud
Non Displacement Piles

- Crane mounted
- Self-errecting hydraulic rigs
- Excavator mounted
- Pendulum borers
- Rig weight 2 – 80T
- Rotary torque = 5 – 300 KNm

No Displacement

- Void formed by Excavation
  - Supported
  - Unsupported
    - Permanent (Casing)
    - Temporary
      - Casing
      - Mud

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## Crane Mounted Rigs

<table>
<thead>
<tr>
<th>Rig</th>
<th>Weight (T)</th>
<th>Power (BHP)</th>
<th>Torque (KNm)</th>
<th>Max. Pile Diameter (m)</th>
<th>Max. Pile Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTC-S</td>
<td>40+8</td>
<td>127</td>
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<td>210</td>
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</table>
Crane Mounted Rigs

Kauri Point Wharf, Auckland

Bowden Road, Mt. Wellington

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## Hydraulic Rigs

<table>
<thead>
<tr>
<th>Rig</th>
<th>Weight (T)</th>
<th>Power (KW)</th>
<th>Torque (KNm)</th>
<th>Max. Pile Diameter (m)</th>
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</tbody>
</table>

Notes: (1) Theoretically can drill up to 2.4m diameter
LoDril Hydraulic Rig

Reach = 6.0m
Minimum Headroom = 8.0m
Hydraulic Rigs

Huntly

Busway, Auckland

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Hydraulic Rigs

Newmont Gold, Waihi

BNZ, Auckland
Mini-pile Rigs

- Weight = 12.5T
- Torque = 13.5KNm
- Mini-piles, Anchors, Soilnails
- Drilling methods to suit ground conditions:
  - Augers
  - Rotary (drag, tricone, etc.)
  - Top / down hole hammers
Non-displacement Piles - Methods

• Cased bored piles
• Fluid supported bores
  – Water
  – Bentonite
  – Polymer
• Continuous Flight Auger (CFA)
Cased Bored Piles

- Mini piles: 100 – 600mm diameter
- Typically: 600, 750, 900, 1200, 1500, 1800, 2100, 2400mm diameter
- Casing: temporary or permanent
- Reinforced concrete filled
Cased Bored Piles – Casing design

- Earth & water pressures
- Buckling Pressure, \( q_{\text{crit}} = \frac{3EI}{R^3} \)
- Theoretical

### Casing Wall Thickness (mm)

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<tr>
<th>Casing Dia</th>
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</tbody>
</table>

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Cased Bored Piles – Casing design

• Installation requirements
  – Top ring
  – Lead shoe
  – Teeth
Cased Bored Piles – Design

- Typical Ks values
- Cased bored piles
  - disturbed zone
    - driven
    - vibrated
    - rotated
  - soil type
- Concrete pressure
- $K_s = 0.7$ (approx.)
Bored Minipiles - Design

- Typical Ks values
- Grouted mini-piles
  - Many drilling & casing methods depending upon soil type
- Grout pressure & grout permeation
- $K_s = 0.7$ to $2.5$
Cased Bored Piles – MHX Testing

- 1800mm dia.
- 20m ECBF socket
- Bored dry with smear removed with reamer
- Standard base cleaning
- Water filled bore open for 42hrs
Cased Bored Piles – MHX Testing

- Very weak ECBF
- UCS = 0.7 – 2.0 Mpa
- 20m ECBF socket
- Osterberg load cell 6m above pile base
- Est. 24MN capacity above and below

Manukau Harbour crossing, Auckland
Cased Bored Piles – MHX Testing

Mobilized Unit Skin Friction Curves
Test Pile - Mangere Bridge - Auckland, NZ
- PRELIMINARY RESULTS -

![Graph showing unit skin friction curves vs. average zone movement](image-url)
Cased Bored Piles – Testing

Mobilized End Bearing
Test Pile - Mangere Bridge - Auckland, NZ
- PRELIMINARY RESULTS -

Unit End Bearing (kPa)

Downward Pile Tip Displacement (mm)
Cased Bored Piles – Dart 9 Testing

- 2No. 600mm dia
- Bored / drilled dry
- Grooved
- Pumped dry
- Constructed in a single shift
- Former tube
Cased Bored Piles – Dart 9 Testing

• Video clips
Cased Bored Piles – Dart 9 Testing

- Test Pile 1
- 11.0m Former
- 3.0m Socket
- Very weak ECBF
- UCS = 2 – 4 Mpa
- USF = 475 KPa
Cased Bored Piles – Dart 9 Testing

- Test Pile 2
- 13.5m Former
- 3.0m Socket
- Very weak ECBF
- UCS = 2 – 4 Mpa
- USF = 545 KPa
Fluid Supported Bores – Bentonite

- Naturally occurring mineral
- Open cast mined around the world
- Sodium or sodium activated
- Clay with mineral Montmorillonite
Fluid Supported Bores – Bentonite

Panel / Bore Stability Assessment:

Huder Madrid 1972 approach

Location: 1.5m Diameter Pile in Silt
Panel length / Bore diameter, B (m) = 1.500
Depth to Groundwater level (m) = 1.500
Depth to Bentonite [-ve above G.L.] (m) = 0.000
Surcharge at ground level (KN/m²) = 0.000

Stratigraphy / Soil Parameters

<table>
<thead>
<tr>
<th>Strata Description</th>
<th>Depth to strata (m)</th>
<th>Density ( \gamma ) (KN/m³)</th>
<th>Effective ( \phi' ) (deg)</th>
<th>Total ( c' ) (KPa)</th>
<th>( C_u ) (KPa)</th>
<th>( C_u/z ) (KPa)</th>
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</thead>
<tbody>
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<td>Fill - Stone</td>
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<td>36</td>
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<td>Silt / Sand</td>
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<td>16</td>
<td>28</td>
<td>0.0</td>
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<td>0</td>
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<td>28</td>
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</tbody>
</table>

Soil arching around a slurry trench

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Fluid Supported Bores – Bentonite

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**Active Pressure**

- **Bentonite Pressure**

---

**Pressure (KPa)**

- **Depth (m)**

---

- **Active Pressure**
- **Bentonite Pressure**
Fluid Supported Bores – Bentonite

Add 20KPa surcharge

Minimum Casing

Potentially Unstable

1.0m drop in Bentonite level
Fluid Supported Bores – Bentonite

- Maintaining a positive fluid pressure
  - Minimise fluid loss into soil
  - Formation of “Filter cake” or effective “Membrane”

Support fluid pressure <= water pressure
>> INSTABILITY
### Fluid Supported Bores – Bentonite

- Bentonite properties
- SPERW (2nd Edition 2007)

<table>
<thead>
<tr>
<th>Property to be measured</th>
<th>Test method and apparatus</th>
<th>Compliance values measured at 20°C</th>
<th>Freshly mixed</th>
<th>Ready for re-use</th>
<th>Sample from excavation prior concreting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>Mud balance</td>
<td>&lt;1.10 g/ml</td>
<td>&lt;1.25 g/ml</td>
<td>&lt;1.15 g/ml</td>
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<tr>
<td>Fluid loss (30 minute test)</td>
<td>Low-temperature test fluid loss</td>
<td>&lt;30 ml</td>
<td>&lt;50 ml</td>
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<tr>
<td>Filter cake thickness</td>
<td>Marsh cone</td>
<td>&lt;3 mm</td>
<td>&lt;6 mm</td>
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<tr>
<td>Viscosity</td>
<td>Fann viscometer</td>
<td>30–50 seconds 4–40 N/m²</td>
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<td>Shear strength</td>
<td>Sand screen set</td>
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<td>30–50 seconds 4–40 N/m²</td>
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<td>(10 min gel strength)</td>
<td>Electrical pH meter to BS 3445: range pH 7 to 14</td>
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</table>

* 2% prior to concreting if working loads are to be partly resisted by end bearing
Fluid Supported Bores – Bentonite

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Bentonite Storage

THL, Tauranga
Bentonite Conditioning

THL, Tauranga
Fluid Supported Bores – Bentonite

- Effect of auger / digging bucket movement
  - The speed of lift
  - Bypass area / geometry
  - Fluid viscosity

Potential loss of support pressure & turbulence
Fluid Supported Bores – Bentonite
Fluid Supported Bores – Bentonite
Fluid Supported Bores – Bentonite

- Removal of poor quality bentonite
  - Removal of contaminated bentonite
  - Replacement with clean bentonite
Fluid Supported Bores – Bentonite

• NLRT Tension Test
  – 750mm Dia.
  – 12.0m Former
  – 6.5m Socket
  – Bentonite filled for 30hrs
Fluid Supported Bores – Bentonite

- NLRT Tension Test
  - Very weak ECBF
  - UCS = 0.5 – 1.5 Mpa
  - USF = 385 KPa
Base Grouting

• Improve pile base after pile concreting
  – Install a TAMs (tube-a-manchettes) in the reinforcement cage
  – Crack pile concrete
  – Grout to criteria of volume and pressure
Base Grouting – TAM test
Base Grouting
Base Grouting
Test Pile Results
Test Pile Results

![Graph showing load vs. settlement for test piles. The x-axis represents load (kN) ranging from 0 to 10000, and the y-axis represents settlement (mm) ranging from 0 to 14. The graph includes multiple load-settlement curves.]
Test Pile Results

Percentage of head load vs. Depth (m) for increasing applied load.
Test Pile Results

Ult. Shaft Friction
• 40 – 150 KPa
• 90 KPa Average

Ult. End Bearing
• 12 MPa +?

Ult. Pile Capacity
• 15 – 17 MN
Integrity Testing

Theoretical

Actual Placed

Concrete Volume (m³)

Depth (m)

Over supply = 2.9m³ (28%)

Under supply = 1.7m³ (41%)

Actual Placed
Theoretical

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Construction – Cross-hole Sonic Logging (CSL)
Construction – CSL
Cross-hole Sonic Logging - 3D Tomography
Fluid Supported Bores – Polymer

- Many types / trade names
- Industrially produced chemical
- Variety of other components
- More expensive
- 1 to 2 kg/m³
## Fluid Supported Bores – Polymer

### Comparison of Bentonite & polymer mud properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Bentonite</th>
<th>Polymer</th>
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<tbody>
<tr>
<td>Fluid</td>
<td>Thixotropic</td>
<td>No shear strength</td>
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<tr>
<td>Marsh Cone Viscosity (secs)</td>
<td>32 to 50</td>
<td>32 to 120</td>
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<tr>
<td>Density (g/cm³)</td>
<td>1.03 to 1.25</td>
<td>1.02 to 1.1</td>
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<tr>
<td>pH</td>
<td>7 to 11</td>
<td>6 to 11.5</td>
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</table>
Fluid Supported Bores – Polymer
Fluid Supported Bores – Polymer

Sediment samples after 18hrs fluid contact

Wet Sediment  Dry Sediment  Dry Sediment  Wet Sediment

POLYBORE  Water

Centreport, Wellington
Fluid Supported Bores – Polymer

Canary Wharf BP1
Fluid Supported Bores – Polymer

Canary Wharf BP1

<table>
<thead>
<tr>
<th>Pile Ref.</th>
<th>Pile Diameter (m)</th>
<th>Pile Length (m)</th>
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<th>Construction Time</th>
<th>Pile Capacity (KN)</th>
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<td>0.75m</td>
<td>28.0m</td>
<td>Polymer</td>
<td>37 hours</td>
<td>8300</td>
</tr>
<tr>
<td>TP2</td>
<td>0.75m</td>
<td>26.0m</td>
<td>Polymer</td>
<td>12 hours</td>
<td>7300</td>
</tr>
<tr>
<td>TP4</td>
<td>0.75m</td>
<td>28.0m</td>
<td>Bentonite</td>
<td>12 hours</td>
<td>8300</td>
</tr>
</tbody>
</table>
Fluid Supported Bores – Polymer

Canary Wharf BP1
Fluid Supported Bores – Polymer

• Benefits
  – Simpler mixing (less energy)
  – Smaller Storage
  – No conditioning plant
  – Broken down to neutralise and dispose of
  – Better friction capacity?
Fluid Supported Bores – Polymer

• Risks
  – More sensitive mud system / control
  – “Black box” guarded technology
  – No national / international standards
  – Reliant on “membrane” & viscosity
  – Greater potential for losses = cost
  – Reinforcement bond?
CFA Bored Piles

- Boring
  - Flighting
  - Polishing
  - Loosening
- Concreting
  - Poor base
  - Necking
  - Blockages
- Cage insertion
# CFA Bored Piles

<table>
<thead>
<tr>
<th>Ground Conditions</th>
<th>Drill</th>
<th>Conc.</th>
<th>Cage</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Very Soft Clays</td>
<td>✔✔✔</td>
<td>×</td>
<td>✔</td>
<td>Concrete instability / integrity</td>
</tr>
<tr>
<td>2. Soft to Stiff Silts / Clays</td>
<td>✔✔✔</td>
<td>✔✔✔</td>
<td>✔✔✔</td>
<td></td>
</tr>
<tr>
<td>3. Very Loose / Loose Sands</td>
<td>✔✔✔</td>
<td>✔✔✔</td>
<td>××</td>
<td>High permeability can make cage insertion problematic</td>
</tr>
<tr>
<td>4. Dry Sands / Sandstones</td>
<td>✔✔✔</td>
<td>✔</td>
<td>×××</td>
<td></td>
</tr>
<tr>
<td>5. Dense Wet Sands</td>
<td>✔✔✔</td>
<td>✔</td>
<td>✔✔✔</td>
<td></td>
</tr>
<tr>
<td>6. Gravels &amp; Cobbles &lt;150mm</td>
<td>✔✔</td>
<td>✔✔✔</td>
<td>✔✔</td>
<td>OK provided material will flight</td>
</tr>
<tr>
<td>7. Boulders</td>
<td>×</td>
<td>✔</td>
<td>✔</td>
<td>Obstruct or deflect auger</td>
</tr>
<tr>
<td>8. Weak Rocks &lt;5MPa</td>
<td>✔✔</td>
<td>✔</td>
<td>✔✔</td>
<td>Rock head and pull down required</td>
</tr>
<tr>
<td>9. Moderately Strong Rocks &gt;5MPa</td>
<td>×</td>
<td>✔</td>
<td>✔✔</td>
<td>Refusal and reduced friction</td>
</tr>
<tr>
<td>10. Voided Ground</td>
<td>✔✔✔</td>
<td>×</td>
<td>×</td>
<td>Integrity, loss of concrete</td>
</tr>
<tr>
<td>11. Soft / Loose over hard</td>
<td>×</td>
<td>✔</td>
<td>✔</td>
<td>Flighting, settlement &amp; void potential</td>
</tr>
</tbody>
</table>

✔✔✔ = No real Issues to ✔ = particular care required,  
×- ××× = potentially significant issues, refer to Manager Engineering for mitigation measures / alternatives

“If in doubt  ASK”
CFA Bored Piles

<table>
<thead>
<tr>
<th>Rig</th>
<th>Weight (T)</th>
<th>Torque (KNm)</th>
<th>Max. Dia (m)</th>
<th>Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR30</td>
<td>36</td>
<td>121</td>
<td>0.75</td>
<td>18.5</td>
</tr>
<tr>
<td>SR50</td>
<td>53</td>
<td>180</td>
<td>0.60, 0.90</td>
<td>21.0, 18.0</td>
</tr>
</tbody>
</table>

- Fully instrumented
CFA Bored Piles

- Real time monitoring during construction
- Operators guide
- Quality records
CFA Bored Piles

- Boring
  - Torque
  - Depth of auger tip
  - Rotation speed
  - Penetration rate
CFA Bored Piles

- Concreting
  - Depth of auger tip
  - Concrete pressure
  - Concrete overbreak
  - Lift speed

right from the start: www.brianperrycivil.co.nz
CFA Bored Piles - Cages

- Specifically designed for insertion into concrete:
  - Rigid
  - Fewer large diameter bars
  - Minimum of 75mm cover

- Cage dimensions:
  - General OD: 450 - 900mm
  - Cage Toe OD: 75mm
  - Main Bar & Links:
    - 3.0m (max)
  - Former Ring & Skid Spacers:
    - 1.5m (min)
  - Tapered Cage End
  - Welded Band
  - Welded Band

- Additional components:
  - Cage Gen. OD
  - Welded Band
  - Former Ring & Skid Spacers
  - Tapered Cage End
  - Welded Band

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CFA Bored Piles

Project Eastport, Auckland
CFA Bored Piles

Harbour Link, Tauranga

right from the start: www.brianperrycivil.co.nz
CFA Bored Piles – Integrity Testing

• Non-destructive “transient dynamic response” testing (Testconsult TDR2)

• Limitations
  – Upper portion
  – Slenderness
  – Rapid soil stiffness changes

• Wave matching for diameter
CFA Bored Piles – Integrity Testing

Date: 16/03/2010 10:35
Site: RUAKURA
Job No.: 27181
Pile No.: 15D
Pile type: CFA
Diameter: 600 mm
Given length: 6.87 m

**Graphs:**
- Stiffness: 0.40 MN/mm
- Frequency (Hz)
- Velocity (m/s)

Remarks:

Right from the start: www.brianperrycivil.co.nz
CFA Bored Piles – Integrity Testing

<table>
<thead>
<tr>
<th>Pile properties</th>
<th>Soil properties</th>
<th>Pile data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (m)</td>
<td>Vel (B) m/sec</td>
<td>Date</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>Density Kg/m³</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>70</td>
<td>16/03/2010 10:35</td>
</tr>
<tr>
<td>2</td>
<td>70</td>
<td>Site</td>
</tr>
<tr>
<td></td>
<td>1500</td>
<td>RUAKURA</td>
</tr>
<tr>
<td>6.55</td>
<td>70</td>
<td>Job No</td>
</tr>
<tr>
<td>600 mm</td>
<td>1500</td>
<td>27181</td>
</tr>
<tr>
<td>6.87 m</td>
<td>70</td>
<td>Pile No</td>
</tr>
<tr>
<td></td>
<td>1854</td>
<td>15D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pile type</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CFA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diameter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>600 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Given length 6.87 m</td>
</tr>
</tbody>
</table>

Right from the start: www.brianperrycivil.co.nz
CFA Bored Piles – Project Eastport

- 600mm dia.
- 1.5m Socket
- CFA anchor piles
- Weak ECBF
- UCS = 5 Mpa +
- Pult = 4500 KN
CFA Bored Piles

Project Eastport, Auckland

UEB > 12 MPa & USF > 400 KPa

right from the start: www.brianperrycivil.co.nz
Design of Piles in Stiff Clay

Test Pile Comparison

- Pile construction using good practice and control $\alpha = 0.65$
- Comparison pile installed to measure the effects of over rotation $\alpha = 0.45$
CFA Bored Piles

- Suited to all soils & weak rocks found in all major NZ urban areas
- Quiet & very low vibration
- Pile capacity benefits over bored pile
- Bearing piles, hard firm secant piles
CFA Bored Piles – Displacement

- Soil Displacement as the auger penetrates the ground:
  - Enhanced bearing capacity
  - Minimal pile spoil
CFA Bored Piles – Displacement

• Limited improvement where:
  – SPT ‘N’ < 10
  – Undrained behaviour
  – Crushable soil grains

• Typical Ks values = 0.8 to 2.0
SPERW
2nd Edition 2007

- Client, Consultant & Contractor developed
- Specifications
- Construction guidelines
Key Points

- Methods to suit all soils & weak rocks in NZ.
- Quiet & very low vibration methods available
- Large diameter single pile / single column
- Plunged column for top-down basements
Key Points

• Construction methodology affects capacity

• Load tests:
  = knowledge↑
  = risk↓
  = reduction factors↑

• ICE Specification?