Risk Management for Piles & Deep Foundations
by Martin Larisch

Wednesday 21/11/2018
Safety is the biggest risk for this type of work, a strong safety culture is the key for a successful outcome.
Defects due to inclusions and insufficient tolerances
Defects due to workmanship or insufficient materials
Defects due to workmanship or insufficient materials
It is really confusing!!!
Definition of risk:

‘A situation involving exposure to danger’

‘A probability or threat of damage, injury, liability, loss, or any other negative occurrence that is caused by external or internal vulnerabilities, and that may be avoided through pro-active action.’
Main Drivers for successful risk management:

- Resources (numbers, experience, qualification)
- Pre-planning (tender & construction phase)
- Quality of the design
- Clear focus on the owner’s business needs
- Co-operative and motivated teams
- Strong commitment by all stakeholders to equitable risk allocation, attention to effective risk assessment, analysis and management
Risk Management

 expectations

 communication
Selected RISKS related to piling & deep foundations:

**General:**
- Safety
- Program
- Budget
- Ground conditions
- Constructability
- Obstructions in the ground
- Design assumptions (performance criteria)
- Necking
- Collapsing ground
- Eccentricity
- Etc..
Design → Construction → Performance
EXAMPLE – Load Settlement Estimate (Fleming, 1992)

**Bored pile in clay:**
- L = 10m
- Diameter = 450mm
- Base resistance = 3 MPa
- Shaft resistance as below

- 30 kPa shaft friction
- 35 kPa shaft friction
- 40 kPa shaft friction
How do design models correlate with site conditions? How do we assess / verify our design parameters?
“And the best thing is: we reduced the geotechnical investigation by 50%”
Reinforcement detail on the drawing (left) and on site (right)
Construction tolerances must be communicated & understood
Construction tolerances must be communicated & understood
Construction tolerances
- Allow for vertical and horizontal tolerances in your pile design
- Ensure contractors can commit to stricter tolerances
- Ensure water proofing performance and durability requirements are met

Remediation:
- Use of highly workable grout
- Proper planning
- Re-design of foundations
- Design pile caps with 3 piles
Fluid supported excavations
The most common drilling support fluids for deep foundations are:

- Water

- **Bentonite** (mineral slurry)
  (keeps solids in suspension – fluid needs to be cleaned and circulated, which is typically time consuming)

- **Polymer**
  (solids settle to the bottom of the excavation where they can be removed by purpose built cleaning tools – no fluid circulation required)
Effect of auger / digging bucket movement:

- The speed of lift
- Bypass area / geometry
- Fluid viscosity

Potential loss of support pressure & turbulence
Suitable ground conditions

- Loose to very dense sands (bentonite)
- Stiff to hard clays (polymer)
- Layered ground conditions (bentonite or polymer)

Fluid supported piles should be considered carefully for:

- Gravels and cobbles
- Soft soil conditions
- Soil conditions with obstructions and cavities
- Contaminated groundwater / marine conditions
Maintaining a positive fluid pressure
- Minimise fluid loss into soil
- Formation of “Filter cake” or effective “Membrane”
- Bentonite filter cake formed by clogging’ and ‘bridging’

Support fluid pressure $\leq$ water pressure
$\gg$ INSTABILITY
The filter cake thickness is a function of bentonite quality
Drilling fluids with different fluid-loss behaviours are shown below (water vs bentonite)
The thin wet layer is where the bentonite platelets and hydrostatic head of the fluid created an impermeable membrane/barrier (the wall cake) which stabilizes granular soils such as sand.
Stability of bored piles and diaphragm walls under fluids

Minimum Casing depth

Potentially Unstable

1.0m drop in Bentonite level
Principle hole ‘cleaning’ mechanism of polymer fluids

(Photo courtesy of KB International)
Table C18.1  Typical tests and compliance values for support fluid prepared from bentonite manufactured in the UK

<table>
<thead>
<tr>
<th>Property to be measured</th>
<th>Test method and apparatus</th>
<th>Compliance values measured at 20°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Freshly mixed</td>
</tr>
<tr>
<td>Density</td>
<td>Mud balance</td>
<td>&lt;1.10 g/ml</td>
</tr>
<tr>
<td>Fluid loss (30 minute test)</td>
<td>Low-temperature test fluid loss</td>
<td>&lt;30 ml</td>
</tr>
<tr>
<td>Filter cake thickness</td>
<td>Marsh cone</td>
<td>&lt;3 mm</td>
</tr>
<tr>
<td>Viscosity</td>
<td>Low-temperature test fluid loss</td>
<td>30–50 seconds</td>
</tr>
<tr>
<td>Shear strength</td>
<td>Marsh cone</td>
<td>4–40 N/m²</td>
</tr>
<tr>
<td>(10 min gel strength)</td>
<td>Pann viscometer</td>
<td>n/a</td>
</tr>
<tr>
<td>Sand content</td>
<td>Sand screen set</td>
<td>7–10.5</td>
</tr>
<tr>
<td>pH</td>
<td>Electrical pH meter to BS 3445;</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>range pH 7 to 14</td>
<td></td>
</tr>
</tbody>
</table>

* 2% prior to concreting if working loads are to be partly resisted by end bearing.
Exposure to water can reduce the actual shaft resistance in clay/shale. The quality of the filter cake (bentonite) can reduce the actual shaft resistance in granular soil. The accumulation of fines at the pile base can reduce the base resistance significantly.

**Bored pile in clay:**
- L = 10m
- Diameter = 450mm
- Base resistance = 3 MPa
- Shaft resistance as below

**Load applied at pile head (kN):**
- 0
- 100
- 200
- 300
- 400
- 500
- 600
- 700
- 800
- 900
- 1000

**Pile head settlement (mm):**
- 0
- 5
- 10
- 15
- 20
- 25
- 30
- 35
- 40
- 45
- 50

- 30 kPa shaft friction
- 35 kPa shaft friction
- 40 kPa shaft friction
• Fluids will lose their properties after a certain period of time, check the properties frequently if you want to leave excavations open for an extended period of time
• Ensure base cleanliness, especially for polymer fluids
• Be aware of potential reduction of shaft friction in clays when using water or bentonite
• Consider shear thickening and shear thinning behaviour of different fluids during mixing and pumping
• Ensure sufficient concrete workability for wet pours, resistance against bleeding (risk of fluid dilution) and potential chemical reactions with concrete admixtures or ground water
• **ALWAYS KEEP THE FLUID LEVEL >2m ABOVE GWL**
Drilling fluids
- Clean pile base thoroughly
- Use polymer for cohesive soils (avoid clay swelling)
- Use bentonite in granular soils (avoid fluid losses)
- Monitor the fluid properties several times per day
- Ensure polymer won’t react with concrete admixtures

Remediation:
- Use of workable concrete
- Pile replacements ($$)
- Re-design of foundations
Concrete is playing an important part in piling...
Define & understand concrete performance criteria
(e.g. keep tremie pipe embedded into fresh concrete by >3m)
Dry pour (<75mm of water at the base) vs wet pour…
Slump under fluid

- **DRY**: (230mm/370mm)
- **WATER**: (200mm/290mm)
- **POLYMER**: (200mm/290mm)

(Photos courtesy of Active Minerals Australia)
Concrete displacement records
Concrete displacement curves – what happened?
Concrete bleeding under pressure
Concrete bleeding under pressure

- Concrete level
- Groundwater level
- Permeable soil
- Non-permeable soil
- Excess water
- Concrete under head pressure
- $p_{\text{water}}$
- $p_{\text{concrete}}$
<table>
<thead>
<tr>
<th>Test Method and properties assessed</th>
<th>Suggested value for structural element of length ( l ) and for optional pouring conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
</tr>
<tr>
<td><strong>Slump</strong></td>
<td></td>
</tr>
<tr>
<td>( h ) (mm)</td>
<td>( \geq 140^* )</td>
</tr>
<tr>
<td><strong>Slump flow</strong></td>
<td></td>
</tr>
<tr>
<td>( D_{\text{final}} ) (mm)</td>
<td>-</td>
</tr>
<tr>
<td>( T_{\text{final}} ) (sec)</td>
<td>-</td>
</tr>
<tr>
<td><strong>L-Box</strong></td>
<td></td>
</tr>
<tr>
<td>Travel distance from bars (mm)</td>
<td>( &gt; 200 )</td>
</tr>
<tr>
<td>Filling Ratio</td>
<td>-</td>
</tr>
<tr>
<td>( T_{\text{end}} ) (sec)</td>
<td>-</td>
</tr>
<tr>
<td>L-Box Passability (mm)</td>
<td>( \leq 40 )</td>
</tr>
<tr>
<td><strong>Bauer filtration</strong></td>
<td></td>
</tr>
<tr>
<td>Filtration loss (l/m³)</td>
<td>( \leq 30 )</td>
</tr>
<tr>
<td>Filter cake thickness (mm)</td>
<td>( \leq 150 )</td>
</tr>
</tbody>
</table>
Concrete bleeding under pressure
- Reduce water content to about 180l/m³ and then further adjust during trials
- Ensure at least 500kg/m³ of fines (< 0.6mm) in your mix
- Carry out lab and field trials

Remediation:
- Shotcrete
- Cathodic protection ($$$)
- Re-design of piles
- Pile replacements ($$)
- Removal of defect sections
Piles can be subject to necking if the following occurs:

- Very soft layers are below a layer of fill
- The pressure of the fill causes the soft layer to move laterally into the pile excavation if concrete pressure is insufficient
- Low cut off levels can be the reason for insufficient pressure
- Necking can also be caused by piling rigs (ground pressure)
Pile integrity testing

Detect pile damages during installation, NOT afterwards when the structure is built.
Low strain integrity tests (PIT)
Low strain integrity tests (PIT)

- PIT tests (identifies defect and inhomogeneous areas)
- Non destructive test method involving hammer impact at the pile top and measurement of resulting pile top motion
- Low strain compression wave travels down the pile shaft
- Wave will be reflected when change of impedance occurs (at pile toe, inhomogeneous areas, cracks, necking or bulging)
- Suitable for small diameter piles (typically up to 900mm) and 20-25m depth
Low strain integrity tests (PIT)

1. P19
   - 2200mm BORED PILE
   - GRADE 85 MPA CONCRETE
   - 15/11/2008 11:36:44 a.m.
   - x 20  L/D=12 (D=220 cm)
   - 27.30 m

2. CP12
   - 1800mm BORED PILE
   - GRADE 85 MPA CONCRETE
   - 15/11/2008 12:12:42 p.m.
   - x 20  L/D=15 (D=180 cm)
   - 26.87 m


**CHL/CSL – Cross hole sonic logging**

- Cross Hole sonic Logging (CHL) is a non destructive test method which transfers ultrasonic pulses through concrete from one probe to another.
- Time between pulse generation and signal reception and strength of the received signal is measured.
- Signal gives a relative measure of concrete quality between transmitter and receiver.
- CHL inspects the structural integrity of a pile and the location of potential defects.
- Changes in arrival time and/or energy level of the sonic pulses emitted by the probes is considered indicative of possible defects.
- CHL won’t provide any information about the concrete cover of the pile.
CHL – Cross hole sonic logging
CHL – Cross hole sonic logging

Access Tube Layout - P14

Legend:
- Scanning Path
- Obstructed Path

Centre - Centre Distances
1 to 2: 883mm
2 to 3: 883mm
3 to 4: 883mm
4 to 5: 883mm
5 to 6: 883mm
1 to 6: 883mm
1 to 3: 1529mm
2 to 4: 1529mm
2 to 5: 1529mm
3 to 5: 1529mm
2 to 6: 1766mm
3 to 6: 1766mm
1 to 4: 1766mm
1 to 5: 1529mm
4 to 6: 1529mm
CHL – Cross hole sonic logging
Dynamic pile testing

Detect pile damages during installation, NOT afterwards when the structure is built.
Why would we do it?

• Required by specification or national code;
• Determine pile capacity based on test results rather than text book formulae (get REAL results);
• Monitor and ensure pile integrity;
• Improve quality of driving criteria for untested piles;
• Reduce geotechnical factor of safety;
• Carry out remote testing for safety & cost savings

**VALUE ENGINEERING**
  – No sacrificial test piles required (time & cost savings)
  – Building of pile load test data base (for future designs)
  – Utilizing real data to calibrate design models
Dynamic Pile Load Testing (PDA)
REMOTE Dynamic Pile Load Testing
lower cost & effort

Testing Engineer
OFF SITE

Site Engineer
ON SITE

Site Engineer attaches gauges

Site Engineer connects test computer

Testing Engineer logs in

Testing Engineer provides instant feedback
What can we do with dynamic pile testing?

- Monitor driving stresses;
- Measure hammer efficiency;
- **Infer** geotechnical strength of pile (for driven piles and bored piles up to 1,200mm and about 20m depth);
- Ensure piles are not damaged

The global piling industry is still heavily relying on pile driving formulae from the 1930’s, rather than testing piles on site.
Driveability Analysis:

- Model pile driving
- Hammer Size
- Estimate risk of damage
- Estimate risk of refusal
- Estimate pile lengths
- Driving criteria
  - Premature Refusal
  - Hammer too small
  - Over-stressing of piles
  - Insufficient capacity
## Drivability analysis (model and predict performance)

<table>
<thead>
<tr>
<th>BOREHOLE</th>
<th>MODEL</th>
<th>ESTIMATED REFUSAL LEVEL AT 2.5 MM DRIVING SET [m RL]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5.6T DROPHAMMER</td>
</tr>
<tr>
<td>BH1</td>
<td>LB</td>
<td>-26.8*</td>
</tr>
<tr>
<td></td>
<td>UB</td>
<td>-26.8*</td>
</tr>
<tr>
<td>BH2</td>
<td>LB</td>
<td>-25.5</td>
</tr>
<tr>
<td></td>
<td>UB</td>
<td>-23.7</td>
</tr>
</tbody>
</table>
Drivability analysis (model and predict performance)

<table>
<thead>
<tr>
<th>BOREHOLE</th>
<th>MODEL</th>
<th>5.6T DROPHAMMER</th>
<th>13.5T DROPHAMMER</th>
<th>JUNTTAN HHK-9S</th>
</tr>
</thead>
<tbody>
<tr>
<td>BH1</td>
<td>LB</td>
<td>311</td>
<td>378</td>
<td>254</td>
</tr>
<tr>
<td></td>
<td>UB</td>
<td>315</td>
<td>380</td>
<td>257</td>
</tr>
<tr>
<td>BH2</td>
<td>LB</td>
<td>289</td>
<td>370</td>
<td>253</td>
</tr>
<tr>
<td></td>
<td>UB</td>
<td>289</td>
<td>370</td>
<td>253</td>
</tr>
</tbody>
</table>
Effective use of dynamic testing (PDA) can provide:

- capacity
- resistance distribution
- design feedback
- time effects
- hammer performance
- stress control
- pile integrity
- group interaction
“In spite of their obvious deficiencies and unreliability, pile driving formulas still enjoy great popularity among practicing engineers, because the use of these formulas reduces the design of pile foundations to a very simple procedure. The price one pays for this artificial simplification is very high.”

- Karl Terzaghi (1942)
Summary:

- Effective risk management involves clear and effective communication amongst all parties involved in a project, right from the start;

- Geotechnical risk is always significant;

- The better the information, the better the quality of the answer;

- Engineering can help you save money;

- Installation effects and environmental boundary conditions should be considered in the design phase;

- Designs should accommodate safety and ease of construction;

- Construction verification provides valuable feedback
“And the best thing is: we reduced the geotechnical investigation by 50%”