SEMINAR ON PILE LOAD TEST IN SINGAPORE
DIFFERENT METHODS AND GOOD PRACTICES

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LOAD TESTING USING KENTLEDGE AND
REACTION PILE METHOD

Foo Hee Kang, Managing Director
Resource Piling Pte. Ltd, Singapore
A Keller Group Company
CONTENT

1. Why conduct load test on foundation pile

2. Kentledge load test

3. Comply with guidelines on good practices for pile load test using Kentledge method in Singapore (Issue by GeoSS on 01-09-2011)

4. Different method of load testing

5. Reaction pile method
Why conduct load test on foundation pile-

1. Soil condition in Singapore very complex

2. Soil investigation report by soil investigation company unreliable. *(They owe engineer/contractor no duty of care)*

3. Workmanship varies from contractor to contractor

4. Economical design
Geological Map of Singapore
**SUGGESTION:** Ask Soil Investigation Company to put a pipe all the way to the toe of bore hole, Engineer can check bore hole length/soil sample later.
Map of Marina South

- BFC
- CST2
- Garden by the Bay
- CST1
- The Sail
- C421
- C906
- Marina Barrage

Skin Friction:
- Skin Friction 1.8N
- Skin Friction 1.0N

Well established fact:
- Site using Bentonite - skin friction >2.5N
- Site using Polymer - skin friction >3.0N
For bored piers, an empirical relationship \( f_s = K_s N \) is commonly used to determine the ultimate shaft resistance \( f_s \). The value of coefficient \( K_s \) depends very much on the local experience. For stiff to hard cohesive soil, a value of \( K_s \) between 1.5 to 2.5 may be adopted. The value of \( f_s \) should be subjected to a limit of 150 KPa. This includes soils of Bukit Timah Granite and sedimentary Jurong Formation (For effects of construction see 2.4.3). For dense or hard cemented soil in the Old Alluvium, a value of \( K_s \) between 2 and 3 may be adopted, subject to a limiting value of \( f_s = 300 \) KPa. Higher value of \( K_s \) or \( f_s \) may be adopted if substantiated by sufficient load tests in similar soil condition. This method is not suitable for very soft to soft cohesive soils where SPT N-value does not provide a representative measure of the soil resistance (Chang and Broms 1991; Chang and Wong 1995; Poh and Chiam 1993; et al. 1985; Ho and Lim 1994; Orihara and Khoo 1998).
Kentledge Load Test
### Kentledge Load Test – Failure Criteria

**Failure Criteria**

An example of the failure criteria of a pile is as follows:

<table>
<thead>
<tr>
<th>Maximum Settlement</th>
<th>Nominal working load &lt; 65 T</th>
<th>0.2mm/T but not more than 13mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nominal working load &gt; 65 T</td>
<td>25mm</td>
</tr>
<tr>
<td>Residual settlement</td>
<td>Nominal working load &lt; 100 T</td>
<td>5mm</td>
</tr>
<tr>
<td></td>
<td>Nominal working load &gt; 100 T</td>
<td>13mm</td>
</tr>
</tbody>
</table>

Consulting firms and agencies may have their own specifications, but the failure criteria would be likely similar to the one mentioned above.
Kentledge Load Test

• Prior to commencement of piling work, at least one Instrumented Ultimate Load Test must be conducted to verify the Ultimate Skin Friction and End Bearing.

• Every 100 pile casted, 1 pile must be tested.
Kentledge Load Test

This Load Testing are either:

1. Kentledge Load Test
2. ‘O’ cell Test
3. Reaction pile / Reaction Pile Load Test

System
Kentledge Load Test

Biggest Kentledge Load Test by Resource Piling Pte Ltd
(1800 ton)
On Year: 1989
Kentledge Load Test

Steel Mats
Due to the presence of soft layer and heavy load, there are four reaction piles plus 144m² of steel mat support for this 3500 ton Kentledge Load Test.

Ultimate Test Pile at BFC. Used 144 m² at steel mat to support 4,000 ton Kentledge Load Test. Settlement less than 100mm.
Kentledge collapse at other company site Jan/2011
Comply with guide lines on good practices for pile load test using Kentledge method in Singapore issued by Geoss on 1/9/2011.
2.0 DESIGN OF THE SETUP FOR PILE LOAD TEST STARTS IN DESIGN OFFICE

Planning of pile load test setup should start from the design office. The design of the kentledge setup should be carried out by a Professional Engineer, PE.

2.1.1 LOAD TEST EXCEEDING 3000 TONNES

For larger load test exceeding 3000 tonnes, the project team can consider using steel plates, tension piles or ground anchors as the reaction load or adopting other alternative method of testing like bi-directional load test.

Large load test exceeding 3000 tonnes using concrete blocks should only be carried out by competent Specialist Builder (Piling Works) and PE who has the relevant experience.
2.1.2 WEIGHT OF KENTLEDGE

The total weight of Kentledge should be greater than maximum test load. This is to ensure the Kentledge will remain stable during the test. It is common to adopt at least 10% extra weight excluding those of test beams.
2.1.3 KENTELEDGE BLOCKS ARRANGEMENT

Kentledge blocks arrangement should be designed by PE. The pattern of the blocks arrangement should take into account stacking sequence and designed to enhance stability of the individual block as well as the whole of the Kentledge setup.

2.1.4 KENTELEDGE HEIGHT TO WIDTH ASPECT RATIO

The height to width ratio of the Kentledge setup should not be more than 1.5 for stability. For area with neighbouring structures/buildings, the ratio should be reduced to not more than 1 by increasing the width of kentledge.
5700 ton Kentledge Drawing

H/W < 1.5
If the width = 15 m

Maximum height = 1.5x1.5 = 22.5m

For normal case

For area with neighbour structure/ building within Toppling Zone

Maximum Height = 15m
2.2.1 CHECK GEOTECHNICAL BEARING CAPACITY OF KENTLEDGE BASE

The factor of safety for allowable bearing capacity for foundation supporting the Kentledge can be computed based on conventional Terzaghi’s bearing capacity equation or other methods using sound engineering principles. This geotechnical factor of safety should generally be in the order of 2.5 to 3, with upper value to be adopted for large load test or load test near neighbouring structures/ buildings.
**Buisman-Terzaghi Equation**

Fig. 3.14 The problem of bearing capacity of shallow footings.

\[ q_0 = cN_c + qN_q + \frac{1}{2} \gamma BN_\gamma \]

Buisman-Terzaghi equation
Example 2: 2760 ton Kentledge Load Test at C920

2760 ton Kentledge at C920, adjacent to Bukit Timah Road / Sharky Road.

The bearing area of the steel mat is not enough. LTA do not allow permanent or support like bored pile because the test pile very near to the boundary line and future tunnel. Only removable foundation system are allowed.

Precast 15m x 17m concrete slab as footing to support the 2760 ton Kentledge.
Check stress on ground

3.0m x 3.0 m opening

15.0

7.0m  3.0m  7.0m

work out the maximum allowable bearing capacity of soil using Bulisman-Terzaghi equation

\[ q_a = cN_c + qN_q + \frac{1}{2} rBN_r \]

BH- ABH 216

H = 4.3 m

H = 8.5 m

H = 0.5 m

Layer 1: The soil below the platform consist of back filled hard core & Sandy Silt Material

- \( c = 0 \)
- \( \varnothing = 30 \)
- \( q = 0 \)
- \( r = 19 \text{ kN/m}^3 \)
- \( r_{sub} = 9 \text{ kN/m}^3 \)
- \( B = 15.0 \text{m} \)
- \( N_r = 22.4 \)

shape factor  

\[ = 1 - 0.4B/L = 1 - 0.4 \times 15/17 = 0.65 \]

\[ Q_{ult} = 0.5 rBN_r \times \text{shape factor} = 0.5 \times 9 \times 15 \times 22.4 \times 0.65 \]

\[ = 982 \text{ kN/m}^2 = 98.2 \text{ ton/m}^2 \]

Load on ground = 12.8 ton/m²

Factor of Safety = 98.2/12.8 = 7.67 > 3.0  OK
B. Layer 2:

The soil at Layer 2 consist of Soft Marine Clay Material

Assume:

\[ c = 0 \]
\[ \phi = 22 \] (Base on table 5.1.1. Geotechnical design parameters for earth retaining system, \( \phi = 23 \), on the safe side use 22)
\[ q = 0 \]
\[ r = 16 \text{ kN/m}^3 \]
\[ r_{sub} = 6 \text{ kN/m}^3 \]
\[ B = 15.0 \text{m} + 2 \text{H} = 15.0 + 2 (4.3) = 23.6 \text{m} \]
\[ L = 17.0 \text{m} + 2 \text{H} = 16 + 2 (4.3) = 24.6 \text{m} \]
\[ N_r = 7.13 \]

Shape factor:

\[ = 1 - 0.4B/L \]
\[ = 1 - 0.4 \times 23.6/24.6 = 0.62 \]

\[ q_{ult} = \frac{1}{2} rB N_r \times \text{shape factor} \]
\[ = \frac{1}{2} \times 6 \times 23.6 \times 7.13 \times 0.62 \]
\[ = 313 \text{ kN/m}^2 = 31.3 \text{ ton/m}^2 \]

Load pressure on Layer 2 = \[ 3148 / (23.6 \times 24.6) \] kN/m\(^2\)
\[ = 5.42 \text{ ton/m}^2 \]

Factor of Safety at Layer 2 = \[ 31.3 / 5.42 = 5.77 > 3.0 \], OK
Reinforce Concrete Footing

Steel Mats
RC Platform
A8 Steel Mesh
30 mm Cover
30 mm Cover
T20 @ 200mm c/c, both direction
RC Details
Concrete Grade 30 Mpa

Steel Mats

GL
500 mm Thick Concrete Platform

12.6 m
15.0 m
12.6 m
15.0 m

Total Load on Concrete Platform = 31480 kN
Pressure on Ground = 31480 / 246 = 128 kN/m²
Moment (ult) at edge of steel mats = 128 x 1.2²/2 x 1.4
= 129 kNm/m

Steel Area Required
= \frac{120 \times 10^6}{0.87 x 460 x (0.9 x 460)}
= 779 mm²/m

Provide T20 @ 200mm c/c at bottom,
As Provided = 1570 mm²/m
OK

Top reinforcement, 1 layer of A8 mesh (nominal)
2.2.3 DIFFERENTIAL AND CONSOLIDATION SETTLEMENT OF KENTLEDGE BASE

As a good guide, the calculated differential settlement for Kentledge base should be within 1 in 150.

2.2.5 DEEP FOUNDATION

If shallow foundation is insufficient to achieve adequate factor of safety or when settlement will be excessive, deep foundation will be required.
10 nos of 1050mm casing, drive up to 13m top of F2

UTP4
Good Practice on Kentledge Load Test

Example: 4700 ton Kentledge Load Test at BFC Phase 1

The first 12m of earth are “hydraulic fill”, bearing capacity very high. During Ultimate Test Pile stage, a few 4,000 ton Kentledge Load Test were conducted, using steel mat to support the 4,000 ton Kentledge. The footing settlement is less than 100mm.

After the grouting work by others, the platform are badly disturbed. Additional pile (either permanent working pile or combination of permanent working pile plus temporary bored piles must be used to support the Kentledge.
Kentledge Footing Layout

Additional Pile to be installed (Ø1100mm)
SP1(R5) & SP2(R5)

Test Pile R5

Sector 2c

Existing Piles Proposed to Built up to ground level (R7, R17, R27 & R3)
2.3 DESIGN OF STRUCTURAL MEMBERS

The structural members shall be checked for lateral torsional buckling.
SECONDARY BEAM

MAIN BEAM
Instrumentation should be installed to monitor the stability of the Kentledge setup, from the stacking of Kentledge to load testing stage.
Good Practice on Kentledge Load Test

Good Practice on Kentledge Load Test start on site

1. Set up the Kentledge based on drawing issued by office.

2. Check by a senior staff or full-time test pile foreman.

3. Check & ensure that a 700mm to 1000mm collar casing is casted at the pile top to prevent pile top failure. The position of the collar casing must be at the center of the pile.

4. Place the test pile jack at the center of the pile.

5. Set up settlement marker on the steel mat.

6. Take settlement marker reading during stacking and testing time. At least 3 times a day overnight, noon & evening.

7. SMS the settlement marker reading to Project Manager to check.
Ground level of 4 corner a.106.630.b.106.605.c.106.625..d.106.590.
Steel mate level a.106.986.b.106.965.c.106.959.d.106.990

Tai Seng street,
UTP-1 kentledge settlement readings (1300hrs)
A-0mm
B-5mm
C-10mm
D-2mm,Avg sett-4.25mm,tot stacking blocks-40pcs.

1900hrs
A-1mm
B-15mm
C-26mm
D-6mm,avg sett-12mm,tot stacking blocks-176pcs.tks

Tai Seng street,
Kentledge settlement,
A-39mm
B-64mm
C-59mm
D-34mm,avg sett-49mm,tot test blocks on top-966nos.tks
If left side settle more than the right side, shift the crane position, load the right side first.
Photograph of Collar Casing
The test pile head always bigger than the jack because of that, there is a bursting pressure acting on the pile. Without additional reinforcement, the pile head will damage during jacking.
Steel Box Design

Important note on steel box design

The vertical member of the steel box must be at least 200mm to 350mm away from the edge.

Reason:

In the event that the pile head fails during testing, the load out in the pile wall suddenly transfer to the steel mat, if the vertical member is at the edge, the sharp edge if the steel box will transfer, suddenly line load on the steel mat, the top flange of the steel mat can be deformed, load to structural failure. If that happen, the bearing capacity of the footing will reduce, and lead to bearing capacity failure.
Steel Mats

Steel Mat consist of 6 nos of 338mm x 350mm x 106kg/m of beam weld together.

Length: 5.4m, 6.6m, 9.0m

If the top flange damage, the moment of internal reduce by 30% to 60%.
If the flange is damaged, the steel mat fails structurally. The bearing capacity of the footing outside the steel box will reduce significantly, leading to bearing capacity failure.
Photograph of Steel Box
Different Method of Load Testing
‘O’ Cell Test
Up to 2009, the biggest PDA test on bore pile is 2,000 ton. In June 2010, Resource succeed to manufacture a PDA test frame, able to drop a 60 ton hammer with the new test frame for PDA test. Can conduct PDA test up to 5000 ton.
Stanamic Load Test
Use sand bags for load test, in India
Steel Plates
Dimension of concrete blocks and steel plate different, Failure mode will be different.
CONCRETE DENSITY = 2.45 Ton/Cumm
H/W RATIO = 19.2/13
= 1.477 < 1.5 OK

STEEL DENSITY = 7.85 Ton/Cumm
 WHEN KENTLEDEGE TILT, STEEL PLATE TOPPLE OR SLIDE?
Reaction Pile Method
Test Development on Reaction Pile Test

- ~1000 tons
- 1500 tons
- 5380 tons
- 2500 tons
Figure 7.3 – Testing rig for compressive test on pile using tension piles for reaction (after Tomlinson 1995)
7600 ton Reaction Pile Test
**Structural Design**

- Cross Beams
- Main Beams, Secondary Beams, Transfer Beams
  - Load Spreading by UDL
  - Minimize Cantilever Arm
- Columns/Stanchions Installed In Reaction

**Columns and Reaction Piles Connection**

- Anchorage / Bonding

**Reaction Piles Design**

- Structural Tension Capacity of Reaction Piles
- Steel Reinforcement and Lapped Length
- Skin Friction for Tension Piles
  - Factor of Safety > 2.0
Reaction System,
Winner of Safety Innovation Award (Gold) in July 2014
Kentledge Height Reduction

A 7,068 ton Kentledge using concrete blocks (left) would require employees to work at a maximum height of 21.2 m whereas a Reaction load test of the same capacity would require employees to work at a much reduced 6.4 m.
Toppling Zone

Toppling zone

Area = 5,300 m²

Area = 900 m²

Height: 21.2m
Height: 6.4m

78.6m

78.6m
Kentledge Lift Reduction

Lift reduction

Kentledge: 4,000 lifts

Reaction System: 100 lifts
Kentledge Traffic Reduction

Traffic reduction

Kentledge: 450 trips

Reaction System: 25 trips
## Projects completed (>5000t)

<table>
<thead>
<tr>
<th>Project</th>
<th>Test Load</th>
<th>Done on</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oasis Hotel @ Peck Seah St.</td>
<td>5380t</td>
<td>2012 Aug.</td>
</tr>
<tr>
<td>M+S Project @ Ophir Road</td>
<td>7652t</td>
<td>2012 Nov.</td>
</tr>
<tr>
<td></td>
<td>7652t</td>
<td>2012 Nov.</td>
</tr>
<tr>
<td></td>
<td>6240t</td>
<td>2013 Feb.</td>
</tr>
<tr>
<td></td>
<td>5046t</td>
<td>2013 Apr.</td>
</tr>
<tr>
<td></td>
<td>6240t</td>
<td>2013 Mar.</td>
</tr>
<tr>
<td></td>
<td>7532t</td>
<td>2013 May</td>
</tr>
<tr>
<td>TRX(Tun Razak Exchange @ Malaysia)</td>
<td>7500t</td>
<td>2013 Oct</td>
</tr>
<tr>
<td></td>
<td>7500t</td>
<td>2013 Oct</td>
</tr>
<tr>
<td>Tampines Town Hub @ Tampines Ave.4</td>
<td>7068t</td>
<td>2013 Nov</td>
</tr>
<tr>
<td>Seng Kang Hospital</td>
<td>5700t</td>
<td>2014 Jan to May</td>
</tr>
</tbody>
</table>
5.4 Project similar size/nature/complexity

2. M+S Project at Ophir Road
Main Contractor : Bachy Soletanche
Piling Contractor : Resource Piling
Total Contract Value : 51.5 Million

Scope of Works :
Bored Pile with Pre-founded Column (Max. Size Ø2500mm) : 486 nos.
Conduct ULT : 3 nos.
Conduct WLT : 5 nos. (Maximum Test Load : 7500 tons)
Diaphragm Wall : 727m x 1m thick

Complexity/Challenges
D-Wall and Piling next to existing MRT Structures and underground station
Interfacing works between D-Wall, Bored Piles and Test Piles

Completion Period
50 days ahead of schedule
3. SENG KANG INTEGRATED HOSPITAL

Main Contractor: Resource Piling

Total Contract Value: 66 Million

Scope of Works:
- Bored Pile (Max. Size Ø2200mm): 1035 nos.
- Secant Pile: 1438 nos.
- Conduct ULT: 6 nos.
- Conduct WLT: 11 nos.
- Diaphragm Wall (T-Panel): 276m x 1m thick

(Maximum Test Load: 5700 tons)

Complexity/Challenges:
Mega Government Piling Project to finish within 1 year
Interfacing works between D-Wall, Bored Piles and Test Piles

Completion Period:
4 Months and 5 days ahead of schedule
Reaction Method
P-150 (2200 mm)
Settlement at 200% = 10.25 mm

Kentledge Method
P-796 (1600 mm)
Settlement at 200% = 10 mm
Load vs Settlement Curve at Pile Top
(Scale Rules Readings)
(Ultimate Test Pile: Pile Ref_ULT-8)

Marina South pile cast by other contractor

Confirm that skin friction – 2.5N is better than 1.8N by multiple cell method
TIME LINE TO CONDUCT 1000 TON LOAD TEST

- Kentledge Stacking: 1-4
- Reaction pile Setup: 1-4
- Testing: 5-8
- Remove: 9

TIME LINE TO CONDUCT 5000 TON LOAD TEST

- Kentledge Stacking: 1-10
- Reaction pile Set up: 1-10
- Testing: 11-15
- Remove: 16

Load test using reaction pile method
Safety and productivity can go hand in hand.

5000 Ton Kentledge load test = 25 Days
5000 Ton Reaction Pile Test = 8 Days
Experience in Malaysia
In Johor Bahru, for all tests exceeding 1000 ton, it is cheaper to construct load tests using Reaction Pile Method.
Bored Piles Socketted into Limestone

TRX, 16m deep socket into Limestone, Kaula Lumpur
Melawati Mall, Kaula Lumpur

CBP = 834 nos, Foundation Pile (1000 to 1800) = 438 nos, Ultimate Load Test = 1 nos, Working Load Test = 6 nos

2400 tons 4285 tons
Either Kentledge or Reaction, depend on soil condition
Kentledge Load Test

Reaction Pile Test

BEST WAY TO CONDUCT LOAD TEST
Use Kentledge load test for smaller load
Use reaction pile test for bigger load
Congested site with high LAD better to use Reaction pile method
THANK YOU