Presented by: Mark Hinton
Chief Geotechnical Engineer, Energy (Major Projects)

The Use of Micropiles to Support Basement Retaining Wall

On behalf of:
Paul A. Nowak Chief Geotechnical Engineer
Mark Scorer Senior Geotechnical Engineer
To Begin at the Beginning

30 storey towers
5 storey podium
5 storey basement

Kinaxixi Market 2008

ATKINS

ISMM
## Project Introduction

<table>
<thead>
<tr>
<th>Kinaxixi Multicomplex Development</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Project Description</strong></td>
</tr>
<tr>
<td>Large mixed use commercial development with floor area &gt; 250,000m² comprising:</td>
</tr>
<tr>
<td>• Two 31 storey towers (one residential and one commercial)</td>
</tr>
<tr>
<td>• Five storey shopping centre and amenities plaza</td>
</tr>
<tr>
<td>• Five basement levels for car parking</td>
</tr>
<tr>
<td><strong>Location</strong></td>
</tr>
<tr>
<td>Luanda, Angola</td>
</tr>
<tr>
<td><strong>Client</strong></td>
</tr>
<tr>
<td>Kinaxixi S.A. (Overall); Sigma Group (Atkins Client)</td>
</tr>
<tr>
<td><strong>Designer/Consultant</strong></td>
</tr>
<tr>
<td>Space Group (Architectural/Structural design); Atkins (Foundation re-design)</td>
</tr>
<tr>
<td><strong>Main Contractor</strong></td>
</tr>
<tr>
<td>Somague (Superstructure); Franki (Piling and temporary works)</td>
</tr>
<tr>
<td><strong>Contract Value</strong></td>
</tr>
<tr>
<td>Initial value ~ $800 million but with Kinaxixi 2 &gt;$1 billion; Atkins Design / supervision</td>
</tr>
<tr>
<td><strong>Procurement</strong></td>
</tr>
<tr>
<td>Most Contracts direct with Client; Atkins Standard International Contract with Sigma</td>
</tr>
</tbody>
</table>

**Figure 2**: Location of Kinaxixi MXD in the Central Business District of Luanda

**Figure 3**: Architects impression of the Kinaxixi MXD
Geology

Kinaxixi Site
Geology

- Luanda Formation
- Marine deposits – mainly sands (coarse, medium & fine) with subordinate mudstones and sandstones
- High lateral variability in soils
Site Investigations

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Recovery</th>
<th>DSC</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>MEDIUM TO COURSE SAND, Very Dense, Greyish Brown</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FINE TO MEDIUM SAND, Very Dense, Greyish Brown with Yellowish Orange Spots</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MEDIUM GRAINED SAND, Very Dense, Orange</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FINE TO MEDIUM GRAINED SAND, Very Dense, Orange Coloured Brown</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SPT Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Phase (10 cm)</td>
</tr>
<tr>
<td>2nd Phase (15 cm)</td>
</tr>
<tr>
<td>N</td>
</tr>
<tr>
<td>N</td>
</tr>
<tr>
<td>Penetration</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>30-30</td>
</tr>
<tr>
<td>14</td>
<td>30-30</td>
</tr>
<tr>
<td>15</td>
<td>Ref.</td>
</tr>
<tr>
<td>16</td>
<td>Ref.</td>
</tr>
<tr>
<td>17</td>
<td>Ref.</td>
</tr>
<tr>
<td>18</td>
<td>Ref.</td>
</tr>
<tr>
<td>19</td>
<td>40-40</td>
</tr>
<tr>
<td>20</td>
<td>Ref.</td>
</tr>
<tr>
<td>21</td>
<td>Ref.</td>
</tr>
<tr>
<td>22</td>
<td>Ref.</td>
</tr>
<tr>
<td>23</td>
<td>Ref.</td>
</tr>
<tr>
<td>24</td>
<td>Ref.</td>
</tr>
<tr>
<td>25</td>
<td>Ref.</td>
</tr>
<tr>
<td>26</td>
<td>Ref.</td>
</tr>
</tbody>
</table>

N60 vs Depth (m)
Foundation Arrangement

Tower A – 30 storeys
Raft + pad foundations

Podium – 5 storey basement + 5 storey podium: pad foundations

Tower B – 30 storeys
Raft + pad foundations

Footprint 190m x 120m

Plaza – 5 storey basement: pad foundations
Foundations – $q_{\text{allowable}}$ & $q_{\text{actual}}$

Tower A
- $q_{\text{allowable}} = 560 \text{ kN/m}^2$
- for $\delta_v = 50 \text{ mm}$

Tower A
- $q_{\text{actual}} = 700 \text{ kN/m}^2$
- $\delta_v = 160 - 220 \text{ mm}$

Tower B
- $q_{\text{allowable}} = 385 \text{ kN/m}^2$
  - for $\delta_v = 50 \text{ mm}$

Tower B
- $q_{\text{actual}} = 800 \text{ kN/m}^2$
  - $\delta_v = 120 - 140 \text{ mm}$
Foundations – $q_{\text{allowable}}$ & $q_{\text{actual}}$

**Typical Pad N2**
- $q_{\text{allowable}} = 420 \text{ kN/m}^2$
- for $\delta_v = 25 \text{ mm}$

**Typical Pad N19**
- $q_{\text{allowable}} = 300 \text{ kN/m}^2$
- for $\delta_v = 25 \text{ mm}$
- $q_{\text{actual}} = 840 \text{ kN/m}^2$
- $\delta_v = 55 - 70 \text{ mm}$

**Typical Pad N2**
- $q_{\text{actual}} = 619 \text{ kN/m}^2$
- $\delta_v = 45 - 60 \text{ mm}$
Ground Model
SPT Profile

Approximate Ground Level

Approximate Excavation Level

SPT N = 8 + 2.8x (Design Line)

Tests undertaken from original ground level
SPT Sand

Tests undertaken from base of excavation
DPSH

New boreholes data received (Sept 2011)
BH01
BH02
BH1
BH2
Soil Properties – Stiffness Profiles

Stiffness Profiles

Profile used for Pile Design
Atkins called in – May 2011
PERIMETER RETAINING WALL

- Horizontal loads
- Pile reinforcement – cover and penetration
- Basement floor slabs
- Sewage
- Gunite arch

Figure 6: Foundation Plan and drawing of original perimeter wall design

Figure 7: Grouting behind north wall (05/12/2011)
**Assessment Report - Retaining Wall**

**Structural Summary**

<table>
<thead>
<tr>
<th>Pile Spacing</th>
<th>Bending</th>
<th>Shear</th>
<th>Required BS8110</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.65m</td>
<td>1.1</td>
<td>0.5</td>
<td>1.4</td>
</tr>
<tr>
<td>2.0m</td>
<td>1.0</td>
<td>0.4</td>
<td>1.4</td>
</tr>
</tbody>
</table>

**Conclusion:** The wall is not satisfactory in its current form as the permanent retaining structure.
ROLES & RESPONSIBILITIES

- Initial Site Visit & Technical Review
- Detailed Review Phase
- Detailed Re-Design Phase
- Site Supervision

Geotechnical Resident Engineer
- As-built Survey
- Micropile Static Load Test

Figure 4: View of the site from the northwest corner (22/05/2011)
Figure 5: Failure in the northeast corner (22/05/2011)
Revised Retaining Wall

Plan

Capping/transfer Beam

Floor Props

RC Wall

Soldier Pile

RC Wall

Soldier Pile

250 mm Micropile

Vertical Section
STATIC LOAD TEST
Planned, Specified and Supervised
Two static load tests on two trial micropiles:
- 12m depth for working capacity 800kN
- 10m depth for working capacity 600kN
Verify the capacity and performance

Figure 17: Measurements being recorded during Static load test

Figure 18: Results from Static Load Test 1 (12m long micropile)
Success!
– Settlements Controlled

Example graphs showing differential settlements:
- Tower bases < 1:750
- Between pads < 1:500

BE Settlements:
- Raft A: without piles
- Raft B: with piles

Nonlinear E

Differential settlements:
- Tower bases < 1:750
- Between pads < 1:500

Diagram showing settlement profiles and load transfer mechanisms.
TITAN 52/26 Micropile

Figure 12: Typical cross-section of Ischebeck Titan micropile

Figure 14: Trimmed grout body with free length of steel bar to allow connection

Figure 13: Constituent parts of TITAN micropile

Figure 15: Modified sacrificial drill bit to increase diameter of grout body
Extension of Kinaxixi I