Foundation Design & Construction in Hong Kong – Present & Beyond?

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Our Theme

• A brief look at where we are
• Issues still bugging us
• Where do we go now?
Common Foundation Types in Hong Kong

Mini-piles

Steel H piles

Large diameter bored pile

Driven

Prebored

1 MN

4 MN

6 MN

Up to 100 MN

New Publications in Hong Kong

ARUP
Progress in Last 5 Years ......

Li et al (2000)
“Design of Deep Foundations in Hong Kong – Time for change?”

(1) End Bearing Bored Piles on Rock

- Predominately using presumptive values
- Bearing pressures generally regarded as very conservative

GEO Publication 1/2006 provides an alternative approach
(2) Bell-out / Rock Socket

- Many queried the actual effectiveness of bell-out (eg Lumb)
- A convenient way to address bearing pressure being too conservative?

Typically 10MPa

Half-addressed by Code of Practice for Foundation (BD, 2005)

Typically 5 – 7.5 MPa

(3) H-pile Driven to Rock

- Shallow rockhead
- Pile driven into rock
- Loading tests tend to produce positive results

Shallow rockhead

Addressed by Code of Practice for Foundation (BD, 2005)
(4) Negative Skin Friction

- Drag on piles due to settling ground
- Transient loads results in temporary settlement
  - Addressed by Code of Practice for Foundation (BD, 2005)

(5) Issues Requiring More Progress

- Use of hydraulic hammer to achieve final set
- Bored pile on rock – how to deal with soft materials at the interface
Bored Piles

Design & Construction Issues with Bored Piles

- Bearing pressure on rocks
- Combined end bearing and rock socket
- 45º load spread
- Pile base imperfections
Bearing Pressures on Rock

- First appear in 1990
- Considered to be very conservative
- Many full-scale pile loading tests had been undertaken since
- Used until 2005

Loading Tests by West Rail

- Presented in many previous occasions
- In the Technical Memorandum, 50% increase in bearing stresses were approved by BD
- Various other loading tests also support this
Bearing Stresses in the New Code of Practice for Foundations (BD, 2005)

- A new prescriptive bearing stress for highly to completely decomposed rocks
- No change to the other categories
- A new prescriptive bearing stress for fresh rock – note the requirement of 100% total core recovery (TCR) and no weathered joints

End Bearing on Rock – Alternative to Presumptive Values

Mobilised Bearing Pressure $q$ (MPa)

Recommended allowable bearing pressure

Bearing pressure that can induce settlement of ~1% of the pile dia. at the base

Legend:
- Bearing pressure substantially mobilised
- Degree of mobilisation of bearing pressure unknown

Extracted from GEO Publication 1/2006 (In Press)
**The Use of Rock Socket**

- Data published in recent years
- Many used Osterberg Cell at pile base - direct measurement of socket behaviour

**Load Deflection Behaviour of Rock Sockets**

- Graphs showing load deflection for different grades of rock.
Combined Rock Socket and End Bearing

- Rock socket behaves in a ductile manner
- Should allow direct combination of both without the need of further loading test
- Provide a robust alternative to the use of bell-out if the socket length to pile diameter ratio is around 3
- Max ratio allowed by BD (2005) is 2 (or 6m whichever is less)

45° Load Spread

Under the strange rule, there is no need for any load spread check in this case!
Pile Toe Imperfections

- Major issue a few years ago
- Less so nowadays, but not completely resolved
- The use of pressure grouting is still routinely done as a remedial measure

Study by the HK Contractor Association (2001-2002)

- Thin layer of soft materials at pile base does not always require remedial works
- Factors to be considered:
  - A single pile or pile group?
  - Probing at centre of pile or edge of pile?
  - “unbound” aggregate, soil inclusions or coreloss
- Suggested a rational approach to the problem
### Prescriptive Approach – An Example

<table>
<thead>
<tr>
<th>Interface Soft Layer Thickness</th>
<th>Investigation</th>
<th>Remedial Works/Proposal</th>
<th>Further Investigation</th>
<th>Remedial Works/Proposal</th>
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<tr>
<td>S ≤ 100</td>
<td>N/A</td>
<td>Flush clean + normal grout</td>
<td>N/A</td>
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<tr>
<td>100 &lt; S ≤ 150</td>
<td>N/A</td>
<td>Flush clean + pressure grout</td>
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<td>100 &lt; S ≤ 150</td>
<td>Flush clean + pressure grout</td>
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<td>150 &lt; S ≤ 200</td>
<td>Pressure jet clean + pressure grout</td>
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<td>S &gt; 200</td>
<td>Further investigation + submit remedial proposal</td>
<td></td>
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</table>

**Concrete pile**

**Coring tube**

**Thickness Of soft Material -**

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**Driven H-piles**
Design & Construction Issues with Driven H-piles

- Pile driving formula
- Final set problems
  - Whipping of piles
  - Long piles

Shall We Keep Using Hiley Formulae?

- Different views
- “Simple is beautiful” vs “Too simple, sometimes ….”
- If we were to vote ….
The Driving Formulae

- Hiley (1925)
- In 1960, more than 450 formulae of slight variations to Hiley
- HKCA (1994) – lumped various efficiency terms into a single factor $K_h$
- HKCA (2004) – uses energy measured from PDA
- Gradually increasing experience in modelling the efficiency of hydraulic hammers in Hiley Formula
- Difficulties encountered in long piles

Development of the Wave Equation

- Isaacs (1931) – First used 1-D stress wave theory in pile driving analysis
- Smith (1960) – forms the basis of modern wave equation analysis
- Development of bonded resistance strain gauges
- Research work at Case Institute of Technology
- CAPWAP, GRLWEAP
- At present, limited to detect pile defects, measure hammer efficiency
A State of Confusion

- Different departments have different approaches
- ASD approach: Use of CAPWAP to determine pile capacity and calibrate against parameters in the Hiley Formula
- Private projects: essentially HKCA (1994), with trial piles to establish $k_h$ and PDA/CAPWAP
- Contractors do not know how small the set needs to be in order to pass the loading tests

Long Piles – Big Hammers

- Ideal Situation: SPT $N > 200$ at around 30-40m; set usually achieved 3-5m into the saprolite
- For longer piles, the length effect of Hiley Formulae starts to show
- Even 20t hammers dropping from 4m is not enough
- So-called “Driving to refusal”
Required Set for Long Piles at a Particular Site
(over 4000 piles, 35-80m long)

Hypothetical Allowable Set
Whipping of Piles

Why Does This Happen?

- Happens mostly in sites with soft deposits in the upper layers (e.g., reclamation)
- Let go in its weaker axis with insufficient lateral restraint during driving
- Some contractors attempt to avoid this by reducing the drop height and carry out final set a few days later
Signs of Whipping from Shaft Shortening Measurements

- Static load tests carried out at a particular site with thick layer of soft soils
- Signs of whipping

More to Tackle .................

- Residual settlement on pile loading tests
- Use of pile raft (settlement reducing piles)
- Use of base-grouting in competent soils
- Ultimate limit state design?
- etc etc
- Encourage rational designs when time and resources are available
### Typical Set Table

<table>
<thead>
<tr>
<th>File</th>
<th>Pile</th>
<th>Blow Efficiency</th>
<th>Efficiency of Blow</th>
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<td></td>
<td>s = (W * h * k) / R - C / 2 WHERE C = Cp + Cq + Cc = W + P * e^2</td>
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</table>

#### Efficiency of Blow

\[
S = \frac{(W \cdot h \cdot k)}{R - \frac{C}{2}}
\]

Where:
- \( W \) = Weight of Pile and Helmet
- \( h \) = Drop of Hammer
- \( k \) = Efficiency of Hammer
- \( R \) = Driving Resistance
- \( C \) = Temporary Compression of Pile Head

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<tr>
<th>Blow</th>
<th>Efficiency</th>
<th>File</th>
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</table>
Driving formulae, such as the Hiley formula, have no longer a place in serious foundation engineering. They only prevail because they are so simple so they can be used with total disregard for reality. If the pile, hammer, site parameters, etc. are not a part of the formula, then, they will have no effect on the results, right?

I would disagree that the Hiley Formulae has little place within modern piling practice, as I used to work as a designer for a piling contractor who installed many MCPS (1,000,000 linear meters/year), using the Hiley formulae. I would agree that, as long as the efficiencies of the rigs (weather, drop height, energy transfer, etc.) are monitored and understood then the correct set should be achieved. Reliance should never be solely placed on any type of dynamic analysis. The only real way to test a set calculation is to carry out a static load test upon a dubious pile. Or even a dynamic test with further CAPWAP analysis if this is all that is available. For a CAPWAP analysis I have found that a reduction on the calculated value by 20% tends to correlate more accurately with static load test results. These options may not be available if the job is small.

return