Instrumentation and Software as part of Observational Engineering

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IOM3
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Why OE? Manage Uncertainty

• Confirmation of expectations
  – Confirm design prediction
  – Confirm assumptions
  – CAUSE – EFFECT - INFLUENCE

  – Tunnel convergence
  – Retention systems
  – Concrete strain monitoring
  – Groundwater
  – Areas for improvement
Intelligent Tunnels

- We already do some of this but it is mostly manual and takes time
- Can this be automated in software

Examples
Liantang/Heung Yuen Wai Boundary Control Point Tunnel (Dragages/Bouygues)
Harbour Area Treatment Scheme – Phase 2
Mined Tunnels: Liantang, HKG
The Site: Challenges

- Large span, low cover
- Second tunnel to be excavated
- High anchored wall
- Hard rock EPB TBM with high temporary construction loads
- Poor ground, uncertain design performance
Tunnelling induced movements were considerable but rock was encountered in the bottom of the excavation.
Analysis — Settlements at the Portal

Settlements of the crown were up to 70mm
With a similar amount of lateral movement
Analysis - Complex 3D Interaction

This wasn’t convergence but actually out of the excavation demonstrating the impact of stress relief as the slope and portal were cut back.
1. Is Adit closure strut needed?
Taking out the Invert Strut
The tunnel was excavated by heading and bench with steel supports. The contractors design alternative was to remove the invert rib and transfer the load to the elephants foot while the invert was excavated and to prove that a subsequent invert closure beam was not required. To do this they had to prove the absence of bending within the ribs. 3 sets of 2 strain gauges were installed either side of the neutral axis.
Instrument Design: Logging

Wired

- Multi cables
- Junction boxes
- Multiplexers
- Data loggers
- EMI issues
northbound was removed no additional south bound settlement was observed close to the portal due to the presence of the anchored wall
Analysis - Loads in Supports

Crown

Considerable bending but not effect from bench removal

Sidewall

Loads reduce during invert strut removal resulting in settlement but bending reduces over time with the loads becoming axial proving that the final invert strut is not required.
Analysis - Loads in Supports

Crown of C11R8 exceeds envelope of FOS 1.4
### TOP HEADING CLOSURE

<table>
<thead>
<tr>
<th></th>
<th>Total Nos of canopies</th>
<th>Nos of canopies closed</th>
<th>Nos of days saved</th>
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<tr>
<td>Southbound tunnel</td>
<td>11</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Northbound tunnel</td>
<td>14</td>
<td>4</td>
<td>20</td>
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<tr>
<td><strong>Total</strong></td>
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<td><strong>32</strong></td>
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### BENCH

<table>
<thead>
<tr>
<th>Bench advance &amp; Top heading configuration</th>
<th>Conventional design</th>
<th>Observational design</th>
<th>Days saved</th>
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<td></td>
<td>Nos Ribs</td>
<td>Nos of days</td>
<td>Nos Ribs</td>
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<tr>
<td>Southbound tunnel</td>
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<td></td>
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<tr>
<td>1.5m (TH invert closed)</td>
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<td>24</td>
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<tr>
<td>4.5m (TH invert NOT closed)</td>
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<tr>
<td>Northbound tunnel</td>
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<tr>
<td>1.5m (TH invert closed)</td>
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<td>1.5m (TH invert NOT closed)</td>
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<td>4.5m (TH invert NOT closed)</td>
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<td><strong>295</strong></td>
<td><strong>156</strong></td>
<td><strong>161</strong></td>
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2. Stability of the Tied Back Wall
Wall design – Anchor mobilisation

Close to the portal each of 7 rows of anchors was instrumented in 9 locations along its length to assess the load build distribution and capacity.
 Loads in the Wall

View for comparison with predictions and overlain with construction progress events
3. Concrete Monitoring
VW is not the only (or the best) solution

Resistive gauges with embedded electronics and temperature compensation reading dynamically using resistor capacitance time constant rather than static voltage

HB = Half Bridge Strain Gauge
CM = Crack Meter

6-lead RJ11 cables
Strain Gauge Leadwire
Crack meter Leadwire
Strain Gauge Module (SGM)
Crack Meter Module (CKM)
Data Logger Module (DLM)
Components: Measurement

- **Half Bridge Strain Gauges** – The foil strain gauges are low power, has a small footprint (120x15x5mm), and are specifically designed to be embedded in concrete with microstrain range of +/-2,000.

- **Strain Gauge Module (GSS-SGM-485)** – GSS designed, built and programmed this module to be embedded in concrete to collect readings from all strain gauges directly attached via dual RS485 bus. This SGM module fits in a small case (89x35x30mm) and has 3 strain gauges attached.
Components: Datalogger/Comms

- **Datalogger Module (GSS-DLM-485)** – GSS designed, built and programmed this module to schedule SGM readings via dual RS485 bus and crackmeters directly via leadwires and store this data on microSD card. The data can be collected wirelessly via Bluetooth or manually by removing the microSD card. The DLM fits in a bespoke case with a small footprint (150x70x50mm) and is powered by 2 hot swappable 8.5Ah batteries.
Lab Trial - Setup

• Concreting a standard beam test with 3 gauges
Lab Trial - Test

• Flexural test to failure
4. Groundwater Control: HATS2

- 240 wireless groundwater monitoring points around western HK Island
- No surface expression allowed
Groundwater Control

Two piezos with tips in rock and in soil 1 & 2 on either side of a Fault - Tunnel driven left to right - Completely different signatures. The fault is a barrier to water flow and separates the rock into domains.

Real time monitoring of groundwater during successive drill and blast cycles
Areas of improvement

- Remove all the wiring
- Multi function
- Clean data
- Simple installation
- Remote control
- Low power
- Low maintenance
Summary

• Important to get effective feedback on deviation from design prediction
• Important to have a full understanding of behaviour: influence, cause, effect and consequence before proper mitigation can be designed
• Smart systems automate these processes and mean that in depth assessments normally carried out after a failure can be undertaken before one
Thankyou