OBSERVATIONAL METHOD

Use of “review” and “back analysis” to implement the “Best Way Out” approach.

By

Duncan Nicholson, Director
Ove Arup and Partners Ltd

TERRASOL
Bureau d’Ingénieurs-Conseils en Géotechnique Immeuble Central Seine
42-52 Quai de la Rapée
CS 71230
75583 Paris CEDEX 12
FRANCE
Contents

• Peck’s Observational Method (OM) Principles
  - “Ab Initio” and “Best way Out”

• Ciria (1999) R185
  - OM Definition and Process

• “Predefined Design” and OM “Best Way Out”

• “Best way out” processes
  - Trigger Values
  - Review and back analysis

• Basement Case Histories
  - Kings Place
  - Nicol Highway
  - Canary Wharf Crossrail Station

Conclusions
History - Key dates for UK

40 to 60’s - Terzaghi and Peck
1969 - Peck’s Rankine Lecture
Early 1990’s - Channel Tunnel, Limehouse Link Projects
1994 - Geotechnique Symposium in Print
1995 - EC7 OM Clause
1996 - ICE and HSE - NATM publications
1999 - CIRIA - OM Report No 185
2001 - ICE Managing Geotechnical Risk
2006 - Geotechnet - www.geotechnet.org
Peck’s (1969) Observational Method – Eight Ingredients

1. **Sufficient SI** to establish general nature / properties of deposits.
2. Assess **Most Probable** and **Most Unfavourable** conditions.
3. Establish **Design** based on **Most probable**.
4. Select **Monitoring parameters** and calculate values.
5. Calculate values for **most unfavourable** conditions.
6. Select design **modification options**.
7. **Monitor** and **evaluate** actual conditions.
8. **Modify** design to suit actual conditions.
Peck (1969) OM applications

“Ab Initio” OM - planned from start of work

- Harris Bank – Chicago strut monitoring
- Bay Transit Tunnels – Volume loss

“Best way out” OM – introduced during work

- Cleveland Ore Terminal - soft clays – stockpiles of iron ore
- Cape Kennedy Causeway – Hydraulic fill

Goals

• Clarify OM definition and process

• Integrate OM process into modern design

• Focus on “Ab Initio” applications – better planning
CIRIA (1999) - OM Definition

• The Observational Method in ground engineering is a continuous, managed, integrated, process of design, construction control, monitoring and review which enables previously defined modifications to be incorporated during or after construction as appropriate. All these aspects have to be demonstrably robust. The objective is to achieve greater overall economy without compromising safety.

• The Method can be adopted from the inception of a project or later if benefits are identified. However, the Method should not be used where there is insufficient time to implement fully and safely complete the planned modification or emergency plans.
Ciria (1999) R185 Figure 1.2

The OM Process

Focused on Ab Initio OM applications
Design Parameters - Peck’s (1969) OM and Current Codes

- **Peck (1969)**
  - OM conditions/values
- **UK Current Codes**
  - CIRIA C580
  - Eurocode – EC7

- **Most Probable**
- **Not used**
- **Most Unfavourable**
- **Worst credible**
- **Mod Conservative or Characteristic**
- **Not used**
### Predefined Design Process

- Permanent works
- One set of parameters (MC)
- One design / predictions
- Outline construction method

- Trigger values

- Contractor’s temp design / method statement

- Monitoring checks trigger values not exceeded
  - If exceeded back analyse
  - Introduce OM - Best Way Out

- Emergency plan

### The OM Process - Ab Initio

- Temporary works (mainly)
- Two sets of parameters (MC + MP)
- Two designs / predictions
- Integrated design and construction methods
- Methods relate to triggers

- Comprehensive and robust monitoring system
- Review and modify process
  - Contingency plan
  - Improvement plan

- Emergency Plan
Change from “Pre-defined” design to “Best Way Out” approach

PRE-DEFINED DESIGN
- DESIGN & PLANNING
  - CONSTRUCTION CONTROL
  - MONITORING
  - REVIEW
  - COMPLETE REDESIGN REQUIRED

CONTINUE CONSTRUCTION
- ACCEPTABILITY CRITERIA EXCEEDED?
  - No
  - Yes

STOP WORK AND/OR IMPLEMENT EMERGENCY MEASURES TO SECURE SAFETY
- FEASIBILITY ASSESSMENT - IS OM ‘BEST WAY OUT’ SUITABLE?
  - No
  - Yes
  - INITIATE OM ‘BEST WAY OUT’ APPROACH

RECOVERY USING OM ‘BEST WAY OUT’ APPROACH

OM INITIATION STAGE
- NATIONAL & CORPORATE POLICY
- CORPORATE & PROJECT ORGANISATION
- DESIGN & PLANNING
- CONSTRUCTION CONTROL
- MONITORING
- REVIEW
- TRIGGER CRITERIA EXCEEDED?
  - Yes
  - No
- IMPLEMENT PLANNED MODIFICATION (INCLUDING CONTINGENCY PLANS) OR EMERGENCY PLANS

INITIAL RECOVERY DECISION-MAKING
Recovery using OM – “Best way Out” at “Design and Planning” Stage

- Four Processes:
  - R – Review
  - A – Back Analysis
  - D – Design remaining work
  - O - Output
Eurocode EC7 Cl 2.7 (1989 and 1995)

• Recognised prediction is difficult in Geotechnics – OM used in these cases.

1) Establish limits of behaviour.
2) Acceptable probability actual behaviour within limits.
3) Monitoring plan, response times and contingencies.
4) Contingencies adopted if real outside acceptable range.
UK Design Codes - Soil Strength Parameters

Soil Strength Parameter Results

No of Readings

1 in 1000

1 in 20

1 in 2

Most Unfavourable

Characteristic material property (used in structural engineering)

moderately conservative

Most Probable

Soil Strength Parameter Results

(Eg Undrained strength, SPT etc)
Ideal EC7 Predicted versus Measured Performance

"Ideal" distribution of measured deflections

Predicted most probable value

Predicted EC7 Characteristic Value (SLS)

Most Unfavourable (ULS)

No. of readings

Deflection (δ)

5%
Trigger Criteria

Traffic light conditions include:-

- **Green** = Safe site condition.
- **Amber** = Decision stage
- **Red** = Implement planned modifications
- **Emergency** = Evacuation
  (Not normally part of OM. Required under CHSW Reg (1996). Relates to Ultimate Limit State.)
Ideal EC7 Predicted versus Measured Performance

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<th>No. of readings</th>
<th>Deflection (δ)</th>
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<td>&quot;Ideal&quot; distribution of measured deflections</td>
<td>Predicted most probable value</td>
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<td>Predicted EC7 Characteristic Value (SLS)</td>
<td>Trigger implement</td>
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<td>Amber trigger - decision</td>
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<td>GREEN</td>
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5%
Ciria (1999) Fig 3.13 Multi Stage Excavation

The diagram illustrates a multi-stage excavation process, with stages labeled 0 to 4 on the x-axis (Construction Stages) and predicted and measured values on the y-axis. The graph shows:

- 'Characteristic' prediction
- 'Most probable' prediction
- Measured values for two scenarios

The graph includes areas for ULS (most unfavourable), SLS (Characteristic), AMBER (Most probable), and GREEN. The graph also highlights the concept of contingency and modification.
HSE ‘Discovery – Recovery’ Model
e.g., for tunnelling

From HSE, 1996

Red trigger

Amber trigger

Level of risk

Unacceptable risk level (1)

Failure (3)

Late discovery

Early discovery

Start of adverse event

Tunnelling process in a stable condition

Recovery with late discovery

Recovery with early discovery

Decision making

Action

Early return to stable condition

Later return to stable condition

Shaded area indicates increased risk from late discovery

From HSE, 1996

ARUP
Case Histories

- Kings Place - London
- Nicol Highway Collapse - Singapore
- Canary Wharf – Crossrail Station Box
- Donegall Quay - CFA piles
Kings Place – OM – Ab initio

- Damage assessment trigger
  - 50mm max wall deflection

- Diaphragm Wall
  - 1.0m thick

- 1 level of temporary corner props

- 16m retained height

- Observational Method
Kings Place - Instrumentation

- 14 no. inclinometers + 14 no. survey targets
- 32 no. strain gauges at props
- 40 no. Ground survey stations
Frew predictions “Last Stage” data

- Red Trigger
  - Based on adjacent buildings
  - Exceeded with time
  - Review lead to relaxing trigger

- Characteristic
  - Wall design

- Most Probable

Legend
- FREW - MC
- FREW - MP
- Last Stage N2
- Last Stage W2
- Last Stage S2
- Last Stage E2
Back Analysis - LS Dyna - 3D model

• Small Stain Model
• 3D geometry

• Assess effect of
  – berm excavation sequences
  – corner effects

• Soil parameters refined.

• Goal to assess “Characteristic” and “Most Probable” sets of parameters

• Monitoring data compared to numerical analyses.

• Refine trigger criteria for Observational Method
Analysis Summary

• Approx 600,000 elements in 32 material sets.

• 5 Analyses varying:-
  – Soil parameter.
  – Suction limits.

• Stages representing 8 steps of excavation modelled.

• Site data compared to model data.

Vertical movement during excavation stage.
MP and MC Ls-DYNA vs. “Last Stage” data

- Monitored data set matching last stage of model sequence.
- Based on Suction limit of -100kPa. - “AnisoBRICK”
- Consolidation
Nicoll Highway Collapse – Not Observational Method
Public Inquiry – Key Lessons

1. Soil model in Plaxis over estimated Marine Clay strength
Key Lessons cont’d

2. Waler connection under capacity

Many other Contributory Factors

- Monitoring and review regime – not effective
- Back analysis process – not rigorous
Public Inquiry Lessons

1. Design
   • Independent check required

2. Construction Quality
   • Management / Interpretation of data / instrumentation

3. Contractual Arrangement
   • D and B – Production pressure

4. Management/Culture
   • Effective risk management
   • Managing uncertainties and quality

Comment
   • Design errors were made.
   • Back analysis process did not pick them up properly!
Nicoll Highway Collapse – Implementing lessons

Technical
- International Conference on Deep Excavations
  28 – 30 June 2006, Singapore

Legislation
- Building and Construction Authority (BDA)
  - Advisory Note on Deep Excavations (5-May 2005) –
    Temporary Earth Retaining Structures (TERS)
  
  - Updated to Advisory Note 1/09 (2-April 2009)– Earth
    Retaining or Stabilising Structures (ERSS)
  
  - Updated to
    Advisory
Canary Wharf Crossrail Station – Lessons learned

Crossrail Station at Canary Wharf

Client - CrossRail

Project Manager – Canary Wharf Contractors Limited

Main Contractor – Laing O’Rourke

- Geotechnical risks
- Conventional design – with triggers
- Review process.
- OM Ab Initio modification on final dig stage
- Monitoring – Exceeding Triggers
Canary Wharf Crossrail Station Layout

Geotech risks:-
Adjacent buildings
Dock structures
DLR
Geology along the station box

- **Lambeth Beds - sand**
- **Terrace Gravel**
- **Dock silt**
- **Thanet Sand**
- **Lambeth Beds - clay**
- **Lambeth Beds - sand**
- **Harwich Formation - sand**
- **Dock Bed, ~+95**
- **Dock Water, ~+104.3**
- **Base slab +77**
- **Toe of tubular piles**

**Geotech risks:**
- Lambeth Clay – Drained?
- Harwich sand - short circuit?

ARUP
Working with stakeholders – Final scheme evolved from many inputs

- Construction in a drained dock - asymmetric loading

Two types of retaining wall – tied back and bermed cantilever walls

Risk Register:- Risk Matrix set out Who owned which Risk.

Geotech risks:- Adjacent buildings? Leak from south Adam place
Tie Back System

Anchor tie

Interlocking Giken tube

Wall pile

Marine deck

Steel casing

Anchor Pile

Lambeth Beds - clay
Thanet Sand

Lambeth Beds - sand

Harwich Formation - sand

Lambeth Beds - clay
Soil-structure interaction – finite element model
Exaggerated Plaxis displacement plot

Finite element method – capturing out-of-balance loading (sway) and ground movement

Geotech risks:- Adjacent buildings?

Terrace Gravel
Harwich Formation
Lambeth Beds
Thanet Sand

SOUTH
Existing Cofferdam
Station Box
North Dock

NORTH
Billingsgate Market

KPMG Building
Station Box
North Dock

SOUTH NORTH
Giken push in process
1.2m dia tubes with Crush Auger

Using reaction from 3 pre-installed casing to install the 4th casing

Chuck designed to extend to receive and push in the 5th casing partially
Monitoring system

- 19 full monitoring sections – inclinometers (manual), load cells and prisms (real time)
- Groundwater and dock water monitoring
- Web based access of monitoring data

Geotech risks:
- Instrumentation
- Getting datum readings.
- Does system work.
- Ownership issues.
- Stressing sequence.
Dock fully drained – mid March 2010
Inclinometer readings
– main wall and anchor pile
Dock silt removal and secant piling

Dock silt removal – dig and dispose

Guide wall installation

CFA piling of female soft pile

Dock silt removal – wash and pump
Triggers Exceeded

Geotech risks:
- No allowance for UXO probe
- Gradual “creep”

Impact of UXO probing on wall deflection and piezometer readings

UXO Probing
Air flush rotary percussive
15m from wall or leakage
Plunge column installation

Column tolerances
- +/- 25mm in plan
- 1 in 400 verticality

Pile tolerances
- +/- 25mm in plan
- 1 in 75 verticality

Precast guide hole for 2.1m pile
Plunge column guide frame installation
Plunge column installation (18m long, upto 27t)
Level -3 slab nearing completion
Level -6 excavation, blinding, reinforcement etc
OM – Best Way Out – Review and Modify soil parameters

- Tunnel alignment prevented evenly spread of anchor piles
Back analyse
Review soil parameters
Redesign - Remove berm and intermediate props
OM – Best Way Out – New triggers

- The 2D simplified design approach verified using a 3D model when a revised construction sequence was proposed.
Donegal Quay Development

Footprint Area ~ 35 m x 140 m
Ground Conditions – Geotechnical Profile

MADE GROUND
SLEECHE / ALLUVIUM
SAND (GLACIAL)
Silty CLAY / CLAY (GLACIAL)
SANDSTONE

Legend:
- Made Ground [MG]
- Alluvium [ALV]
- Peat [PEAT]
- Glacial Tills Deposits [GTC]
- Stratified Sandstone - Mottled Band
- Stratified Sandstone - Biocomposite Formation [BC]

Plan:
- Asphalt
- Concrete
- Sand SP
- Silty SAND
- Sandy Silt
- Organic CLAY
- Gravelly Silt
- Clay
- Silty gravelly SAND
- Silty sand
Soil properties

Undrained Strength (kPa)

SPT Profile

GLACIAL SAND

GLACIAL CLAY

SLEECHEH

SAND (Medium dense)

ARUP
Construction Sequence

- **Stage 1:** Site preparation.
- **Stage 2:** Install Sheet Pile walls.
- **Stage 3:** 2.0m excavate – remove obstruction / timber piles
- **Stage 4:** Install CFA pile approx 27m deep.
# Sheet Pile Installation

![Sheet Pile Installation Image](image_url)

## Task Progress

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<th>Task Name</th>
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**Sheet Piling (Dec 05-Feb 06)**

*Note: The image shows a construction site with a focus on the installation of sheet piles during December 2005 to February 2006.*
**Phase 1 Excavation to +1.5 mOD**

![Construction Image]

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Excavation (March 06)
Inclinometers 14 March 2006 - Cantilever dig

Inclinometer 4
Deflection 28mm

Inclinometer 5
Deflection 15mm
# Timber Pile Extraction

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Timber Pile Extraction (April 06)
Inclinometers 12 April 2006 - Timber Pile Extraction

Inclinometer 3
Deflection 12mm

Inclinometer 4
Deflection 25mm
# CFA Piling Works and Prop Installation

### CFA Piling and Prop Installation (April–July 2006)

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Inclinometers - 02 May 2006 - CFA Flighting of Sleech

Inclinometer 4
(With rotation during concreting)

Inclinometer 5
(Without rotation during concreting)

Deflection 75mm

Sleech
Sand
Pile 382 – Concreting Revs - 4 rev/m

Pile 252 - No rotation during concreting

No Conc. Press.

Rotation

Conc. Press.

No Rotation
Over rotation and flighting
- soft clays and loose Sand
- interbedded soils

Minimise flighting

Maximises concrete pressures

Meet EN1536 - Cl 8.4.6.5

Use powered auger cleaner enables auger to be extracted safely without rotation

Used on all soil types

Auger diameters 300mm – 2000mm

About 1m reduction to drilling depth

Alternatively - Use cased CFA

Dawson Construction Plant Ltd
## Settlements
Sheet piles/ Dig / CFA piling

<table>
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<tr>
<th>Date</th>
<th>Settlement (mm)</th>
<th>Annotation</th>
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- **CFA Piling**: S~85mm
- **Cantilever dig**: S~55mm
- **Sheet Piling**: S~20mm

*Trigger set at 50mm for whole construct!!*

**Review**  – What was causing movement

- Reassessment of trigger values – impact on utilities / buildings
Donegall Quay Comments

Construction processes cause ground movements

- Wall installation
- Pile installation
- Anchor installation

Specify limits and incorporate into movement calculations

- Amber trigger= 3mm
- Red trigger= 5mm

These movements occur rapidly and continuous monitoring required until process is checked!!
Conclusions

• Peck (1969) set out the Principles of OM
  • “Ab Initio” and “Best Way Out”

• Ciria (1999) R185 considers only the Ab Initio approach.

• Develop use of Conventional design – review - best way out

• Kings Place – reassessment of triggers set by adjacent buildings

• **Nicoll Highway collapse** - Not OM – Lessons on back analysis and redesign processes.

• **Canary Wharf Crossrail Station** - Use of Review  Back Analysis and Best Way Out

• **Donegall Quay** – Impact of wall / pile / Anchor installation effects
Thank you for your attention.

Any Questions?