Joint Meeting BGA and CFMS

Friday 2nd December 2011

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

ARUP

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
2003	- Ciria C580 – Embedded retaining Walls.
2006	- Geotechnet - www.geotechnet.org

Peck's (1969) Observational Method – Eight Ingredients

1. **Sufficent 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

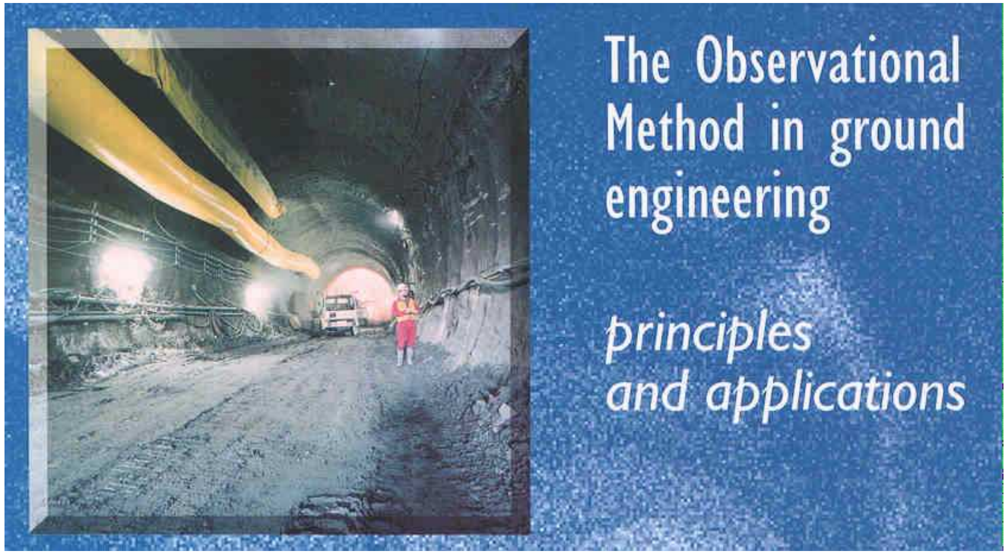
"Ab Initio" OM - planned from start of work

- 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

Ciria (1999) Report 185 - Nicholson, Tse and Penny



Goals

- Clarify OM definition and process
- Integrate OM process into modern design
- Focus on "Ab Initio" applications – better planning

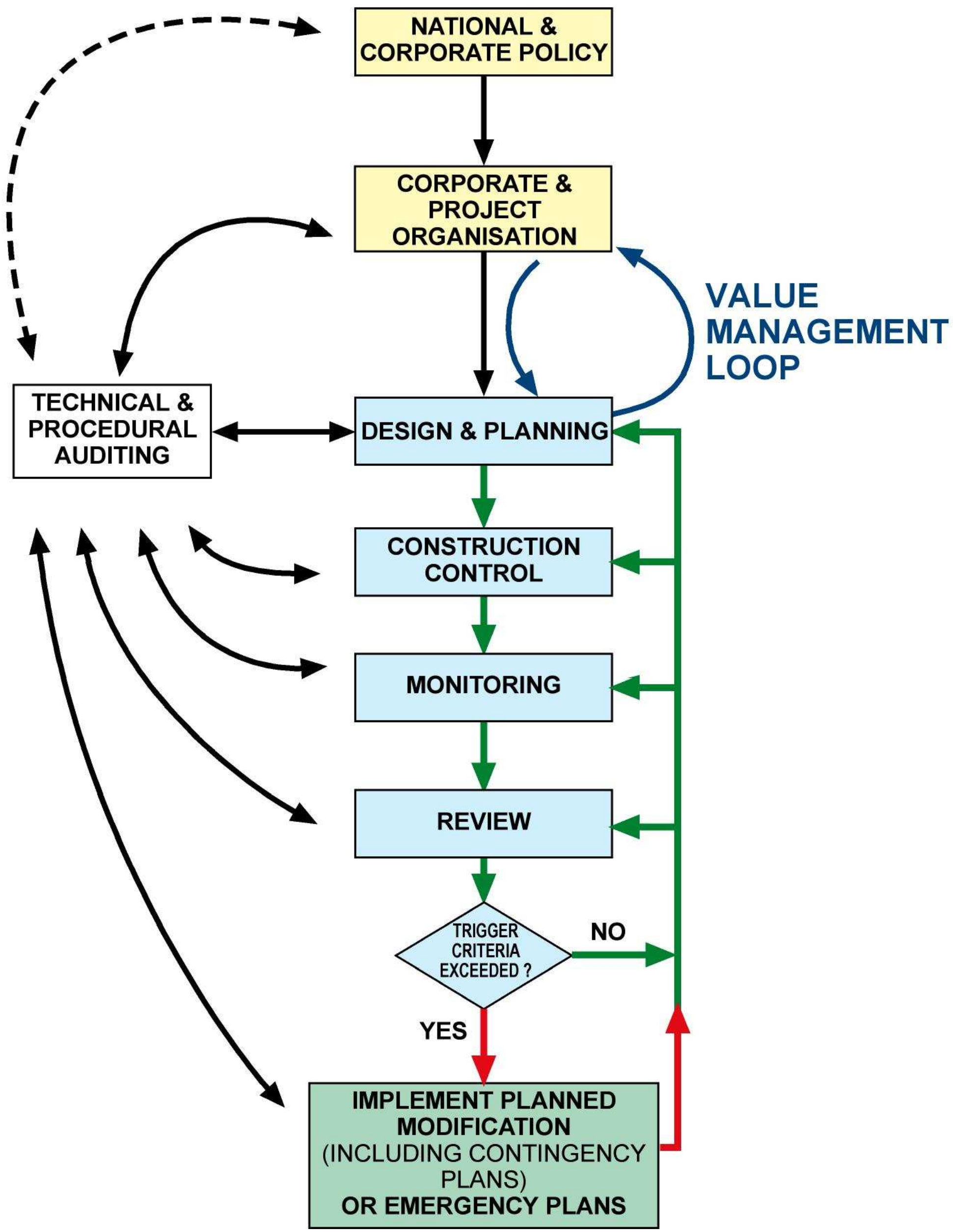
CIRIA (1999) - OM Definition

- 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

ARUP

Design Parameters - Peck's (1969) OM and Current Codes

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

Peck (1969)	UK Current Codes
Most Probable	**Not used**
Not used	**Mod Conservative or Characteristic**
Most Unfavourable	**Worst credible**

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

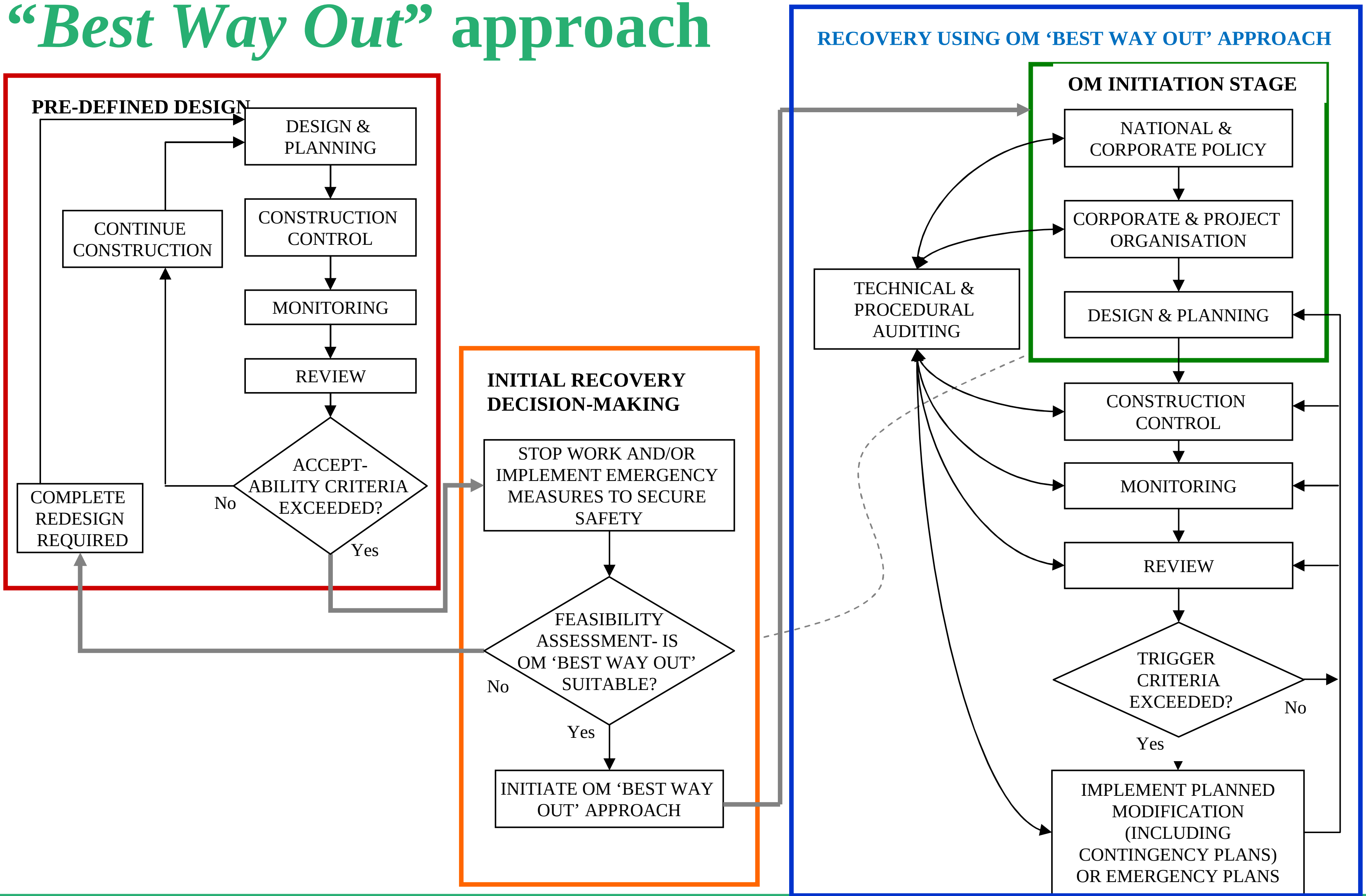
- Temporary works (mainly)
- Two sets of parameters (MC +MP)
- Two designs / predictions
- Integrated design and construction methods
- Methods relate to triggers

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

- Emergency Plan

ARUP

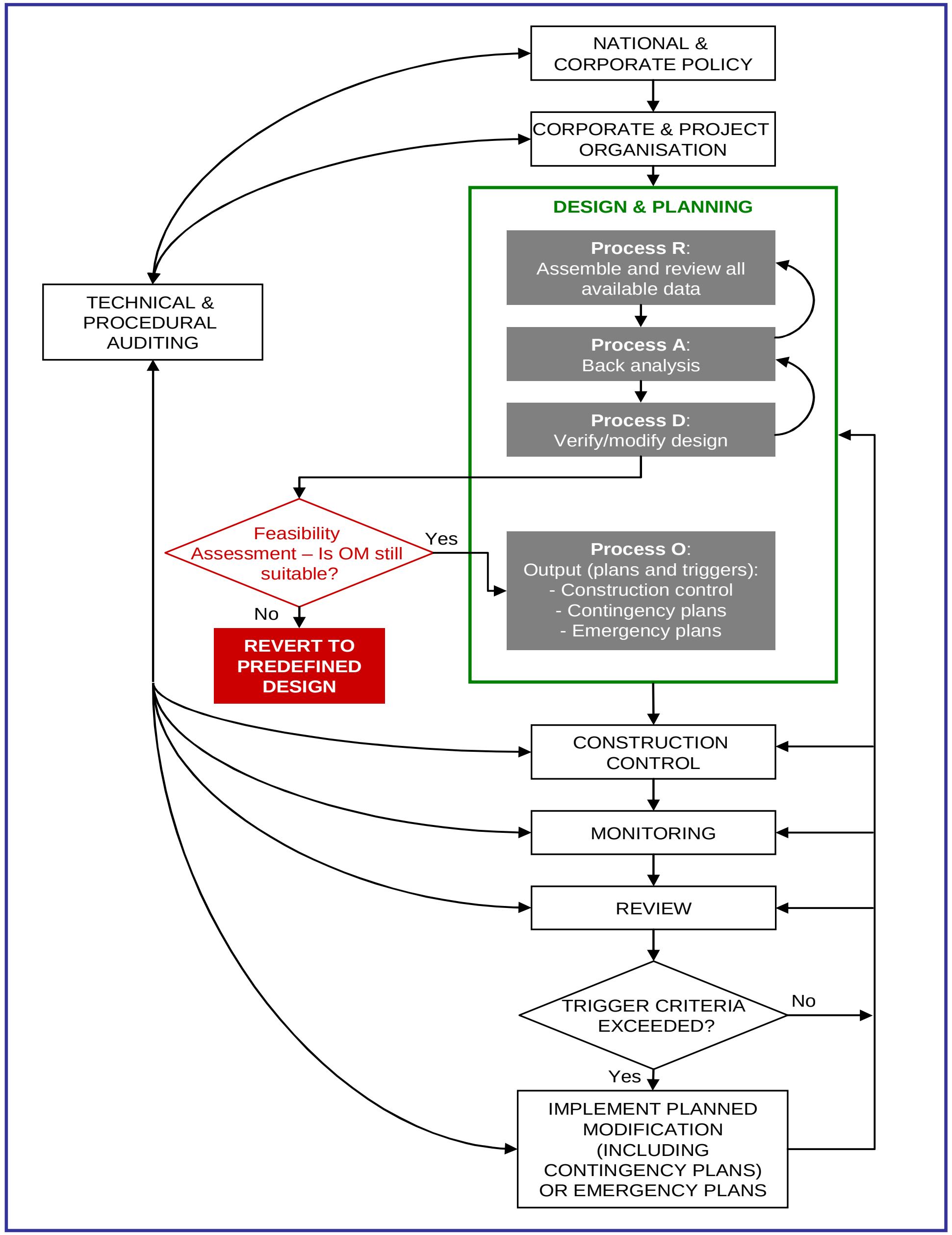
Change from "*Pre-defined*" design to "*Best Way Out*" approach



ARUP

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 and1995)

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

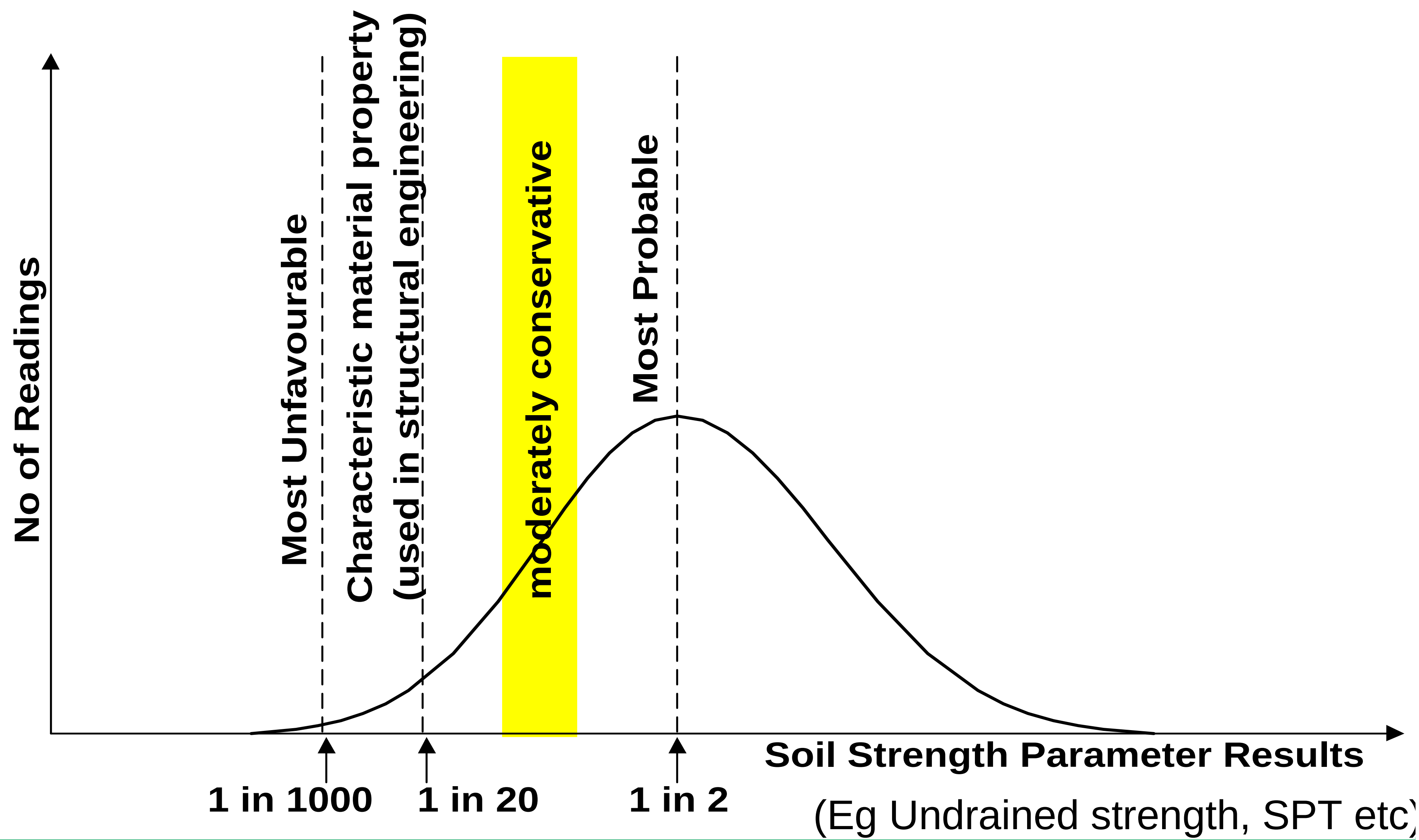
1) Establish limits of behaviour.

2) Acceptable probability actual behaviour within limits.

3) Monitoring plan, response times and contingencies.

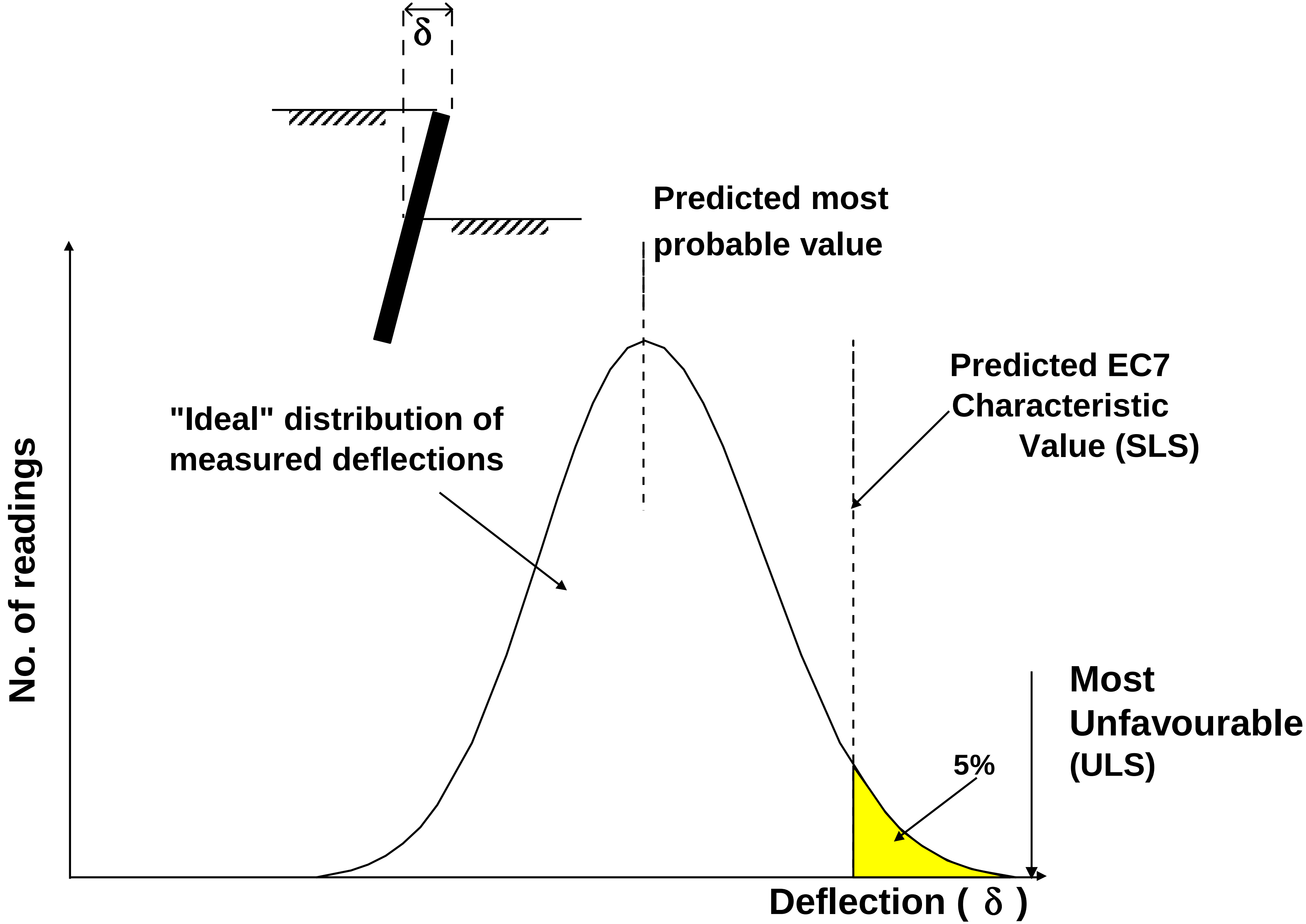
4) Contingencies adopted if real outside acceptable range.

UK Design Codes - Soil Strength Parameters



ARUP

Ideal EC7 Predicted versus Measured Performance



Trigger Criteria

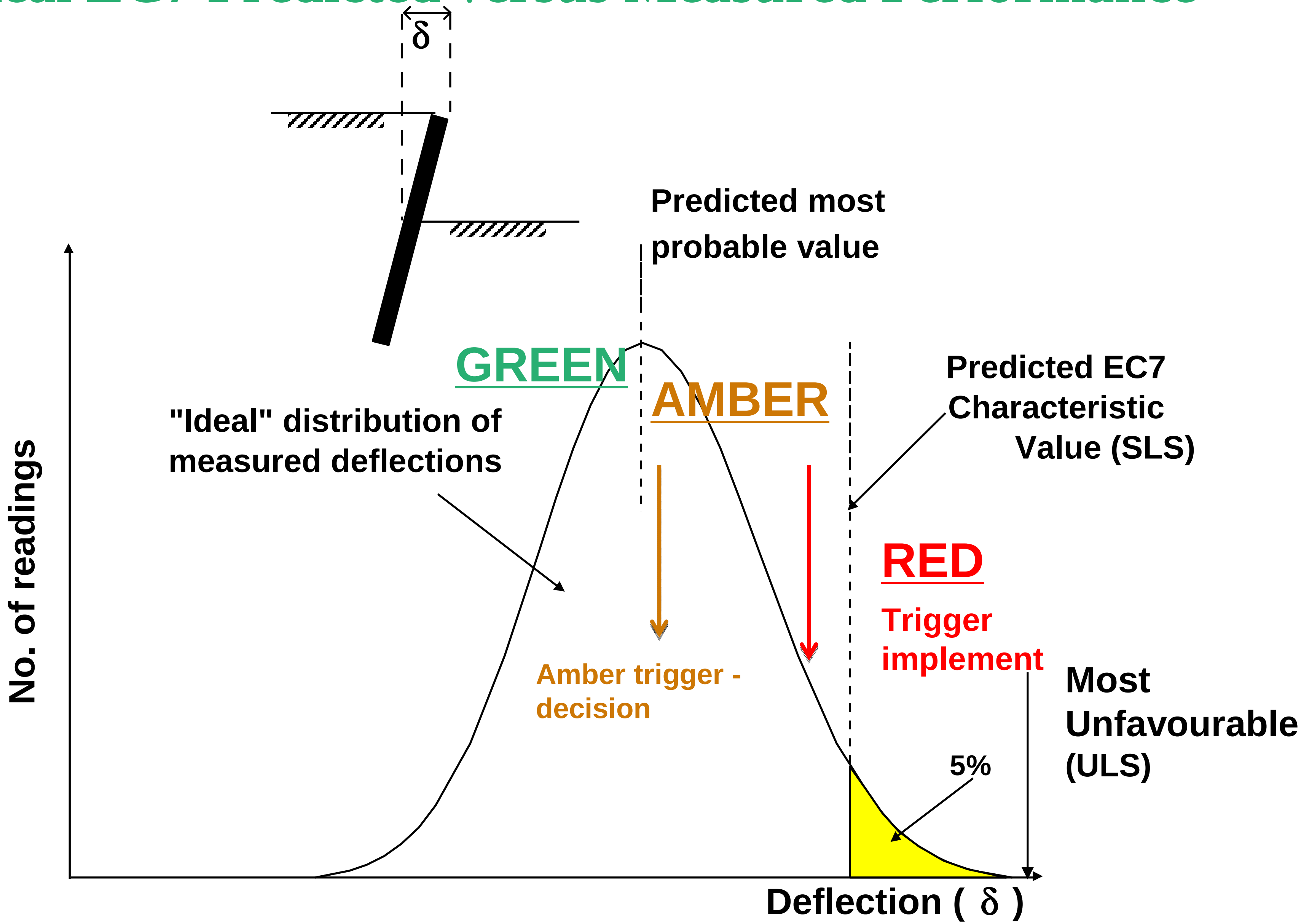
Traffic light conditions include:-

- **Green** = Safe site condition.
- **Amber** = Decision stage
- **Red** = Implement planned modifications
- **Emergency** = Evacuation

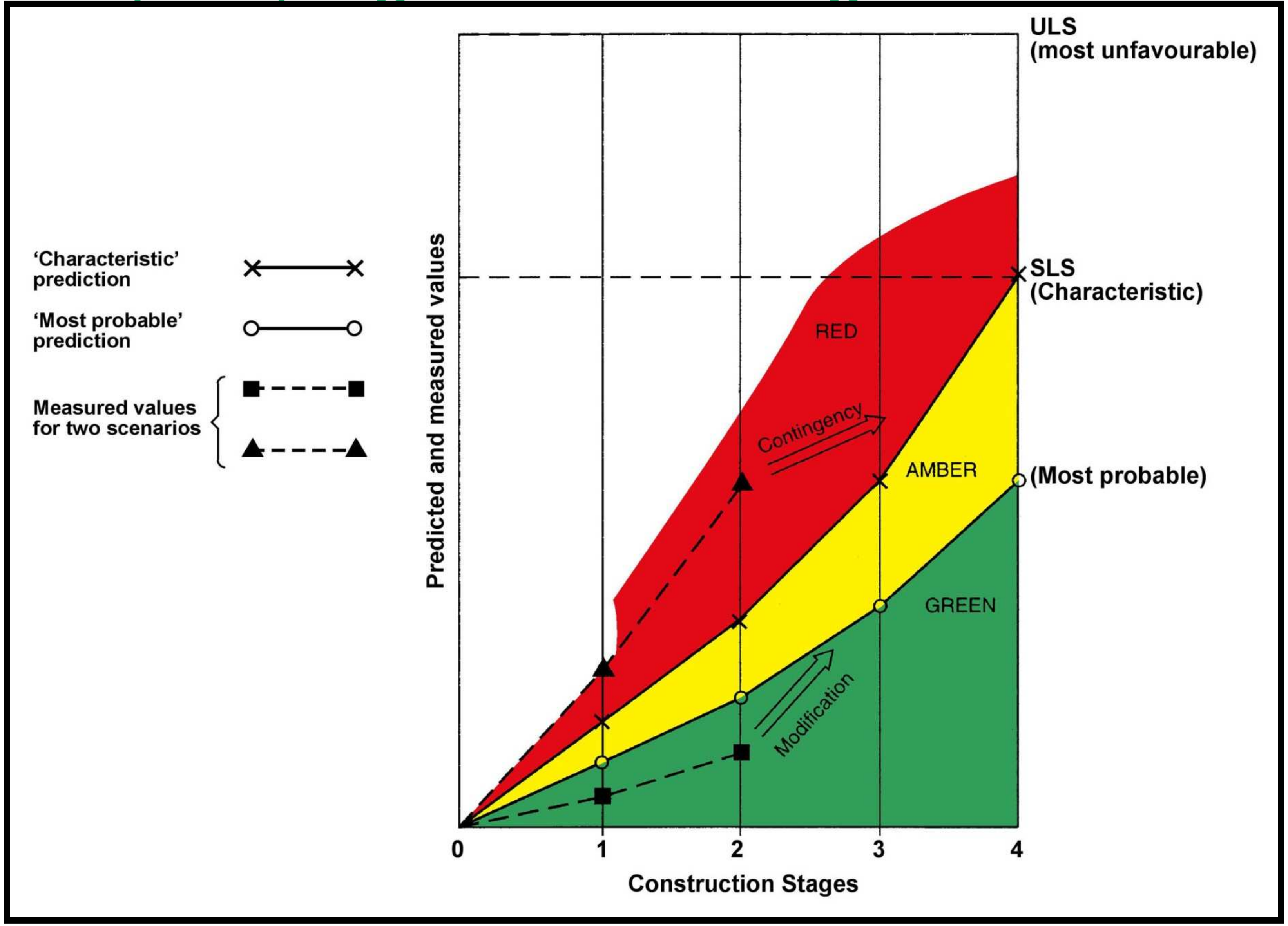
(Not normally part of OM. Required under CHSW Reg (1996). Relates to Ultimate Limit State.)

ARUP

Ideal EC7 Predicted versus Measured Performance

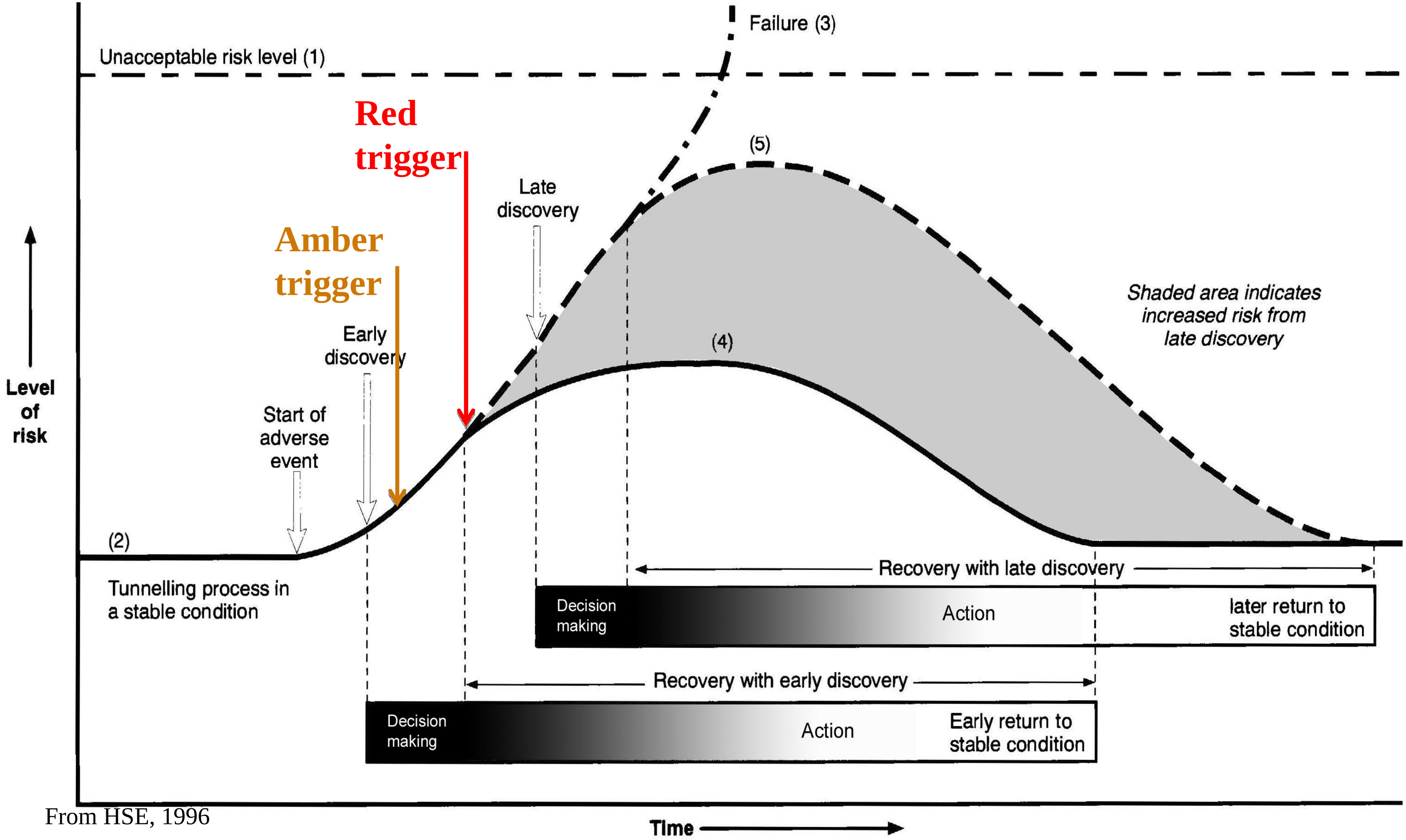


Ciria (1999) Fig 3.13 Multi Stage Excavation



ARUP

HSE 'Discovery – Recovery' Model eg for tunnelling



From HSE, 1996

ARUP

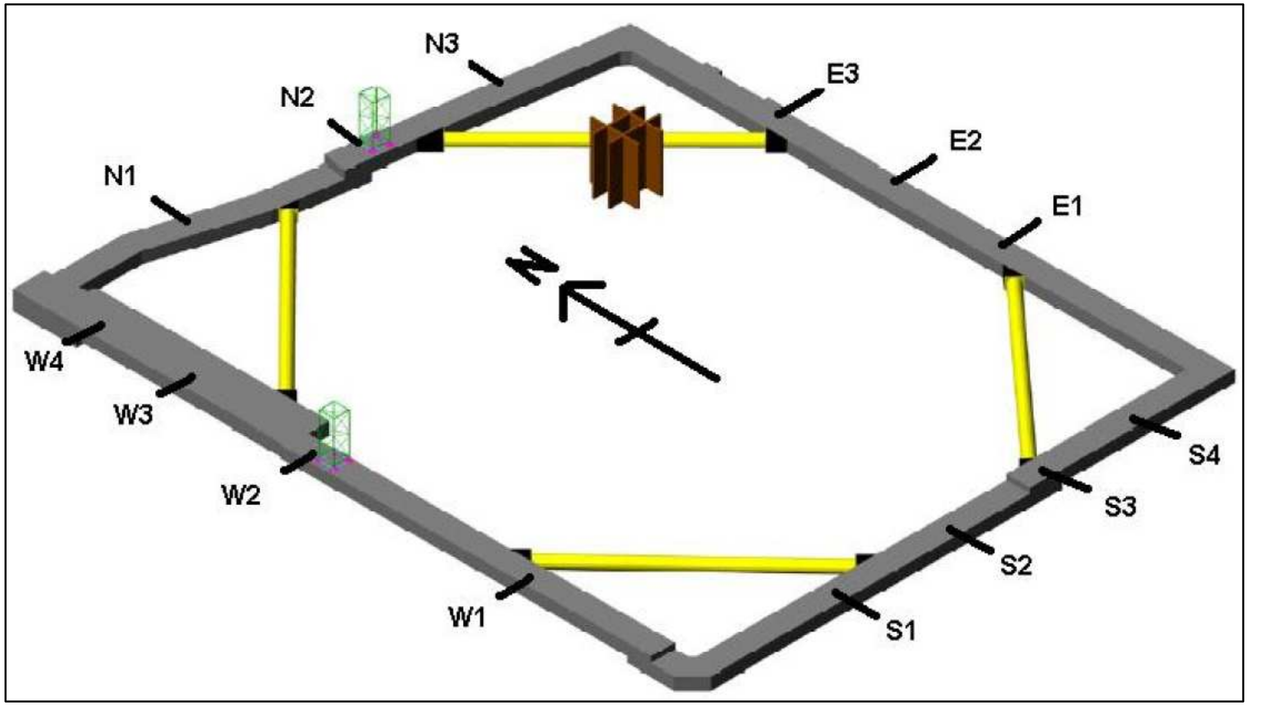
Case Histories

- Kings Place - London
- Nicol Highway Collapse - Singapore
- Canary Wharf – Crossrail Staion Box
- Donegall Quay - CFA piles

Kings Place – OM – Ab initio

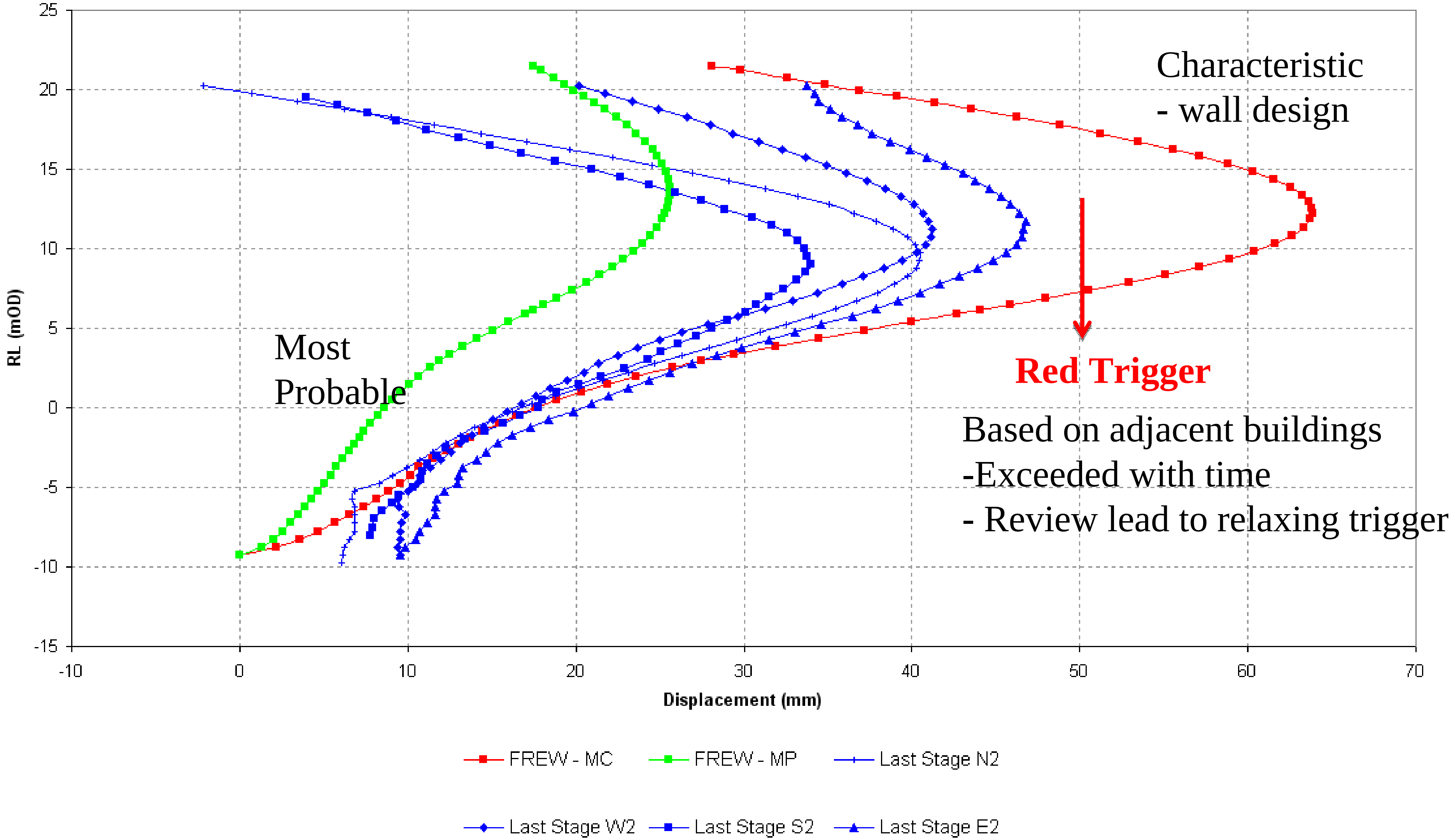
- Damage assessment trigger
  - 50mm max wall deflection
- Diaphragm Wall
  - 1.0m thick
- 1 level of temporary corner props
- 16m retained height
- Observational Method

Kings Place - Instrumentation



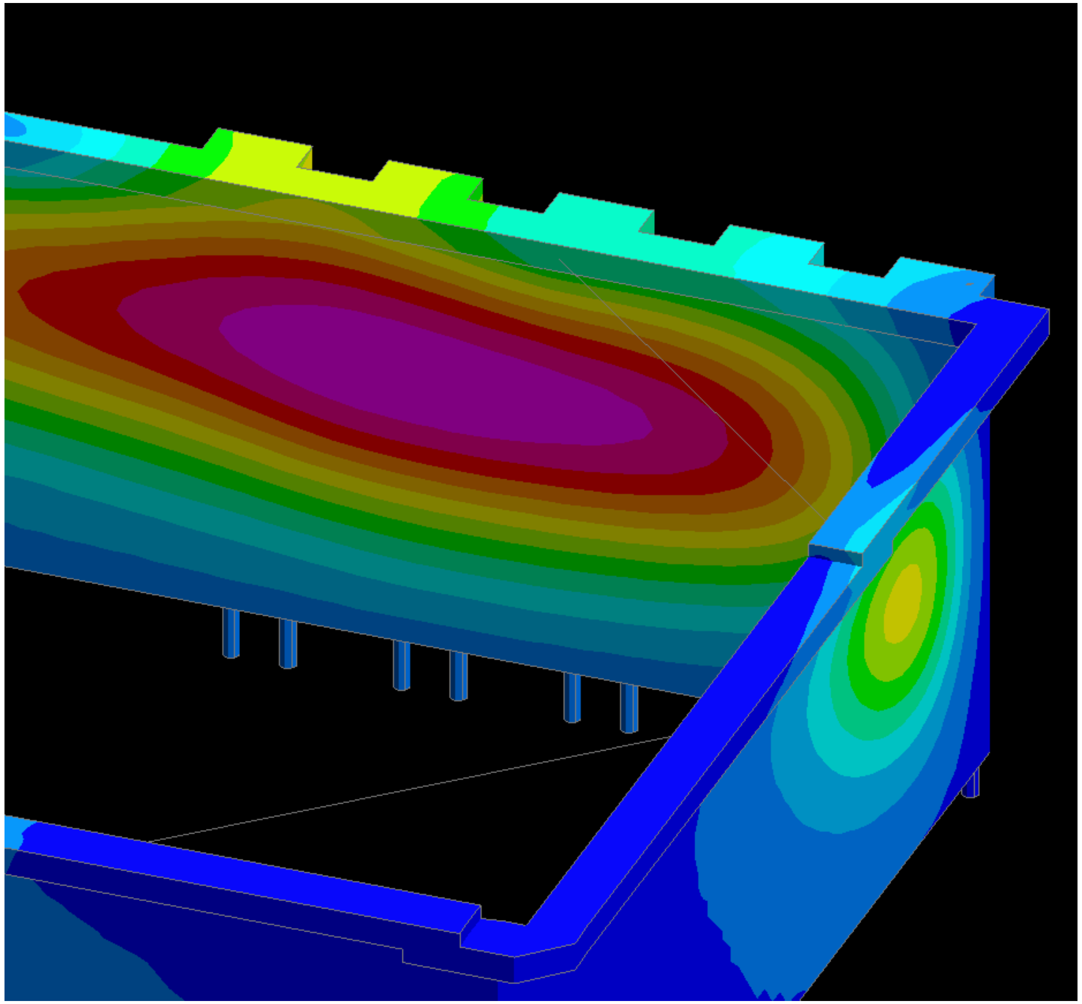
- 14no. inclinometers + 14no. survey targets
- 32no. strain gauges at props
- 40no. Ground survey stations

Frew predictions “Last Stage” data



ARUP

Back Analysis - LS Dyna - 3D model



- Small Stain Model
- 3D geometry

- Assess effect of
  - berm excavation sequences
  - corner effects

- Soil parameters refined.

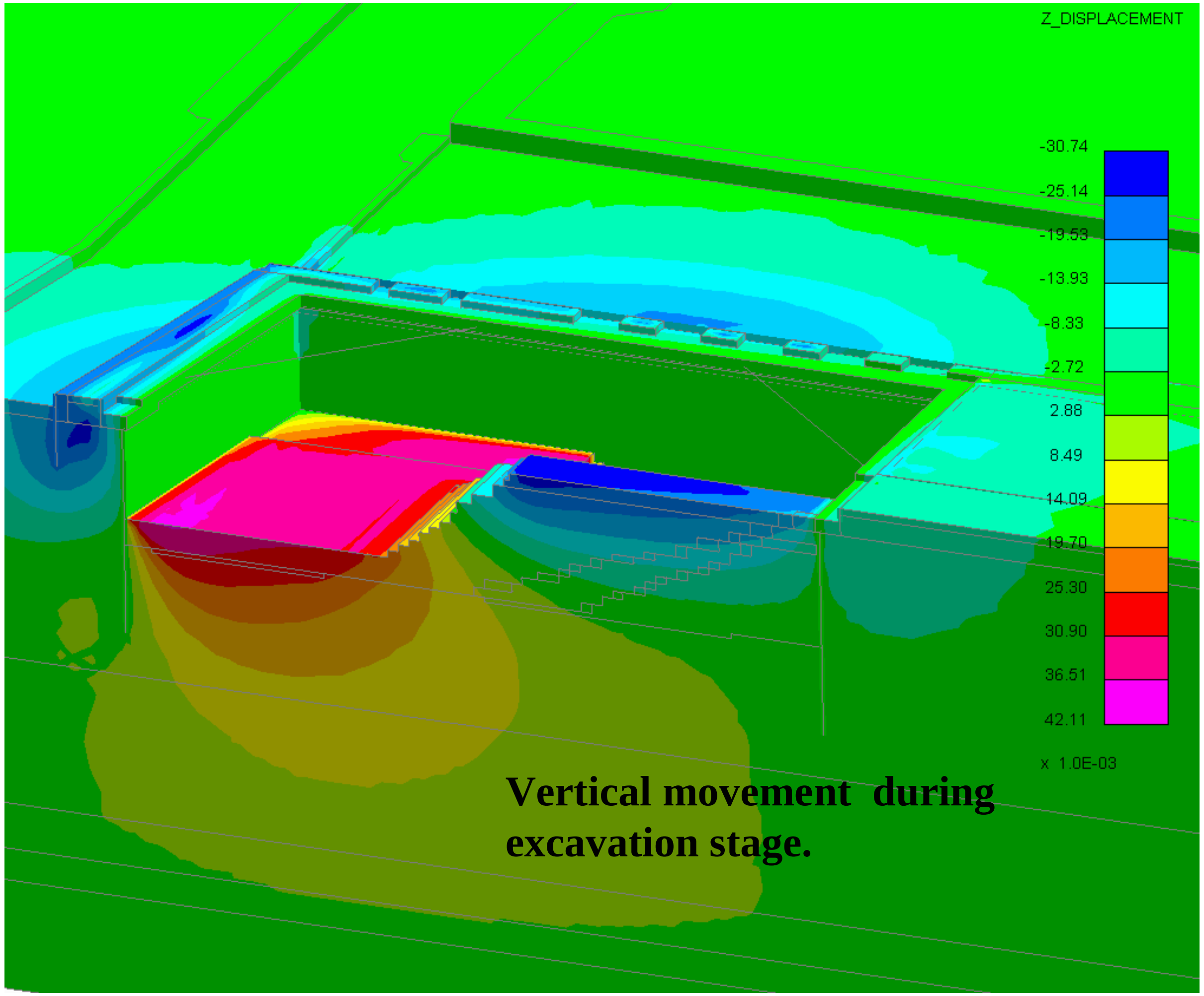
- Goal to assess “Characteristic” and “Most Probable” sets of parameters

- Monitoring data compared to numerical analyses.

- Refine trigger criteria for Observational Method

Analysis Summary

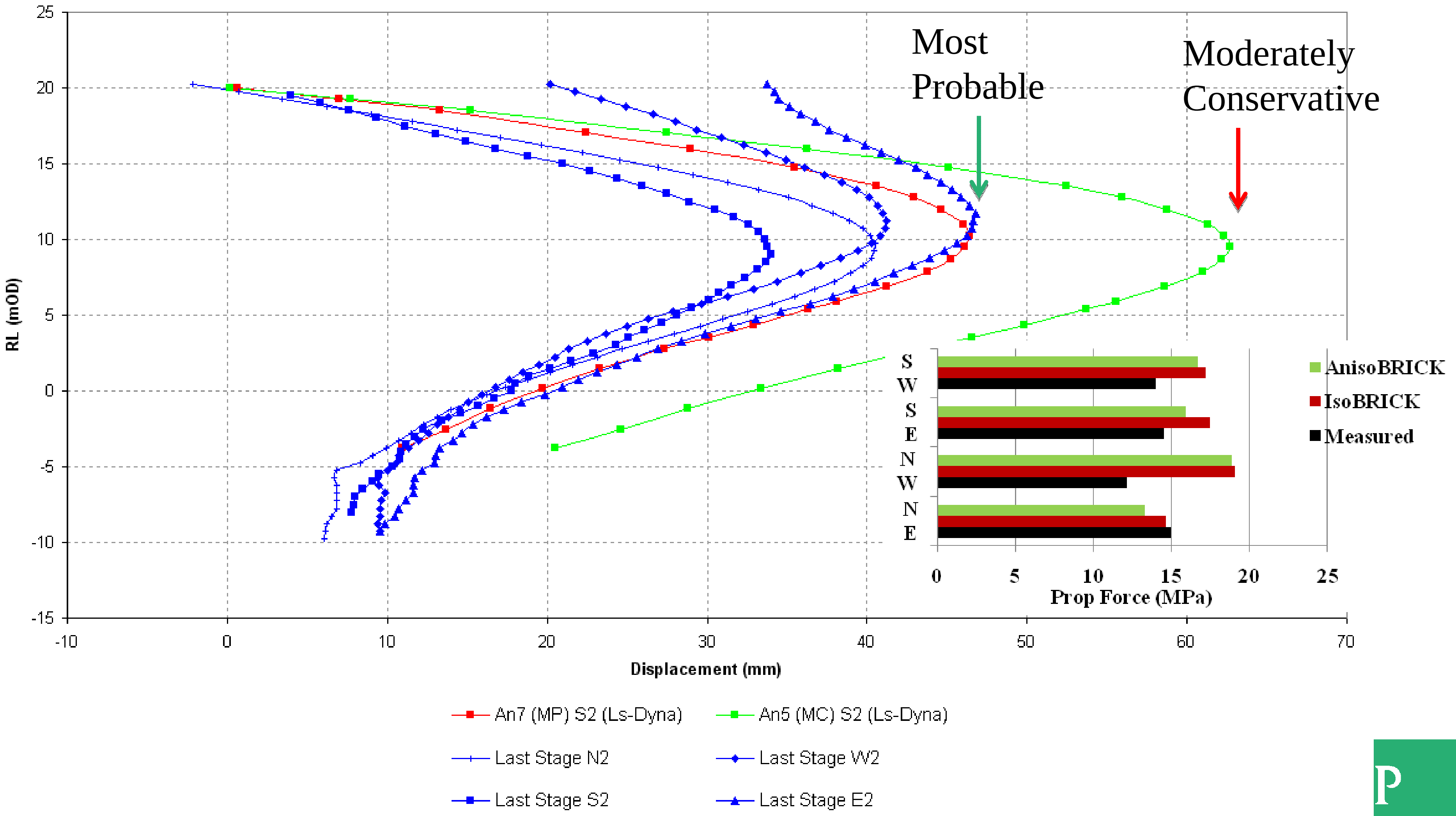
- **Approx 600,000 elements in 32 material sets.**
- **5 Analyses varying:-**
  - **Soil parameter.**
  - **Suction limits.**
- **Stages representing 8 steps of excavation modelled.**
- **Site data compared to model data.**



Vertical movement during excavation stage.

MP and MC Ls-DYNA vs. <u>“Last Stage”</u> data

- Monitored data set matching last stage of model sequence.
- Based on Suction limit of -100kPa. - “AnisoBRICK”
- Consolidation

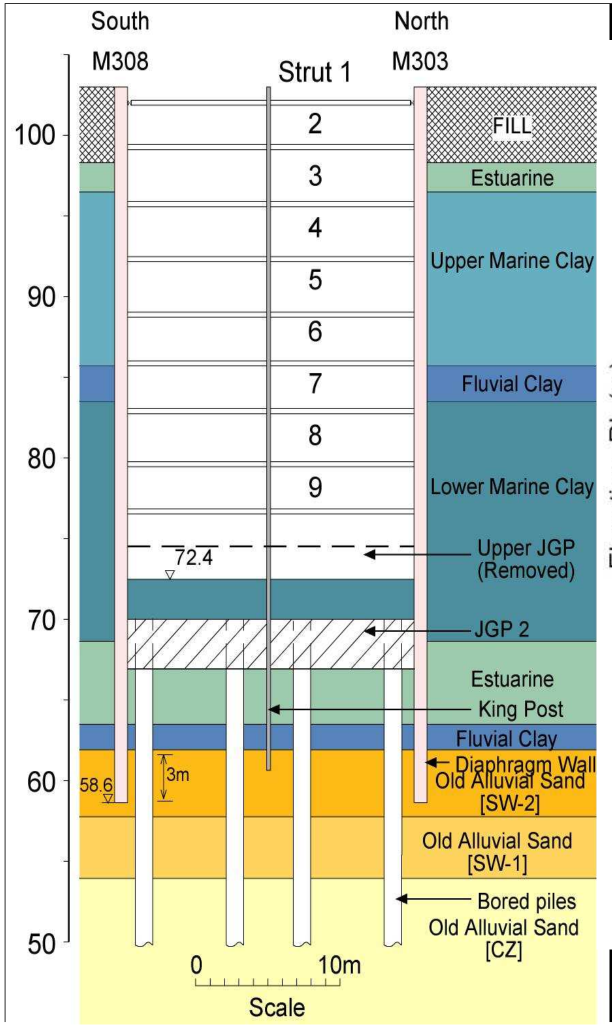


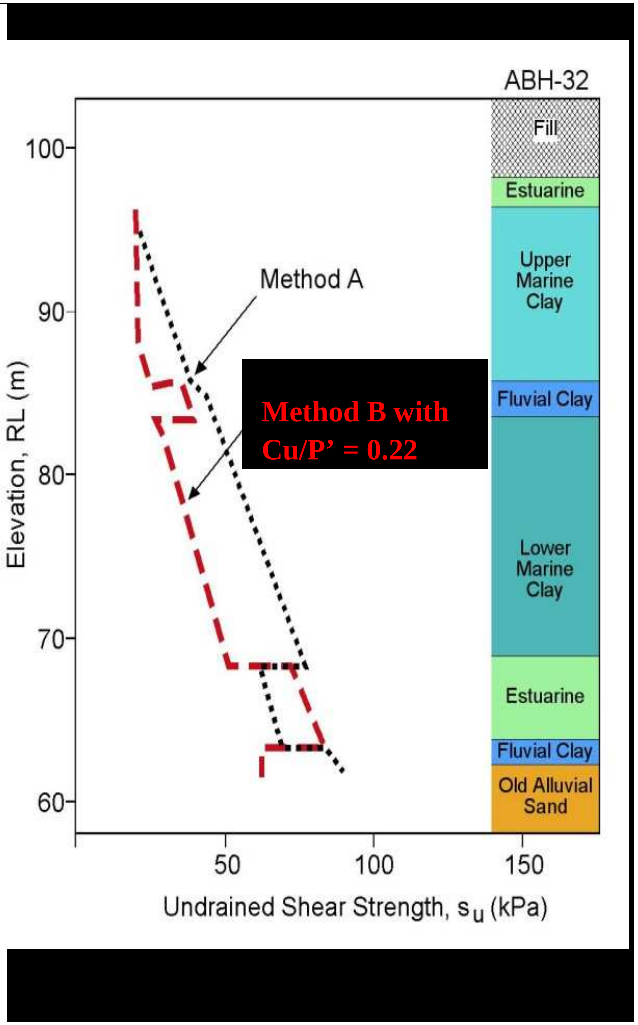
P

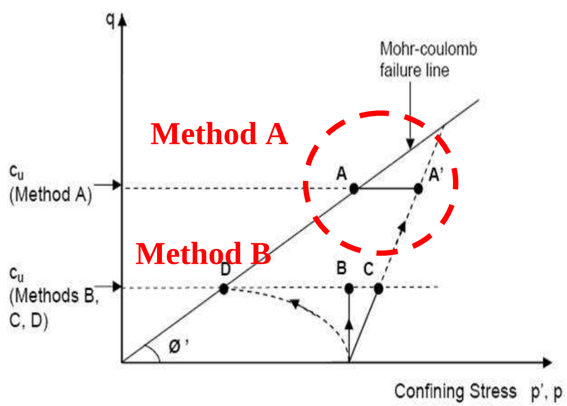
Nicoll Highway Collapse – Not Observational Method

Public Inquiry – Key Lessons

1. Soil model in Plaxis over estimated Marine Clay strength

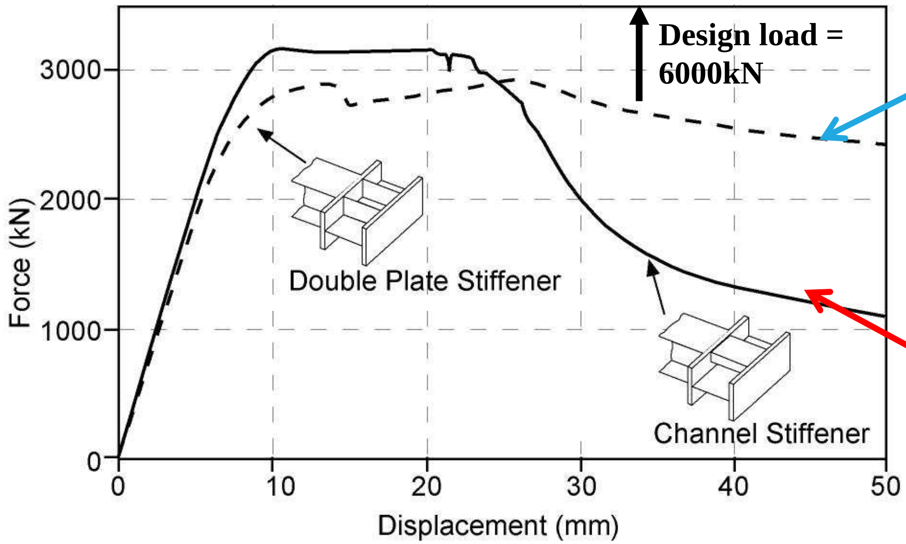


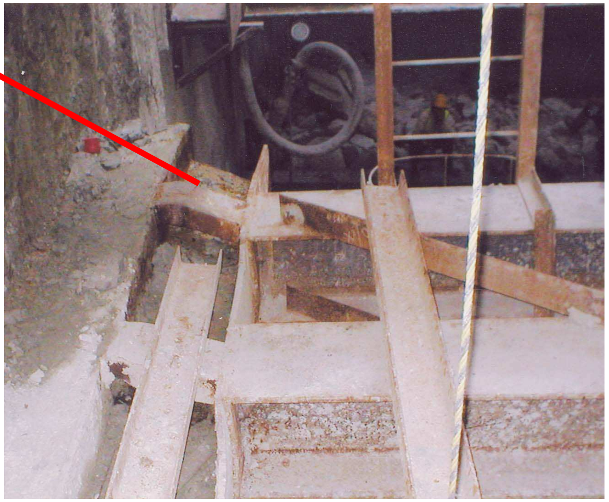




Key Lessons cont'd

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

- Public Enquiry – Magnus et al, (2005)
- 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

ARUP

Canary Wharf Crossrail Station – Lessons learned

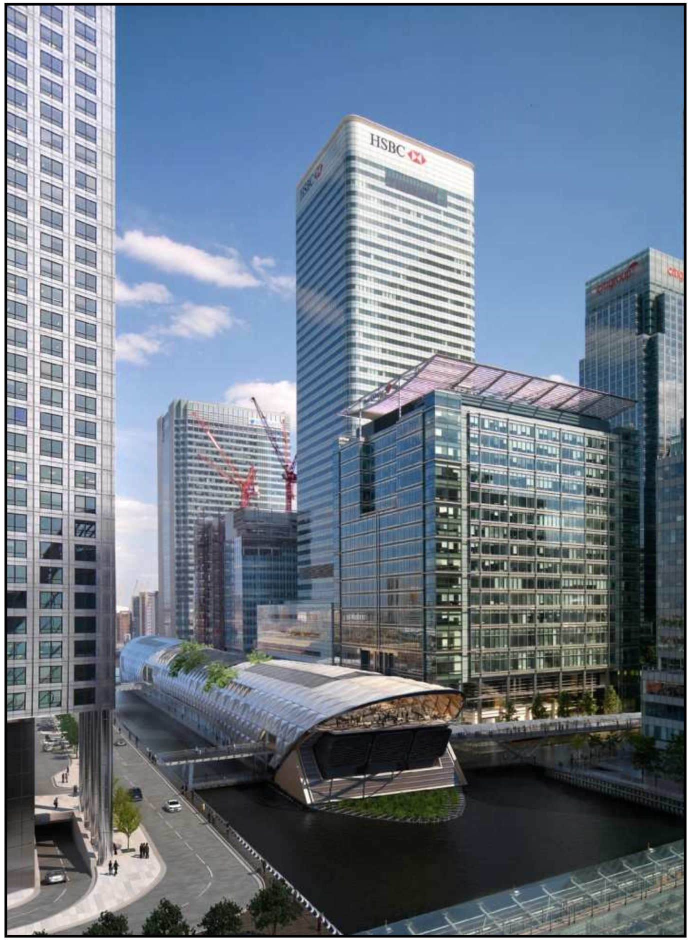
Crossrail Station at Canary Wharf

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

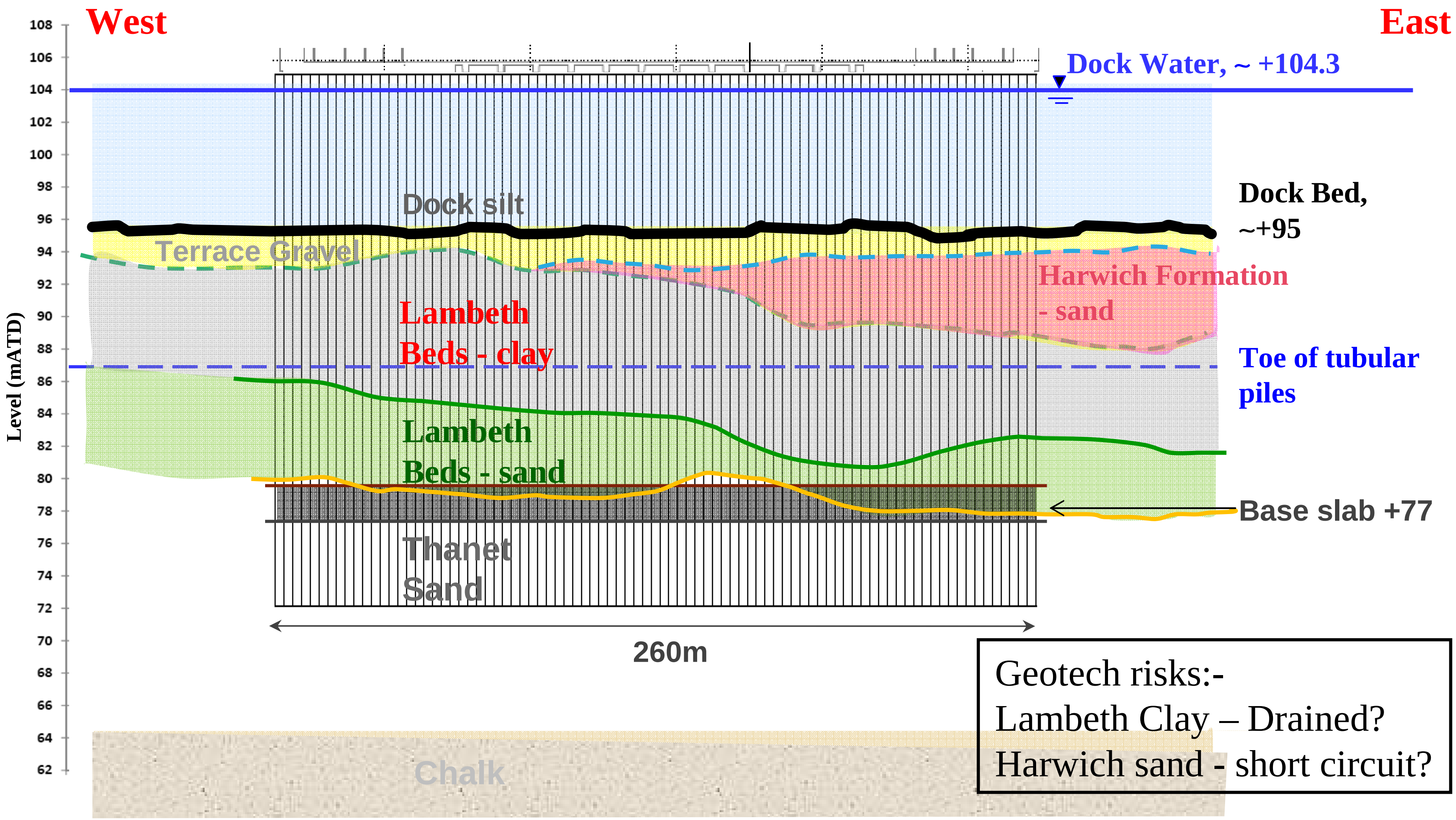


Canary Wharf Crossrail Station Layout

Geotech risks:-
Adjacent buildings
Dock structures
DLR

ARUP

Geology along the station box

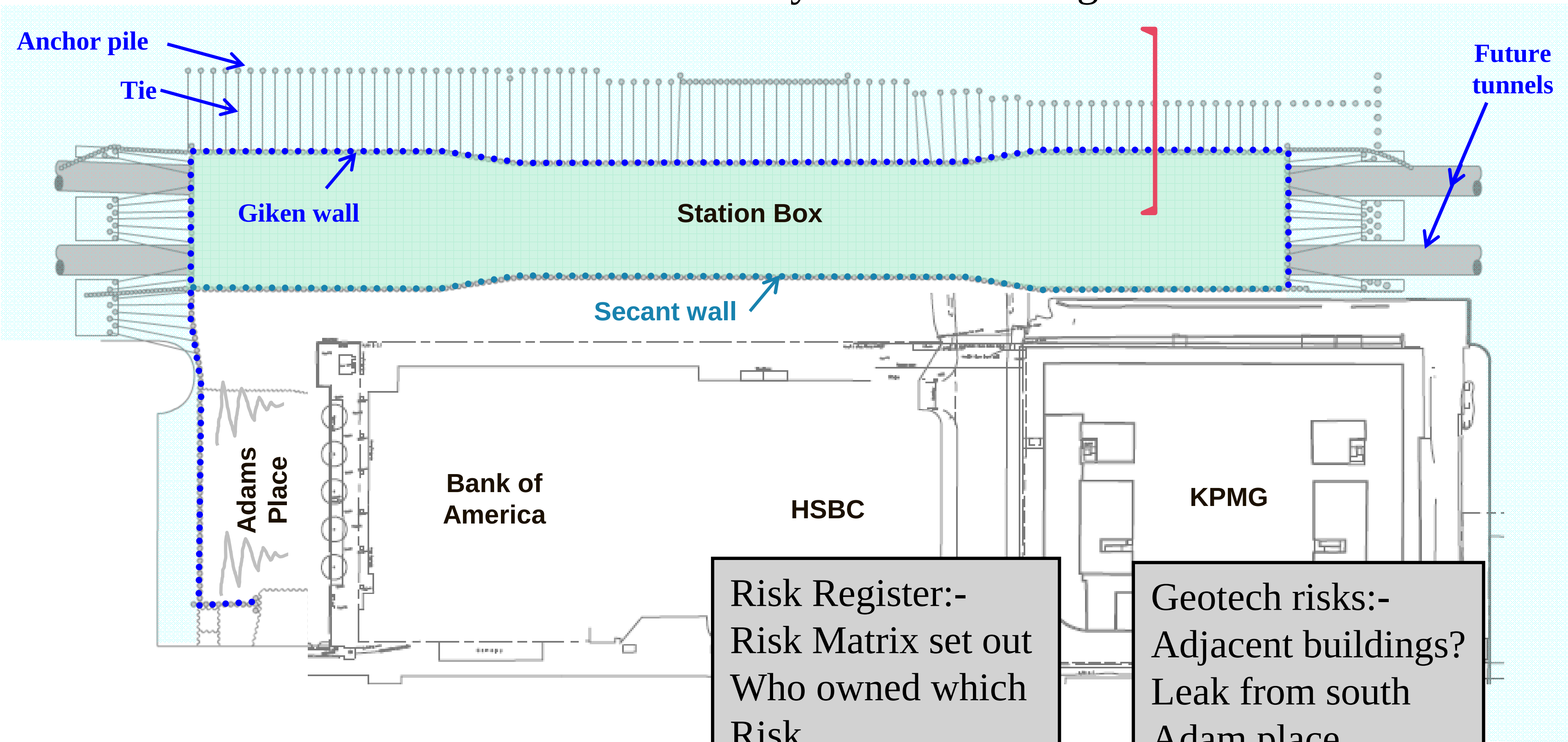


Geotech risks:-
Lambeth Clay – Drained?
Harwich sand - short circuit?

ARUP

Working with stakeholders – Final scheme evolved from many inputs

- Construction in a drained dock - asymmetric loading

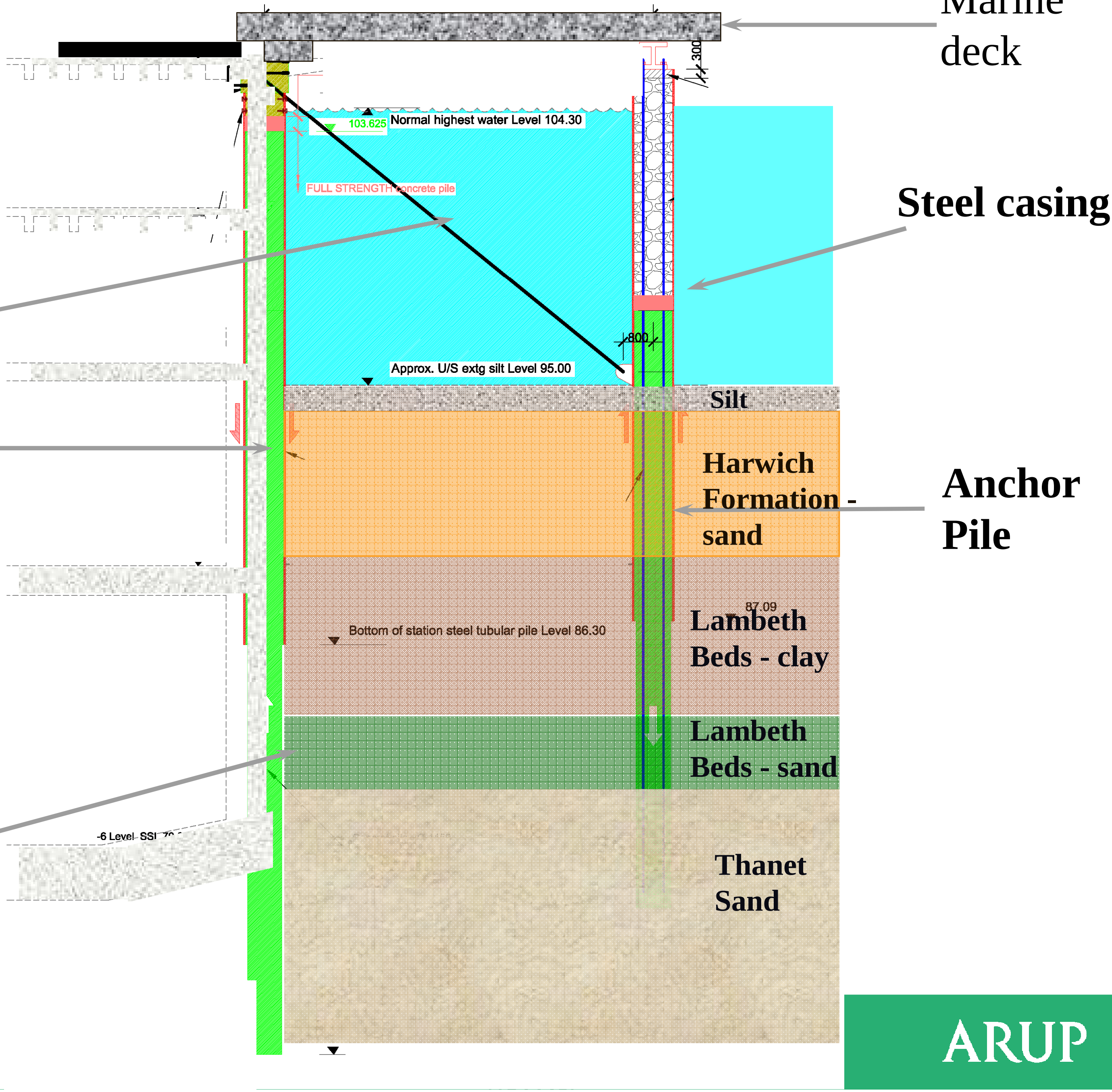


Risk Register:-
Risk Matrix set out
Who owned which
Risk.

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

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

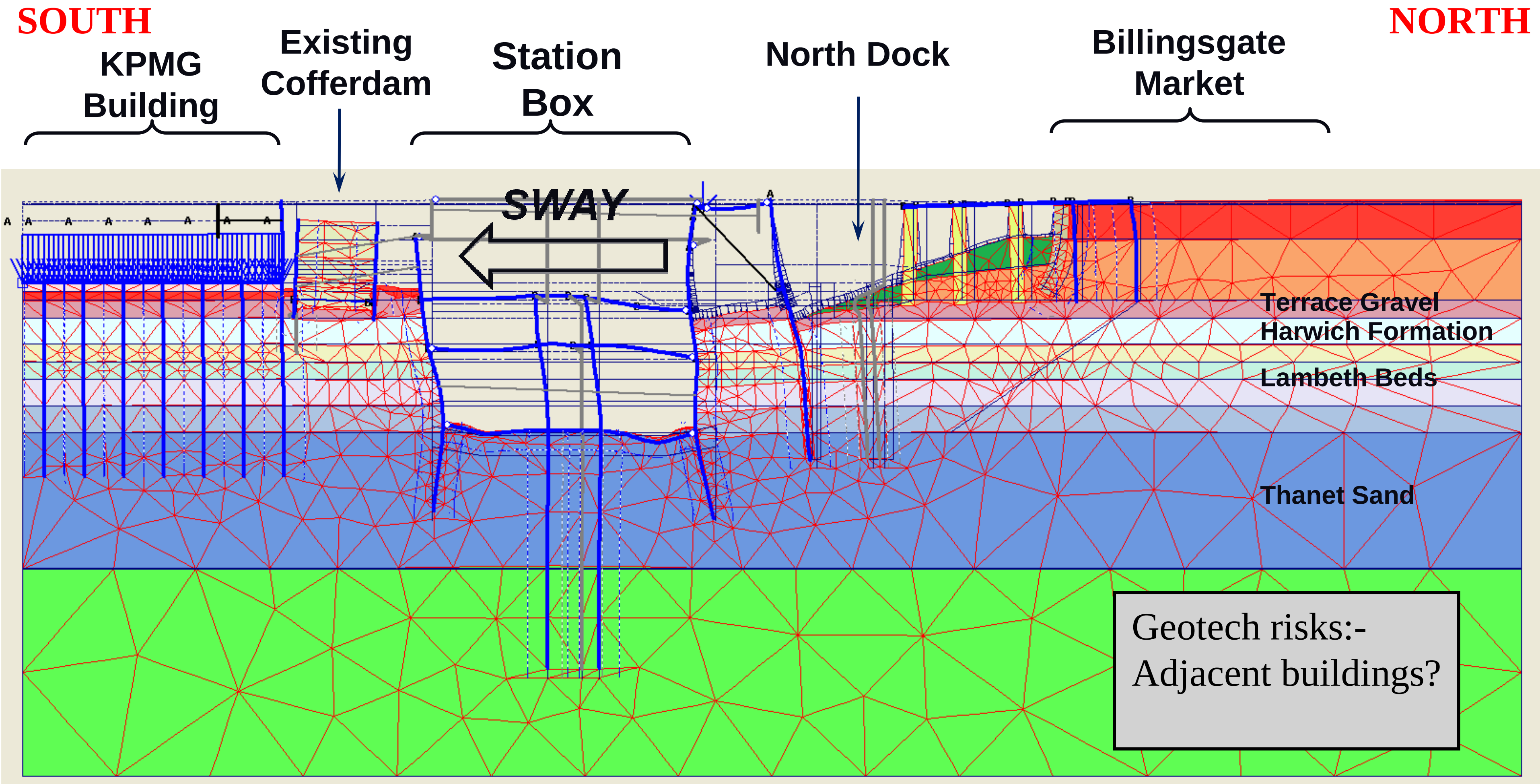
Tie Back System



ARUP

Soil-structure interaction – finite element model

Exaggerated Plaxis displacement plot



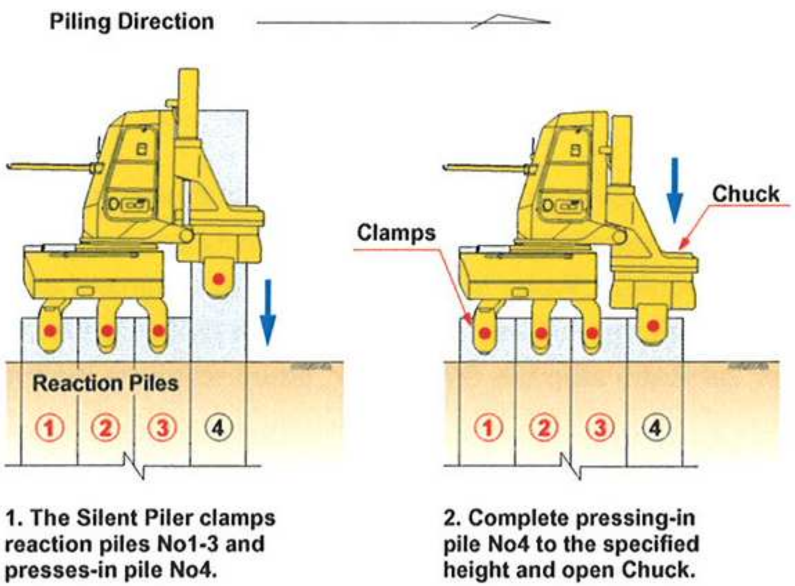
Finite element method – capturing out-of-balance loading (sway) and ground movement

Giken push in process

1.2m dia tubes with Crush Auger

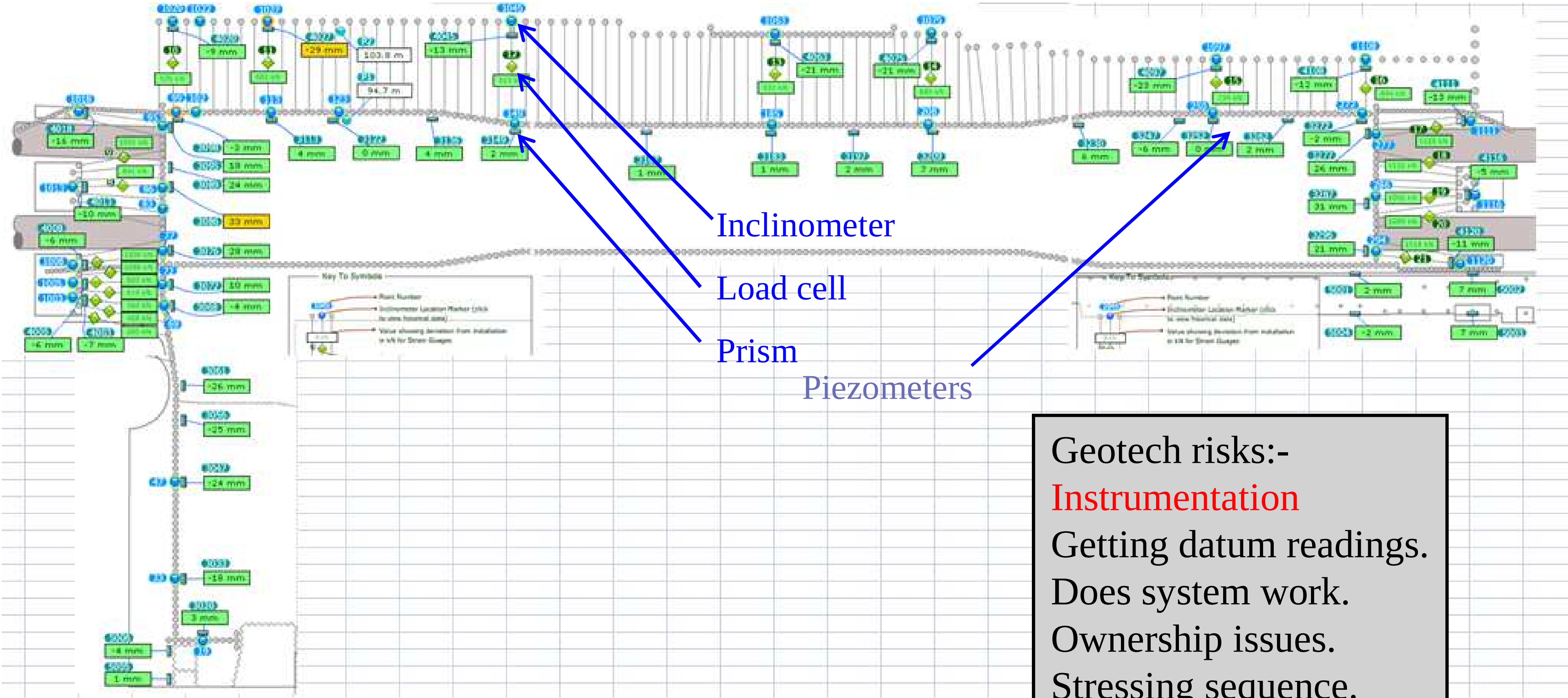
Using reaction from 3 pre-installed casing to install the 4th casing

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



ARUP

Monitoring system

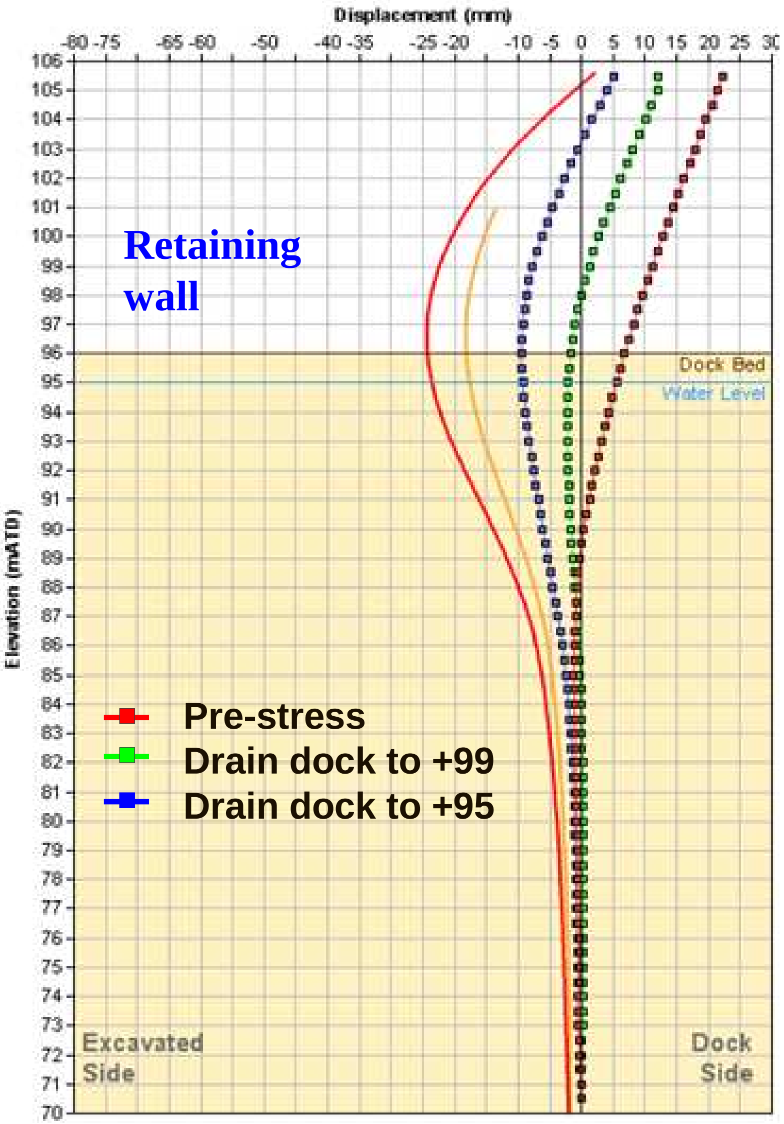


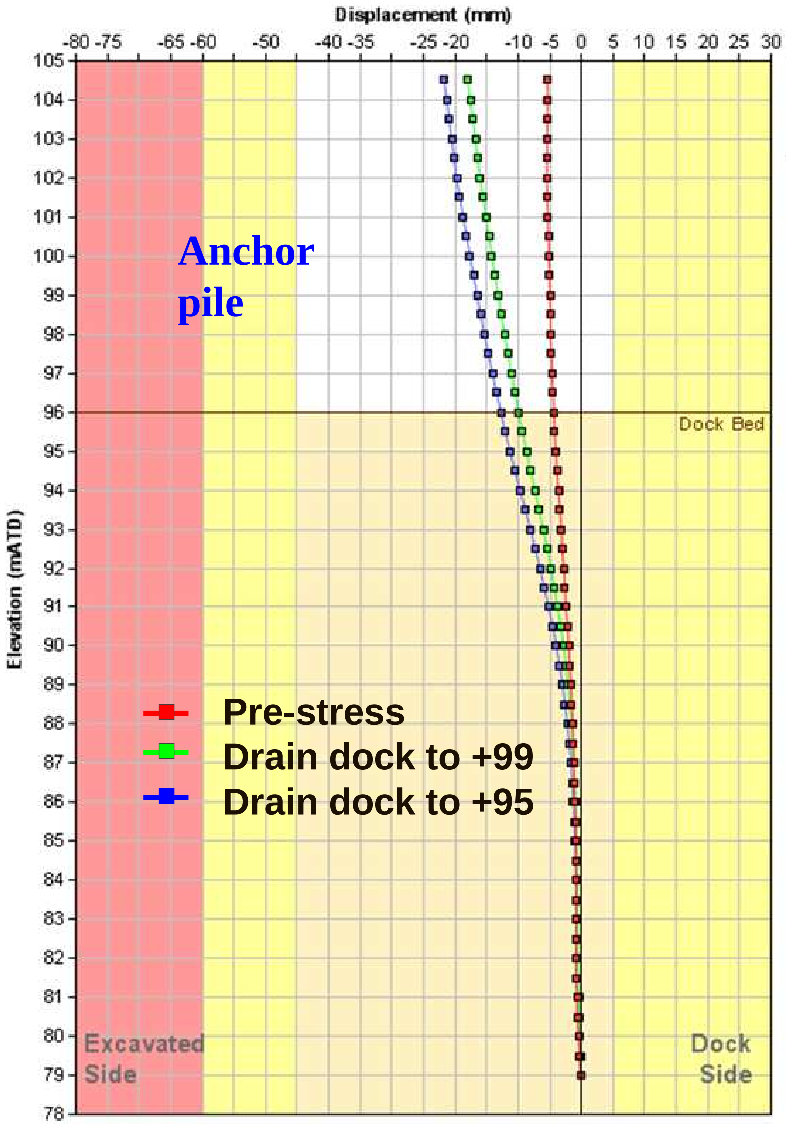
Geotech risks:-
Instrumentation
Getting datum readings.
Does system work.
Ownership issues.
Stressing sequence.

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

Dock fully drained – mid March 2010

Inclinometer readings – main wall and anchor pile





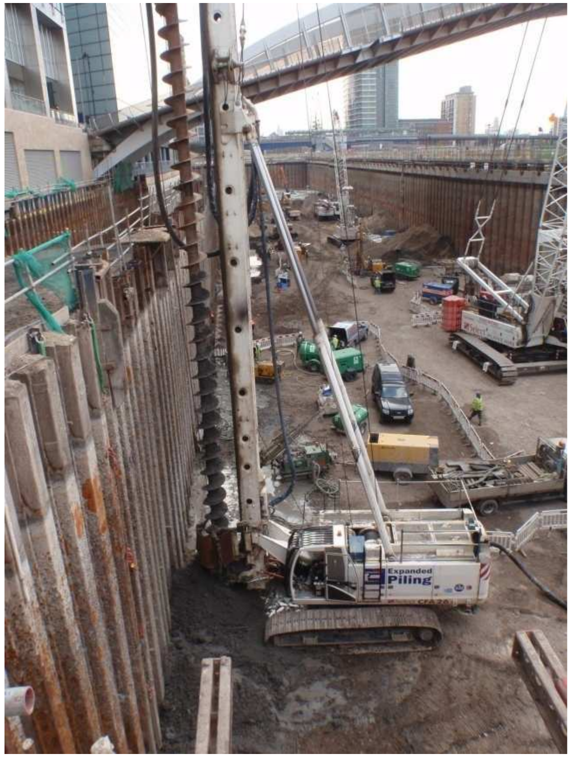
ARUP

Dock silt removal and secant piling

Dock silt removal – dig and dispose

Dock silt removal – wash and pump

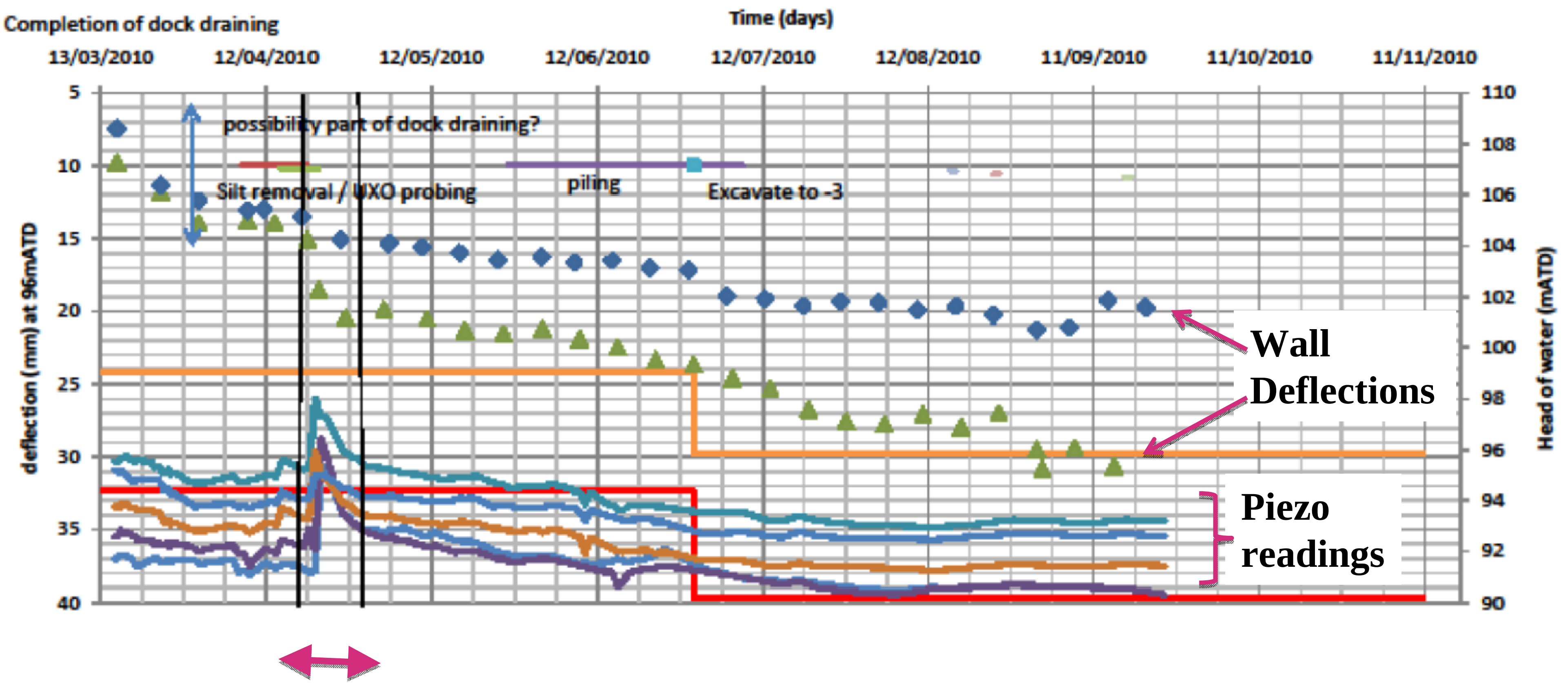
Guide wall installation



CFA piling of female soft pile

Triggers Exceeded

Geotech risks:-
No allowance for UXO probe
Gradual "creep"



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

Impact of UXO probing on wall deflection and piezometer readings

ARUP

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

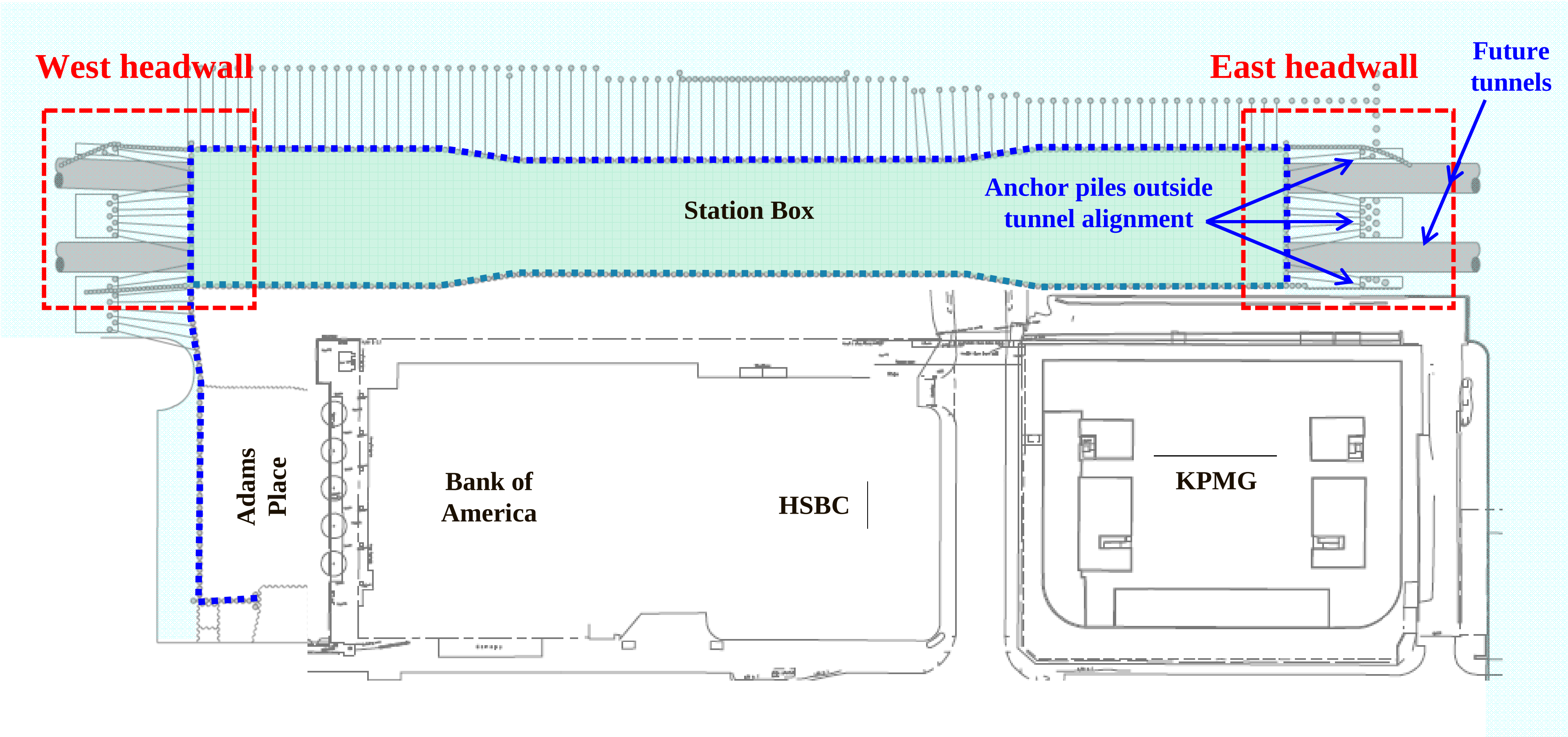
ARUP

Level -6 excavation, blinding, reinforcement etc

ARUP

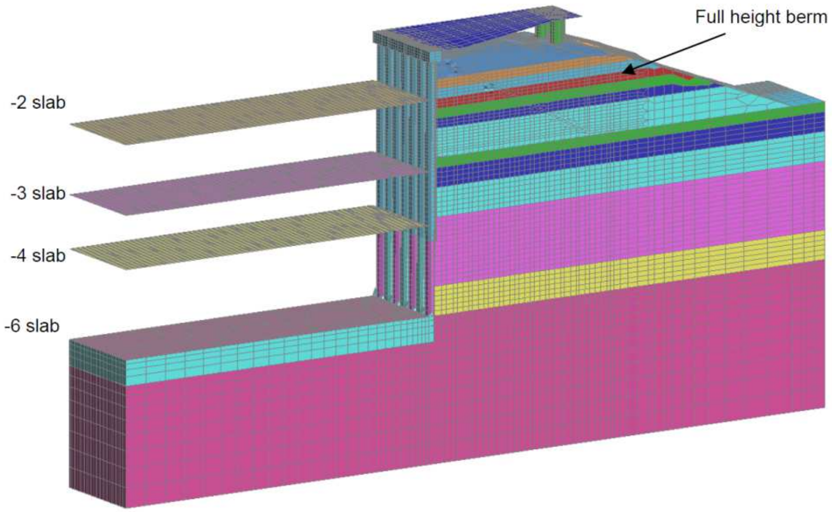
OM – Best Way Out – Review and Modify soil parameters

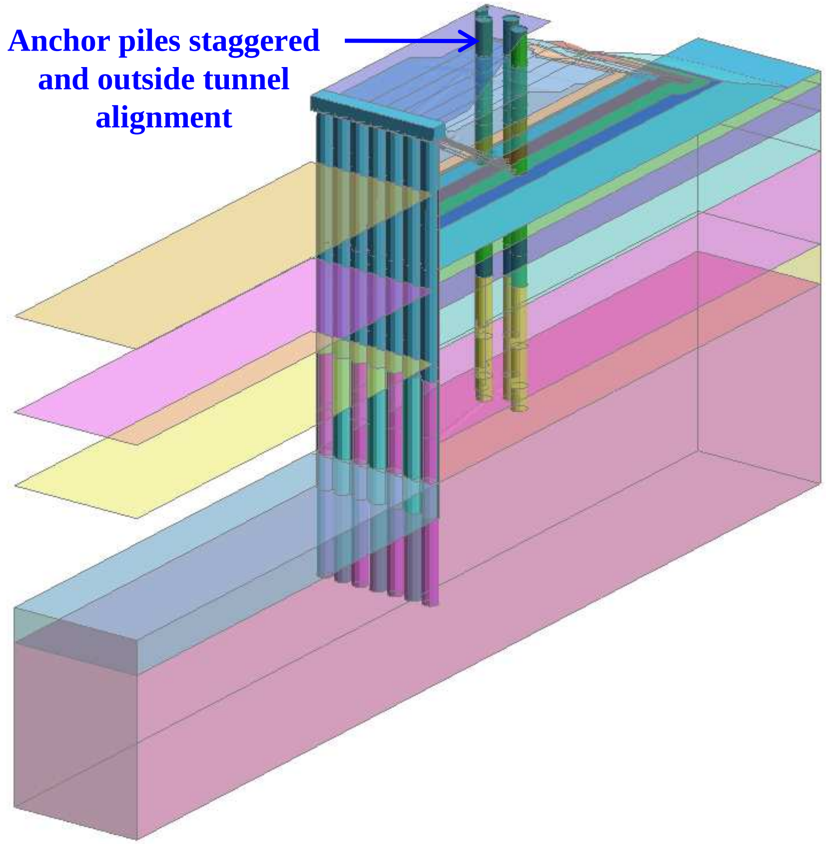
- Tunnel alignment prevented evenly spread of anchor piles



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

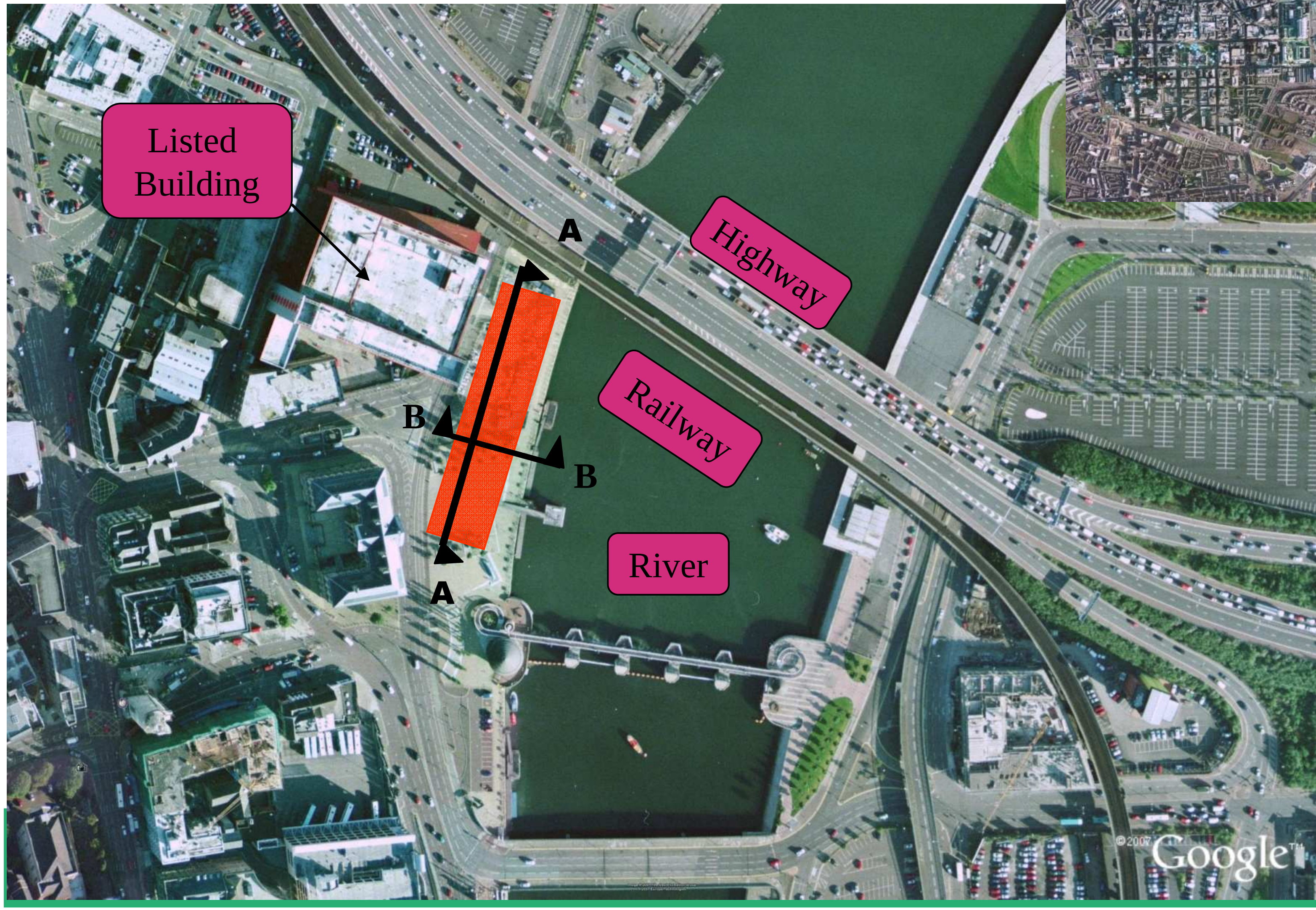


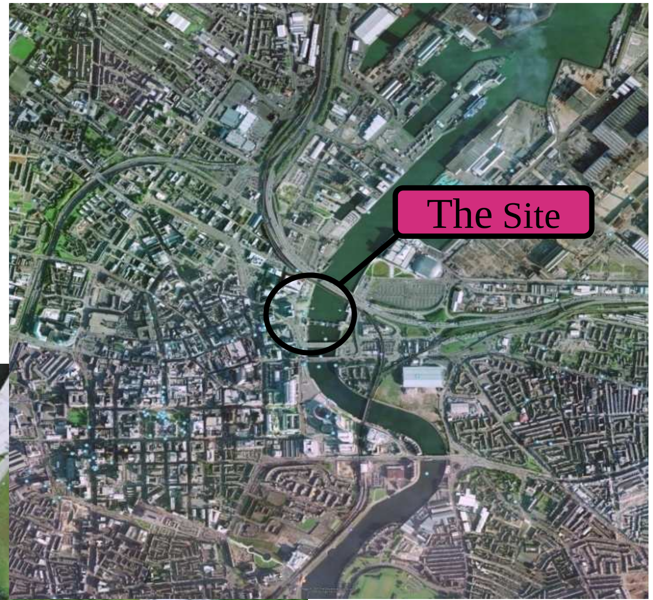


ARUP

Donegal Quay Development

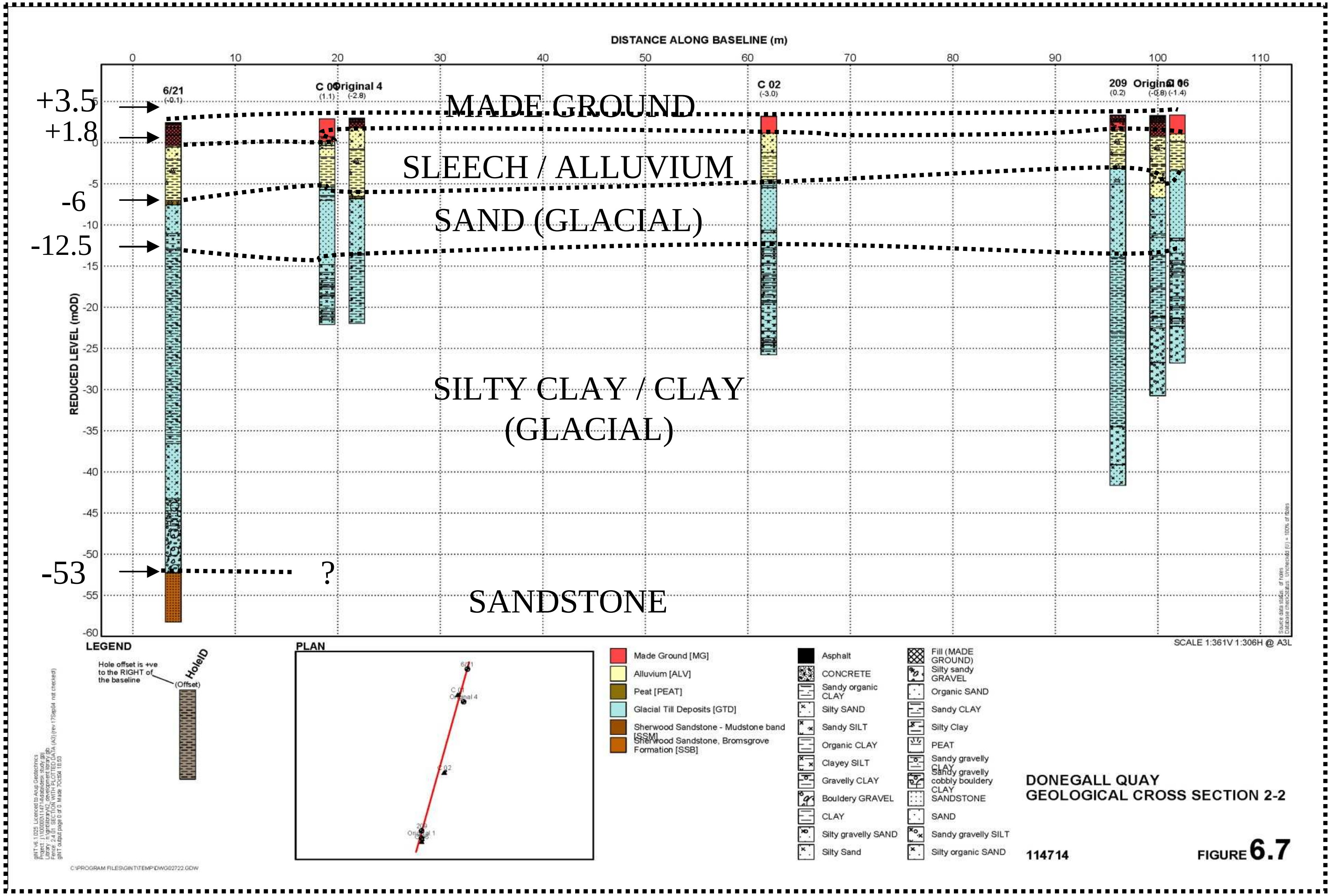
Footprint Area ~ 35 m x 140 m





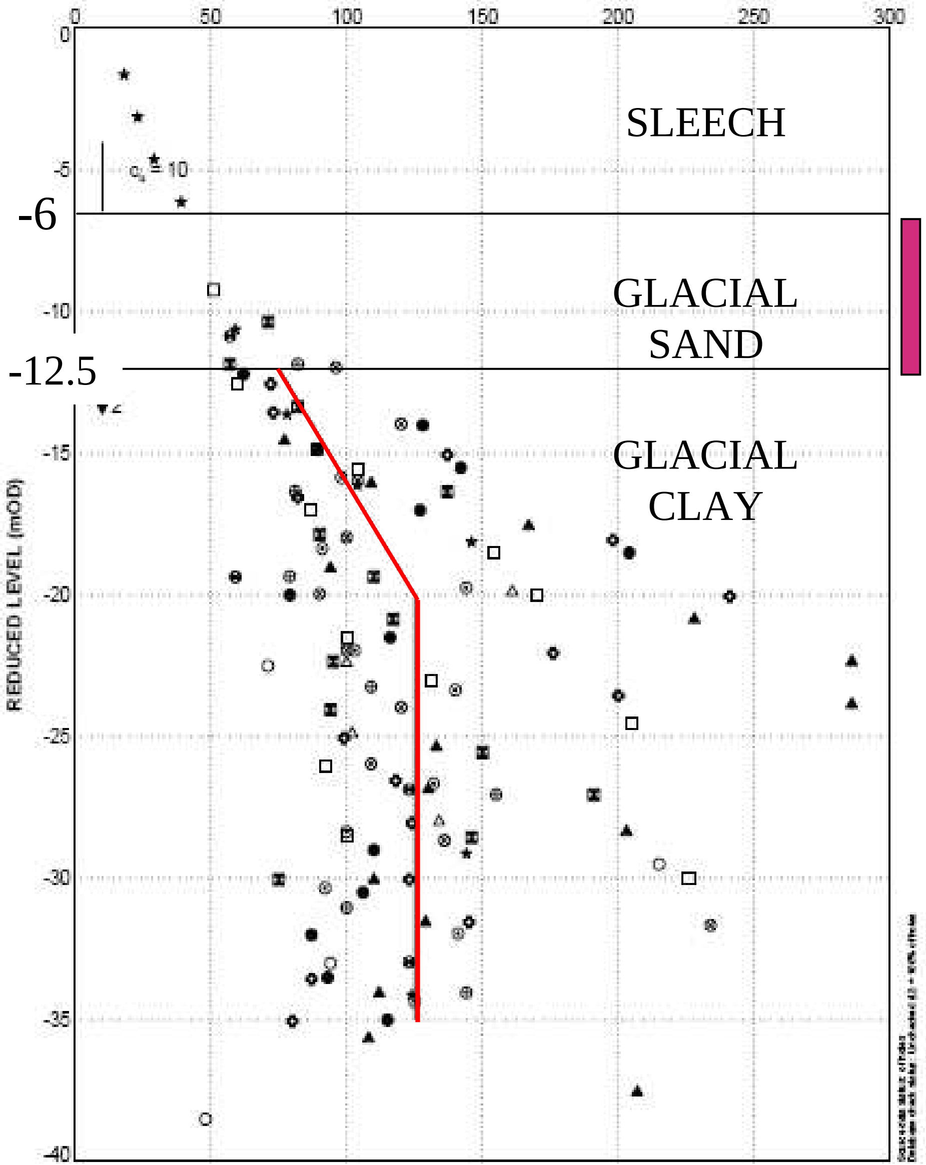
ARUP

Ground Conditions – Geotechnical Profile

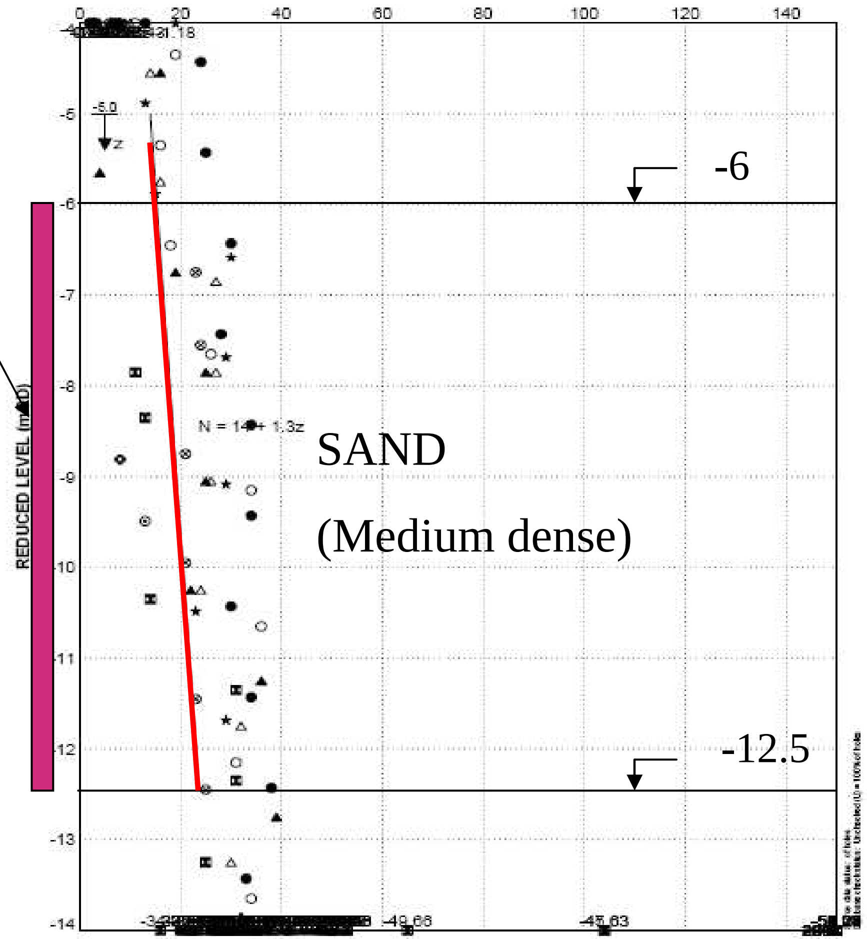


Soil properties

Undrained Strength (kPa)



SPT Profile

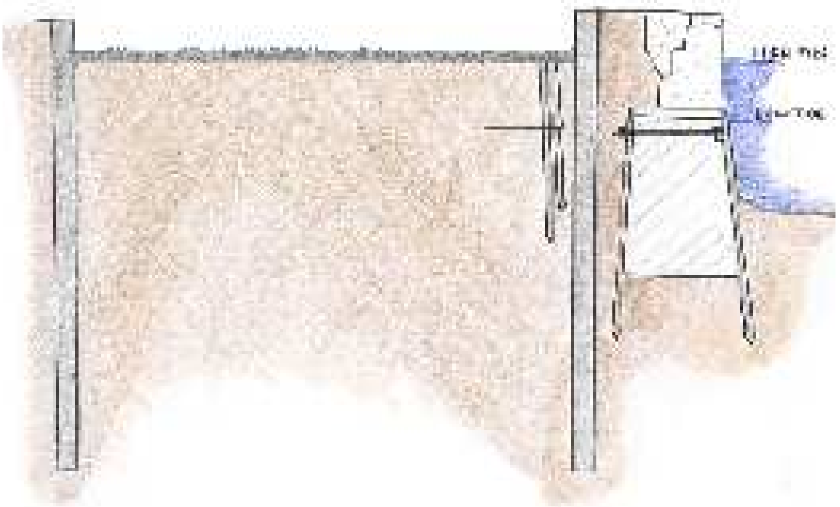


ARUP

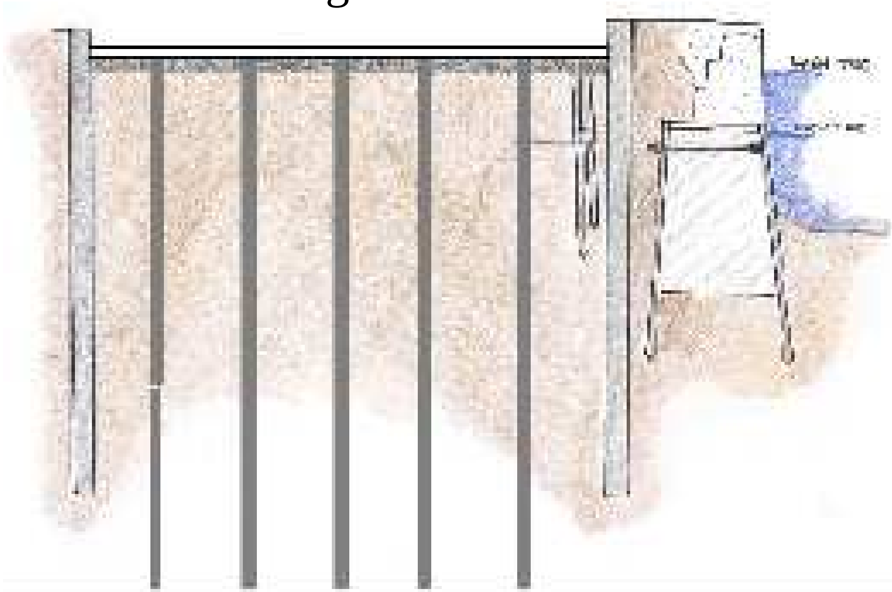
Construction Sequence

- **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.**

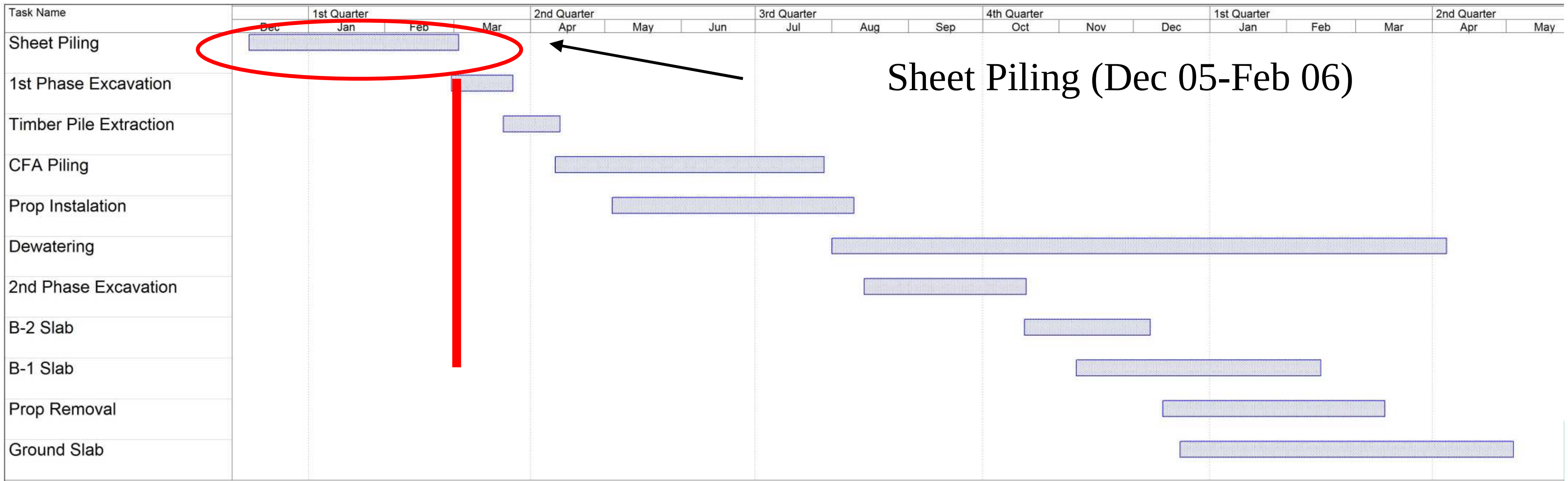
Stage 3



Stage 4



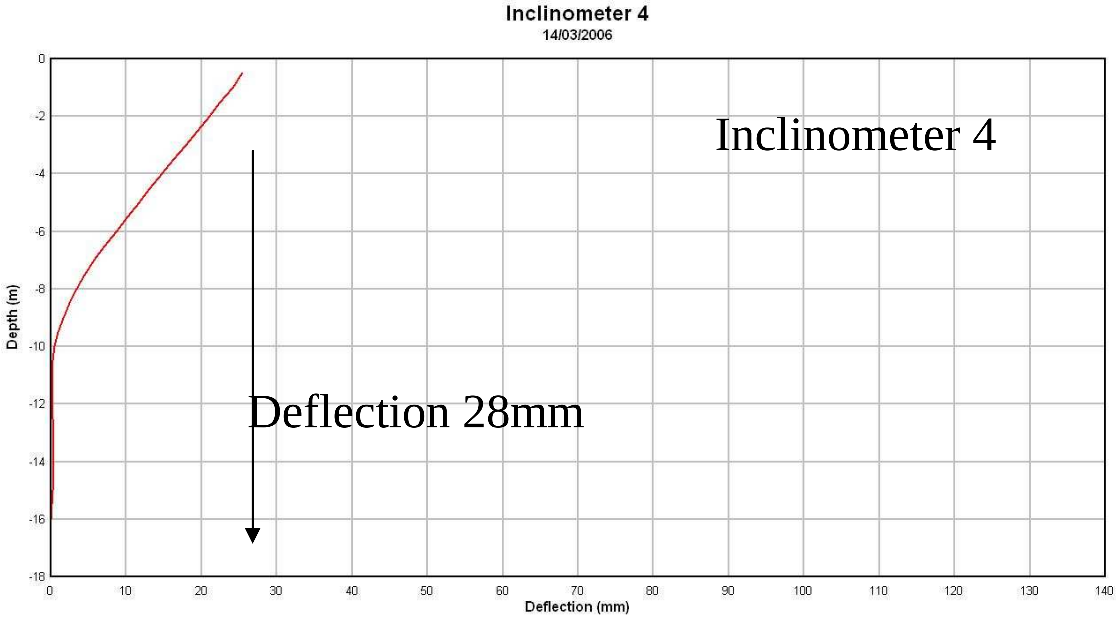
Sheet Pile Installation

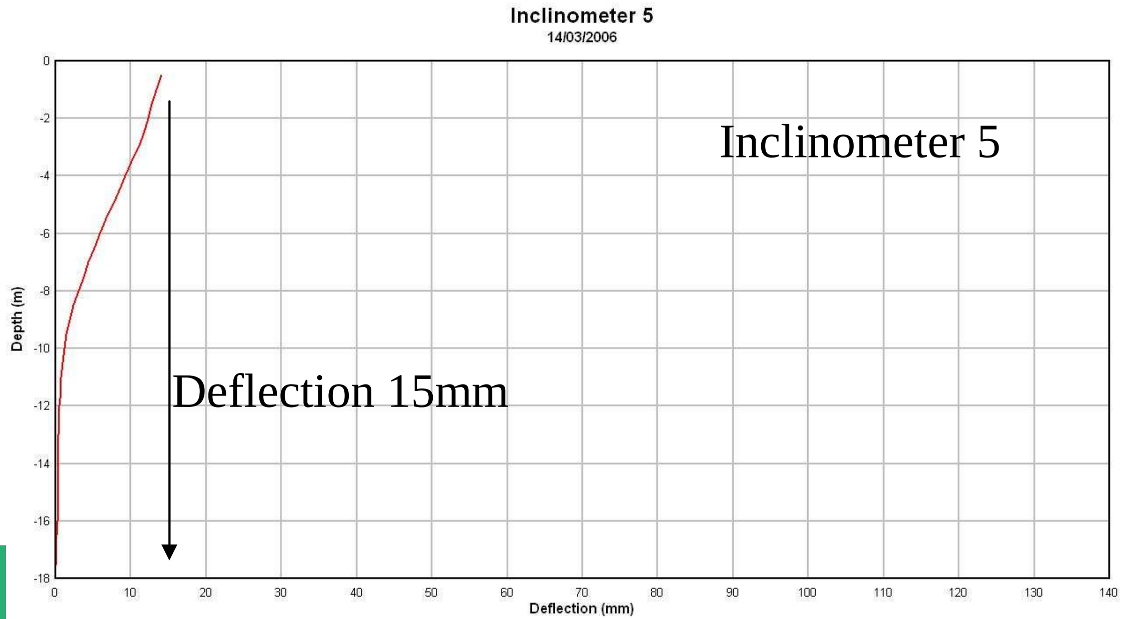


Sheet Piling (Dec 05-Feb 06)

Phase 1 Excavation to +1.5 mOD

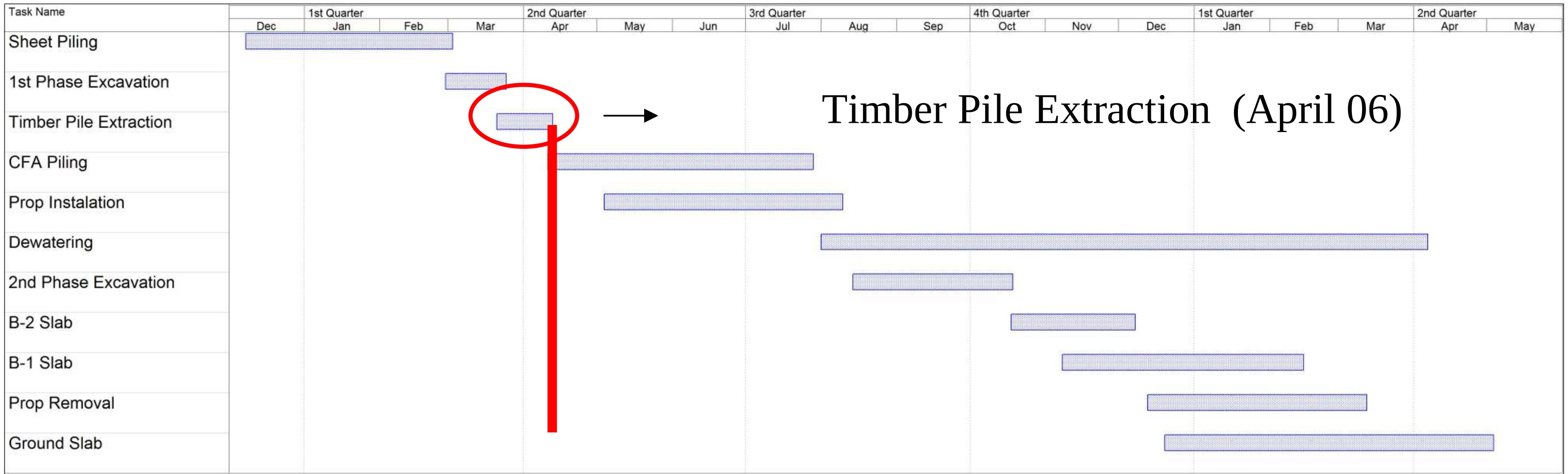
Inclinometers 14 March 2006 - Cantilever dig



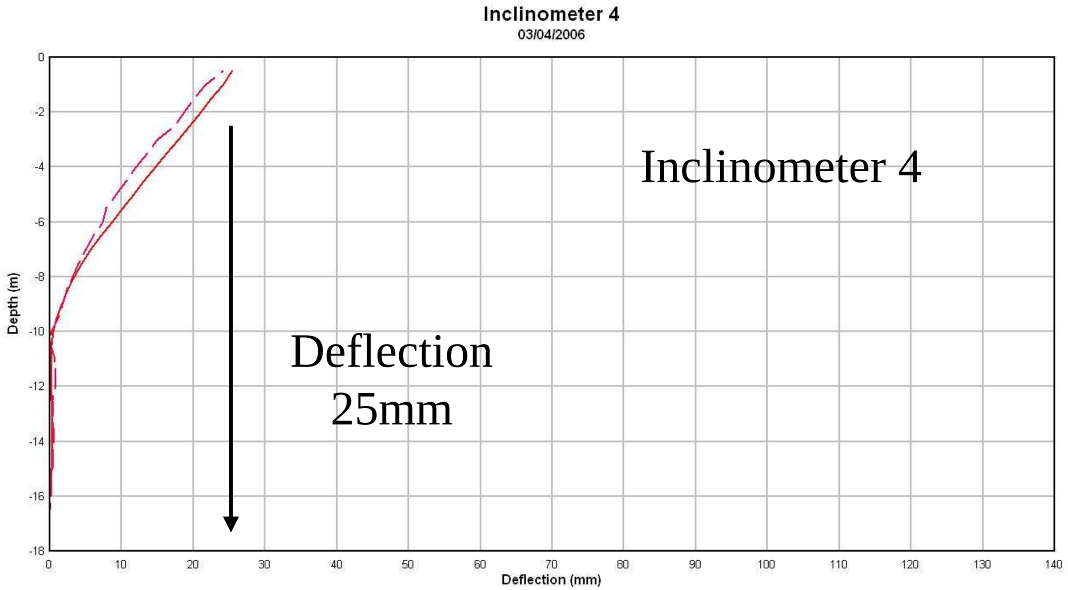


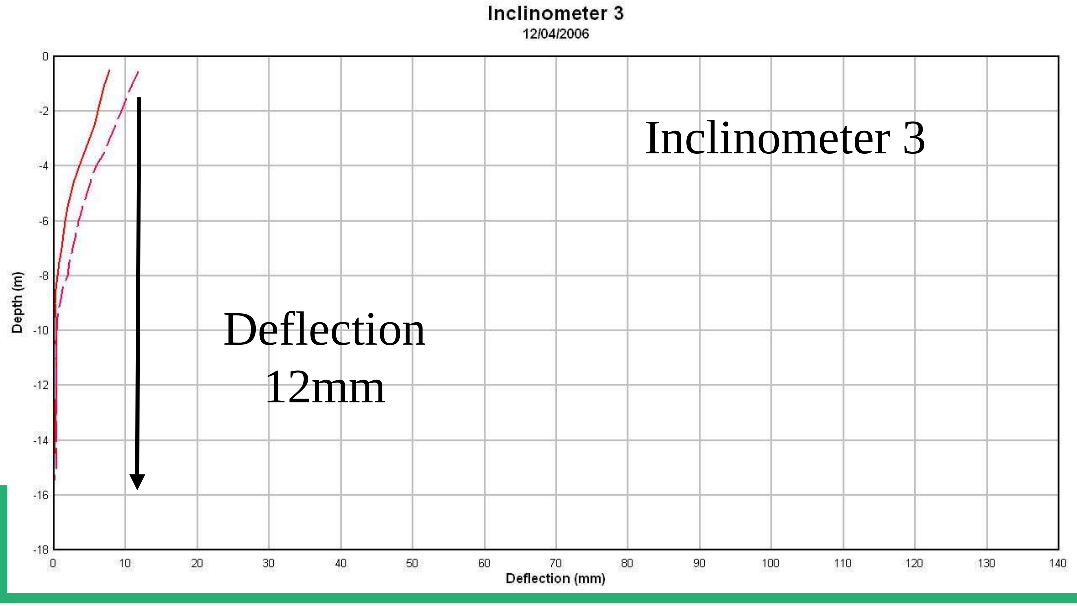
ARUP

Timber Pile Extraction

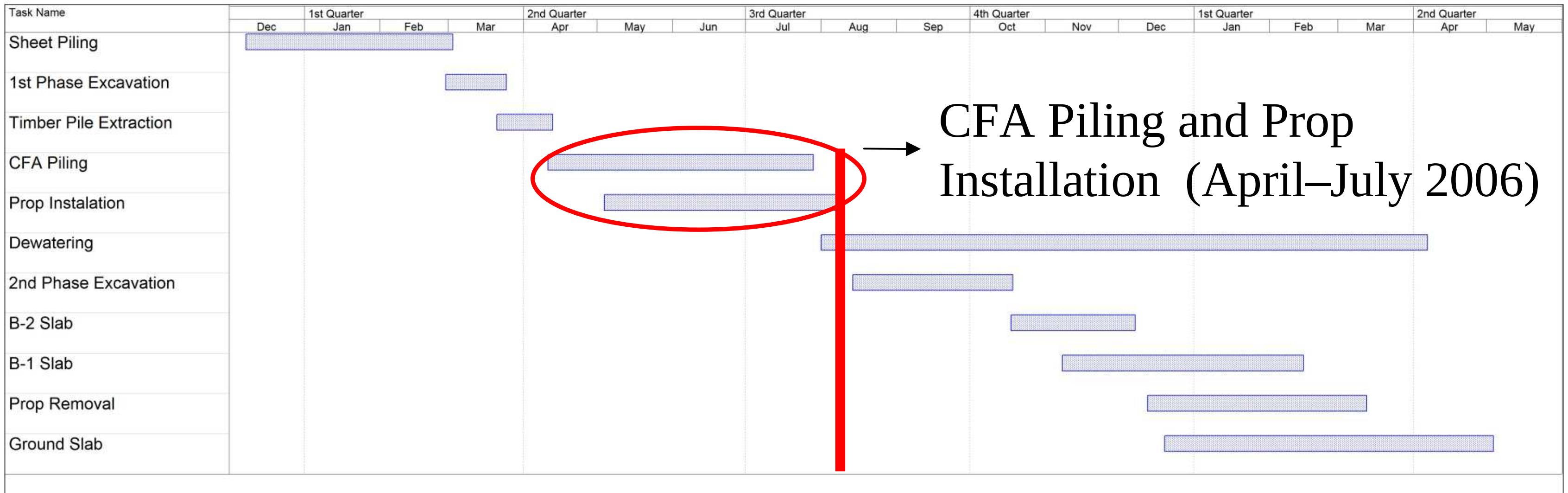


Inclinometers 12 April 2006 - Timber Pile Extraction

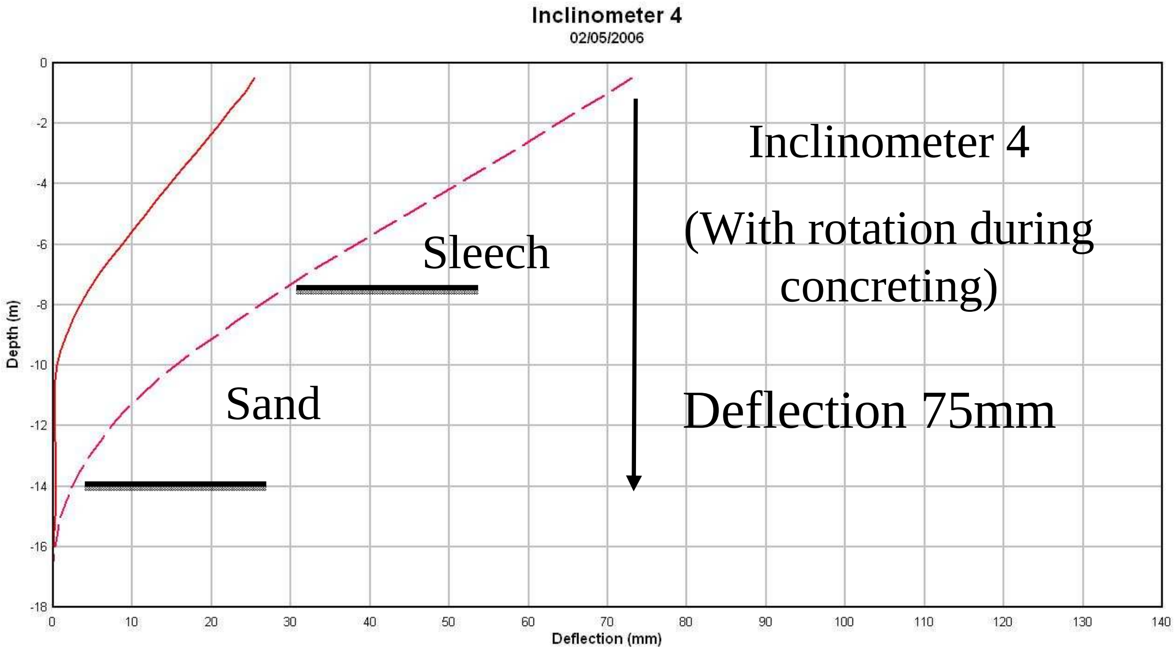


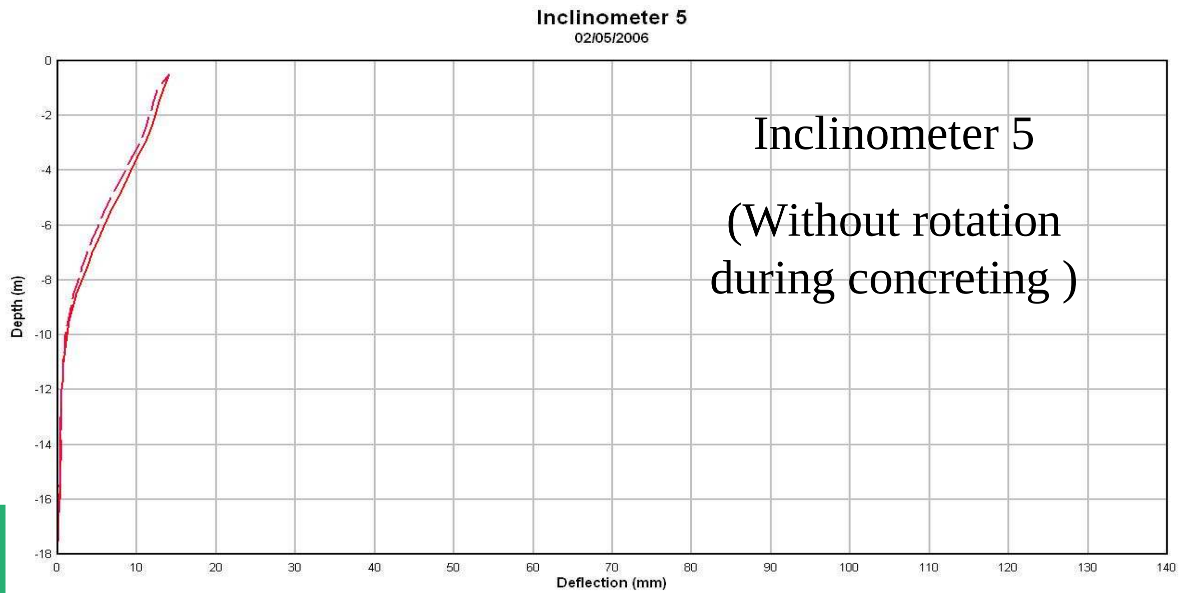


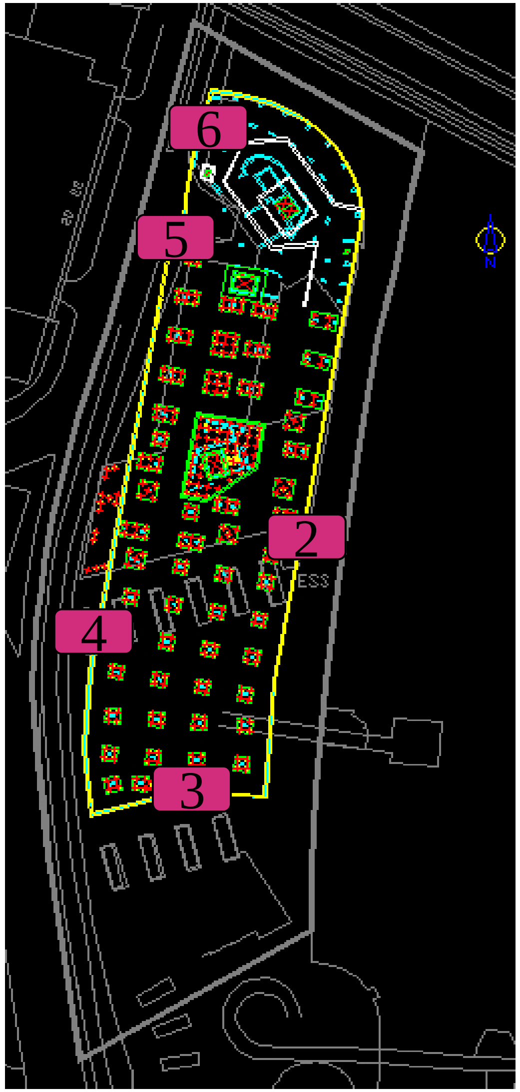
CFA Piling Works and Prop Installation



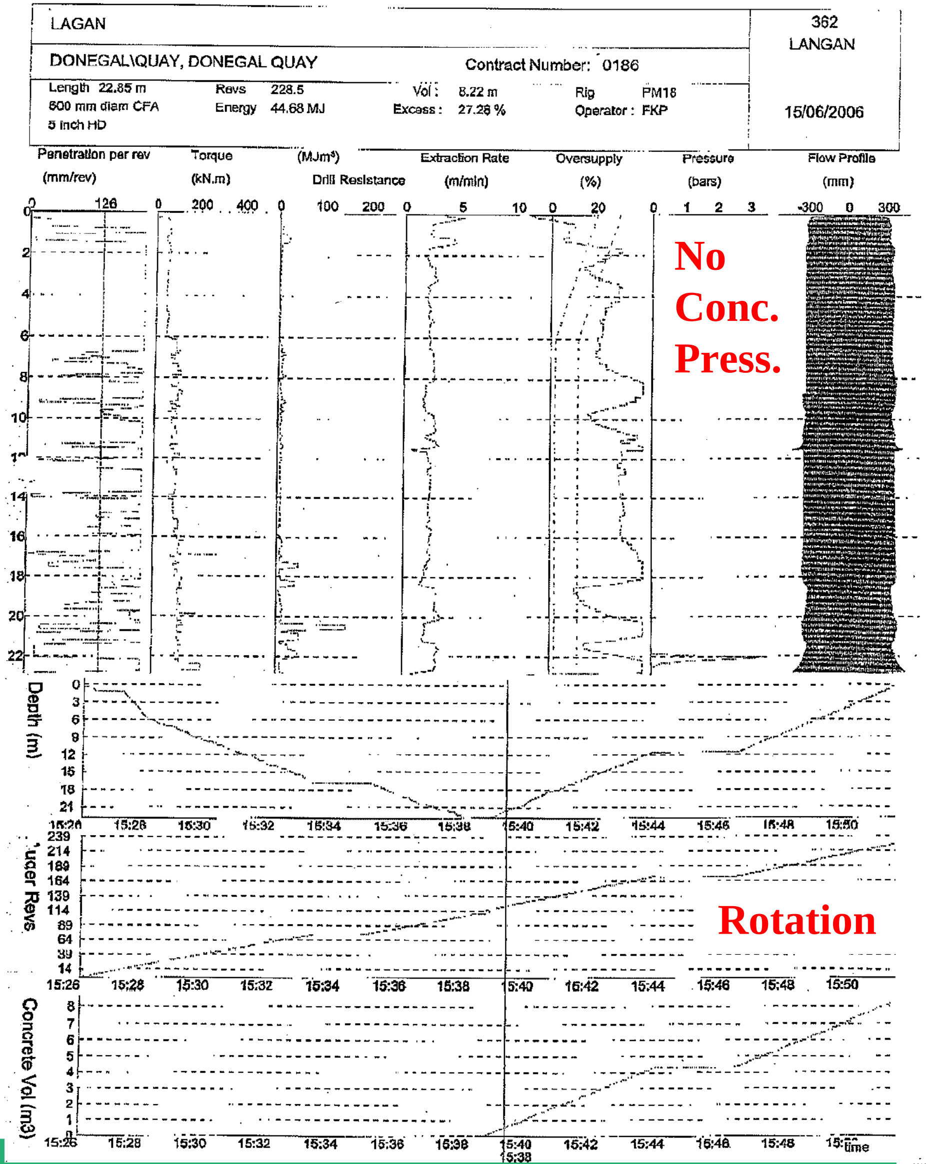
Inclinometers - 02 May 2006 - CFA Flighting of Sleech



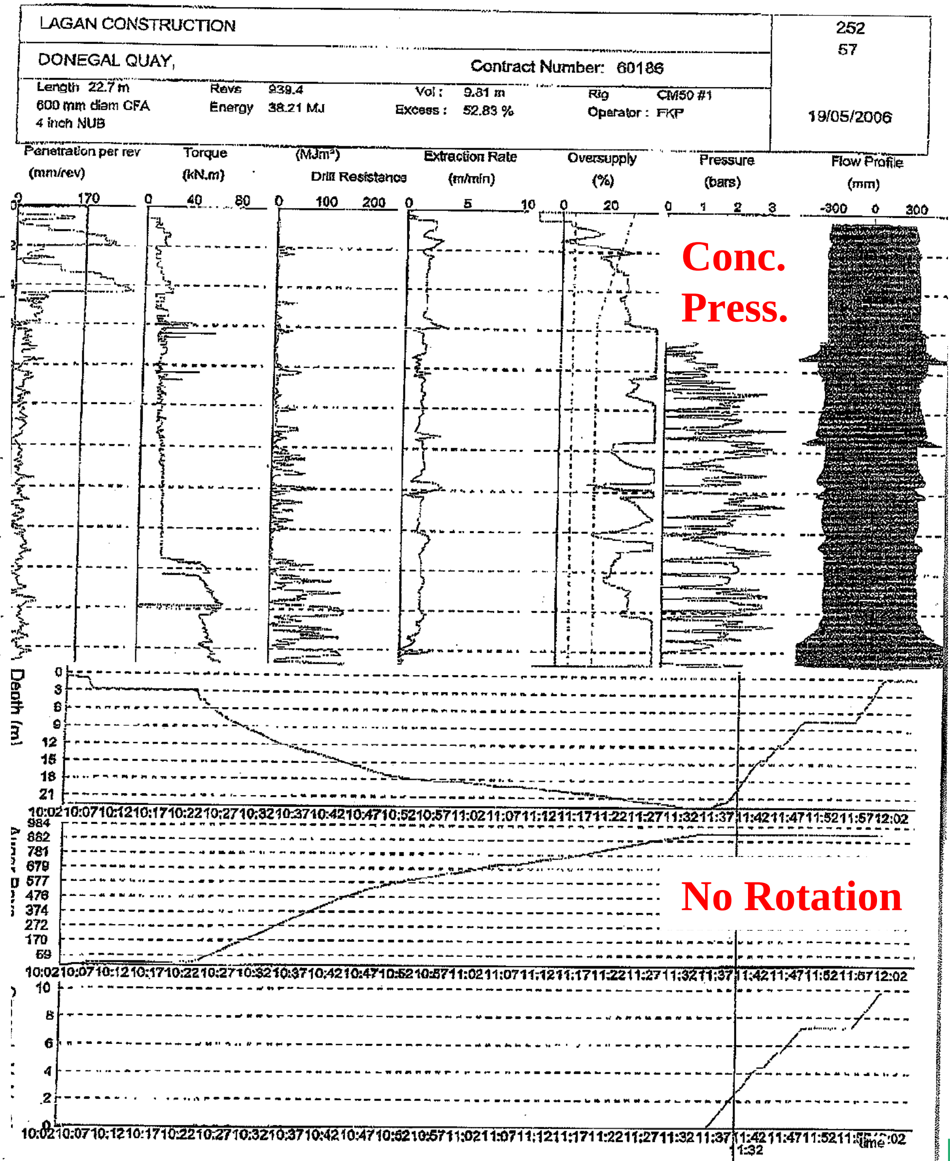




Pile 382 – Concreting Revs - 4 rev/m



Pile 252 - No rotation during concreting



ARUP

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

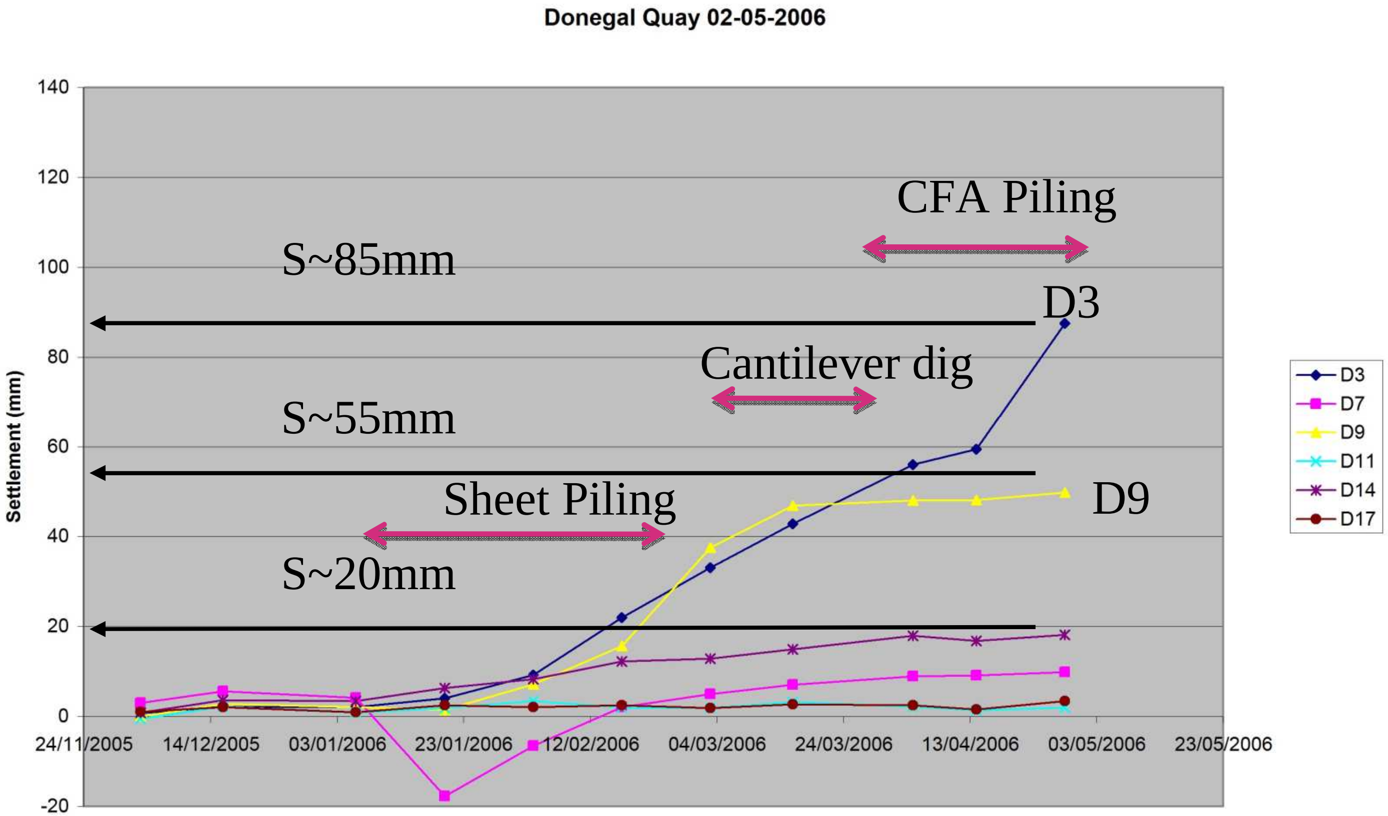
Auger diameters 300mm – 2000mm

About 1m reduction to drilling depth

Alternatively - Use cased CFA

Dawson Construction Plant Ltd

Settlements
Sheet piles/ Dig / CFA piling



Trigger set at 50mm for whole constract!!

Review – What was causing movement

- Reassessment of trigger values – impact on utilities / buildings

ARUP

Donegall Quay Comments

Construction processes cause ground movments

- 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?