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Cambridge Centre for
**Smart Infrastructure
and Construction**

地盤工事におけるOMの国際的動向

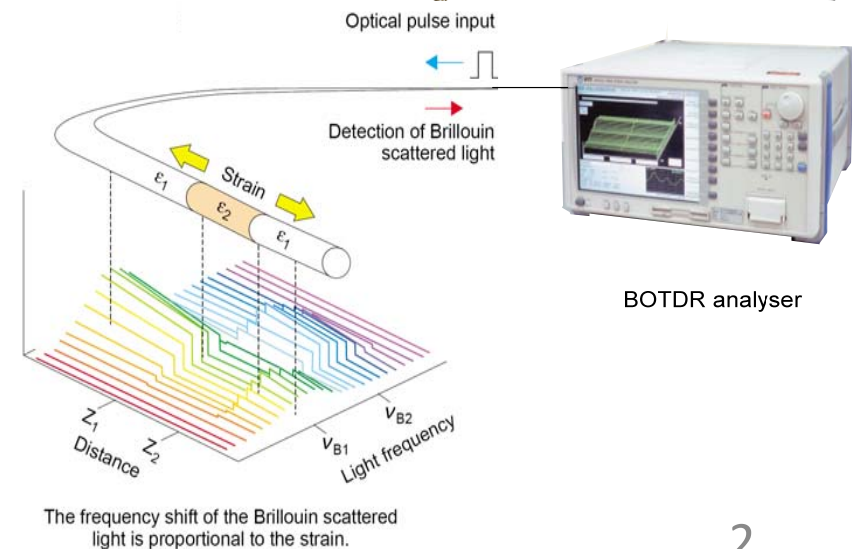
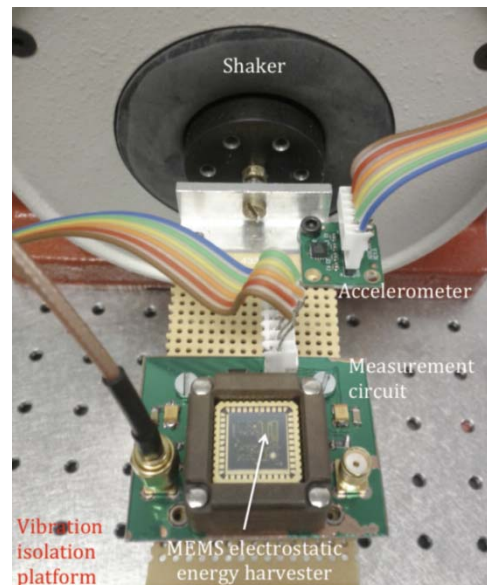
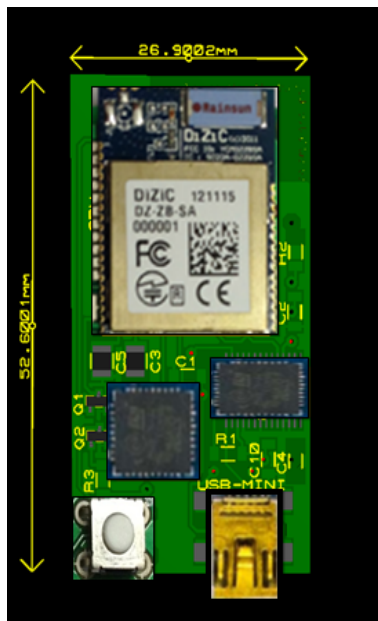
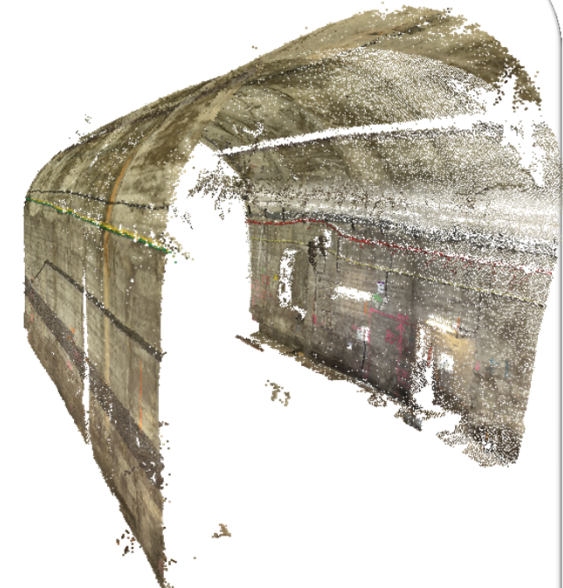
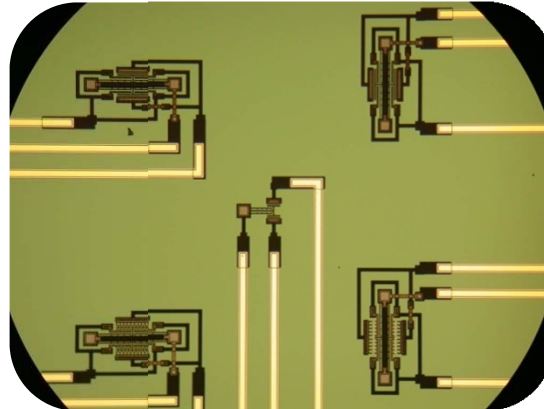
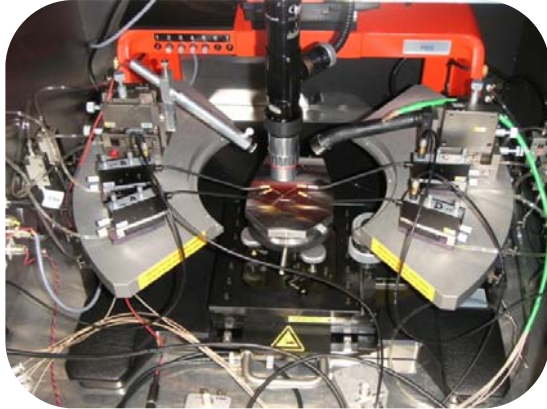
Kenichi Soga, Cambridge University

With help from Duncan Nicholson, Arup



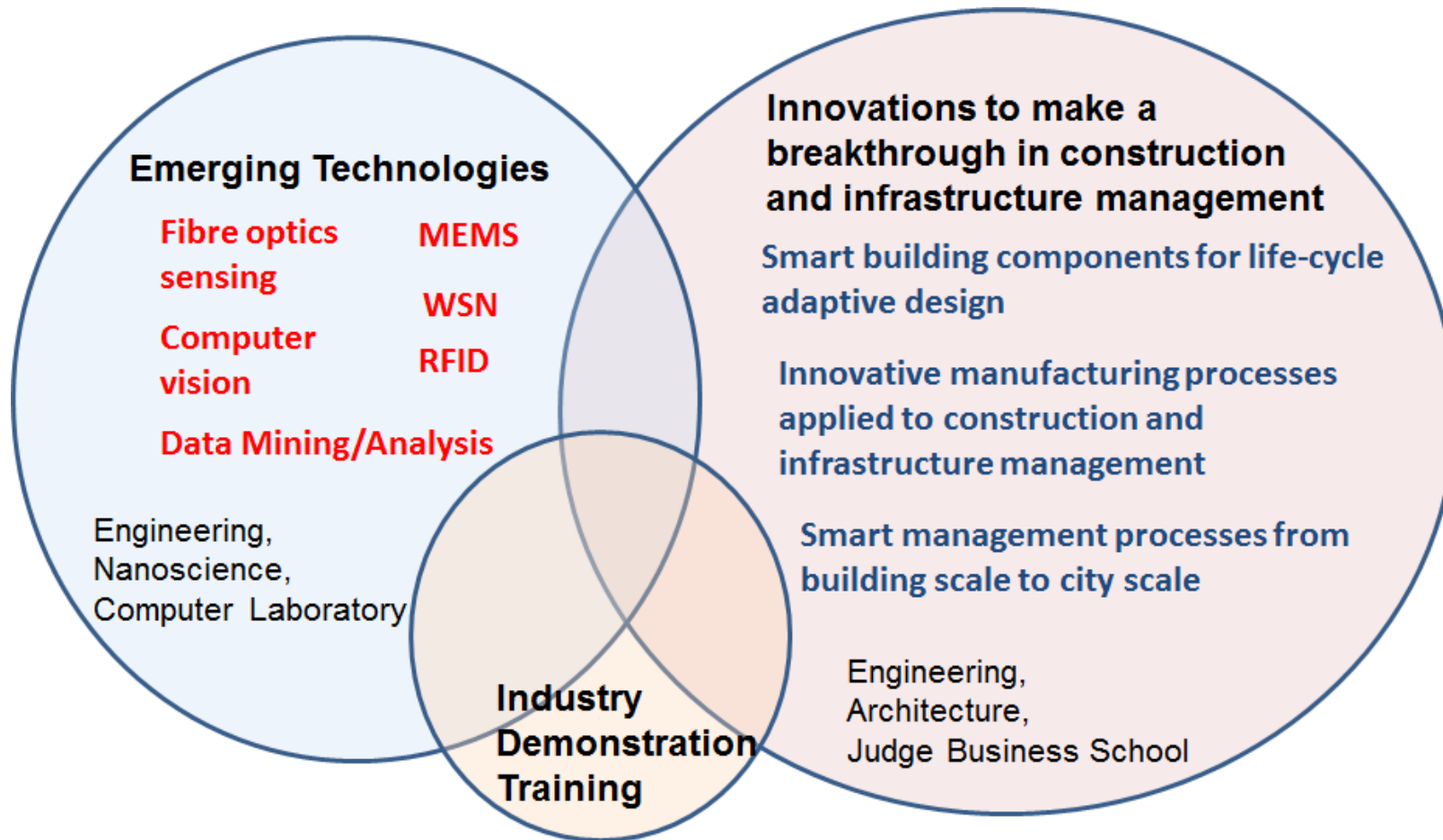
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- Fibre optics distributed sensors
- Micro-Electro-Mechanical Sensors
- Wireless Sensor Network
- Computer Vision
- Power Harvesting
- Active RFID





Cambridge Centre for
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EPSRC

Engineering and Physical Sciences
Research Council

Technology Strategy Board
Driving Innovation



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UK Government £10m + Industrial support - £7m

Construction Sector

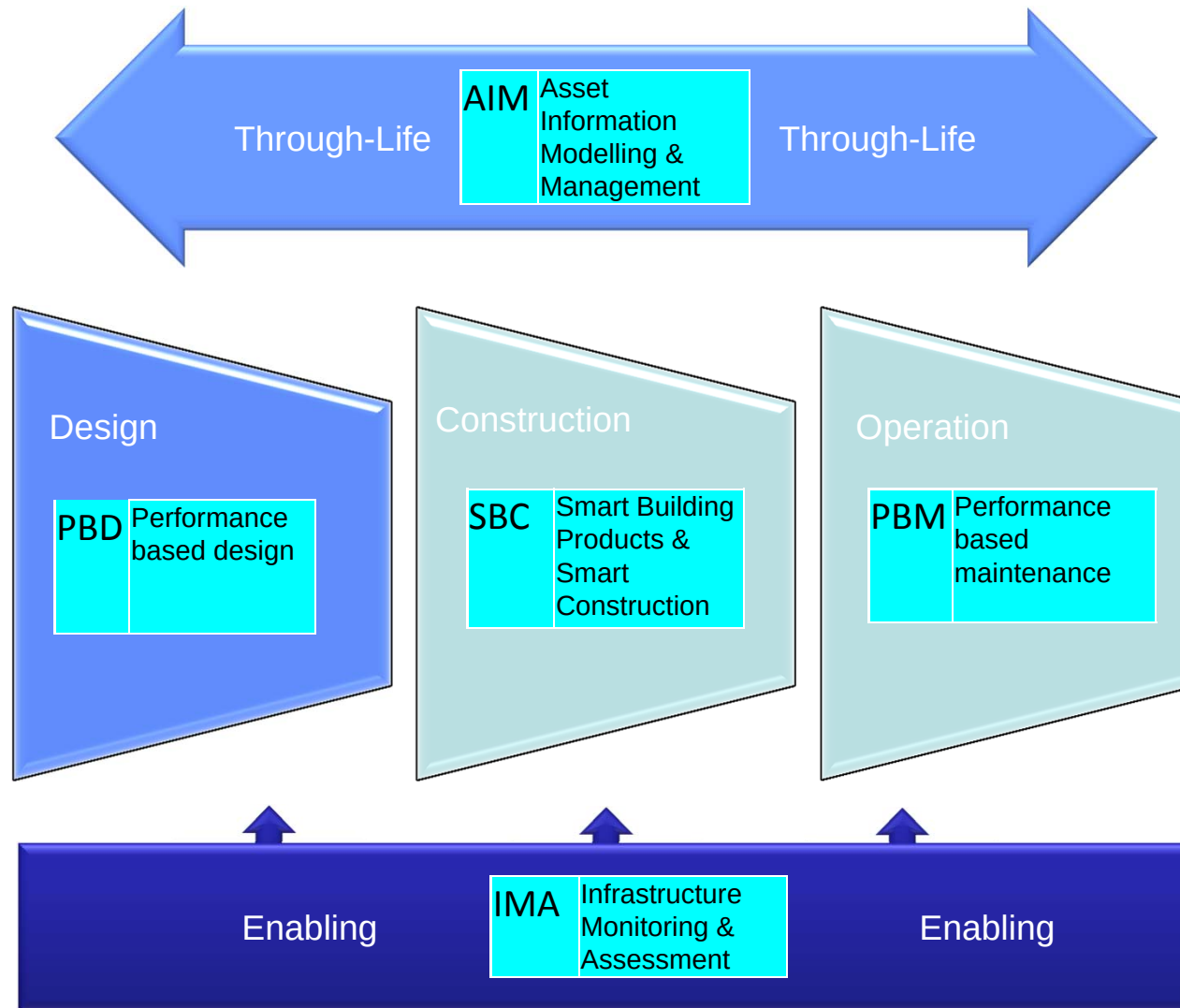


Infrastructure Sector



Manufacturing, Electrical & Information Sectors





History

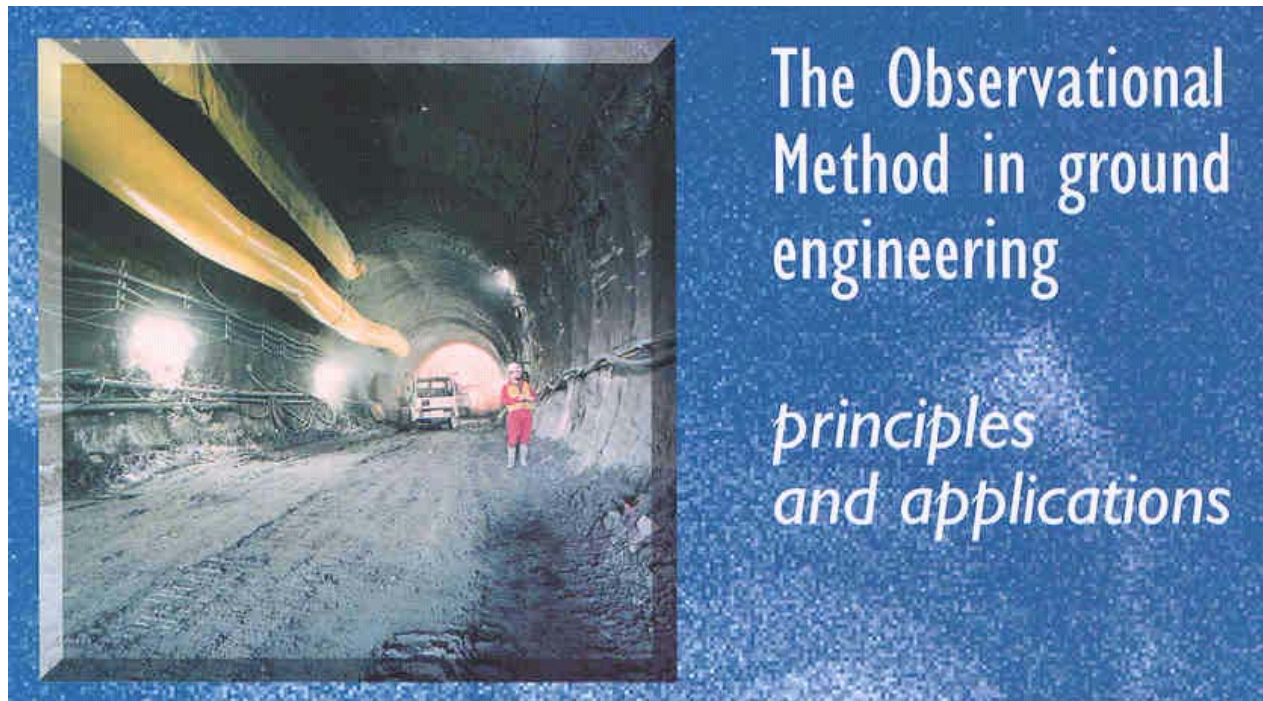
- **1969** - **Peck's Rankine Lecture**
- Early 1990's- Channel Tunnel, Limehouse Link Projects
- **1994** - **Geotechnique Symposium in Print**
- **1995** - **EC7 OM Clause**
- 1996 - ICE and HSE - NATM publications
- **1999** - **CIRIA - OM Report No 185**
- 2001 - ICE Managing Geotechnical Risk
- 2003 - CIRIA C580 – Embedded retaining Walls.
- 2006 - Geotechnet - www.geotechnet.org

Peck's (1969) Observational Method – Eight Ingredients

1. **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.

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.



Goals

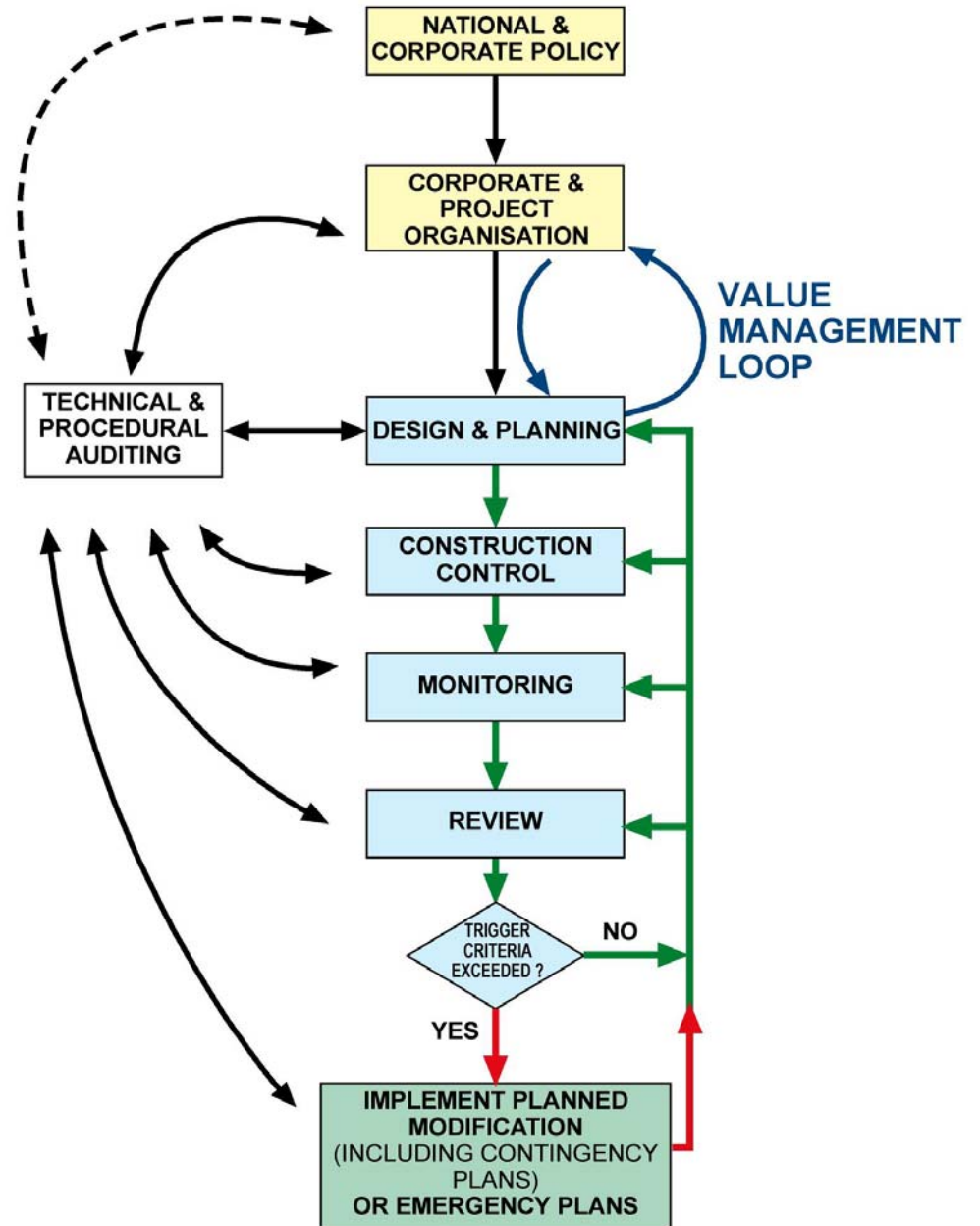
- Clarify OM definition and process
- Integrate OM process into modern design
- Focus on “Ab Initio” applications – better planning

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



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

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**

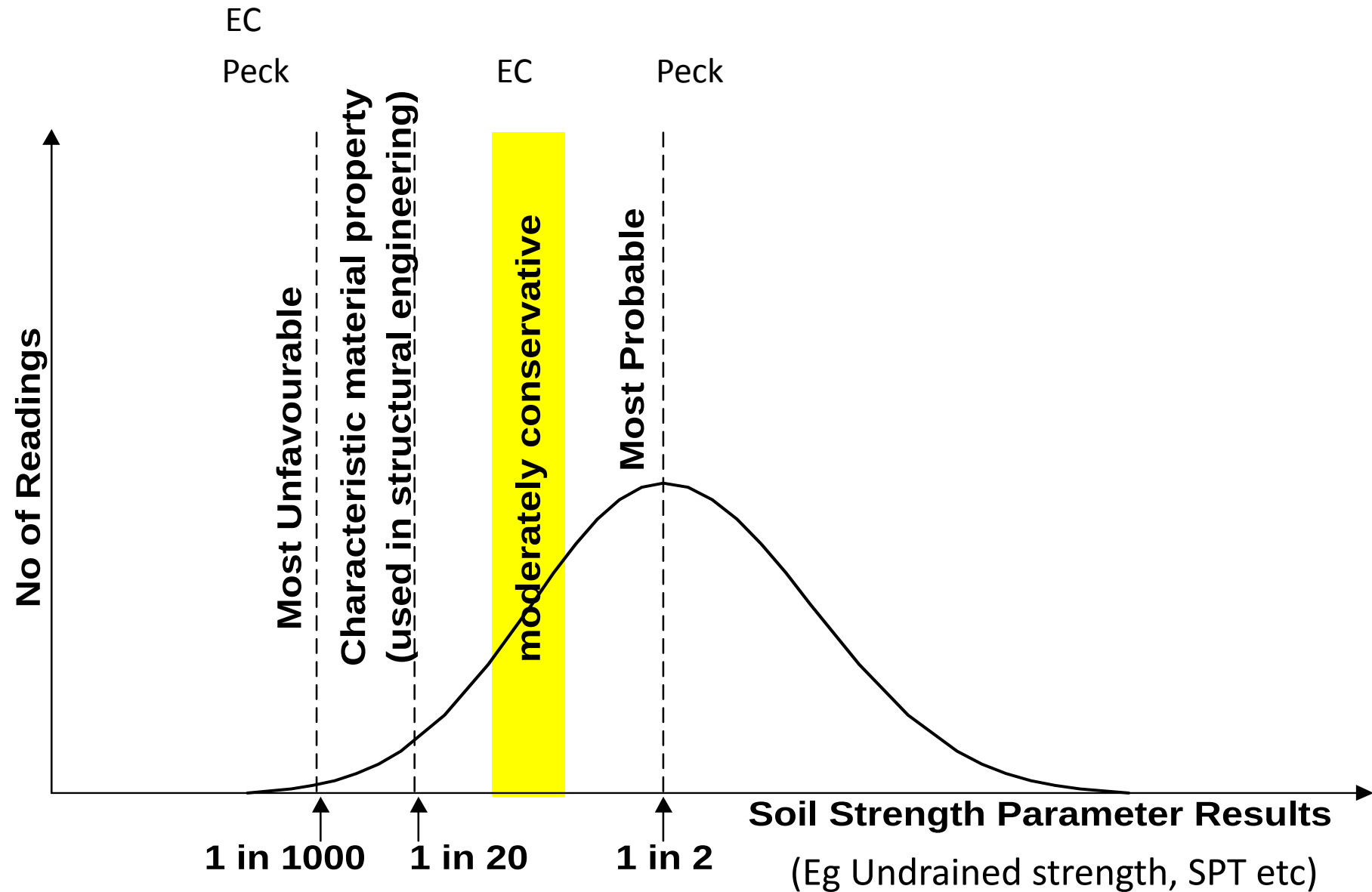
Most Unfavourable

Not used

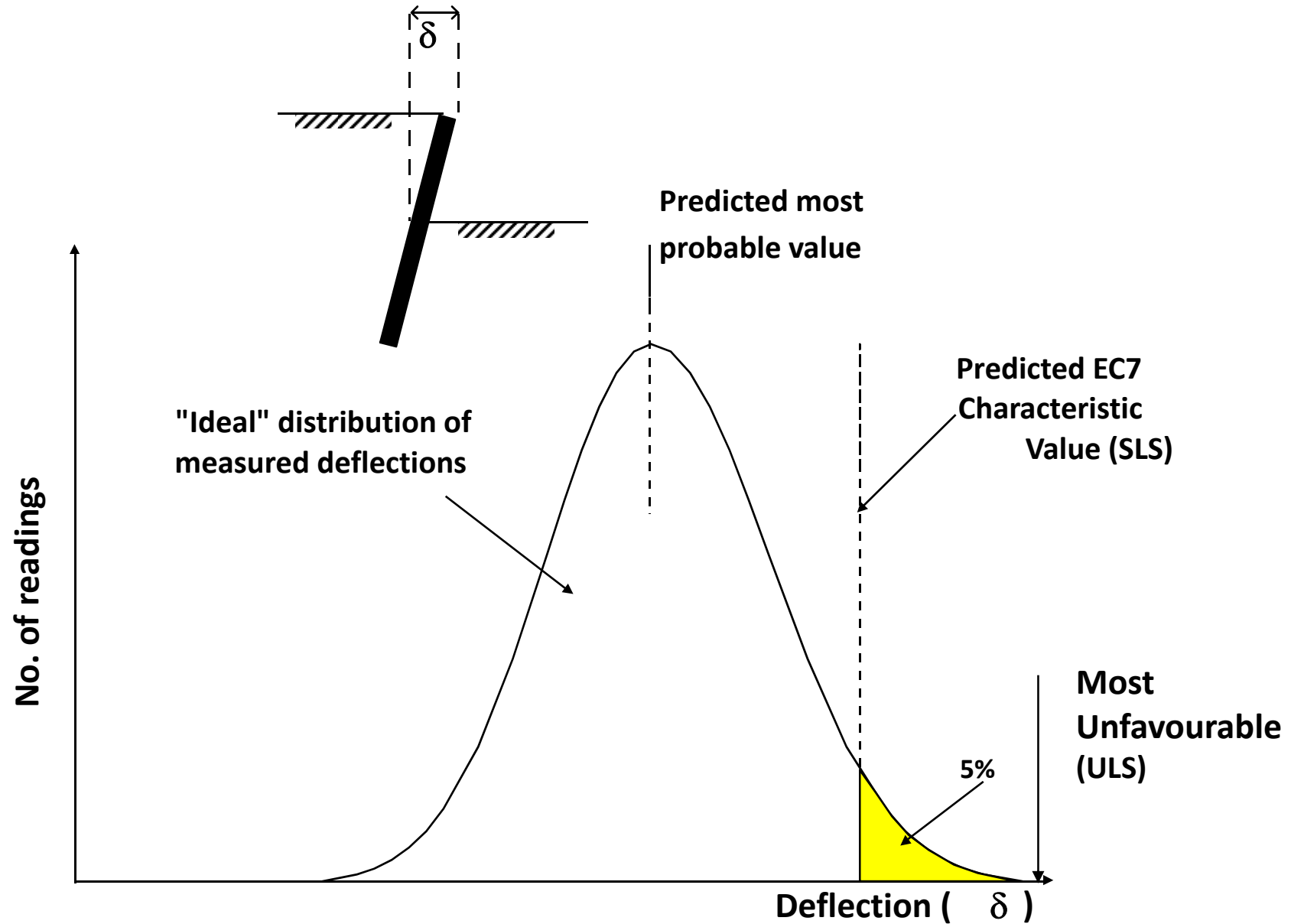
Mod Conservative or
Characteristic

Worst credible

UK Design Codes - Soil Strength Parameters



Ideal EC7 Predicted versus Measured Performance



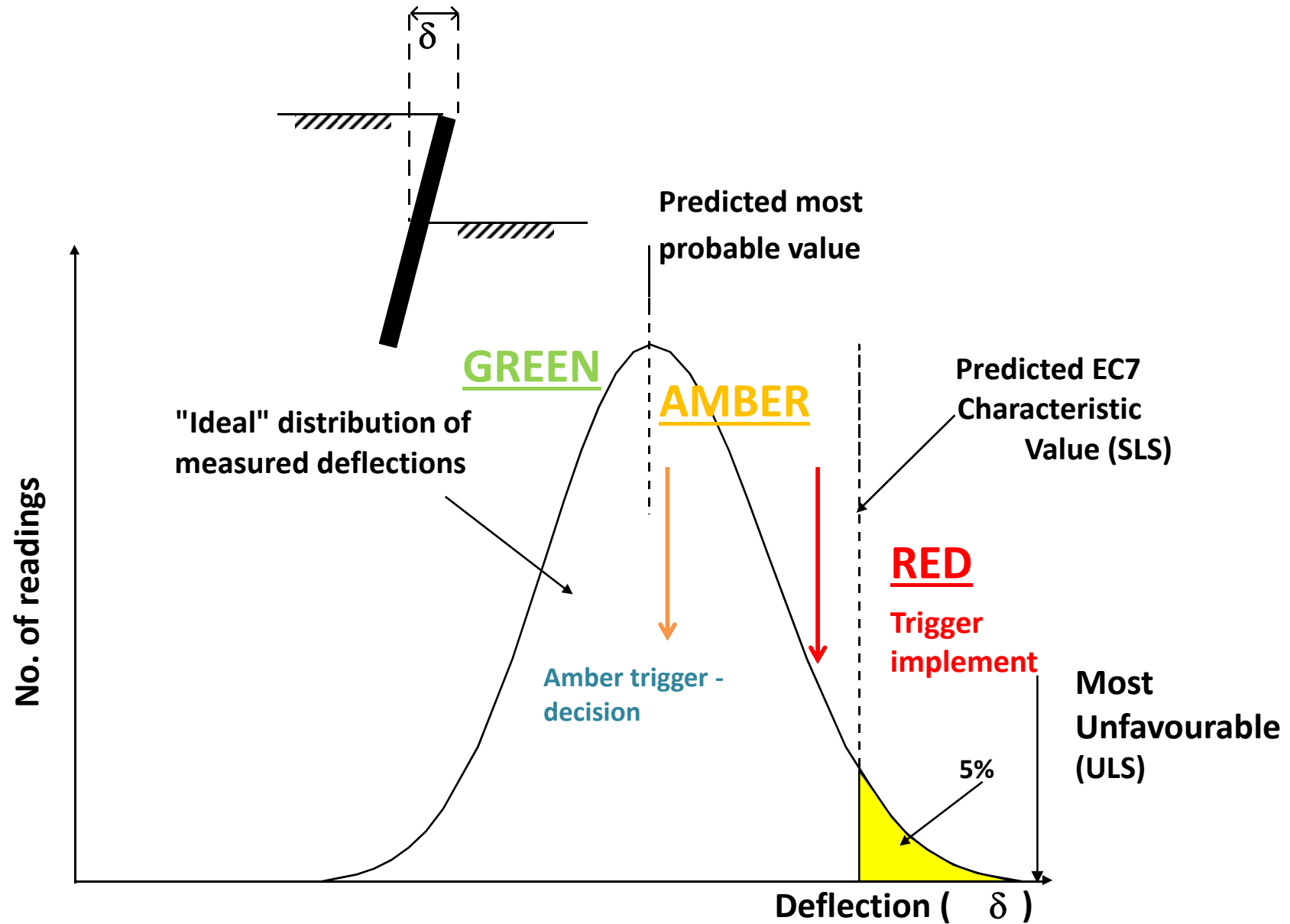
Trigger Criteria

Traffic light conditions include:-

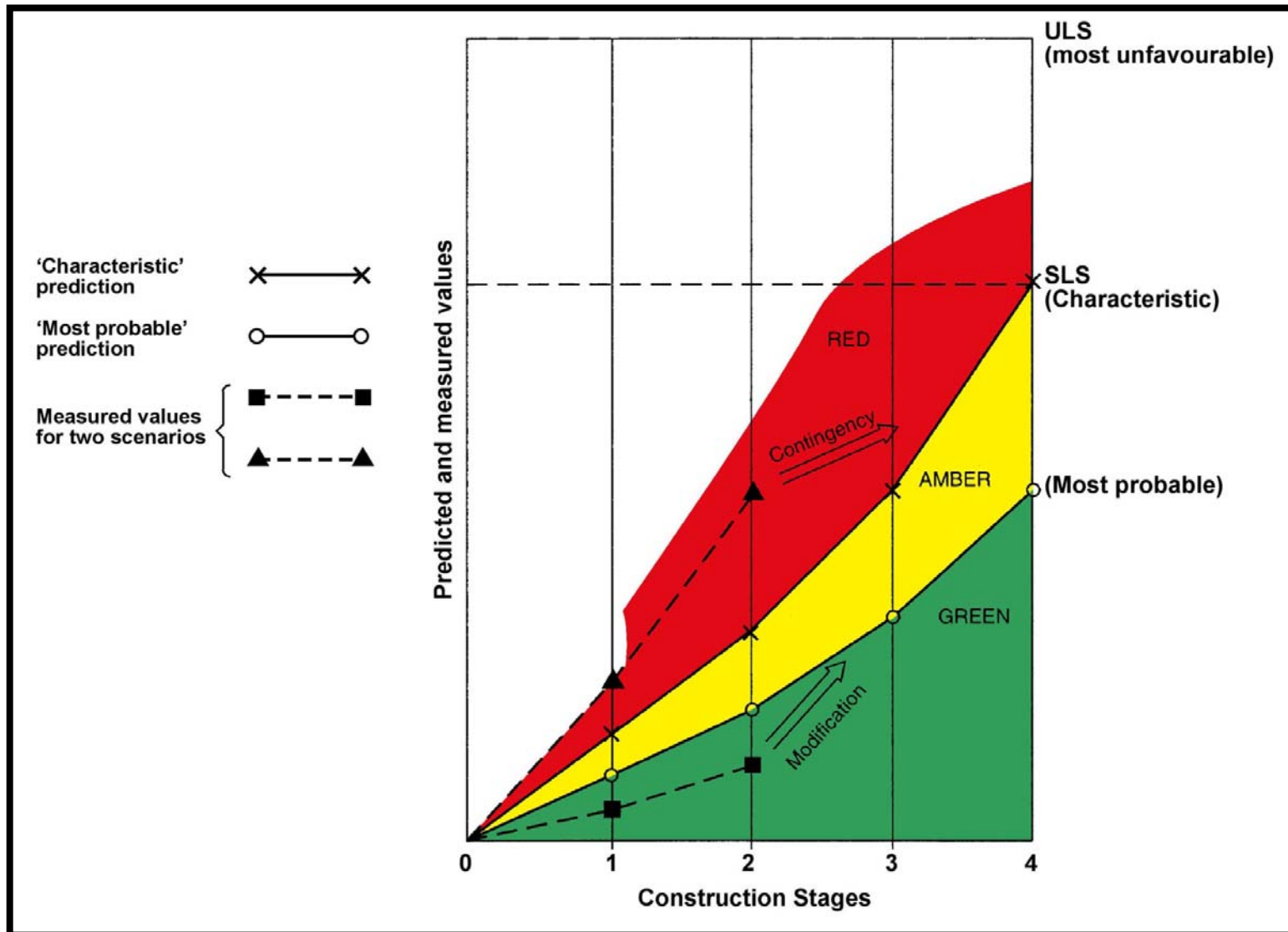
- **Green** = Safe site condition.
- **Amber** = Decision stage
- **Red** = Implement planned modifications
- **Emergency** = Evacuation

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

Ideal EC7 Predicted versus Measured Performance



CIRIA (1999) Fig 3.13 Multi Stage Excavation



New Civil Engineer

nce

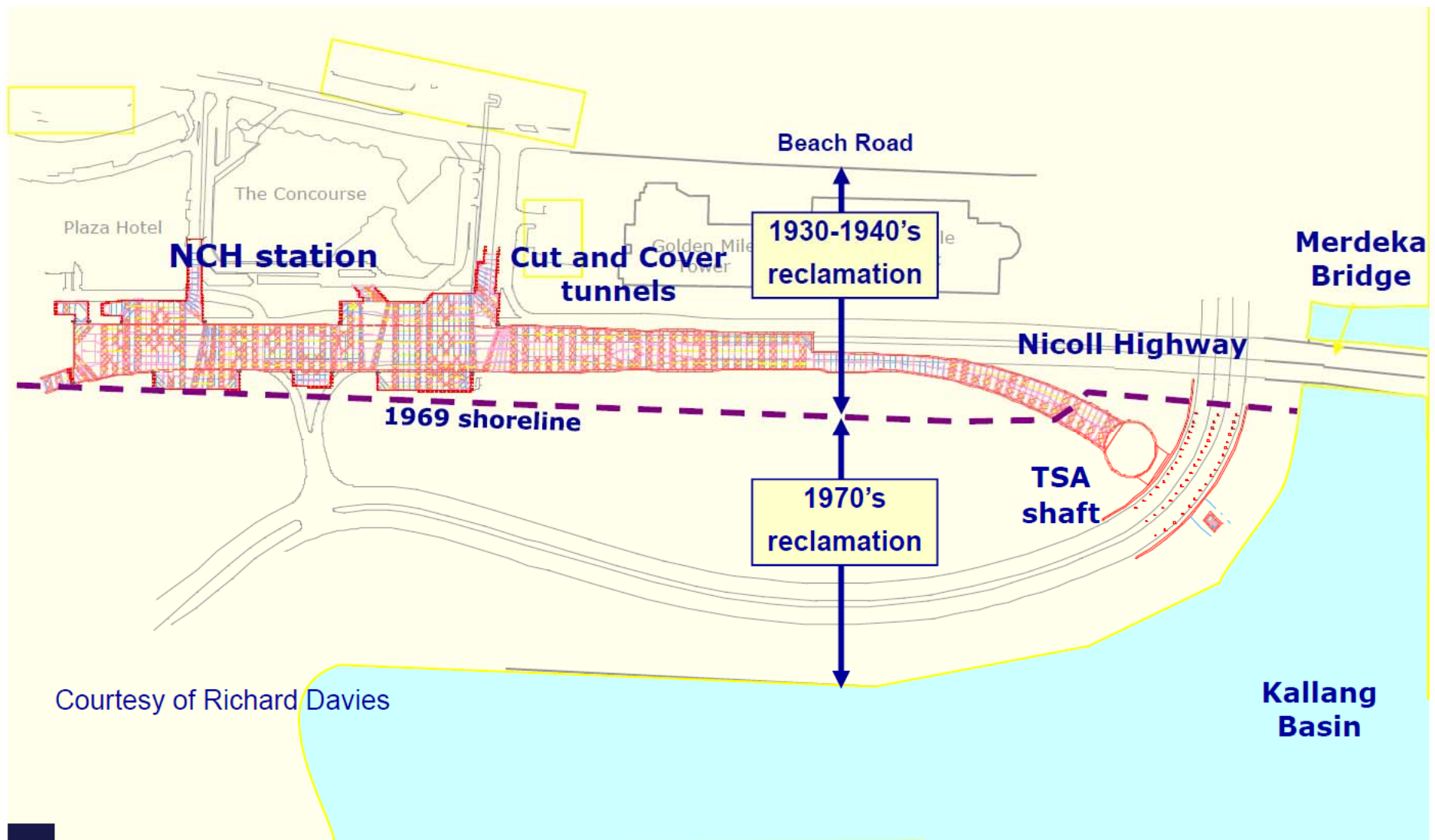
www.nceplus.co.uk

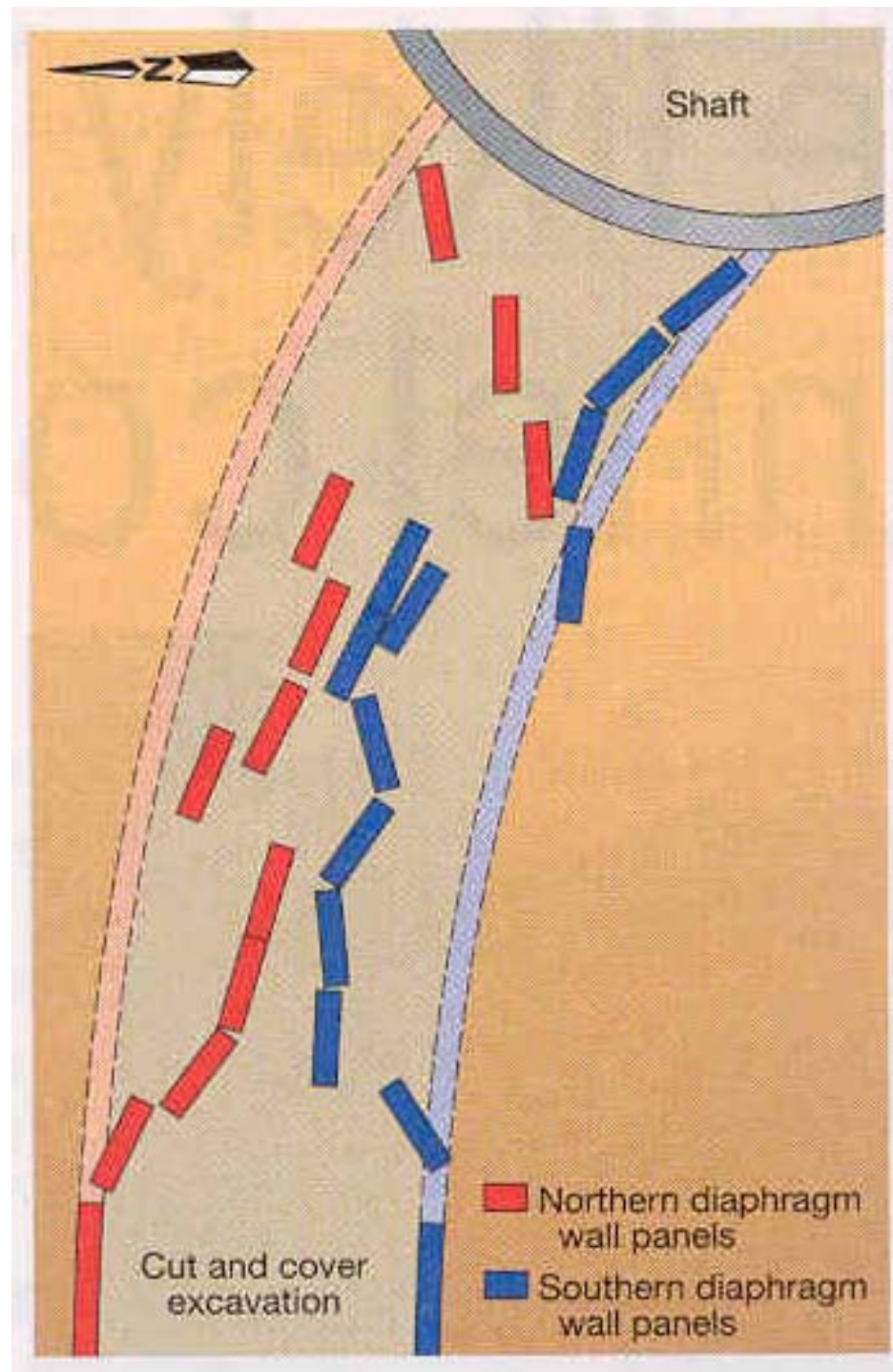
Magazine of the Institution of Civil Engineers
29 April 2004

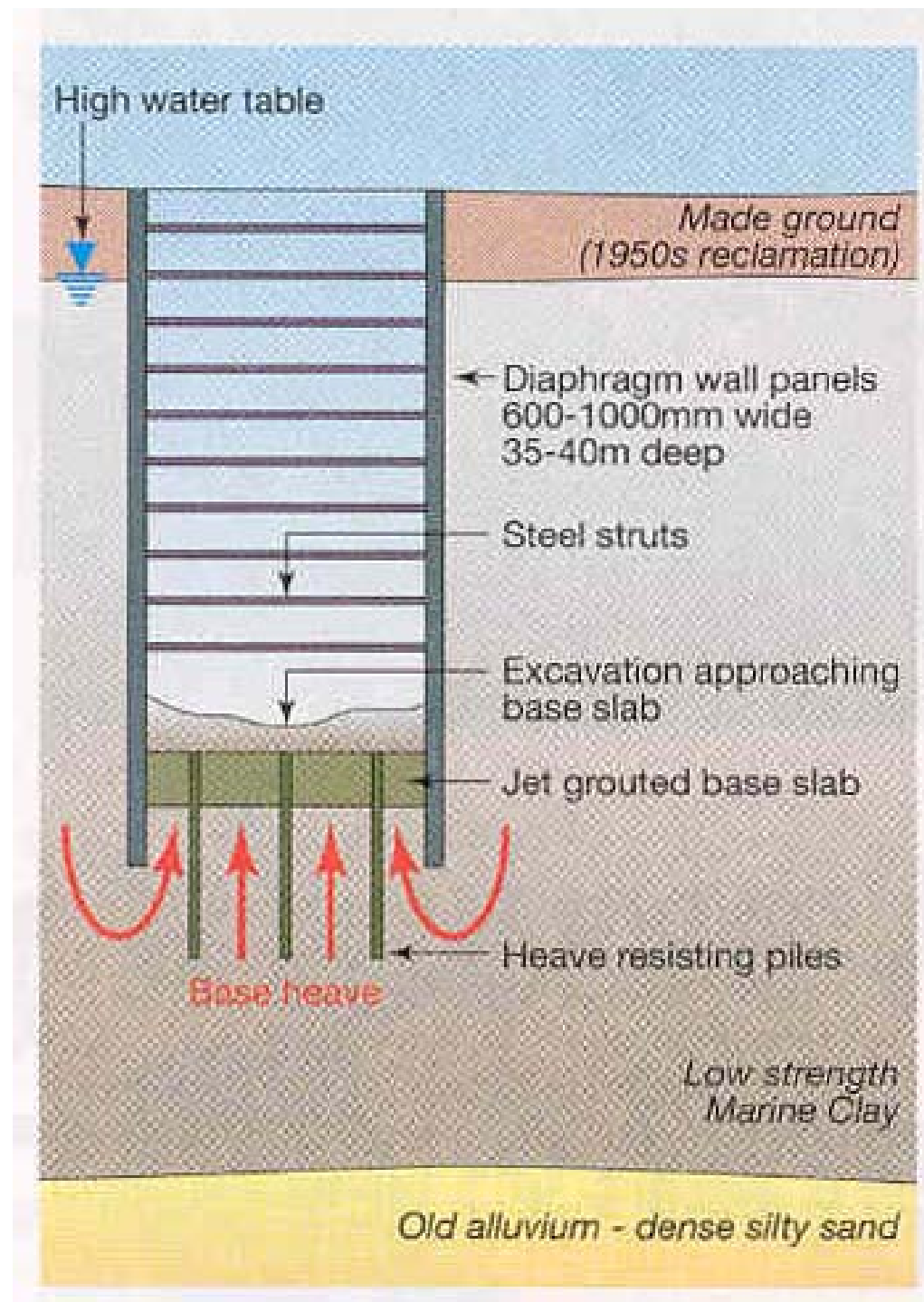
Singapore cut and cover collapse

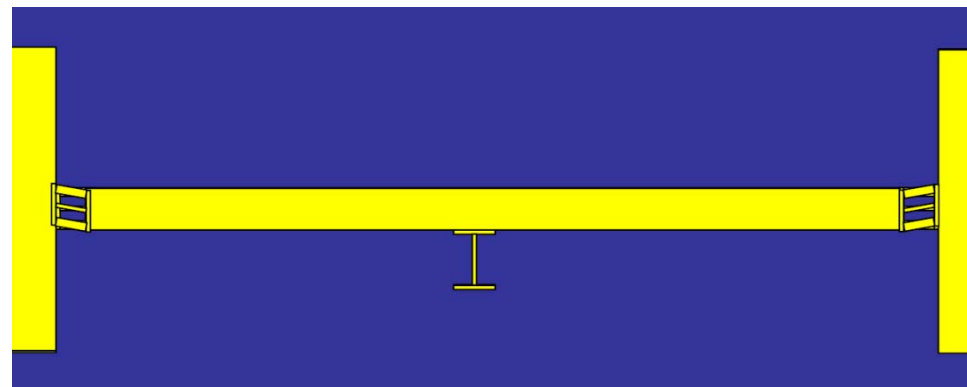












Hight, GCG



SOUTH

ABH 31

M309

M304

ABH 32

NORTH

100
90
80
70

Fill
Upper estuarine

Upper
Marine
Clay

Upper F2

Lower
Marine
Clay

Base marine clay

Old
Alluvium

Fill
Upper estuarine

Upper
Marine
Clay

Upper F2

Lower
Marine
Clay

Top of OA

Lower
estuarine

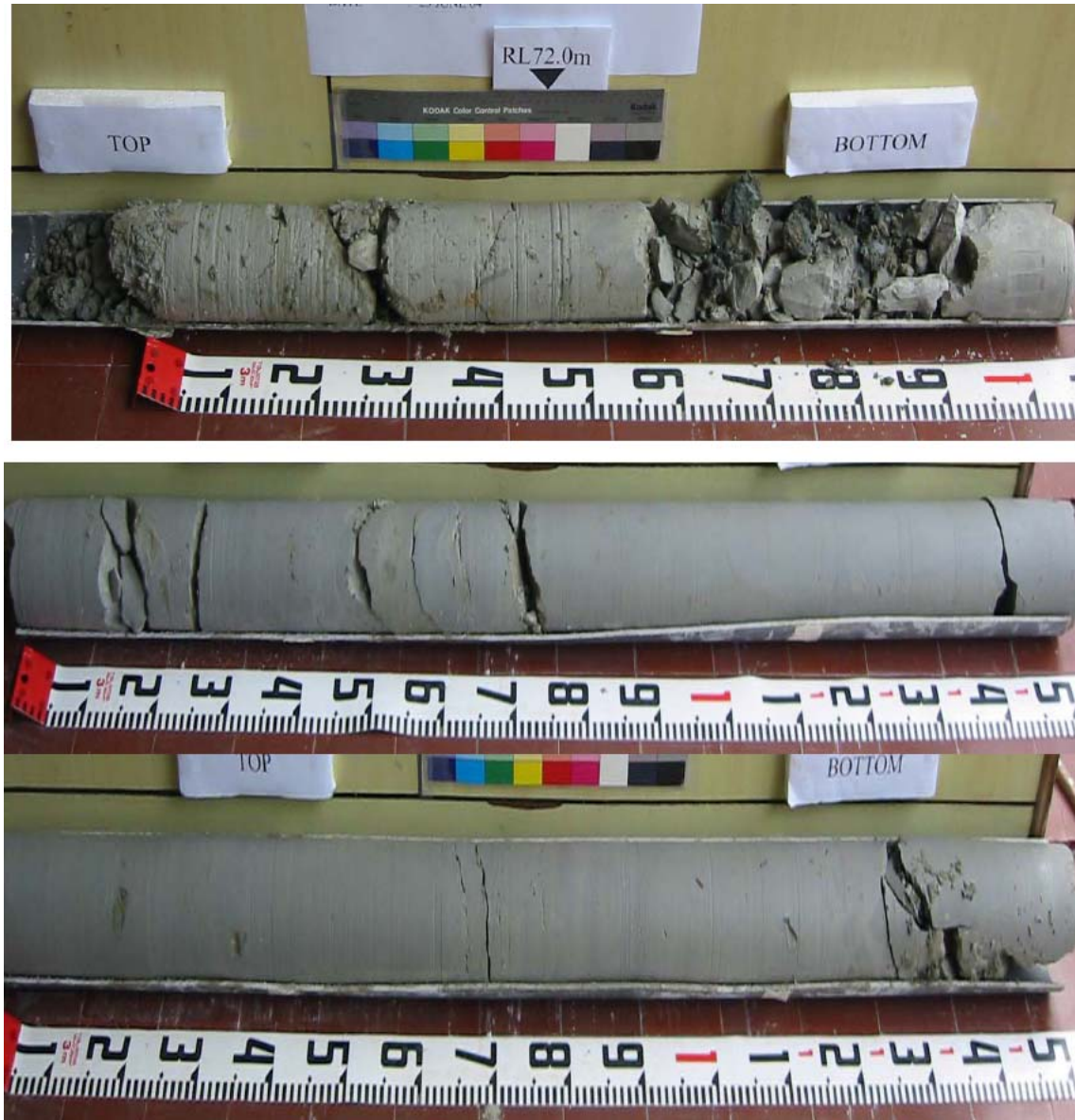
Lower F2

Old
Alluvium

Typical section in M3

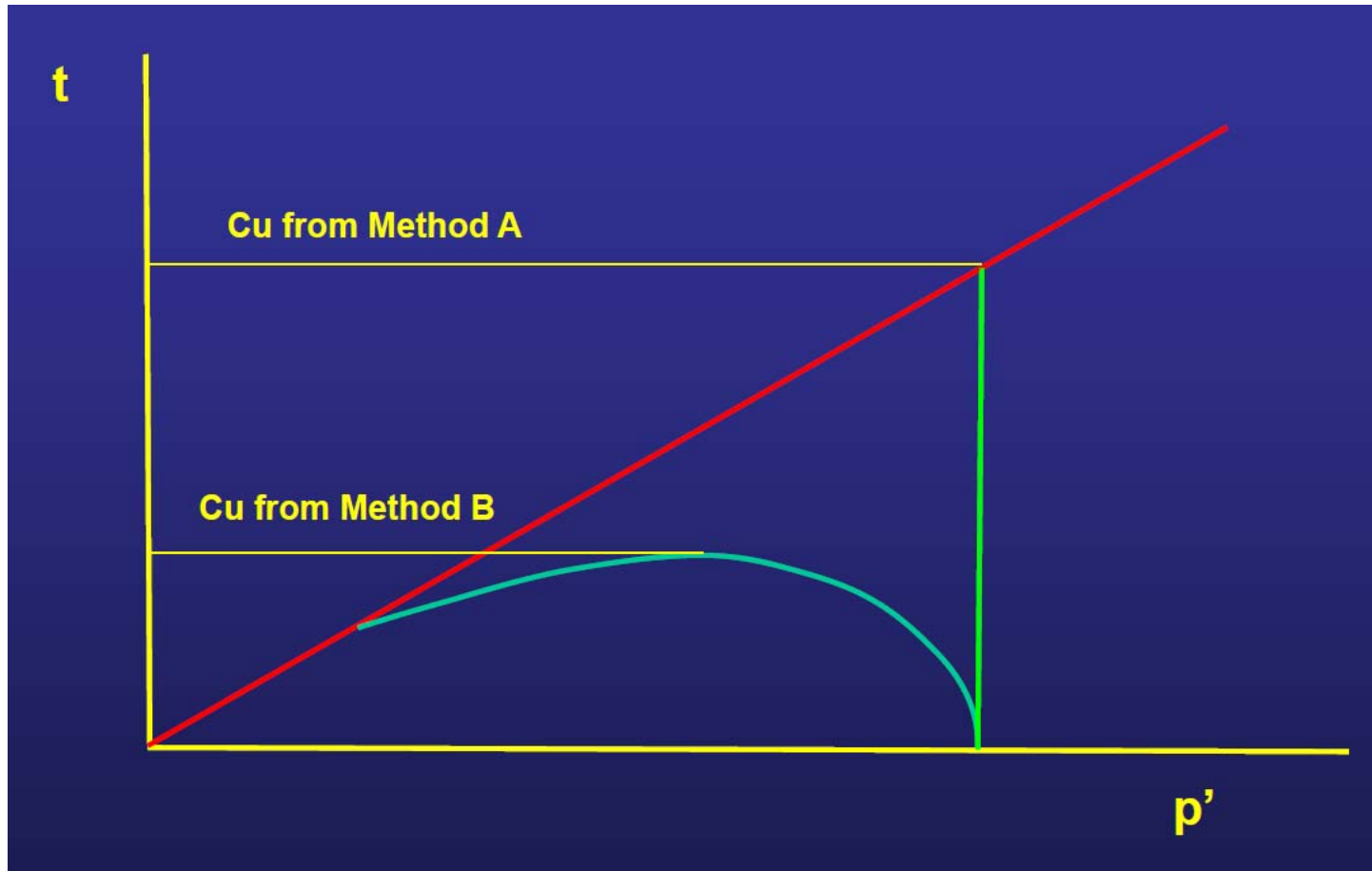
Hight, GCG

Quality of Jet Grouting



Hight, GCG

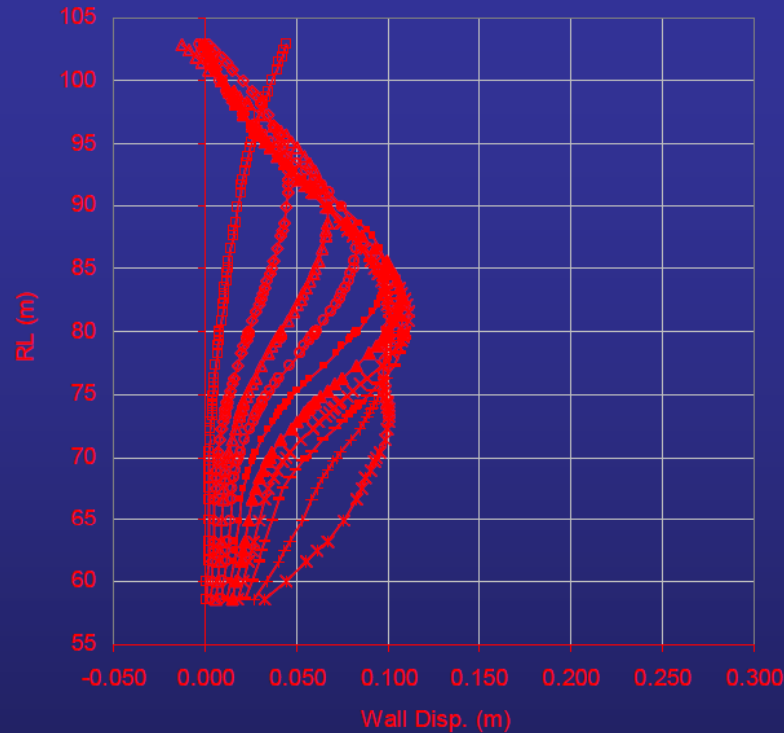
Grouted material (brittle) – Soft Clay (ductile)
Mass properties?



Hight, GCG

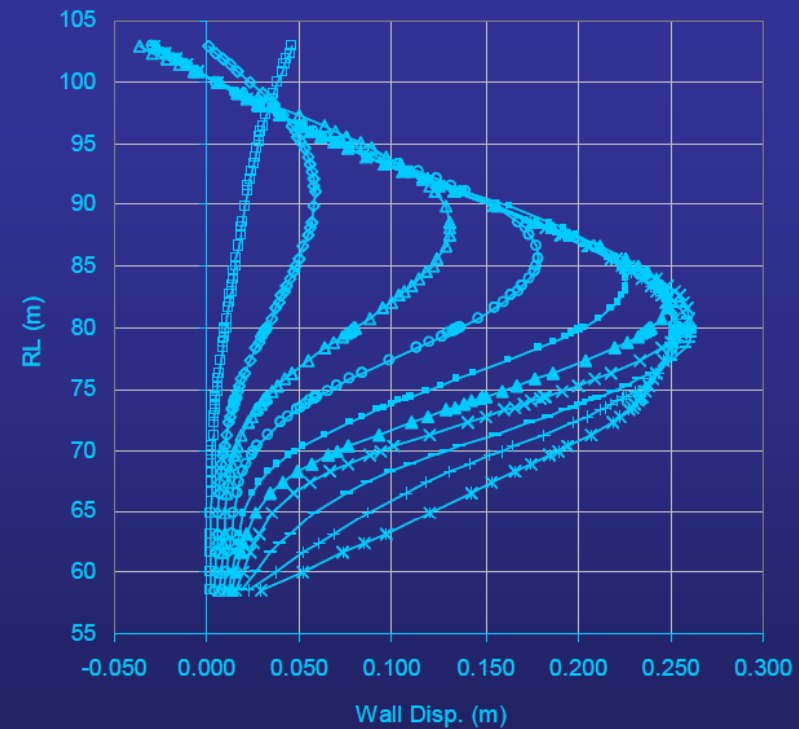


Method A



—□— Exc to RL 100.9 for S1 —◇— Exc to RL 98.1 for S2 —△— Exc to RL 94.6 for S3
 —○— Exc to RL 91.1 for S4 —■— Exc to RL 87.6 for S5 —▲— Exc to RL 84.6 for S6
 —×— Exc to RL 81.6 for S7 —+— Exc to RL 78.3 for S8 —+— Exc to RL 75.3 for S9
 —*— Exc to RL 72.3 for S10

Method B



—□— Exc to RL 100.9 for S1 —◇— Exc to RL 98.1 for S2 —△— Exc to RL 94.6 for S3
 —○— Exc to RL 91.1 for S4 —■— Exc to RL 87.6 for S5 —▲— Exc to RL 84.6 for S6
 —×— Exc to RL 81.6 for S7 —+— Exc to RL 78.3 for S8 —+— Exc to RL 75.3 for S9
 —*— Exc to RL 72.3 for S10

M3 - South Wall Displacement Method A versus Method B

Back Analysis

- (1) Develop a model of the events, leading up to the failure, using the available evidence.
- (2) Make adjustments to parameters, design methodologies or assumptions within credible bounds until the model matches the actual behaviour observed in the field.
- (3) Assess validity of the original design method and the development of subsequent design modifications with greater confidence.
- (4) A vital tool in recovery of unexpected events or problems before failure occurs

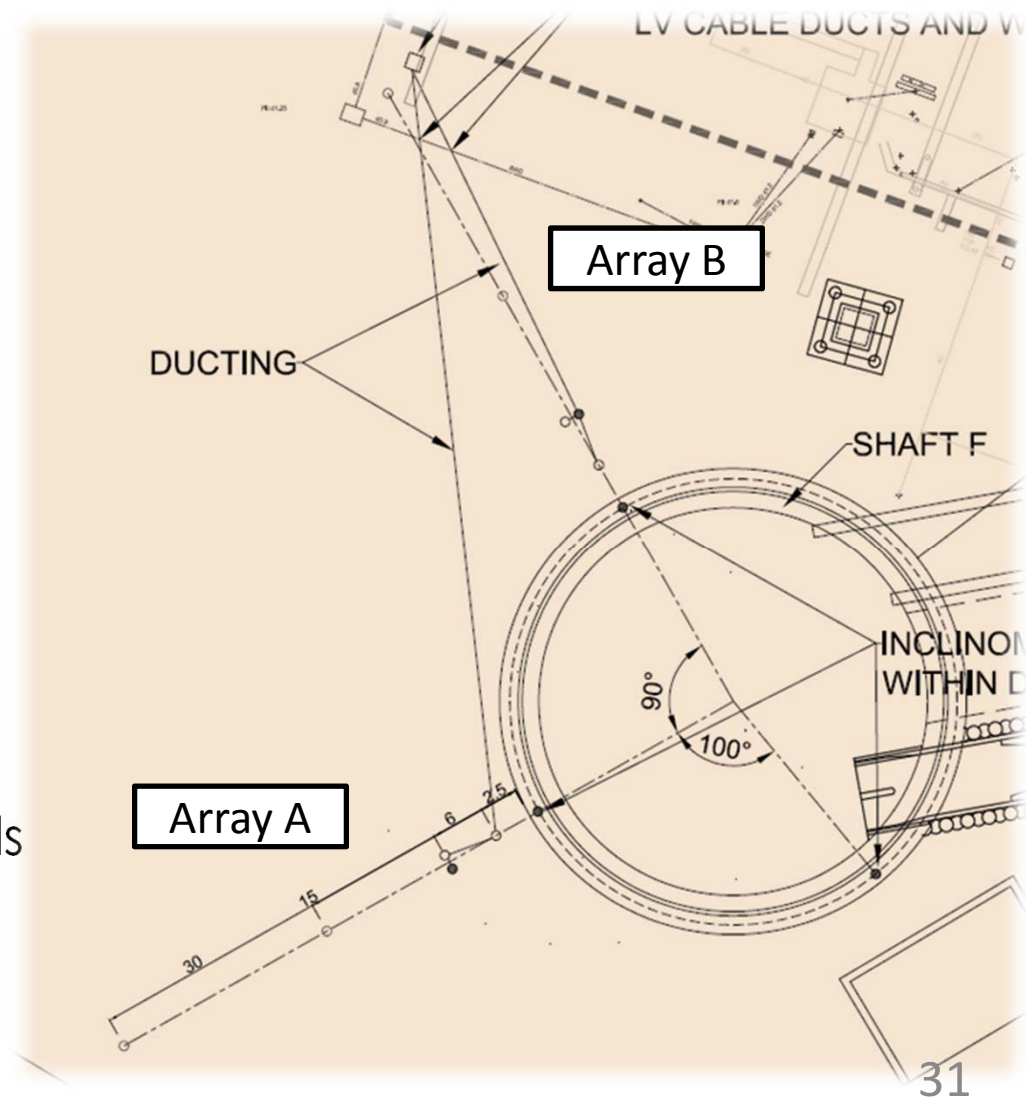
Construction Sequences

'I had ...failed to examine all the available evidence with an open mind....pre-occupation with the wrong phenomenon created a blind spot to the significant phenomenon'. (Peck, 1969)

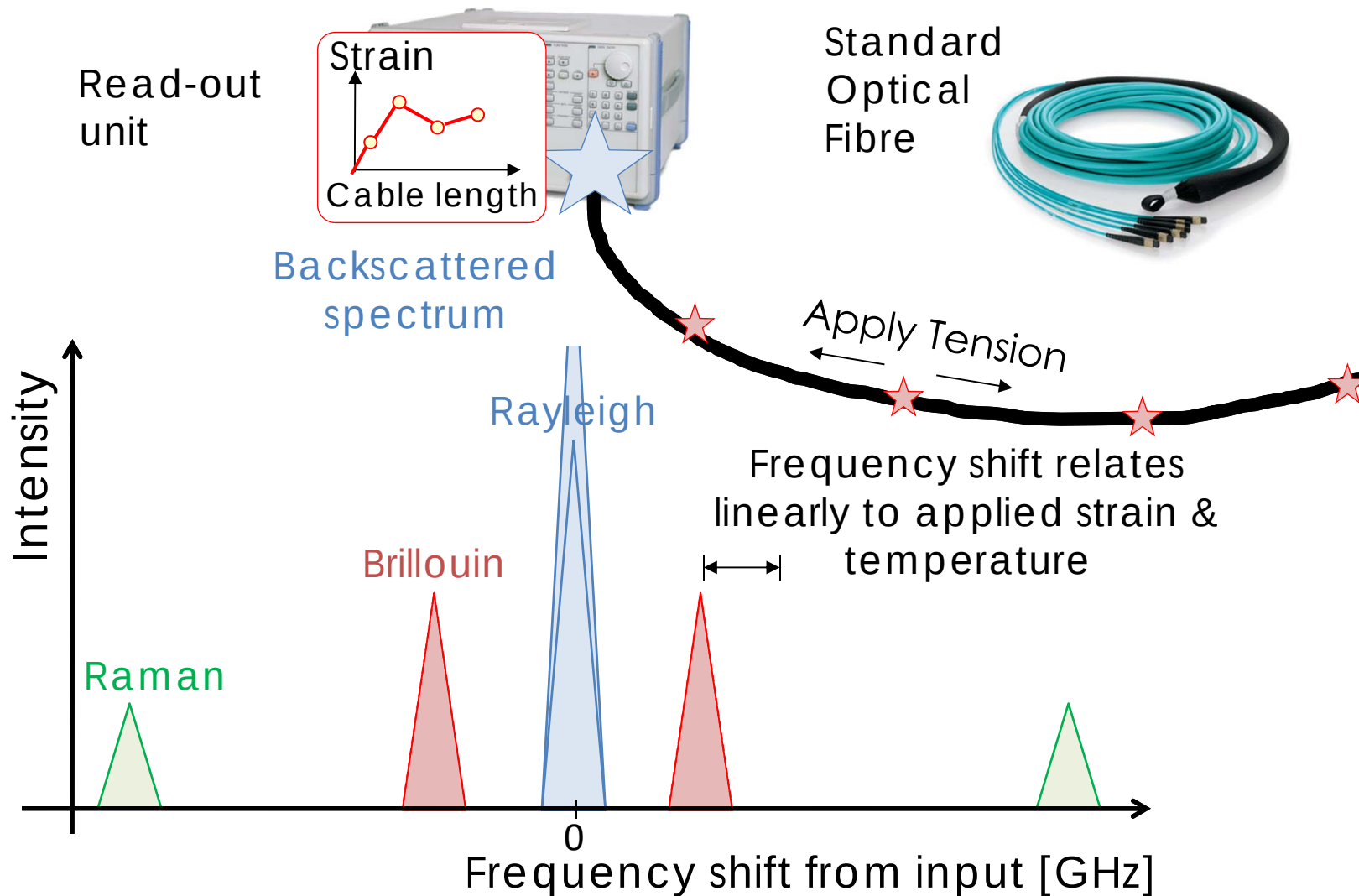
Understanding the actual conditions and behaviour operating in the field, rather than justifying the original design assumptions.

Overview

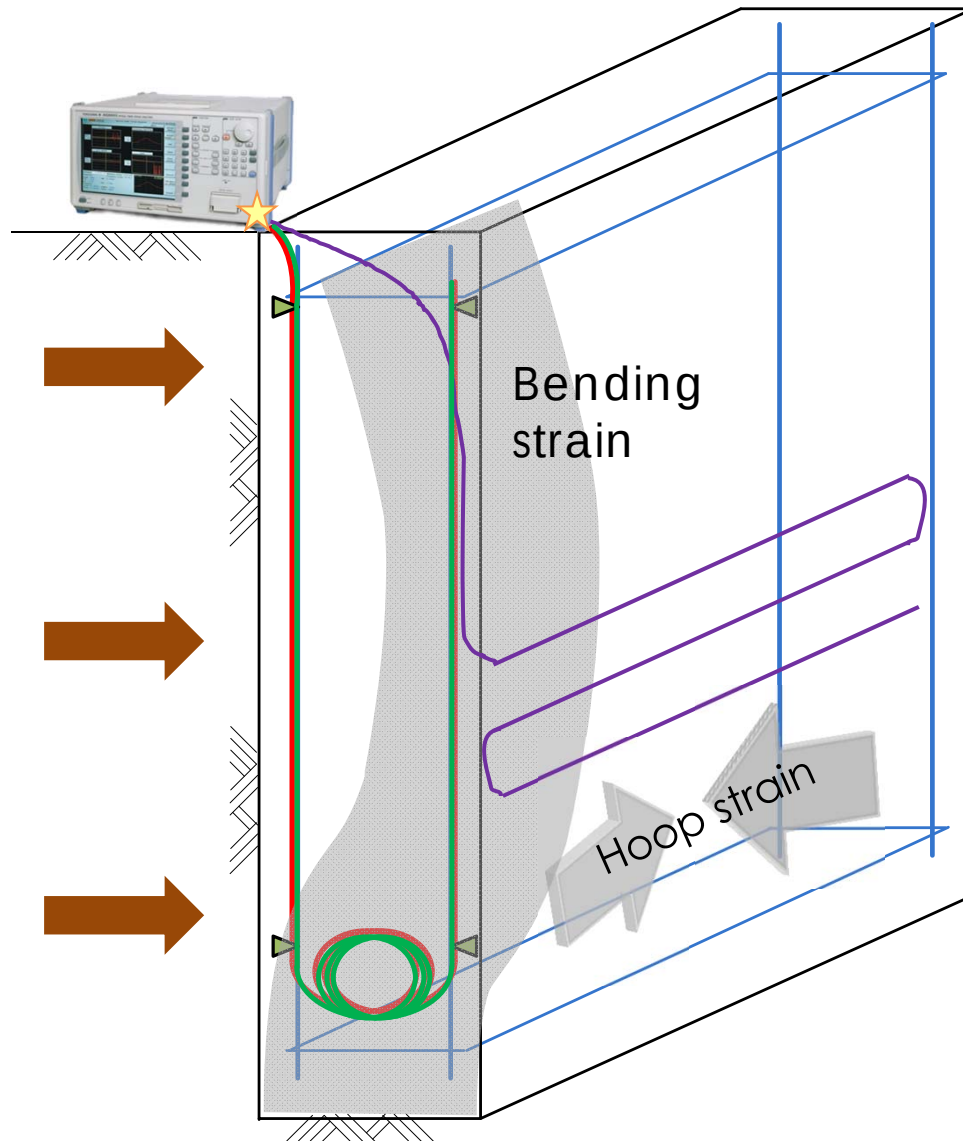
- Abbey Mills shaft:
 - 30m diameter
 - 73m deep
- Diaphragm walls:
 - 1.2m thick
 - 84m deep
- Monitoring:
 - Fibre optics in 3 panels
 - Inclinometers in 3 panels
 - Inclinometers & Extensometers in surrounding soil



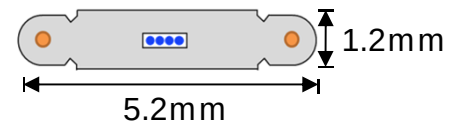
Fibre Optics Monitoring



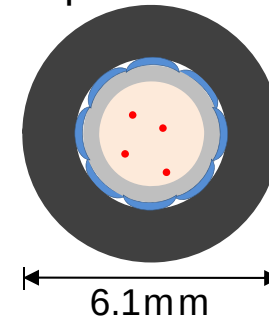
Fibre Optics Installation



Strain cable



Temperature cable



Monitoring

1. Dewatering trial

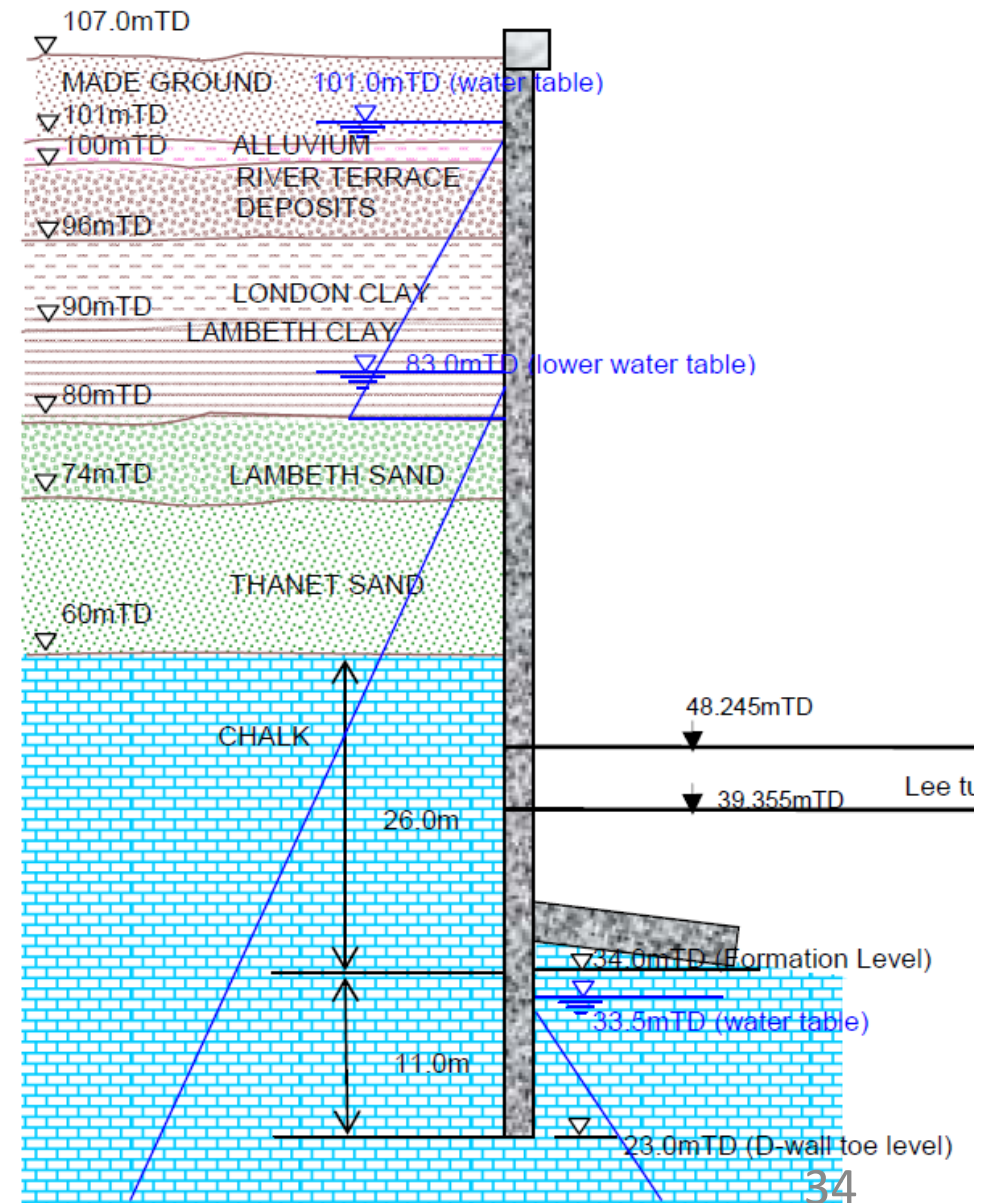
Before shaft excavation

Water table lowered to test if dwalls are waterproof

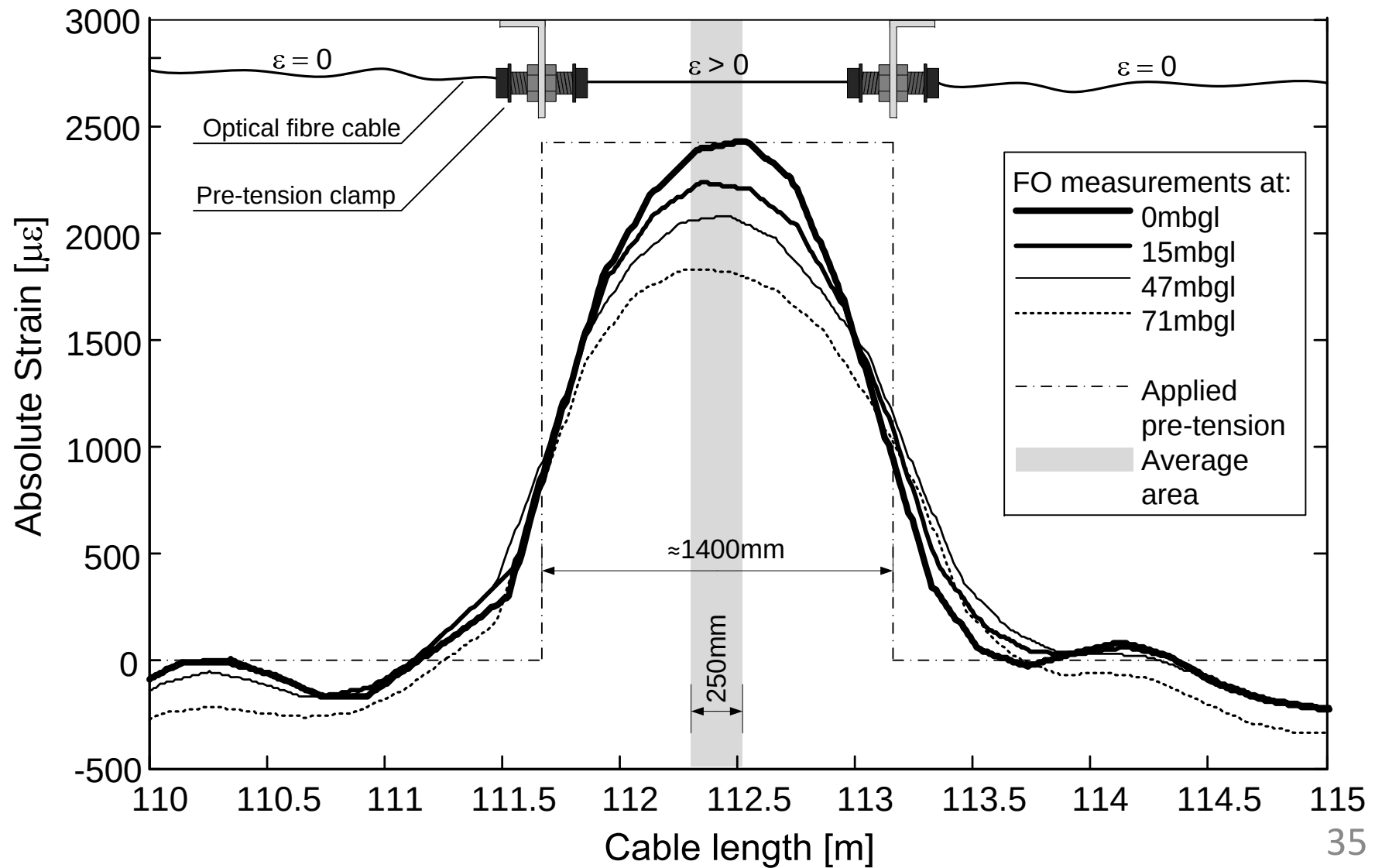
Take reading before dewatering and after.

2. Shaft excavation

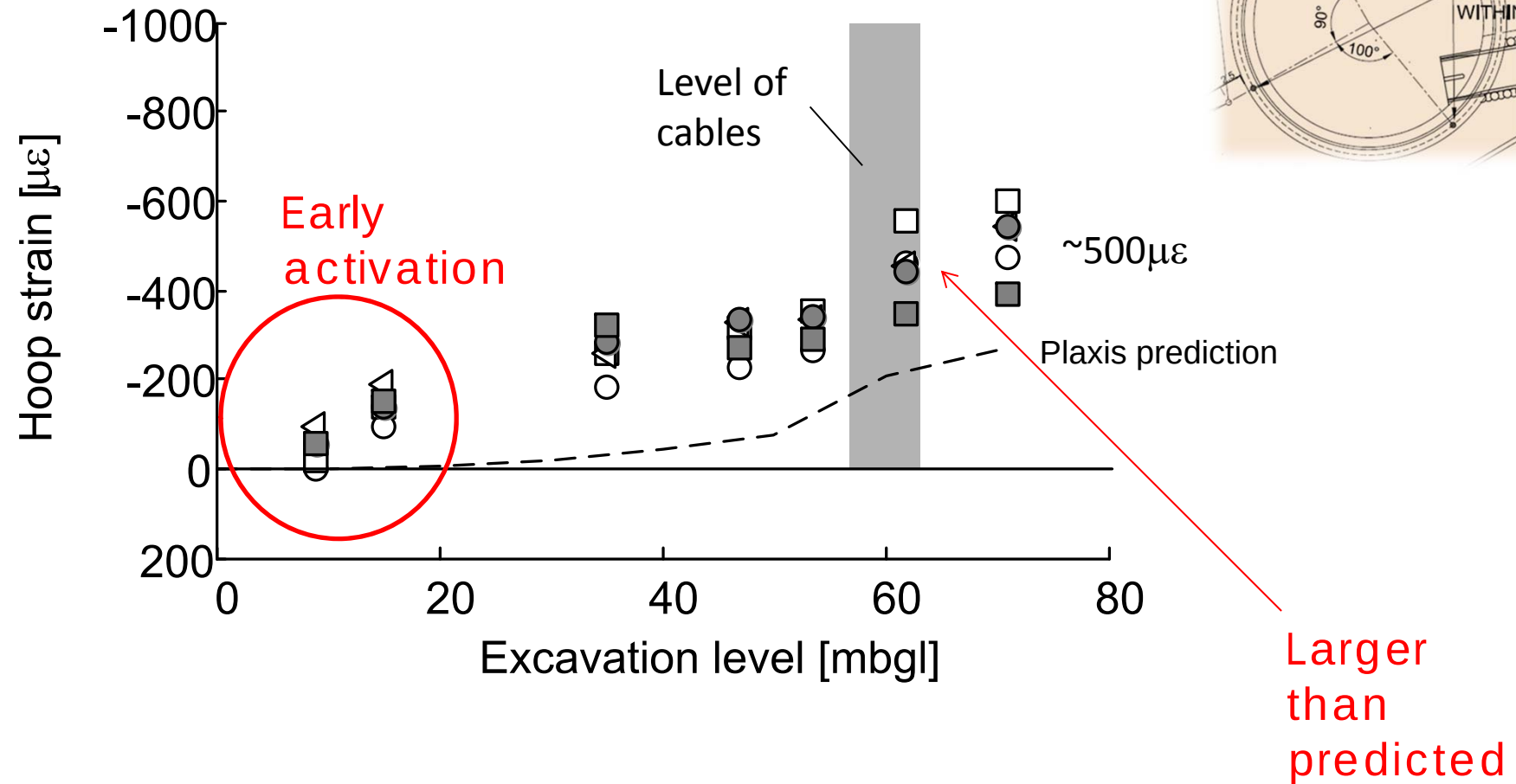
Take readings at several excavation depths.



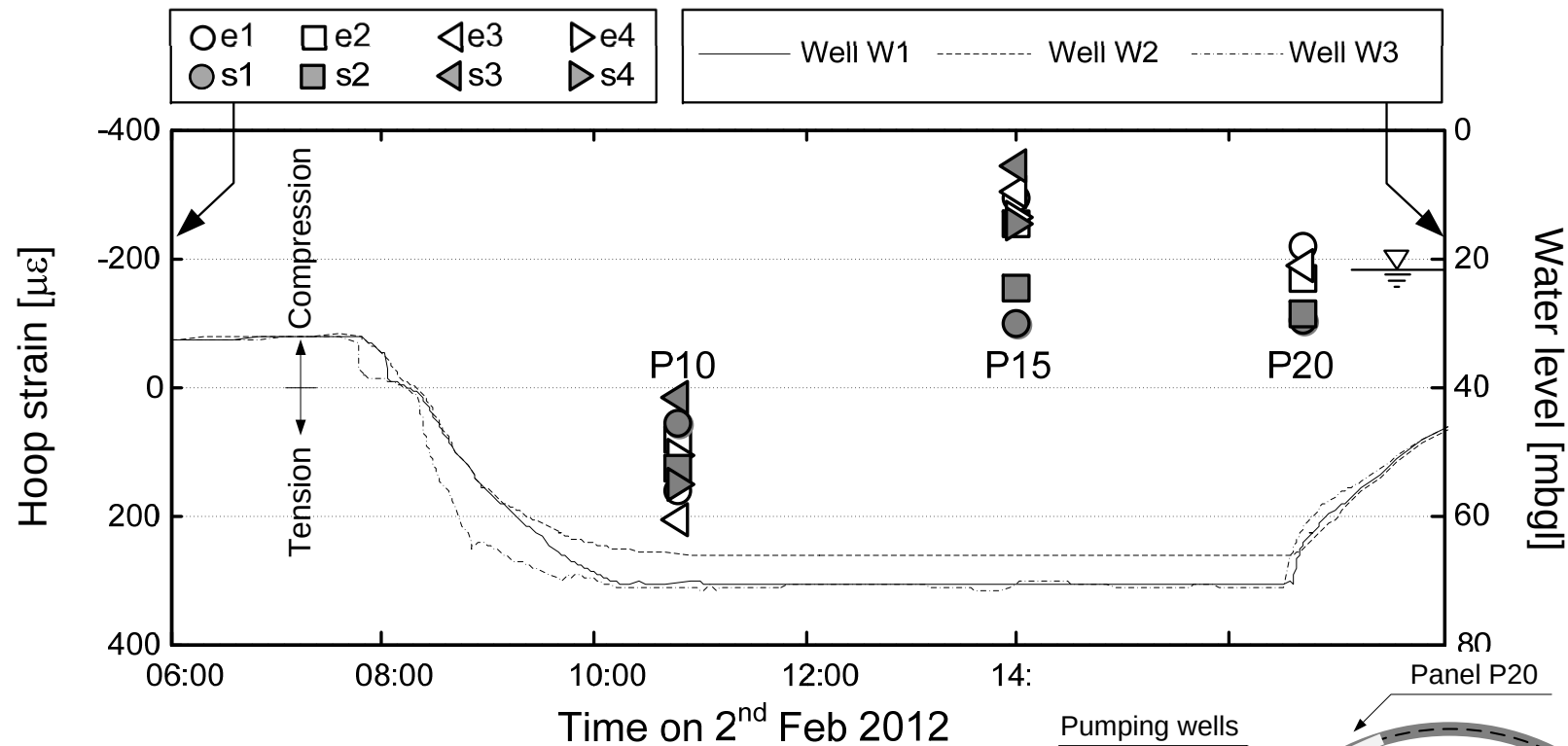
Analysis - Hoop



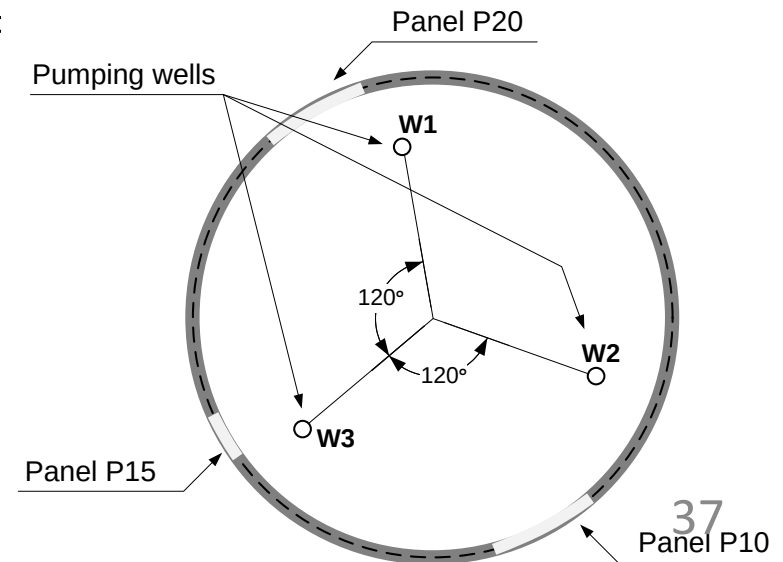
Results – Hoop Strain



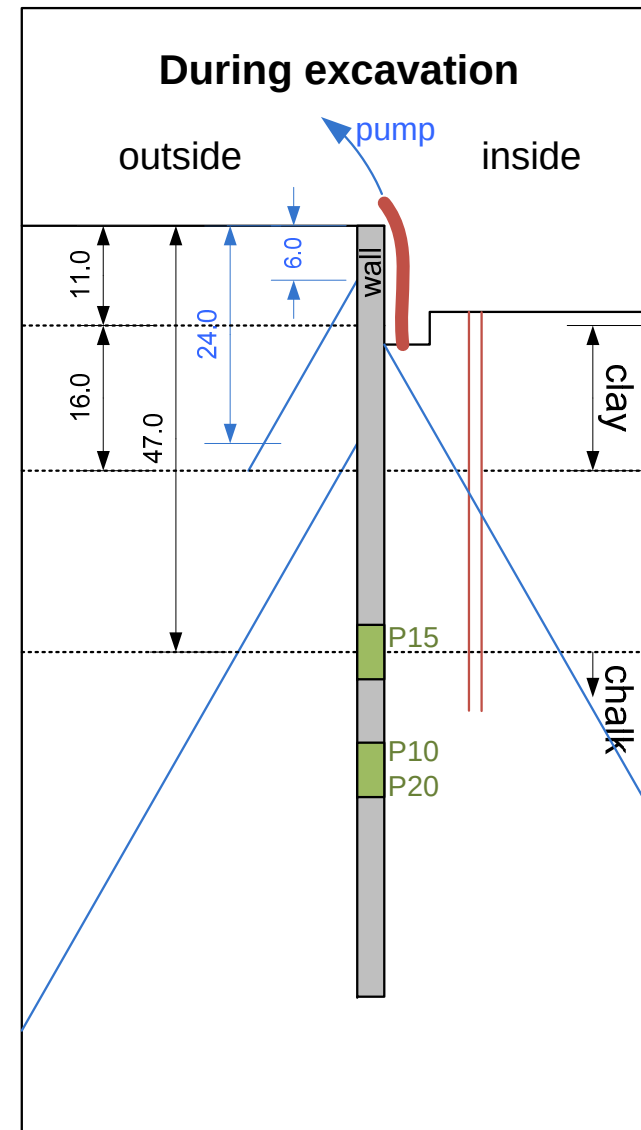
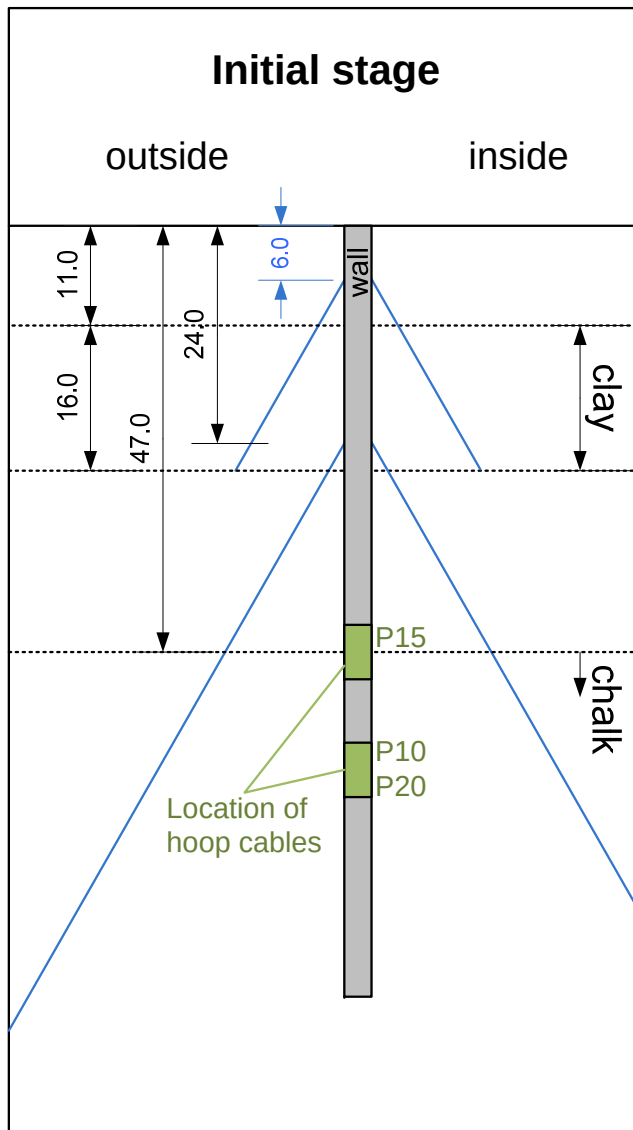
Results – Hoop - Dewatering



- P15/P20 in compression
- P10 far away from well / measurements taken directly after lowering the water table



Early activation due to hydraulic connection



Construction sequences

Model all stages of the construction and match the observed behaviour **at each and every significant construction stage.**

The construction sequence and geometry of the **'as-built' works**

The soil conditions and material properties determined from the model are **realistic and compatible**

within the range of foreseeable parameters from the site investigation data

compatible with empirical correlations for that soil type.

Paddington Station Main Box

2 panels

Installation: Oct 2012 – Jan 2013

Baseline: Feb 2013

Monitoring: May 2013 – Aug 2014 (estimated)

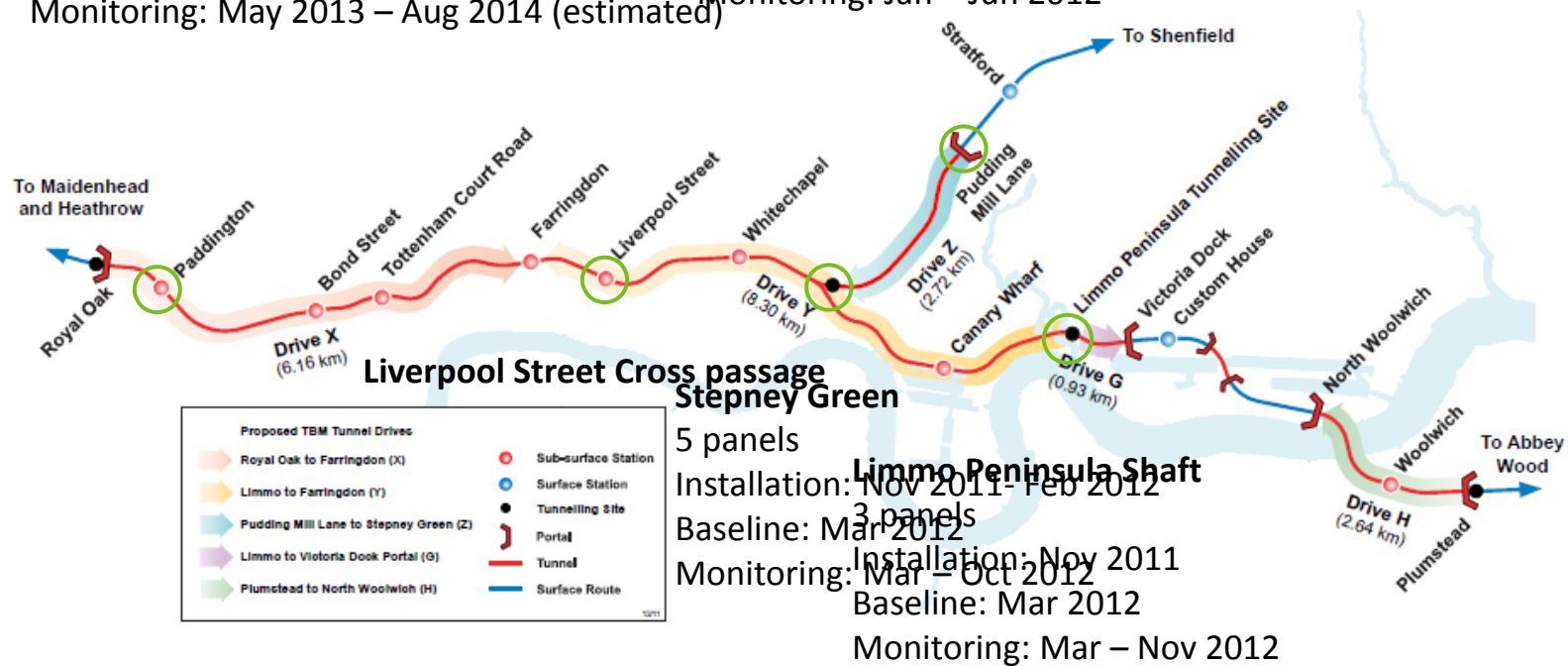
Pudding Mill Lane Portal

3 panels

Installation: Jan 2011- Mar 2011

Baseline: Jul 2011

Monitoring: Jan – Jun 2012



Efficient interpretation of monitoring data

Outline objectives of research:

- Review clarity of monitoring data presentation;
- Linkage between construction progress, design and monitoring results;
- Data interface for transfer of monitoring data;
- Use of laser scanning and photogrammetry (documentation and change monitoring);
- Improving monitoring viewer systems and use of dashboards; and
- Long term storage of monitoring data & collation of case studies.

Industrial steering panel set up to offer guidance to study

ARUP



itmsoil



Other important issues

- National and corporate policies in providing an appropriate framework for use of the OM.
- Project organisation and culture to support to the OM.
- Open communication approach to investigating and resolving unexpected events.

OM and Performance based design

The purposes of the back analysis process is

- (a) to refine the designer's understanding of the actual behaviour of the structure, and
- (b) to reduce the level of uncertainty

for this project as well as **future projects**.

