THE OBSERVATIONAL METHOD

Lessons learnt and future potential



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INTRODUCTION

Terzaghi (1961), in his lecture on the past and future of applied soil mechanics, warns about the misuse of soil mechanics, stating that there are –

> *Many situations when the geological conditions preclude the possibility of making an accurate performance forecast.*

Terzaghi describes case histories where:
OM used to avoid 'uneconomical design', whilst maintaining safety

Outline of Presentation

1. **Essence of the O.M. + Achieving Agreement**
2. **Case Histories: embankment on soft clay; dewatering; retaining wall.**
3. **Lessons Learnt + Future Opportunities**



Paper in conference proceedings provides further detail

ESSENCE OF THE O.M.

The key to success:

‘Identifying the critical observations and having the means to obtain and act upon them in a safe and timely way’

The Commercial Challenge

The need to (potentially) modify the design during construction creates considerable commercial and organisational tensions, e.g. roles/responsibilities, payment mechanisms, risk ownership, etc.

‘The 5 Key Requirements’

1. the critical observations can be obtained reliably + within acceptable timescales

2. Timely contingencies (often beneficial changes) can be implemented

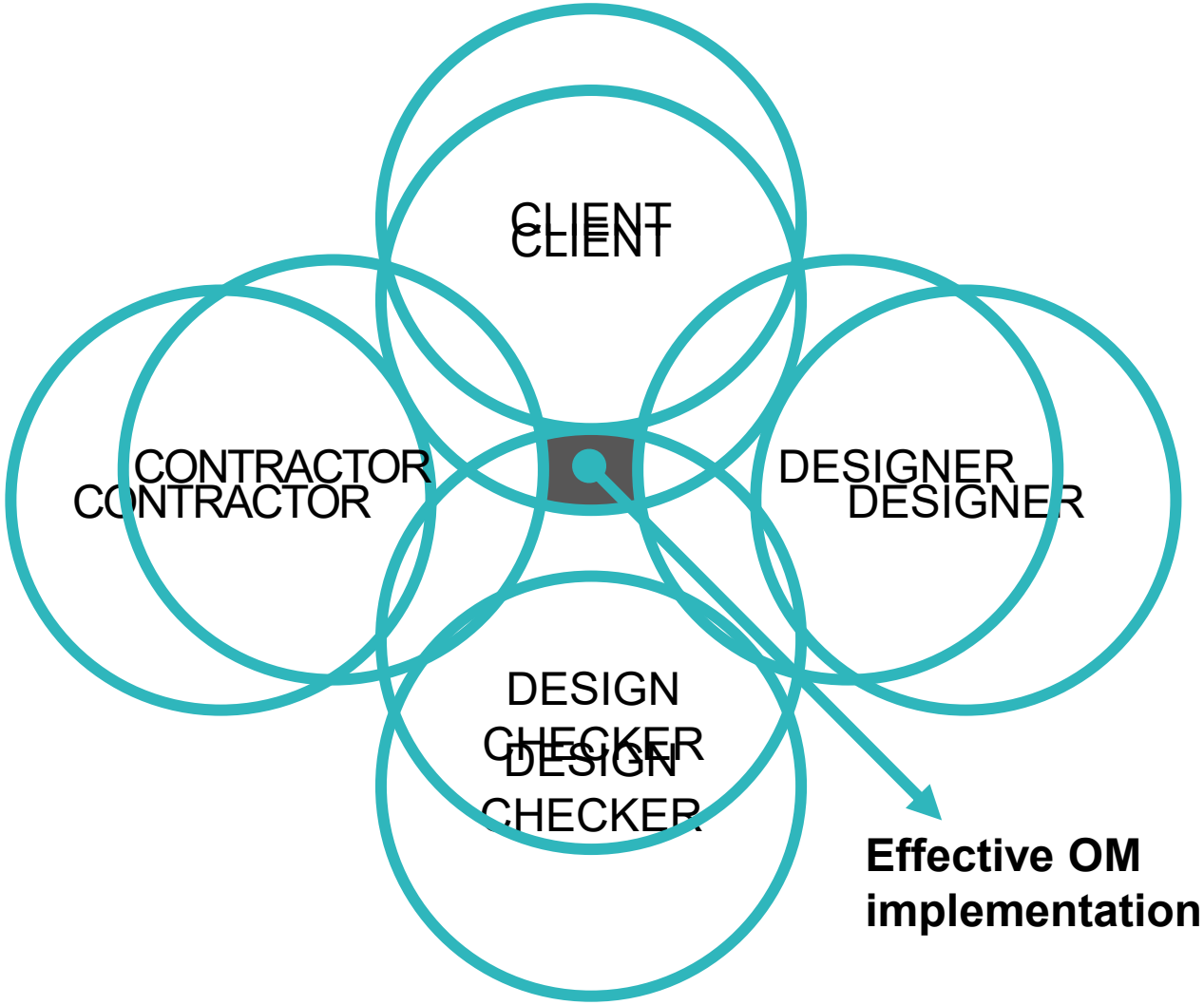
3. Ground + Structure(s) are NOT prone to sudden or progressive collapse – understand behavioural mechanism(s)

4. All above MUST BE MET for all foreseeable conditions, from most probable to worst credible.

(Time factor is critical)

5. There is full stakeholder support

What does the observational method need to succeed?



1. Close co-ordination, across several Parties (across several Contracts)
2. Early investment – EXTRA effort needed to evaluate viability + detail (I&M, performance limits, contingencies, etc)
3. A non-adversarial environment
4. Trust between the client, contractor and designer (+ I&M specialists)
5. **A commercial framework that encourages the above**

These requirements are not generally met by many conventional contracts.

New Stimulus for wider O.M. use - A Value Engineering clause is a critical catalyst for stimulating the use of O.M. (allows benefits to be shared). Latest versions of – NEC4 + FIDIC Contracts provide a better commercial framework for O.M.

Key factors in achieving agreement to use O.M.

Can be most difficult aspect of OM implementation

Difficulty varies, typically

- Temporary works: relatively simple
- Permanent works: more difficulty
- Potential impacts on existing infrastructure: can be complex, if many stakeholders.



Number of Stakeholders increasing

Commonly – need an ‘OM Champion’ to advocate for its use.

Independent Design Checkers – expertise? motivated? timing + process?

Factor	Issues
Convincing Business Case	Practical benefits need to be clear, eg cost/time savings, safety/risk improvement, etc. Advantages need to be compared against conventional base case.
Sound Technical Basis	Multi-disciplinary skills often needed, eg structural + geotechnical. Evident to stakeholders?
Risk Management	Maintaining acceptable level of safety is essential. Wide range of risks both technical + commercial. Risk perceptions typically vary across stakeholders.
Trust	Critical for any OM application. Requires time + good relationships.

The O.M. can be simple (+ can be used on small projects)

Paper – ‘case history 1’ Embankment on Soft Clay

- Key question: Field value of Cv
- Time period for consolidation + strength gain?
- Original design specified construction period of 12 weeks + then a delay period of 40 weeks, prior to bridge construction

Very simple I&M, managed by small team

Simple Contingency – toe berm

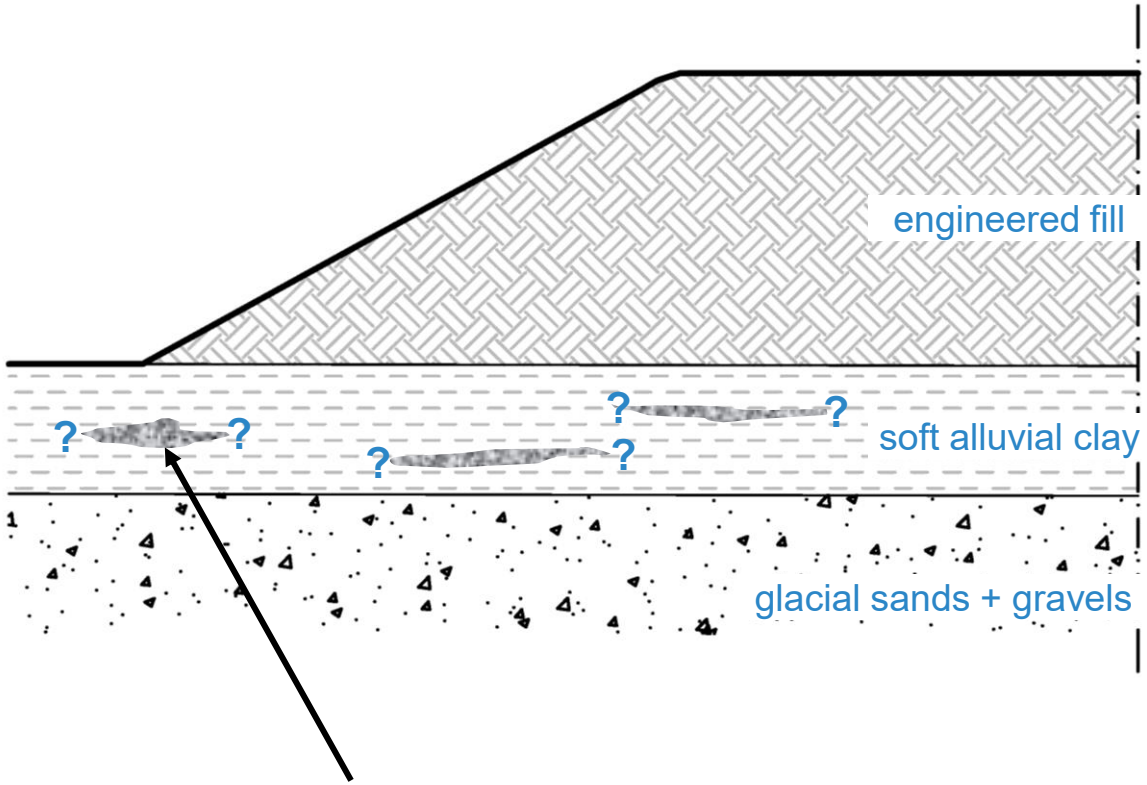
No complex analyses - simple 1D consol + L.E. stability checks, robust empirical relationships

Outcome:

Construction duration – halved

Consolidation – practically complete, 8 – 10 weeks

Overall saving – 30 weeks



Continuity of silt + sand layers within soft clay ?

Case History 2: Crossrail, Blomfield Box

‘Groundwater can seep through any theory’

Deepest excavation in project – 42m deep

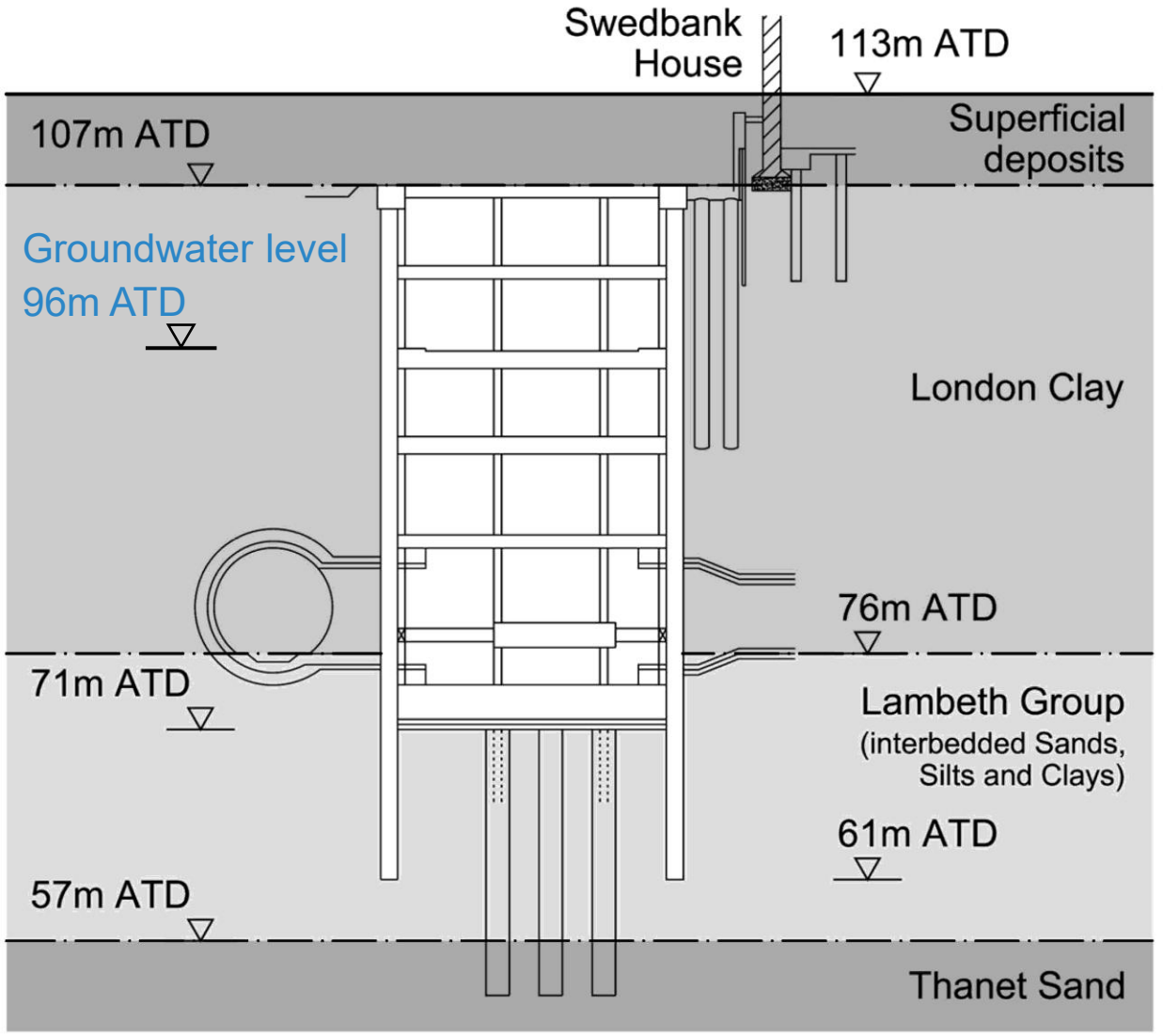
Penetrates into Lambeth Group – complex heterogenous deposit, groundwater pressures circa 250kPa

Conventional dewatering design – if worst credible, then shaft not buildable.

O.M. – used to optimise timing, location + type of GW control.

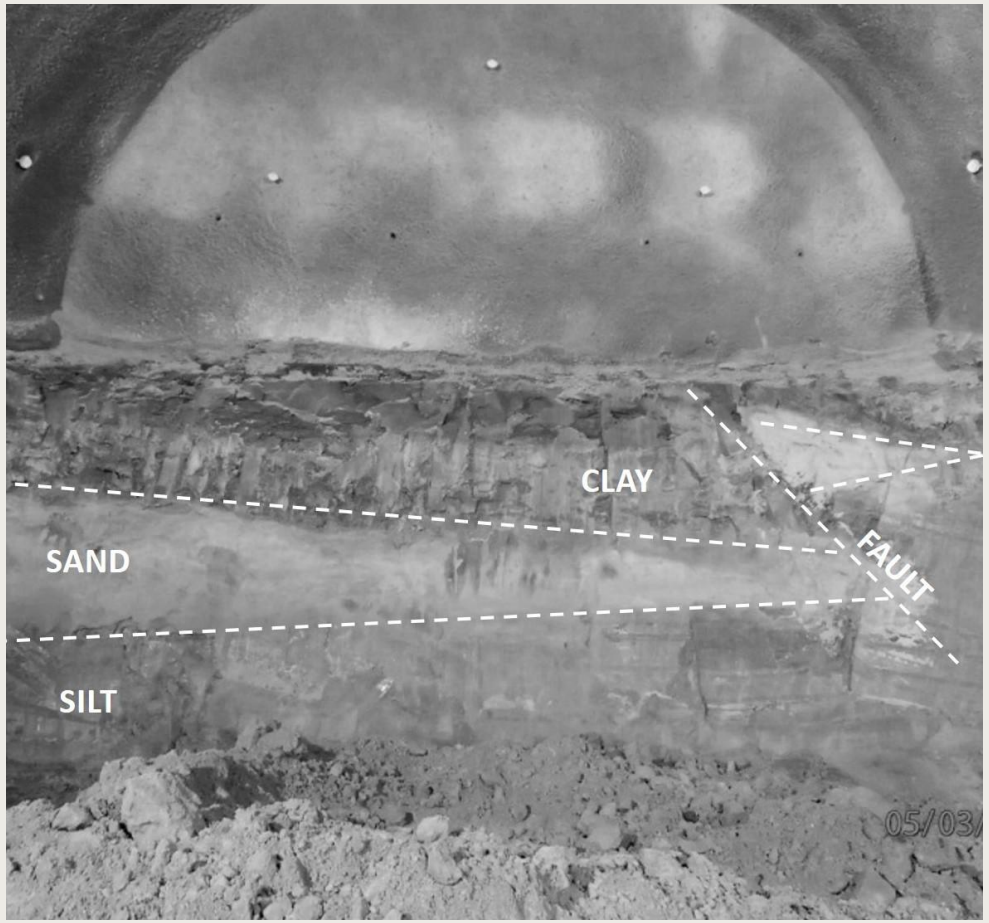
Conditions from ‘worst credible’ to ‘best case’ used to develop Tool Box + commercial agreement

Dewatering for tunnel works (separate contract) – likely to influence shaft works (??)

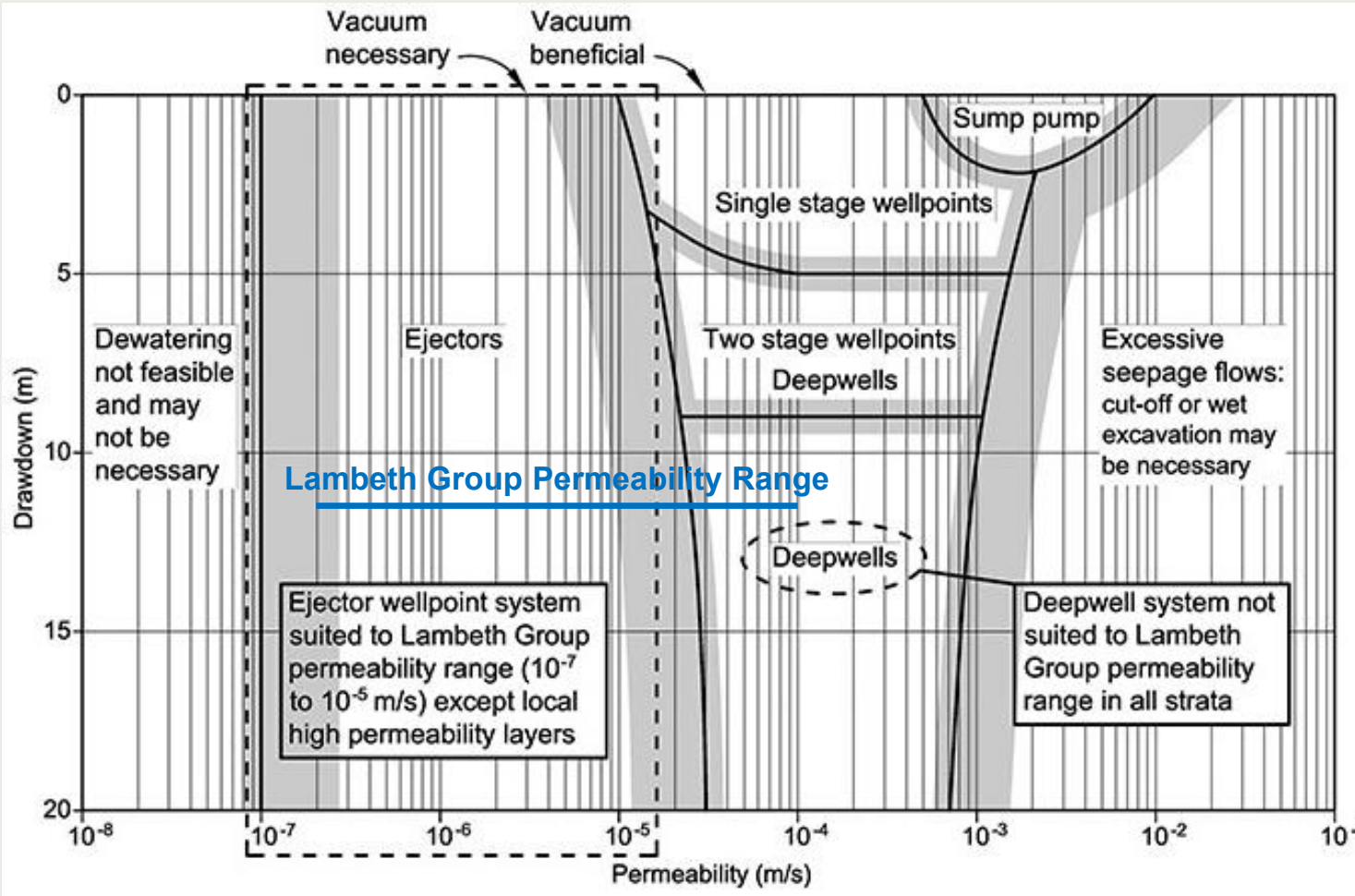


Case history 2: Crossrail, Blomfield Box

Lambeth Group exposure in a tunnel (remote from works)



Wide range of Lambeth Group permeability – both ejectors + deep wells needed



Case history 2: Crossrail, Blomfield Box

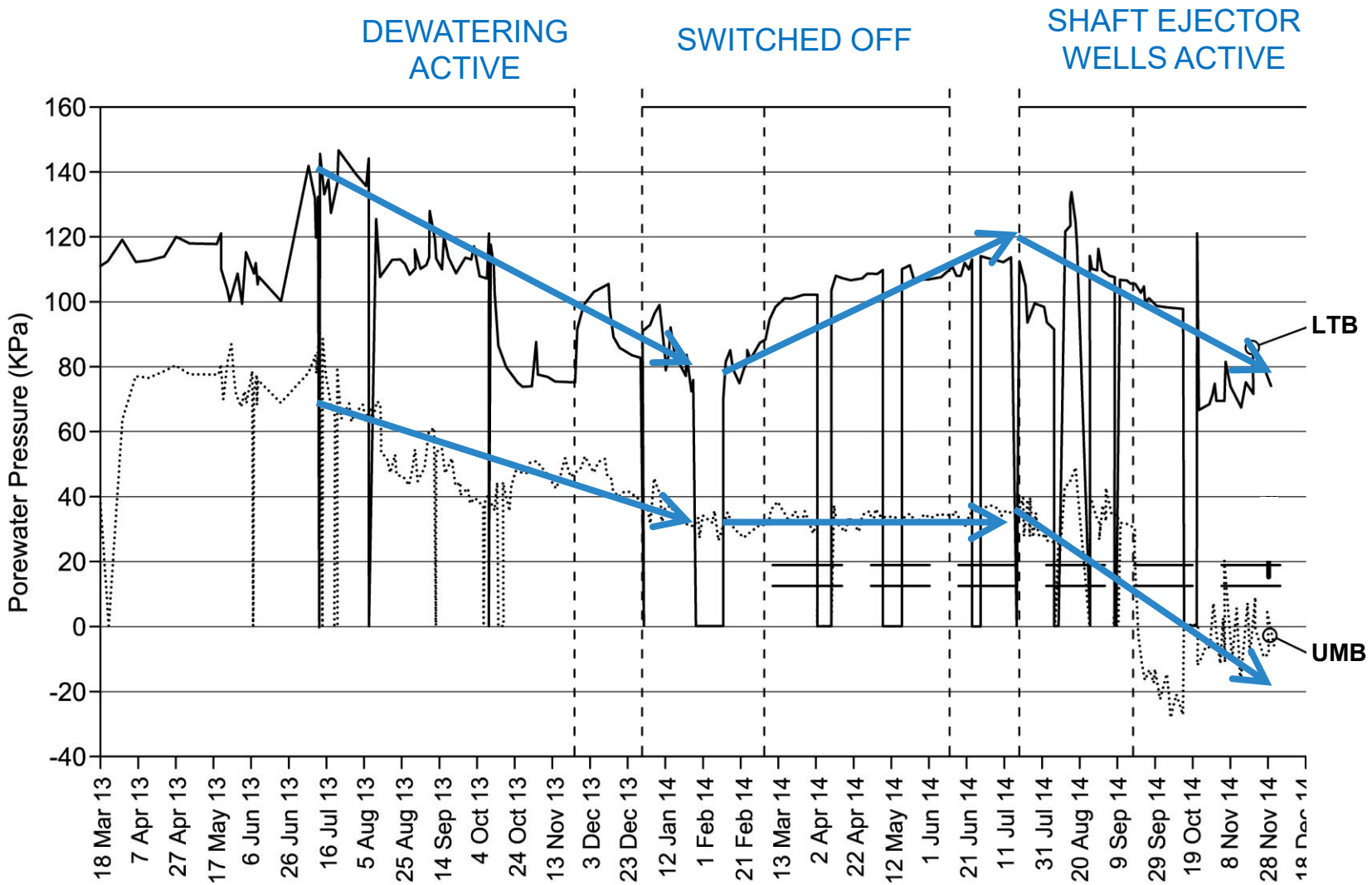
Varying GW recharge for sub-layers in Lambeth Group

Separate Tunnelling works influenced conditions below shaft

When dewatering switched off – LTB + UMB sand channel showed very different behaviours.

LTB was recharged by remote GW source

UMB + LTB – 2 different hydrogeological systems



Note: Lambeth Group sub-layers
UMB – upper mottled beds
LTB – Laminated Beds

Case history 2: Crossrail, Blomfield Box

O.M. via Progressive Modification

Dewatering installed incrementally
- Deep Wells
- Ejector wells
- Passive wells

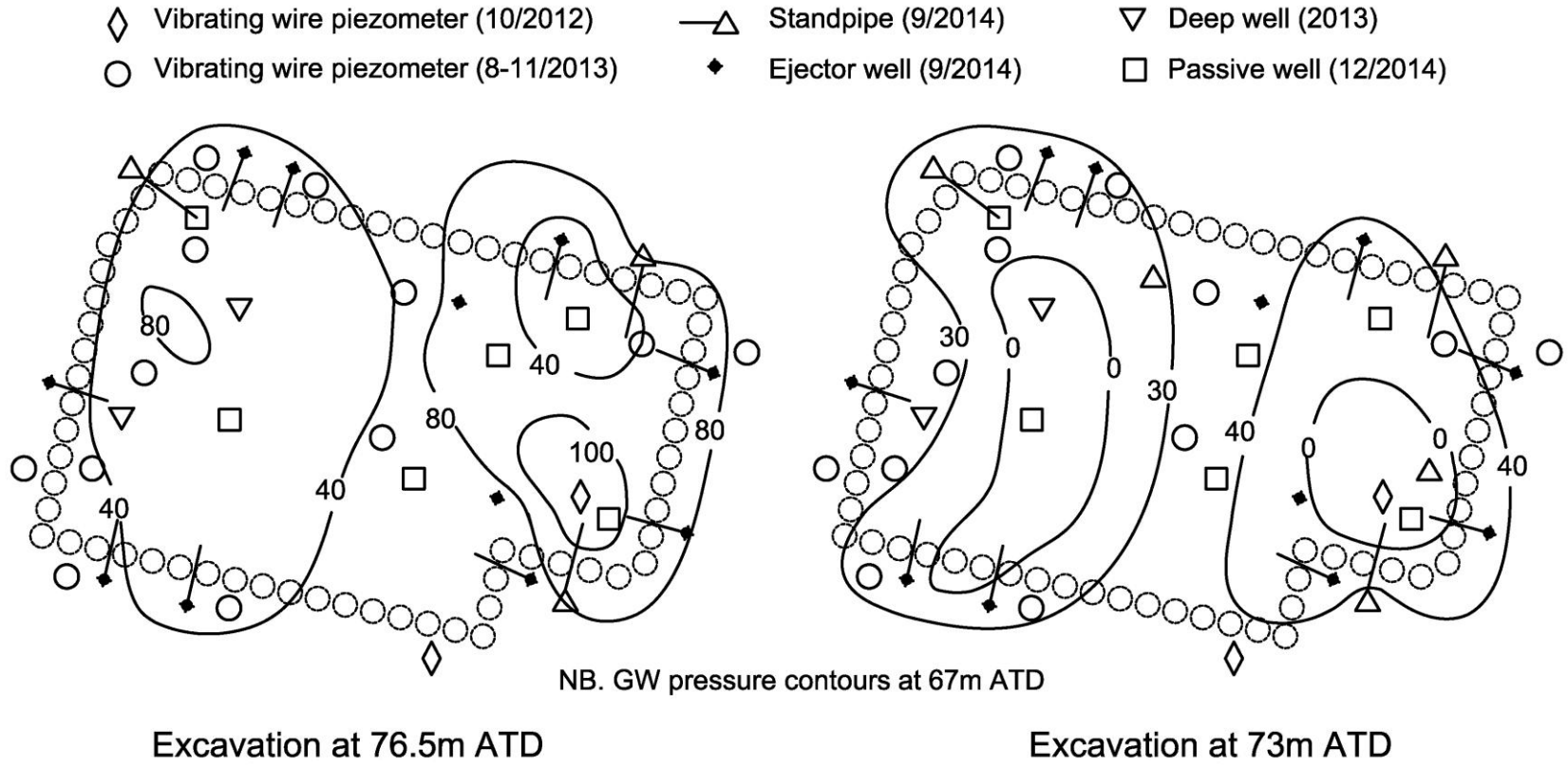
Depth > 35m – challenging!

Conditions below east worse than below west (local faulting)

Dewatering contingencies applied in targeted locations.

Groundwater Conditions – asymmetrical below excavation

Extra focus on LTB sub-layer, in eastern area



Case history 2: Crossrail, Blomfield Box

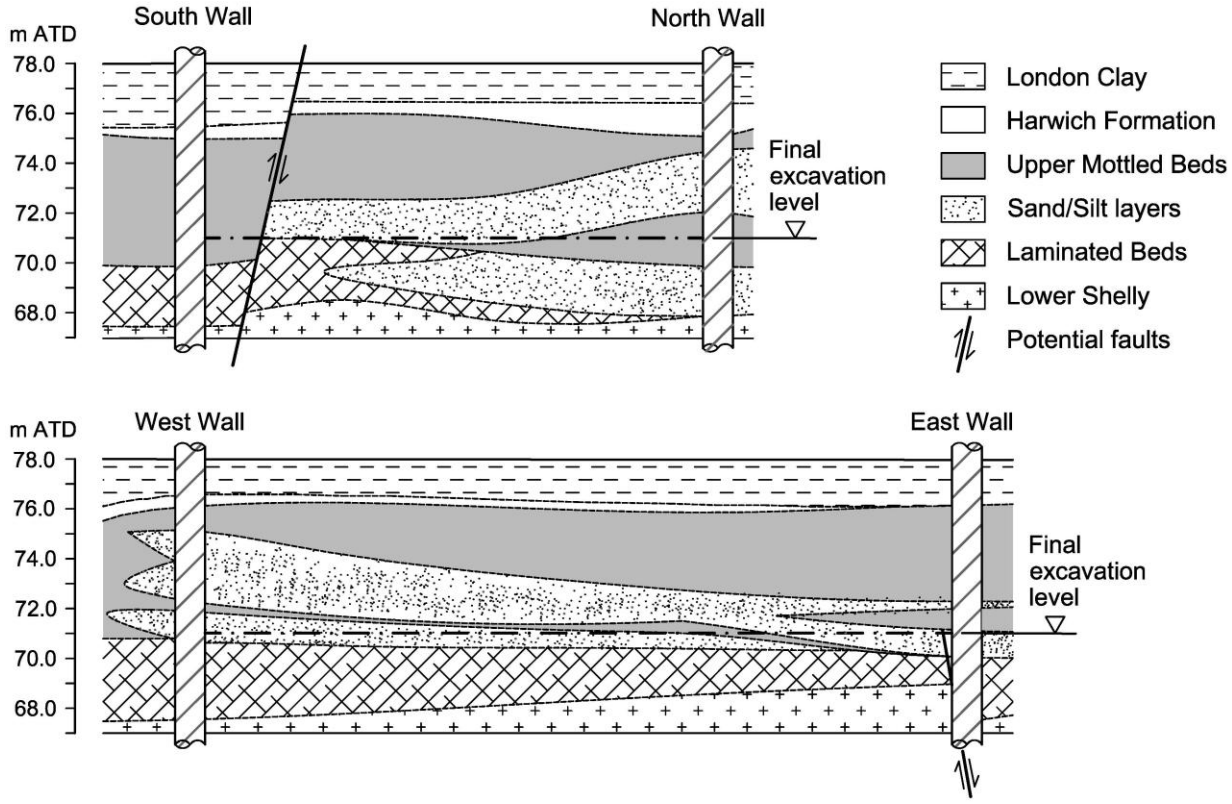
Terzaghi noted that most failures due to: '*unanticipated action of water*' and importance of '*minor geological details that are unknown*'

Outcome of O.M.

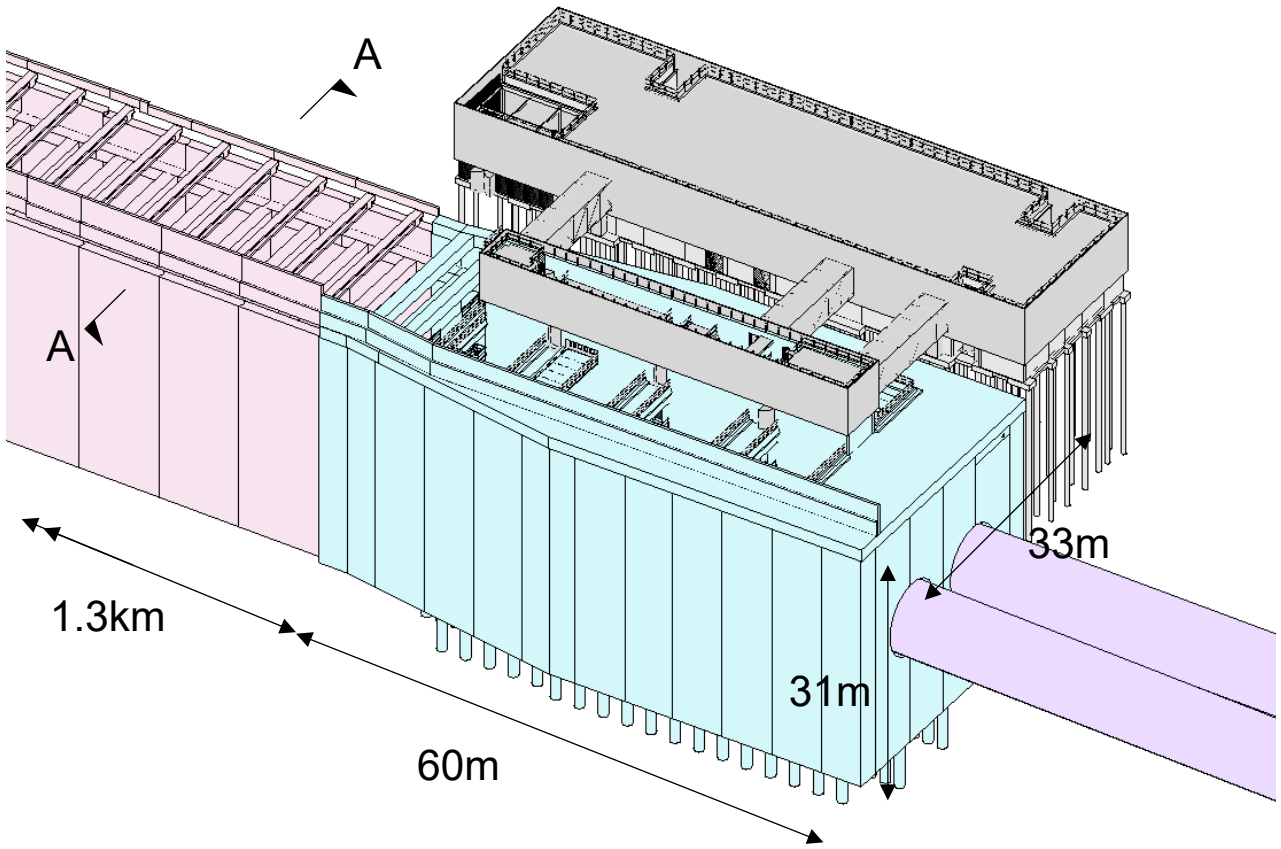
Dewatering successful, safety assured whilst time + cost savings achieved.

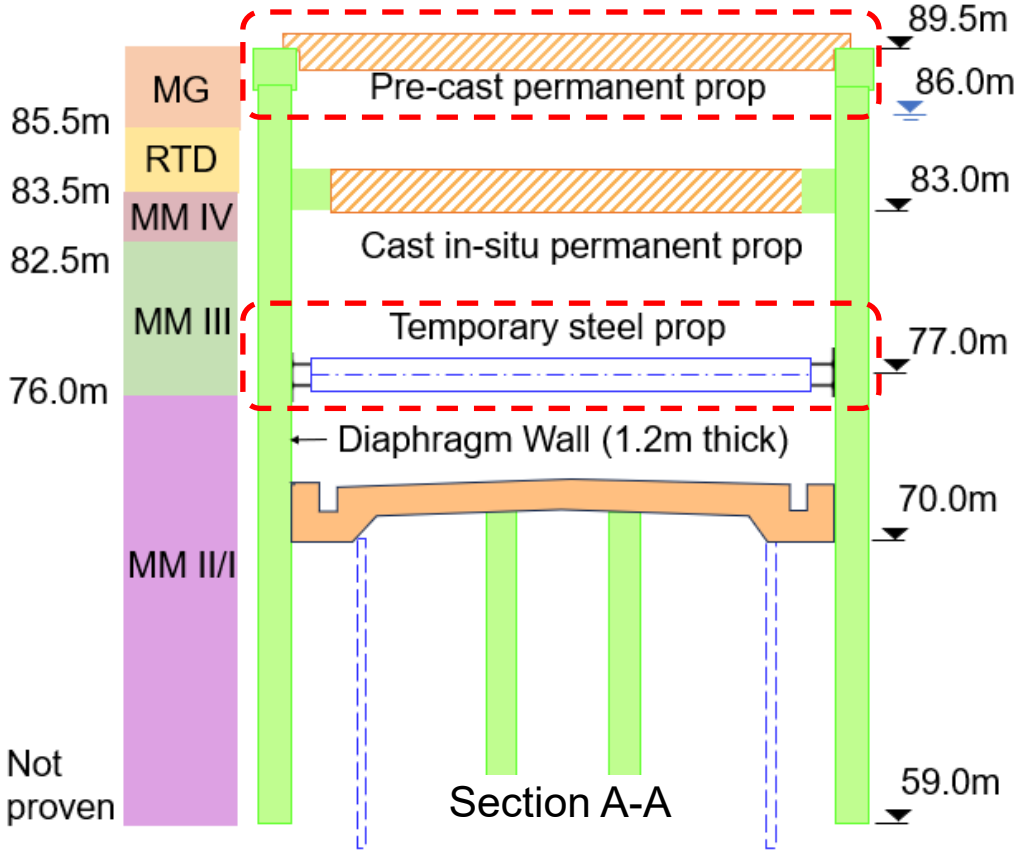
O.M. saved 50% of wells (c.f. conventional design)
Well locations optimised

Complexity of Lambeth Group inter-layering and local faulting revealed by field logging



Case History 3 – HS2, early use of R.T.B.A.





MG: Made Ground, RTD: River Terrace Deposit, MM: Mercia Mudstone

Site Geology – Mercia Mudstone dominant deposit. No precedent experience for this type of works.

Case History 3: HS2

Mercia Mudstone: Intermediate Geomaterial (IGM, US practice) - stiff clay to weak rock, **intrinsically difficult to characterise**

Conventional EC7 – ‘characteristic’ parameters

O.M. – 1. optimise support system + 2. safely manage local worst credible conditions

Achieving agreement to use O.M.

Early Client engagement to streamline the assurance/checking process

RTBA effectiveness – via ‘technology trial’ on early portal works

Verification process– workshops held with checker at key stages
All data reviewed
RTBA – calibrated vs previous stages, prediction for subsequent stages.
Agree subsequent works.

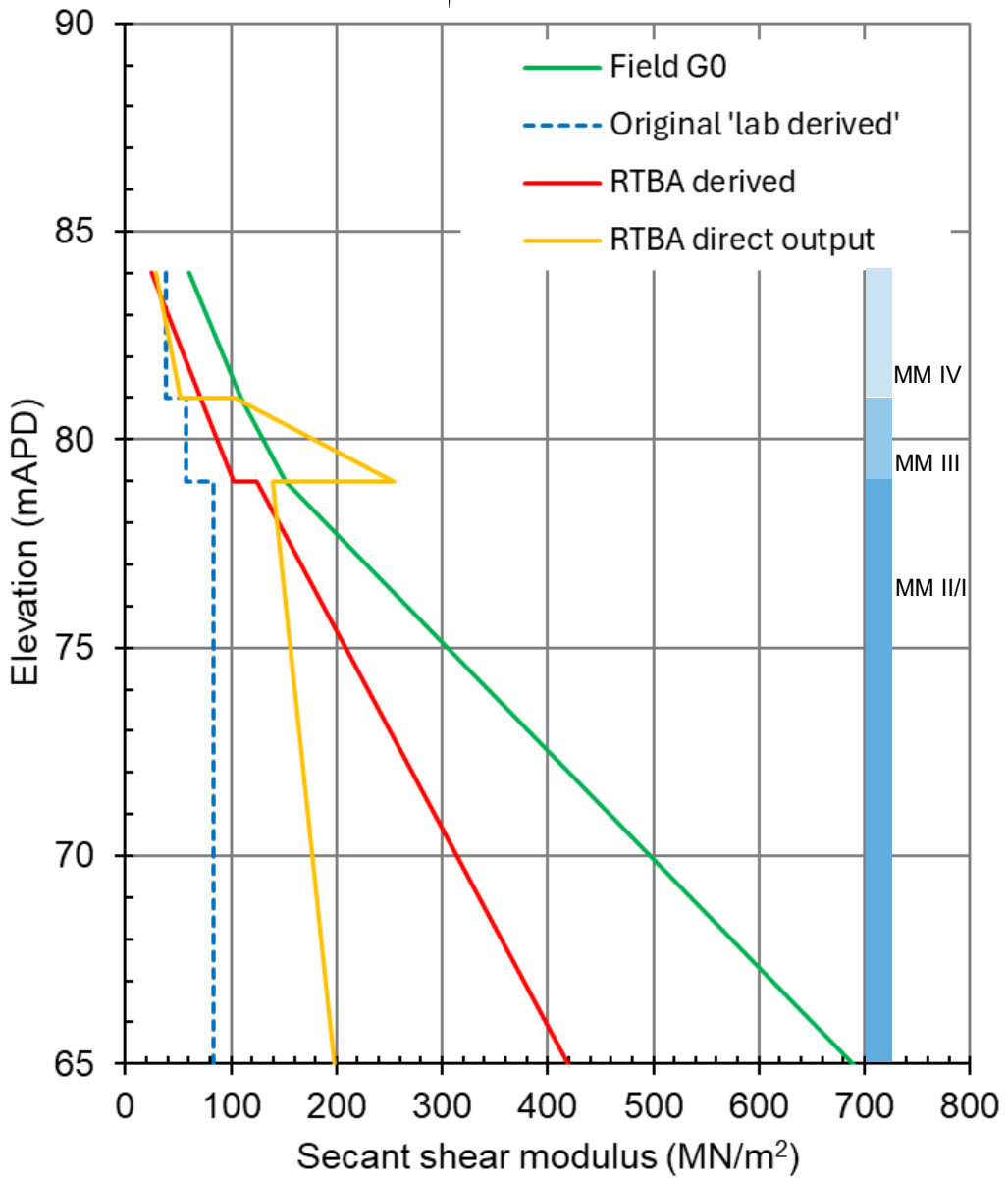




R.T.B.A. technology trial

Revealed 2 potential pitfalls.
First Issue-

- RTBA algorithm calculates a mathematical optimum, but not necessarily ‘geotechnically reasonable’
- Interrogation of analyses – sometimes indicated more reasonable fits ‘just beyond’ mathematical optimum
- RTBA code – updated to make these more transparent to users
- HENCE, NEED FOR EXPERT JUDGEMENT



RTBA technology trial, second issue



Critical that RTBA is not 'contaminated' by unreliable I&M data !!

Instrumentation & Monitoring

Key principles -

focus on critical observations + comprehensive construction records

- Critical Observation – wall deflection
- Primary system: ODS supplemented by IPI/SAA.
- ODS - Provide **rapid**, wall convergence checks (minimal interpretation, simple / robust).
- Site records - key to **explain** cause of movements (e.g. temporary stockpiles).
- Each instrument answered a **specific question**; data overload avoided.

Instrumentation and Monitoring Plan





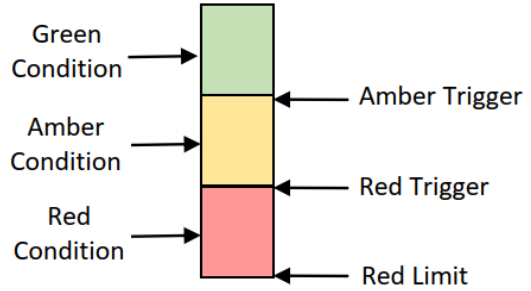


Optical Displacement Sensor (ODS)

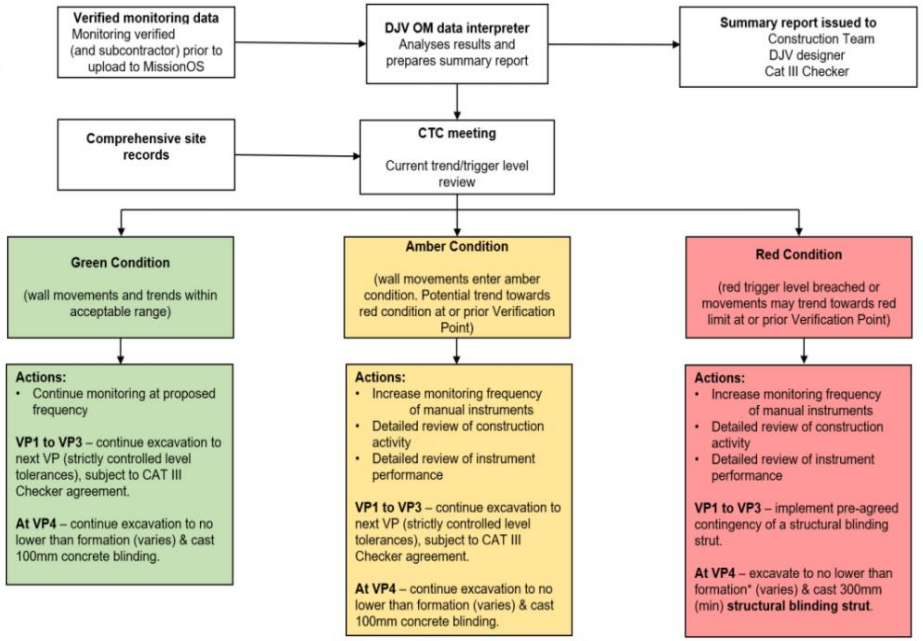
Performance Limits, Construction Control + Observed Performance

- Red Limit: driven by structural design, SLS crack width + wall flexural stiffness.
- Red Trigger: driven by site logistics for contingency
- Amber Trigger: minimise false alarms, adequate band width to red trigger
- **Pre-agreed** actions:
  - Amber trigger→ proceed with increased scrutiny
  - Red trigger → deploy contingency
- Pre-designed + Pre-planned Contingency: 300 mm structural concrete, cast on excavation + **installable within 24 hours**.

Bulk of works – small wall deflections.
Cantilever < 0.1%H, Propped walls < 0.05%H
Except – local impact of Storm Babet, see Paper.



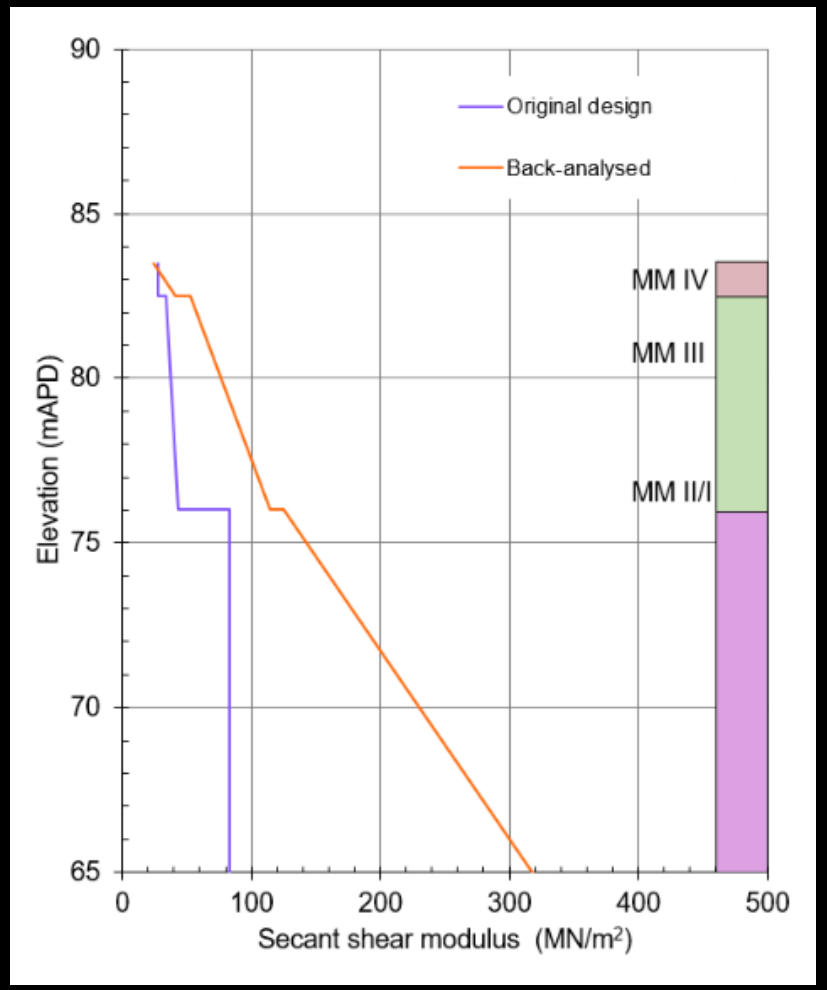
Definition of Trigger Levels



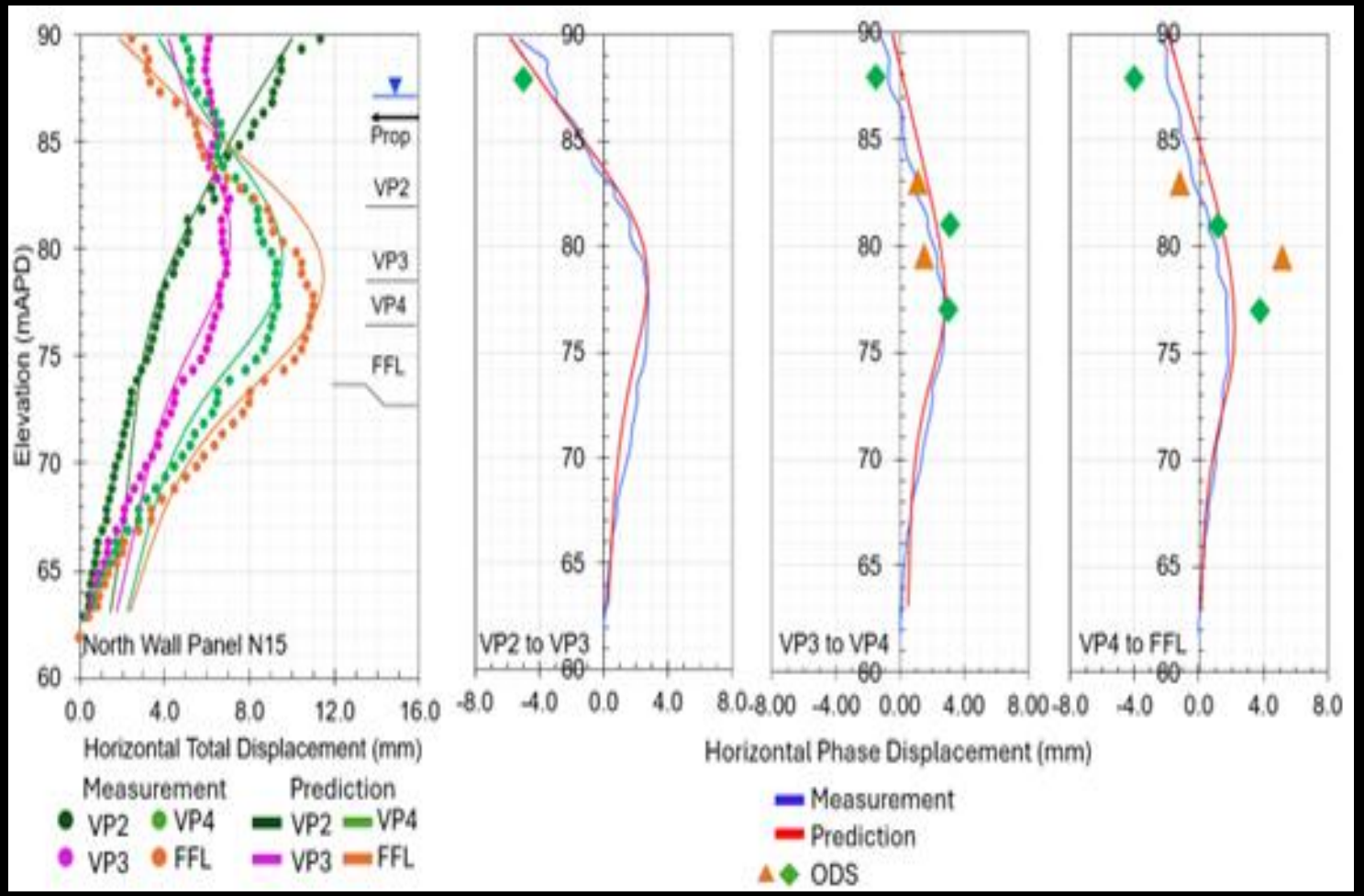
Site control chart

Back-Analysis Results vs Observations

Mobilised stiffness – 80-90 % field Go, multi-propped walls; 50-70% field Go cantilever walls



Comparison of secant shear modulus values



Results of near real-time back analysis

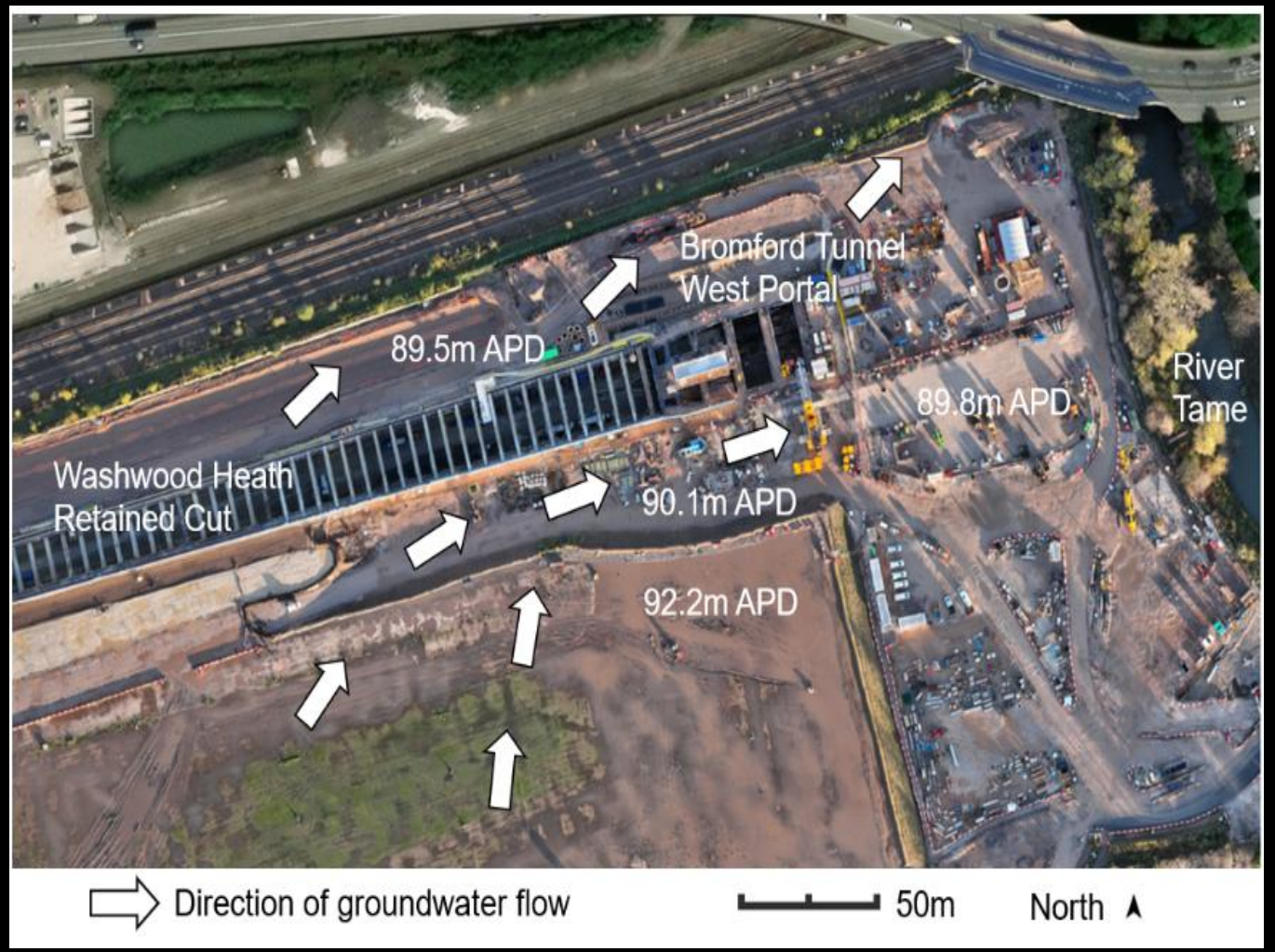
Localisd impact of extreme weather event – Storm Babet

- Groundwater flow concentrated in sub-surface ‘channel’ (local faulting / open fractures?), adverse impact on South Wall (panel S15), wall displacement nearly double N15, negligible impact on North Wall.

OM - enabled **early** detection of accelerated movement + **timely** contingency action.

Climate change + more extreme weather :

Greater impacts on future projects?





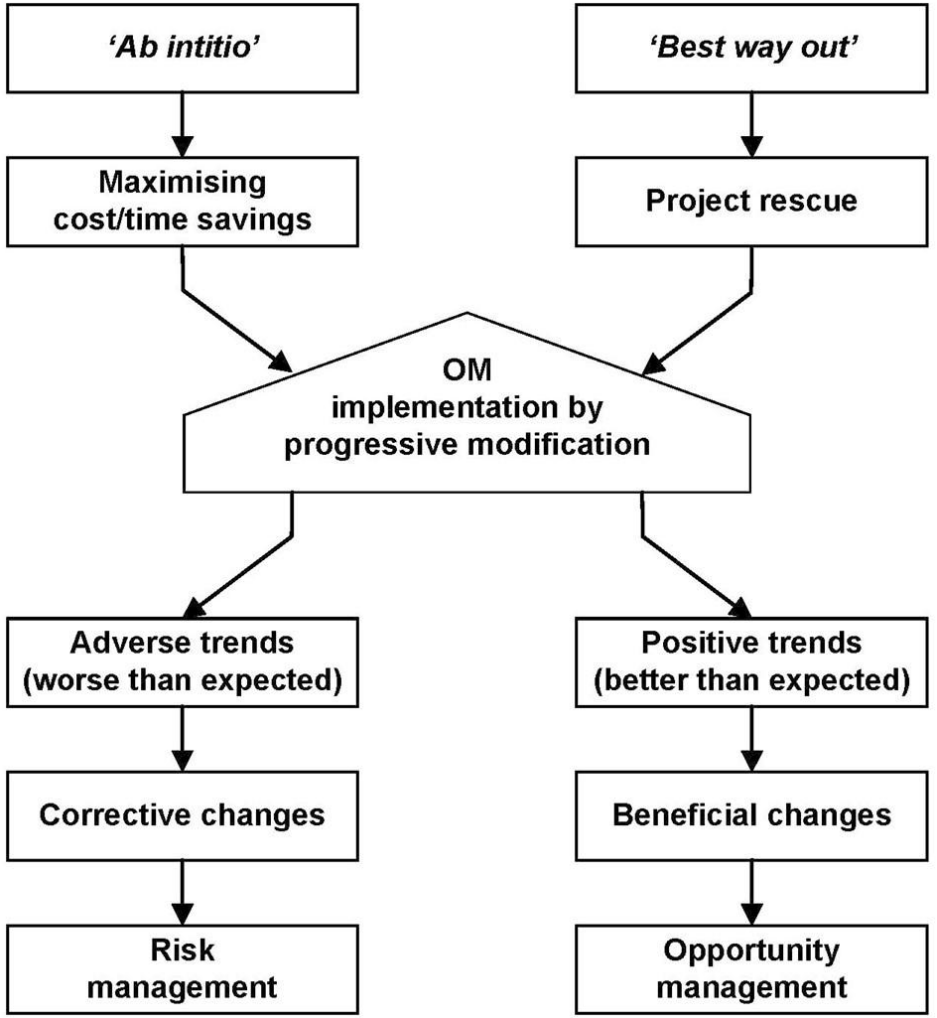
Key Project Outcomes

- Significant programme and cost savings – over 6 months
- Vast majority of temporary props removed – over 3000 tCO_2e savings
- Removal of time constraint for top permanent prop installation – greater construction flexibility, improved site access.
- Enhanced safety through the elimination of temporary works
- R.T.B.A. – supported mega-scale O.M. + design checker approvals.
- Back-analysis: Field Go best basis for ground stiffness; tunnel portals Gmob > 80% Go; Cantilever walls Gmob – 50-70% Go

Lessons Learnt

The Power of Progressive Modification – Proactive rather than Reactive

- Start OM with risk judged acceptable by all Parties, does not need to be ‘worst credible’ or ‘most probable’
- Monitoring trends carefully tracked, design modifications introduced on a step-by-step basis, as construction proceeds
- Typically, best basis for achieving agreement for OM across multiple stakeholders
- Extra focus on demonstrating safety
- Often – changes are **BENEFICIAL**



All case histories in Powderham + O’Brien implemented OM through Progressive Modification

Progressive Modification, all OM categories can be addressed.

LESSONS LEARNT

Uncertainties – not just the Ground Parameters

Ground engineering – many different types of uncertainty, including structural performance; construction processes.

All uncertainties need to be assessed + managed

Some are not amenable to analysis, e.g. removal of old foundations – common cause of ground movements in urban areas.



LESSONS LEARNT:
Instrumentation, Monitoring & Observations

Reliability is crucial !! Procurement + Organisational Issues

- **Design** – Primary Instruments = the Critical Observation for Construction Control (only a single set of traffic lights!)
- **Procurement** - Person responsible for quality, need motivation + authority. I&M should be seen as a professional service.
- **Early Installation of systems** – baseline data; review + checks (verify reliable)
- **Observations** – Construction records critical.

- **Reporting** – all key stakeholders get ‘real-time’ access. Pre-agreed formats, communication routes.

LESSONS LEARNT:
Contingency Measures

Speed of installation + simplicity are crucial

- **Creative thinking** – may unlock OM opportunity
- **Identification, Design + Planning** - requires close collaboration between designer + contractor (and sub-contractors!)
- **Mobilisation to site** - all materials / equipment must be mobilised and be ready to go
- **Timescales** - reporting + interpretation of I & M vs time for deformation to become critical
- **Practical + robust** - site logistics

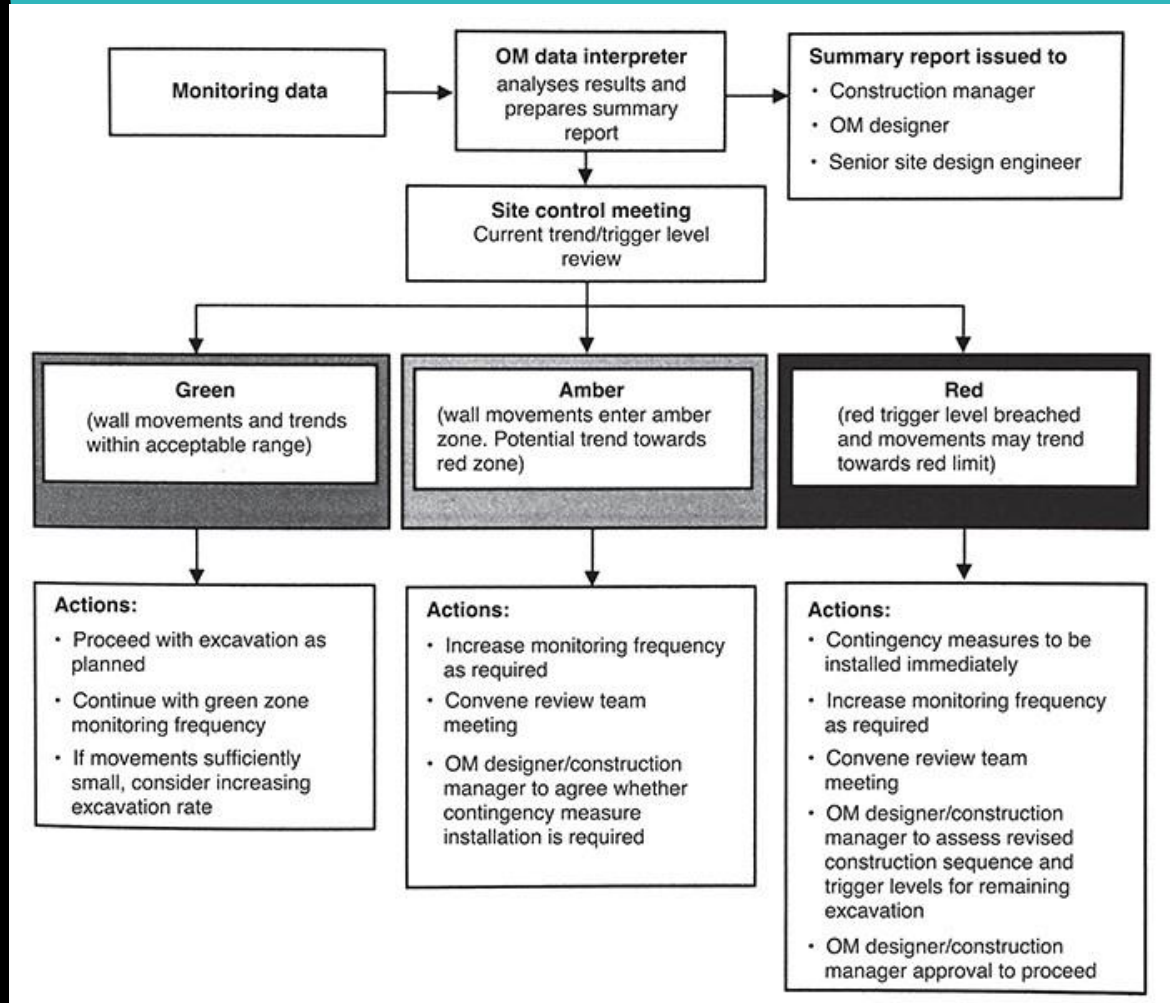


LESSONS LEARNT

Effective Communications and Ownership of Actions

- Practical implementation – keep as simple as possible, essential for effectiveness and safe implementation.
- Ownership of Actions - specific roles + responsibilities must be established
- Set up a collaborative ‘OM Team’ on site
- Produce construction control charts
- Key data + site observations, recorded on a regular, unambiguous basis.

<u>Rigorously implemented</u>



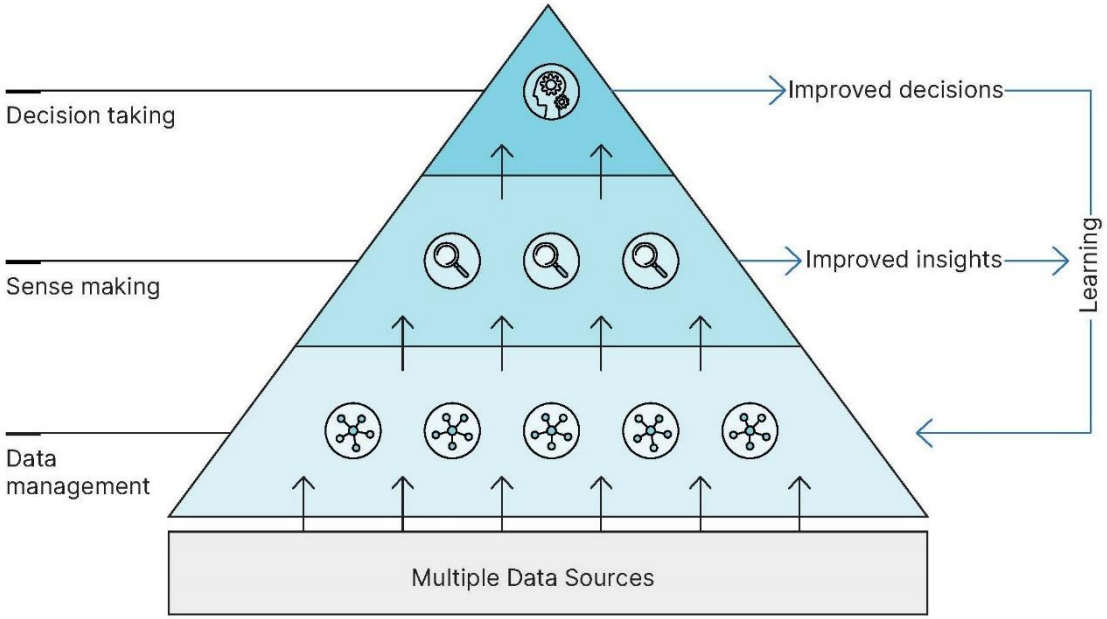
FUTURE POTENTIAL – Better Project Outcomes

O.M. + Modern Instrumentation/monitoring + Data Management systems+ R.T.B.A.

- Integrated + hosted on an **‘O.M. data platform’**
- Rich Data + Accessibility = POTENTIAL for another step-change in Geotechnics

Benefits

- Close gap between theory + reality
- Stronger connection design to construction
- Lessons Learnt from past projects → beneficial re-use for future design



The information value chain: showing the connection between data and better decisions that lead to **better outcomes**

FUTURE POTENTIAL - use of O.M. during design life / operations

Asset management + adaptive design

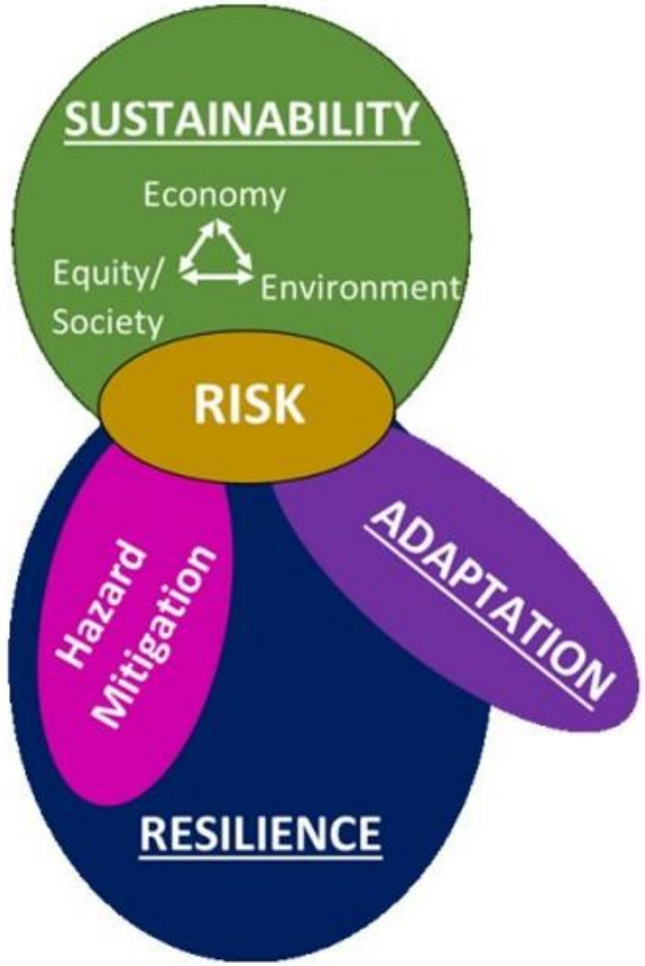
Balance sustainability and Climate Resilience

Asset Management

- ageing existing infrastructure
- understand deterioration + mechanisms of behaviour
- basis for more sustainable future, use of ‘OM Data Platforms’ to create more ‘intelligent’ Digital Twins
- Long-term use of O.M. to safely / cost-effectively manage infrastructure operation

Adaptive Design

- design of new infrastructure
- balance carbon consumption for new build vs climate resilience
- design for future modifications, based on observed behaviour
- implement ‘contingencies’ (modification) on basis of performance



CONCLUSIONS



Conclusions – Part 1

O.M. implementation needs to be:

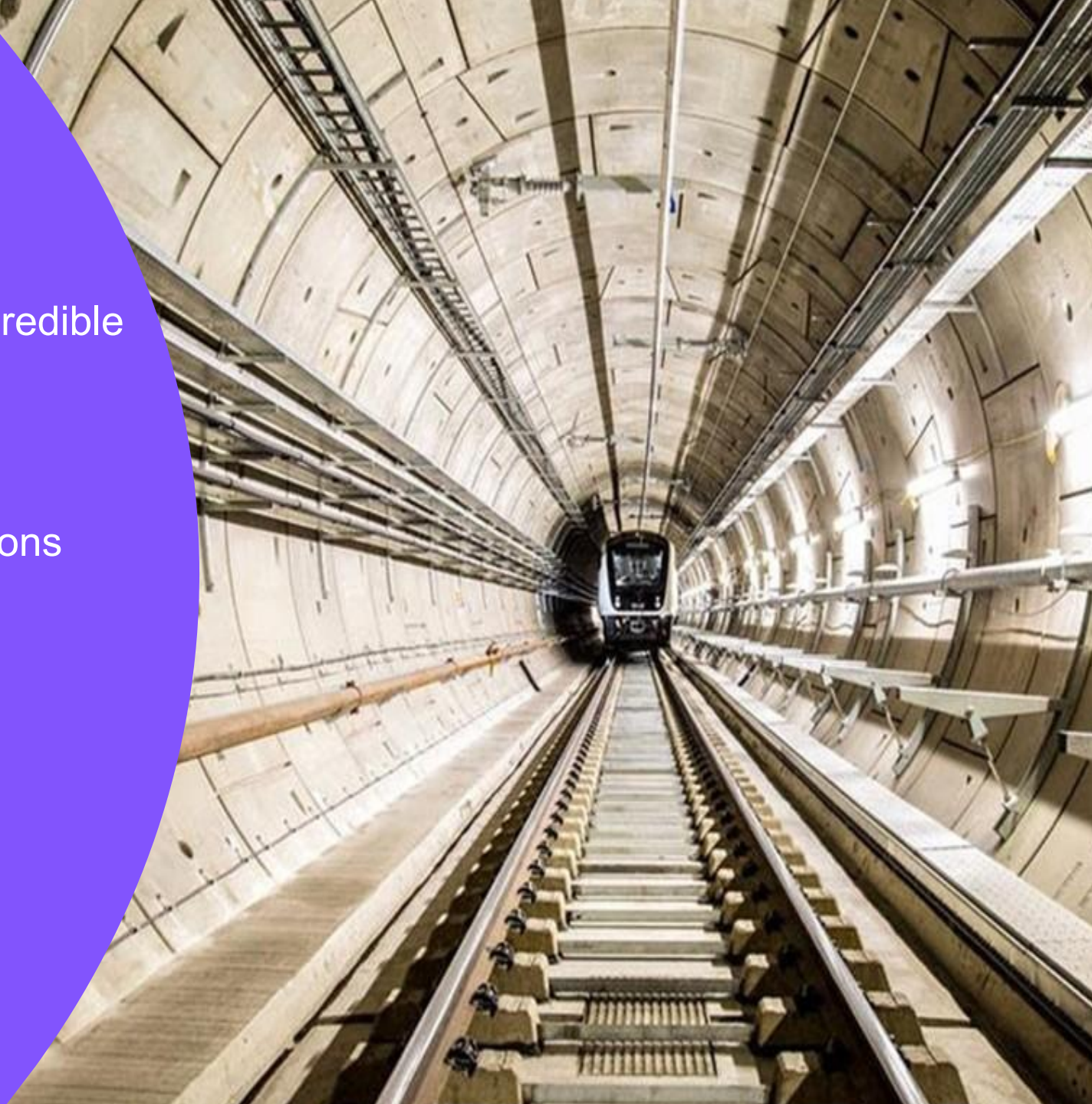
‘Comprehensive’ – Most Probable to Worst Credible

‘Rigorous’ – apply the ‘5 key requirements’

‘Pragmatic’ – e.g setting performance limits

‘Simple’ – communications + contingency actions

- **I&M – quality (not quantity)**



Conclusions, part 2

The O.M. is a powerful, practical technique which can provide huge benefits.
Wide range of different applications.

It has been **under-used**, typically due to:

- Contracts
- Industry culture (attitudes/organisation)

These can be over-come, but needs **strong advocacy**

- Some modern Contracts provide more incentive
- Modern Technology + O.M. could trigger a step-change improvement in Geo Practice.



The Observational Method is a Team Effort

Acknowledgements

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