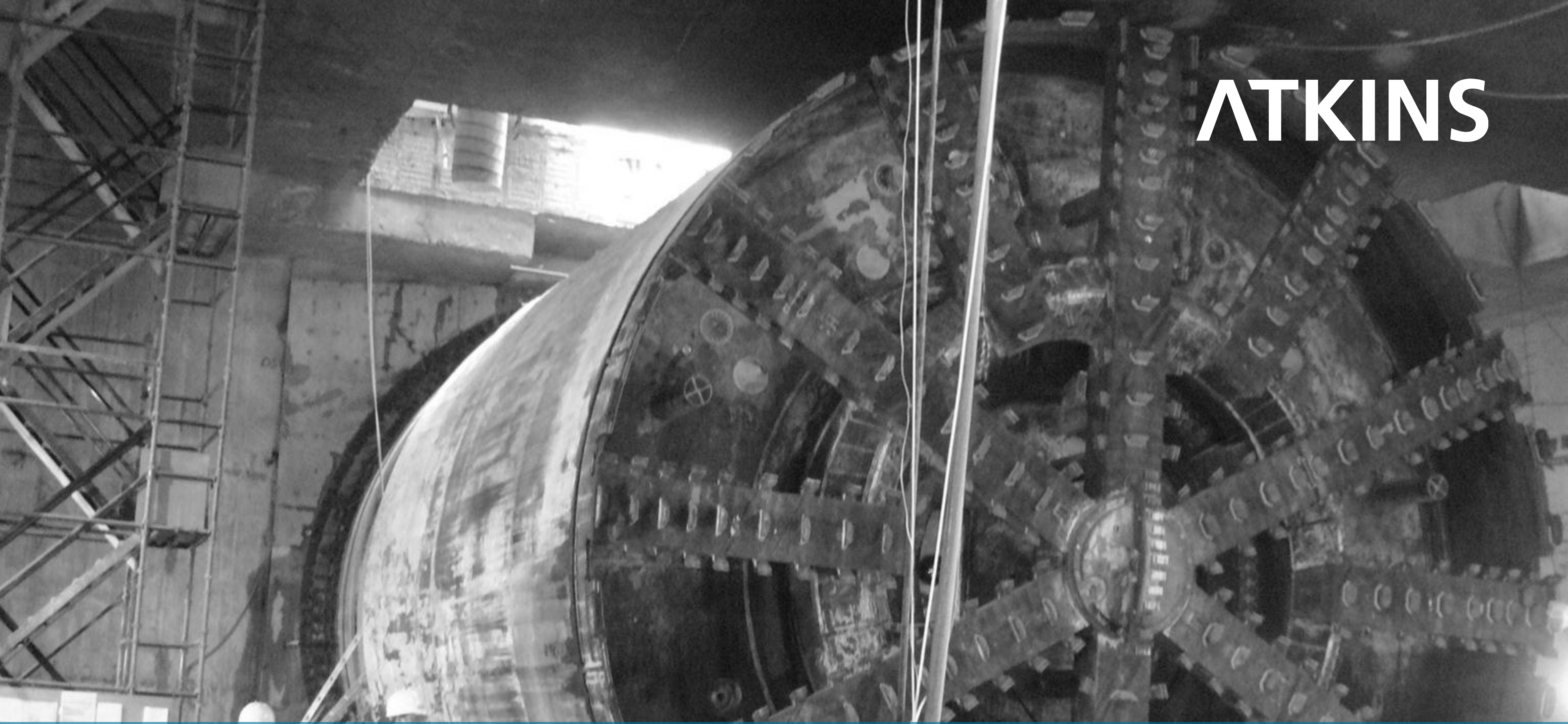

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Ground Engineering Design and Construction Experience in the Region

Paul Groves

Head of Tunnels & Ground Engineering

Atkins Middle East

What are the critical issues?

Geotechnical Investigation Practices:

- Clients often see geotechnical investigations as an exercise that needs to be done without knowing the benefits than can arise
- Quality of investigation practice is very variable
- Geotechnical interpretative reports are often produced by SI contractors
- SI contractors often provide the only supervision themselves
- Required SI standards and methods are often very low

Geotechnical Design issues:

- Contract specifications often demand use of inappropriate codes or mixtures of codes
- Approval bodies often misunderstand the difference between soil and rock (the weak rock : hard soil material range)
- Approval bodies staff generally have not had engineering geological understanding
- Geotechnical design is often overly conservative

What are the critical issues?

Things are getting better!:

- The rise or Design & Construct contracts
- Field data of major projects validating geotechnical parameters by back-analysis
- Better SI contractors
- Supervision of SI by the designer is becoming more accepted and even mandated in some cases
- Clients are now better informed and have more experienced staff
- Precedence of works contracts recognising unforeseen ground conditions as a latent condition

Qatar geotechnical work

Project	Type of Project	SI Scoping Management and Supervision	Desk Studies and Risk Assessments	Geotechnical Interpretation	Geotechnical Design and Advice
Khalifa, Rayan and Al Bustan Road	Infrastructure / Highways	✓	✓	✓	✓
Doha Metro (Tender)	Infrastructure /Heavy Civils		✓	✓	✓
Abu Hamour (Tender)	Infrastructure /Heavy Civils		✓	✓	✓
GEC Doha West	Infrastructure / Highways	✓	✓	✓	✓
Lusail	Infrastructure / Highways		✓	✓	✓
Doha Ceremonial Road	Infrastructure / Highways	✓	✓	✓	✓
Dukhan Highway	Infrastructure / Highways	✓	✓	✓	✓
Education City	Infrastructure/ Structures		✓	✓	✓

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Investigation Methods Issues


Conventional Wash-Boring

DRILLING EQUIPMENT:	Acker AD-II				
SIZE & TYPE OF CASING:	5" Steel Casing				
DRILLING METHOD:	Straight Rotary				
CORE BAR.:		LENGTH:		BIT:	
SAMPLER:	S.P.T.	WEIGHT:	63.50 Kg	DROP:	76 cm

GROUND WATER			
DATE	TIME	WATER DEPTH	CASING DEPTH
13-09-2011	10:00	2.60	None

DRILLER:	Rahman Malik
GEOLOGIST:	Abdullah

DEPTH (m)	DESCRIPTION	PROFILE	SAMPLES NO.	SAMPLES PENET BL/15cm	ROCK REC. %	ROCK RQD. %	REMARKS
0	Brown, medium dense, clayey medium to fine SAND with sub-angular to sub-rounded gravel of igneous origin.		1	7 10 13			SPT at 0.00 meters
1.5	Changing to dense.		2	40 50/8			SPT at 1.50 meters
3	Brown, very dense, poorly graded GRAVEL of igneous origin with sand & clay.		3	50/13			SPT at 3.00 meters
4.5	Brown, very dense, clayey fine to coarse GRAVEL with sand.		4	50/11			SPT at 4.50 meters
6	--- Ditto ---		5	50/3			SPT at 6.00 meters

Strata boundaries defined by SPT shoe samples

Investigation Methods Issues

Rotary coring using double tube core barrel

Typical core recovery

Investigation Methods Issues

Extremely weak, clayey Sandstone
[comparable samples from wash-boring
described as dense, clayey Sand]

Investigation Methods Issues

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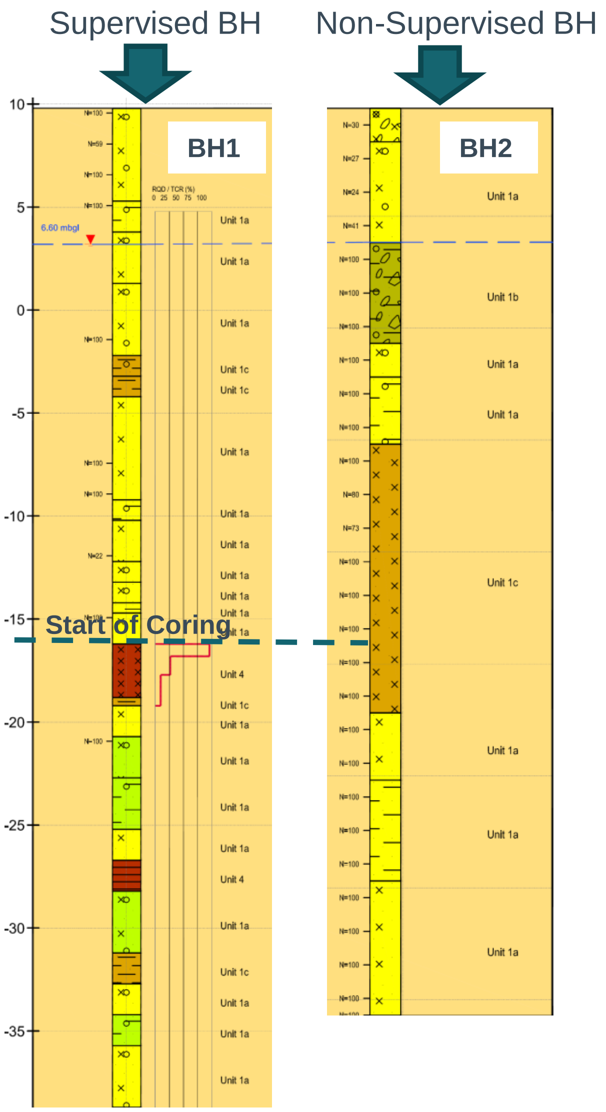
Extremely weak, sandy Mudrock
[comparable samples from wash-boring
described as hard, sandy Clay]

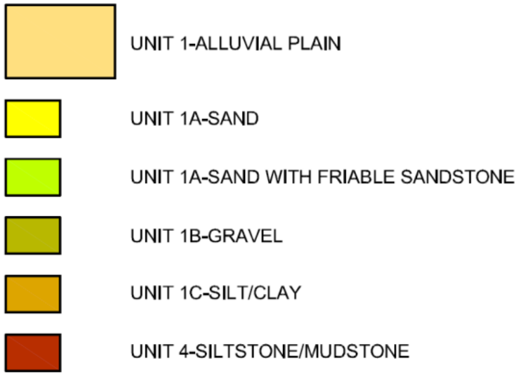
Investigation Methods Issues

Extremely weak, clayey Sandstone
[comparable samples from wash-boring
described as dense, clayey Sand with gravel]

Investigation Supervision



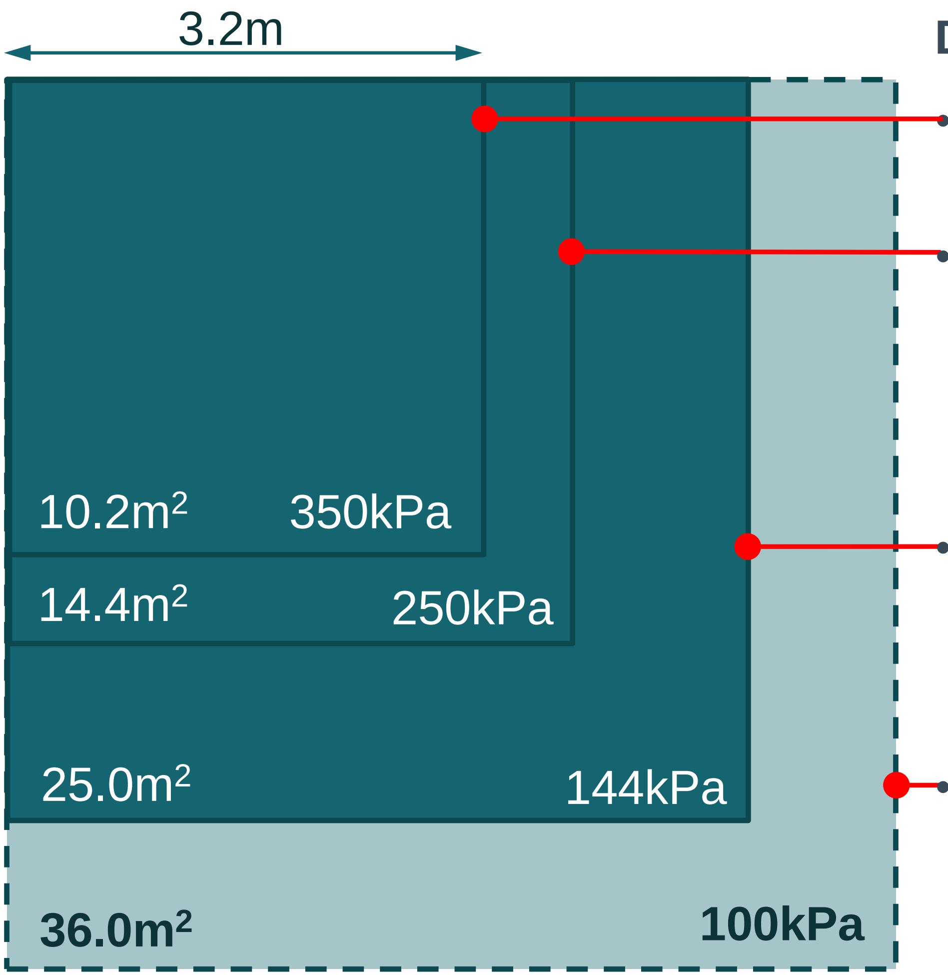
- Two Boreholes (BH) undertaken within 15m, one supervised, one not.
- Wash boring technique used in BH2 – where rock was never established.
- Wash boring <u>not</u> used in BH1and corable material established after approx 25m depth.
- Difference results in significant difference in piles design.



Mixing codes

Impact of mixed codes on design outcome:

Single Type F1 pad: 360 tonnes working load, deflection controlled (<25mm)



Design progress:

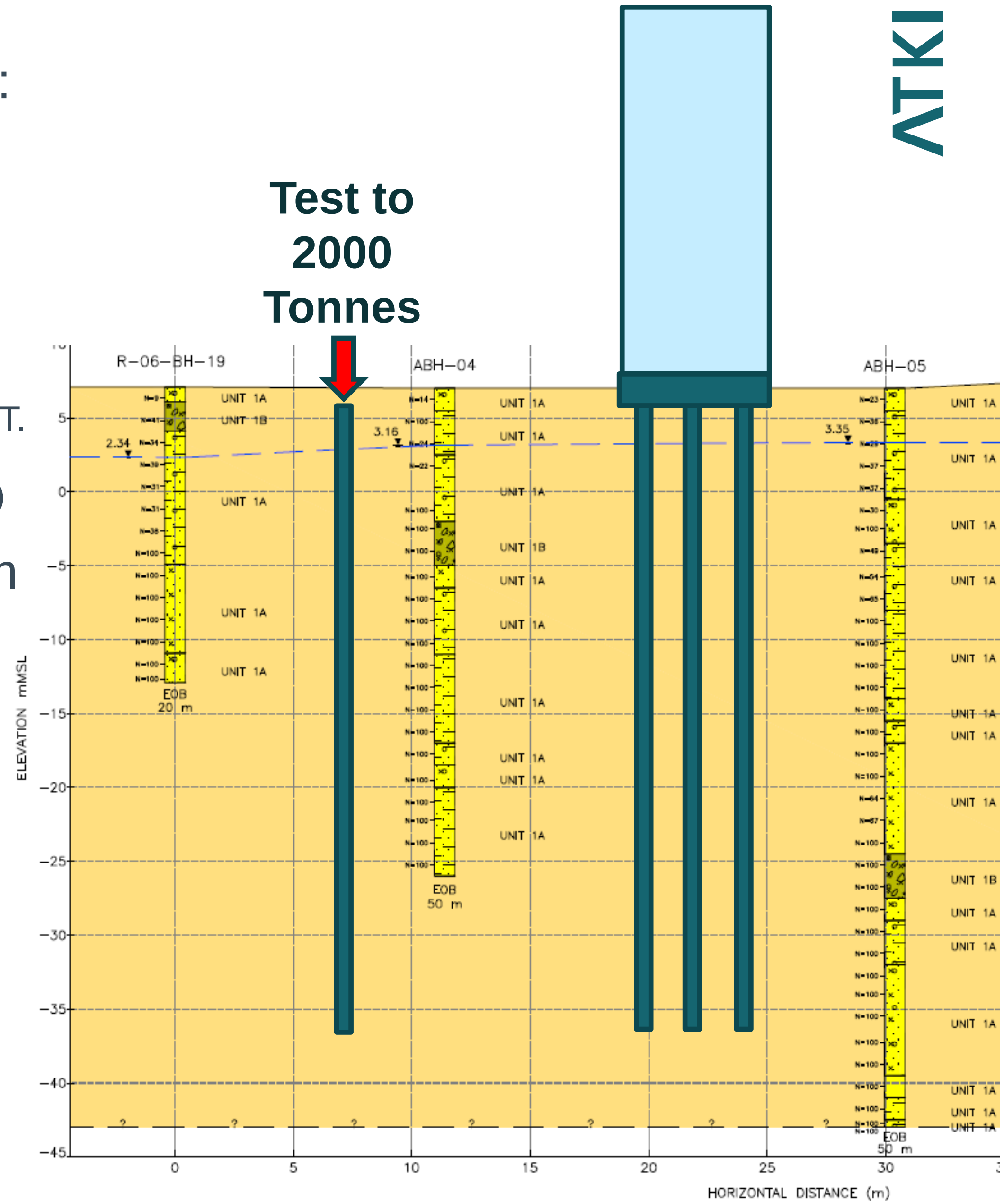
- Use of Burland & Burbridge method (to BS code)
- Requirement to use "stress-strain" method instead, where we used $E' = 1N_{60}$ for soils with low fines content. E' corrected to E_m for the settlement calculation.
- Requirement to use $E' = 0.7N_{60}$ for all soils with fines content between 10-35%. E' corrected to E_m in the calculation.
- E' rather than E_m should be used, if adopted for this F1 pad this would increase dimension or even need piles.

Mixing codes

Assuming ground is soil

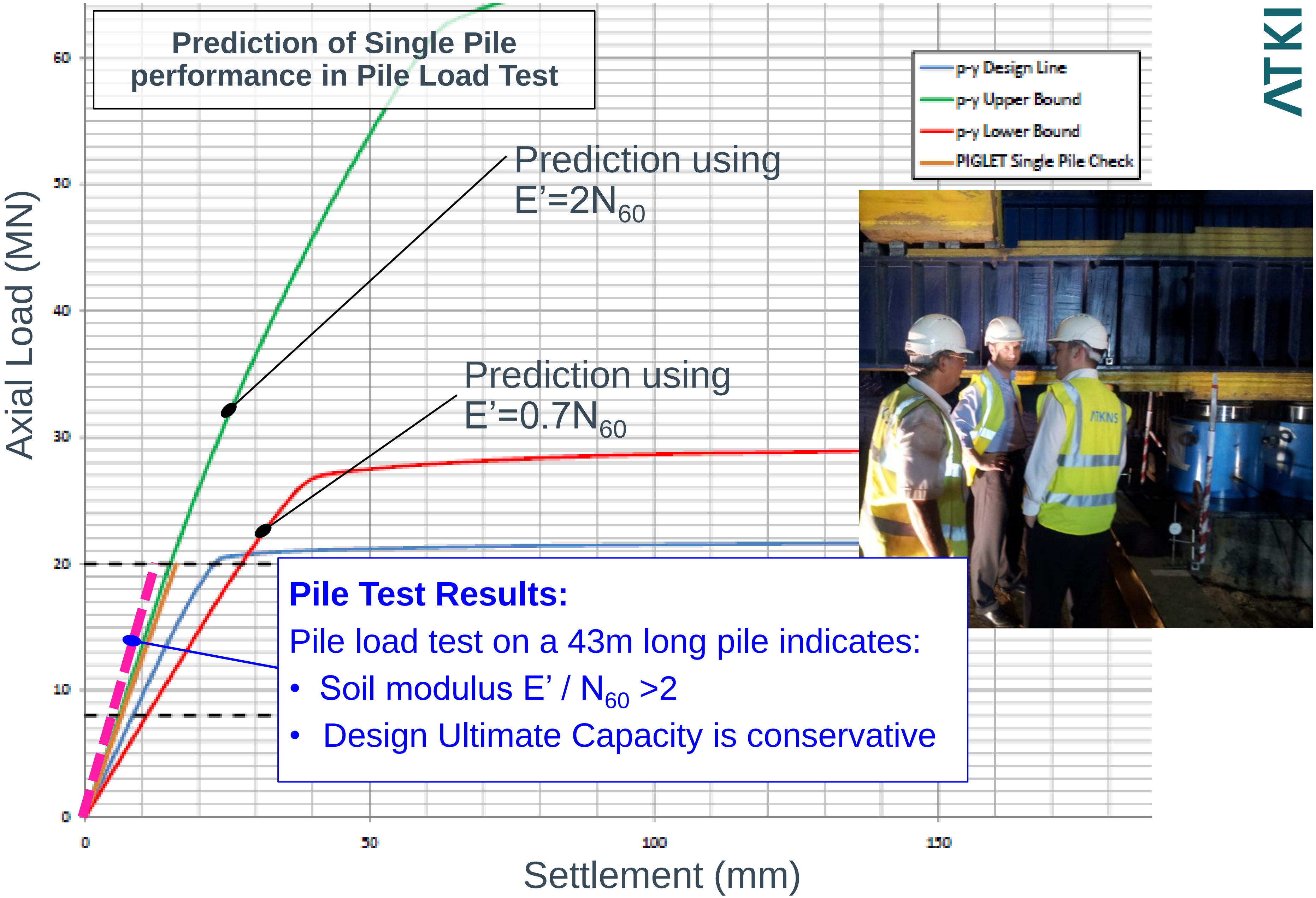
Tall building with circular footprint:

- Preliminary pile group design:
    - 43 Piles – ⦰1.2m, L=43m
    - Working load 800 Tonnes
    - Max settlement V=48mm (H<6mm)
    - Pile Group settlement analysis by PIGLET. Shear modulus derived from E’ (where E’=1N for sands and E’=1.2N for gravels)
- Pile load test to 2.5*x*WL on 43m long pile undertaken
- Actual pile settlement at 2000 Tonnes <13mm



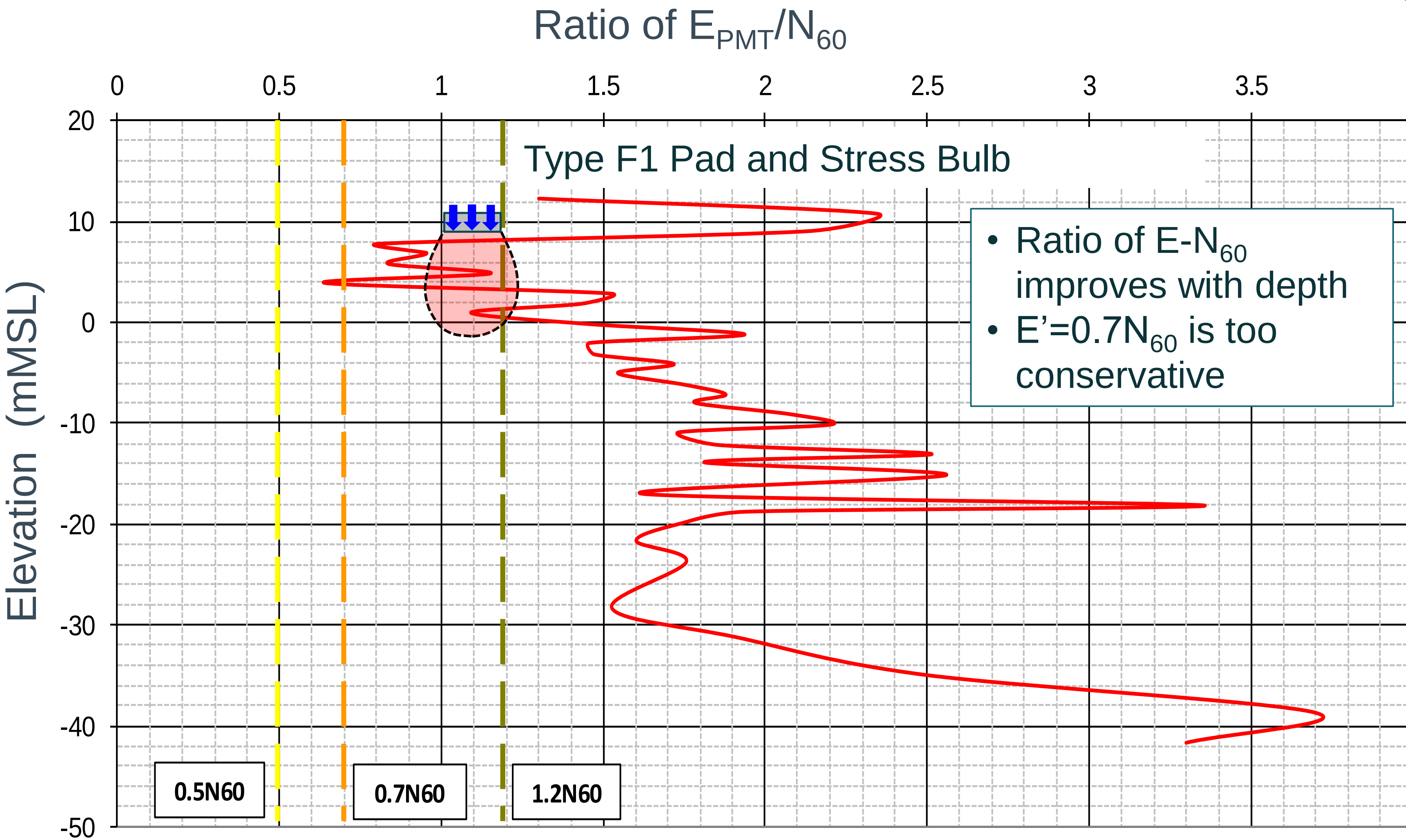
Assuming ground is soil

Assuming ground is soil



Ignoring field data

Site-wide Pressuremeter test results E_{PMT} / SPT N_{60} distribution



Impact on construction

Use of in-situ field data

INVESTIGATIONS:

Boreholes

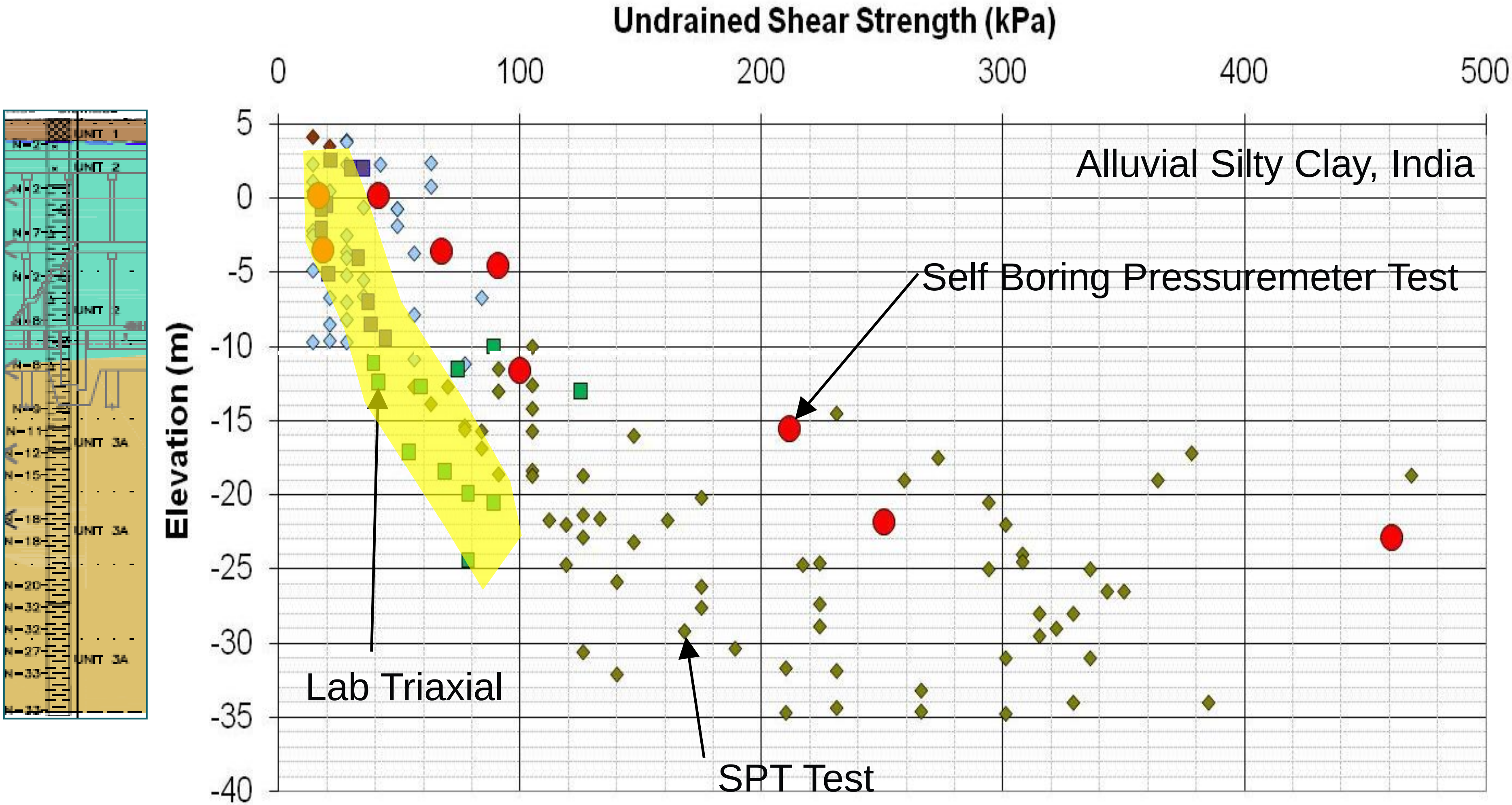
Laboratory testing

How to interpret?

- Develop geological model
- Design investigations
- Supervise SI
- Correlate in-situ and lab test data and geological model

Use of in-situ field data

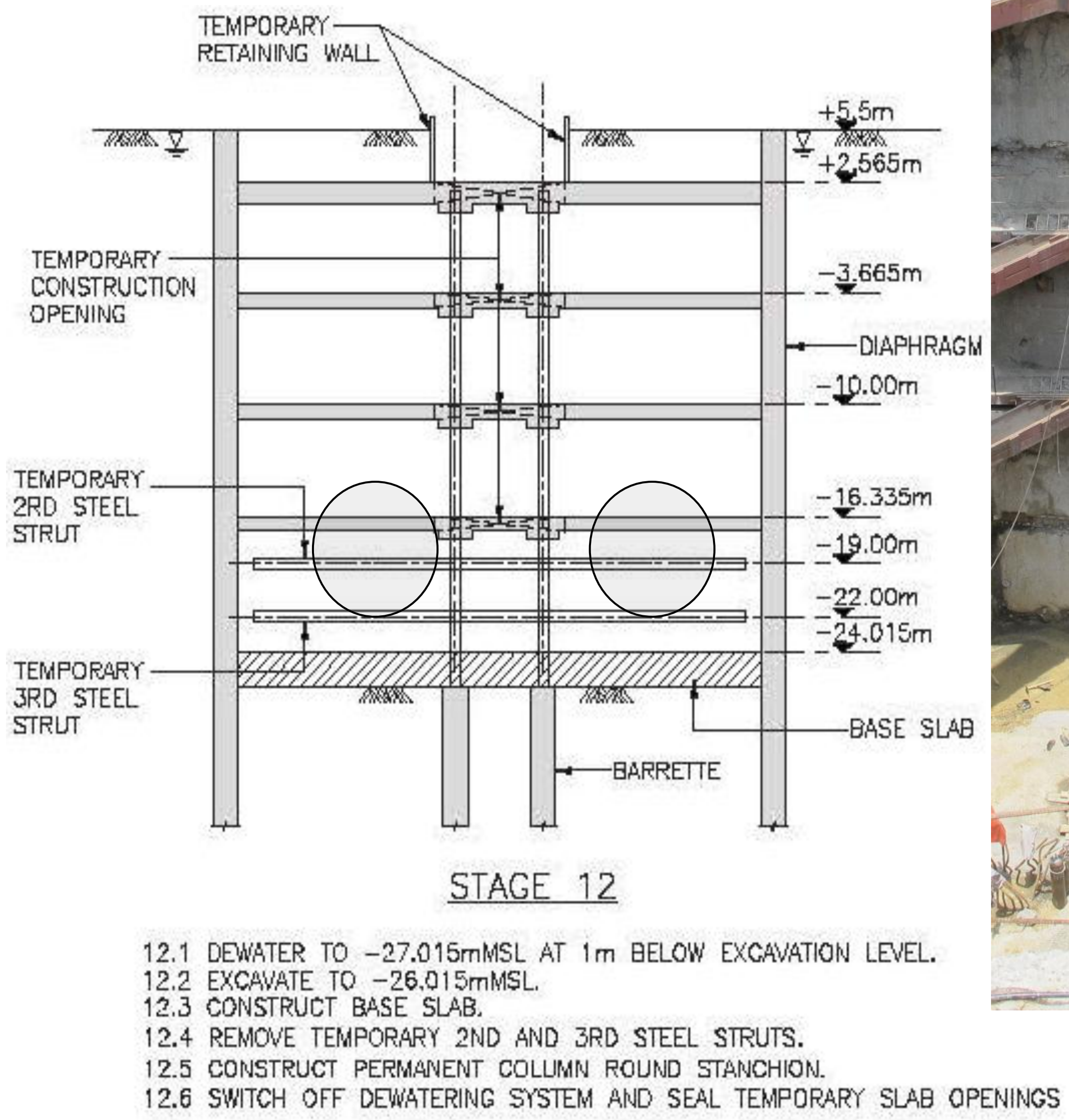
Investment in high quality SI to achieve efficient works design

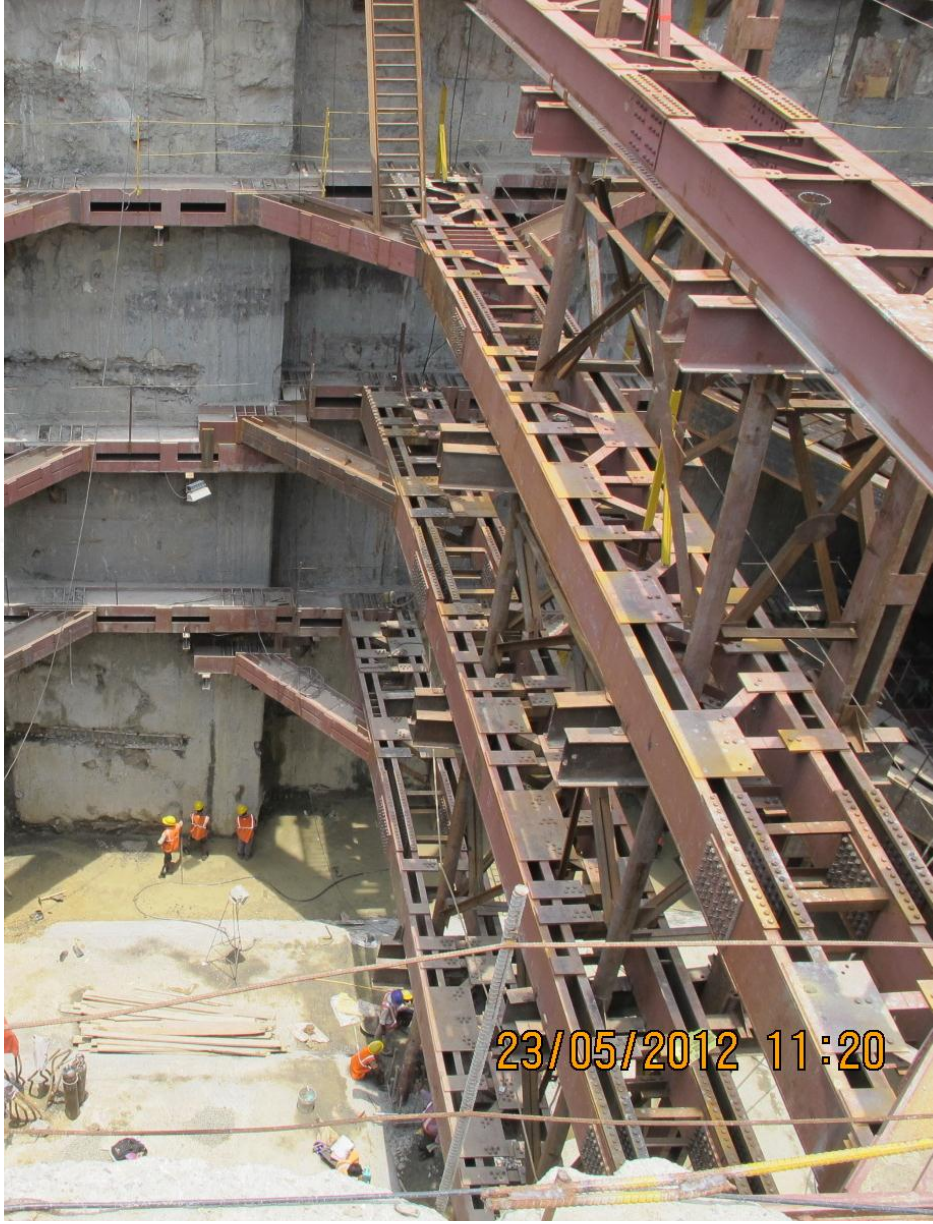


Tunnel Linings

- Parameter certainty limits reinforcement weight

Deep excavations





Top-Down Metro Station and Bottom-up Cross-over Box
32m deep, 25m wide

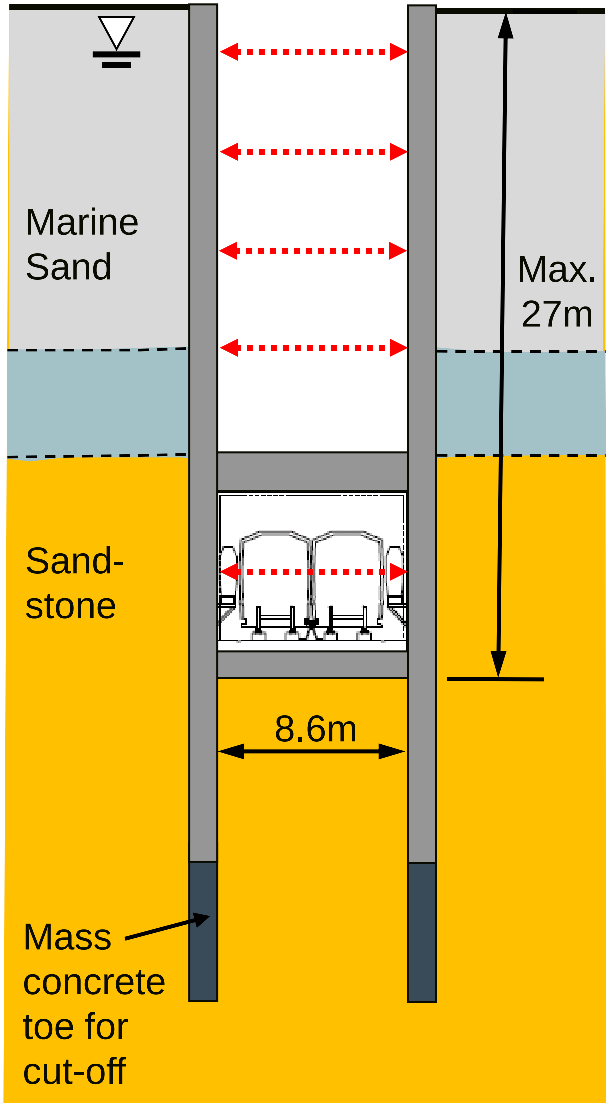

Kolkata – Howrah Maidan Station
• Excavation commencing in main station box
• Crossover box excavation complete & preparing to commence TBM operations
• Base slab cast in Crossover
28/06/2012 17:09

Back-analysis

Dubai Metro Cut & Cover Tunnels:

- 4No. Ramps from stations on 4% grade (1.7km)
- Top down construction with permanent Diaphragm Walls
- D-Walls between 0.8m and 1.2m thick
- Temporary struts (Yong Nam type)
- Designed as “Fully fixed” wall-slab joints
- Durability provided by concrete mix design and Contract requirements (<30mm deflection, <0.2mm crack width)

- Observed ground better than suggested by early SI
- This led to campaign of in-situ testing, close monitoring, back-analysis and strut optimisation
- Amended design for RL and changed SI practices for GL
- Atkins supervised GL SI



Back-analysis

Dubai Metro Cut & Cover Tunnels:

Multi-level strutting

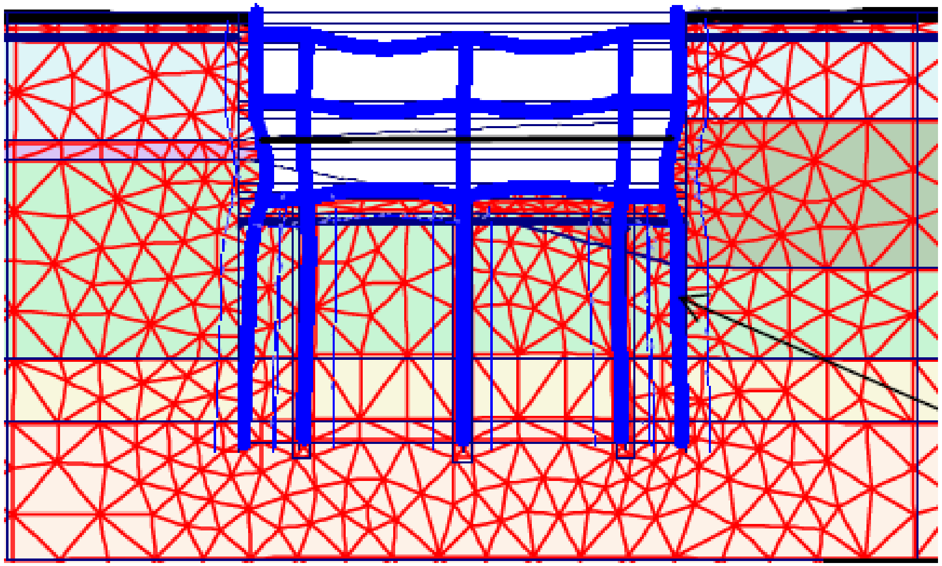
Slab joint coupler protection

Tunnel portal to trough section with permanent RC struts

Diaphragm wall reinforcement cage being lowered into cut wall slot

Back-analysis

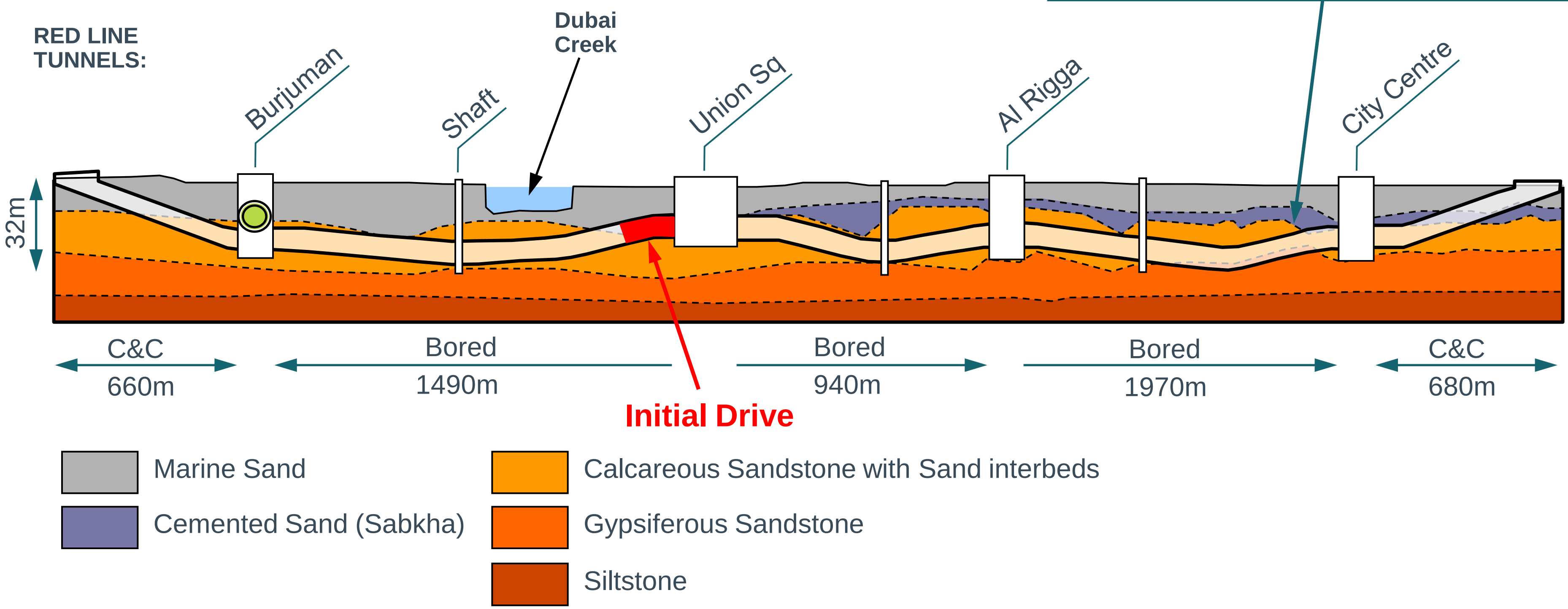
Dubai Metro
12 Top-Down Metro Stations:
Union Station



Back-analysis of tunnelling V_L%

Observational approach – Example: Tunnelling beneath piled buildings

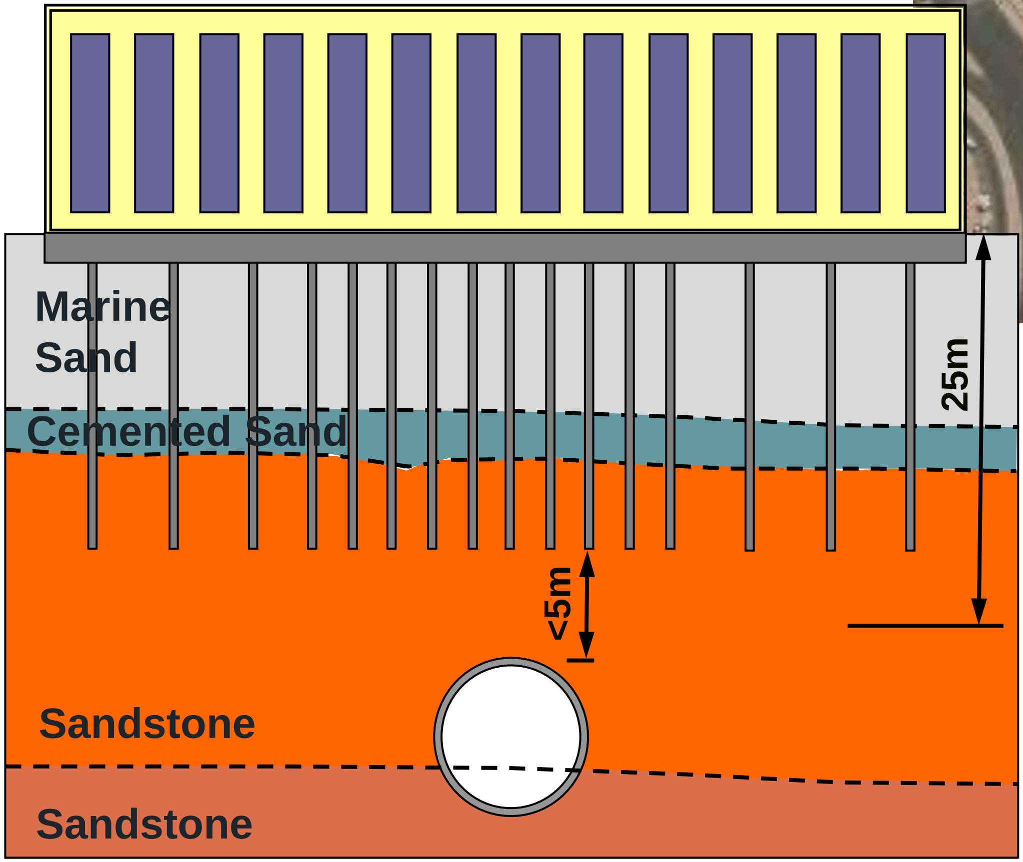
- Initial design of EPB Operating Pressures
- Incorporation of Initial Drive findings
- Validation of predictions



Back-analysis of tunnelling V_L%

Dubai Metro – Red Line:

- DNATA Building is at worst risk
- Frame structure over tunnel with cover of 3-5m to pile toes



- Tunnel-Pile interaction analysis to determine tolerable Volume Loss
- V_L <0.5% tolerable
- Preferable to manage using TBM Operational Pressures rather than intrusive mitigation

Back-analysis of tunnelling $V_L\%$

Detailed Design – TBM face/Annulus grout pressure design

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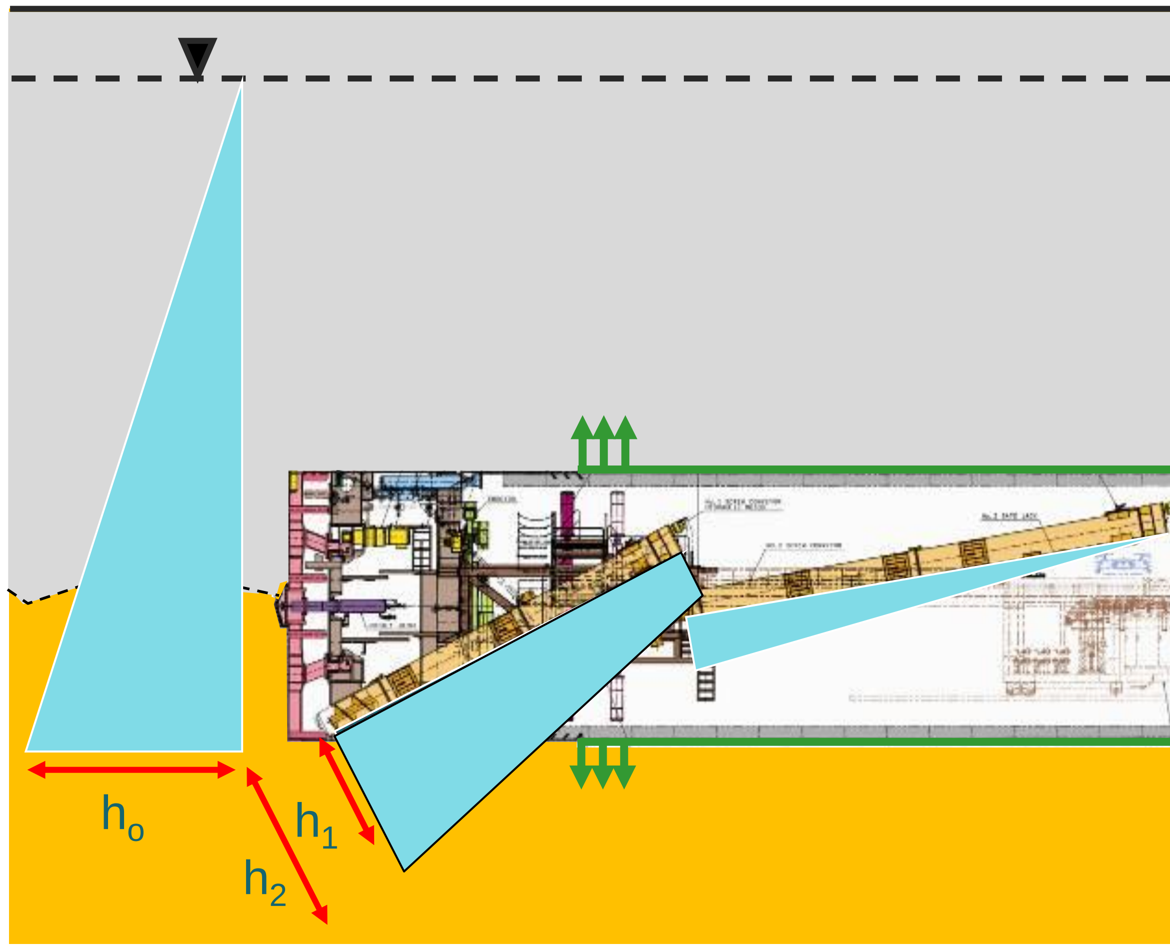
TBM Operational Parameters:

- Intention to limit settlement
- Face pressure based
- Annulus grout pressure
- Pressures can be calculated analytically
- No precedent experience of TBM so Trial Initial Drive important for validation



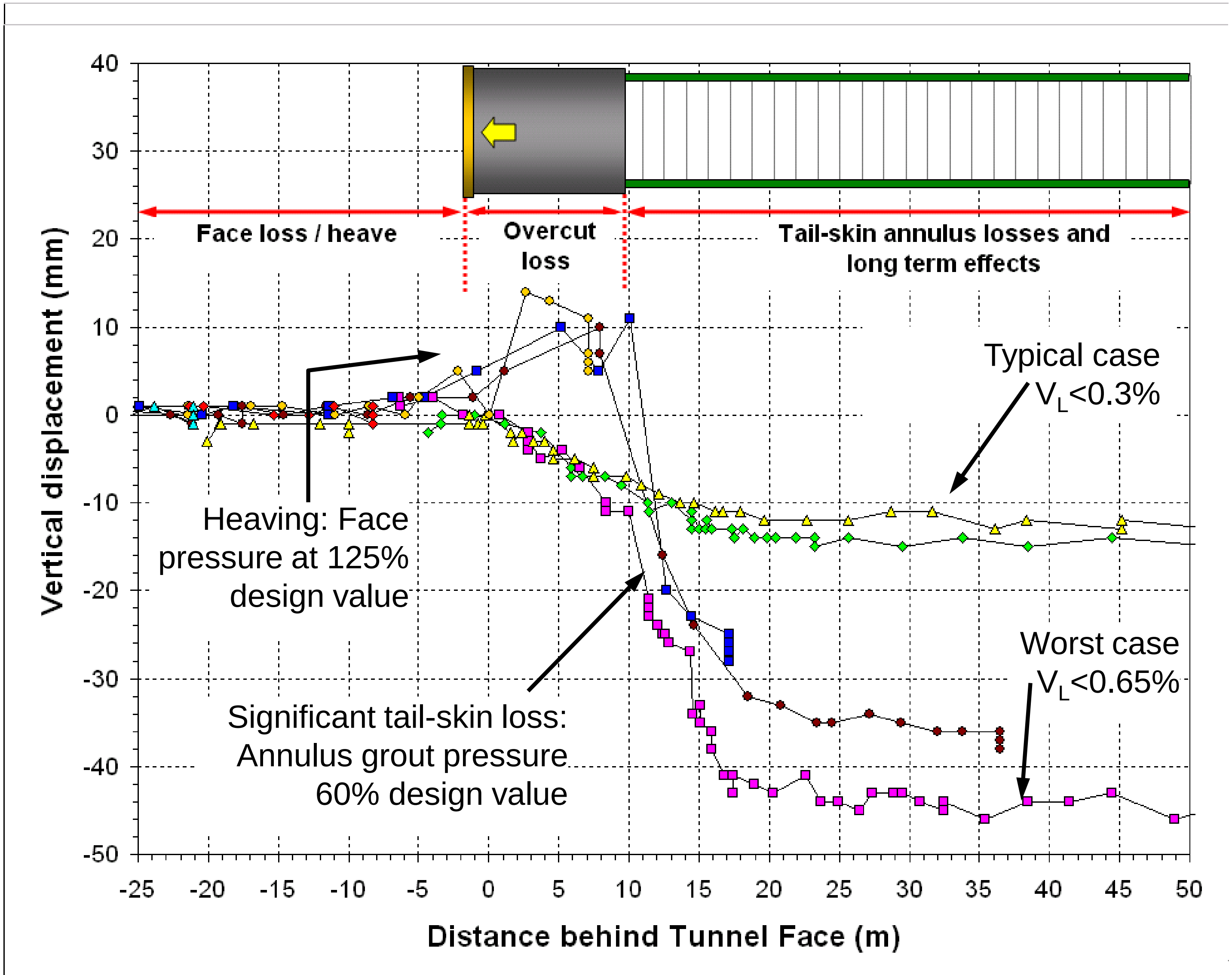
Ratio of h/h_o is linearly proportional to achievable effective face pressure

Back-analysis of tunnelling V_L%

RED LINE

100m Initial Drive:

Settlement data for mixed face tunnelling



Back-analysis of tunnelling V_L%

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FEM Analyses (FLAC3D and PLAXIS3D)

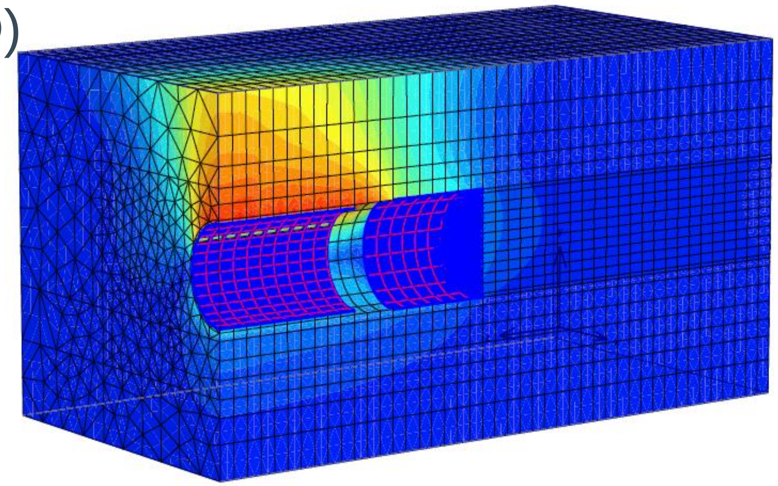
Back-analysis of Initial Drive & sensitivity analysis

Calibrated models for:
- RL validation of calculations
- GL design to calibrate the analytical calculations
- Reassessment of DNATA

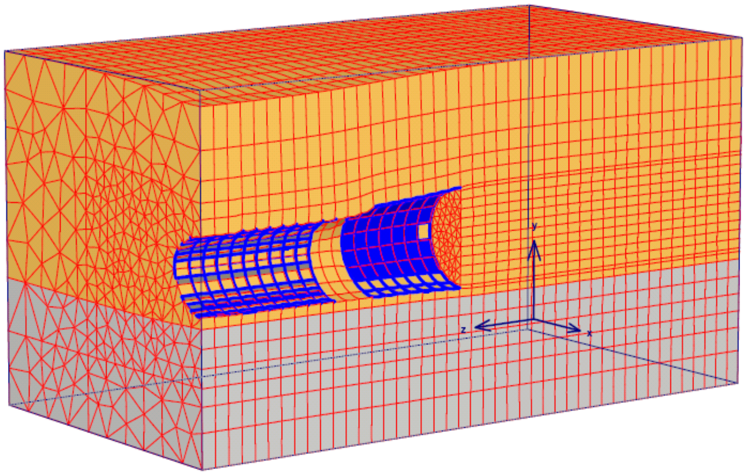
Analytical calculations (FoS 1.2) are reasonably conservative

Gave confidence for GL design in extensive mixed conditions

DNATA: We reduced pressures: Settlement was negligible



Displacement contours



Deformed mesh

Back-analysis of tunnelling V_L%

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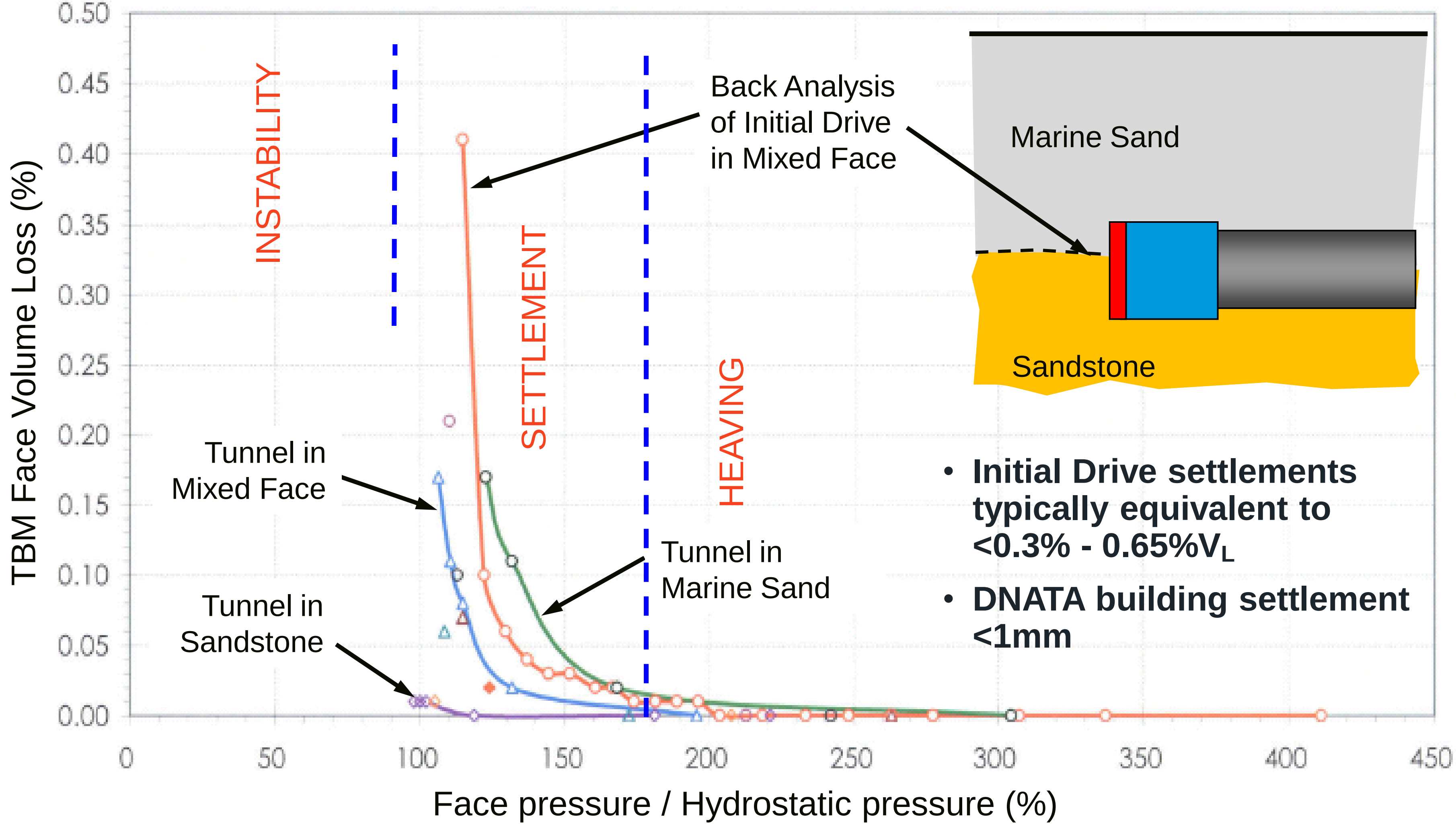
FEM Analyses (FLAC3D and PLAXIS 3D):



- **Initial Drive settlements typically equivalent to <0.3% - 0.65%V_L**
- **DNATA building settlement <1mm**

Back-analysis of tunnelling V_L%

Conclusions

Future trends:

- Better understanding of the geotechnical characteristics of the weak rocks in the region
- Improving geotechnical investigations practices
- Cleaner application of codes (EN introduction is significant)
- More cost-effective projects