Bored Tunnelling in Urban Environments.

Design and Construction Issues - what can be a problem and why!

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- 18 years of International Experience (UK, USA, Singapore, Hong Kong, Australia, Chile, Canada)
- Engineering Consultant for: Arup & Atkins
- Government Clients : Land Transport Authority
- Geotechnical and Tunnel Design (Bored Tunnels, NATM and Hard rock caverns and tunnels)
- Technical Director Amberg - Singapore

Singapore
- North East Line MRT
- KPE Road Tunnel
- Airport Link, Brisbane

Australia
- Airport Link, Brisbane

United States
- 2 Ave high Speed Train Tunnel
- East Side Access Project
- SCL MRT Tunnel
- No. 7 Line MRT Tunnel
- 60th Street Subway
Idea behind the presentation

The best way to improve is to share our experiences

“We learn more from our failures than our successes”

“Insanity: doing the same thing over and over again and expecting different results.” – Albert Einstein

As an industry or a project - “…we are only as strong as the weakest link”

“If anything can go wrong it will – Murphy Law & “Hope for the best, but plan for the worst”
Presentation Overview

• Problems and issues that can occur on tunnel projects
  – Planning
  – Procurement
  – Design
  – Construction
  – Supervision

• Ground Risk and Geotechnical Baseline Reports (GBRs)
  – Understand these are now being used in KL

• Case Study: Miami Port Tunnel, USA
  – Tunneling in Karstic Limestone
  – How to manage Ground Risk
Building Large Infrastructure Tunnel Projects

- **VARIOUS DISCIPLINES**
  - MEP
  - Architects
  - Traffic
  - Quantity Surveyor
  - Scheduler
  - Geotechnical
  - Structures
  - Survey & Alignment
  - Rail
  - Legal
  - Environmental
  - Fire
  - Contractors & Sub Contractors
  - Safety & Risk

- **MANY ASSUMPTIONS**

- **NUMEROUS INTERFACES**

- **POTENTIAL PROBLEMS**

- **WORK IN PARALLEL**
DESIGN & CONSTRUCTION OF TEMPORARY WORKS FOR TUNNELS

CONSTRUCTION MANAGER

OWNER & CONSULTANT

CONSULTANTS

CONTRACTORS

Project Planning

Preliminary Engineering & Site Investigation

Contract Documentation

Contract Procurement

Detailed Design

Construction Activities

Construction Supervision & Quality Control

Instrumentation & Monitoring

Statutory Approvals

Construction Impact Assessment

DESIGN & CONSTRUCTION OF TEMPORARY WORKS FOR TUNNELS
Problems for the Tunnels in an Urban Environment

• Planning Problems
  – Not getting the information needed from 3rd parties
  – Not getting agreement particularly access and land requirement
  – Not considering ground risk and construction techniques during the planning
  – Limited ability for alternatives and VE options
  – Be clear about what you want – minimize changes (i.e. Addendums)

• Design problems
  – Approvals
  – Poor geotechnical interpretation
  – Design changes – Contract and Client making last minute changes
  – Projects are becoming harder – more experience is needed
  – Incomplete information – too many assumptions
  – Not looking at the details of the design and the risks
  – Design codes & numerous approaches
Problems for Tunnels in an Urban Environment

• Construction problems
  – Unforeseen conditions
    • Different ground conditions
    • Obstructions or utilities
  – Access and site constraints
  – Interface with 3rd parties
  – Construction impact, noise, vibration and movement
  – Cut and Cover - Gaps in retaining wall & Strut and King Post details
  – Bored Tunnel – Face stability, mixed face ground and interventions

• Instrumentation problems
  – Looking at the results in isolation
  – Assessing the timing as well as the magnitude of the movements
  – Delays in getting the results

• Construction Supervision
  – Roles and responsibilities
Project Planning

Who plans a tunnel project, planners, architects, engineers (road, rail, water etc.) or tunnel engineers?

**What do we want to build?**
- What is the intended purpose?
- What is the required size and shape of the structure?

**What is the structure to be designed for?**
- What is the design life?
- What are the constraints on movement, groundwater drawdown and vibration?
- What are the inflow and requirements for the structure?
- What are the waterproofing requirements?

**Where can we locate the structure?**
- What is the location in plan and depth?
- Are there adjacent sensitive structures?
- Are there interfaces with 3rd parties?
Project Planning

CONSTRUCTION CONSIDERATIONS

How will we build the structure?
• What excavation techniques will we use?
• Where will the work area and site access be located?

COST & SCHEDULE CONSIDERATIONS

What is our budget & schedule?
• How much will it cost? What is our budget
• How long will it take?
• When do we need it to be operational?

CONTRACT

How will we procure the work?
• What type of contract will we use?
• What construction documentation will we need?
• What approvals will be required?

Who plans a tunnel project, planners, architects, engineers (road, rail, water etc.) or tunnel engineers?
OUTLET CAVERN

18m cavern
30m cavern
10m tunnel

EXAMPLE PROJECT – PLANNING CONSIDERATIONS
Planning Stage – Examples of other problems
Do we really want to ……

• Propose a large cut and cover under a road without verifying utility locations
• Launch a TBM from a station excavation directly under a main road or a river
• Start a bored tunnel with very low cover
• Located a cross-passage in mixed face round or at the deepest points of the alignment
• Have a tight radius curves in areas of poor ground
• Put two construction shafts side by side for adjacent contracts
• Plan to have interventions for the TBM in mixed face ground
• Be so close to the buildings – property line issues
Project Planning

What do the planners (owner or consultant) need to consider:

• How will value engineering alternatives be handled?
• How will the contractor build the tunnels / station? (what techniques could be used, what space and access will be needed?)
• What information do they need to collect, when do they need it and from who? (i.e. building or utility information)
• What approvals will need to be obtained?
• Who do the project interface with?
• Where will the contract boundaries be?
• What are the risks involved? How will ground risk be managed?
• Do they understand the ground conditions / risks?
Project Planning

What can owners do before contract award to help:

- Risk workshops (or use Review Boards)
- Contractor Involvement (use of workshops)
- Understand possible Value Engineering options and how will this be managed
- EIA and planning documents should not limit alternatives
- Collection of information (foundations, building condition)
- Acquire land and access (permanent and temp land - site offices)
- Approvals and involvement with 3rd parties
- Site Investigation (do it early and do a lot)
- Prepare very good contract documents inc. GBR
Different procurement methods will place the risk with different people.

Very important that the risk are therefore understood and clearly communicated.
Contract Documentation

• This is where all risk and quality issues are identified and responsibility transferred.
• Must have right documents for contract used – documents will be different
• Each project will have its own unique set of issues
• Key Documentation
  – Condition of Contract
  – Drawings
  – Historical documents (as built)
  – Design criteria
  – Specifications (PS and M&W)
  – Geotechnical Reports (GIR, GDR)
  – Most important of which is the Geotechnical Baseline Report (GBR)
Detailed design –  
SCL Project, HK

Mixed face geology
Bored Tunnels close to
foundations for building
viaduct
Two subway crossings
3 different construction
interfaces
Two deep excavations
next to adjacent
buildings
Constructions –
foundations to remove
Detailed design – SCL Project, HK

- Highly variable ground - Fill, Marine Clay, Alluvial, Granite (CDG to SDG)
- 3.5 bar water pressures (maximum allowed)
- Variable rockhead

West

TBM Launch Shaft

Southbound SCL

TBM Launch Shaft

Northbound SCL

East

ADMIRALTY STATION

EXHIBITION STATION

Fill

Weathered Granite

Marine Clay

Granite

Alluvial Deposits

Final Southbound Rockhead

Final Northbound Rockhead
Detailed Design - An overview

- We are becoming more and more adventurous as design tools and construction equipment develop (i.e. TBMs)
  - Tunnel Cover,
  - Proximity to tunnels and buildings,
  - Tunnel Size
  - Use of Ground Improvement Techniques

- Tunnel design is difficult – no direct methods, combination of empirical, analytical and numerical techniques.

- Tunnel design - an art as much as a science

- Every design has some kind of significant assumption – very much based on experience and local approach

- Each consultants and each country will have there own approach and codes to use
Problems with Geotechnical Interpretation

- True interpretation or join the dots
  - What about photolineament surveys
  - Historical land use maps
  - Desk Study
  - Previous Projects

- Significant implications
  - Retaining wall designs
  - TBM machine selection
  - Settlement estimates
  - Segment designs
  - Intervention locations
Detailed Design – Bored Tunnels

- Typical design approach
- Design codes

However what about
- Face pressure,
- Dry soil volumes,
- Break-in and breakout (ground treatment, tunnel eye design shotcrete dome),
- Slurry requirements,
- Abrasion of ground,
- Connection and waterproofing details,
- Intervention locations and air pressure
Detailed Design – Cut and Cover

• Typical design approach

• Design codes

• Finite Element
  – Drained v Undrained
  – Modeling groundwater (steady state and transient flow)
  – Boundary Conditions

• King post design
  – Connection details

• Waler design (and stiffners)
  – Connection details

• Strut design
  – Single strut failure

Retaining Wall System Design

1. Site Investigation
2. Wall Type Selection
3. Performance Criteria Selection
4. Seepage Analysis
5. External Stability
6. Wall Component Design
7. Vertical Capacity of Wall
8. Structural Resistance
9. Deflections and Soil Deformation
10. Specifications

(A) Geometry
  (a) Embedment
  (b) Support locations

(B) Loading
  (a) Earth pressures
  (b) Support loads

(C) Bending Moments

(A) Bending Failure

(B) Shear Failure

AMBERG ENGINEERING
Construction Impact Assessment

- Typical Design approach
- Estimating movement – show different approaches (empirical v numerical)
- Building damage assumptions
  - Foundation type
  - Building type and
  - Existing condition
Building Damage Example
Singapore

- 7mm settlement recorded
- Very large structural cracks observed
- Building needed to be evacuated and
  Adjacent Construction
- Significant remediation work
- Monitoring not extending far enough
Building Damage Example
Hong Kong

Poor Existing Condition
Illegal modifications
Unable to gain access during planning
Statutory Approvals

• Do the organizations understand what we are doing

• Do we understand what they want and what they are concerned about, this should be known and understood prior to contract award

• What is needed by them and when do they need to respond to us
Statutory Approvals – Examples of Problems

- Airlock door on TBM
- Sinkhole and road closure
- New requirement on Cross Rail

All 3rd party authorities have to sign a permission to proceed form before work can start.

Independent checking engineers are employed by the 3rd Parties and review the construction impact work.
Problems with Construction Work

- Very Expensive $$$$ 
- Large Schedule Impact - delay 
- Loss of life and damage to property
Problems for the Tunnels an Urban Environmental

• A UK Study found 361 cases of tunnel collapses and emergency events (between 1979 and 2010)
• Over 400 death in the above period
• Loss of credibility to the tunneling industry
• Joint Code of Practice
• JCOP mandates the use of GBR (see paragraphs 7.2.5 to 7.2.8) – very controversial
• No GBR – No insurance
• A sign of things to come
Problems for the Tunnels in an Urban Environmental Context

### Cause of Tunnel Failures

- **Low Overburden**
- **Influence of Water**
- **Ground Conditions**
- **Design Error**
- **Obstructions**
- **Construction Error**
- **Unknown or...**

The chart illustrates the frequency of various causes of tunnel failures.
Construction Activities – Bored Tunnels

- Soil management – how is dry soil volume calculated
- Procedure for clearing blockages - flushing head
- Machine selection
- Disturbance from previous construction i.e. utilities
- Low cover – including culverts and drains above
- How is face pressure calculated
- Tunnel Breakin & breakout
- Tunnel interventions, - Singapore 80% of all ground loss incidents
- Mixed face ground
- Contingency plans not being ready
Construction Activities – Bored Tunnels
Construction Problems – Cut and Cover

Deep Excavation

Road
Utility Crossing
Groundwater Inflow

Pavement

Building
Survey Points

Collapse

Gaps in Wall

Final Condition

- Cracks observed
- Water pipe burst
- Sudden ground loss
- Road collapse
- Still no settlement

Leaking Water pipe
Building adjacent to existing structures

Verification of toe depth and groundwater cut-off

Use of JGP for Ground Improvement

Construction Problems – Cut and Cover
Instrumentation & Monitoring

- Trigger, Design and Allowable - Should change during the constriction
- Not always magnitude but the timing – instrumentation viewed in the context of the work
- Instrumentation damage (Singapore 50% in ground instruments lost)
- Are true measurements being taken i.e. deep settlement markers
- Timing of the results – a day late is too late – problems already happened – if you wait for settlement it is often too late
Examples of currently used instrumentation reports

Cut and Cover Example

Bored Tunnel Example
Bored Tunnel Example

Tunnel SB

LG6541
2mm
2mm

LG6542
2mm
5mm

LG6543
7mm
10mm

LG6544
16mm
22mm

Tunnel NB

LG6545
12mm
15mm

LG6546
5mm
10mm

LG6547
2mm
2mm

Survey Pt

Latest
Design
%
Comment

LG6541
2mm
2mm
100%
OK

LG6542
2mm
5mm
40%
OK

LG6543
7mm
10mm
70%
OK

LG6544
16mm
22mm
72%
OK

LG6545
12mm
15mm
80%
OK

LG6546
5mm
10mm
50%
OK

LG6547
2mm
2mm
100%
OK

Latest reading
Design Value

Settlement Curve

Distance y (m)

Vertical Displacement (After 2 Tunnels)
Horizontal Displacement
Tunnel 1
Tunnel 2
Vertical Displacement (After Tunnel 1)
Example of annotated instrumentation
Instrumentation Recommendations

• Engineers familiar with the design must interpret instrumentation data – not the CM
• The timing of the movement is as important as the amount
• Trigger and design values should consider the stage of the excavation
• Instrumentation results should be reviewed with the Contractor
Construction Supervision

- i.e. Design responsibility (who does what, when and why)
- Who is in the loop and why (don’t send something unless it needs action)
- What is the role of the CM
  - At risk (take the design and are responsible for construction)
  - Not as risk (watch the contractor - with no responsibility)
- KPIs and Instrumentation
  - understanding them – understand the design assumptions
  - not a tick in the box
Final thoughts

- Don’t start or move forward until you are ready
- Make informed decisions have all the information needed
- Clearly specify who is responsible and for what
- Always have a Plan B for critical path activities
- Be clear about what you want and what you will provide
- Minimise the number of changes
- Don’t cut corners – Penny wise pound foolish
Part II –
Geotechnical Baseline Reports
What is a Geotechnical Baseline Reports

• In the last 10 years it has become the key document for tunnel construction
• Used extensively in the USA and more recently in Europe and Australia
• Contract document for the allocation of commercial subsurface construction risk
• Defines “who pays for what” in the ground by setting a contractual baseline for site conditions
• GBR’s are used during the
  – Preparation of bids
  – Resolution of disputes
• Overly principle: to produce “clarity and fairness” for bidding and execution
What is a Baseline?

- A contractual statement of the conditions to be encountered during subsurface construction.

- Used to determine when Differing Site Conditions (DSC) exist.
  - More adverse than baseline = DSC (Owner pays more)
  - Less adverse than baseline = not a DSC (Contractor’s problem)
GBR Example: 
Deep Excavation in KL – Smart Tunnel Project

Example of North Ventilation Shaft at Jalan Cheras

Ref Paper: Siow Meng Tan
34m variations in rock level, voids found
GBR Example:
Dwallow installation depth

Ground Level

Proposed Cut and Cover Structure

Boreholes (pre-award)

Soft Clay

Competent Bearing Stratum (Rock)
GBR Example: Dwall installation depth

Design Requirement from Design Criteria (for the example):

Depth of rock affects the cost of construction
GBR Example: Dwall installation depth

TENDER DOCUMENTS

- Geotechnical Data Report (factual)
- Drawings
- Specifications
- Design Criteria Manual

Typical Contractor Procurement without a GBR
What depth to unweathered rock should the Contractor base his bid on?

1) optimistic? - $

2) best guess? - $$

3) pessimistic? - $$$$
Consider using a baseline.

A contractual statement of the conditions to be encountered.
GBR Example: Dwall installation depth

- Tenders received.
- Suppose our optimistic contractor is low bidder and is awarded the contract.

![Diagram of Dwall installation depth with optimistic contractor's assumption and baseline.](Attachment)
What is a GBR not!

- It is not a design document and should not be considered an interpretation of the ground condition.
- It should not include the words could, shall, may, might, possible etc…
- It should only address baselines that are relevant to the construction of the tunnel.
- In principal, GBRs are not for risk mitigation or safety (despite JCOP).
- A commonly used guidance document in the USA (and now elsewhere) is the ‘ASCE Gold Book’.
Important to remember

Baselines must therefore be:

- Clear, unambiguous, no repetition
- Must be able to measured
- Must relate directly to a potential claim
- Must clearly state what needs to happen in the event of a change
- Must clearly state what is paid for the event of a change
Examples of Common Tunnel Baselines

- Amount of faulted ground
- Amount of mixed face ground
- Obstructions (what to expect)
  - Natural – boulders
  - Man made – old foundations etc
- Top of rock
- Groundwater inflow, rock permeability
- Rock strength, quality and abrasivity
- Water level (and pressure)
- Soil strength
Where to Set the Baseline?

- Baselines are not statements of geotechnical fact. (You can set them wherever you want!*)
- Common policy or approach—set baseline at slightly worse than expected.
- Where to set depends on risk allocation strategy of the Owner. As such, Owner must be actively involved in setting baselines!
Important to remember

Ultra-conservative baselines reduces chance of a (legitimate) claim but....

Large contingency (risk) bidding + no claims > Reasonable bidding + some claims

Accepting some of the risk can lower total outturn cost. Also recent US experience show that very conservative baselines are often considered to be misleading.
Who sets the baseline and when?

- **Single-staged GBR**: Owner (with his Engineer) sets baselines pre-tender.
- **Multi-staged GBR**: some baselines by Owner (pre-tender) and some by Contractor (submitted with his bid).
- **Common to all**: The GBR must be finalized **before** the Contract sum is determined.
Baselines cannot be “wrong”

• There is not necessarily an “error” if a baseline is exceeded.

• Exceeded baselines do not necessarily increase the total outturn cost. (Owner would have likely received a lower initial cost.)

Regardless of the baseline:

• Responsibility for the safe execution of the Works, as always, remains with the Contractor

• Exceeding the baseline is no excuse for not performing the Works in accordance with Contract Documents!
So what are the problems / challenges

- **Engineers (and Geologists):** struggle to develop specific numerical baselines for the wide variety of geotechnical properties
  - What parameters or ground behaviour need to baselined?
  - How do you quantify these baselines
  - GBRs are very difficult to write !!!!!!!!

- **Contractors:** are frustrated because they are not provided the baselines they actually need

- **Clients:** feel taken advantage of when baselines are used to justify claims in a manner not intended or when DRBs disagree with the baselines provided.
Common problems

- Baselines can be used against you
- Ambiguity advantage of contractor
- Baseline things you can easily measure
- Need to consider Contractors means and methods
- Should be relevant – best way to think of all the claims that can happen and then how you would demonstrate the problem and then think what baseline could help
Dwall Example of a GBR

• “For the purpose of preparing his bid for the installation of the Dwall at xxxxxx, the contractor can assume that the top of rock (defined as TCR > 50%) will be no deeper than El xxxxx between station x to y.

• The top of rock shall be verified by drilling a borehole adjacent (no less than 1m away) to any panel where the depth of rock is believed to be lower than this.

• The core shall be inspected Jointly by the Engineer and Contractor and a final rock level shall be agreed.

• If the rock level is deeper than shown, then the additional costs for the construction of the Dwall will be paid. However no labour or overhead costs will be paid and no extension of time shall be given.”
For GBRs to work

- Everyone must be on board
  - Contractors rights
    - Baselines presented should be reasonable
  - Owners rights
    - They should expect Contactors will consider the intent of a baseline and not take them in isolation

- Contractor must be able to demonstrate impact
  - he can not simply claim if the ground is different

- Owner must be clear about what he will pay for

- Owners must help prepare the GBRs
Why have a GBR?

- Can lower cost of project
- Transparent (fair) bidding environment
- Simplify claims assessment (saves time)
- Puts identification & allocation of ground risks at the forefront (makes insurers happy!)
- Secondary purpose: enhance Contractor’s understanding of the design
Conclusions & Recommendations

- GBRs are for allocation of commercial subsurface construction risk not design
- They are very hard to write and a bad GBR is worse than no GBR
- GBRs do not have to be multi-staged but it can help
- Do not include any interpretation
- Baselining design parameters not recommended.
- Baselining ground behavior can be a useful approach.
Questions ?
Part III Case Study
Miami Port Tunnel
Case Study: Miami Port Tunnel

- Introduction / Overview
- Contract Structure & Project Financing
- Site Geology
- Issues for the Bored Tunneling work – Karstic Limstone
- Risk of Differing Ground Conditions & GBR
- MAT alternative design
- Current progress
- Conclusions & Lessons learnt so far
Case Study: Miami Port Tunnel – Introduction

1. Reduce Traffic impact to Downtown Miami
2. Improve Port access
3. Improve traffic safety
Total Length 4200 ft or 1.28 Km
Case Study: Miami Port Tunnel – Introduction

- **Total Length**: 4200 ft or 1.28 Km
- **Diameter**: 12.5m

<table>
<thead>
<tr>
<th>Designed by:</th>
<th>Tunnel Outside Diameter (OD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDOT</td>
<td>40-ft</td>
</tr>
<tr>
<td>MAT</td>
<td>41-ft</td>
</tr>
</tbody>
</table>

Total Length 4200 ft or 1.28 Km
Case Study: Miami Port Tunnel – Contract Structure & Project Financing

- **Client**: FDOT (Florida)
- **PPP** (Public Private Partnership) – first tunnel in USA!
- **Concession Team** (MAT – Miami Tunnel Access)
  - **Contractor**: Bouygues (France)
  - **Investment Bank**: Babcock & Brown (Australia) later changes to Meridiam (France)
  - **Tunnel Operator**: Transfield Services (Australia)
  - **Consultant**: Jacobs Engineering (USA)
Case Study : Miami Port Tunnel – Contract Structure & Project Financing

• Funding obtained by FDOT for $900M
• Concessionaire is responsible for the
  – Finance
  – Design
  – Build
  – Operate and
  – Maintenance
• 35 year concession
• Some $400M will be paid in construction milestone payments
• Then availability payments will be made during the future operation of the tunnels
Case Study: Miami Port Tunnel – Contract Structure & Project Financing

• Advantages of PPP are
  – Achieve the most efficient possible design, construction and maintenance
  – Receive a high level of quality, availability, upkeep, safety and service
  – Share risks with private partners that are experienced in mitigating them
  – Agree to a long term, guaranteed cost structure for the project
  – Facilitate a predictable and efficient implementation process
Case Study: Miami Port Tunnel – Site Geology

1. Fill: Typically dredged loose sand and limestone rock overlying naturally occurring loose silty fine sand to sandy silt (soil)
2. Miami Limestone: Soft rock, weakly cemented, very porous and permeable (soil)
3. Transition Zone: Sand with limestone highly permeable (soil like)
4. Fort Thompson Formation: Limestone and cemented sand (rock)
Case Study: Miami Port Tunnel – Issues for Bored Tunneling Works

- High groundwater inflows
- High grout volumes
- Need for pre-treatment
- Mixed face conditions and face instability
- Problems for shaft retaining walls, anchors etc – variable rock head
Case Study: Miami Port Tunnel – Risk of Differing Ground Conditions & GBR’s

• Significant potential for ground risk
• A $180 Million Geotechnical Contingency Fund
  – Mitigate extra work and costs and delay costs resulting from differing ground conditions
  – The first $10 million – borne solely by the concessionaire
  – The next $150 million – borne solely by the client (FDOT)
  – The last $20 million – borne solely by the concessionaire
• Extra work costs and delay costs for changes geological conditions that exceed $180 million are deemed extraordinary geotechnical losses.
Case Study: Miami Port Tunnel – MAT Interpretation

- Looked at geology in more detail with 8 geological units compared to 4
- Assessed the geology in terms of how it would impact tunnelling and grouting i.e. strength and permeability
## Case Study: Miami Port Tunnel – MAT Interpretation

<table>
<thead>
<tr>
<th>MAT layer #</th>
<th>MAT designation</th>
<th>FDOT designation</th>
<th>Ground properties – MAT interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fill</td>
<td>Fill</td>
<td>Sand and gravel.</td>
</tr>
<tr>
<td>2</td>
<td>Compressible silty sand</td>
<td></td>
<td>Soft plastic cohesive soil.</td>
</tr>
<tr>
<td>3</td>
<td>Miami Limestone</td>
<td>Miami Limestone</td>
<td>Limestone – soft rock, very weakly cemented (soil type behavior); low porosity; fairly consistent.</td>
</tr>
<tr>
<td>4</td>
<td>Sandy transition</td>
<td>Sandy transition</td>
<td>Sand with limestone – highly permeable soil like behavior with inclusions and interbedded zoned of limestone.</td>
</tr>
<tr>
<td>5</td>
<td>Upper Fort</td>
<td></td>
<td>Limestone with some sand – porous soft rock with sand zones.</td>
</tr>
<tr>
<td>6</td>
<td>Fort Thompson rock</td>
<td></td>
<td>6-a: Cemented sand/shell, with some sand – very porous rock with sand, well cemented. 6b: Cemented sand/shell – very porous, well cemented, consistent rock.</td>
</tr>
<tr>
<td>7</td>
<td>Loose to medium sand</td>
<td></td>
<td>Sand with inclusion and interbedded zones of sandstone – can be present 1) very loose soil, 2) potentially voidy condition, 3) vuggy soil filled zones and 4) isolated zones of hard rock</td>
</tr>
<tr>
<td>8</td>
<td>Key Largo formation</td>
<td></td>
<td>Sandstone, interbedded with sand lenses, zones, seam and occasional sand/silty sand pocket – very porous, well cemented, interbedded soft rock with sand.</td>
</tr>
</tbody>
</table>

Identified how the geology will specifically impact the tunnel construction work.
Case Study: Miami Port Tunnel – MAT Design improvements or changes

- The detailed geological interpretation allowed MAT to select its tunnel construction means and methods
  - The need for the EPBM to operate in closed mode while performing grouting
  - The need for ground improvement at the invert of the TBM to improve loose soil at the invert –
  - Selection of the appropriate conditioning agents, either polymer or foam for the different ground conditions encountered

- Extended the use of the bored tunnels to improve cost-effectiveness and reduce risks associated with the open cut
  - Identified areas of pre-grouting need during tunnelling as part of their tender

- Prepared a new GBR for the Contract (2 stage) to incorporate the agreed changes
Case Study: Miami Port Tunnel

Current Progress

Last month – 4 months after starting – 1245’ of the 4200’ total 20’ day on average – operates 20 hrs day (7 to 11am maintenance)

TBM used for both tunnel - 6 month both ways
Case Study: Miami Port Tunnel – Conclusions & Lessons learnt

Contract Setup: The PPP model has allowed a guaranteed cost structure to be put in place, with risked being shared by all parties.

Innovation: from the MAT team has allowed the length of risky cut and cover excavation to be reduced and the use of the TBM to be maximised.

Contingency Fund: Use of contingency fund to reduce Contractors adding contingency, reduced overall costs of the project.
Case Study: Miami Port Tunnel – Conclusions & Lessons learnt

GBR: Use of a two stage GBR getting input from the Contractors and agreeing on the document before you start has reduced future uncertainty in terms of claims.

Re-interpretation: Looking at geology as it impacts TBM not just the lithology has allowed the Contractor to select the correct means and method for the Project.

Planning: Adequate time for planning is the only way to achieve the best value solutions.