Lining Considerations for Road Tunnels

Insights from the Huguenot Tunnel Project

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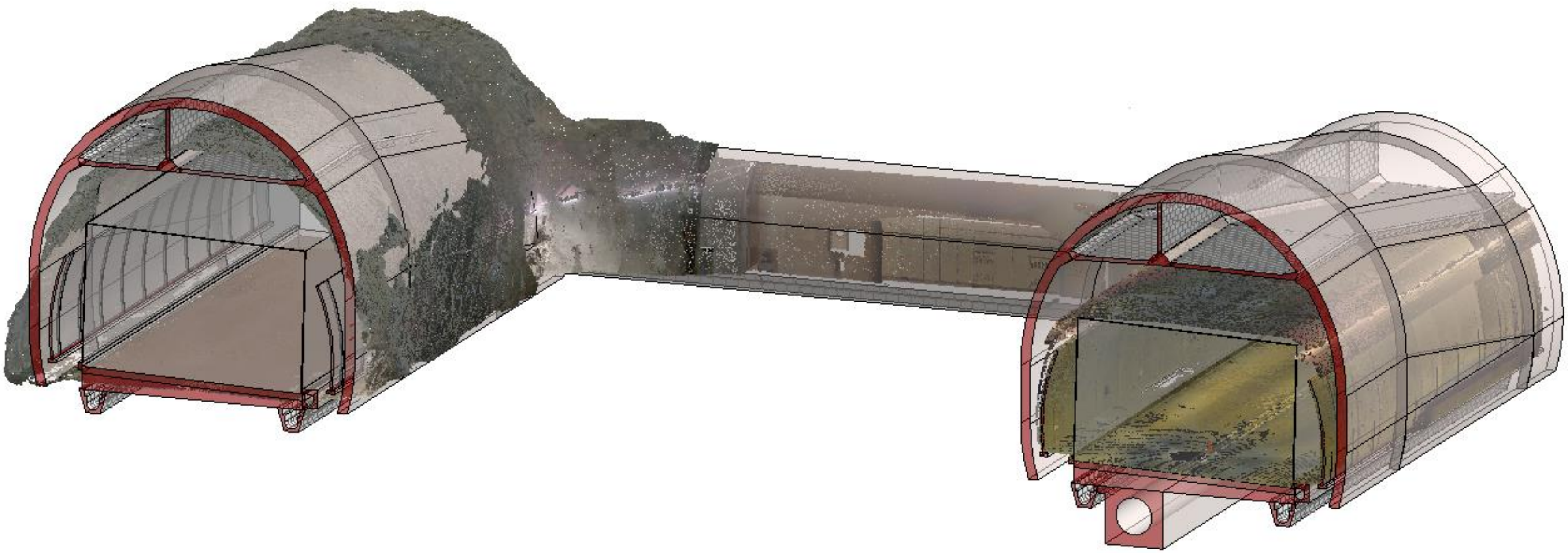
Introduction

Definition and Functional Requirements



Scope

- Deep tunnels in hard rock
- Constructed by drill and blast methods
- Tunnels 300 – 5 000 m long
- Lining considerations applicable to road infrastructure
- Primarily concrete linings (cast in-situ or spray-on)

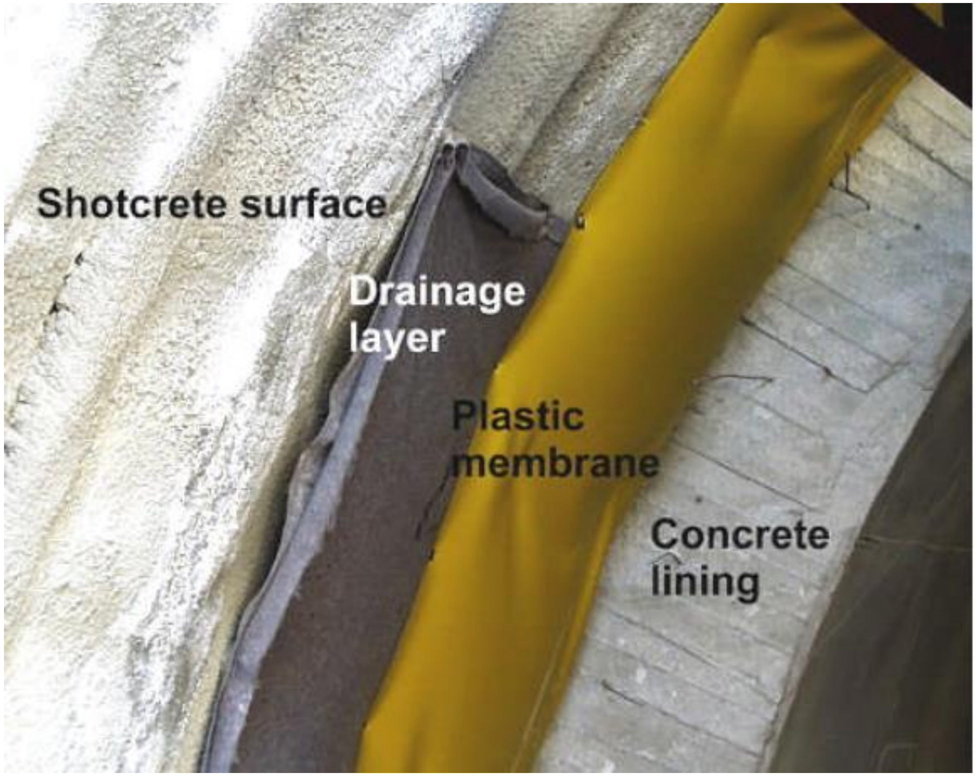
What is a Tunnel Lining?

<u>Definition:</u>

A **permanent** support structure to the periphery of a tunnel or shaft excavation

<u>Lining Components:</u>

- **Rock surface:** cleaned and scabbled
- **Regulating layer:** (shotcrete) to provide even surface
- **Drainage:** to channel water to the invert drainage system
- **Membrane:** prevents water penetrating the concrete
- **Concrete:** structural and dimensional integrity

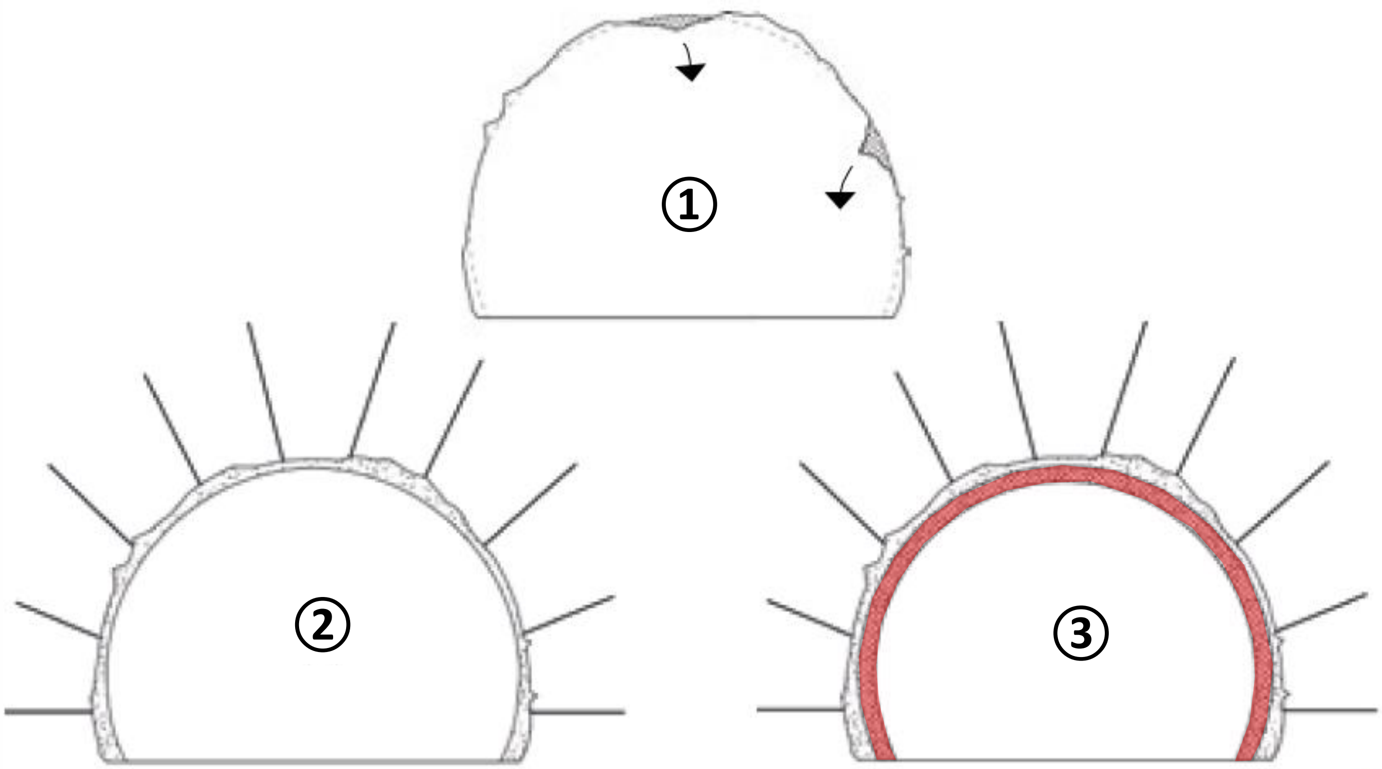


Construction Sequence

① Tunnel excavation (e. g. drill and blast or mechanised excavation)

② Installation of **temporary support** behind the working face (safety, controlled deformation)

③ Installation of the **permanent support** structure (“tunnel lining”)

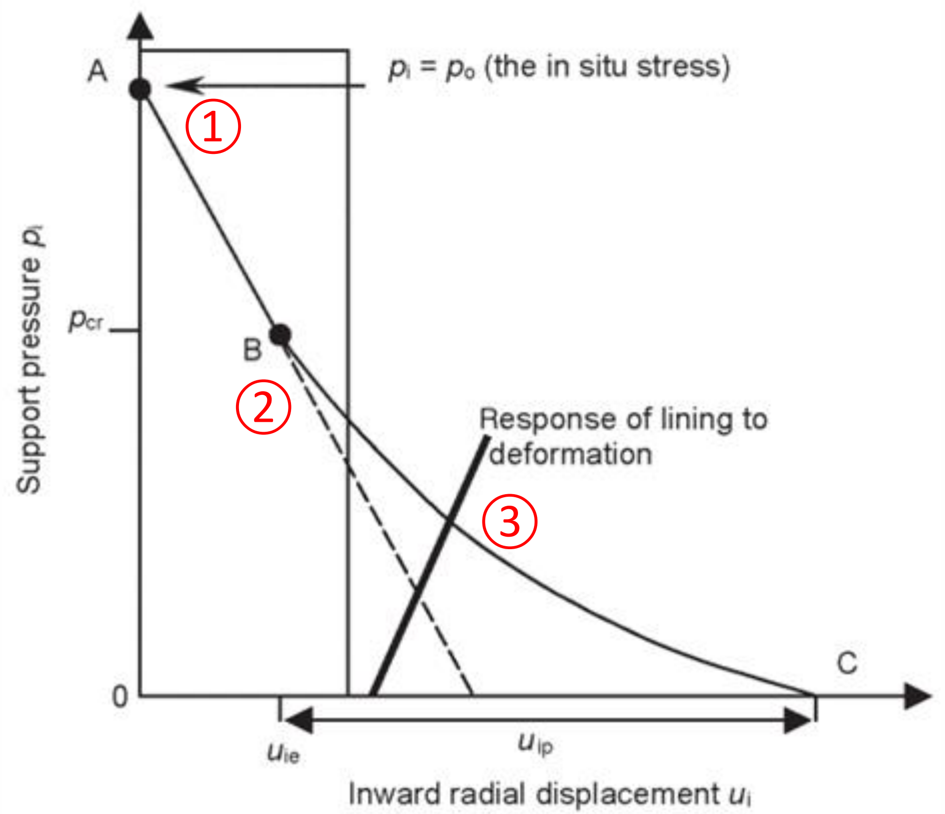


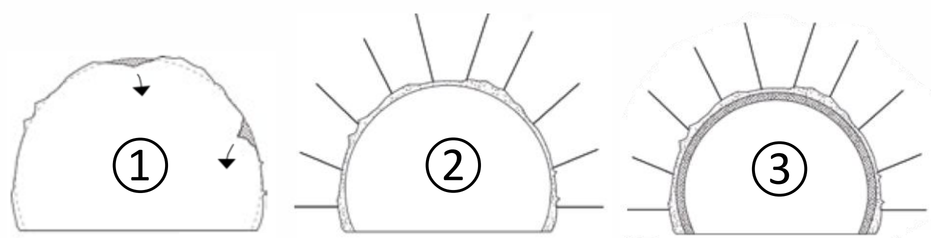
The Ground Reaction Curve (GRC)

① As the tunnel advances, the rock deforms inward. The deformation is initially elastic (points A-B), becoming plastic (points B-C) at a critical pressure (p_{cr})

② Primary support is installed to limit the deformation in the short term (safety during construction)

③ A lining is installed later to ensure long-term stability (if needed)



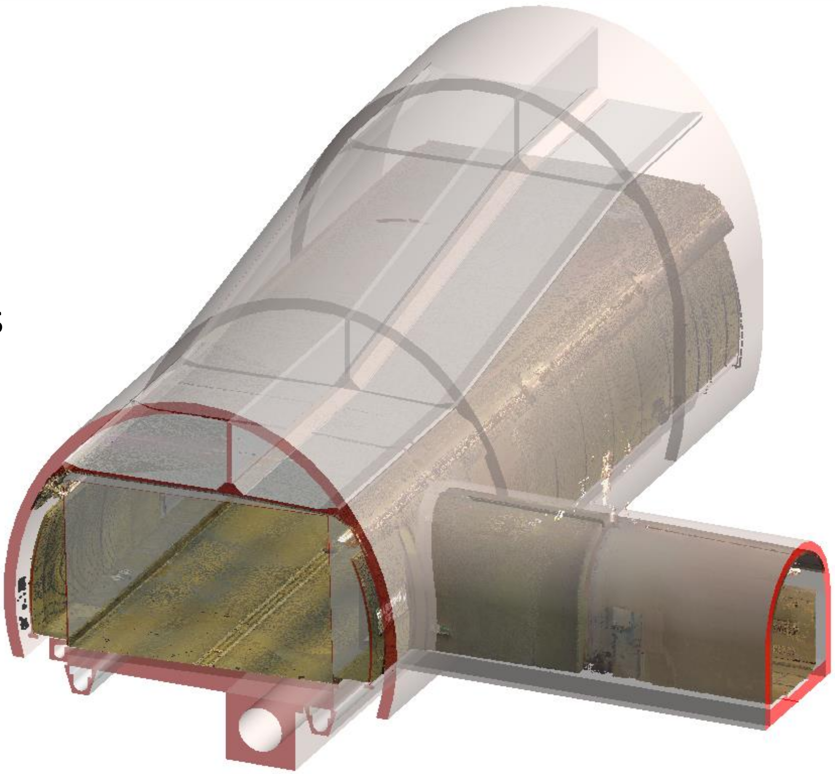


Functional Requirements

Structural: to support the exposed ground, thus maintaining the required operational cross-section and, if required, to provide a barrier to the passage of groundwater

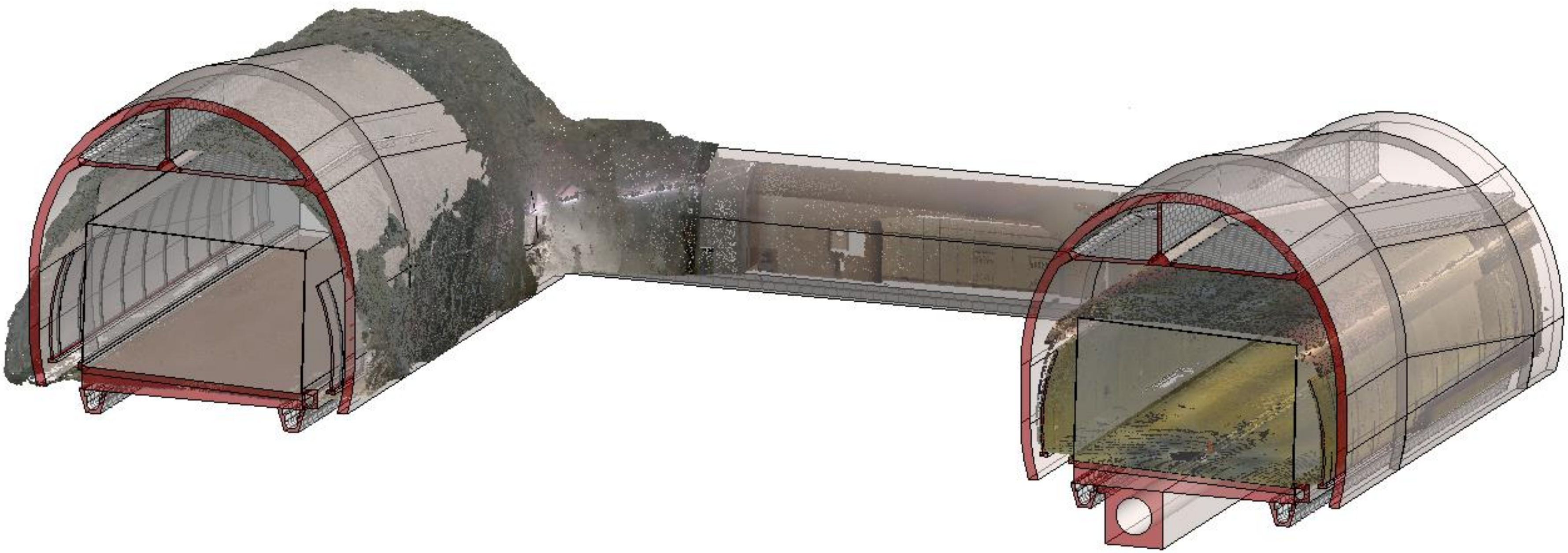
Operational: to provide an internal surface and environment appropriate to the tunnel functions

- Fireproofing
- Durable
- Minimise downtime
- Reduced surface roughness (ventilation)
- Concealment of utilities
- Aesthetically pleasing to the road user
- Enhance tunnel lighting
- Environmentally conscious

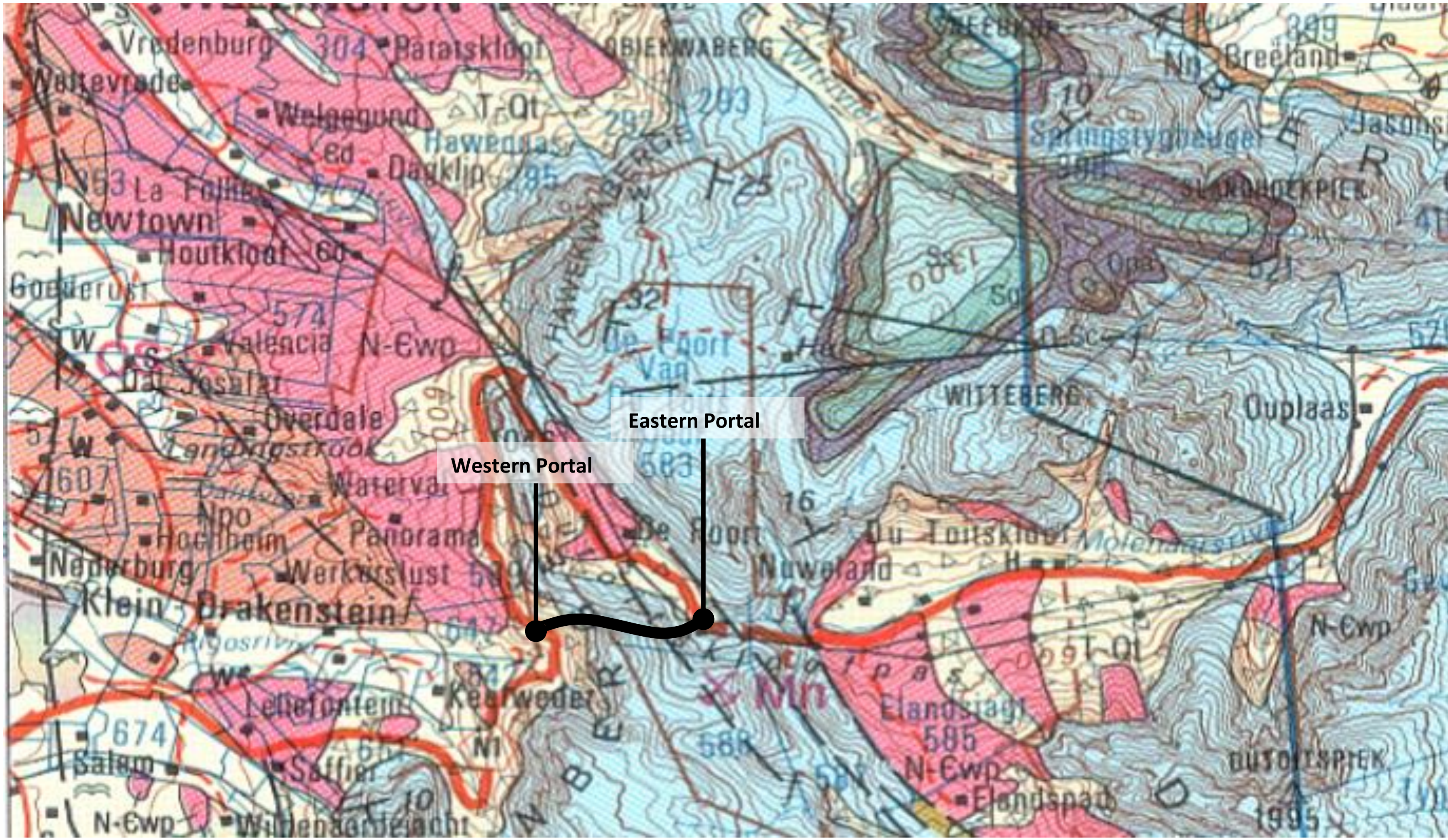


The Huguenot Tunnel

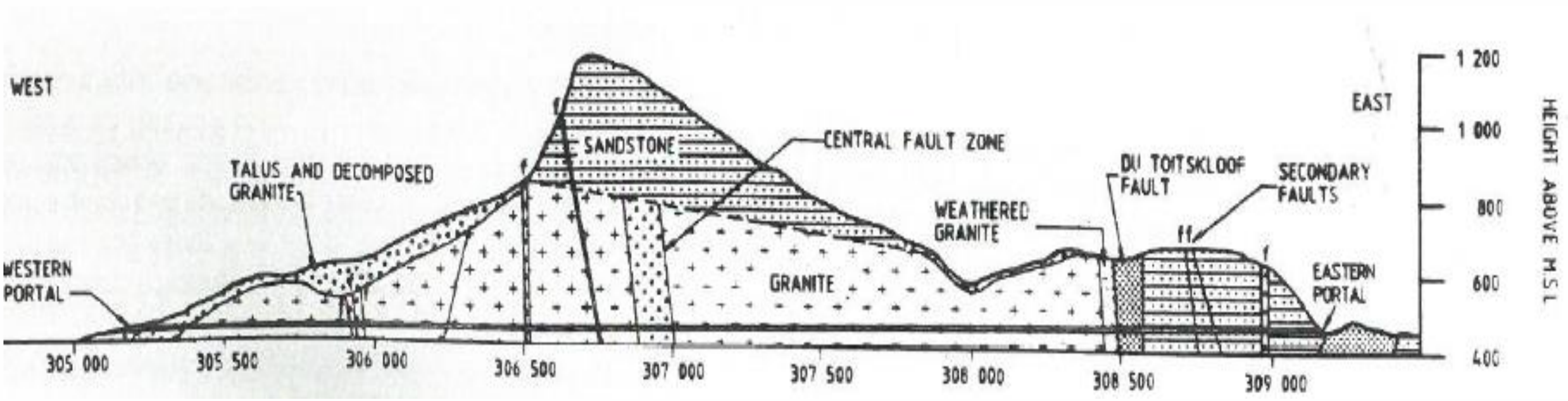
Background and Status Quo



Geological Setting

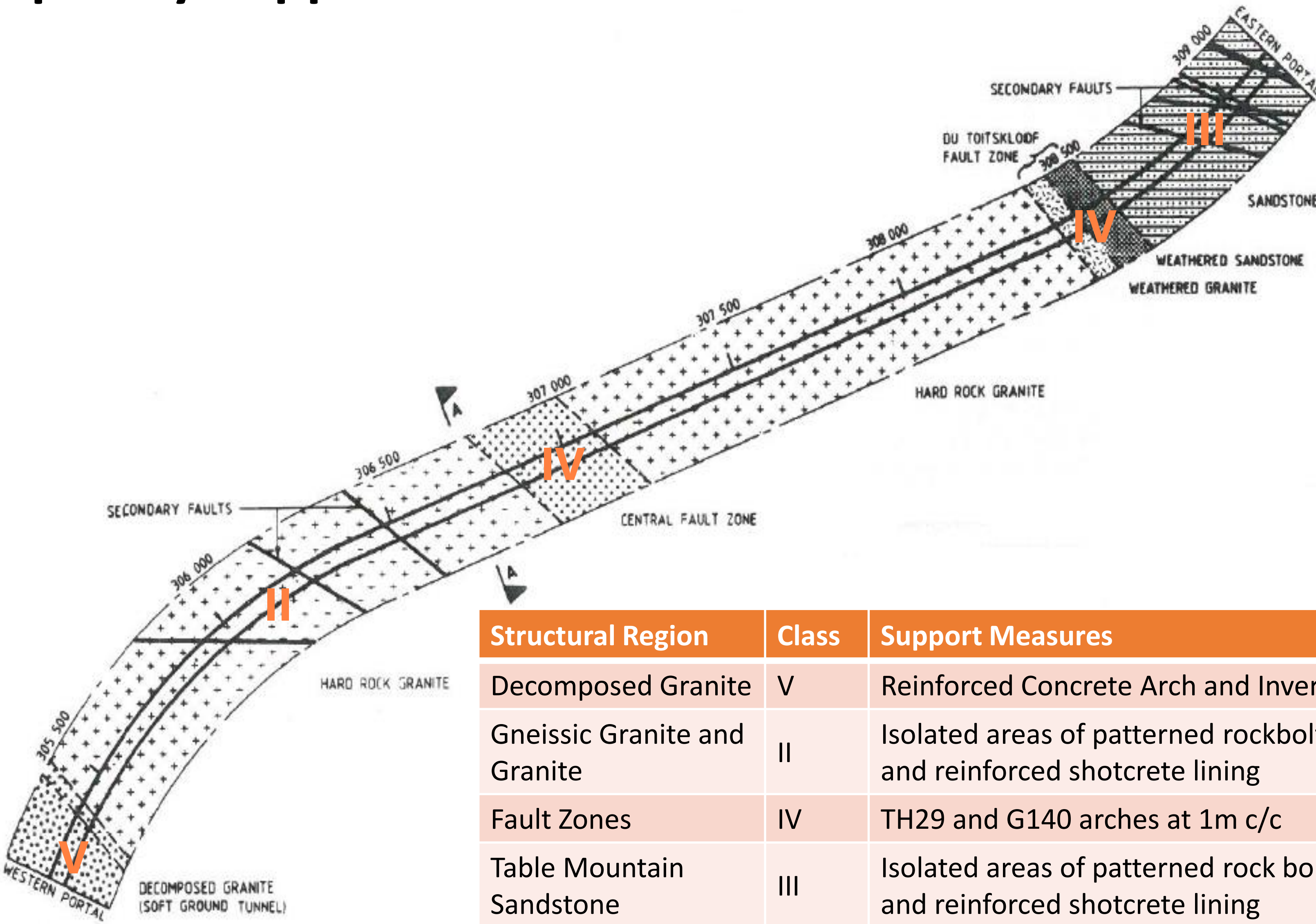


Rock Mass Characteristics



Structural Region	Length	Percentage	RMR
Decomposed Granite	135m	3.6%	9 (Class V)
Gneissic Granite and Granite	2 710m	71.2%	72 (Class II)
Fractured Granite	200m	5.3%	52 (Class III)
Fault Zones	190m	5.0%	26 (Class IV)
Table Mountain Sandstone	570m	14.9%	56 (Class III)

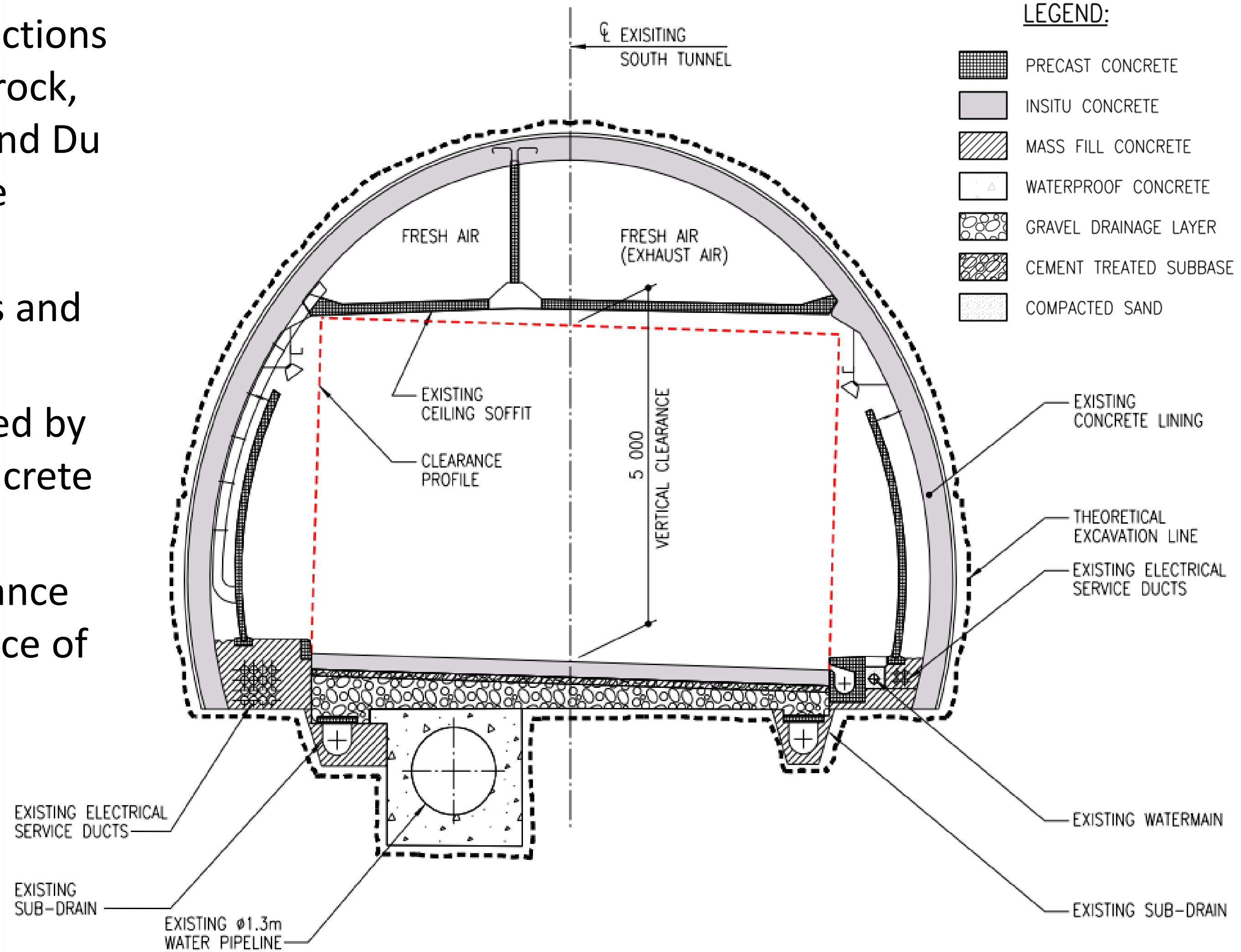
Temporary Support



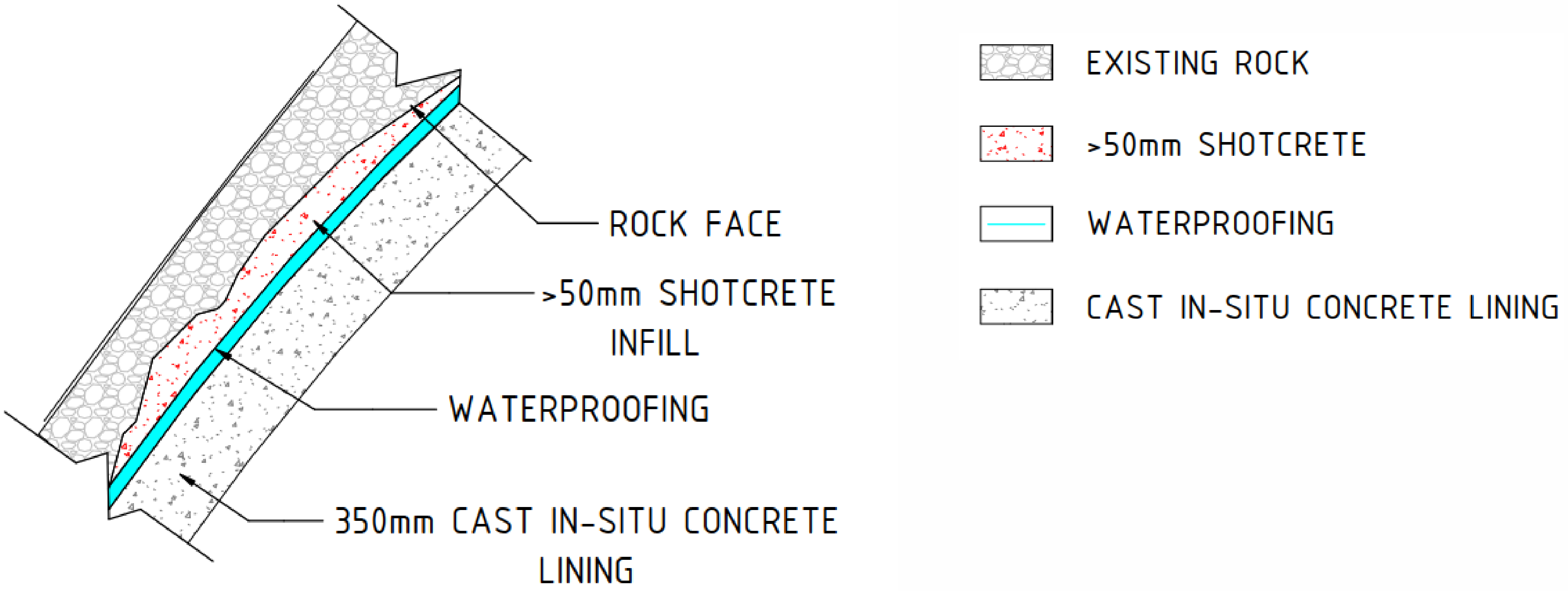
Structural Region	Class	Support Measures
Decomposed Granite	V	Reinforced Concrete Arch and Invert
Gneissic Granite and Granite	II	Isolated areas of patterned rockbolting and reinforced shotcrete lining
Fault Zones	IV	TH29 and G140 arches at 1m c/c
Table Mountain Sandstone	III	Isolated areas of patterned rock bolting and reinforced shotcrete lining

South Bore Tunnel Profile

- Four typical cross-sections – soft ground, hard rock, Central Fault Zone and Du Toitskloof Fault Zone
- Primary support comprises rock bolts and shotcrete
- Fault zones supported by steel arches and concrete invert arch
- Traffic vertical clearance of 5 m. Total clearance of 5.25 m



South Bore Tunnel Lining Detail



North Bore Tunnel Profile

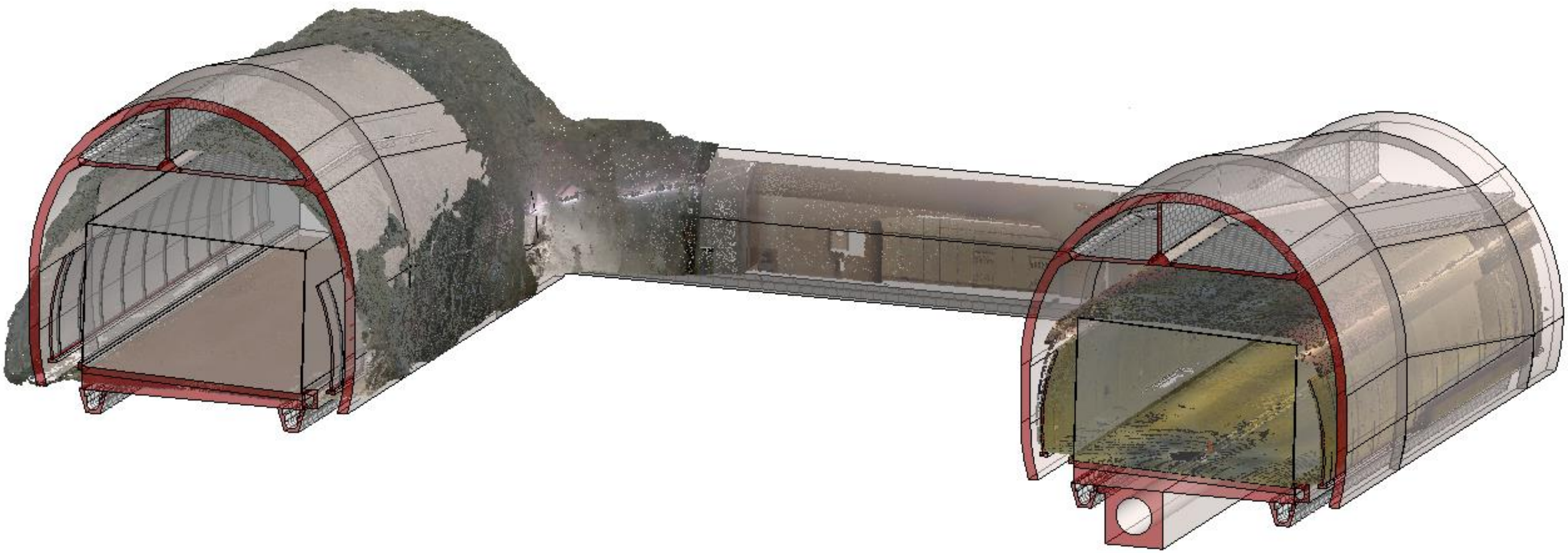
- Concrete lining has been installed over the soft ground section
- The remainder of the tunnel comprises only primary support (rock bolts, shotcrete, steel arches)
- Auxiliary support and barring down carried out in 2011

North Bore Tunnel Profile

- Temporary support showing signs of deterioration (corrosion of rockbolts, debonding of shotcrete, cracking of shotcrete)
- Auxillary support was installed in early 2000s
- Tunnel excavated on the basis that it would be lined in the future

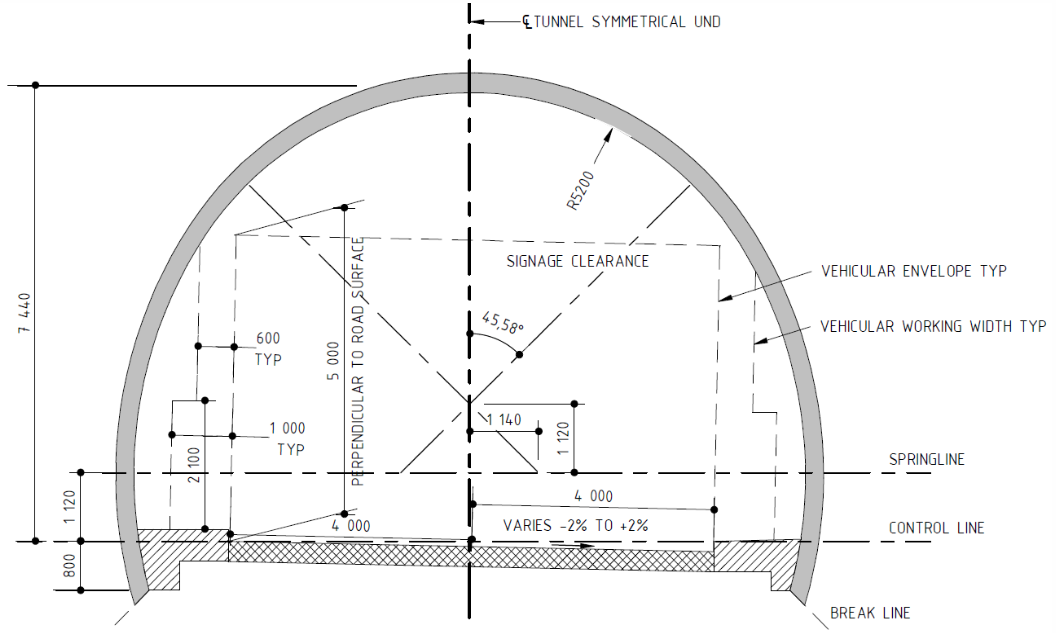
Lining Design Considerations

Design Basis



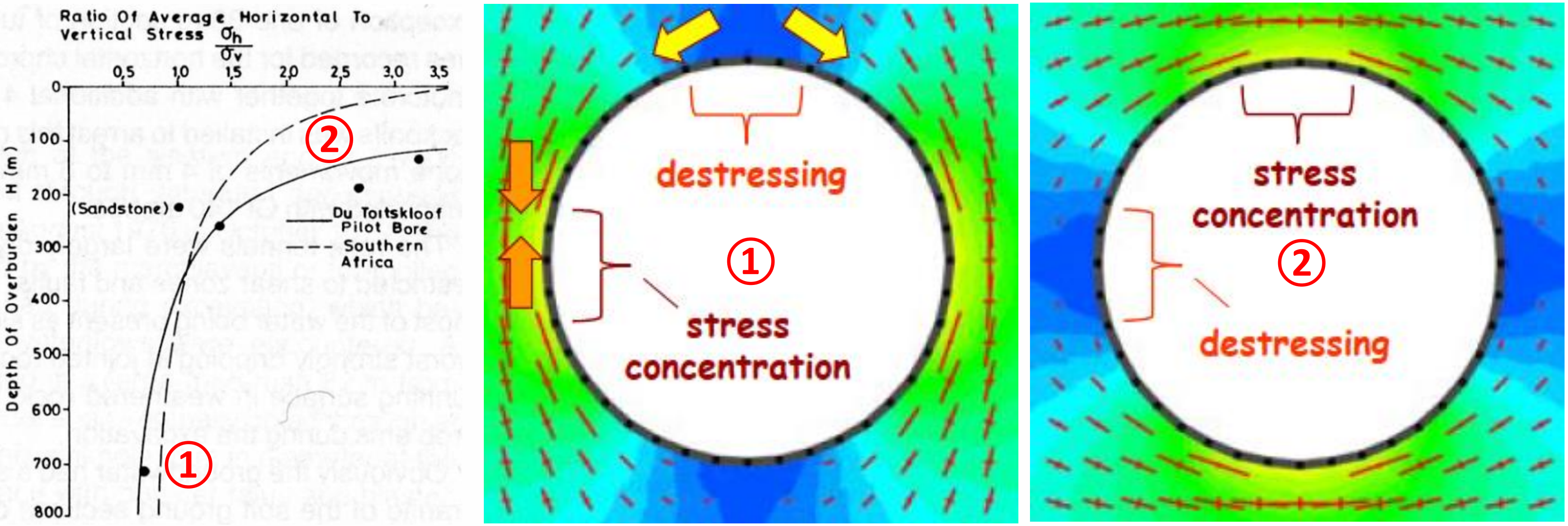
Design Standards

- CD 352 Design of Road Tunnels (formerly BD 78/99)
- Directive 2004/54/EC of the European Parliament and the Council on Minimum Safety Requirements for Tunnels in the Trans-European Road Network
- UK Road Tunnel Safety Regulations 2007 N0 1520. Original I Volume 3A – Engineering Section 3
- British Tunnelling Society and The Institution of Civil Engineers – Specification for Tunnelling (Third Edition)



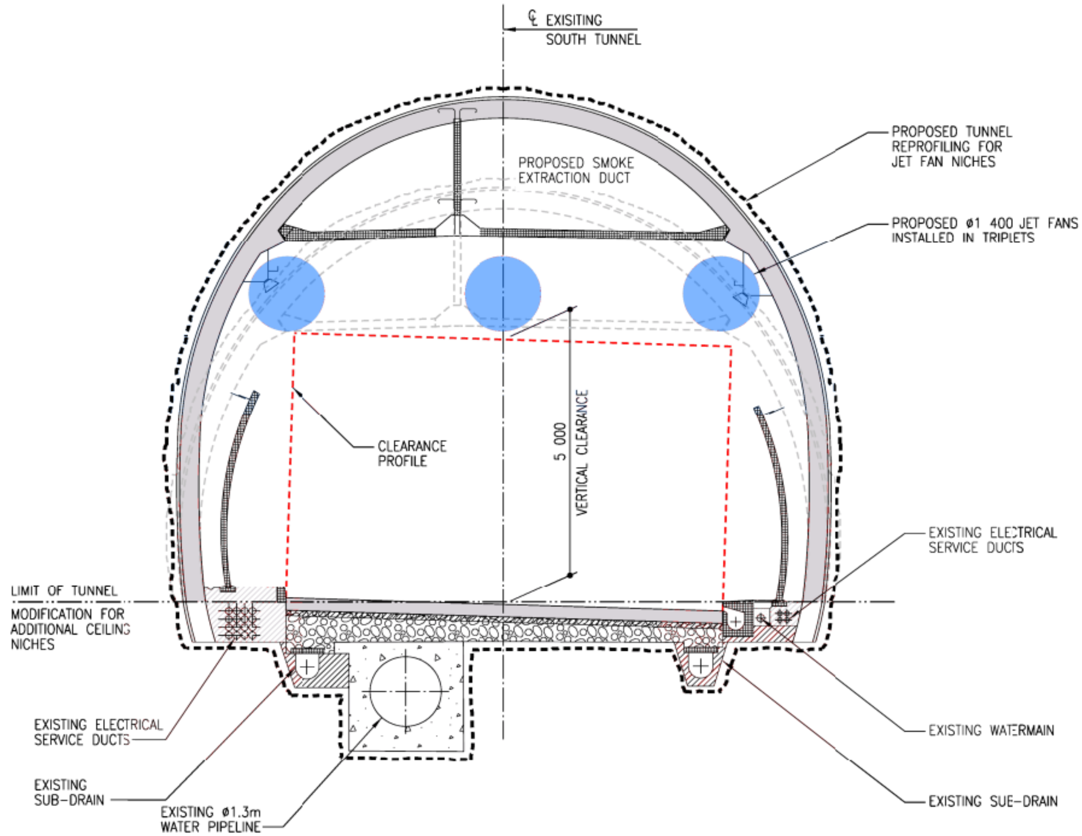
Design Criteria

- High aesthetic finish; compatible with state-of-the-art electronic systems
- The tunnel lining must maintain structural integrity for the requisite fire load (100 MW)
- Unreinforced linings preferred (corrosion; constructability)
- Localised rock loads considered based on anticipated block sizes
- Variable stress conditions and changing overburden depths considered



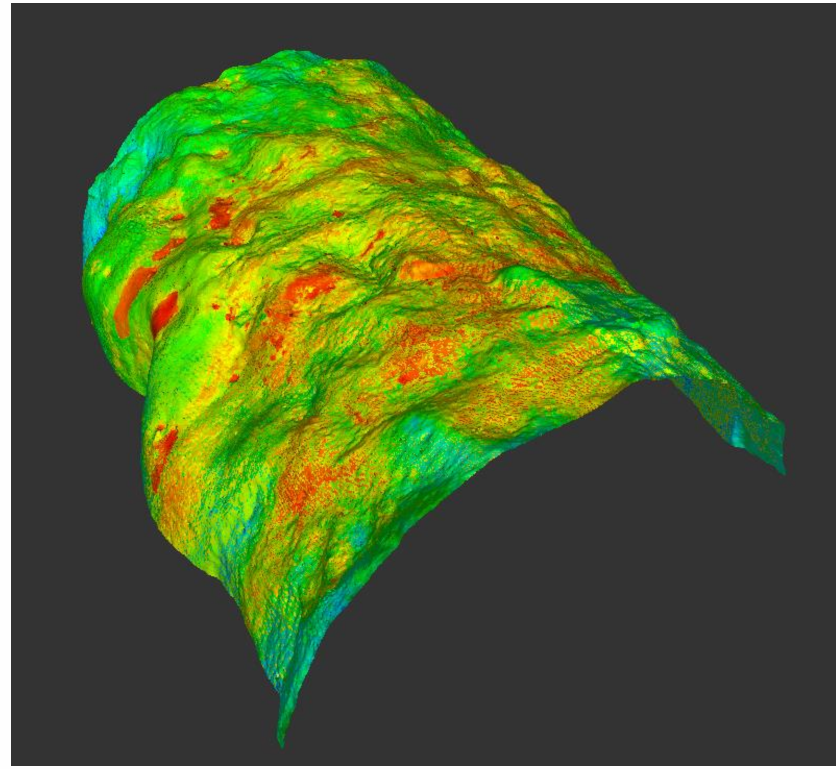
Ventilation-Lining Dependency

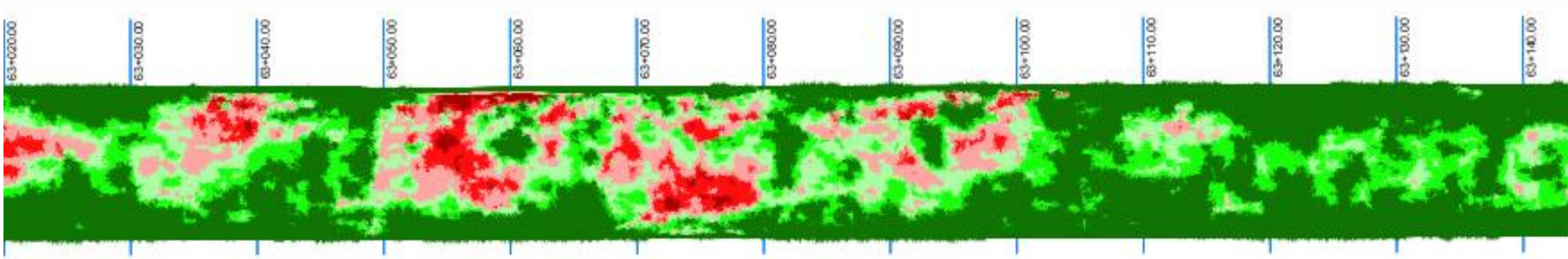
- The ventilation design requires a continuous 12 m^2 exhaust duct and jet fans
- The preferred method is to reprofile the tunnel crown locally to accommodate jet fans
- This minimises disturbance to the South Bore, while avoiding the risk of other options (e. g. lowering the invert in the fault zones)



Existing Excavation Geometry

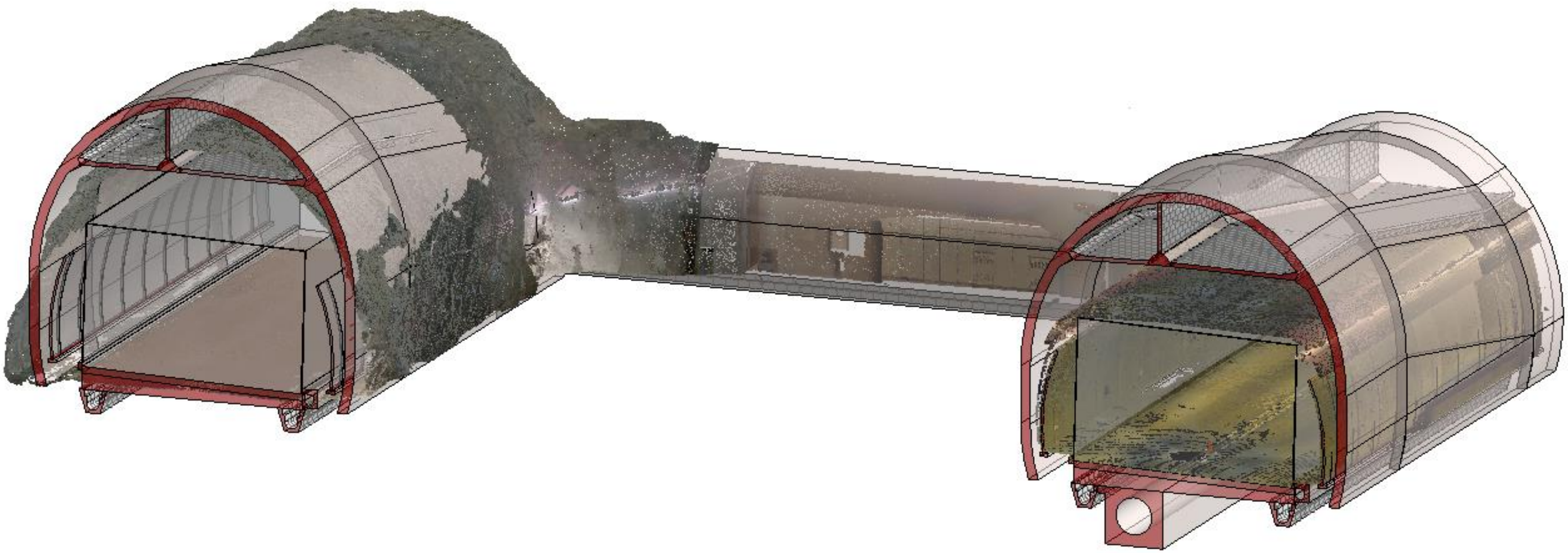
- Detailed clash-detection surveys have been carried out to confirm available space for tunnel lining
- North Bore Tunnel periphery is very rough and requires extensive (localised) reprofiling and backfilling



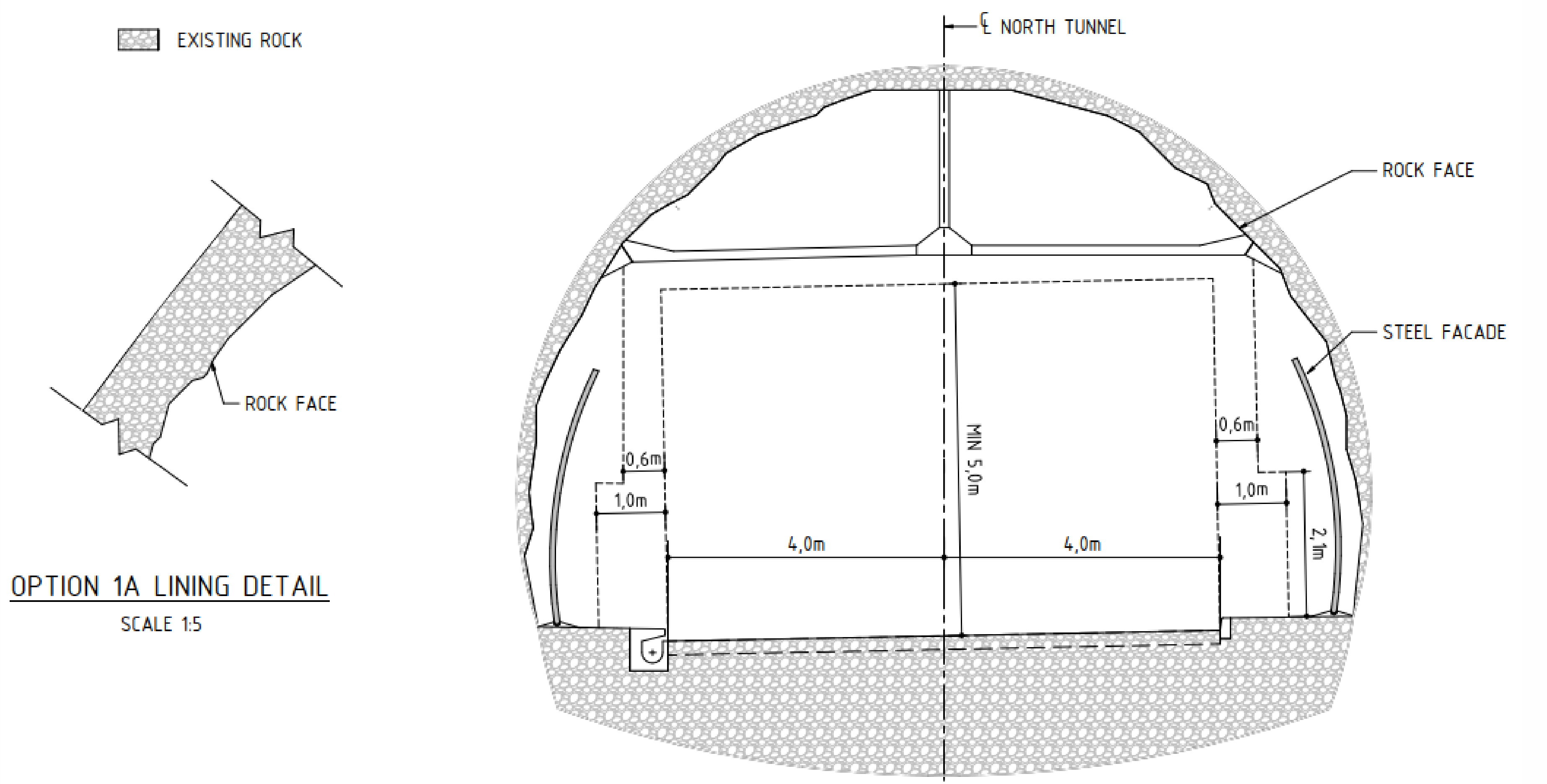


Lining Design Considerations

Lining Materials and Construction Methods



Unlined Tunnel with Facade

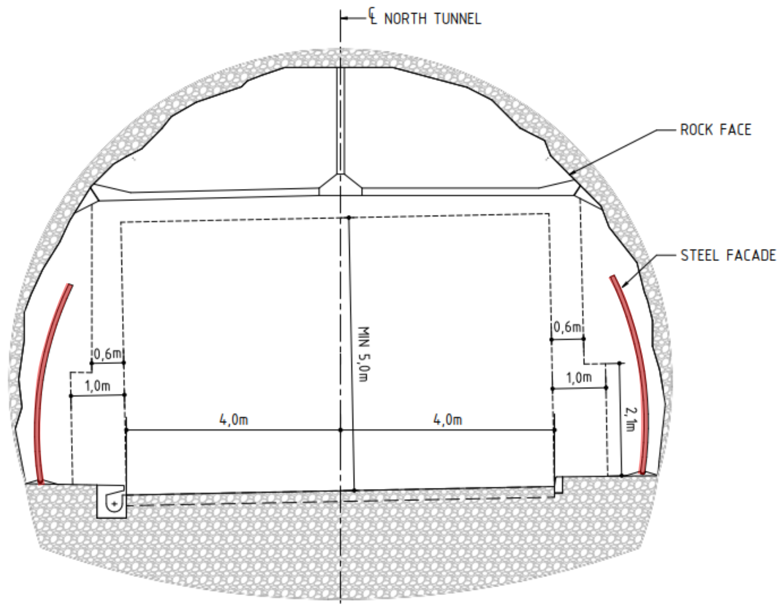


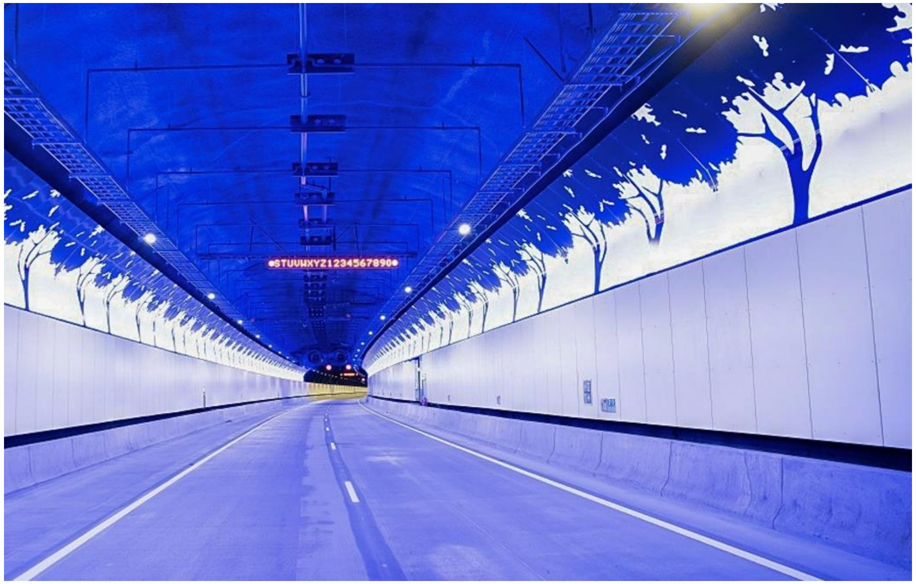
Unlined Road Tunnels

- Large sections of the Huguenot Tunnel comprise excellent rock conditions and minimal groundwater inflows
- Cntrasted by exceptionally poor zones (faults and soft ground)
- Unlined tunnels generally require dedicated ventilation tunnels
- Unlined tunnels can be alarming/ distracting to the road user

Lighting and Aesthetic

- Tunnel linings need to enable a high aesthetic finish and enhanced lighting of the tunnel;
- They need to be easy to clean and maintain
- Optimise airflow through the tunnel





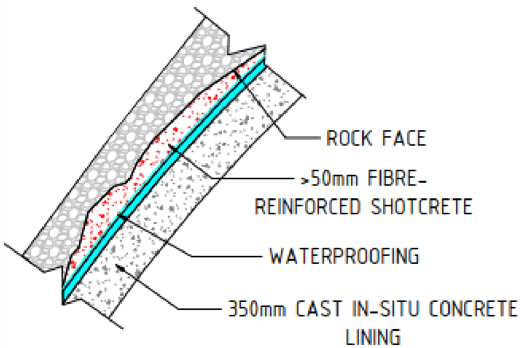
Cast-in-Situ Concrete Linings (with Sheet Waterproofing)

EXISTING ROCK

>50mm FIBRE-REINFORCED SHOTCRETE

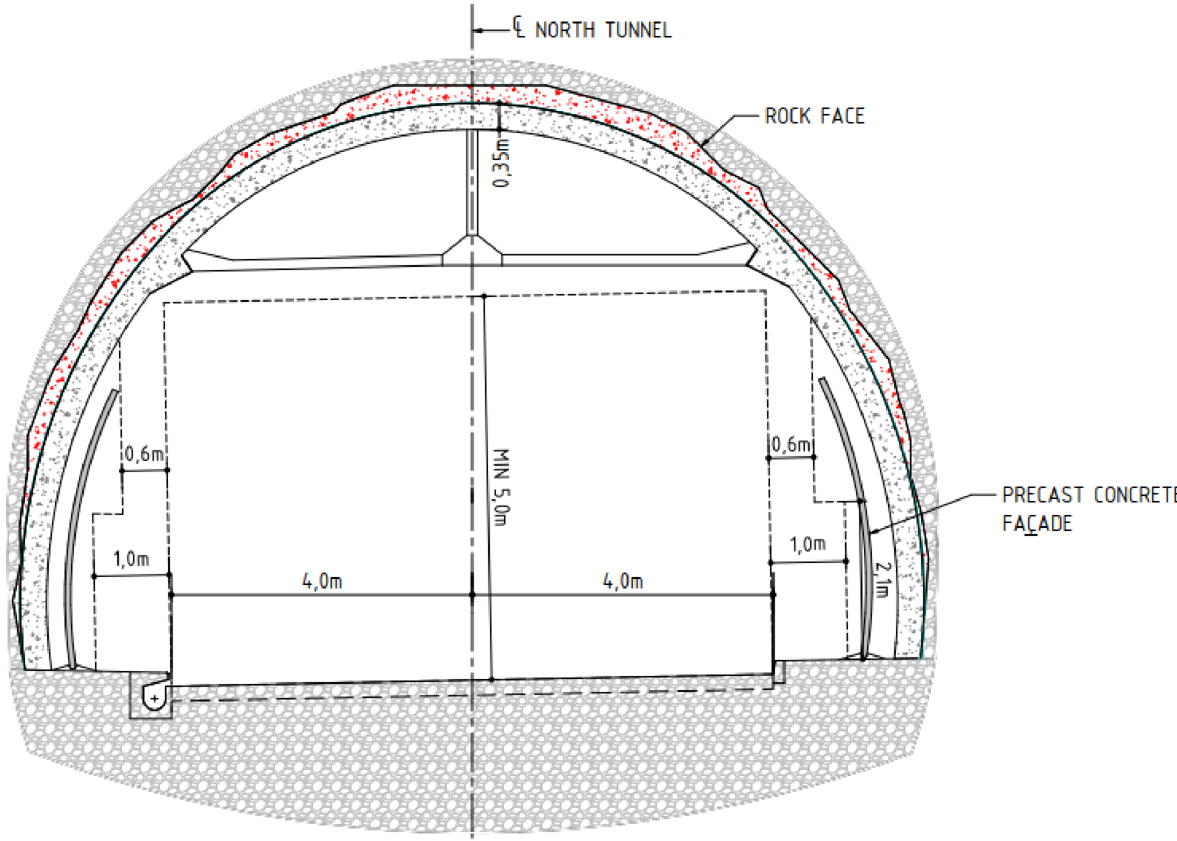
WATERPROOFING

CAST IN-SITU CONCRETE LINING



OPTION 2 LINING DETAIL

SCALE 1:5



Cast In-Situ Considerations

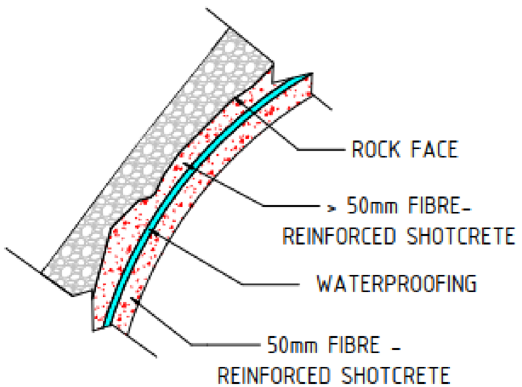
- Cast in-situ concrete for long tunnels (>500 m) require custom-built formwork
- This can lead to long establishment times
- Formwork must accommodate construction vehicles and emergency egress
- Cast in-situ concrete is well-established and presents consistent production rates

Spray-on Concrete Lining

EXISTING ROCK

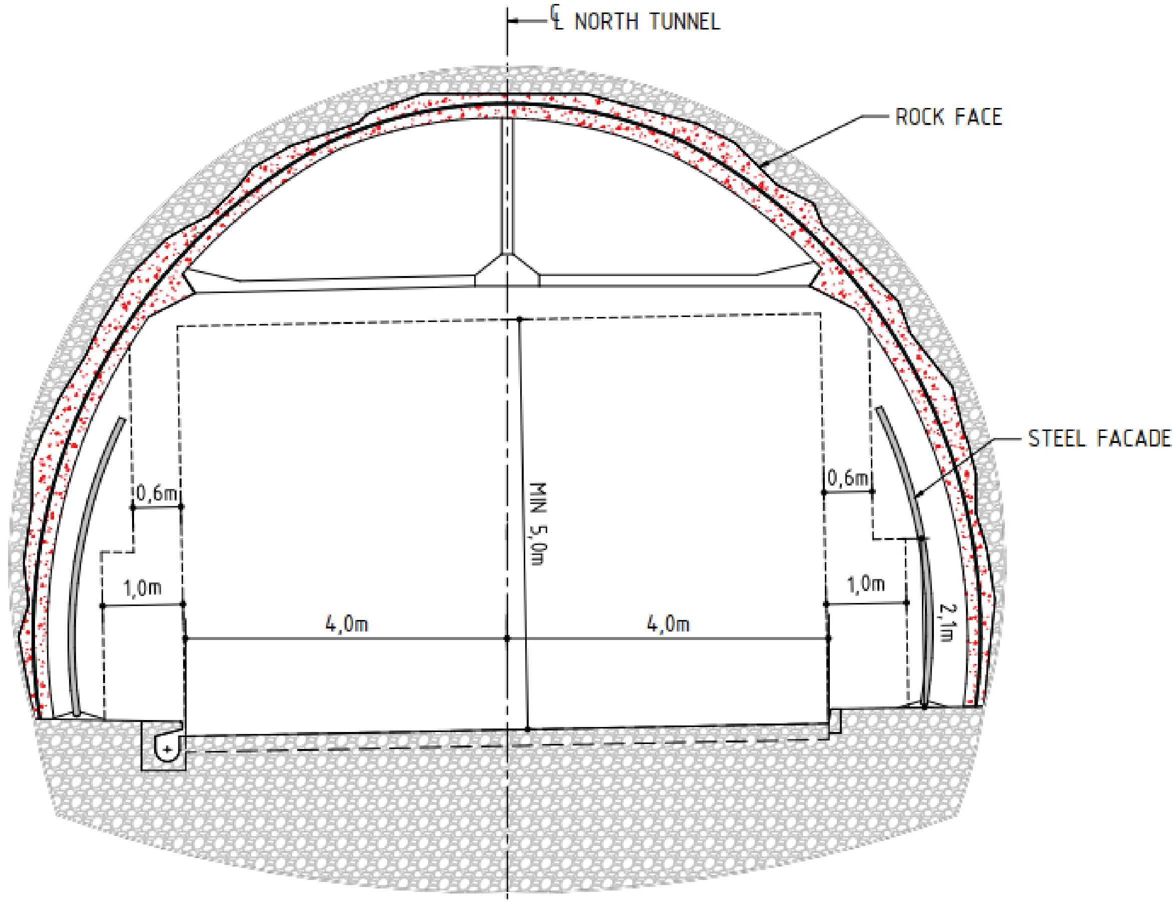
FIBRE-REINFORCED SHOTCRETE

WATERPROOFING



OPTION 3 LINING DETAIL

SCALE 1:5

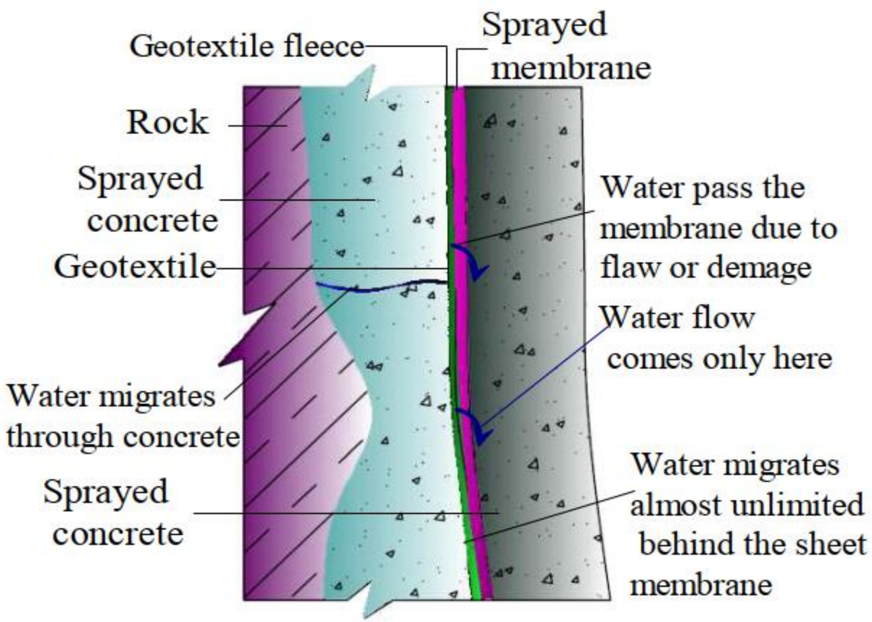


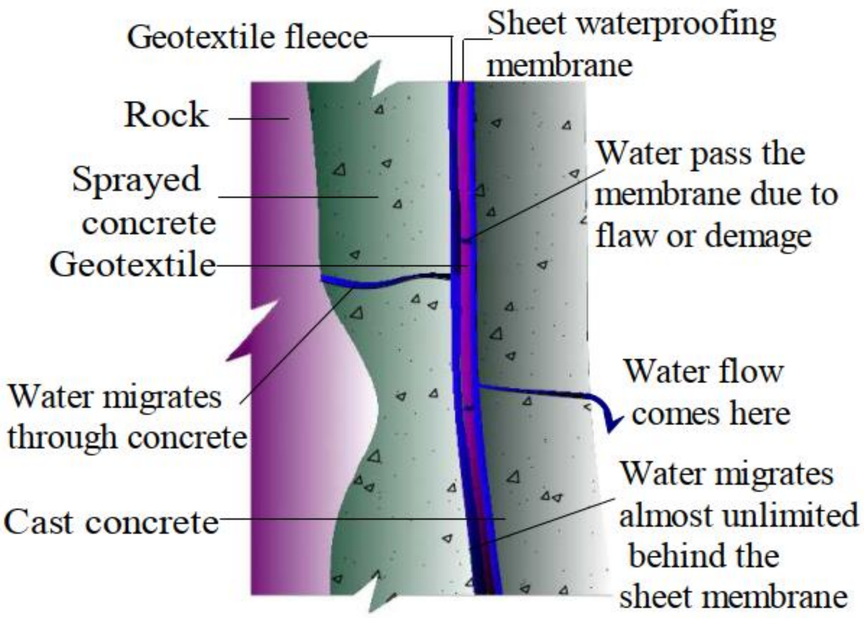
Spray-on Considerations

- Extensively used in Europe for short road tunnels and metro lines
- Sprayed concrete can offer higher production rates
- Useful where tunnel cross-section varies (otherwise requiring custom-made formwork)
- Quality (and minimising rebound) is largely dependent on equipment and operator workmanship
- Steel fibre reinforcement and lower material volumes lead to lower embodied carbon
- Rougher surface for ventilation considerations

Waterproofing

- All membranes require a relatively smooth surface
- Spray-on membranes cannot be installed in damp areas or inflow areas (additional primary drainage needed), e. g. fault zones and much of the Sandstone section.
- Sheet membranes require less specialised equipment and expertise.





Closing Remarks

- Underground construction requires a focus on constructability and adaptability
- Lining design brings together multiple specialist engineering disciplines
- The Huguenot Tunnel lining design needs to accommodate a ventilation system that was not originally envisaged during excavation of the tunnels
- This will require close consideration of the merits of different lining options and the likely adoption of a varied approach