Webinar
Túneles con TBM
Diseño, construcción, servicios y proyectos de ingeniería

CTES COMITÉ DE TÚNELES Y ESPACIOS SUBTERRÁNEOS DE CHILE

26 de Agosto

Introduction

- Evert Sonke
- MSc in Civil Engineering - Delft University of Technology – The Netherlands
- Member of the Royal Netherlands Institution of Engineers
- Former board member of KIVI-TTOW, the Dutch CTES
- In the tunneling business since 1996
- Track record in design and construction of Cut&Cover, Immersed Tube Tunnels and TBM tunnel projects
- Delivered projects in the Netherlands, Belgium, the United Kingdom, Qatar and Egypt
- site-engineer, project-engineer, design manager and Project director for clients, contractors and consultants
- Current position as Technical Director and Global Tunnel Lead Arcadis

2 x 950m
Ø 8.30m

2 x 6600m
Ø 11.30m

2 x 1490m
Ø 10.50m

2 x 1330m
Ø 11.00m

2 x 5500m
Ø 13.03m

1 x 3300m
Ø 13.03m

Arcadis – Tunnel Projects

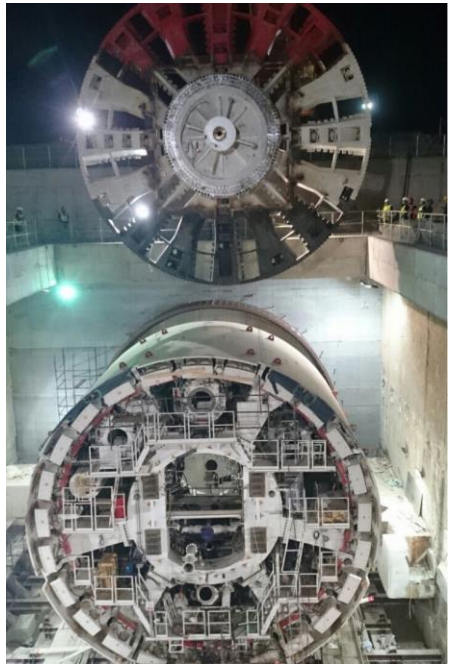
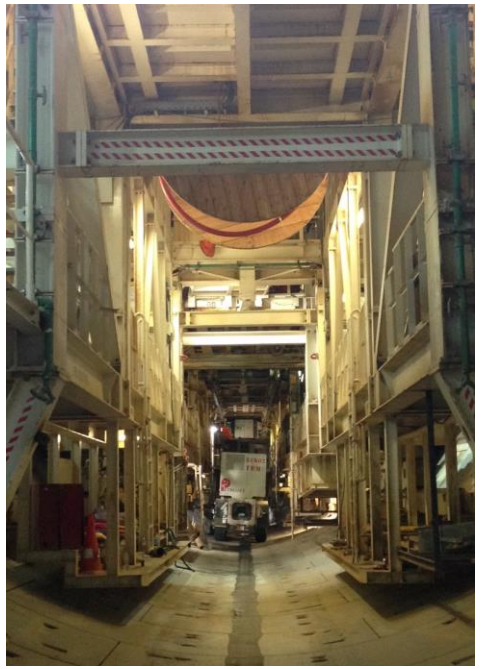
- Lower Thames Crossing (UK)
- Thames Tideway Tunnel (UK)
- Cross Rail (UK)
- Cross Rail 2 (UK)
- Trans Pennine Tunnel (UK)
- Koning Willem-Alexander (NL)
- Ketheltunnel (NL)
- Trentemoult (Nantes, Fr)
- Siaix tunnel (Fr)
- Dudulu – Bostanci Metro (Turkey)
- Unkapani Golden Horn (Turkey)
- Doha Gold Line (Qatar)
- Doha Red Line (Qatar)
- Ismailia Road Tunnel (Egypt)
- Kai Tak Development Trunk Rd T2 (Hong Kong)
- Fourth Cross-Harbor Rail Tunnel (Hong Kong)
- Grand Paris Express – various lines (Fr)
- Amsterdam Metro (the Netherlands)
- Brussel Metro Line North (Belgium)
- Metro line 2,3, 4 and 6 Santiago de Chile (Chili)
- Metro Sao Paolo (Brasil)
- Linea Amarillo Tunnel (Peru)
- Metro New York, East Side Access (NYC, USA)
- LA Metro Regional Connector (USA)
- Sydney WestConnex (Australia)
- Sydney Metro (Australia)
- Melbourne Metro (Australia)
- DTSS-07 Singapore
- Ahmed Hamdy Tunnel (Egypt)

An overview of methods and solutions as applied on some of our tunneling projects

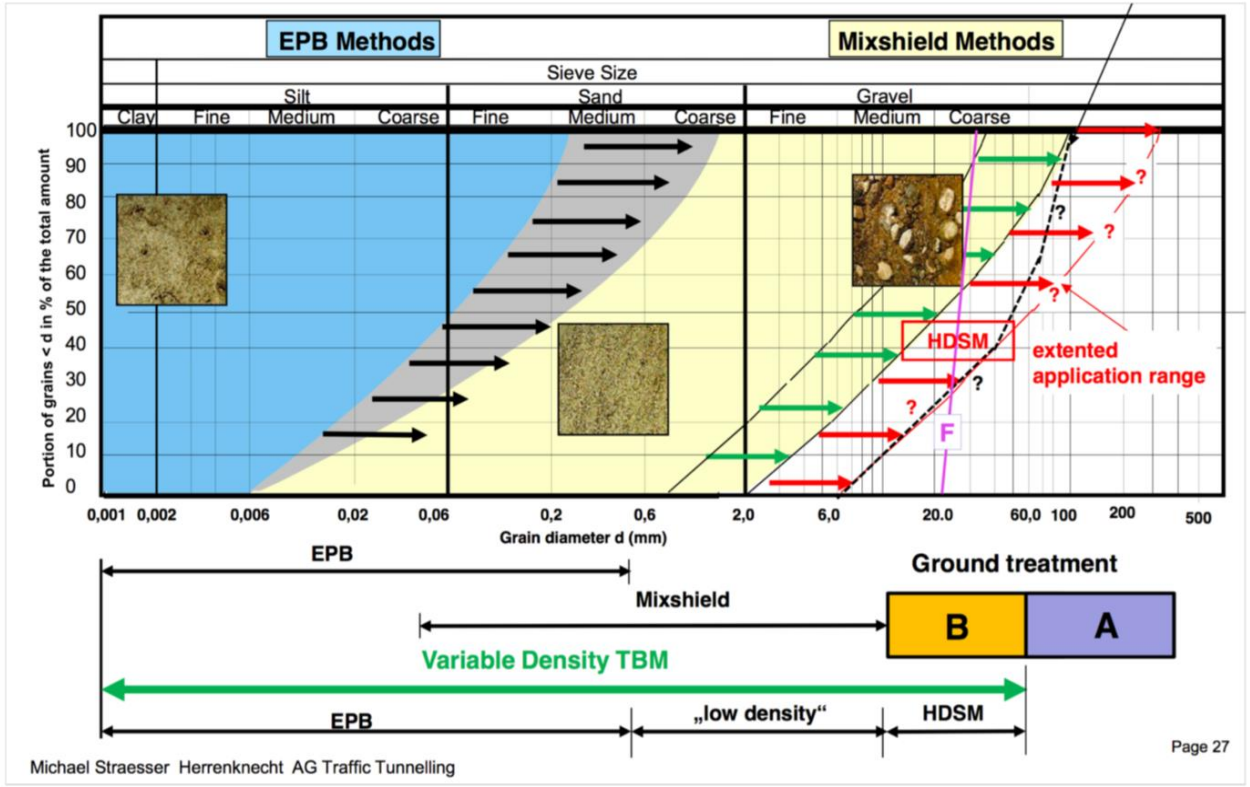
- TBM technology
- Lining Design
- Launch shaft concepts
- Site Logistics
- Special structures

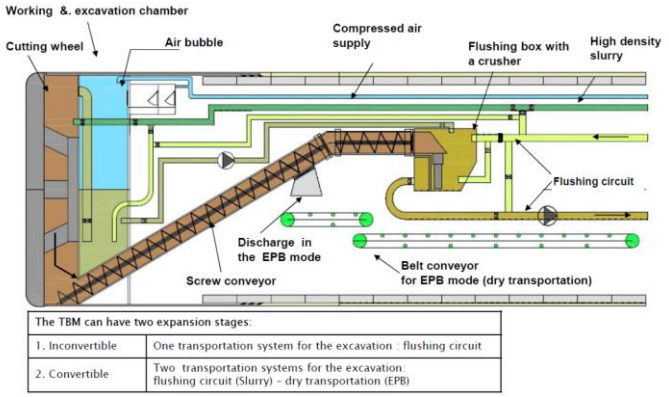
All referred or shown projects are Arcadis tunnel Projects. Where not the case this is mentioned

TBM Technology

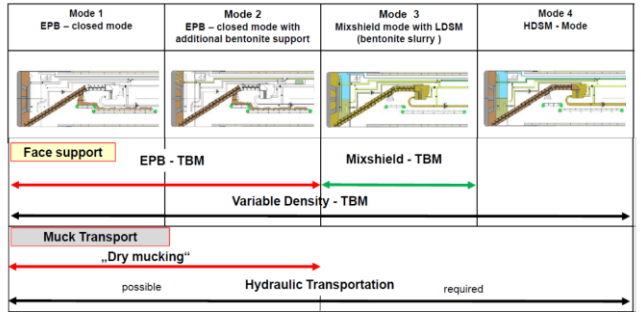

Note: pictures from Ismailia Road Tunnel (Egypt)





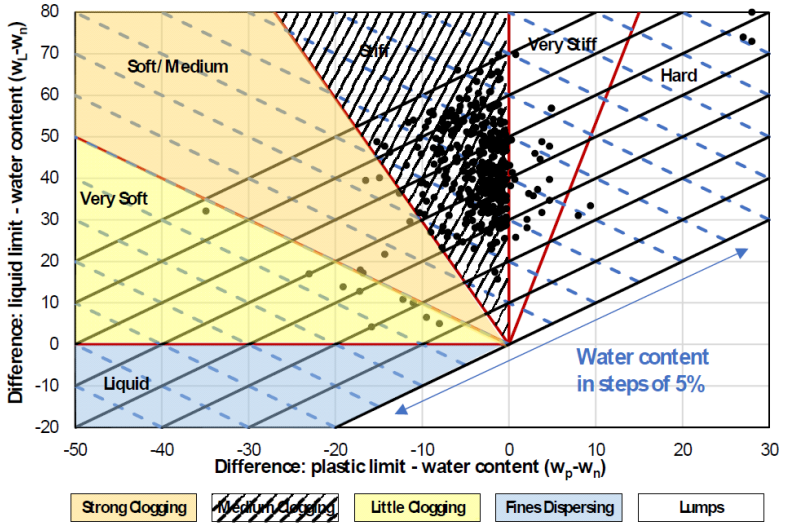
The TBM can have two expansion stages:	
1. Inconvertible	One transportation system for the excavation : flushing circuit
2. Convertible	Two transportation systems for the excavation: flushing circuit (Slurry) – dry transportation (EPB)

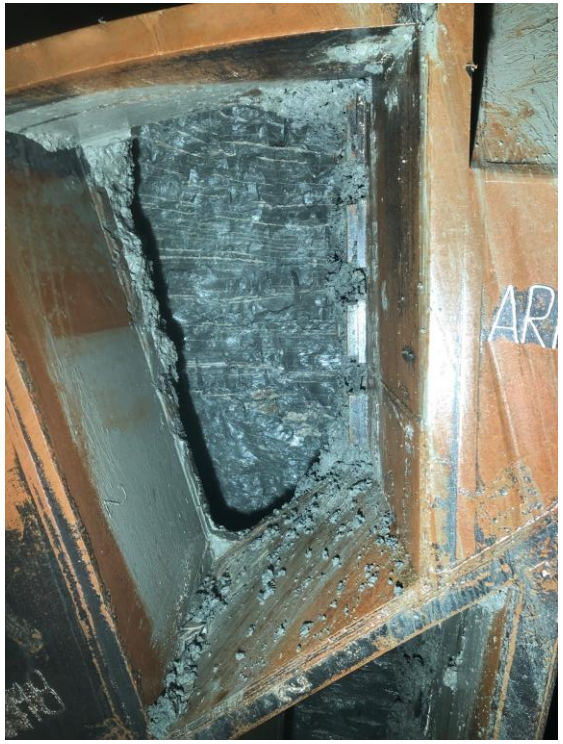
WORKING MODES OF THE VARIABLE DENSITY - TBM.



- EPB / Slurry type TBMs have been around for many years
- Innovation has resulted in growing overlapping application ranges
- Recently Variable density TBMs have been developed and implemented
- Experience shows <u>average</u> advance rates in clay (like in Santiago) between 10-15 m / day can be achieved
- Potential risk of clogging of clay is something to be evaluated and considered in the TBM and cutterwheel design

Liefkenshoektunnel – Clogging of the cutterwheel clearly seen – not an Arcadis project

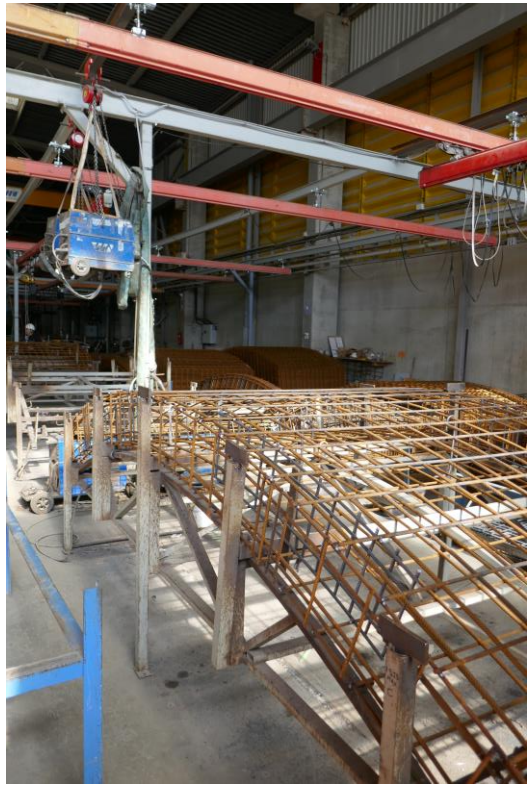
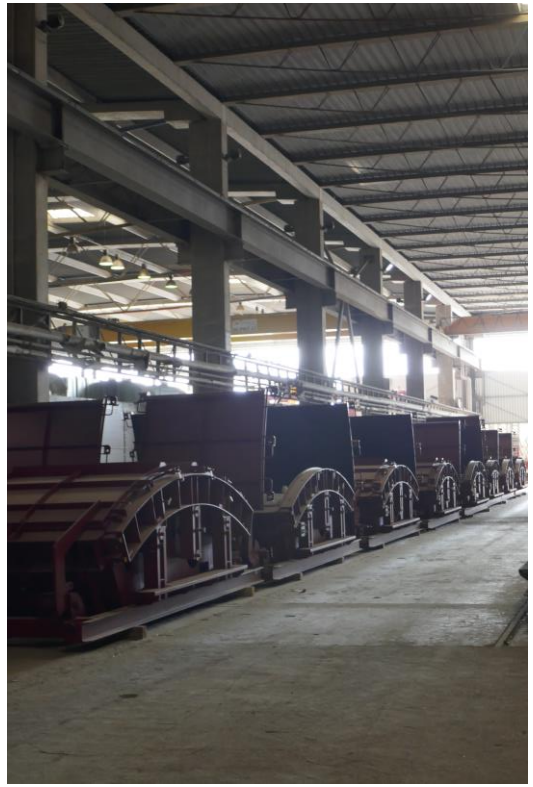


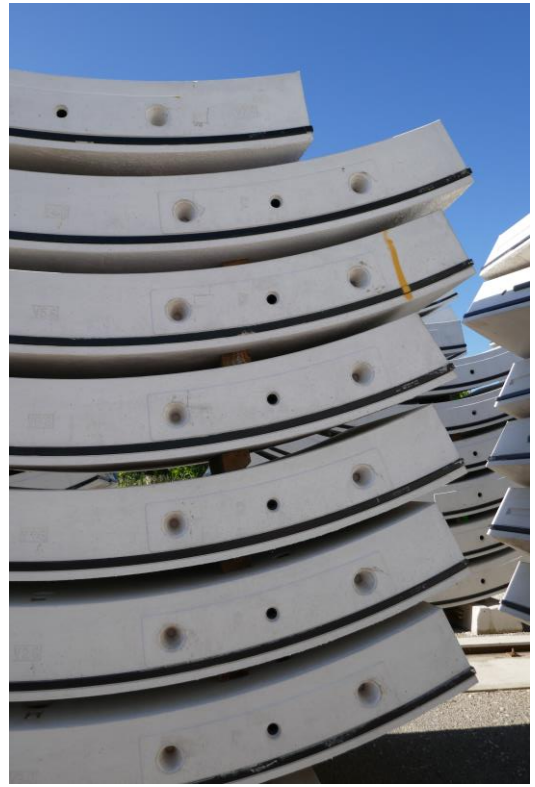


Face of the TBM in mudstone at Ahmed Hamdi tunnel. No clogging and dry face

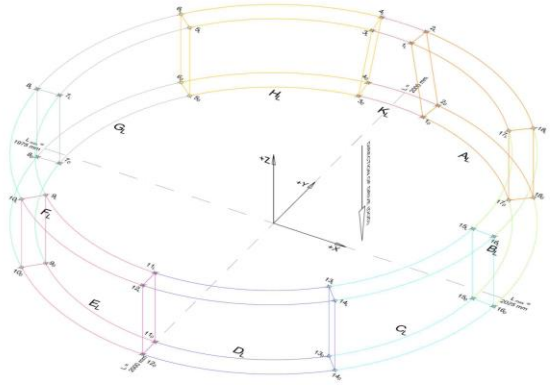
- Evaluation of clogging potential during tunneling for silty clay/mudstone (Diagram after Hollman and Thewes, 2013)
- Note: Data shows test result for Ahmed Hamdi Tunnel (Egypt)

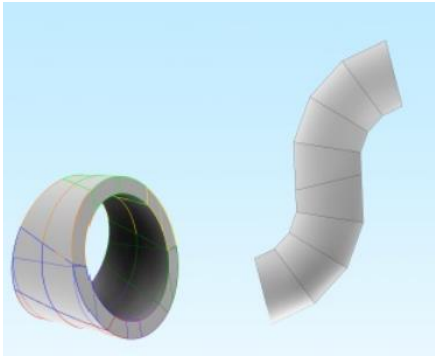
Lining Design



Note: pictures from segment factory Line 15 Grand Paris Express

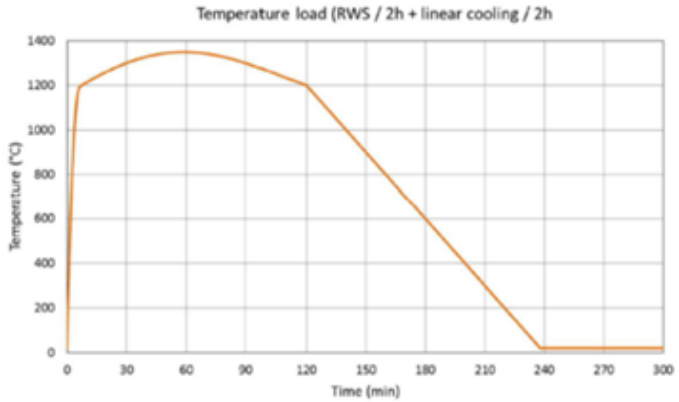




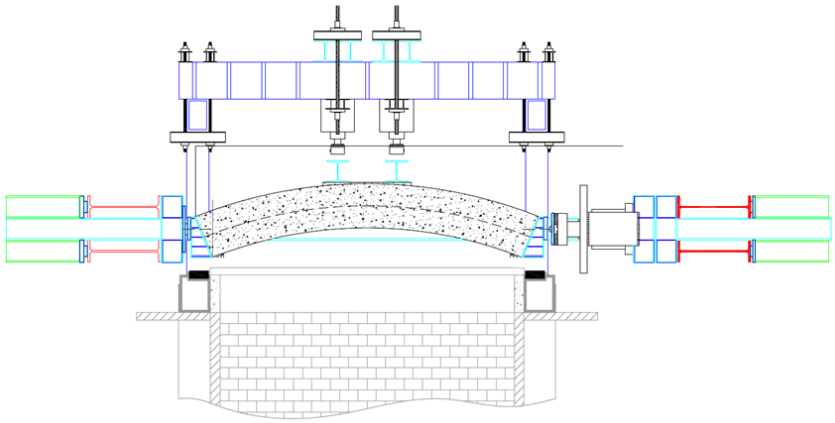
Different options for Lining Design

- Width
  - Limitation to weight and available space in TBM
  - For large TBMs 2.0m for smaller normal between 1.2 and 1.5m
- Tapering (small variation in width)
  - Always tapered ring to allow adjustement to alignment
  - Tapering in order of 25-50 mm depending on diameter and alignment
  - Note: the TBM has to be able to follow the aligment and corrections, the lining has to follow the TBM (with smaller radius)
- Left and/or right rings (to prevent keystone position in invert of the tunnel) or one uniform ring
- Small or large keystone concept
- Reinforcement in rebar/Steel Fibre Reinforced Concrete (SFRC) or Hybrid
  - SFRC is developing (see picture from 2018, courtesy COWI) but still many projects apply rebar.

- Fire resistance of the lining is often an issue in (road) tunnels
- Due to spalling large sections of a lining can be damaged in case of a fire.
- The higher the concrete strength, the higher the density and the higher the Risk of spalling
- One solution to protect the lining is by applying external fire protection (a cladding), the other nowadays more preferred option is the application of PolyPropyleen (PP)-fibers.
- The performance of the PP-fiber-Concrete mixture needs to be tested in full scale tests for the specific condition (concrete mix, loads and other relevant conditions)



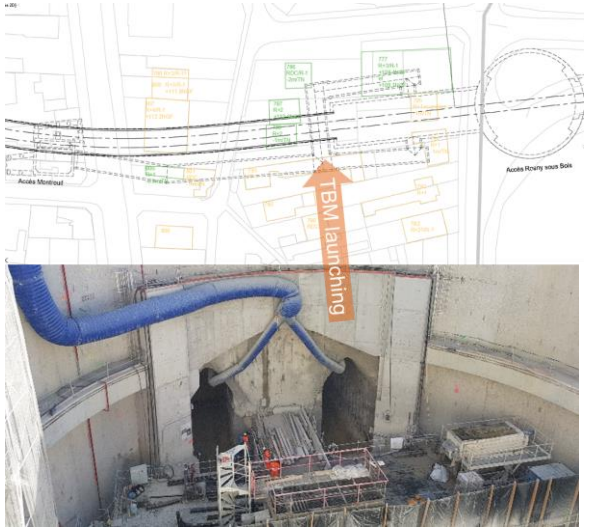
Temperature load - RWS fire curve (truck) with cool down according to RABT



Test facility at CSTB lab (France)

Testresults including segment joint (Ismailia Road Tunnel) – limited spalling due to PP-fibers (2kg/m3)

Launch Shaft Concepts



- Many concepts for Launch shafts available
- The overall concept the launch shaft is
  - Facilitate the launch of the TBM
  - to transfer the loads from the TBM drive to the surrounding soil (up to a certain lenght)
  - Often to function as Station or Service building location at later stage
- Dimension of the shaft will depend on the concept of tunneling with a single or dual bore, the ground cover at launch and length of TBM
- Length of TBM for a typical metro Project will be about 85m long
- Where often we choose a 1D distance between two bores the width of a launch shaft can be limited by minimizing the distance between TBM's at launch.
- A distance of 0.5D has always been a safe assumption but recent projects have even show smaller distances can be achieved when taking ground improvements into account.
- Ground cover at launch shall be optimized but going to 0.7D is most often feasible
- To allow erection of the shield it is required to have an envelop around the TBM in launch position. A margin of around 2.5 meter at each side of the TBM is a safe assumption

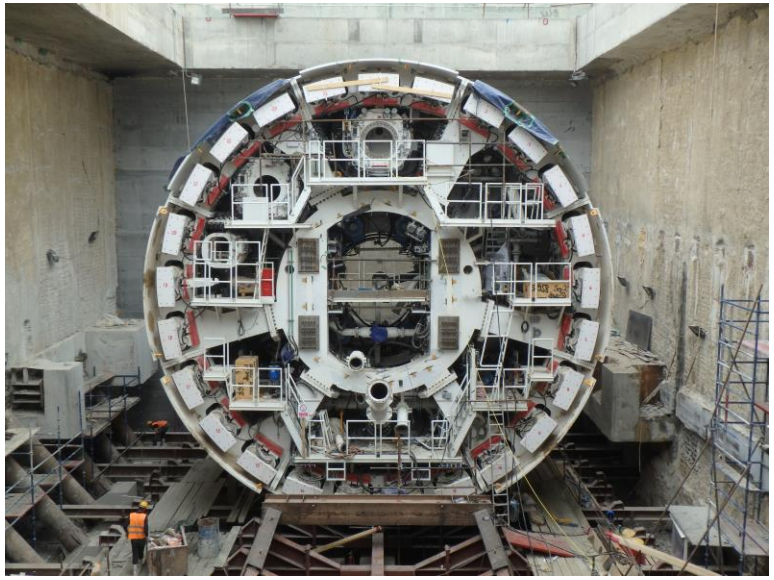
Amsterdam North-South Metro Line – construction of two bores on top of each other

Note: this concept was not an Arcadis design

- If not guided by site restrictions (space and ground water) an open cut with front wall is the most simple solution

- In case of space restrictions or high groundwater table a rectangular box in d-wall or other retaining structure is the next option
- Dimension of the box will depend on the concept of tunneling with one single or dual bore, the ground cover at launch and length of TBM

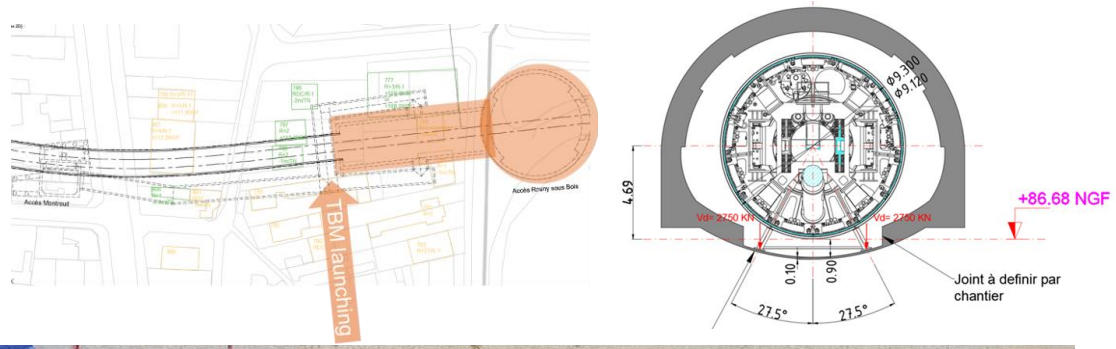
Melbourne Metro – TBM Launch from box shaft (anchored and strutted d-walls)



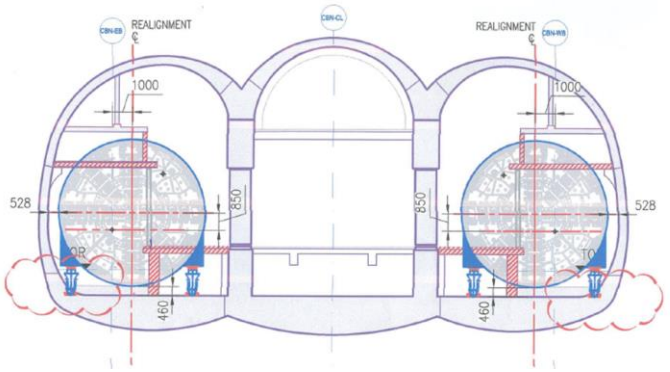
Ismailia Road tunnel – TBM Launch from two separate box shafts (anchored and strutted d-walls) for scheduling reasons

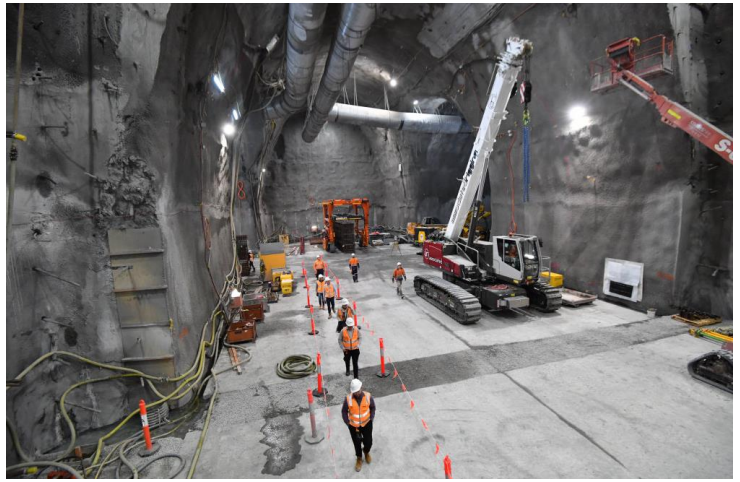
Nice (France) Tramway – TBM Launch from box shaft (anchored and strutted d-walls)

- In case of limited space preventing a open cut or box solution a TBM can be launched from a cavern connected to a shaft.



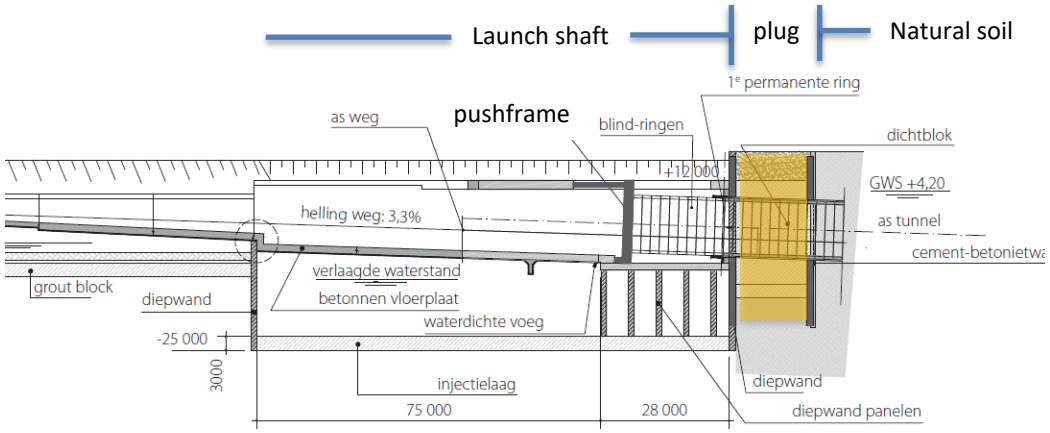
Line 11 – Grand Paris Express

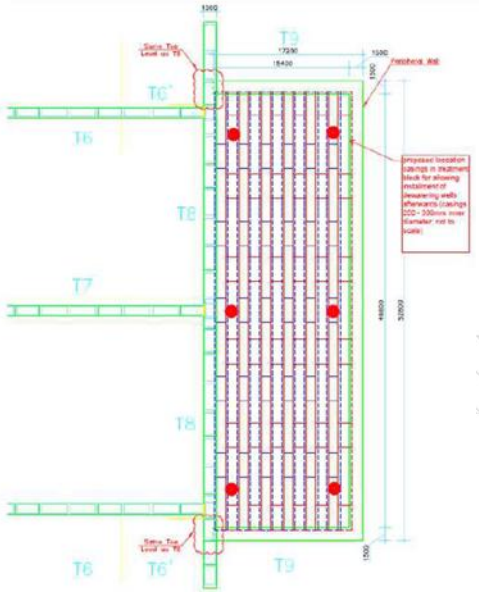


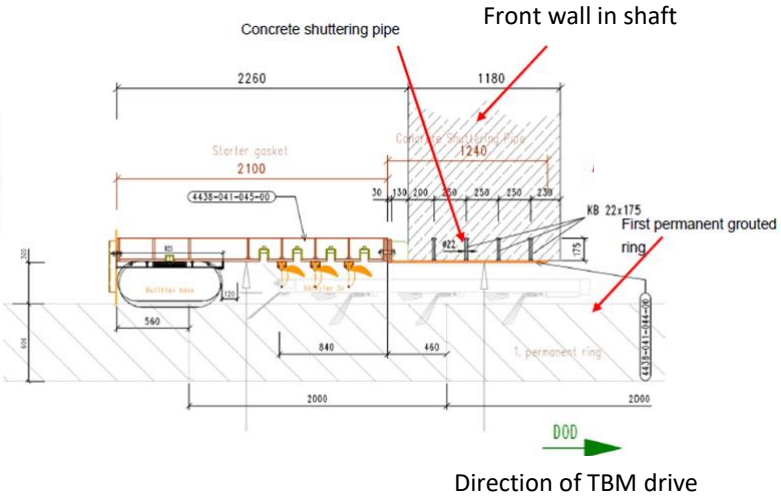


Melbourne Metro – State Library Station

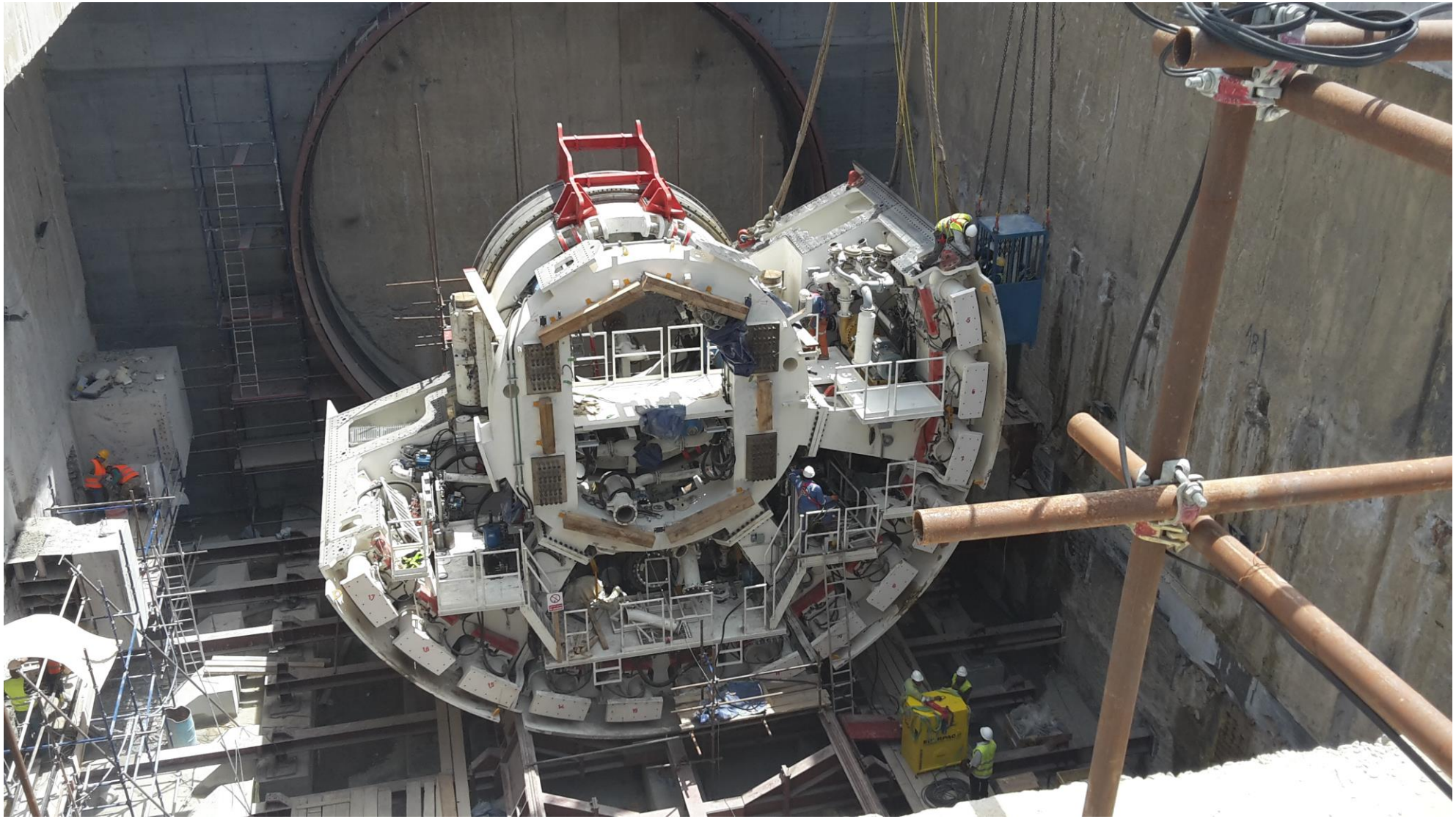
- To launch the TBM an interface construction between shaft and soft soil is needed to allow safe start of the excavation.
- This structure, often refered to as plug (constructed in a soft concrete, overlapping D-wall panels or soil improvement) bridges the soil over the opening in the shaft
- The lenght of the plug is designed to allow break-out into the natural soil while protecting flow from the face of the TBM and allow grouting of the first lining rings







Launch Shaft Concept



Line 15 – Grand Paris Express

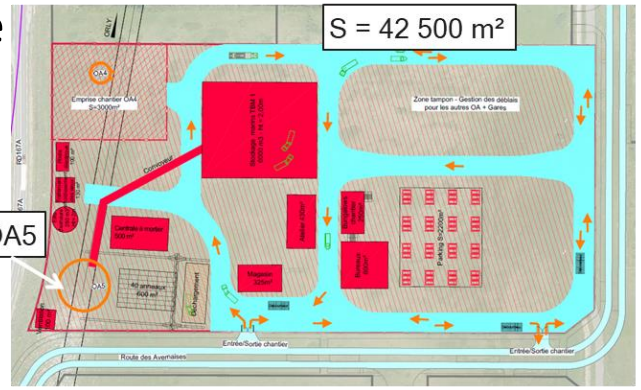
Amsterdam North-South Metro Line
(no design Arcadis)

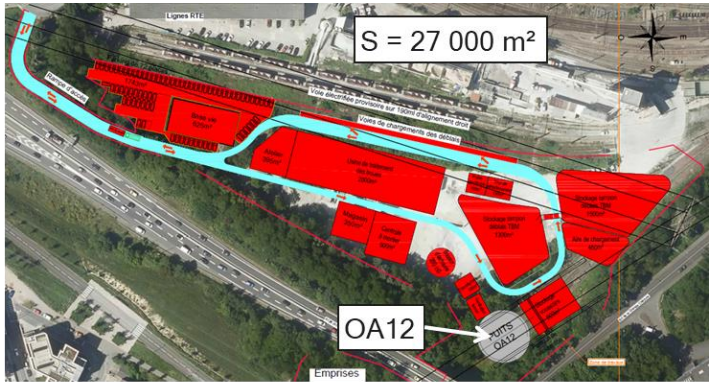
Rijnlandroute Tunnel – the Netherlands
(no design Arcadis)

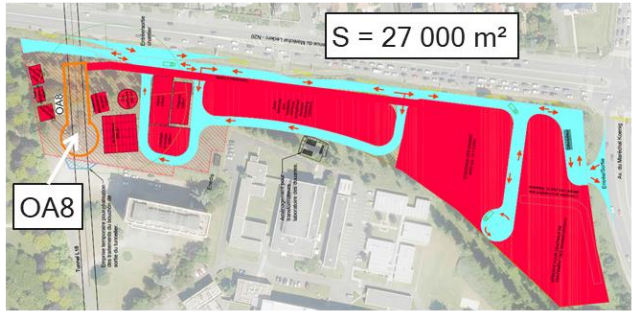
An alternative for the plug has over the last years been introduced in the form of a steel or concrete cillinder to launch the TBM. This solution is sometimes preferred due to costing or to available space issues

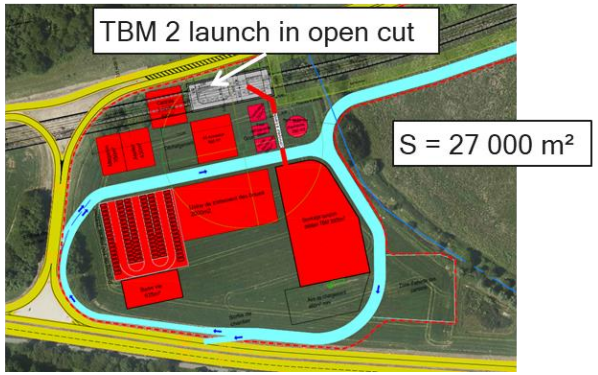
Site Logistics

- TBM projects require additional site installations and area's to support the tunneling
- In many cases jig saw puzzle in urban area.
- Depending on Slurry/EPB differences will occur
- As example the various sites for Line 18 in Paris are depicted.
- Enough lining rings on site for some days to allow progress in case transport is blocked and for small repairs
- Enough m2 for excavated muck is required
- In case of Slurry TBM the site will need bentonite plant and tanks
- Location for grout batching plant



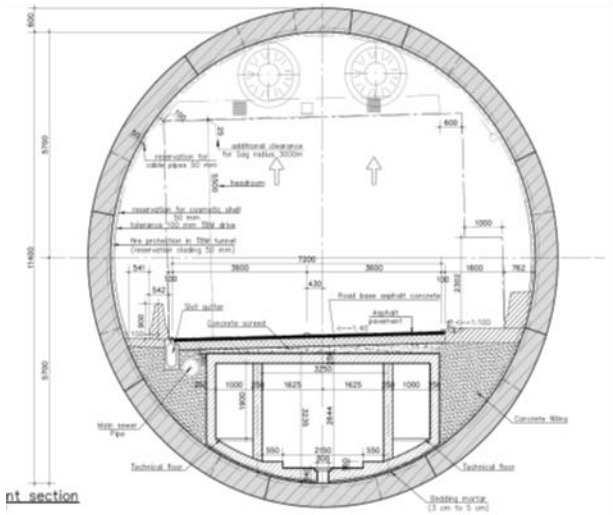


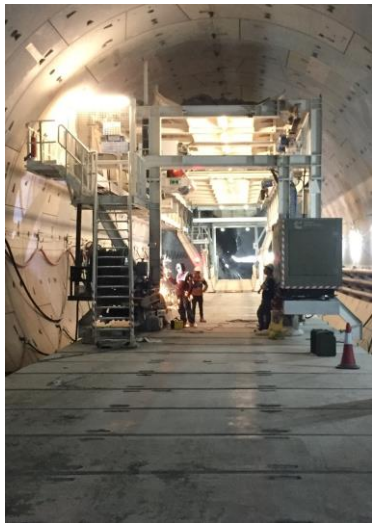


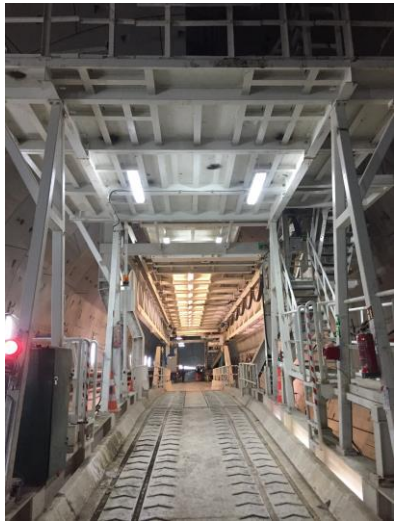


- The design (rail/metro or road) of the tunnel will require fitting out not just lining construction
- One can choose to perform fitting out in parallel to the TBM drive.
- Civil fitting out includes cross-passages, deep pump sumps, culverts, trackslab
- For shorter and smalle diameter sections it seems best to fit out after TBM drive
- When in parallel fitting out is implemented the impact on the TBM logistics has to be considered.
- Continues feeding of the TBM with personal, segments and grout is required and logistics must not limit the advance rates of the TBM drive.
- The preferred concept shall be considered during design.

Logistics and fitting out



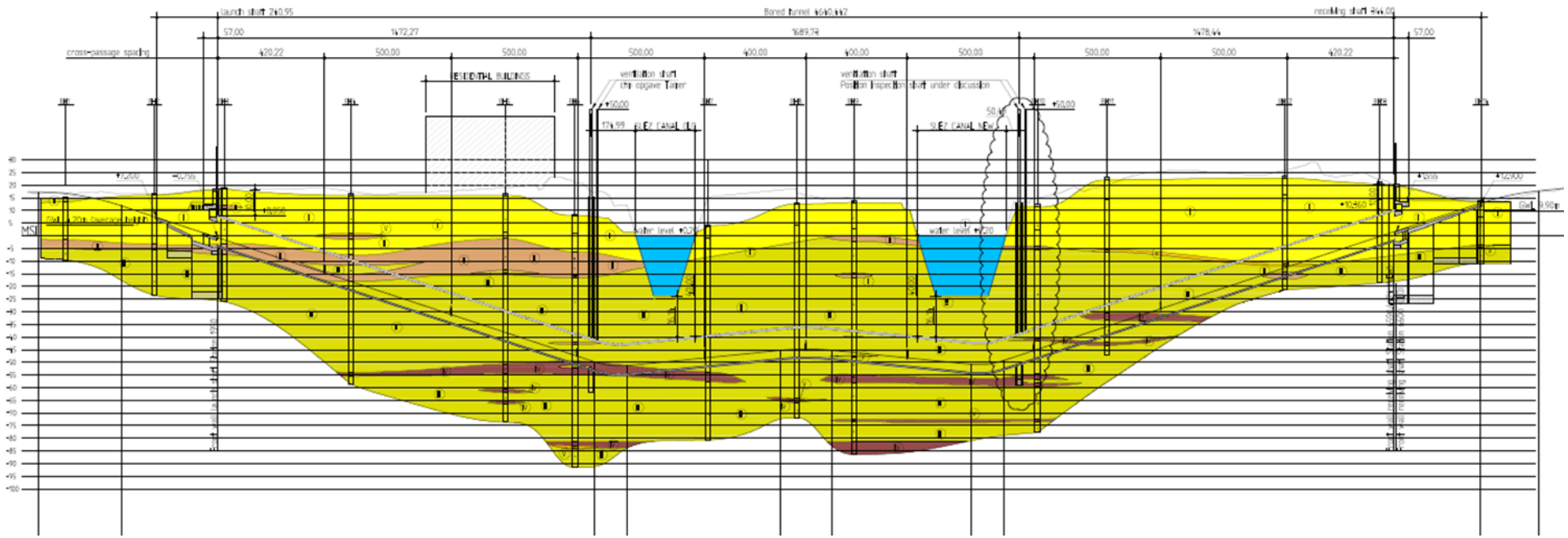




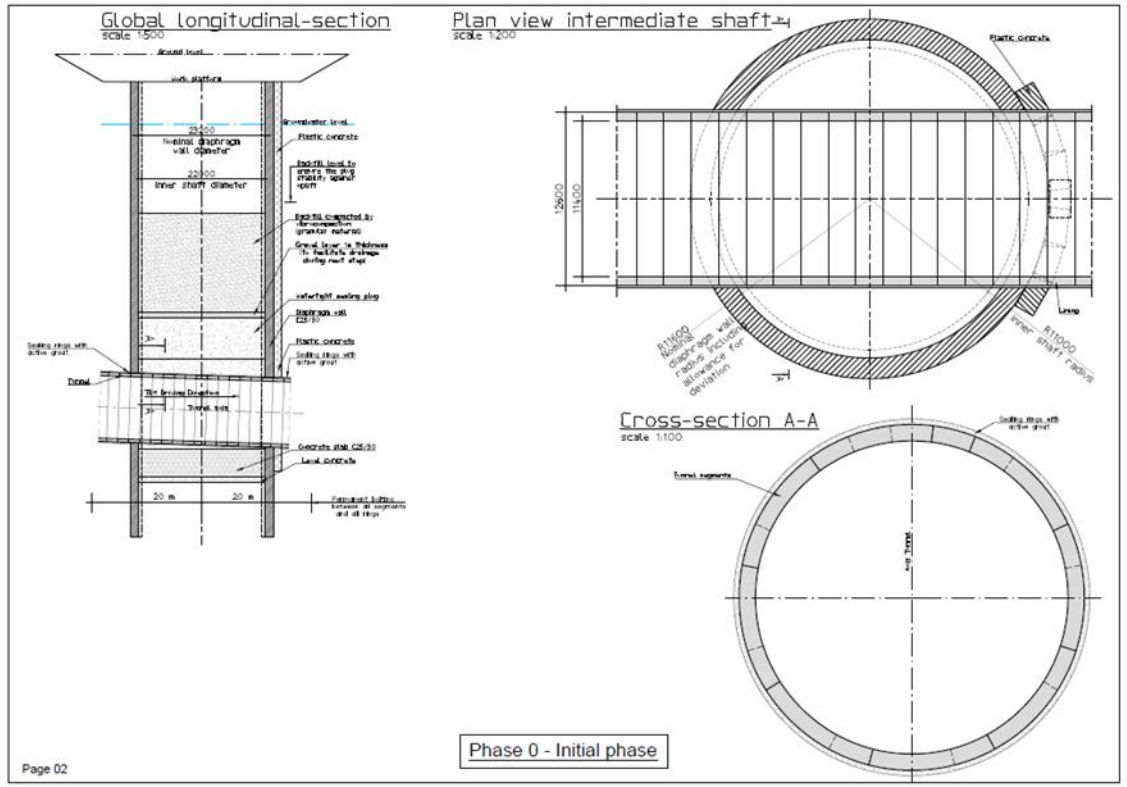
Independent Gantry Crane

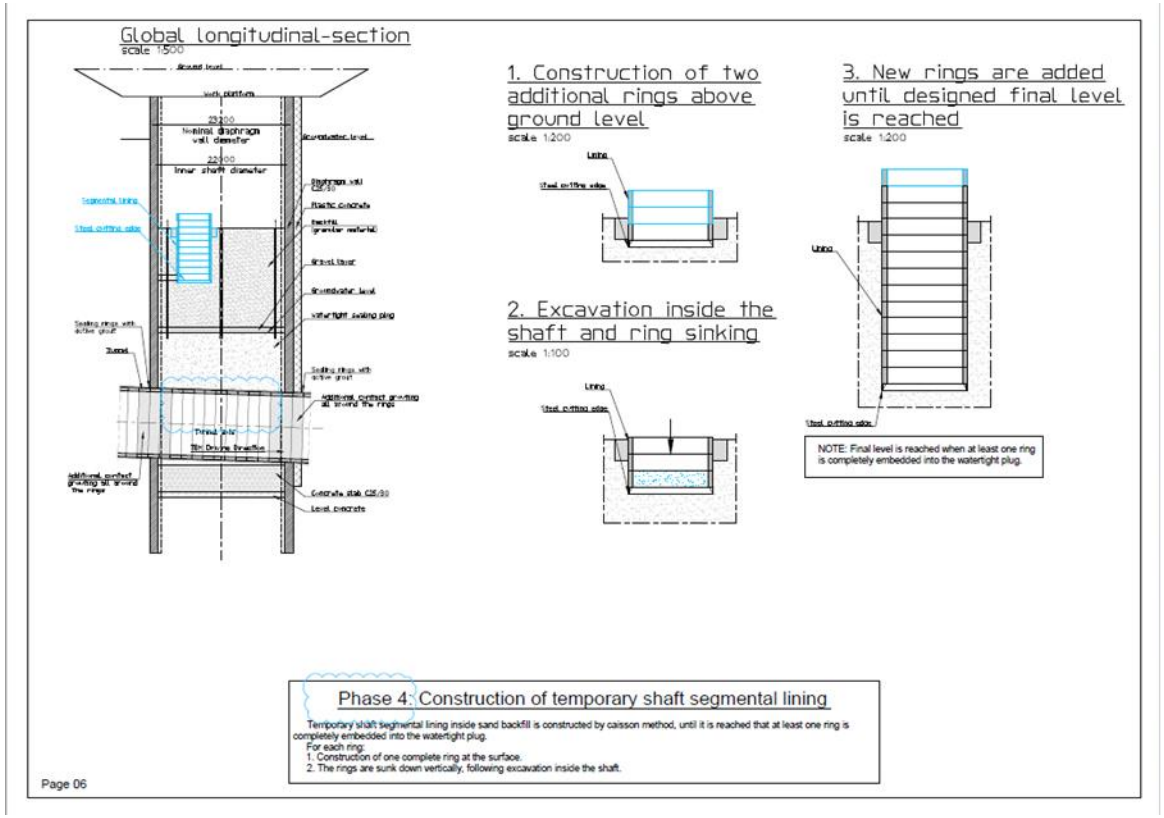
Special Structures

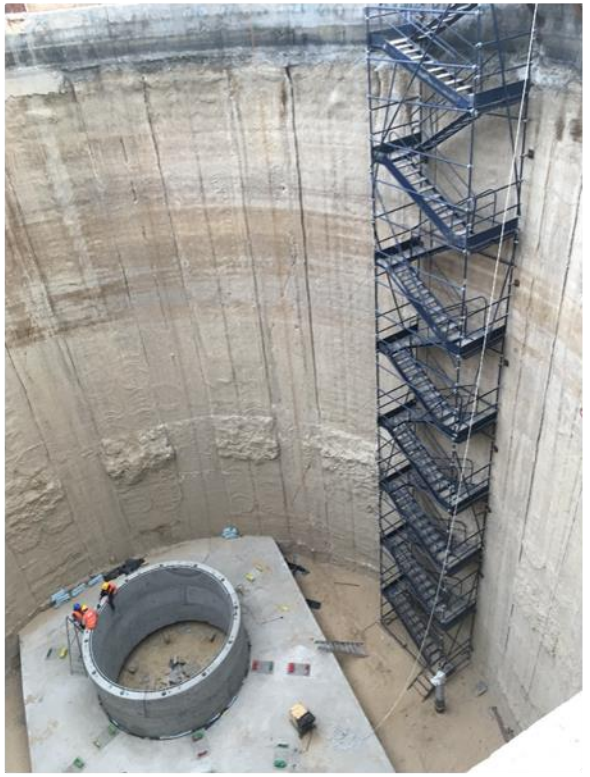
- Deep intermediate shafts for TBM intervention and ventilation



Intermediate shafts

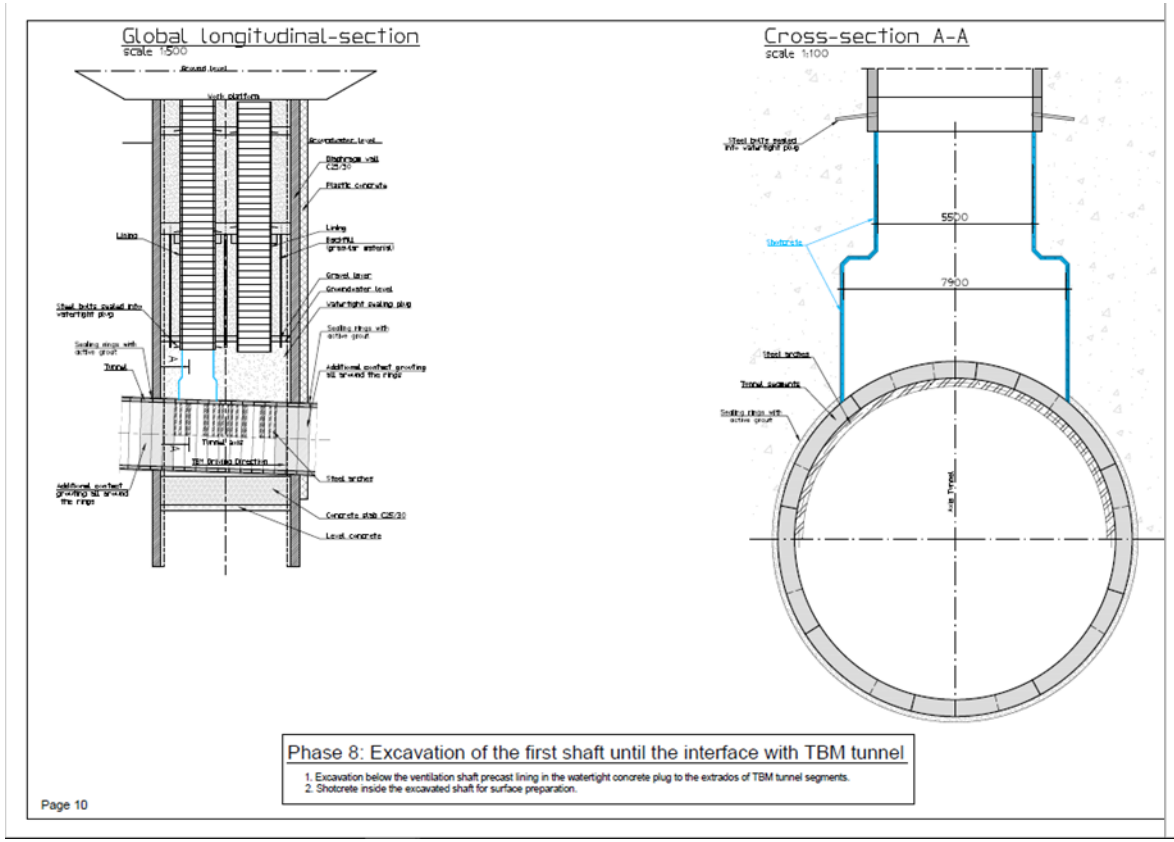


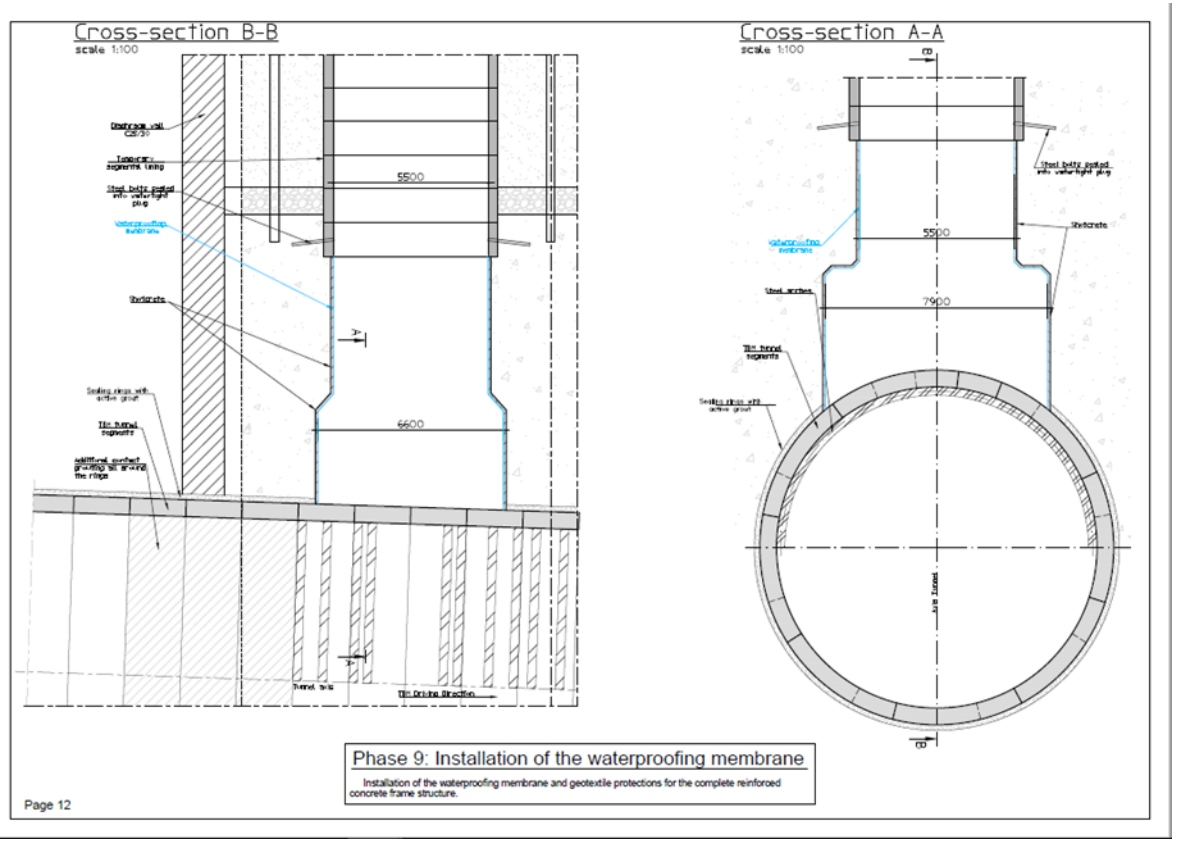


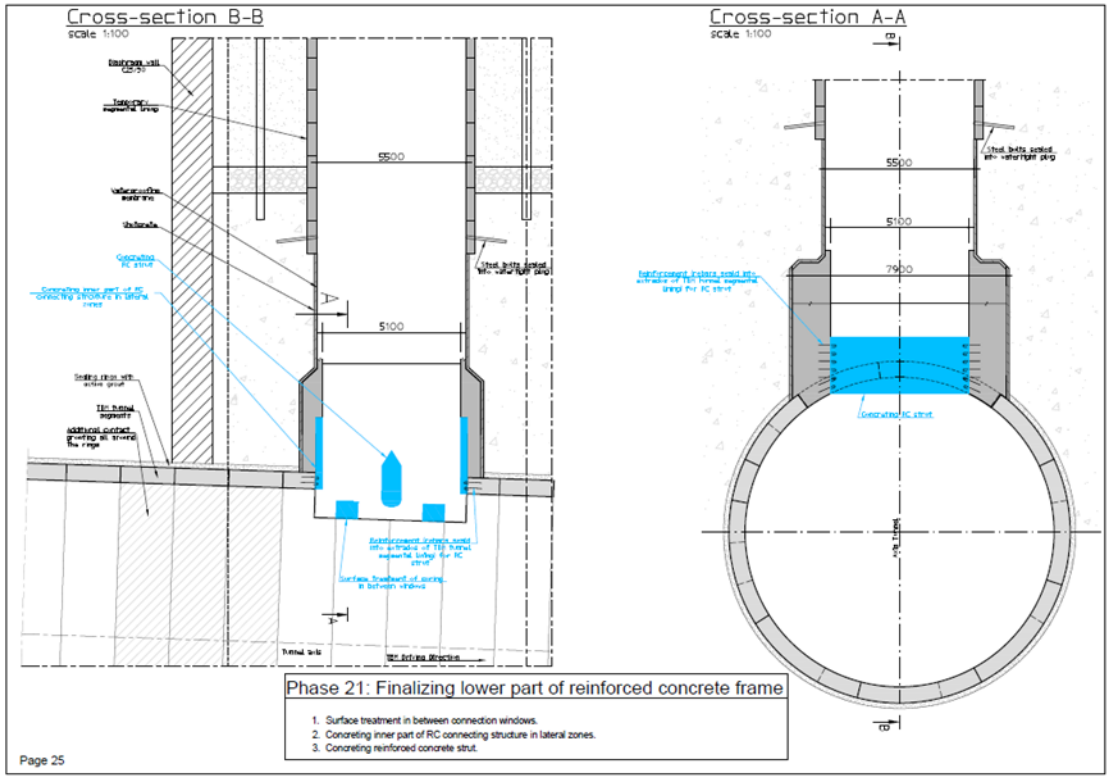


Note: the vertical shafts were constructed with lining segments for Napels Metro

Intermediate shafts







Phase 21: Finalizing lower part of reinforced concrete frame

1. Surface treatment in between connection windows.
2. Concreting inner part of RC connecting structure in lateral zones.
3. Concreting reinforced concrete strut.

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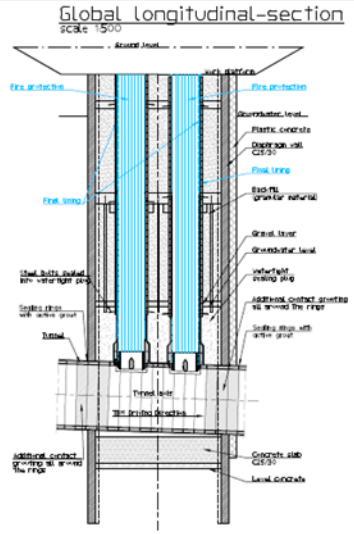

Phase 24: Construction of final ventilation shaft lining and fire protection

Creation of final ventilation shaft lining by successive concreting phases, from the top of the reinforced concrete frame to the ground level.
For each zone:

1. Installation of the waterproofing membrane.
2. Installation of reinforcement and formwork.
3. Concreting the upper shaft section.
4. Installation of sprayed fire protection on entire shaft surface (final lining and reinforced concrete frame).

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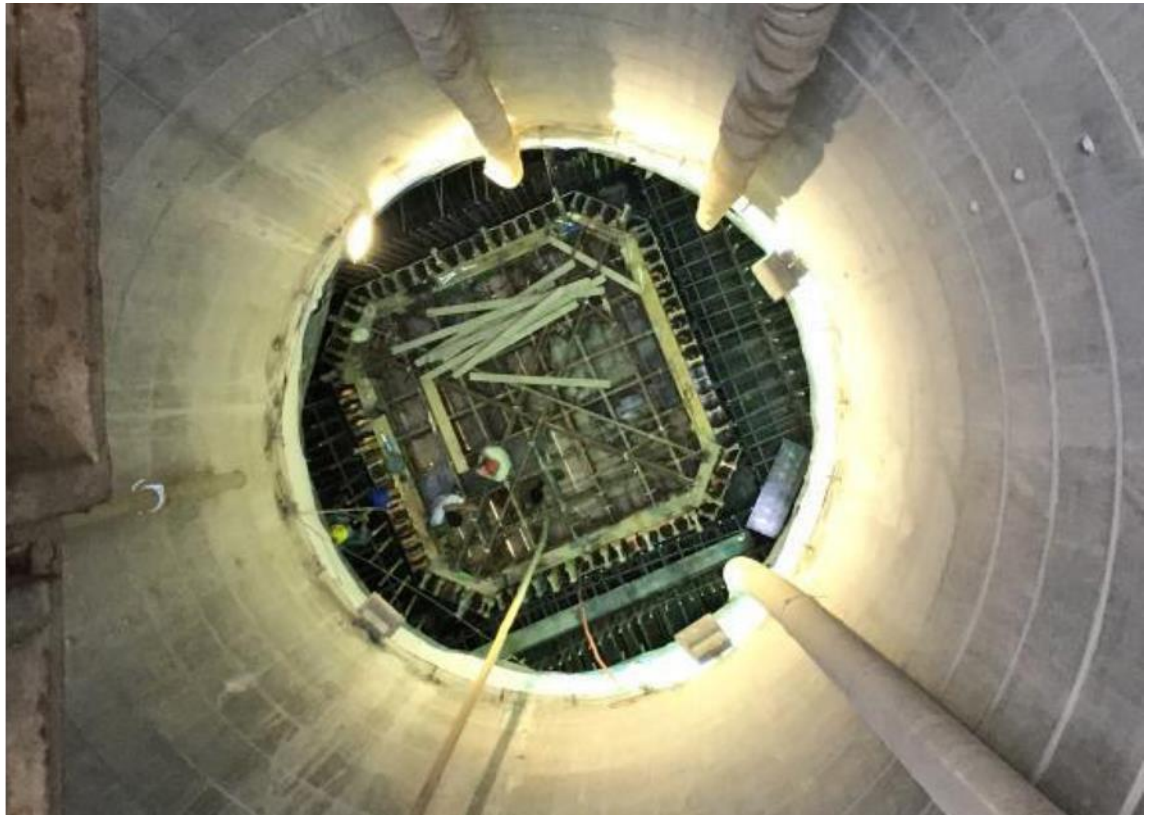
Intermediate shafts



Thank you for your attention !

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