Metro Kuala Lumpur – The Chemical Contribution

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Topic 2. Mechanised Tunnelling in Development and Use

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1. Introduction

Malaysia's first Mass Rapid Transit (MRT) project was officially launched on July 8th 2011. The total length of 51km stretches across Klang Valley, 9.5km running underground with 7 stations across the busiest city center of Kuala Lumpur. MRT is expected to be in operation by end of 2016. The project was awarded to MMC Gamuda KVMRT (T) Sdn Bhd.

Fig.1 *Overview of the MRT route with highlighted underground section (source: T&T 2014)*

The geological conditions of the Klang Valley makes tunnelling beneath Kuala Lumpur extremely challenging - cutting through 2 totally different geological formations: The Kenny Hill Formation (consisting of metamorphosed sedimentary rocks) and the Kuala Lumpur Limestone Formation (with highly developed, erratic karst features).
The project was divided therefore into 4 launching shafts with 2 totally different TBM types for each geological formation: EPB TBMs for the Kenny Hill Formation and Variable Density (VD) TBMs for the Limestone Formation.
This paper gives an overview about the experiences of the use of soil conditioners on the EPB TBMs drilling through the Kenny Hill Formation, the tail sealants used, the determination of the best annulus grout formulation as well as the leak sealing repairs of the concrete lining.

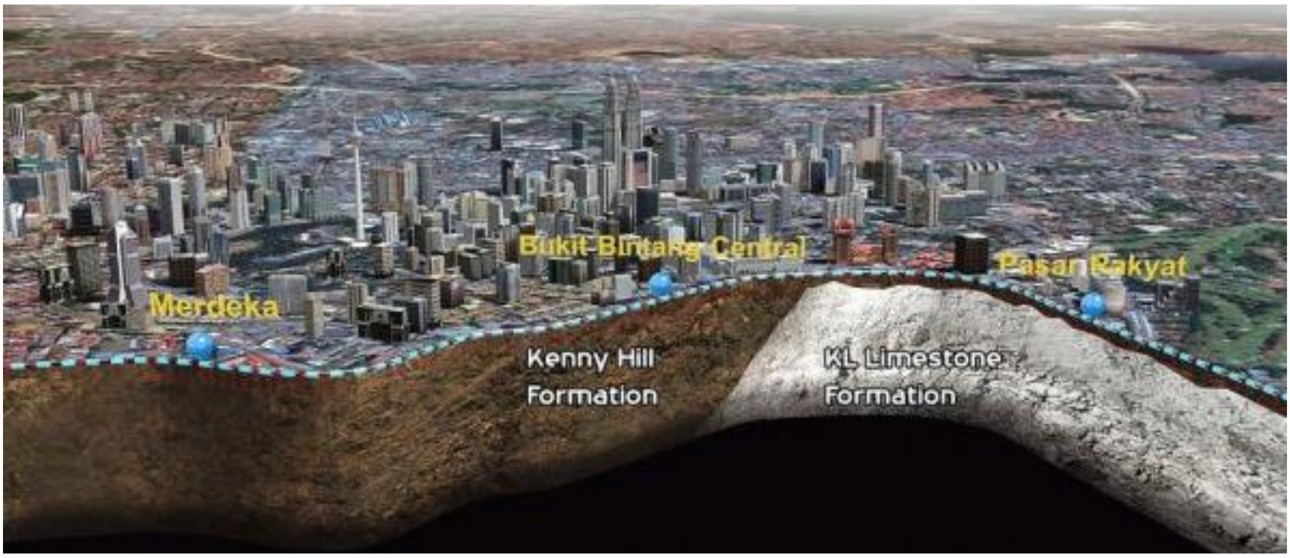


Fig. 2 *Main geological ground formations of Central Kuala Lumpur.*

2. Project overview and TBM sequencing

Initially it was foreseen to launch the Earth Pressure Balance TBMs at Semantan North Portal and Pudu Shaft running direction KL Sentral and the Variable Density TBMs from Cochrane Station and Inai Shaft.

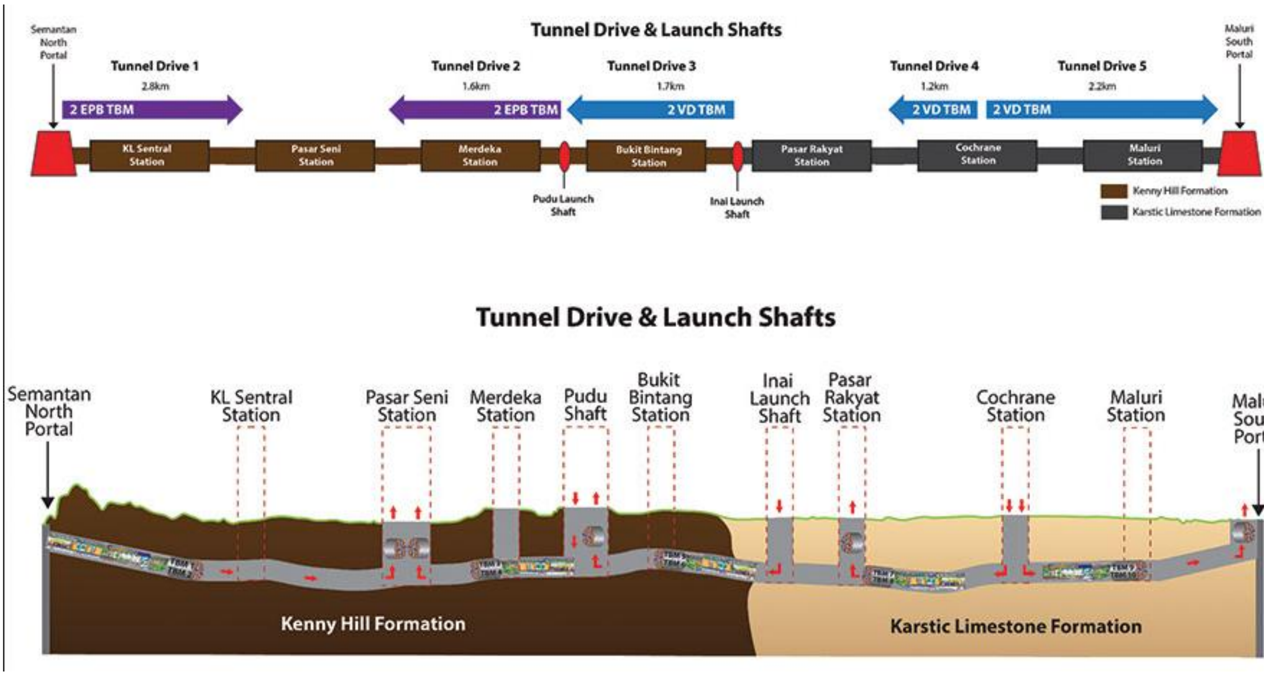


Fig. 3 *original TBM sequence plan (source: T&T 2014)*

10 TBMs were planned to be used for this project to take tunnel boring off the critical path: 6 VD TBMs and 2+2 EPB TBMs.
Their sequence needed to be adapted due to high TBM progress and delays at shaft construction:

1. The lower VD TBM operating in stacked tunnel configuration from Cochrane station arrived early at Pasar Rakyat station which excavation was running behind, so the decision was made to continue tunnelling through the station zone until Inai Shaft.
2. Due to the Inai Shaft being located in difficult karstic limestone and good progress of the TBM from Cochrane station, it was decided to continue that lower TBM to Bukit Bintang station.
3. Both VD TBMs tunnelling between Inai Shaft and Pudu Shaft were converted to full EPB mode at the boundary of Limestone/Kenny Hill Formations.
4. Change of TBM sequencing at Pudu Launch Shaft was necessary due to delays in construction – delay mitigation by starting the upper EPB TBM in a stacked configuration first.

The focus of this paper with regards to the soil conditioning issues is on the EPB drive with Herrenknecht TBM S-796 from Pudu Shaft to Pasar Seni Station, starting in May 2014 and finishing January 2015.
The documentation of the Variable Density (VD) TBMs will be given in a separate paper

3. EPB TBM specification

The S-796 EPB TBM has a cutterhead diameter of 6.620 mm, the installed power reaches approx. 1.280 kW (breakout approx. 2.500 kW) together with a cutterhead torque of 4.239 kNm.
The total TBM length incl. backup reaches 120m, weight including backup: 800t.
The TBM is designed for a maximum EPB pressure of 5bar at axis level and to drive a minimum radius of 150m. Segmental design is steel fibre reinforced, universal 7+1 with a ring length of 1400 mm.

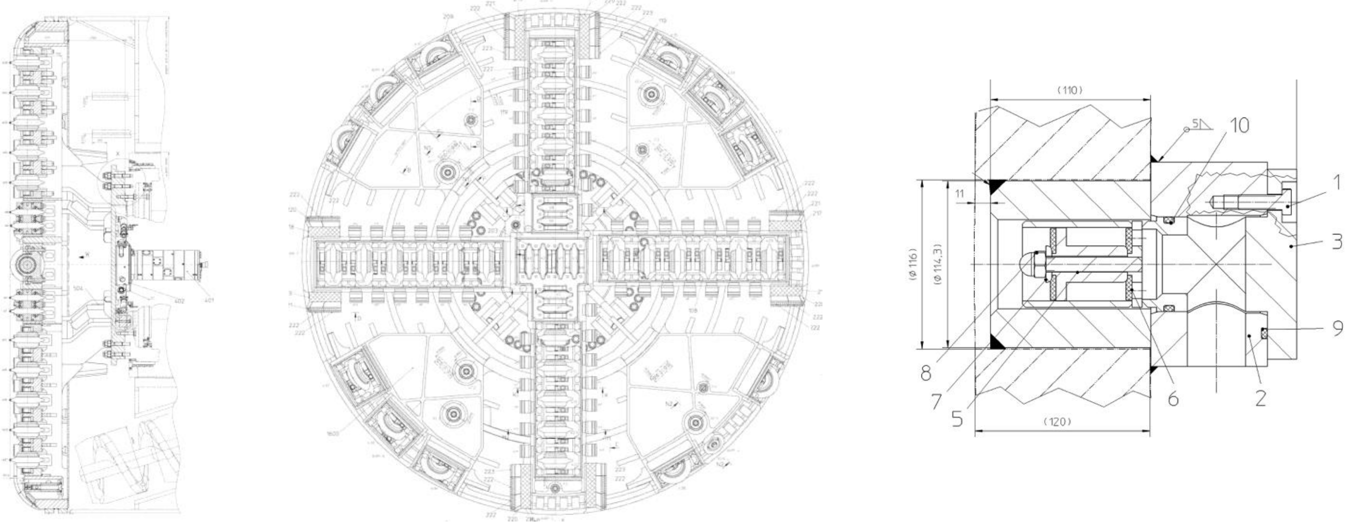


Fig. 4 *Cutterhead design (side and front view), foam nozzle detail*

The soil conditioning system installed is the standard Herrenknecht system with one dosing pump serving 5 independent foam nozzles at the cutterhead (at radius 700mm, 1850mm, 2150mm, 2550mm and 2955mm).

4. Soil Conditioning for the EPB TBMs

The geological conditions of the Klang Valley make tunnelling underneath Kuala Lumpur extremely challenging. Generally, mining at closed EPB mode was pretty straight forward, however some efforts were necessary to avoid the blocking of the cutterhead when mining the higher SPT'N' ground with increased amount of fine particles. EPB pressures were ranging from 2-3 bars and will be discussed in detail together with other TBM parameters in chapter 4.2 and 4.3.

4.1.1 Kenny Hill Sand grain size distribution

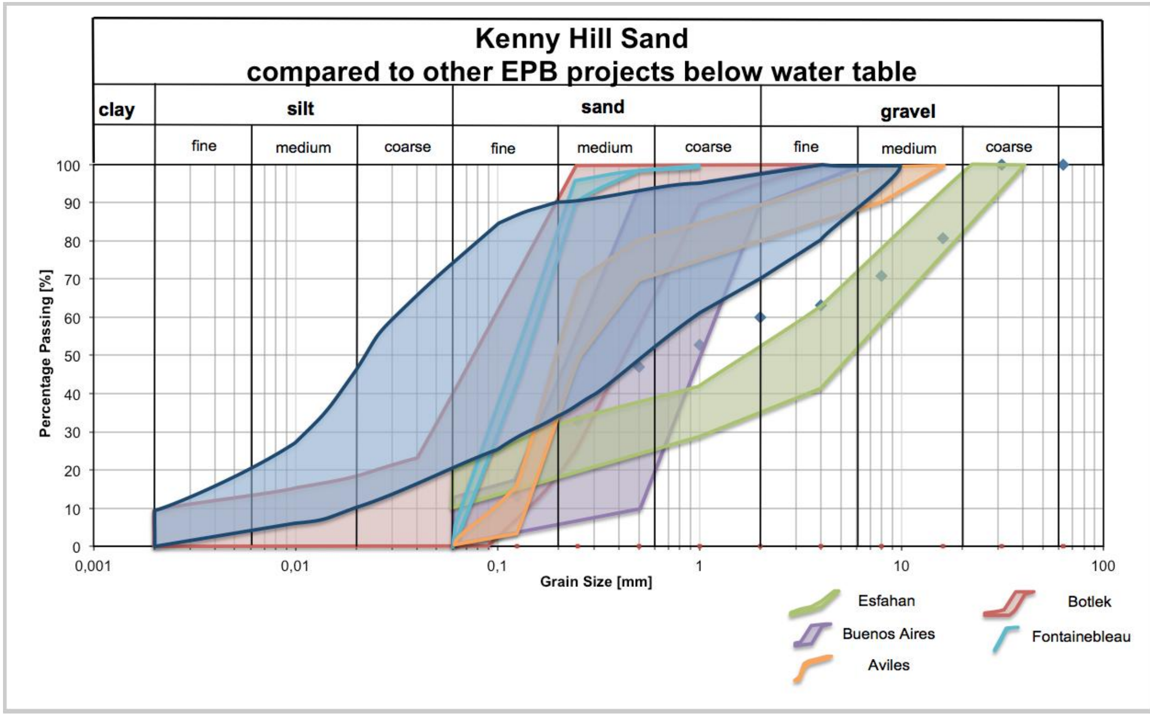
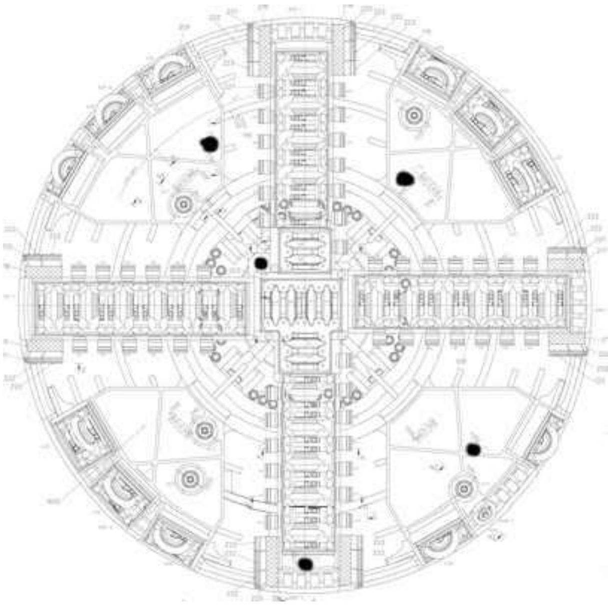


Fig. 5 *Grain size distribution of Kenny Hill Formation compared to other selected EPB drives*

Kenny Hill Formation ranges from silty sand to clayey silt, implicating a certain clogging risk for the cutterhead due to the large amount of fine fractions as well as a wear risk in case of increased sand and gravel (at the Semantan to Pasar Seni Drive the TBMs encountered a 150m long quartz section. The measured UCS was 250 MPa, highly abrasive).

4.1.2 Soil conditioning parameters used



- Cutterhead nozzles
  (F1, F3, F5: Foam + polymer; F2; F4: Water)
- Working Chamber nozzles
  (F6, F7: Water + polymer)
- Screw Conveyor nozzles
  (F8: Foam, seldom used)

- FIR approx. 50 to 55%
- FER approx. 3 to 4
  (due to the 2-3 bar confinement pressure)
- Water consumption around 12 m^3 per ring

The average consumption of foaming agent was around 100 litres/ring, polymer consumption around 10 litres/ring if necessary.
Both short chain (anti-clay, decrease of cohesion) and long chain (increase of cohesion) polymers were used depending on how abrasive or sticky the soil appeared to be.

Fig. 6 *Cutterhead with foam nozzle positioning F1-F5*

4.1.3 Soil conditioning images

***Fig. 7** Excavated soil: coming out of the screw conveyor, muck car*

Using the soil conditioning parameters listed in 4.1.2 the result was mostly a nice plastic soil paste with slump values around 100. This muck consistency allowed good material flow through the cutterhead – with special focus to the cutterhead centre.

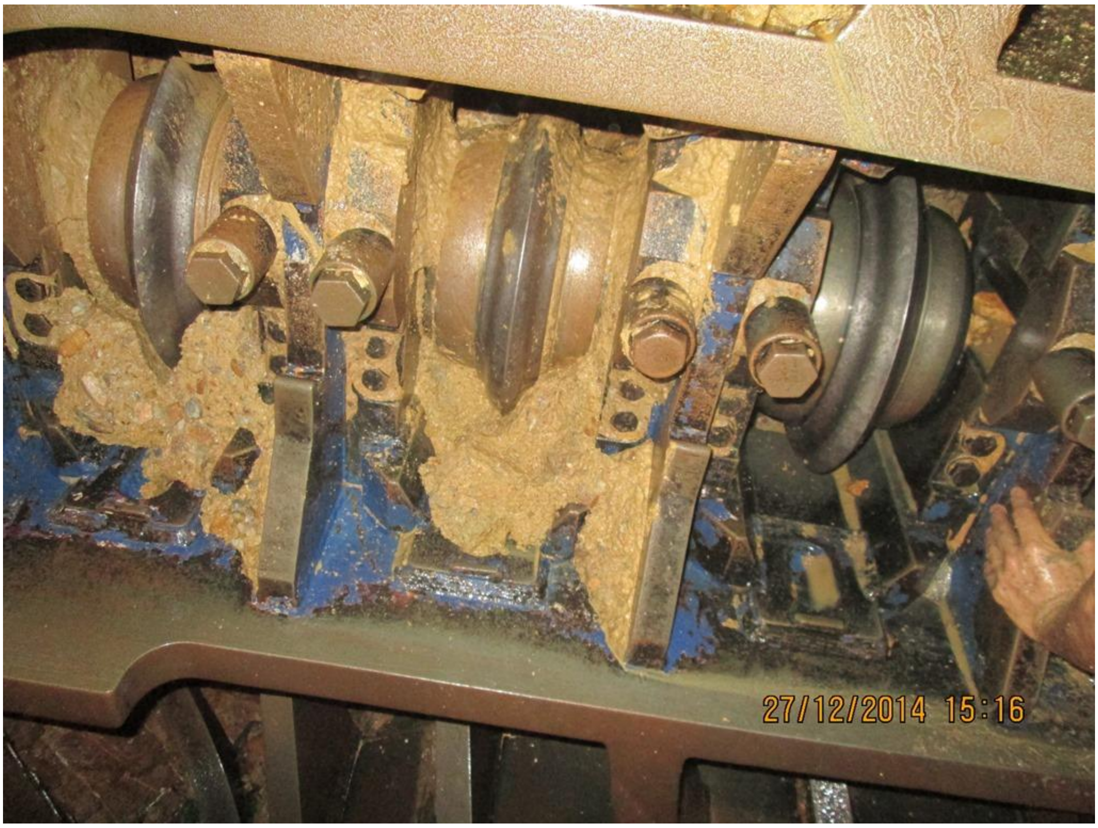


***Fig. 8** Cleaning of blocked cutters*

Increasing SPT 'N' values of the soil - increase of the fine content - can lead to clogging problems at the cutterhead. In most cases, the cutter housing is the critical area – as to be seen in figure 8.
The cutterhead blocking was reduced by adapting the TBM driving parameters as well as the soil conditioning: using of additional anti-clay polymer.

4.2 Drive 1: Pudu Shaft to Merdeka Station

Generally, the CW torque remained at a relatively high level of 3-4 MNm with EPB spring line pressures between 2.5 and 3.0 bars, increasing in case of cutterhead blockage in the centre region and between the arms.
General TBM advance rates reached around 30mm/minute and were reduced to 15-20 during the railway underpassing and continuation to Merdeka Station.

4.2.1 Railway crossing before Merdeka Station

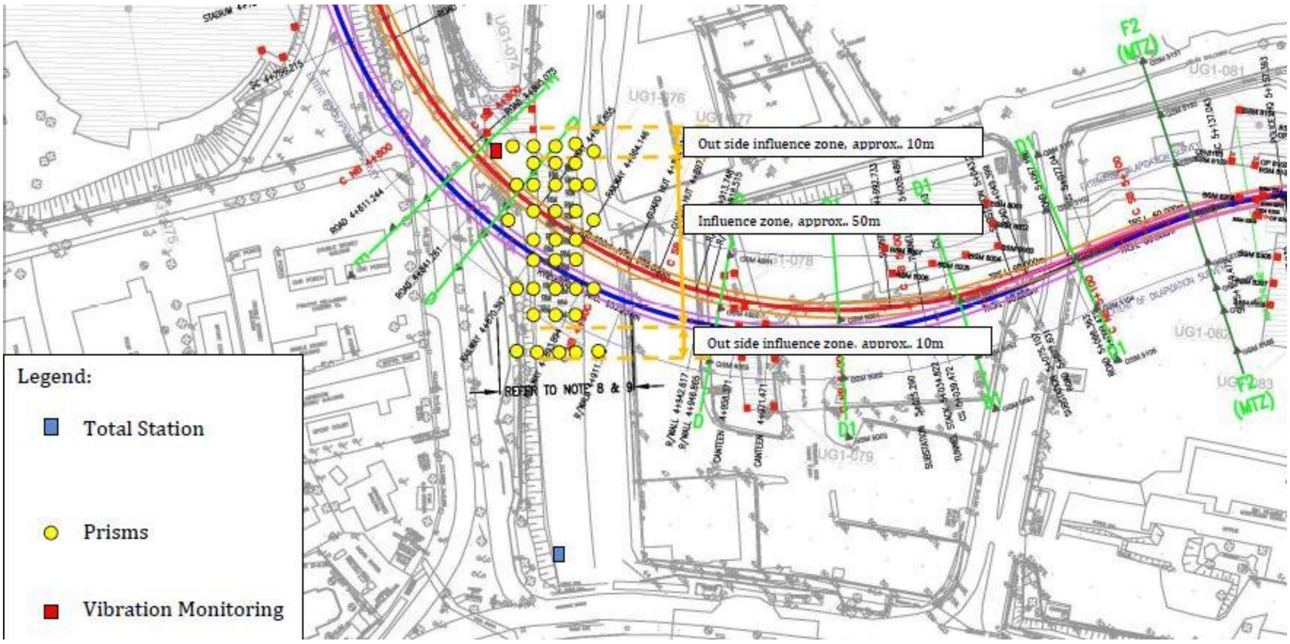


Fig. 9 *railway crossing at LRT Station Hang Tuah*

Prism monitoring (settlement control) and vibration control were undertaken to secure the proper functioning of the railway line. Monitoring showed little to no movement, despite the fact that no prior ground improvement could be realised due to unfavourable geology for injection or grouting.

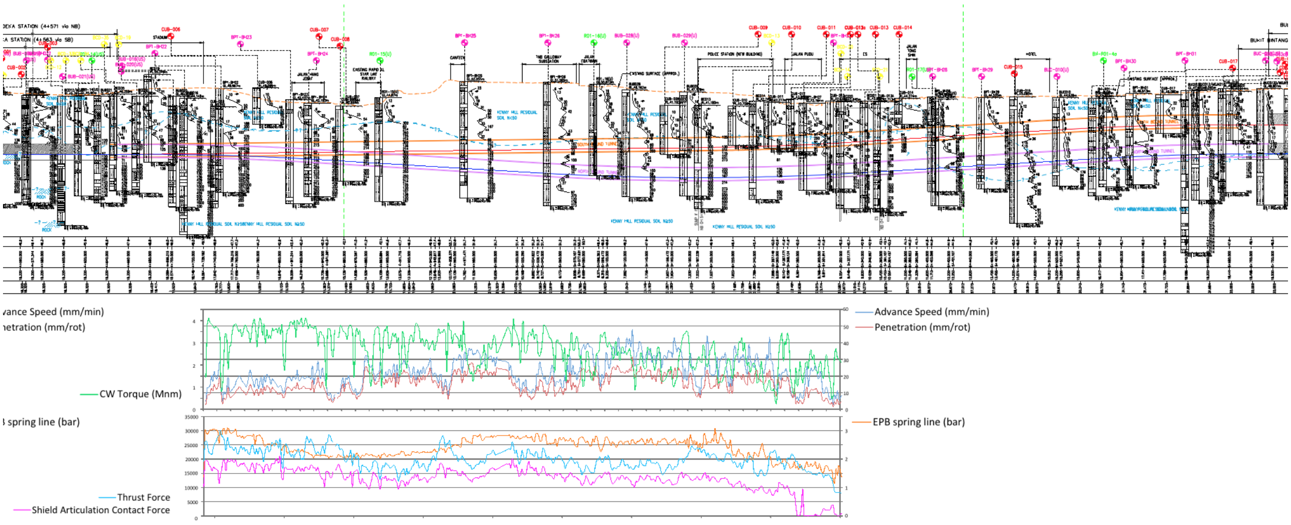


Fig. 10 *combination of Kenny Hill Geology (borehole log) and related upper TBM parameters*

4.3 Drive 2: Merdeka Station to Pasar Seni Station

The TBM continued with relatively low but steady advance speed of around 10-20mm/minute and CW torque values around 3-4 MNm (at 3 bar spring line pressure).
Torque values significantly lowered down to 1-2 MNm when the EPB pressure was allowed to drop down to 2-2.5 bar.

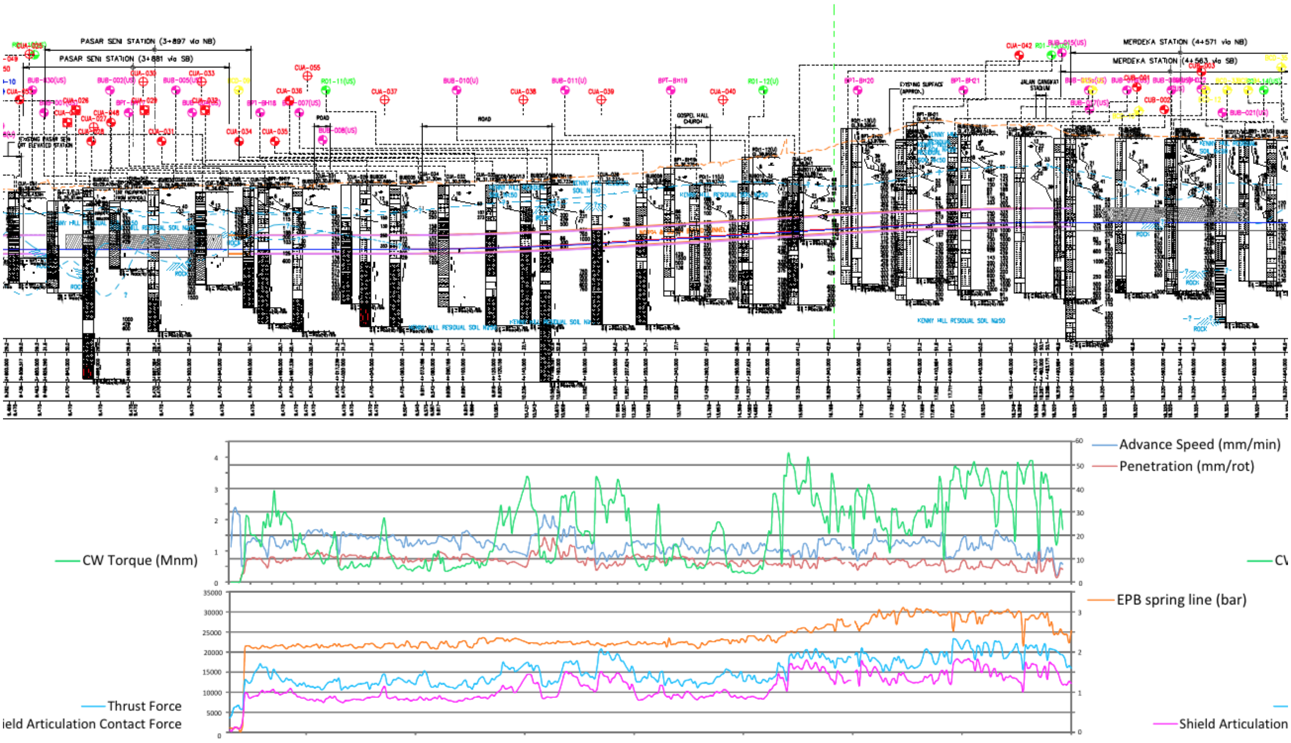


Fig. 11 *combination of Kenny Hill Geology (borehole log) and related TBM parameters*

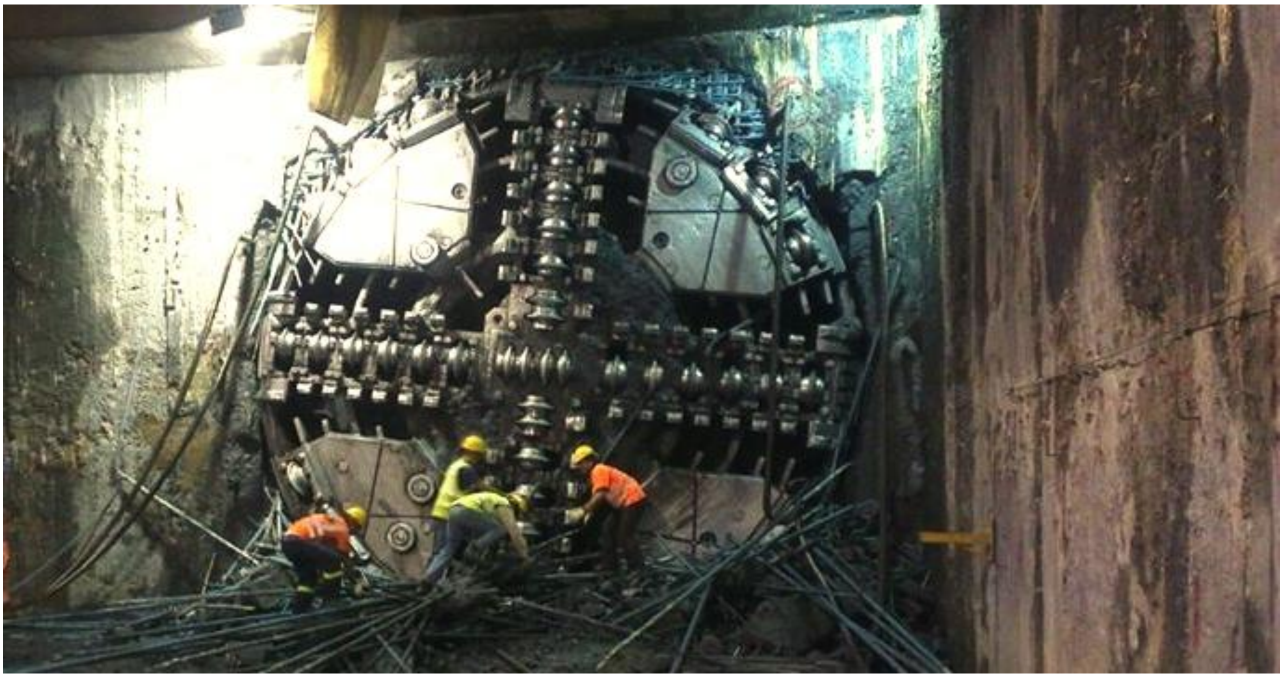


Fig. 12 *S-796 breakthrough at Merdeka Station*

Fig. 13 *Breakthrough at Pasar Seni Station*

5. Admixtures for the Annulus grout

For the first launched VD TBMs at Cochrane Station, the project required an annulus grout strength development of >0.2 MPa after 1 hour and >0.3 MPa after 2 hours for the early support of the 4ths built ring onwards - whereas the common strength requirements reaching generally only >0.05 MPa after 1 hour.
Subsequently, numerous lab trials were carried out. To be able to meet the specifications, Normet developed for this project a new admixture, TamCem 9BFG, presenting also additional cost savings for MMC Gamuda by reducing mainly the amount of cement by 17% (but also Sodium Silicate) in the grout mix design. TamCem 9BFG was used for the entire underground project for KL Metro.

Fig. 14 *Standard Herrenknecht 2k injection system, invert view*

Generally, 5 m^3 of annulus grout have been used per ring at around 1-2 bar above confinement pressure.

5.1 Mix design

Open time approx. 24 hours
Gel time approx. 8 seconds
Compressive strength > 0,5 MPa after 2 hours

Component A	Component B
825 kg water	80 litres
3-4.5 kg stabilizer	
30 kg Bentonite	
250 kg Cement	

6. Tail Sealant for TBMs

Normet supplied TamSeal TG1 to various machines of the project. As indicated before, the annulus grout pressures were kept at 1-2 bars above the EPB pressure level - resulting in 4-5 bar final grout pressure which needs to be sealed. 6 injection points for each front and rear chamber were used - TamSeal TG 1 secured a dry invert.

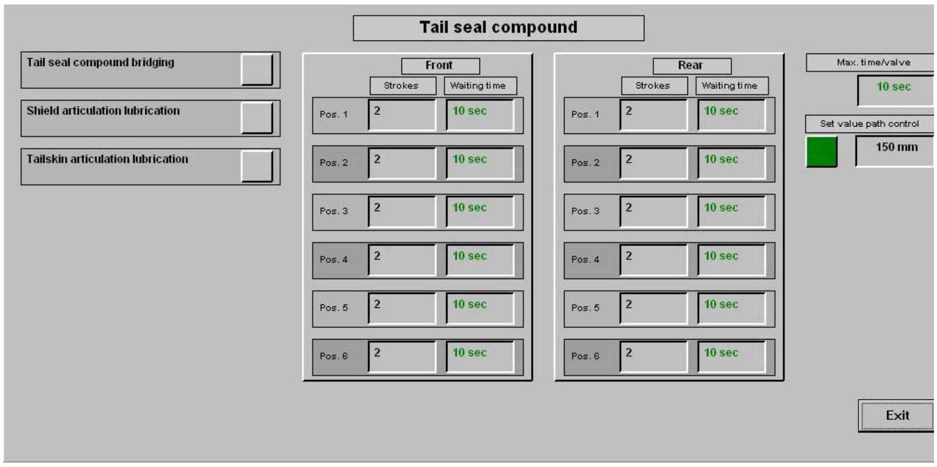


Fig. 15 *Detailed tail sealant settings used for TamSeal TG1*

The pressure control regulation was not used due to limited amount of pressure sensors installed and was also not necessary due to the homogeneous TBM advance rates.

7. Leak sealing repair of concrete segmental lining

In Kuala Lumpur's previous TBM project – SMART – acrylic gel was used for leak sealing and found to be of higher efficiency (less secondary leakages) compared to polyurethane injections. PU not being generally disallowed by the Client MRTC, MGKT and its Supervising Consultants decided finally after additional trials realized by various manufacturers, to use acrylic gel for crack sealing of the concrete tunnel segments.
Normet proposed and supplied the use of TamAcryl 3000 for leak sealing to the TBM tunnels by MMC Gamuda, providing on-site training as well as know-how to apply the product.

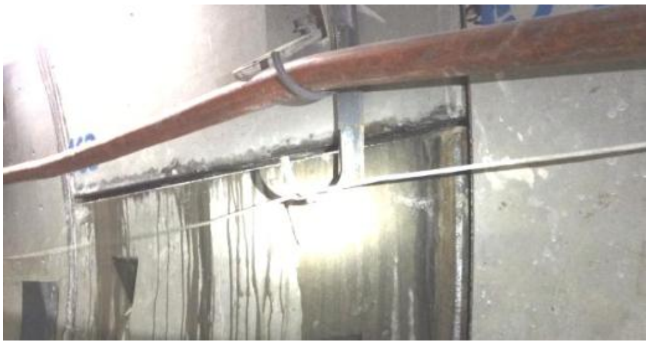


Fig. 16
Example of water leakage through the gasket which needs to be treated

Fig. 17
Drilling and 16mm metal packer installation
4 packers used for 1400mm joint

Fig. 18
Connecting packers to a suitable pump (TAM TP-2), dual line pneumatic pump

Start injection of TamAcryl 3000, chosen gel time approx. 45 second

Continue injecting until Acryl gel comes out along the gasket

Fig. 19
Completed water sealing repair with dry segment

8. Summary

Normet's speciality chemicals for TBM tunnelling used at Metro Kuala Lumpur Metro performed well and contributed significantly to the overall success of the project, flanked of course with support of specialists on site.