Real-time prediction during TBM advance

Risk management through the BEAM in Doha Metro Project

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THE PROJECT

Doha Metro Project (Qatar):
- four lines for a total length of 358 km
- 119 km underground and 100 stations

Gold Line: totally underground for a length of 14 km with 11 stations. Underground section of two twin tunnels at an average distance of 10 m

Tunnel excavation: 4 EPBs (Earth Pressure Balance) Boring diameter: 11.50 m Lining: precast segments reinforced by steel fibers. 6+1 Universal design type, 1.5 m length, inner diameter: 6710 mm and a thickness of 330 mm

THE BEAM TECHNOLOGY

BEAM = Bore Tunneling Electrical Ahead Monitoring, developed by the GET Company is a geophysical ground prediction technique especially designed for TBM operations.

BEAM is a non-intrusive focused-electrical induced polarization ground prediction technique, permanently operating while the TBM advances.

The system measures two basic parameters:
- Resistivity (ohm meter): low and high frequency alternating current is applied to measure corresponding resistivity of the rock mass. It is sensitive to the hydrogeological conditions of the rock mass, i.e. the presence of groundwater. Lower values of resistivity provide indication of the presence of water in the rock mass.
- PFE (= Percent Frequency Effect): sensitive to the grade of fracturing of the rock. Calculated by a relationship between the low frequency and high frequency resistivity. It characterizes the mobility of ions in the water and moisture containing fracture and karst space of the rock mass.

The BEAM system is able to provide in real time an hydrogeological classification and interpretation of the rock-ground mass in front of the TBM.

Data acquisition is performed automatically and continuously whereby measured data is attributed to a small sensitivity zone located about 3-times the tunnel diameter ahead of the face.

GEOLOGY

Main formations encountered along the TBM drives (Figure 1):
- RUS formation: it includes basically soft limestone, dolomitic limestone and gypsum and has a thickness of about 100 m, with evident phenomena of gypsum’s dissolution, thus generating cavities and sub-sections.
- Dammam: this formation lies above the RUS and covers the majority of Qatari area. It includes Upper Limestone, Midra Shale, Lower Limestone and it can reach up to 30 m of thickness.
- Simsima: it is made by dark white to slightly brown limestone, medium grained, with presence of gypsum and dolomite, irregular joints filled by siltstone and clay.

The two main problems related:
- local presence of large water inflows originated by Karst phenomena
- excessive consumption of cutting tools (cutters) due to a non-ideal selection of the tool types and cutter-head arrangement.

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CORRELATION WITH RQD

A correlation between RQD and resistivity had been already proposed (Hong, 2015):

\[
r = 100 \times \left(\frac{100 - RQD}{r_1}\right) + \frac{RQD}{r_2}
\]

being r the electrical resistivity of the rock mass, r1 the electrical resistivity of the joints and r2 the one of the intact rock.

By analyzing the data available in Doha, a very loose inconsistent correlation of the RQD value with the PFE index has been observed.

In the future, a clearer correlation will need:
1. Defining the analysis through available boreholes lying on the tunnel axis;
2. Broadening the pool of data.

Nevertheless, since RQD values are measured in a linear basis and they are constrained to the direction of the boreholes (as well as of the joints), a “tight” correlation between RQD and PFE index might be difficult to achieve.

PFE AND TBM PERFORMANCES

A certain correlation has been observed between the TBM penetration rate and the PFE values, as shown for TBM no. 6 (Figure 4):

- Good correlation between PFE values and TBM penetration/advance has been found
- By analyzing the data available in Doha, a very loose inconsistent correlation of the RQD value with the PFE index has been observed.

CONCLUSIONS

- BEAM has been useful to plan cutter-head interventions in the right tunnel sections
- Good correlation between PFE values and TBM penetration/advance has been found
- Good correlation between the resistivity and presence of water in the rock mass recorded
- Grade of reliability: ~80% ⇒ awareness of expected geology ahead of TBM + better planning

Further future analyses:
- Analysis of correlation between the PFE index and RQD values shall be improved
- The reliability of these results shall be confirmed by enlarged pool of data (i.e. different soils)

WATER PRESENCE’S FORECAST

BEAM has been a useful tool in the decision-making process to carry out cutter-head’s checks and cutter changes, with an accuracy around 80% on average 4.5 times water in flows encountered when accessing the excavation chamber confirmed the forecasts of the BEAM system.

During normal operation, the decision to stop the TBMs for cutter-head interventions were based on the assessment of the BEAM’s report, selecting a channeling where small-medium risk of water inflow + karst cavities were foreseen.

Figure 1. Geology

Figure 2. BEAM system’s display

Figure 3. The BEAM system

Figure 4. TBM 6 performance and PFE

Figure 5. Dry Cutter-Head inspection

Figure 6. Average advance rate compared to PFE for the 4 TBMs