ARTICLE

Preventing tunnel vision in underground projects: geological and construction risks

Going underground has reduced travel time, minimised obstacles and protected water reservoirs for thousands of years, with the oldest construction dating back to the 22nd Century BC at Babylonia. By their very nature, tunnels are dependent on geotechnical and hydrogeological conditions. Being constructed in soil-like material or hard rock, under the sea or inside aquifers in mountains, they are susceptible to geotechnical and construction risks which, if ignored, can result in fatalities, damages and lengthy litigation proceedings.

"Constructing a tunnel or an underground excavation in an unknown or poorly described geotechnical environment can cause a series of failures at the tunnel's structure."

What are the most common tunnelling techniques?

Tunnels, irrespective of their purpose or final use, are constructed mainly with conventional (NATM, SEM, SCL, ADECO-RS and Drill & Blast) or mechanised techniques (TBM). The conventional techniques, excluding Drill & Blast, refer to similar methods. NATM (New Austrian Tunnelling Method), SEM (Sequential Excavation Method) and SCL (Sprayed Concrete Lining Method) are the exact same technique, whilst ADECO-RS (Analysis of Controlled Deformation in Rocks and Soils) utilises the core of ground ahead of the face. Typically, conventional tunnelling is linked with long tunnels in rural environments or short tunnels in urban environments, whereas the cost of a TBM (Tunnel Boring Machine) is high, both in money and time, and is based on the convergence-confinement method.

The mechanised technique with TBM can be further split into different machine types related to the ground and hydrological conditions, i.e. EPB (Earth Pressure Balance), slurry, rock and so on. The mechanised techniques are based on full-face support (in soil like materials, soft rocks and in the underground water table) and have the advantage of limiting disturbance to the surrounding ground and produce a smooth tunnel wall. Tunnels constructed with TBM reduce the cost of the tunnel lining, making them suitable for urban areas.

What are the geological risks in tunnelling?

Whilst tunnels make life easier, during construction, various geological risks lurk, linked mainly with the uncertainty of the geological and hydrogeological conditions. These risks have a higher likelihood of occurrence in rural environments where geotechnical investigation is limited due to access limitations or budget restrictions compared to urban environments.

Such uncertainty in conditions may result in the wrong estimation of the tunnel's geotechnical profile and the pre-determined excavation, impacting the support methods and systems that are implemented. The lack of predicting and understanding of the geotechnical profile, and potentially challenging conditions such as faults, thrusts and shear zones; pockets of soft material; saturated sand deposits; highly fractured, poor quality rock; karstified limestone; and high groundwater pressures, present significant geotechnical risks for tunnel construction.

The geotechnical risks are associated with safety issues, undesirable construction impacts (such as procurement of materials with a long lead time that were not in the original programme) and project delivery on time and within budget. If the risks are not properly mitigated, the consequences can be costly, including reduced tunnel advance rates, programme delays, personnel and public safety issues, and environmental or third-party impacts, such as damages on existing buildings or utilities.

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What are the construction risks in tunnelling?

Constructing a tunnel or an underground excavation in an unknown or poorly described geotechnical environment can cause a series of failures at the tunnel's structure. Depending on the geotechnical material where the tunnel will be excavated, the groundwater regime, the overburden and the potential of induced stresses due to the proximity of active faults, thrusts and folds can result in different types of failures. These can include:

- the tunnel's crown collapse;
- the squeezing of the section and failure of the support's structural capacity;
- settlements propagated at the surface in shallow tunnels;
- flooding of the tunnel; or
- structurally controlled instabilities (wedge failure).

This is not an exhaustive list of the potential risks in tunnels but are some of the most common. Based on recent studies[1] a total of 378 incidents have been recorded during tunnelling since the beginning of the database from 1980 to 2019.

The main reasons for the construction risks associated with the geological uncertainty (geotechnical risks) are design errors, the lack of personnel awareness, deviation from agreed procedures or even acceleration of works to meet the construction programme or to achieve contract bonuses. The underestimation of the construction risks may result in fatalities, loss of equipment, programme delays or even problems with the budget and funding. All the above issues may result in arbitration or litigation to be properly solved.

How are tunnelling techniques related to risks?

The major difference between conventional and mechanised techniques, especially in soft rock and soil-like materials, is that the first is based on the relaxation of the surrounding rock mass to undertake the primary support for a portion of the developed stresses, whilst the latter is based on the full support of the excavation face to equilibrate the horizontal stresses (and water pressure if the excavation is under the aquifer) by applying a face pressure. Nevertheless, from the different methods of excavation, it has been evident that 48% of the incidents recorded were in NATM tunnels and 34% in TBM tunnels, whilst the remaining failures (18%) were either in Drill & Blast or open cut excavation tunnels (Cut & Cover).

Conventional vs mechanised techniques: which is riskier?

Conventional techniques are more vulnerable to geotechnical risks and are liable for more construction risks than mechanised techniques. Conventional techniques require the surrounding mass to relax prior to the installation of the primary support for the support system to undertake less loading than the in-situ stresses, therefore, part of the surrounding mass to enter the plastification zone and start converging.

1 Konstantis, S. & Spyridis, P. Tunnel failure trends and risk management, Tunelling Journal, October/November 2020.

The cost of inaction: what are the consequences and how can risks be mitigated?

A failure to identify geotechnical risks can lead to fatalities and damages to equipment, which impacts the construction programme and budget.

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Recent research[2] highlighted that fatalities in the tunnel construction industry between 1972 and 2012 were approximately 2.5 to 3 times higher than fatalities in all other construction industries, highlighting the importance of robust risk management.

Whatever the consequences, the impact on the programme can be critical; not only for the construction phase but also for the viability of the project itself and the funding.

"Being proactive about the identification of geotechnical and construction risks by engaging experienced and skilled individuals can help to avoid 'tunnel vision' in challenging underground projects."

For the tunnel project to be viable, certain mitigation measures must be identified and implemented for the risks to be reduced. These include:

— **Avoiding or reducing the risk** by increasing the geotechnical investigation budget, trusting an experienced designer and properly educating the construction personnel.

— **Applying risk mitigation measures** to decrease the severity or consequences of a risk by properly designing the excavation method and support system, as well as improving the stability conditions of potentially unstable ground or wedge.

— **Improving communication** with independent technical advisors that can opine on the potential risks.

Being proactive about the identification of geotechnical and construction risks by engaging experienced and skilled individuals can help to avoid 'tunnel vision' in challenging underground projects. Although susceptible to risks, tunnels will always be required for many different purposes, but detailed risk identification can result in a more efficient method of construction and avoid the potential of arbitration or litigation.

2 Kikkawa N, Itoh K, Hori T, Toyosawa Y, Orense RP. Analysis of labour accidents in tunnel construction and introduction of prevention measures. Ind Health. 2015;53(6):517-21. doi: 10.2486/indhealth.2014-0226. Epub 2015 May 29. PMID: 26027707; PMCID: PMC4667042.

EVANGELOS GEORGOPOULOS
Senior Consultant - Construction Solutions, Qatar
+974 4404 1694
Evangelos.Georgopoulos@fticonsulting.com