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Difficult ground conditions? Use the right chemicals! Chances–limits–requirements ☆

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ABSTRACT

The optimum solution for a successful TBM drive in general and especially in difficult ground conditions can only be reached by combining adequate mechanical solutions together with the use of suitable chemicals as well as working with experienced TBM drivers.

Especially in EPB tunneling, the correct choice and use of well adapted soil conditioners can make a considerable difference for the success of a tunneling project – both in highly permeable grounds as well as in sticky clays. Originally difficult ground conditions can be transformed into (easier) manageable ones.

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0. Introduction

More and more TBMs are working in mixed face conditions due to their large diameter or increase demands in tunnel construction (alignment restrictions) – but also due to the fact that tunneling is nowadays possible through almost all geological conditions.

The above statement generally being correct – it shall be highlighted that the TBM itself, the soil conditioning system and the soil conditioners used have to scope with these increased requirements. Interesting jobsite examples in this aspect would be Kuala Lumpur Metro System, Miami Port Tunnel or Kaiser Wilhelm Tunnel Cochem.

The following aspects are given from a chemical supplier's point of view – to the best of our knowledge and making no complete claim instead the purpose is to highlight important facts and examples.

1. TBM design – the mechanical contribution

Nowadays the critical geological areas of a TBM project shall be well detectable by combining the tunnel alignment with the geological profile. Soil permeability, Atterberg limits, overburden, mixed face conditions, water pressure, fault zones and earlier experiences from nearby tunnels, all these parameters are normally known before excavation begins.

Consequently, the TBM shall be equipped with the necessary configuration with additional flexibility towards the soil conditioning system and the pre-injection system. The TBM must have a suitable cutterhead design in order to allow a good muck flow through both the cutterhead and the working chamber.

The final decision regarding the TBM design shall be made by experienced contractors or consultants and not only by the TBM supplier.

1.1. Cutterhead design/torque

The soft ground/hard rock repartition of the tunnel alignment has to be considered when designing the cutterhead, amongst other factors, a balance of hard rock and soft ground excavation tools is needed. Clayey soils generally require a more open cutterhead (especially in the center region: defining only opening ratios is not sufficient) than gravelly sands (where mechanical stabilization may have positive effects). The opening dimensions also have to correlate with the excavation screw design. All these criteria can be contradictory – often resulting in a quite general shield design. Subsequently decisive factors for successful TBM tunneling are:

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1. Generally open cutterhead center (not only when tunneling through clayey soils).
2. Wide disk windows in order to allow material flowing through the remaining opening.
3. Sufficient amount of independent foam injection ports (with a 1 to 1 connection to a foam generator) at the cutterhead in order to allow the chemicals and water to be present at the point where they are most needed (even if the consequence is a more complex rotary union).

A plugged cutterhead results in a difficult material flow through the cutterhead and also limits the flow through the working chamber, increasing the muck temperature and tool wear – ultimately reducing the lifetime of the main bearing seal system or the risk of failure.

The cutterhead torque is another very important factor, especially when driving through clayey soil with high EPB pressures. Without sufficient torque, the TBMs are often driven

1. In compressed air mode – resulting in increased settlement and surface collapse risk as well as increased difficulties to control the ground water properly.
2. With a very liquid muck – resulting in transportation and disposal difficulties.
3. Very slow advance speed – therefore not matching the foreseen progress rates resulting in project delays.

In general all these results are not positive for TBM tunneling and for the given project in detail – highlighting the cutterhead torque as a decisive factor for successful TBM tunneling (see Fig. 2).

1.2. Injection ports – amount and placement

The amount of foam injection ports at the cutterhead restricts the amount of soil conditioner and water that can be injected during TBM advance. Limited amount of soil conditioner and/or water will result in increased muck consistency (increased torque values) or reduced TBM speed.

The positioning of the injection ports is of high importance too – they shall be well distributed over the cutterhead (cutterhead shall not turn for an extended period of time without close injection of soil conditioners) and take special care of high risk areas such as the cutterhead center (necessity of multiple ports). Furthermore, consideration should be taken that an injection port may get clogged – there is a need for redundant design at critical areas so that the TBM can continue tunneling for a while without getting any problems: TBMs are unfortunately seldom stopped when a foam injection port gets clogged.

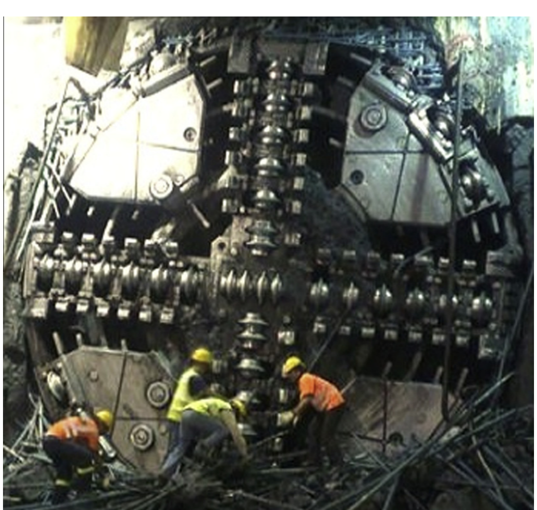

Fig. 1. Example of a plugged cutterhead center, closed disk windows, insufficient number of foam injection ports (Malaysia 2014).

1.3. Soil conditioning system – as flexible as possible

It is a known fact that modern soil conditioners can change the behavior of a soil quite drastically, let it be highly clogging clay soil or highly permeable sandy/gravelly soil: soil conditioning plays an important role regarding the overall project success. Therefore it is essential that the TBM is equipped with the necessary tools to effectively allow and control the application of these modern soil conditioners:

1. Two dosing pumps (one for foam and one for polymer, can also be used for redundancy purposes).
2. Two water booster pumps (for independent and sufficient water supply, redundancy purposes).
3. Static mixer (efficient mixing of foam concentration and polymers with water), no installation of intermediate foam/polymer solution tanks).
4. Efficient foam generators (especially at low FIR ratios, continuous foam flow, no free air release) (Storry et al., 2013).
5. Efficient non-return valves (not destroying the foam).
6. Efficient foam nozzles (not destroying the foam, not easy to get plugged by the soil).

Special interest shall be paid to the interface between the soil conditioning system and the TBM driver. The on-site experience generally shows the necessity for:

1. Separate and easy to use foam screen (as user interface for the TBM driver, see Fig. 3).
2. Water/foam selectors (for an automatic switch between foam and or water injection).
3. Quick rider (for a quick FIR change of all foam lines, avoiding switch-off of foam lines).
4. Color code for rapid identification of functionality and anomalies.

1.4. Pre-injection – be prepared for the unforeseen

Some TBM projects do require a separate pre-injection concept and the necessary installation on-site, regardless of the TBM type. Especially for multi-mode TBMs operating through fault zones or extremely difficult geology, pre-injection becomes a more and more vital issue. Important questions are

1. Necessity of umbrella type only or 360° pattern?
2. Injection through shield only or also through the cutterhead?
3. Possible length of the drilling rods.
4. Drilling angle.
5. Separate drilling installation or system based on the erector? (see Fig. 4).
6. One component pump (cements, nanosilica) or two component pumps (PU).

2. Soil conditioning – the chemical contribution

2.1. Foams

Foams are the backbone structure of the soil conditioning system. When foams are well distributed inside the conditioned soil, they are responsible for its compressibility, its reduced inner

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