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TBM tunnelling under adverse geological conditions: An overview

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ABSTRACT

The adverse geological conditions frequently encountered during TBM tunnelling present great challenges, and may trigger potential hazards if no precaution and treatment measures are taken. Comprehensive studies on adverse conditions are essential and critical to successful TBM tunnelling. In this overview paper, attempts are made to define the adverse geological conditions for TBM tunnelling. A simple classification and the influencing factors related to the adverse geological conditions are presented for better understanding of the topic. The main problems involved and the corresponding mitigation measures for TBM tunnelling under adverse geological conditions are discussed. Finally, further research needs for better coping with these problems are emphasized.

Contents

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1. Introduction

Tunnel Boring Machines (TBMs) have been applied widely in civil and construction engineering due to its advantages on rapid advance and safe operation, e.g., in favourable ground conditions, the encouraging advance rate can be up to 10 m/h (Barton, 2000). Nevertheless, as TBM performance is greatly affected by a wide range of geological conditions, the TBM method sometimes were not applied successfully in some adverse ground conditions. Such kind of adverse ground conditions can be produced "by either a rock mass of very poor quality causing instability of the tunnel or a rock mass of very good quality determining very low penetration rates" (Barla and Pelizza, 2000; Laughton, 2005). During TBM excavation, the geological factors can cause serious problems such as tunnel instability, high cutter wear, steering difficulties, large water inflow, and ineffective cutting. The adverse geological conditions can greatly influence TBM performance, which lead to low penetration rate, high additional cost, long downtime or even indefinite delay (e.g., Barton, 2000; Barla and Pelizza, 2000; Laughton, 2005; Shahriar et al., 2008; Zhao and Gong, 2006; Zhao et al., 2007).

Case studies indicate that the adverse geological conditions can severely influence TBM advance rate and cutter wear, and lead to very low TBM utilization and high additional cost. In some extreme cases, TBMs may be jammed or buried in squeezing ground, severe rock burst conditions or faulted zones. The adverse geological conditions that affecting TBM excavation can be summarized into four types, namely, the mixed-face ground, fractured rock mass, highly stressed rock mass, and rock mass with limited boreability.

TBM tunnelling depends on the interaction between the machine and the ground. The rock breakage process by TBM cutters and TBM excavation efficiency are related to the rock mass properties. The key issue for TBM excavation is to match the mechanical parameters of the grounds and the operational parameters of the machines (Barla and Pelizza, 2000; Zhao et al., 2007).

This paper reviews TBM tunnelling under various adverse geological conditions. The four types of adverse geological conditions for TBM tunnelling are respectively defined and classified. The problems induced by adverse geological conditions are reviewed from the TBM tunnelling cases, and the corresponding measures to cope with these problems are then summarized from three aspects, namely, TBM selection and modification, ground conditioning and treatment, and TBM operation optimization. Furthermore, the key issues in TBM tunnelling under adverse geological conditions are reviewed and discussed, which are the theoretical foundations for TBM tunnelling safety and efficiency. Finally, future research topics for TBM applications in adverse ground conditions are proposed.

2. TBM tunnelling in mixed ground

2.1. Definition and classification for mixed ground

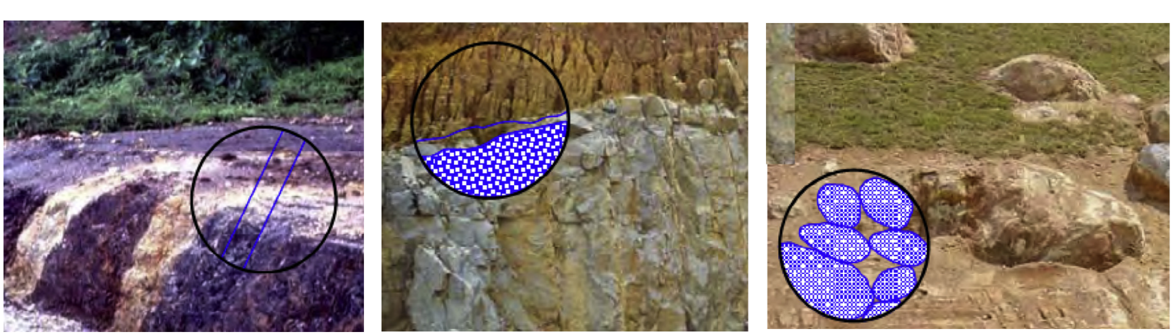
Mixed grounds are encountered frequently during TBM tunnelling for either mountain tunnels or urban underground infrastructures. The mixed ground refers to simultaneous occurrence of two or more geological formations with remarkably different mechanical, engineering geological or hydrogeological properties, or the same geological formation with different weathering grades (Steingrimsson et al., 2002; Zhao et al., 2007; Toth et al., 2013). Specifically for TBM tunnelling, some different definitions have been proposed based on the consideration of different geological parameters and their influences on TBM performance (Büchi, 1992; Toth et al., 2013).

According to case studies (Bosse Marc, 2005; Zhao et al., 2007), the mixed grounds can be generally classified into three types, as shown in Fig. 1:

(1) Layered or banded ground formed by sedimentary beddings, dykes, faults or shear zones;
(2) Interface ground of soil and rock, typically weathered materials above bedrocks;
(3) Mixed face with cobbles or corestones surrounded by soils or soft formation.

2.2. Main problems of TBM tunnelling in mixed ground

Generally, the problems encountered during TBM tunnelling in mixed grounds mainly concentrate on the interaction between the TBM cutter/cutterhead and the excavation face. Due to conspicuous difference in mechanical properties of various geological formations at the excavation face, the cutters working on the stronger part of the face take up more thrust than those on the weaker part, leading to uneven pressure on the tunnel face. The uneven face pressure, as well as the intense vibrations induced by cutters rotating from soft soil to hard rock, can lead to extremely abnormal cutter wear and face stability problem, including over-excavation at the tunnel face in soil or weak formations, leading to settlement and ground collapse, creating problems, especially for the built-up areas. The mixed-face condition is generally accompanied with abundant groundwater due to high permeability of the interface between different formations, which highly affect face stability, causing difficulties in muck conveying and tunnel support (Zhao et al., 2007). Furthermore, large pebbles and corestones that are not fragmented sufficiently in the mixed ground can block muck movement in the cutterhead chamber as well as in the conveyor system.



(a) Layered or banded ground (b) Interface ground of soil/rock (c) Mixed face with locked cobblestones/rock blocks with soil

Fig. 1. Three types of mixed ground (after Toth et al., 2013).