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Effect of adverse geological condition on TBM operation in Ghomroud tunnel conveyance project

Ebrahim Farrokh *, Jamal Rostami

Dept. of Energy and Mineral Engineering, Pennsylvania State University, University Park, PA, USA

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ABSTRACT

With the planned length of 36 km, Ghomroud tunnel is one of the longest tunnels under construction in central Iran. About half or 18 km of this tunnel was excavated by a double shield TBM. Several adverse geological conditions encountered, consisting of ground squeezing and face collapse, hindering TBM performance, and caused several TBM stoppages and jamming. This paper presents the impact of ground conditions on machine performance based on the information obtained from field observations and geotechnical site investigations. As built geological conditions are described while the method and results of tunnel convergence measurements and their impacts on tunneling operation is examined. Based on the detail study of the available geological information and tunnel convergence measurements, it was evident that the existence of weak structures in rock mass resulted in high rate of the convergence, which was the dominant factor in the TBM jamming. Since it was not possible to make observation and measurements of geological parameters when working in a lined tunnel built by a shielded machine, an attempt was made to correlate TBM operational parameters and ground convergence. The preliminary result of the analysis has indicated a good correlation among machine's operational parameters and tunnel convergence. If the system is fully developed, these parameters can be used as an indicator of the potential for high rates of convergence. An early warning on ground convergence is essential for taking precautionary measures to avoid TBM from getting jammed by squeezing ground.

1. Introduction

Tunnel boring machines (TBM) have been used for excavation of water tunnels because of their high excavation rate and circular tunnel profile which is the preferred choice for such applications. Range of application of TBMs has expanded considerably in past two decades. Although a more comprehensive tunneling machine classification and selection chart has been developed by ITA/IATES, for simplicity, it is possible to classify the rock TBMs into three classes according to Barla and Pelizza (2000). This includes:

1. Open type or unshielded TBM (for hard and sound rock formations consisting rock classes I and II according to RMR classification).
2. Single shield TBM (for weak to very weak rock formations in relatively short tunnels).
3. Double shield TBM (for weak to hard rock formations in relatively long tunnels).

The use of shield around the TBM allows the machine to pass through weak grounds and tunnel through adverse geological conditions. However, TBM may get stuck (including shield jamming and cutterhead blocking) in the complicated geological structures, especially under high cover in weak rocks. This could cause major delays and impose a heavy and expensive burden on the tunneling operation.

Machine stoppage in adverse ground is bad news in many respects as it was reported in some tunnel projects such as Evinos-Mornos tunnel in Greece (Grandori et al., 1995) and Plave II in Slovenia (Guetter and Weber, 2001). Obviously, the passage of time has a negative impact on the situation. Also, the process of releasing the machine is very labor intensive since it can only be done by manual labor and thus is very slow and dangerous. Therefore, examining the possibility of machine jamming due to adverse ground condition is an important step in tunneling operation involving the use of shielded machines. When such conditions are encountered, work schedule should be modified to expedite efficient and rapid tunneling through such ground and performing more extensive maintenance in stable grounds. This paper presents a case study of Ghomroud tunnel project in central Iran where study of ground convergence and machine parameters has led to

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* Corresponding author. Tel.: +814 8659926.
E-mail address: exf170@psu.edu (E. Farrokh).

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development of a method to evaluate ground conditions from within the machine.

In previous articles by the same authors (Farrokh and Rostami, 2007, 2008), the project was described and a discussion of the geology and machine performance was offered while the main focus of the paper was to explore relationships between tunnel convergence and chip size as well as TBM parameters in different sections of tunnel. This included low to high squeezing conditions. The results indicated that analysis of machine's operational parameters as well as grain size distributions can be used as an indicator of high deformations in the wall and potentials for ground squeezing. This article is a follow up with focus on specific areas of tunnel near to TBM jamming through observation of TBM parameters and their variations leading to the jamming. The conditions of these areas are typical of adverse geology in tunneling operations. Although the study is in its preliminary stage, the results to date seem to be promising. The outcome could allow the operators to identify potential for high convergence before the TBM is jammed by squeezing ground or a face collapse is encountered.

2. Project descriptions and geology

One of the new components of water conveyance system in central Iran is a 36 km water conveyance tunnel from Dez River to Golpayegan dam reservoir (Ghomroud water conveyance tunnel) with excavated diameter of 4.5 m. A brief overview of the project has been provided in previous publications by the authors and is not repeated here (Farrokh and Rostami, 2007, 2008). The tunnel is lined with hexagonal shaped pre-cast segments to an ID of 3.8 m. To date, over 18 km of tunnel has been successfully excavated and the TBM continues to work as the share of the current contractor has been increased and they are allowed to continue tunneling until they meet up with the other tunneling operation underway in the opposite direction.

The tunnel is driven in Sannandaj-Sirjan geological zone of central Iran. This zone consists of series of asymmetric foldings and faults and has experienced mild to high metamorphisms which have caused schistosity and recrystallization of minerals. The lithology of the area consists of a sequence of Jurassic-cretaceous formations. The cretaceous formations comprise massive limestone and dolomite, while the Jurassic formations mainly consist of slate, schist and metamorphic shale and sandstone units. These rock types have similar geomechanical properties. The rock types along tunnel alignment are classified into four major categories as shown in Fig. 1 (SCE, 2003). The rock formations can be summarized as follows:

I. Highly foliated and schistose rock types (schist, slate). This category covers more than 70% of the tunnel length. In general, they easily separate along the foliation planes, which are highly persistent. The uniaxial compressive strength of this formation was measured at a range of 30–60 MPa.
II. Massive rock types (limestone and sandstone units). Intact strength of these rocks ranges between 40 and 80 MPa.
III. Quartzite and quartz veins. These veins can be seen randomly in different parts of Jurassic formations. The maximum thickness of these veins reaches up to 80 m. Their strength reaches over 100 MPa. The origin of these veins is mainly from pegmatite formations in the area.
IV. Crushed rocks (shear zones). Tectonic activities have caused formation of various faults with thick shear and crushed zones along the tunnel alignment. Most of these faults are of reversed type. In addition some normal and strike slip faults have been observed in the area. Based on the geological studies, about 20 faults were recognized along the tunnel alignment with width ranging from 10 to 50 m. The rock mass is classified as "very poor" by standard systems.

As mentioned, the intact rock strength of the formations are generally medium to low and have low abrasivity, except for quartzite and quartz veins, which are not long sections of the tunnel. Joints, fractures and shear zones have reduced the strength of rock mass where they are present. The majority of the rock masses are classified as weak to fair quality.

Permeability of the rock masses is generally low (with hydraulic conductivity below 10–7 m/s). Ground water condition along the

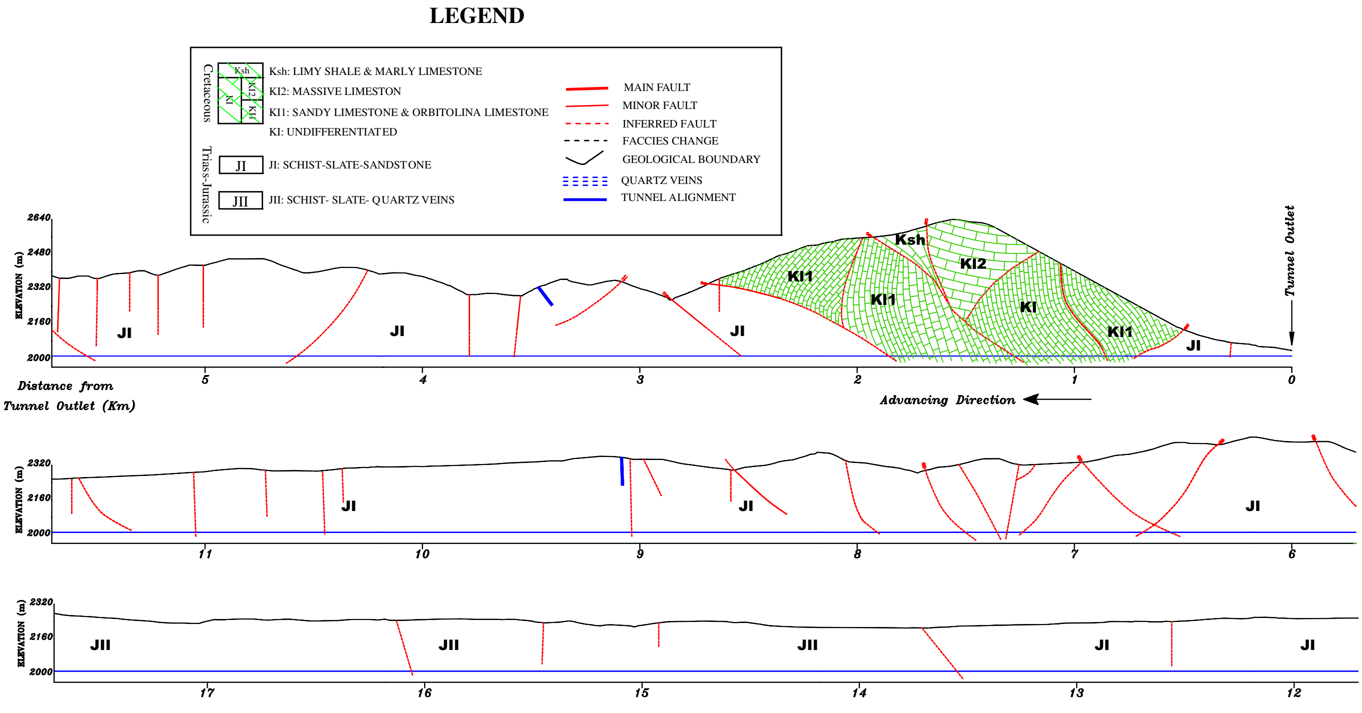

Fig. 1. Longitudinal geological section along the tunnel (SCE, 2003).