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Performance characteristics of tunnel boring machine in basalt and pyroclastic rocks of Deccan traps – A case study

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ABSTRACT

A 12.24 km long tunnel between Maroshi and Ruparel College is being excavated by tunnel boring machine (TBM) to improve the water supply system of Greater Mumbai, India. In this paper, attempt has been made to establish the relationship between various litho-units of Deccan traps, stability of tunnel and TBM performances during the construction of 5.83 km long tunnel between Maroshi and Vakola. The Maroshi–Vakola tunnel passes under the Mumbai Airport and crosses both runways with an overburden cover of around 70 m. The tunneling work was carried out without disturbance to the ground. The rock types encountered during excavation are fine compacted basalt, porphyritic basalt, amygdaloidal basalt, pyroclastic rocks with layers of red boles and intertrappean beds consisting of various types of shales. Relations between rock mass properties, physico-mechanical properties, TBM specifications and the corresponding TBM performance were established. A number of support systems installed in the tunnel during excavation were also discussed. The aim of this paper is to establish, with appropriate accuracy, the nature of subsurface rock mass condition and to study how it will react to or behave during underground excavation by TBM. The experiences gained from this project will increase the ability to cope with unexpected ground conditions during tunneling using TBM.

1. Introduction

The Brihanmumbai Municipal Corporation (BMC) has decided to change all surface water pipelines and to create subsurface systems by constructing tunnels to avoid problems of leakage, unconventional loss and also to protect water from contamination. The water supply systems through surface pipelines in Mumbai are age-old, built for more than 70 years. These supply systems leak frequently and need repeated maintenance. All these pipes are highly pressurized and badly encroached by the population, which makes maintenance difficult. In Maroshi and Vakola sections, these pipes pass below the runways of Mumbai Airport and in case of strong burst it will affect the ground below the runways. The decision for the construction of tunnels was made because tunnels have advantages of low maintenance and less security accident. With the development of tunneling technology, it is possible to excavate tunnels with tunnel boring machine (TBM) under favorable ground conditions instead of adopting conventional methods like drill-and-blast method. For the Mumbai water supply scheme, a hard rock TBM was deployed earlier in 1984 and a tunnel of 3.87 km was driven with 3.5 m diameter gripper type TBM (Tribune no-ITA-AITES). The tunnel was reported successfully excavated in 450 days with a best monthly advance of 376 m. Construction of the tunnels has improved substantially the distribution of water supply system in Mumbai, which is an effective manner. Prior to these projects, worldwide experiences in driving tunnel through basalts and pyroclastics rocks with full-face were limited. The present scheme is a continuation to those successful efforts.

To improve the water supply to Vakola, Mahim, Dadar and Malbar Hill of Greater Mumbai, a 12.24 km long tunnel between Maroshi and Ruparel College is being excavated by TBM. The tunnel is divided into three sections, i.e. Maroshi–Vakola (5.834 km long), Vakola–Mahim (4.549 km long) and Mahim–Ruparel College (1.859 km long) (Fig. 1). The longest tunnel between Maroshi and Vakola has been completed. A vent hole of 30 cm diameter at Chainage 3230 m at Maroshi–Vakola section was drilled for releasing pressure. For constructing tunnels from Maroshi to the vent hole and from Vakola to the vent hole, vertical shafts were constructed at either end. The inlet shafts of 82.0 m and 68.0 m in depth

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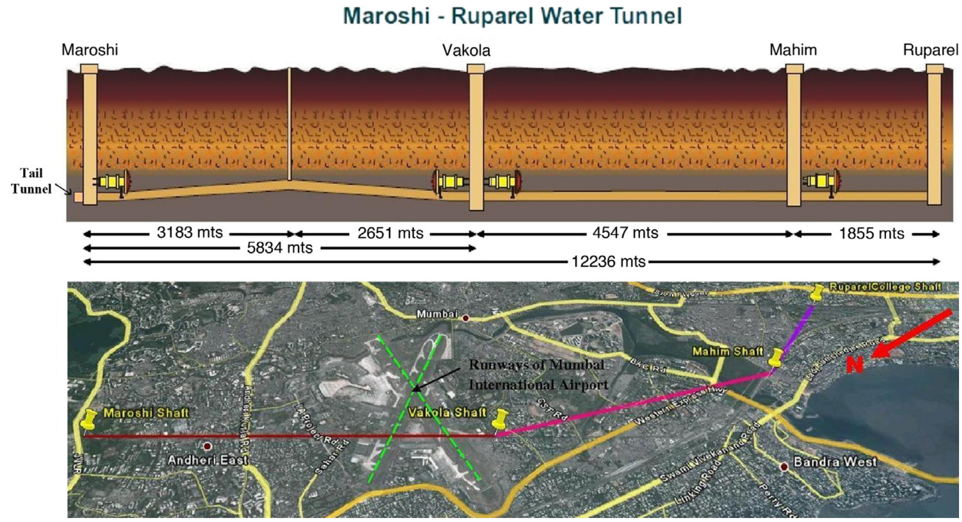

Fig. 1. Longitudinal section and plan of tunnel from Maroshi to Ruparel College.

from ground level, 9.0 m in diameter, were constructed at Maroshi and Vakola respectively to lower the TBMs parts. 5.4 m D-shaped assembly tunnels of 90.0 m and 60.0 m length were constructed for assembly of TBMs. On the opposite side along the tunnel axis, two 50 m long tail tunnels were also excavated to facilitate muck car movement while unloading. Vertical shafts, assembly tunnels and tail tunnels were excavated by conventional drill-and-blast method.

The invert level of tunnels at Maroshi and Vakola shafts is −35.50 m below the mean sea level (m.s.l.) while at the vent hole it is −30.63 m below m.s.l. The excavated diameter of a tunnel was 3.6 m with a designed gradient of 1:600 and its alignment is N30° E – S30° W (Table 1). The tunnel boring was extremely challenging between Maroshi and Vakola section due to heavy water seepage, varying rock strata condition and presence of various weak zones. In this paper, an attempt has been made to establish the relationship between various litho-units, stability of tunnel and TBM performance during the construction of these tunnels. Relationships between rock mass properties, TBM specifications and the corresponding TBM performances have also been established. The rock mass conditions were assessed by precise judgment using forward probing and “3D” geological logging of tunnel walls. Studies indicate that in Deccan traps, variations in rock types, flow contacts, rock strength, and volumetric joint amount with presence of weak zones have predominantly affected the penetration rate and stability of tunnels (Jain et al., 2011).

The rock mass has the characteristics of both the intact rock and the discontinuities, therefore the existing discontinuity conditions certainly affect the rock breakage process. It has been well recognized that joints or fractures have an important effect on the TBM performance (Howarth, 1981; Bruland, 1998; Cheema, 1999; Gong and Zhao, 2009). The discontinuities can facilitate rock breakage, because cracks induced by TBM cutters easily develop with the existing discontinuities. On the basis of a large number of case studies, Bruland (1998) concluded that with the decrease of joint spacing, the TBM penetration increases distinctly.

The influence of joint orientation on TBM penetration rate was widely observed in the tunneling projects (Gong and Zhao, 2009). Aeberli and Wanner (1978) observed that the advance rate of TBM increases with the increase of the angle between TBM axis and the planes of schistosity in a homogeneous schistose phyllite. Similar phenomena were also observed by Thuro and Plinninger (2003) in phyllite and phyllitecarbonate-schist interbedding. Bruland (1998) summarized the effects of joint orientation of different classes and made similar observation. The penetration rate increases with increasing angle between tunnel axis and joint plane as the angle is less than 60°, and then decreases with increasing angle. However, the maximum penetration rate was recorded when the angle was equal to 60°. Bruland (1998) also noted that with the increase of joint spacing, the effect of joint orientation on TBM penetration decreases. Each joint set may have different effects on the TBM penetration rate. The higher the joint density or frequency is, the larger the effect of the joint set on the TBM penetration rate is (Gong and Zhao, 2009).

2. Geology of the study area

Geologically, the entire Mumbai area is occupied by the Deccan basaltic flow and the associated pyroclastic and plutonic rocks of Upper Cretaceous to Palaeogene age classified as Sahyadri Group (Sethna, 1999). Deccan basalt of Mumbai Island is considered to be the youngest basalt of Eocene age (Subbarao, 1988). Overall, the geology around Mumbai indicates presence of ultrabasic, basic and acid differentions with intertrappean beds, agglomerates and tuffs. The ultrabasic differentiates are of limited occurrence. Acid rocks include quartz trachyte. The agglomerate and tuff include reworked materials as indicated by the current bedding as well as graded bedding. The lava pile of Mumbai is intruded by columnar jointed, medium grained doleritic dykes. The rock types encountered during tunneling are fine compacted basalt, porphyritic basalt, amygdaloidal basalt and pyroclastic rocks, namely tuff and tuff breccia with layers of red boles and intertrappean beds consisting of different types of shales. The thickness, presence and structural characteristic of fine compacted basalt, porphyritic basalt, and amygdaloidal basalt vary in different flows, depending on properties of magma, cooling history and geological conditions at the time of formation, which make these rock types suitable or unsuitable for engineering structures. Vesicles and amygdales increase toward the top of a flow unit which in turn merges into the bole at some places. The red bole is overlain by the massive strata of the next younger flow unit. Vesicular basalt with empty gas cavities and amygdaloidal basalt with gas cavities filled with secondary minerals like zeolites, carbonate minerals and secondary silica, i.e. agate, etc., do not have a regular pattern of jointing and are massive, while compacted basalt with no gas cavities is usually jointed.