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Soil abrasiveness for TBM along Tabriz metro tunnel line 2, Iran

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ABSTRACT: Mostly the long tunnels are being excavating with Tunnel Boring Machine (TBM). Soils and rocks types are important in tunneling with TBM. One of the important parameters in such tunneling is abrasiveness of soils and rocks on TBM cutterheads. Several well-known tests and methods already exist for rock; however, there are only few limited methods are available to describe the abrasiveness of soil and its impact on TBMs. In addition to mineral composition, many other textural features also influence abrasivity.

The tunnel of Tabriz Metro Line 2 (TML2), about 22 km, will be located in alluvial deposits that consist of fine-grained soils to coarse-grained soils with some cobbles and boulders. Quartz minerals in silty and sandy soils, also igneous cobbles and boulders are the main material in the deposits of this project that will wear TBM cutters. For estimating abrasiveness of cobbles and boulders, Cerchar test and for estimating abrasiveness of silty and sandy soils, petrography and mineralogy are carried out. The Cerchar tests showed that the cobbles and boulders are very abrasive. Mineralogy of silty and sandy soils indicates that the main abrasive mineral (Quartz) content is between 4% and 20%, with an average about 10%. So, the silty and sandy soils are slightly abrasive to abrasive.

1 INTRODUCTION

Nowadays, in big cities without underground construction, it would be very difficult. Tunnel excavation, using tunnel boring machines (TBM), has become increasingly common in recent years.

One of the risks easily overlooked by engineers and contractors are the effects of soil abrasion on the cost and schedule of a given project. Earth Pressure Balance, EPB, is a mechanized tunneling method in which spoil is admitted into the TBM via screw conveyer (Cochlea) arrangement which allows the pressure at the face of the TBM to remain balanced without the use of slurry. This allows tunneling soft, wet, or unstable ground with a speed and safety previously unavailable.

Tabriz city is one of the biggest cities of Iran with population over 1,500,000. The location of Tabriz city is shown on Iran’s map in Figure 1. Based on the Tabriz metro development plan, four metro lines will be constructed in future. The construction of line 1 with 17km and line 2 with 22km length, have already commenced.

TML2 generally stretches along the west to east direction, from Qaramalek in west to Baseij Square in the east. Tunnel diameter of this line was designed as 9m and the bottom of tunnel will locate at a depth of 20 to 35m. Most parts of TML2 are covered by alluvium deposits. These deposits mostly consist of silty sand to sandy silt soils with some fine-grained layers. There are considerable content of cobbles and boulders in some parts.

Figure 1. Tabriz city location on Iran map

For geotechnical investigation of TML2, more than 100 boreholes, with depth 30 to 45m, were drilled by POR Company and results were presented in a special report (POR Co., 2010). Subsurface layers consist of alluvium layers that were deposited on a weak rock layer. The thickness alluvium varies between 5 and more than 50m. The thickness of alluvium layers is decreasing from west to east. Bedrock layers are consisted of alternation of marlstones, siltstones and sandstones. The groundwater depth along MTL2 varies between 5 and 30m.

2 WEAR AND ABRASION OF SOILS IN TBM TUNNELING

Primary wear and secondary wear of soils on TBM were introduced by Nilsen et al. (1997). Primary wear refers to the expected wear on the excavation tools and surfaces such as drag bits, disc cutters, scrapers and buckets etc. which are designed for excavation and require "normal" replacement at appropriate intervals. Secondary wear, on the other hand, is an unplanned wear and occurs when the primary wear on the cutting tools described above is excessive leading to wear of the structures designed to hold or support the tools in place such as cutting head spokes or cutter mounting saddles and wear on other surfaces not anticipated by the designers and TBM manufacturers (Herrenknecht and Frenzel, 2005).

3 IMPACT OF ABRASIVE GROUND ON TBM TUNNELING

In abrasive ground, wear can occur on several parts of the TBM, including wear on the excavation tools, front, rear and periphery of the cutterhead structure, bulkhead and plunging wall structures, on outlet devices such as screw conveyors on EPB-TBMs or slurry pipes, valves and pumps on Slurry-TBMs. It is clear that during the design phase, TBM manufacturers should have access to objective wear characteristics of the ground to be encountered in order that a rational approach to TBM component selection and wear protection may be adopted. Moreover, during the operational phase when the TBM components are exposed to the abrasive ground, an agreed plan for scheduled inspections and maintenance should be prepared by the contractor. Daily cutter head inspections are common in hard rock TBM drives where cutter head access is relatively easy, however cutterhead inspections on soft ground TBM projects are typically executed where convenient or as indicated due to reduced TBM performance. Typically the presence of groundwater in soft ground tunnels makes cutter head interventions more complicated and time consuming compared to hard rock tunnels. The amount of machinery cuter heads wearing has important roll in designing and saving the time of project.

4 EXISTING TEST METHODS TO DESCRIBE ABRASIVENESS

All rocks and soils consist of minerals, which all have their distinctive scratch hardness. To define the hardness, the Moh's hardness scale is most commonly used. The scale is divided into 10 increments, ranging from talc, with a hardness of 1, as the softest to diamond (hardness 10) as the hardest. The scale is linear from hardness of 1 to 9, with each mineral being able to scratch the one below it in the scale. Among the most common minerals, mica and calcite are very soft (hardness 2.5 and 3, respectively), while feldspar, pyroxene and amphibole may be characterized as medium hard (hardness 6). Quartz and garnet are very hard (hardness 7 and 7–7.5, respectively), and to a great extent, determine the degree of cutter wear. Cutter life can be estimated from the relative percentage of minerals of different Moh's hardness classes (>7, 6, 4–5 and <4). For coarse-grained rock and soil this is most commonly determined by petrographic analysis in microscope. For fine-grained rock and soil it is most commonly determined by X-ray diffraction (XRD), some times supplemented by differential thermal analysis (DTA). The higher the percentage of hard minerals found at the face, the more abrasive the soil or rock, and the shorter the cutter life. In addition to mineral composition, many other textural features, however, also influence TBM performance, such as: grain size, shape and elongation, grain orientation, degree of anisotrpy, grain suturing, interlocking, micro fractures and pores. The use of Moh's hardness therefore is restricted mainly to preliminary estimates of cutter wear. As far as is known, Moh's hardness is not used directly as input in any TBM performance prediction model (Nilsen et al. 2007).

4.1 Test Methods for Rock

For rocks several methods for estimating abrasiveness exist already. The most commonly used are:

- The Vickers test, giving the Vickers Hardness Number (VHN)
- The Cerchar test, giving the Cerchar Abrasivity Index (CAI)
- The LCPC abrasimeter test, giving the LCPC abrasivity index (ABR)
- The NTNU abrasion test, giving the Abrasion Value (AV/AVS)

In the Cerchar test, a sharp steel indenter (hardness of 200 kg/mm^2) of 90 degree cone angle is applied to the surface of a rock specimen with static force of 70 N. The steel point is then slowly moved 10mm on the surface. This procedure is repeated 5 times in various directions on the rock surface, always using a fresh steel tip. The abrasiveness of the rock is obtained by measuring the resulting wear flat on the steel cone with a microscope. The unit of abrasive is defined as a wear flat of 0.1 mm diameter. Figure 2 shows the schematic design of the Cerchar test machine. Also rock abrasive is classified into 5 parts according to Figure 3 based on Cerchar abrasiveness index (CAI).

4.2 Test Methods for Soil

For soils the situation is quite different. There are only very few test methods to describe the abrasive characteristic of soils. Typically tests are limited to describe the hardness of minerals, such as the Vickers Hardness Number (VHN), Mohs hardness, quartz content and abrasive mineral content (AMC), but grain size of the soil is not taken into account (Nilsen et al. 2007).

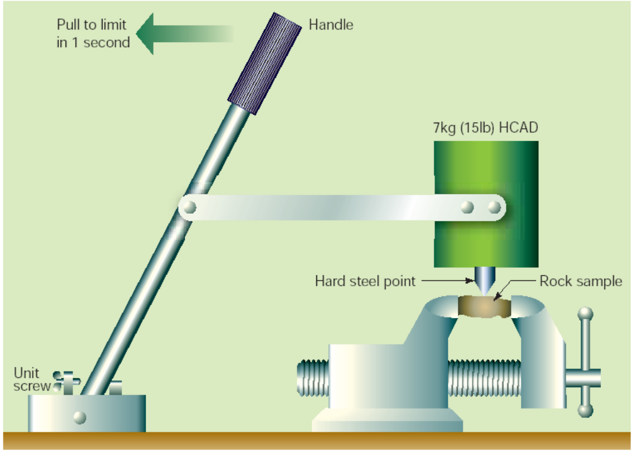

Figure 2. Schematic design of Cerchar test (Nilsen et al. 2007)

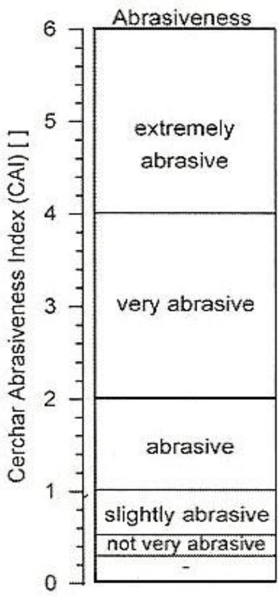

Figure 3. Rock abrasive classification based on CAI (Plinninger, et al. 2003)

5 ABRASIVENESS OF COBBLES AND BOULDERS ALONG TML2

There are cobbles and boulders in some parts of TML2. From Monajjem Street to first of Abbasi Street (about 5 km distance), these particles are considerable. Figure 4 shows a picture of these particles. Based on geology studies, the origin of these particles is Sahand volcanic mountain. For evaluating abrasiveness of these particles Cerchar tests are conducted. The result of these tests is presented in Table 1. The CAI varies between 2.5 and 4.7. According to Plinninger, et al. (2003), these rocks are classified in very abrasive group.

Table 1. Cerchar tests results on cobbles and boulders

Number of borehole	Location	Depth of sample (m)	Rock type	CAI
BH-13	Daneshsara Sq.	15.5	Andesite	3.5
BH-18	Monajjem St.	14.0	Andesite	4.7
BH-27	Fahmideh Sq.	16.0	Sandstone	2.3
TP-7	Abbasi St.	10.0	Conglomerate	2.5
BH-28	Abbasi St.	19.0	Hornblende Andesite	3.8

Figure 4. A picture of cobbles and boulders in the middle of TML2 (Daneshsara square)

6 ABRASIVENESS OF SOILS ALONGE TML2

The silty sand to sandy silt soils are the main group of soils in TML2. Theses alluvial soils originated from igneous and Pyroclastic rocks around Sahand volcanic mountain in south of Tabriz. Based on geological studies, the hardest mineral of these soils is quartz.

For determining quartz and other abrasive minerals content, some samples were obtained from various depths in boreholes. The obtained soil samples were fixed with special resin and then were prepared thin sections for study by microscope. In thin section, the quartz content is estimated based on the occupied area by quartz mineral relation to whole area of section. Figure 5 shows example pictures from these thin sections.

The estimation of quartz content (as main abrasive mineral) in samples is presented in Table 2. The quartz content varies between 4% and 20%, with an average of about 10%. Based on experiments, these soils are considered slightly abrasive to abrasive.

7 CONCLUSIONS

Alluvial deposits along Tabriz metro line 2 are containing silty sand to sandy silts with some boulders and cobbles. These sediments originate from Sahand Mountains and coarse particles are mainly igneous and Pyroclatic rocks.

For estimating ground abrasivity on TBM along MTL2, some tests were conducted on coarse particles and some tests on silty sand soils. For evaluating of abrasiveness of coarse particles (cobbles and boulders) about 5 Cerchar tests are conducted. Based on the Cerchar tests results, the CAI varies between 2.5 and 4.7, so these rocks are classified in very abrasive group.

Mineralogy of silty and sandy soils indicate that the main abrasive mineral (Quartz) content varies between 4% and 20%, with average 10%. So, the silty and sandy soils are slightly abrasive to abrasive.

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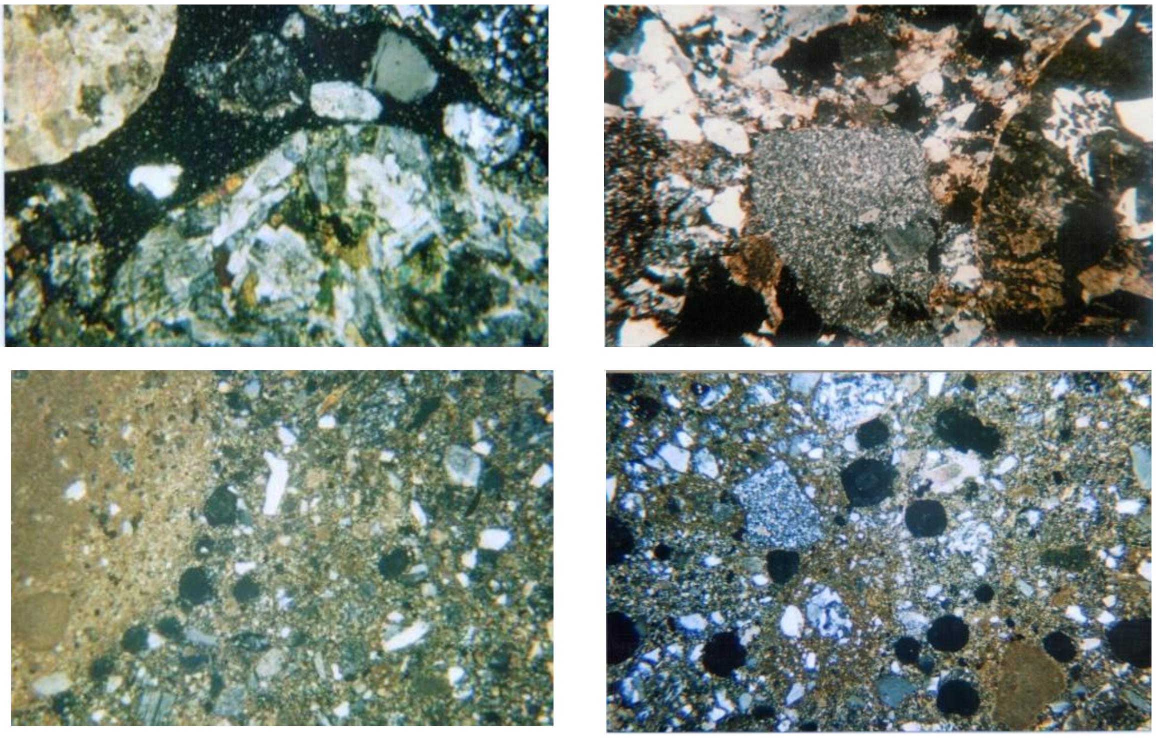

Figure 5. Thin sections of silty sand soil samples (×80)

Table 2. The results of mineralogy of soil samples

Number of boreholes	Sample Depth (m)	Location	Quartz (%)
NW-4	18	Mashinsazi Sq.	5-10
NW-5	22	Mashinsazi St.	5
NW-6	21	Mashinsazi	8
H2B1	29	Basij Sq.	10-15
DH-18	16	Sheshgelan St.	15-20
DH-20	19	Abbasi St.	5
DH-21	19	Azadi St.	5-10
DH-25	15	Tavanir St.	10-15

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