Mechanized Tunnelling Research Project Sponsored By NATO

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1. INTRODUCTION

Turkey has a large potential for tunneling projects in both civil and mining industries. Nearly a total of 140 km/year of various tunnels are being constructed, including mine development, drifts, raises, shafts, hydroelectric projects, highway, metro, sewer and irrigation tunnels. Although rapid excavation systems, i.e. roadheaders and tunnel boring machines (TBM), have been used in few cases, tunnels are mainly driven by the conventional drill and blast methods which are slow and costly. In some cases a misselection of the tunneling machine has a catastrophic effect on tunneling costs. This is because of the lack of research involving optimum cutting head design most suitable for the rock formations and the ground conditions encountered in the tunnel (Bilgin, et al., 1993).

Turkey lies in a geologic area which was significantly altered by magmatic and tectonic activities. Some of the rock formations which will be probably subjected to tunneling excavation activities including high strength rocks, with high regional stresses, faults, joints and rock discontinuities make the problem unique in some cases. A cost and performance assessment model designed to allow optimum design of cutting heads of mechanical excavators (optimum cutter spacing, penetration, cutter geometry) should be developed using high technology research activities. In the past, improper selection of excavation and support systems resulted in an incorrect and inefficient utilization of tunneling equipment, mining machines and support elements. The lack of coordination between the excavation and the support systems during excavation combined with inadequate application of new technologies could additionally severe the problems in many tunneling projects. To solve many aspects of these problems an applied research of 5 years on “Development of rapid excavation technologies for Turkish Mining and Tunneling Industries” is awarded to Excavation Research Group in Istanbul Technical University, Faculty of Mines, Mining Engineering Department, by NATO Science for Stability Programme.

Many government and private companies are contributing for the development of the tunneling industry. The following institutions and companies are among the ones supporting the NATO project (Eskikaya and Bilgin, 1994); I.T.Ü Mining Faculty, D.S.I, State Hydraulic Works, T.C.K, State Highway Organization, D.D.Y, State Railway Organization, T.K.I, Turkish Coal Enterprises, Etibank, Yapi Merkezi, Tekfen Inşaat ve Ticaret A.Ş., Garanti-Koza - Enka - Doğuş Consortium, Akpinar, Kiska Kom Şirketi, Nurol Inşaat ve Ticaret A.Ş, Yücelen Inşaat ve Ticaret A.Ş., Erer Müşavirlik Müh. ve Mütahitlik A.Ş., Hema, Kutlutaş Inşaat ve Ticaret Sanayi Ltd., Güriş,Yeralti Aramacilik, Voest Alpine, Euro Iseki, Geodata.

A typical example to rapid underground development is D.S.I, almost 60 km of tunnels will be driven within State Hydraulic Works (D.S.I) development scheme in few years time. The majority of these tunnels are summarized in Table 1.

Table 1. The majority of the tunnels to be driven by State Hydraulic Works

Project	Tunnel Length (m)	Diameter (m)	Rock Formation
Söyleme Gemlik	6500	5.0	Marl, ophiolite
Imamoğlu	3450	6.5	Sandstone-mudstone
Kargi Dam	1349	8.0	Quartzdiorite, schist
Ilisu Dam	2994	12.0	
Kovabat Dam	1998	7.8	Limestone
Obruk Dam	1350	8	Diabase-Andesite
Kayraktepe Dam	1541	9.8	Meta-Conglomerate
Munzur-Uzunçayir	1344	6.5	Aglomerate-Tufite
Söylemez Dam	990	5.2	Diabase
Alparslan Dam	1631	5.9	Basalt
Kilavuzlu Dam	1428	7.2	Flish
Manyas Dam	1184	8	Limestone-chist
Çataltepe Dam	1000	5	Ophiolite
Yedigazi Dam	1817	8	Sandstone-Siltstone

2. OBJECTIVES

The main objectives of the proposed program are given below.

2.1 Task

In order to fully understand and access the specific problems of the Turkish Tunneling Industry, a series of field investigations will be carried out on current projects. A detailed data base will be created on the following items:

The data will be collected on general layout of excavation methods, advance rates, support systems, muck removal, costs, the geology, rock physical and mechanical properties, environmental conditions such as dust, humidity, noise, etc.

The information on future tunneling project will be gathered and representative samples will be collected for future investigations.

The geologists and tunneling engineers from supporting organizations will take part in collecting field data, which will create a unique opportunity for their active participation in the research program.

2.2 Task 2

As previously discussed, the main problems facing the Turkish Tunneling Industry are extremely slow construction rates and high tunneling costs. It is intended to address these issues within the main goals of Task 2.

It is widely accepted that the maximum advance rates can be achieved with the mechanical excavators, such as full face tunnel boring machines and roadheaders, if they are efficiently designed for the particular rock conditions to be encountered in accordance with the basic principles of the rock fragmentation. More efficient cutting head designs and performance analysis methods can lead to higher productivity, reduced cutter costs, less machine vibration and higher machine utilization, all contributing to lower project costs. However the science of rock fragmentation is still newly developing field that needs more studies, both theoretical and experimental.

It should be also mentioned that there is not an universally accepted model to predict machine performance for any type of rock formation. These questions concerning the optimum cutter spacing, depth of cut, cutting speed, tool geometry, power and tool layout of cutting heads for special rock formations, still needed to be studied and evaluated because of non-homogeneous characteristics of rocks. The most widely accepted solution is to conduct full scale rock cutting tests in the laboratory under controlled conditions. Full scale rock cutting experiments performed on rock samples obtained from future tunneling sites will create a unique opportunity for developing a mathematical model to be used in determining the optimum layout of cutting heads and to predict the performance and cost of mechanical excavation systems.

A linear cutting machine accommodating different full size disk and point attack tools has been constructed with in the frame of Task 2 (Fig. 1). The LCM can take up to 500 kN normal and 150 kN cutting forces. It is designed by Prof. Dr. Levent ÖZDEMIR from CSM according to the needs of the present tunnel boring technology. The cutting speed can increase up to 380 mm/sec and force dynamometer is strain gauge pillar type which can bear up to 500 kNnormal forces.

As a result of Task 2, participating institutions of the research program will gain the knowledge to increase the daily advance rates and decrease tunneling costs by using the more efficiently designed cutting heads and cutting tools.

2.3 Task 3

Microtunneling or small diameter tunneling down to a size of 50 cm is recently developed but fast growing technique for utility, sewer, and water tunnels in urban areas. However this technique is primarily limited to application in soils and softer materials. Unlike surface trenching, microtunneling causes practically no surface disturbance. It also eliminates the reinstatement and remedial work to road surfaces during construction, a very attractive feature for densely populated urban areas, such as Istanbul. The application of these new technologies in urban areas will significantly reduce the environmental problems, i.e., dust, noise, disruption of traffic, etc. It will also decrease the construction time and costs while drastically improving worker health and safety. Despite recent advancement, however, the current microtunneling technology is not capable of effectively excavating hard rock formations and further research is needed to develop this capability.

Within the scope of Task 3, a mathematical model, based on full scale linear rock cutting results with new designed cutters, will be developed. A cutting head for microtunneling suitable for hard rock formations, will be designed, constructed and tested on the drilling and rock boring fixture (DTF). During the drilling tests, physical operation of the cutter head, cutters and the muck collection buckets will be observed. The cutter head performance data, in terms of thrust, torque and power and as a function of penetration rate will be developed. Later, the computer model used in the design and performance evaluation of the cutter head will be run with actual data and validated.

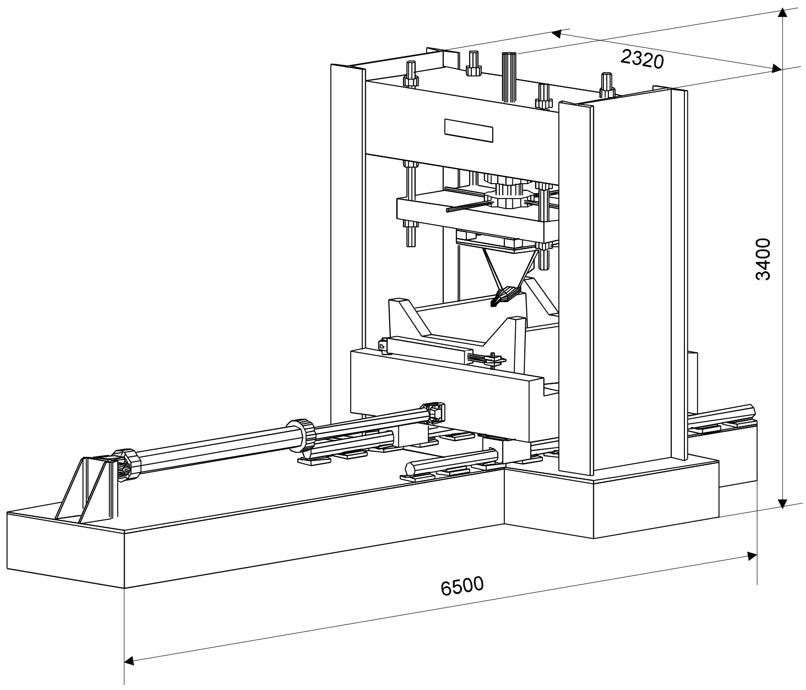

Figure 1. Schematic view of ITÜ LCM

2.4 Task 4

Underground workers usually suffer greatly from the unfavorable environmental conditions existing in tunneling projects, i.e., dust, noise, humidity, etc. An index of liability to severe environmental conditions,

$Il\ (c, m) = f\ (\alpha d, \alpha n, \alpha h.....)$,

will be developed for both classical and mechanized tunnel drivages and the results will be compared to evaluate and revise environmental conditions.

In the above equation:

Il_c = Index of liability to adverse environmental conditions in current tunneling projects,
Il_m = Index of liability to adverse environmental conditions in mechanized tunnel drivages,
αd = Dust level,
$\alpha\ n$ = Noise level, and
$\alpha\ h$ = Humidity level.

A research program dealing with the effect of rock properties and the operational variables of mechanized systems, i.e., speed of cutting, depth of cut, cutter geometry and spacing, on dust generation will be carried out within the scope of Task 4.

As a result of Task 4, underground workers will have more comfortable and safer environmental conditions while being exposed to less dust and noise.

2.5 Task 5

The particular application of mechanical excavators in a tunneling project needs to take into account the type of tunnel support system to be used. The incorrect selection and use of support system can have an adverse effect on the cost of a tunneling project. Within the scope of Task 5, it is planned to collect data from current tunneling projects and to use the accumulated data, with the assistance of computerized data bases, expert systems and numerical modeling techniques, for more efficient tunnel support design.

It is recently reported that 765 tunnels exist within the network of Turkish Railway Organizations. Most of these tunnels suffer from excessive lining weathering and deformation. In-situ coring will be carried out within the lining area to investigate the weathering characteristics of the material. A machine to strip the linings will be designed and new materials suitable for relining will be recommended for future use.

3. FIRST RESULTS

The first data concerning tunnel drivages for Istanbul Metro has been collected and analyzed by research students.

The accumulated data will be used with the assistance of data bases, expert systems and numerical modeling techniques for planning more efficient tunnel drivages in future applications. All the shift data are provided by the contractors, Tekfen and Garanti - Koza-Enka - Doğuş Consortium, showing an excellent example to Industry - University cooperation. Representative samples are collected from tunnel faces and tested in the University Laboratories. Field geologists are assisted the research staff in analyzing the geological data. Although roadheaders, ALPINE ATM 75 and EICKHOFF ET 250 were used for tunnel drivages in Istanbul Metro in the past, the impact hammers are the current excavating equipment. The following Figures 2, 3 and 4 are the typical examples of the variation of net advance rate (m^3/h) with the tunnel chainage for roadheaders and impact hammers. It is obvious that these two excavating equipment behave completely different in the same rock formation which is locally called Trakya formation. The shift and geological data including rock properties are currently being analyzed in order to explain the inconsistency. Figure 5 shows the relationship between net advance rate and rock mass properties for the impact hammer applications. It is interesting to note that this figure shows exactly the same trend as determined for tunnel drivages in Istanbul sewerage project and published in Tunnels and Tunneling June 1988, October 1990.

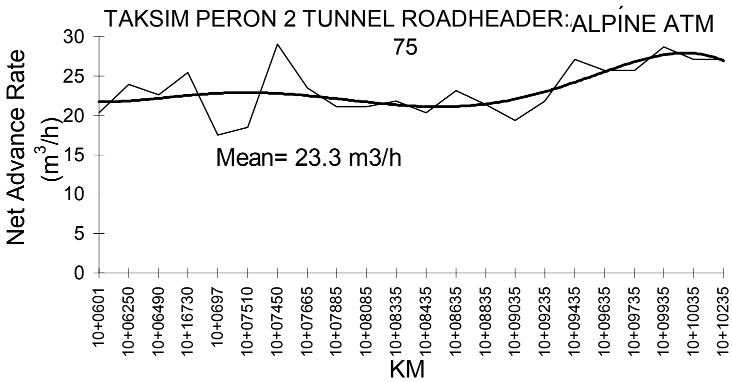

Figure 2. The variation of net advance rate with tunnel chainage in Taksim peron 2 tunnel

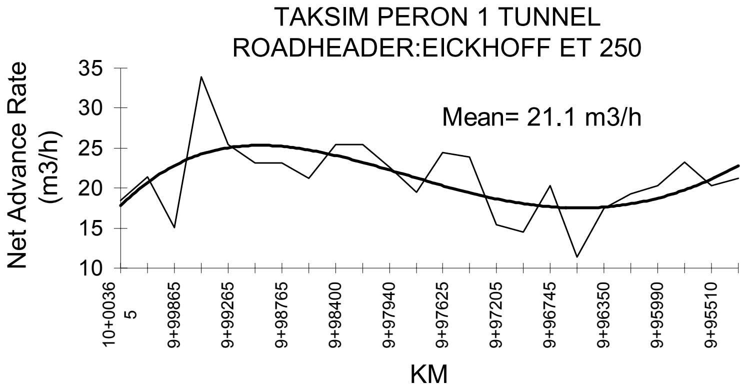

Figure 3. The variation of net advance rate with tunnel chainage in Taksim peron 1 tunnel

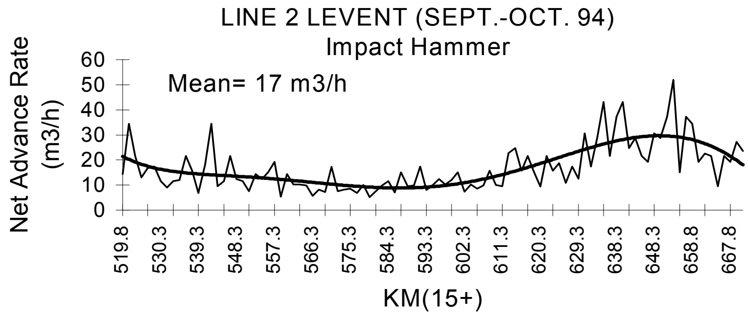

Figure 4. The variation of net advance rate with tunnel chainage in Line 2 Levent tunnel

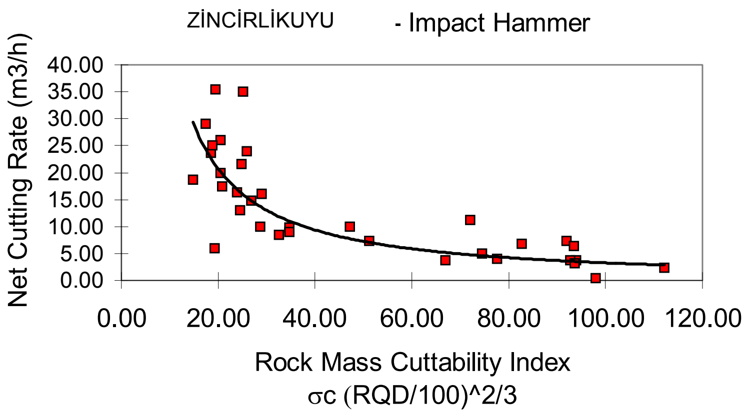

Figure 5. The variation of net advance rate with Rock Mass Cuttability Index

Underground workers usually suffer greatly from the unfavorable environmental conditions of tunnel projects, i.e., dust, noise, humidity etc. Underground measurements were taken during the past six months in Istanbul Metro Tunnels and Middle Annotation Lignite Mine. This gave an opportunity to compare dust and noise levels encountered in tunnel drivages both with roadheaders and impact hammers. Casella 113, a gravimetric dust collector and RS-103 sound level meter were used for in-situ measurements. The following Figures 6,7 and 8 are the typical examples emerged from this investigation. More precise measuring devices will be purchased for further research activities and it is expected that as a result of this study underground workers will have more comfortable and safer environmental conditions and they will be exposed to less dust and noise.

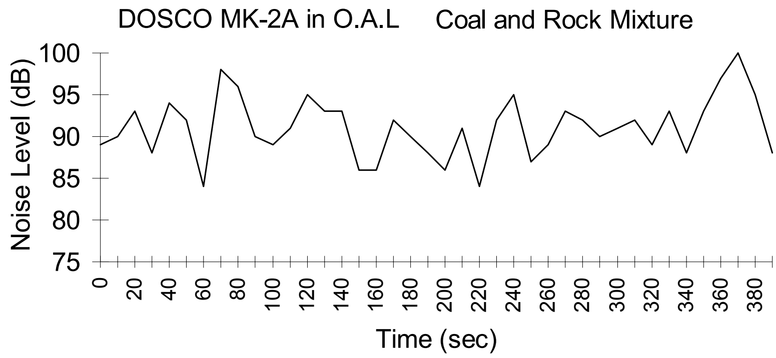

Figure 6. The variation of noise level with time in Middle Anatolian Lignite Mine

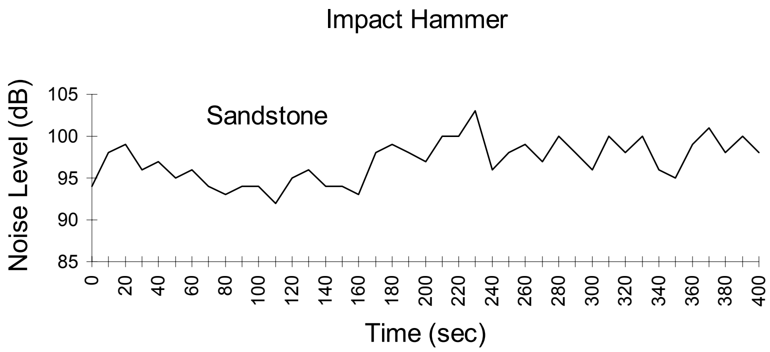

Figure 7. The variation of noice level with time in Istanbul Metro Tunnel

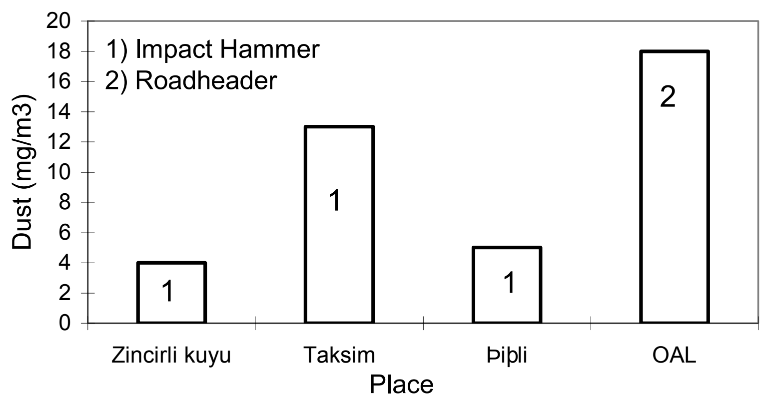

Figure 8. The variation of dust content in air in different tunnels

4.CONCLUSIONS

A well-equipped research center with experienced research staff on rapid excavation tunneling techniques will be established after the termination of NATO, Science for Stability Project.

Field engineers and geologists from the supporting organizations will be involved in collecting field data to fully understand and access the specific problems of the Turkish

Tunneling Industry. This will create a unique opportunity of their active participation in the research program.

Design engineers from machine manufactures and field engineers from contributing organizations will be involved in performing rock cutting tests, designing cutting heads, developing a mathematical model in determining the optimum layout cutting heads and to predict performance of mechanical excavation systems and to evaluate the tunnel support. As a result of this, the practicing engineers will be acquainted with the research results and have the opportunity to dissaminate the test results.

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