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3-D stability analysis and design of the primary support of Karaj metro Tunnel: Based on convergence data and back analysis algorithm

Ali Naghi Dehghan [a,b], Seyed Mohsen Shafiee [c,d,*], Fereydoun Rezaei [e]

[a] Department of Mining Engineering, Science and Research Branch, Islamic Azad University, Poonak, Hesarak, Tehran, Iran
[b] Young Researchers Club, Science and Research Branch, Islamic Azad University, Tehran, Iran
[c] Department of Geology, Islamic Azad University, Kahnooj Branch, Kahnooj, Kerman, Iran
[d] Geological Survey of Iran, Southern Center, Shiraz, Iran
[e] Research Institute of Earth Sciences, Geological Survey of Iran, Tehran, Iran

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ABSTRACT

Design and construction of underground structures are usually being performed based on an approximate understanding of geotechnical parameters, which are essential for selection of construction method and support system. The main purpose of this study is to determine the geotechnical parameters using back analysis based on convergence data, and also to adopt an appropriate primary support system. By installation of suitable support structure, the amount of tunnel ceiling's settlement was reduced to a number lower than the allowable limits. Back analysis was conducted throughout the alternative univariate method by PLASIX 3D Tunnel. The research showed that performed analysis based on convergence data and back analysis can be utilized as a more economical and time-saving method in comparison to consultant Engineers design based on soil mechanic tests. In addition, the parameters obtained from back analysis were greater than soil mechanic test method. Thus, the evaluations show that measurement error in soil mechanic tests is likely the source of this difference.

1. Introduction

Design and construction of underground structures require sufficient geotechnical information about the ground, including various soil types to evaluate appropriate construction methods (Powell et al., 2001). The assessment of tunnel stability can sometimes be best performed by monitoring the soil behavior in the tunnel. The purpose of back analysis is the modification of the parameters used for the design of the support system (Sakurai, 1993; Feng et al., 2000).

General-purpose numerical analysis techniques, such as finite element methods, were developed in the 1960's. The numerical simulation can be used to follow the natural sequence of events involved in construction. Ground deformation monitoring and its application in tunnel design and construction are illustrated using examples from the Jubilee Line Extension of the London Underground, from Lines 2 and 3 of the Athens Metro, and from the 9-km long Kallidromo railway tunnel in Greece (Kavvadas, 2005).

Numerical back analysis is a powerful method, that can be used as a complementary technique to in situ or laboratory experiments to determine geotechnical parameters (Fakhimi et al., 2004). In situ failure, movement or convergence is used to back calculate the physical properties of the soil. These parameters can be compared with those from field measurements to increase the confidence of the design engineer. A number of researches have been performed on back analysis of underground excavations. For example, Shang et al. (2002) used an Intelligent Back Analysis (IBA) to investigate rock and soil mass properties around the tunnels. Based on the engineering applications to approximately 100 tunnel projects in China, it was found that the IBA technique can be successfully applied to tunnel projects in order to predict the in situ stresses and rock mass modulus. Back analysis is a helpful method for the proposed design and construction methods during the construction process. The procedure of assessing the design, construction methods and structure stability is shown in (Fig. 1). Fig. 1 also represents the relationship between back analysis, field measurements and design-construction methods. Overall, back analysis can be used as a reliable method for stability and support structure analysis. The primary support design and the stability analysis of Karaj metro tunnel were conducted by consultant engineers based on laboratory and field data. The surrounding soil of the tunnel in this study consists of 6 layers. The geotechnical parameters of the adjacent layers were estimated by back analysis based on convergence data. 3D stability analysis and primary support design were performed based on back analyzed parameters.

* Corresponding author at: Department of Geology, Islamic Azad University, Kahnooj Branch, Kahnooj, Kerman, Iran. Tel.: +98 917 317 5006, +98 711 620 3955; fax: +98 711 730 4132.
E-mail address: mohsenshafi@gmail.com (S.M. Shafiee).

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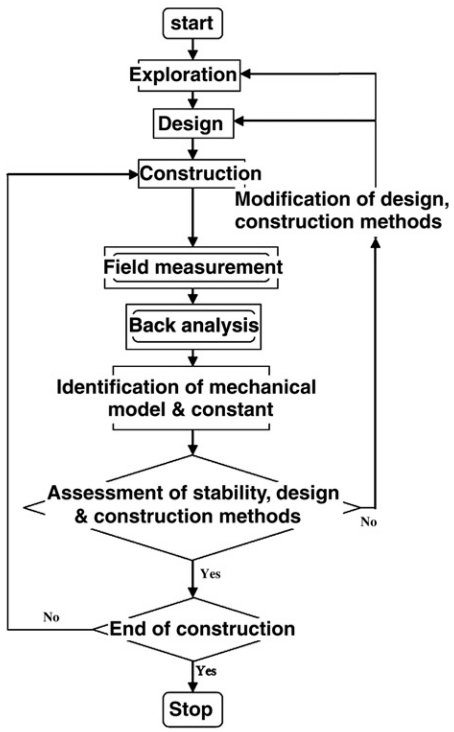

Fig. 1. Cyclic routines in an observational method (Sakurai, 1997).

2. Tunnel and site specifications

Karaj is the sixth largest city of Iran, with a population of over 1 million people. It is located in the west of Tehran. The construction of line 2-part 1 began in 2006. Line 2 is from the northwest to the Southeast and has a length of about 25 km, consisting of 25 stations and two phases. The first phase has a length of about 14 km and consists of 6 parts. Part 1 connects F Station to I Station. The second phase has a length of about 11 km and includes 4 parts, (Fig. 2).

Section 1 of the second line of The Karaj metro tunnel is a 2495-m long horseshoe tunnel from 4 + 550 km to 7 + 045 km, and is located on Shahid Beheshti Street. The original method of construction planned for the Karaj metro tunnel was the New Austrian Tunneling Method (NATM). The NATM method consists of three excavation phases: Top, Box and Bench (Fig. 3). Each tunnel is 8.40 m in width and 7.80 m in height as shown in (Fig. 4). The depth of cover varies from 6 to12 m (average: 10 m). The primary support of the tunnel consists of a 35- cm thick dry shotcrete with wire mesh (ϕ10 @ 150 × 150) together with lattice girders with cured IPE160 steel frames at 120 cm spacing along the tunnel axis on the inner side. The final lining of the tunnel consists of a 35 cm thick reinforced concrete; the detailed description is presented in Table 1.

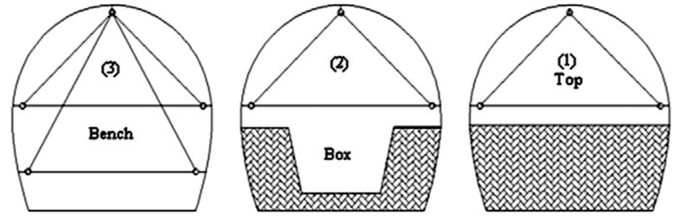

Fig. 3. Excavation sequences.

3. Geotechnical and geological studies

Tunneling runs through young alluvial layers. The major part of the Karaj valley is composed of young and unconsolidated deposits, which were mostly formed from Karaj River and seasonal floods. The sediments can be classified as old river terraces, young terraces and young alluvial fans. The height level of the study region is approximately 1305 m from the average sea level. The sediments could be treated as coarse gravel and sand based on obtained information from the boreholes. Additionally, on the eastern side of the formation and far from the central parts of the Karaj alluvial fans, these sediments become smaller and the strength properties of the soil increase.

The material was classified as three original layers based on the results of the grain size analysis and Atterberg Limits data; Clay–Silt, Sand and Gravel. Soil classification based on mentioned tests cannot be reliable enough. Thus, a standard penetration test (SPT) which is more reliable for engineers was conducted to determine the geotechnical parameters. Therefore, an applicable classification was introduced to

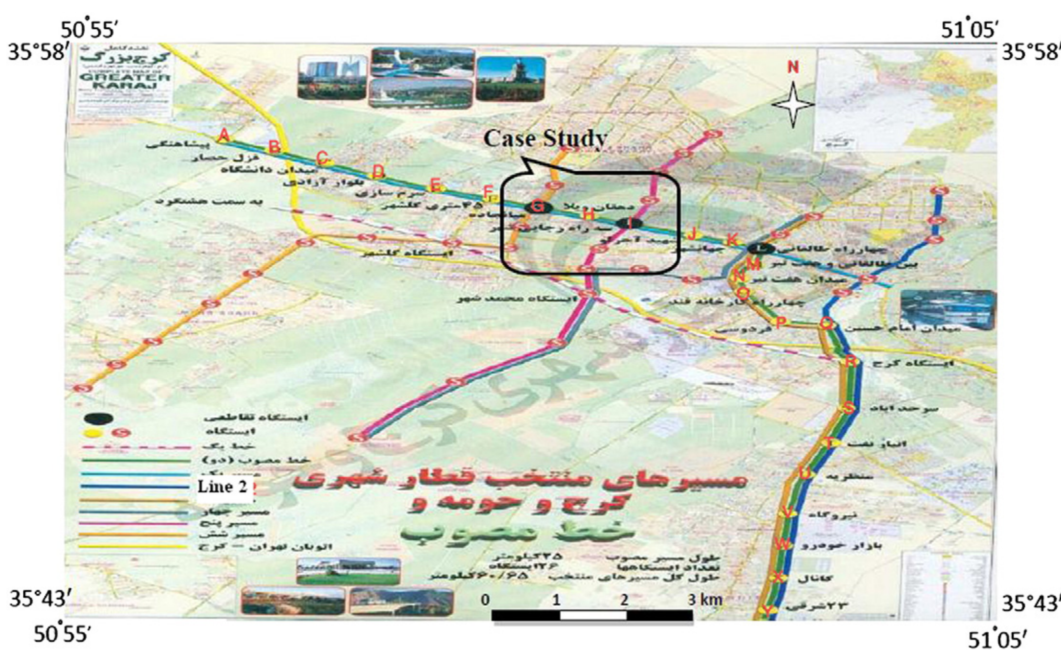

Fig. 2. Karaj tunnel location (line 2—part 1).