Tunnelling and Underground Space Technology 40 (2014) 218–227

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

Reducing deformation effect of tunnel with Non-Deformable Support System by Jointed Rock Mass Model

C.O. Aksoy [a,*], K. Oğul [b], İ. Topal [c], E. Poşluk [b], A. Gicir [b], K. Kucuk [a], G. Uyar Aldas [d]

[a] Dokuz Eylul University, Department of Mining Engineering, Izmir, Turkey
[b] TCDD, 2nd Railway Construction Groupe Management, Bozüyük, Bilecik, Turkey
[c] Dumlupinar University, Department of Mining Engineering, Kütahya, Turkey
[d] Ankara University, Department of Geophsial Engineering, Ankara, Turkey

ARTICLE INFO

Article history:
Received 12 February 2013
Received in revised form 23 October 2013
Accepted 28 October 2013
Available online 19 November 2013

Keywords:
Rock mass behavior
Jointed rock mass
Non-Deformable Support System
Tunnel support design
Numerical modeling

ABSTRACT

Numerical modeling has been used widely in mining and construction industries in recent years. The most important issue in engineering projects designed with numerical modeling is accurate modeling of rock mass behavior. If the rock mass behavior is modeled accurately, fewer problems will be faced during field application of projects. Selection of the true material model is a very important issue in numerical modeling for the tunnel projects. Non-Deformable Support System (NDSS), which will be mentioned in the scope of this research, does not mean that it does not permit any deformation or is a very stiff system. NDSS is a support system that does not permit deformations exceeding specified deformation amounts which are calculated with determination of the accurate rock mass behavior by the true material model and it must be evaluated with support system and excavation advance specifically. The origin of the paper is that numerical modeling provides more comfortable results in tunneling in case one can determine rock mass deformation and failure behavior appropriately. In (NDSS), however, support system element can only be determined by proper numerical modeling analysis. Moreover, deformation values determined by NDSS analysis are accepted as limit values. Therefore, applied support system should be within deformation tolerance limits determined by NDSS analysis. Briefly, this paper is related to NDSS that should be determined by numerical modeling analysis.

In this research, in regard to the excessive deformations in T-35 tunnel which is one of the 33 tunnels of Ankara–Istanbul High-Speed Railway Project, results of the in situ measurements in the tunnel excavated with the new developed NDSS and results of the numerical model made with Jointed Rock Mass Model have been compared. It is determined that the results of the numerical modeling and the in situ measurements are very consistent with each other.

1. Introduction

Two support philosophies have been used recently for tunnels which are deformed extremely. The first one is "Yielding Support System" but the only application of this system found in literature is in squeezing rocks (Anagnostou and Cantieni, 2007; Cantieni and Anagnostou, 2009). The second system is "Non-Deformable Support System". NDSS is mostly used in urban tunnels, however it was also used in squeezing and swelling rocks to solve extreme deformation problems (Aksoy et al., 2012a; Aksoy and Onargan, 2010; Aksoy et al., 2010). The main philosophy in NDSS is not to exceed the deformation tolerances, which are obtained from analyses performed to determine the true behavior of the rock mass.

Designing of the tunnel support in weak rock masses is the most time consuming task of the tunnel engineers. If the realized design is not proper, re-shaping works will become compulsory. To prevent this, in preliminary period, lots of data collection are required. The support design is done using the collected data. Today, numerical modeling is the most widely used method. In numerical modeling, the more you reflect the field conditions to the model, the more you acquire the realistic results. In this case, with realized optimum design, the loss of time and money is prevented. The most important work in numerical modeling made in the rock engineering is to define the behavior of the rock mass (Aksoy and Genis, 2010). Especially, defining the behavior of rocks mass affects the accuracy of the design. Material models as Mohr–Coulomb, Hoek Brown, Hardening Soil, Soft Soil Creep, Jointed Rock Mass etc. are used very often. However, the correct model should be selected to approach the correct result more sensitively.

* Correspoding author. Tel.: +90 232 3017522; fax: +90 232 4530868.
E-mail address: okay.aksoy@deu.edu.tr (C.O. Aksoy).

0886-7798/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.tust.2013.10.016

The determination of the global mechanical properties of jointed rock masses remains one of the most difficult tasks in rock mechanics (Niu et al., 2010). Rock masses are large volumes of rock that contain discontinuities (Ivars et al., 2011). Deformations, as well as failure patterns of jointed rock structures, are mainly governed by those of the joints (Maghous et al., 2007). The joints and cracks of jointed rock masses are the cause for rock masses to be discontinuous and hence they can hardly be described by a precise mechanical model (Sun et al., 2007). A jointed rock mass is an assemblage of intact rock pieces separated by discontinuities such as bedding planes, joints, shear planes, and faults (Singh and Rao, 2005). Deformation-dependent variation in joint transmissivities is essential for investigating excavation-induced changes in flow through a discrete network of joints representing a jointed rock mass (Kim et al., 2004). Many researchers have studied the failure process for the jointed rock mass (Moon, 2011; Hong et al., 2009; Singh, 1973; Gerard, 1982). Dinc et al. (2011) proposed a new approach namely Compressive Strength Reducing Ratio (SRR_C) to determine the strength of the rock mass. The authors reported that geotechnical literature showed that "jointed clays have very similar mechanical behaviors to Jointed Rock Mass".

Tunnel 35, which is one of the 33 tunnels in the extent of Ankara-İstanbul High Speed Railway Project, and a large part of this tunnel is known as Porsuk Formation and this tunnel is driven in a fairly weak and jointed rock. In this study, the analyses of the support system which is designed to solve these problems are given. Deformation up to 350 mm occurred during the tunnel excavation. For this reason, re-shaping workings are often necessitated. To prevent these excessive deformations, new support system was developed by the NDSS principles using numerical modeling. It was seen that the results of numerical model made with finite element software are very close to those obtained in situ measurements in the tunnel excavated with developed Non-Deformable Support.

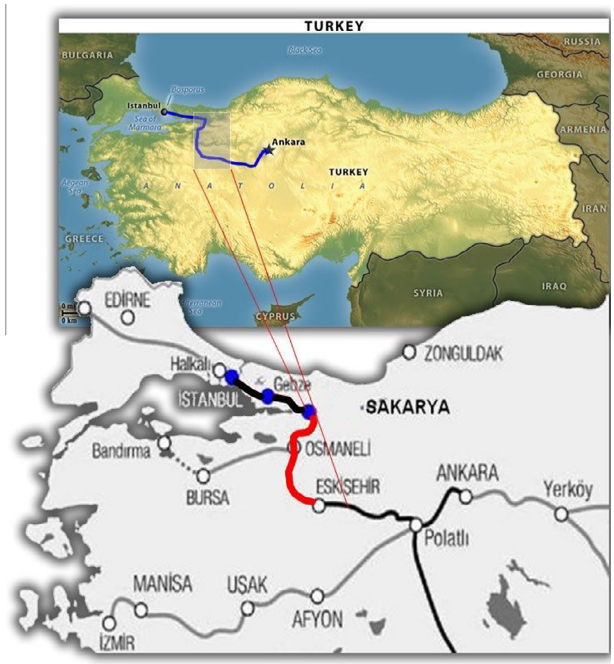

Fig. 1. Location of Ankara–İstanbul high speed railway project.

Table 1
Engineering structure of Ankara–İstanbul high speed rail project.

	Section 1	Section 2	Total
Length	95 km	55 km	150 km
Viaduct	18 (6.120 km)	13 (6.582 km)	31 (12.702 km)
Tunnel	13 (25.700 km)	19 (27.210 km)	32 (52.910 km)
Open-cut tunnel	–	1 (1.090 km)	1 (1.090 km)

(), Total length of engineering structure.

2. General description of the project

The purpose of the Ankara–Istanbul High-Speed Railway Project is to reduce the traveling-time between the biggest two cities, which are Ankara and Istanbul, and to increase the percentage of railway in transportation by creating a fast, comfortable and safe transportation facility. Köseköy-Inönü is the second stage of the Ankara–Istanbul High-Speed Railway Project and is 150 km in length which is designed as Section-1; 95 km (Köseköy–Vezirhan), Section-2; 55 km (Vezirhan–Inönü). The location of the project is given in Fig. 1 and engineering structures of the project are given in Table 1.

2.1. Geological and Geotechnical Description of Tunnel 35

The tunnel route is located between Bozüyük-İnönü and 1 km southwest of Bozüyük (Fig. 1). The thickness of sediments over the tunnel ranges from 10 to 86 m. Tunnel 35 is excavated within dark green–gray weathered basement rocks known as the Bozüyük Granitoid in the inlet portal side. The out portal through the southeast, the Miocene Porsuk Formation uncomfortably overlies the granitoid. The Akpınar Formation lies over these units.

The Porsuk Formation, which overlies the Bozüyük Granitoid with an angular unconformity consists of gravel, sand and clay. It occasionally comprises partial diagenesis. The Akpınar Formation occurring over this unit is composed of clayed-sandy limestones and limestones. The inlet portals are excavated in the Bozüyük Granitoid and outlet portal is excavated in Akpınar and Porsuk formations. During the tunnel excavations, the units of Bozüyük Granitoid, Porsuk and Akpınar Formations were excavated. The lithological information during the tunnel route is given in Table 2. A large part of Tunnel 35 was excavated in the Porsuk formation, which includes the alternation of claystones–sandstones and conglomerates. The length of this part is approximately 2110 m. Between inlet portal and km: 233 + 670, approximately 896 m, was excavated in the Bozüyük Granitoid. Limestone of the Akpınar Formation was excavated before 250 m of the Tunnel 35 exit. Geological map of the tunnel route of the Tunnel 35 is given in Fig. 2. Size and cross-section of Tunnel 35 are given in Fig. 3. Tunnel 35 has a height of 11.40 m and width of 13.30 m. Top heading, lower bench and invert excavations have height of 5.65 m, 2.75 m, 3 m, respectively. Table 3 shows laboratory tests of samples taken along the route of Tunnel 35. Laboratory tests have been carried out according to the standards of ISRM (2007). Cohesions and Internal Friction Angles were defined from the direct shear test.

3. Problem definition and method of solution

3.1. Problem definition

Tunnel route contains 3 different formations, Bozüyük Granitoid, Porsuk and Akpınar Formation as seen Fig. 2. Fig. 4 shows the Porsuk and Akpınar Formations at the outlet portal side of tunnel face around the problematic area. The previously suggested support system was designed by SIAL (2010) to excavate Tunnel 35 within the deformation limit of 80 mm. The calculations were held by finite element software in the report (SIAL, 2010). Tunnel 35 may be deformed as 80 mm according to previous designer