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Technical Communication

Assessment of tunnel portal stability at jointed rock mass: A comparative case study

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ABSTRACT

This paper presents results of a comparative numerical model study at a highway tunnel in Turkey. The tunnel was opened in a sandstone–siltstone rock mass having clear systematic discontinuity sets. In practice, effects of discontinuities of rock mass on tunnel stability are usually disregarded in finite element (FE) models, which are widely used for design of underground structures. To compensate this deficiency, rock masses' geotechnical properties are reduced to simulate effect of discontinuities in FE models. Main objective of this study is to show the effect of systematic and persistent discontinuity sets to FE numerical modeling when discontinuities exist. On this account, two different conditions were modeled to analyze stability conditions in a comparative manner. FE numerical analysis software "Phase^2 8.0" was used for modeling. Results have shown that presence of discontinuities have a significant effect on tunnel stability and model results when FEM software is used for discontinuum media. As a conclusion, in case of using FE numerical models without taking the discontinuities into account would definitively lead to erroneous results in assessing tunnel stability.

1. Introduction

In nature, most of the rock masses contain discontinuities. Especially low stress environments may contain more discontinuities than high overburden areas; such as slopes and near surface excavations [1]. In these areas, discontinuity properties of rock masses are more important than intact rock properties [2]. Therefore, significant effects of discontinuities and lateral pressure coefficient on the failure mode and displacement character of numerous tunnels have been proven by previous studies [1–7]. Discontinuities generally exhibit brittle or strain softening behavior and their residual strength is much lower than their peak strength. So, post-failure behavior of discontinuities leads to development of progressive failure mechanisms. As a result, stresses are redistributed to adjacent areas and joint segments. As a consequence of redistribution of stresses, far tunnel materials and joint segments may fail [8]. Therefore, deformations having an anisotropic character may take place mainly in the form of sliding along discontinuities. Depending on the discontinuity orientation mechanical behavior will be anisotropic elastic or perfectly plastic isotropic. In such cases, elasto-plastic nonisotropic models or discontinuum models would be more appropriate [9]. There are methods used for realistic modeling of discontinuum media such as "Discrete Element Methods" (DEM) [10] and "Discontinuous Deformation Analysis" method (DDA) [11]. These techniques have been available for a long time and their capabilities are well proven. However their use certainly require expertise. Therefore it is not possible to use discontinuum techniques at every project site. On the other hand finite element modeling (FEM) technique is more widely used due to simple modeling procedure and availability of softwares based on continuum modeling. The use of continuum based modeling technique may result in erroneous design if rock mass contains clear systematic discontinuity sets. The main objective of this study is to demonstrate how FEM technique should be applied to obtain realistic results in case of tunnels opened in jointed rock mass. Nevertheless, authors of this study suggest the use of DEM and DDA methods in jointed rock mass modeling. Conversely, most of the field engineers are not familiar with DEM or DDA methods and Phase^2 software based on FEM has been widely used in underground construction industry in Turkey. Therefore, most of the road tunnel projects in Turkey are prepared by using Phase^2 software without considering

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discontinuities in rock mass. This will certainly lead misleading results. However if it is not possible to use discontinuum techniques and FEM has to be used, the methodology presented in this paper should be applied to realistically include the effect of discontinuous media in FEM. Therefore it is suggested that the method presented in this study should be followed to obtain realistic results for FEM.

Discontinuities do not usually used in numerical model studies and instead discontinuity effect is illustrated by simply reducing the rock mass' geotechnical properties. This situation can be explained as follows; if there are continuous discontinuities in the medium, medium is recognized as continuum by FEM designers. Conversely, decreasing geotechnical properties of rock mass do not possibly represent the effects of discontinuity on numerical models in a realistic way because of the fact that existences of discontinuities significantly change stress distribution around the rock mass. Moreover it is rather difficult to predict strength and deformation characteristics of rock masses having discontinuities [2]. For this reason to emphasize the effect of discontinuities at tunnel stability, tunnel entrance portal section was selected for modeling. Rock mass examined around the portal area consists of sandstone–siltstone intercalation, which has two clear discontinuity sets. On this account, two different conditions "discontinuity and no discontinuity (massive) cases" were modeled to show the effect of discontinuities at tunnel excavation in the vicinity of portal area.

As the main objective of this study is to determine the effect of discontinuities or deformation around the tunnel, supporting elements are not applied in our numerical modeling. However, results of this study were compared with actual field deformations data.

2. Location of the tunnel

The Küçükbelvar Highway Tunnel is located in the North Eastern part of Turkey on the route of Kavak–Merzifon road (40°53′28.51″N and 35°35′13.00″E). It connects Samsun to Amasya (Fig. 1). Besides, this route reaches out also to Ankara which is the capital city of Turkey. The tunnel consists of two 345 m long and nearly 11 m wide tubes. The horizontal distance between tubes is 35 m and overburden thickness reaches up to 90 m. In this study tunnel section at km: 88+430 (entrance portal) was modeled, which has only 22 m overburden thickness.

3. Site investigation and engineering geology of the tunnel entrance

Characteristics of the tunnel route in terms of engineering geology were determined by means of field and office studies. These studies include; literature surveys for geological past of the region, determination of geotechnical properties of the rock mass, rock mass classifications studies, discontinuity measurements and geotechnical drillings. At the end of these studies four different geological formations on the tunnel axis have identified; Armutlu Formation, Ağılönü Formation, Quaternary Deposits and Colluvium respectively. Tunnel excavation has been carried out mainly in the Armutlu Formation, consisting of thinly to thickly bedded sandstone–claystone and sandstone–siltstone intercalation, whereas some excavation parts were located in the Ağılönü Formation having brecciaous limestone [12].

Three geotechnical boreholes were drilled along the tunnel axis for site investigation purpose during design stage and tunnel axis was divided into three main sections. At the tunnel entrance; slightly weathered, moderate to high in strength sandstones have been encountered. Intercalation of sandstone and claystone form the middle section, which is mainly controlled by sandstone. A fault has combined the Armutlu and Ağılönü Formations at the tunnel exit. In this section external side of the limestone is highly fractured and brecciaus, but it is mainly represented by conglomerates and interbedded sandstone (Armutlu Formation). Limestone with solution opening is also located at the tunnel exit. This limestone was observed as form of breccia in it is faulty contacts with sandstone, and named as brecciaus limestone. The Brecciaus limestone was moderately weathered and moderate to high in strength [12].

Rock mass around the entrance portal contains two clear discontinuity sets and eventually shallow overburden thickness. Entrance portal was intentionally selected to demonstrate effects of discontinuities. The selected section for analyses is represented with Armutlu Formation (Figs. 2 and 3) and consists of mainly sandstone, siltstone, and partly conglomerates. Conglomerates and sandstones are very strong and thickly bedded. Sandstone siltstone intercalation is moderate to high in strength, medium weathered and fractured. Sandstones are thick in this section, spacing reaches up to 1 m, and persistence reaches up to 12 m. However, in some sections discontinuity spacing is 20–60 cm and descends up to 5–10 cm at crushed siltstone sections.

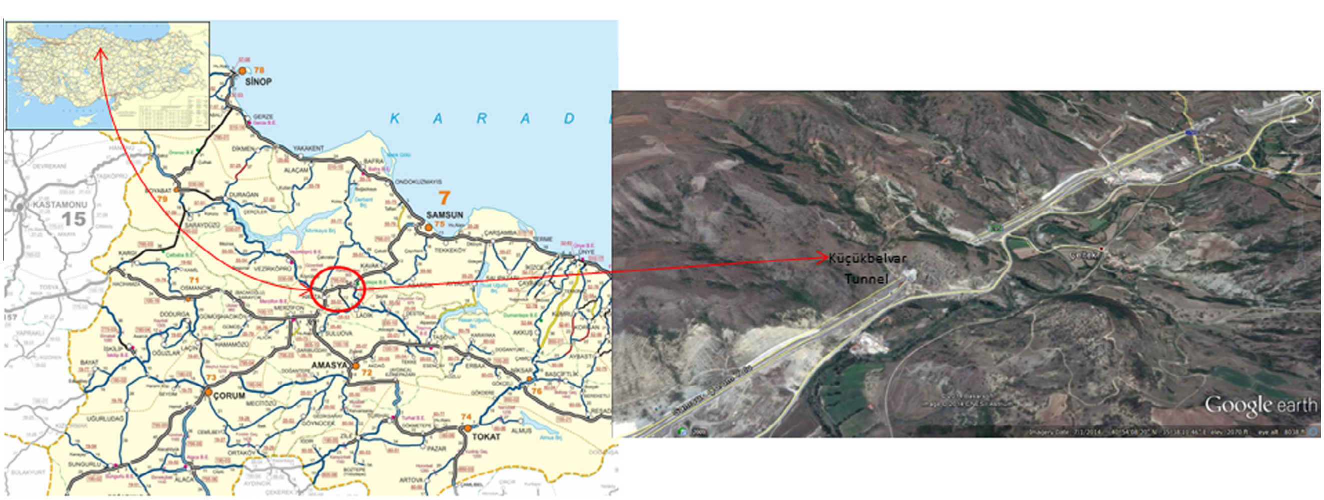

Fig. 1. Location of the tunnel area and its satellite image.