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Finite element model of Cairo metro tunnel-Line 3 performance

S.A. Mazek *, **H.A. Almannaei** [1]

Civil Engineering Department, Military Technical College, Cairo, Egypt

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Abstract The Greater Cairo metro-Line 3, the major project of underground structure in Cairo city, Egypt, is currently under constructed. Ground movement is expected during the construction with tunneling boring machine as Cairo metro tunnel passes through sand soil.

In the present study, finite element model is used to model tunnel system performance based on the case study. An elasto-plastic constitutive model is adopted to represent the soil behavior surrounding the tunnel. The effects are expressed in terms of surface displacement and soil stress change caused by tunneling. The subsoil stresses undergo three phases of change. At these phases, the loading steps of the tunnel construction are predicted using the 2-D finite element analysis.

Ground movement and construction influence are obtained by the numerical model. A comparison is made between the computed tunnel performance and the observed behavior. The comparison reveals a good agreement between the calculated and the observed values.

1. Introduction

Tunneling is an effective solution to overcome high density population challenges such as transportation and utilities activities, so it is increasingly used. Tunnels are used for several purposes such as underground railways, water and power supply, and sewage [1,2]. Several tunnels have been constructed around the world and in Egypt to solve the transportation problems such as the Greater Cairo metro and the El-Azhar road tunnels [1,3]. These tunnels are considered as major projects in Cairo city. There are technologies to assist in excavation such as tunneling boring machine (TBM), new Austrian tunneling method (NATM), immersed-tube tunneling system, and cut and cover method [4].

It is necessary to investigate the geotechnical problems for better understanding the performance of the tunnel system. Many geotechnical problems were encountered during the construction of the Greater Cairo metro, El-Azhar road tunnels, and the Greater Cairo sewage tunnel [5,6]. Most problems are related to the damage of surrounding buildings due to surface and subsurface ground subsidence [5,6]. Finite element method is considered as the most appropriate analytical technique to solve geotechnical problems [7,8].

* Corresponding author. Tel.: +20 1226391261.
E-mail addresses: samazek@yahoo.com (S.A. Mazek), hsnos@hotmail.com (H.A. Almannaei).
[1] Tel.: +20 1144332266.

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Darabi et al. [9] presented an appropriate model to predict the behavior of the tunnel in Tehran No. 3 subway line. They employed empirical methods to determine the variation of radial displacements along the longitudinal direction of a tunnel. They also determined the tunnel deformation using numerical analyses. Elsayed [10] used 2-D finite element analysis to model two phases of tunneling process. First phase, the excavation phase, was responsible to determine the pre-lining rock mass deformations and the reduced in situ stresses. Second phase, the interaction phase, modeled the compatibility of the rock-lining system. The deformations and stresses of the rock-lining system and the final rock mass pressure acting on the lining were determined. Cavalaro et al. [11] analyzed the influence of the contact deficiencies between the segmented tunnel lining during the construction of tunnels and the consequent damage procedure with TBM. They used the finite element analysis to simulate the contact deficiencies.

Kivi et al. [12] investigated settlement control of large span underground station in Tehran metro using 3-D finite element analysis. They discussed the impact of central beam column (CBC) on the rigidity of the supporting tunnel system. Liu et al. [13] discussed the ground movement property caused by shield tunneling and expanding construction. Ground movement and construction influence were obtained by numerical model. Wang et al. [14] used finite element analysis to predict surface settlement above tunnel in clay till. The influence of drainage condition on surface settlement was investigated. Wang et al. [15] applied finite element analysis to investigate the effect of tunneling induced ground movement on buried pipelines. Modeling of geotechnical properties and tunneling procedure is a sophisticated numerical problem [8,16–19].

The Greater Cairo metro tunnel-Line 3 is presented and discussed in the present study as a case study. Line 3 has been constructed since 2011. 2-D finite elements analysis (FEA) is used to understand performance of tunnel system based on a case study. The 2-D FEA is also adopted to estimate surface settlement and vertical displacement at different locations and levels around tunnel system. The constitutive model for this analysis utilizes elasto-plastic materials. A yielding function of the Mohr–Coulomb type and a plastic potential function of the Drucker–Prager type are employed. A linear constitutive model is employed to represent the tunnel liner.

Model boundaries and volume losses (V_L) are discussed to understand the performance of the metro tunnel. The associated stress changes in soil are studied and presented based on different loading steps of the tunnel construction. The results obtained by the 2-D FEA are compared with those obtained by the field measurement to assess the accuracy of the 2-D finite element model. There is a good agreement between readings obtained by both the FEA and the filed data.

2. Greater Cairo metro-Line 3 (case study)

The Greater Cairo metro-Line 3 passes through a wide range of soil condition [20]. Line 3 moves underground from Abbasia station to Attaba station. Line 3 is 4.3 km long. Fig. 1 shows the plan of the Greater Cairo metro-Line 3 [20]. The internal diameter of tunnel liner is 8.30 m, as shown in Fig. 2. Based on the project document prepared by the NAT [20], the soil profile is analyzed and discussed to use soil properties at the 2-D finite element model. Line 3 tunnel was excavated under the central region of Cairo city. Line 3 was built on alluvial deposits through the Nile valley.

3. Soil and metro tunnel interaction

The analyzed project area lies within the alluvial plain, which covers the major area of the lowland portion of the Nile valley in Cairo vicinity [20]. Five distinct soil layers are encountered through the case study [20].

Site investigations along Line 3 alignment indicate that the soil profile consists of a surficial fill layer ranging from 2 to 4 m

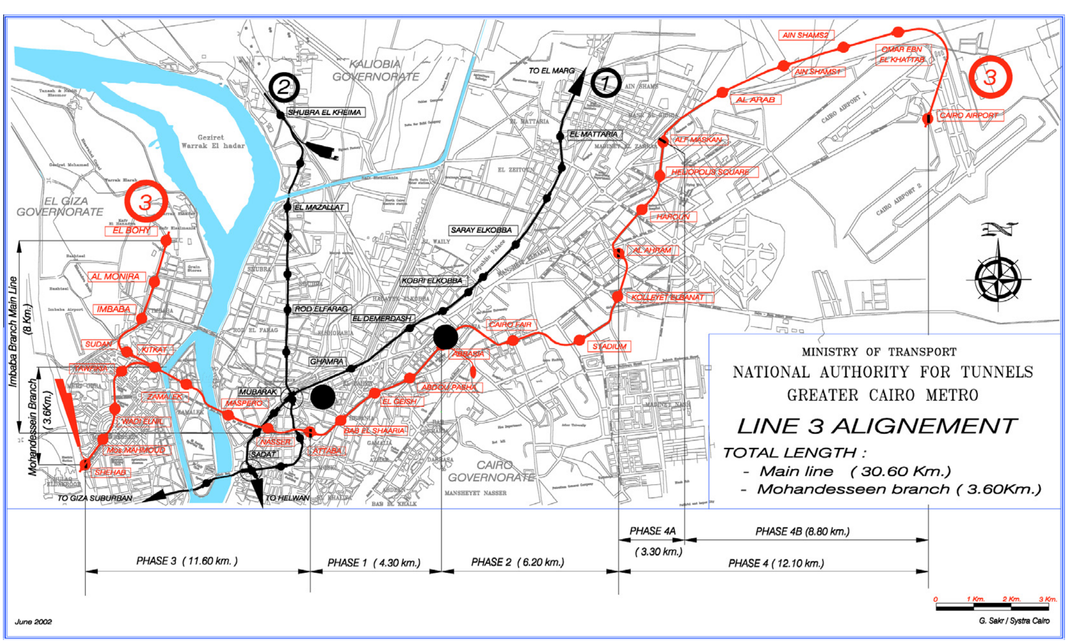

Figure 1 Plan of the Greater Cairo metro (Line 3) (after NAT, 2009).