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Study of Geotechnical Parameters Uncertainties in Analysis of New Tunnel Construction Over the Existing Tunnel

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ABSTRACT: This paper aims to study the problem of a new tunnel construction over – crossing the existing tunnel through the probabilistic point of view. Metro line-7 tunnel above-crossing line-6 tunnel in Tehran was chosen as a case study project. The numerical modeling of the problem was carried out by the FLAC^{3D} software. The parameters of the cohesion and the friction angle of the third layer as well as the surcharge on the ground level were assumed as random variables. Generating the random numbers and fitting the probabilistic distributions to these variables was carried out by the Monte – Carlo method. The displacements at four points of the existing tunnel (line 6) were recorded due to new tunneling, and the appropriate probabilistic distribution was fitted based on the mean, median and skewness of each set of random numbers. According to these probabilistic distributions, the probability of the displacements more or less than a specific displacement can be determined. The results indicate that although input parameters have normal distributions, not all of the outputs have symmetric or normal distributions, and the results of the deterministic method are not the same as the mean values of stochastic approach. As well, the probability of displacements greater than the mean value at the bottom and right side of the existing tunnel is 56 % and 55/5 %, respectively.

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1- Introduction

Rapid development of urban transportation system makes it inevitable to extend urban metro lines as well as to construct new ones. In the underground spaces, it may lead to cross the current lines via excavating new tunnels above or under an existing one. It can change the stress and displacement fields of the soil and rock mass, so the safety and serviceability of the existing tunnel should be assured. Thus, a comprehensive understanding issue of evaluating the effect of new tunneling on the existing tunnel is essential.

Interaction of new and existing tunnels have been studied using different approaches. Fang et al. investigated the response of the existing twin tunnels to the construction of twin tunnels crossing beneath them [1]. Liang et al. used an analytical method and evaluated the effects of an overcrossing tunnel on the existing tunnel [2]. Do et al. evaluated the impact of new tunneling on the existing parallel tunnel using the FLAC^{3D} program [3]. They also simulated twin stacked tunnels and studied the new and existing tunnels interaction [4]. Liu et al investigated the interactions between perpendicularly crossing tunnels in the Sydney region [5]. Standing et al. studied the effect of new tunneling beneath the existing tunnel and verified the results of numerical modeling with the field observations [6].

However, these above-mentioned studies have been analyzed through deterministic methods, while there are various uncertainties in geotechnical problems. That is, for considering the inherent uncertainties of the tunnel's interaction, using the stochastic and probabilistic analyses seems to be a rational approach. The Monte – Carlo method is one of the common probabilistic methods that has been employed in different probabilistic analyses of uncertainties by using random numbers following a special probability distribution [7].

In fact, there is a lack of probabilistic analyses considering the interaction of tunnels, but a number of probabilistic analyses in geotechnical problems can be introduced. In the study by Hoek, the Sau Mau Ping slope stability was investigated from the probabilistic point of view [8]. Oreste used a probabilistic approach for designing tunnel supports according to the hyper static reaction method [9]. Wang et al. performed a probabilistic analysis and evaluated failure probability of the slope by considering the impact of various uncertainties [10]. Pan and Dias conducted such analysis on tunnel face stability considering the effect of spatial variability of random variables [11]. Pan et al. evaluated the stability of a rock slope by this approach, and investigated the correlation between properties of rock mass and their effect on the

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probability distributions and the failure probability [12]. Stability of a deep tunnel studied by Hoek and Marinos was the other attempt [13].

According to literature, there is a very limited number of studies covering the probabilistic analyses especially about the interaction of tunnels. Therefore, this study aims to investigate the interaction of newly constructed tunnel above an existing one from probabilistic point of view.

2- Methodology

The existing circular shaped tunnel is Tehran subway line 6, and the new tunnel running east-west is line 7 of Tehran subway. Both of the subway lines were excavated using an EPB shield TBM machine with a diameter of 9m. The new tunnel (line 7) was excavated perpendicularly over the existing tunnel (line 6) with a clearance distance of 1.8m.

The place where line 7 of subway over crossed the line 6 was selected for modeling. Geologically, this place consists of 4 layers of soil, and the groundwater level is on the level of 17.5m [14]. The numerical investigation was carried out using FLAC3D program. The optimum dimensions of 60m × 60m × 60m were chosen for the model to disregard the boundary effects. The nodes at all sides of the model were fixed on the x – z and y – z planes while nodes at the base of the model were fixed in the vertical direction. The constitutive model at this study was Mohr – Coulomb model with the average values of 0.15 kg/cm^2 and 30° for C and φ, respectively.

The tunnel construction process was modeled using a step – by – step approach. Each step of tunnel excavation advancement was 1.5 m, which is equal to the width of lining ring. The excavation process started with the excavation of the existing tunnel, and the excavation of the new tunnel was started when the model reached to the state of equilibrium. At each step after excavation, the face pressure was applied on the tunnel face, and then the weight of TBM was applied over an assumed range of 60° in the cross-section and over the whole length of the shield (10.5m). The tunnel lining was modeled using liner elements, then the grouting action was modeled behind the segments by applying a uniform pressure as grouting pressure.

The probabilistic analysis at this study was carried out using Monte – Carlo method. Three parameters including the cohesion and friction angle of the third layer (where the existing tunnel was located), and the surcharge on the ground level were assumed as random variables. All of these variables had normal distributions, and the purpose of this study is to find the probability distributions of the existing tunnel displacement. Generating random numbers and fitting the appropriate probability distributions were found using MATLAB software. The appropriate probability distributions were fitted according to the mean, median and skewness values. After generating random numbers for all the parameters, five random numbers for each parameter were selected and the combinations of these numbers were used for numerical analyses at the FLAC^{3D} program.

3- Results and Discussion

The results of this study were obtained as displacements at four points of the existing tunnel including right side, crown, left side and bottom of the tunnel. In case of considering the cohesion as the random variable, the probability of displacements greater than the mean value at the right side, left side and at the bottom of the existing tunnel were 62 %, 53 %, and 65 %, respectively. If the friction angle was the only random variable, displacements at all of the points were symmetric. If the surcharge is considered as the random variable, the probability of displacements less than the mean value at the left side and crown of the tunnel were 43 % and 31.5 %, respectively.

The probability of displacements greater than the mean value at the crown and right side of the tunnel for all the random variables were 56 % and 55.5 %, respectively while at the tunnel crown and at the left side of the tunnel the displacements had normal distributions.

4- Conclusions

In this study, a probabilistic analysis was performed to assess the effect of new tunneling crossing over the existing tunnel. Therefore, a 3D numerical model was developed and the effect of uncertainties of three random variables was investigated. On the basis of probabilistic and numerical analyses, the following results were obtained:

1. Although the input parameters had normal distributions, not all of the outputs had normal distributions.
2. The resulting displacements from deterministic approach were not the same as the mean values of the probabilistic method.
3. According to the probability distributions, the probability of displacements more or less than a specific amount can be determined.

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