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# Assessment of optimum settlement of structure adjacent urban tunnel by using neural network methods

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ABSTRACT

Currently with the spread of tunnel constructions in cities, the proximity of other structures being built close to these tunnels have now become an important subject. Studying the rate of settlement of structures built in the vicinity of these tunnels could be an importance as well. The distance between tunnels and buildings is an important factor which can also be taken to account. Considering some of the parameters in place, favorable results can be achieved in having tunnels and other structures in the close proximity of each other.

In this paper, the settlement of structures with different scenarios has been studied. The proximity of structures and their orientation in comparison with the location of the tunnels has also been a part of this study. Through the Finite Element Method (FEM), and with the use of Neural Network (NN), a various settlement situations have been studied. Using NN on the analysis of the FEM outcome and consideration of the vertical and horizontal distances between the tunnels and constructions with the number of their stories and the diameter of tunnel, relation between the settlements of constructions in any given direction will be immerge. In the study of this matter, the use of methods such as NN and genetic algorithms has not been reported. Using NN to evaluate the results can help to optimize the construction and implementation of underground structures.



## 1. Introduction

For centuries, the most important issue related to the tunnel was digging of tunnels and also the technique and type of tunnel construction. Nowadays, there are various challenges posed in construction of tunnels in the scientific community and Geotechnical world. One of the challenges is its impact on the environment. There are many factors involved in constructing tunnels which must be thoroughly investigated as to its impact in different parts of the world. Numerous studies due to the excavation of tunnels in soil have been done (Ahmed and Iskander, 2011; Ding et al., 2011; Jones and Hunt, 2011; Kuo et al., 2011; Shin et al., 2011; Spyrakos and Vasileiou, 2011; Yang and Wang, 2011). One of the impacts of tunnels on environment is excavation of tunnels adjacent to the structures. Evaluating parameters for tunneling effects on the environment will greatly assist in these study issues (Azadi and Zahedi, 2011; Jinlog and Jiequn, 2011). Static and dynamic behaviors can be placed in this category (Pfeiffer et al., 2008). But the use of optimization problems and algorithms are new. Fuzzy logic, genetic algorithms, genetic programming, and neural network participated in the various areas of science in recent years. The power of neural network optimizes the several parameters on these issues that are important to interact with each other. Besides, using the software based on the neural network is very advantageous and innovative in the topic of tunnel. Tunnel modes and parameters of the surrounding environment, can be assumed for the profile using a neural network for the best route in minimum, maximum, or even obtain optimum (Lau et al., 2010).

According to the description of tunneling effects on the environment, an important parameter that has been studied in this paper is the phenomenon of settlement in a structure above the excavated tunnel by TBM method. The various modes for surface structures on top of the tunnel and the tunnel itself have been assumed and the results and outcomes have been evaluated and analyzed (Lai et al., 2012a,b; Wang et al., 2011a,b; Zhimin and De-An, 2011).

One of the most important issues in design of underground structures is the conditions and design features intended to utilize the best method of stability analysis that is economical in various aspects of simplicity and also the results have to be accurate enough with respect to reliability. Optimizing settlement of structure has been considered during tunnel excavating. In addition, the application of the Neural Network (NN) for the results of finite element method (FEM) is considered very important and useful.

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## 2. Modeling

In this paper, the assumption is that the tunnel excavated by TBM followed by an installation lining. In this manufacturing method, the soil is removed more than the required amount (more than the final diameter) for tunnel. And then lining runs over that. In this method Re-spread tension can be seen. In this study, structure settlement caused by digging a tunnel is evaluated. For this purpose, different diameters of the tunnel structure have been modeled. In addition, the soil layering varies in different models.

### 2.1. Dimensions and materials

The geometric dimensions of base model include a width of 70 m and a depth of 35 m. Geological features in the base model of desired location consider the soil in two layers. The first layer has a thickness of 3 m of filled soil; the second layer has a thickness of 47 m and made of clay, which eventually reaches to rock bed. The base model has not ground water and soil material is drained. Hence, the water level is selected with the bedrock surface. The behavioral model of soil materials is the Mohr–coulomb. And the points A and B have been studied for settlement. Material specifications are shown in Table 1. Table 2 shows specification of the final tunnel and specification of surface structure can be seen in Table 3. These parameters have been used for the amount of settlement. Tunnel model in the early stages of this study is 6 m diameter and 12 m horizontal distance from the center of structure and the vertical distance of 6 m below the structure (the distance from the top of the tunnel). In this model, structure has 6 stories. Local structures and tunnels in the early stages can be seen in Fig. 1. The model is made with 15 nodes type. Mesh size can be seen in Fig. 2.

### 2.2. Software

Calculations and analyses are performed by PLAXIS software. One of the features of this software is modeling with the assumption of symmetry. Because the analysis is asymmetrical, the option of asymmetry is chosen. The next step is using the EPR software. Using the EPR software, the results of the analysis software PLAXIS with neural network methods have been optimized. Meanwhile 25 of data are placed in test network and 76 of the data are placed in training network of this software. New strategy of modeling used in this paper obtained with combined numerical regression symbolic with the evolutionary polynomial regression (EPR). The base of evolutionary polynomial regression method is a dynamic search, in addition to making revolution with analogy to the regression phase (the traditional regression method is based on search by tree structural analysis).

### 2.3. Analysis

In the article, it has been assumed that a long time has passed since the construction of structure and the structure has reached to its final location. Various amounts of the tunnel diameter and horizontal and vertical location of the structure and different layers of soil illustrated in the model have been analyzed.

**Table 2**
Specification of the tunnel lining.

| EA (kN/m) | EI (kN m$^2$/m) | *d* (m) | *w* (kN/m/m) | $\upsilon$ |
|---|---|---|---|---|
| $5.27 \times 10^6$ | $8 \times 10^4$ | 0.3 | 7.2 | 0.15 |

**Table 3**
Specification of surface structures.

| EA (kN/m) | EI (kN m$^2$/m) | *d* (m) | *w* (kN/m/m) | $\upsilon$ |
|---|---|---|---|---|
| $5 \times 10^6$ | 9000 | 0.147 | 5 | 0.1 |

## 3. Interpretation and evaluation of the results

### 3.1. Alterations in the horizontal distance between tunnel and structure

After introduction and preparation of the model, the results are then evaluated. In this model, the center of the tunnel is located exactly at the center of the structure. With the horizontal movement of the tunnel to the left, final location of the points A and B are shown in Table 4 (percent of alterations). It is noteworthy that point A on the left side and point B on the right side of the structure is aligned with the tunnel profile in Fig. 3 (Fig. 3 shows the base model). Diameter of tunnels is 6 and 8 m. Traffic load of 15 kN/m$^2$ is considered to be locating within 6 m of soil.

As it can be seen in Fig. 4, with increasing the distance between the tunnel and the structure, the settlement has a decreasing trend and it seems reasonable. A noteworthy point is the increased settlement of point A while it's located 3 m from the structure. In other words, at beginning of trend, in the point A, structure settlement increases but with greater distance between tunnel and structure, settlement trend starts to decrease. For this reason the entire tunnel is located under the structure (axis to axis) and when tunnel moves to the left, the tunnel crown locates in below of point A. In this case the thickness of the soil reduces sharply and there will be a huge shift. Fig. 4 shows the changes of final structure settlement to displacement of distance horizontal tunnel.

When the tunnel crown is placed in the below of point A, the highest settlement in this point, takes place and then, as the distance of tunnel from structure increases, the settlement rate decreases that the horizontal distance, reaches to 2.3D (14 m). At this time, settlement reaches to nearly zero. About point B; when horizontal distance is approximately equal to D, settlement reaches to zero.

Table 4 shows the percentage of relative settlement changes to the settlement of base model as horizontal distance increases between center of tunnel and structure. Percentage of relative settlement changes to the settlement of base model under the tunnel is zero because in this point, settlement of points A and B are the same. Fig. 5 shows settlement distribution when the tunnel is located exactly below the structure. As it can be seen, settlement of points A and B are the same.

### 3.2. Changes in the vertical distance between tunnel and structure

Changes in the vertical distance between tunnel and structure have been studied in four paths. In the path No. 1, tunnel exactly

**Table 1**
Specification of soil layers.

| Layer | Type of soil | Thickness (m) | Friction angle | Coherence (kN/m$^2$) | Poisson coefficient | Elasticity modulus (kN/m$^2$) | Specific gravity (kN/m$^3$) |
|---|---|---|---|---|---|---|---|
| 1 | Fill | 3 | 23 | 15 | 0.35 | $1.5 \times 10^4$ | 18 |
| 2 | Clay | 47 | 25 | 30 | 0.35 | $2.6 \times 10^4$ | 20 |