

# Back Analysis of Tehran Metro Tunnel Construction Using FLAC-3D

M. Mahdi, N. Shariatmadari

**Abstract**—An important aspect of planning for shallow tunneling under urban areas is the determination of likely surface movements and interaction with existing structures. Back analysis of built tunnels that their settlements magnitude is available, could aid the designers to have a more accuracy in future projects.

In this paper, one single Tehran Metro Tunnel (at west of Hor square, Jang University Street) was selected. At first, surface settlements of this tunnel were measured in situ. Then this tunnel was modeled using the commercial finite difference software FLAC-3D. Finally, Results of modeling and in situ measurements compared for verification.

**Keywords**—Shallow Tunnel, Back Analysis, Surface Movement, Numerical Modeling.

## I. INTRODUCTION

THE need for tunnel design and construction in urban areas, mainly for transportation purposes, has increased markedly in recent years, especially in Tehran city. New tunnels are often required in close proximity to the existing ones and construction must be carried out without damage either to the buildings above the excavation field or to the subsurface infrastructures. During the design stages it is therefore necessary to predict possible interaction effects.

Due to the high interaction between tunneling and existing structures in urban areas, tunneling operations in urban areas draws much attention. This paper describes a thorough analysis of the tunneling influence in soft soils on surface settlements. A combination of in situ observations and numerical modeling was previously adopted to analyze such problem.

The surface settlements,  $S$  above a single tunnel constructed in soft ground are usually assumed to follow an inverted Gaussian curve, i.e.

$$S = S_{\max} \exp(-y^2 / 2i^2) \quad (1)$$

where  $S_{\max}$  is the maximum settlement (over the tunnel axis),  $y$  is the vertical distance from the tunnel axis and  $i$  is the width of the settlement trough [1].

The source of these settlements is the “volume loss” which occurs at the tunnel. It is defined as the additional volume of soil which is excavated over the volume required to house the

final lining. As excavation proceeds, the soil ahead of the face is unloaded so it tends to move inwards. Losses also occur behind the face due to the nature of the shield in which the excavation is being carried out. Many field studies have confirmed (1) to be acceptable for green field sites [2]-[5] while, for structures in urban situations, (1) is no longer valid.

The development of transportation systems in great Tehran city requires the construction of metro tunnels. These tunnels have been driven using the New Austrian Tunneling Method (NATM). NATM is a construction method, where the type and the amount of primary tunnel support is designed on the basis of the anticipated subsurface conditions using empirical classification systems as well as the designer experiences. In situ measurements provide an integral part of the method through providing information about the information of ground and tunnel support and foreseeing problems of lining and face stability. Numerical analysis provides useful means to support decisions taken during NATM design [6]-[8].

This paper presents the results of the finite difference analysis for the subject tunnels compared with actual surface settlements. One single Tehran Metro Tunnel (at west of Hor square, Jang University Street) was selected in this research. At first, surface settlements of this tunnel were measured in situ. Then this tunnel and that's circumstance were modeled using the commercial finite difference software FLAC-3D. Finally, results of modeling and in situ measurements compared for verification.

## II. FIELD SURFACE SETTLEMENTS MEASURING

For field surface settlements measuring, surveying technique was selected. In order to achieve the best results in analysis and tracing the surface settlements profiles, 70 points were selected on the field ground surface and dug for rods installation.

Recoding the height differences before and after the tunnel construction showed the surface displacement. In this case settlements measured after 2 years from the tunnel construction. Finally, model verification has been done by comparison between settlements from 3D model and In situ measurements at S1, S2 and C points. Fig. 1 shows the Locations of points that selected for field measurement on the street surface.

Using in situ construction procedures, at first the head of the main tunnel with the step of 1 meter is excavated. Having shotcreted the head, the bench excavated (with step of 1 meter), shotcreted and finally lined with reinforced concrete as shown in Fig. 2.

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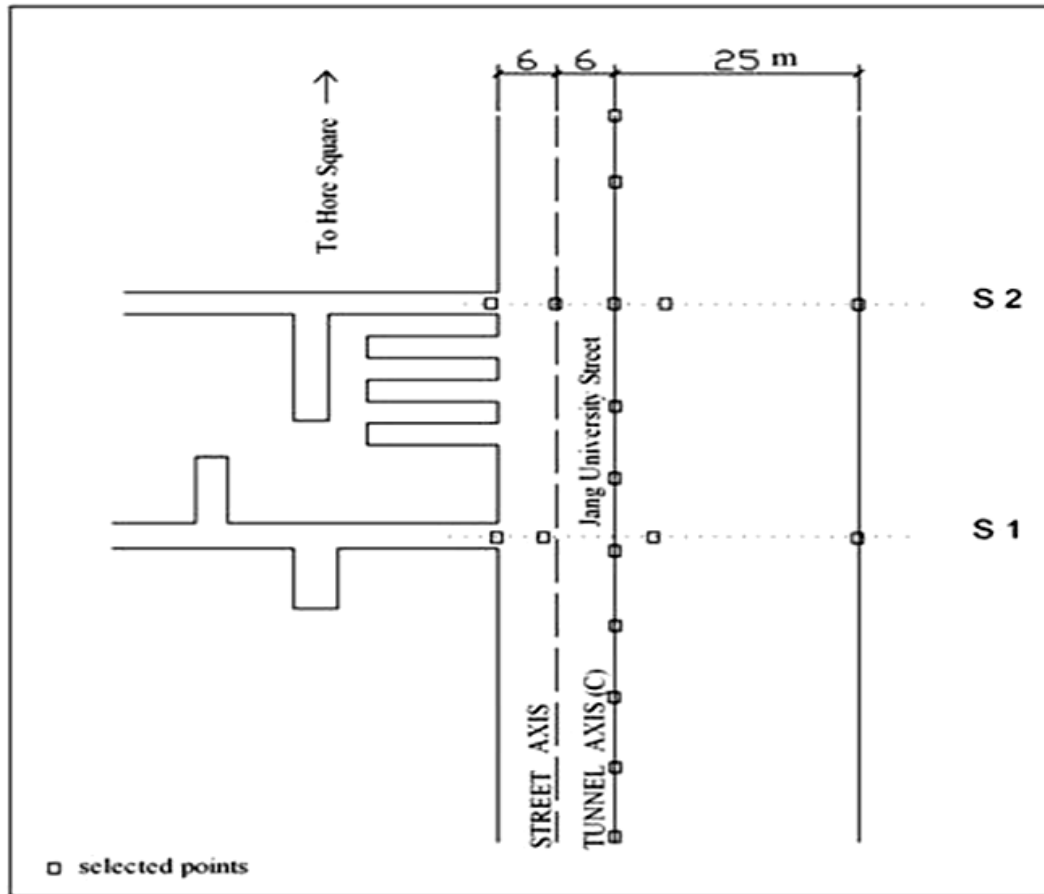


Fig. 1 Locations of points for field measurement

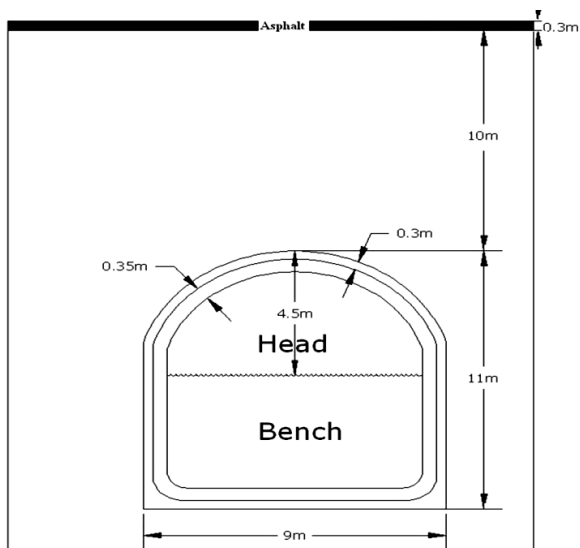


Fig. 2 Tunnel geometry

### III. MODELING WITH FLAC-3D

Fig. 3 shows the mesh used for the tunnels analysis. Concerning the boundary conditions, the displacements are

constrained in three directions at the bottom, while zero horizontal displacement is imposed at the lateral boundaries.

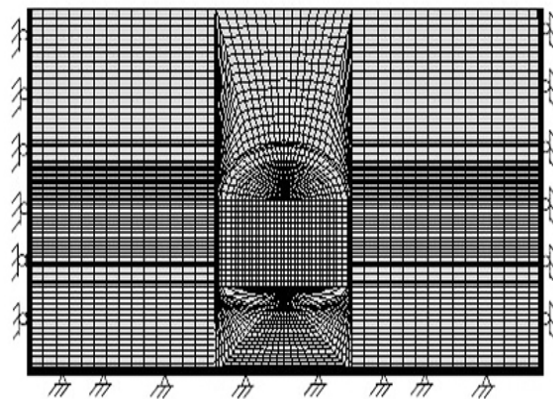


Fig. 3 Mesh used in the analysis of tunnels

Table I summarizes the properties of the soil and the lining used in this study. The soil corresponds to GW-GM. The coefficient of the lateral stress ( $K_0$ ), thickness of the shotcrete, thickness of the lining and thickness of the asphalt are equal to 0.5, 0.35m, 0.30m and 0.40m, respectively.

In all calculations, drainage analysis was performed, meaning that no excess pore water pressures were generated. Consequently, strength parameters based on effective stress were used as indicated in Table I. The results therefore represent the settlements likely to occur over a long period of time.

In all calculations, the analysis procedure began with the definition of initial effective stresses prior to tunnel construction, using ratio value of effective horizontal to vertical stress,  $K_0$  equal to 0.5.

TABLE I  
UNITS FOR MAGNETIC PROPERTIES

Material	E0 (MPa)	$\nu$	C(kPa)	$\phi$ , deg	Dilatancy Angle, deg	Unit Weight (kN/m <sup>3</sup> )	Type of Behavior
Soil	125	0.3	30	40	5	20	Mohr Coulomb
Shotcrete	20000	0.25	-	-	-	24	Linear Elastic
Lining	26000	0.25	-	-	-	25	Linear Elastic
Asphalt	20000	0.25	-	-	-	24	Linear Elastic

So, seven load stages are accounted as below:

1. Construction of the first tunnel head, simulated by activating the tunnel shotcrete and deactivating the soil elements inside the first tunnel head.
2. Exertion of volume loss and activating the tunnel shotcrete for the first tunnel head.
3. Construction of the first tunnel bench, simulated by the tunnel shotcrete activation, and deactivating the soil elements inside the first tunnel bench.

4. Exertion of volume loss and activating the tunnel shotcrete for the first tunnel bench.
5. Activating the first tunnel lining.

Each load stage was carried out using standard nonlinear solution techniques available in FLAC.

#### IV. RESULTS

Figs. 4 to 6 show the comparison of two way ground surface movements' measurements.

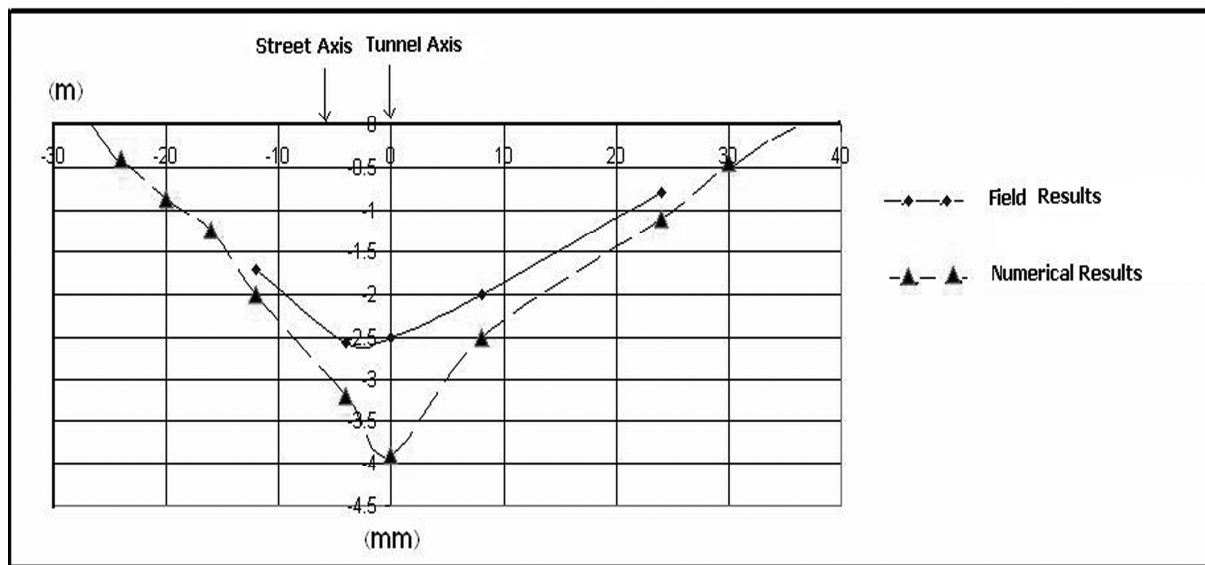


Fig. 4 Comparing measured and estimated surface ground settlements in section S1

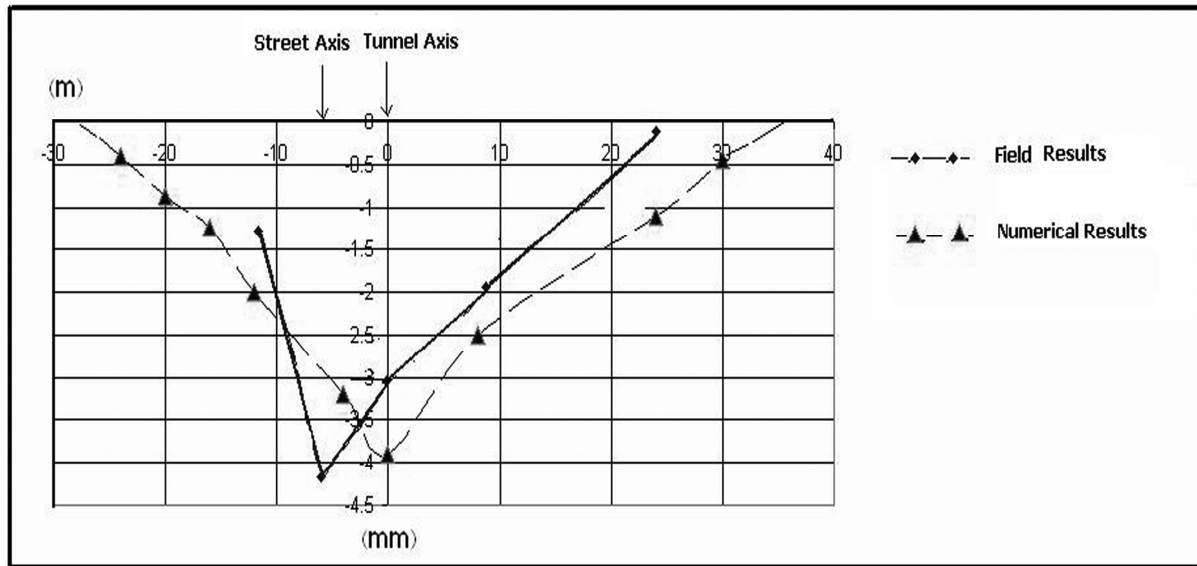


Fig. 5 Comparing measured and estimated surface ground settlements in section S2

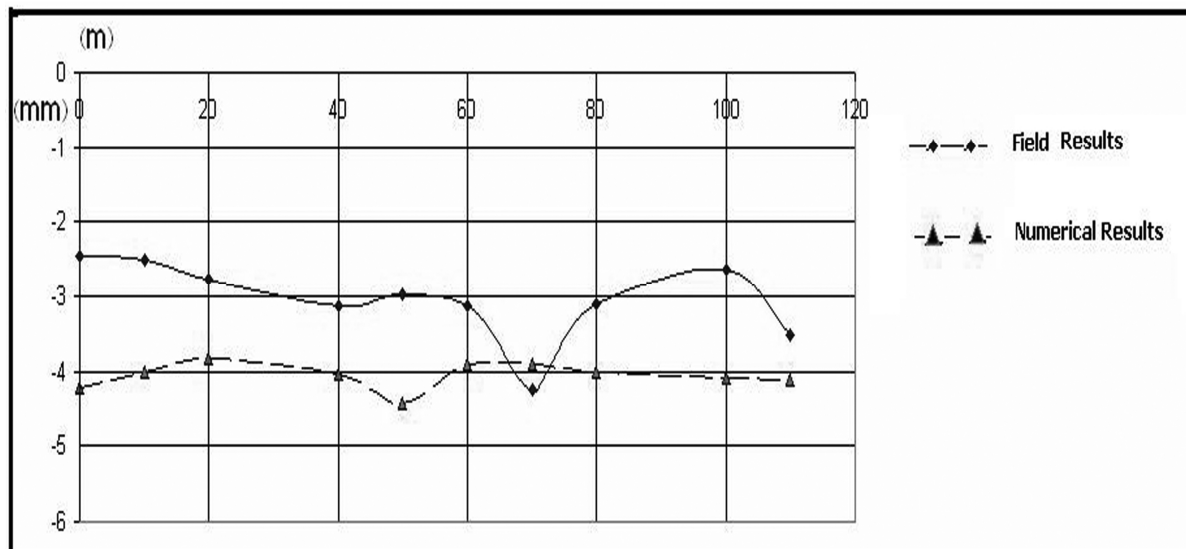


Fig. 6 Comparing measured and estimated surface ground settlements section in tunnel axis

Figs. 4 to 6 show that the deviation of the results is usually 1-2mm. This deviation is so little, indicating that the accuracy of the built model is so appropriate.

The deviation may be caused by factors such as: the constant traffic load applied in the model, probably soil parameters variety in layers and existence of zones, likely local groundwater presence, size of model meshes, model dimensions, shotcrete and lining parameters variety in operation, and other variables in field that cannot be considered explicitly in the modeling.

#### V. CONCLUSIONS

The assessment of the influence of tunneling on adjacent structures is an important issue in urban areas. Therefore, it is

necessary to monitor the ground deformation during tunneling not only to ensure the safety of construction but also to provide important information for feedback analyses.

The results of present analyses and field measurements showed that both methods could be used for the preliminary design of NATM tunneling for the conditions used in this research. And the numerical modeling confirmed that the soil laboratory tests and field measurements that performed for soil parameters extract has a good accuracy.

Consequently, we can be sure about the built model, since the resulted deviation is so little to be neglected. These neglect differences also could be due to reasons such like, the constant assumed traffic loading, presence of zones with different

mechanical properties, errors due to numerical modeling and etc.

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