Numerical modeling of NATM urban tunnels and monitoring-Case study of Niayesh tunnel

Modélisation numérique de tunnels urbains construits par la méthode NATM et étude de cas du contrôle du tunnel Niayesh

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ABSTRACT: The New Austrian Tunnelling Method (NATM) has been adopted extensively as the method of tunneling in Iran. In this study, some numerical models were developed using three-dimensional Finite Element software to analyze behaviour of the east portal of the Niayesh road tunnel that is being constructed in Tehran, with the width of about 14 meters and the height of about 11.5 meters. Stability and performance analyses carried out for initial conditions, during and after construction conditions.
The Eastern portal of the north tunnel located under a reinforced soil slope that is loaded under 4 to 6 story buildings and streets vehicles. Regarding condition of the entrance of the east portal, the pile system in addition with NATM stage construction for tunnel has purposed to stabilize portal area. This procedure of design was controlled by monitoring results which provided by several settlement points on the surface of the highway and some convergence stations placed in the initial lining of the tunnel.

RÉSUMÉ : La Nouvelle Méthode Autrichienne (NATM) a été adoptée largement comme méthode de creusement de tunnel en Iran. Dans cette étude, des modèles numériques ont été développés en utilisant un logiciel par éléments finis en trois dimensions pour analyser le comportement du portail Est du tunnel de l'autoroute Niayesh qui se construit à Téhéran, de largeur environ 14 mètres et hauteur environ 11,5 mètres. Des analyses de stabilité et de performance ont été effectuées pour les conditions initiales, pendant et après construction.
Le portail Est du tunnel Nord est situé sous une pente en sol renforcé chargé par des immeubles de 4 à 6 étages et des véhicules dans les rues. Concernant la condition de l'entrée du portail Est, un système de pieux associé à une construction par étapes par la méthode NATM a été utilisé pour stabiliser la zone du portail. Cette conception a été contrôlée par les résultats d'une instrumentation comprenant plusieurs points de tassement à la surface de l'autoroute et des stations de convergence placées dans le revêtement initial du tunnel.

KEYWORDS: Urban tunnels, NATM, Numerical modelling

1 INTRODUCTION

The project site is located at Tehran. Geotechnical studies have been performed to recognize subsurface layer conditions and to assess the geotechnical parameters. It should be noted that, there is a need to take into account the stability of the portal in the entrance of the tunnels. The main scope of this study is to analyze the stability of the portal of north tunnel-Eastern adit.

The demand for more travel facilities in major cities has led to a significant increase in the interest in development of underground rail or road systems in Iran. The new Austrian tunnelling method (NATM) has often been applied for construction method of many tunnels in alluvial ground. The NATM is a technique in which ground exposed from excavation is temporarily supported by shotcrete as the lining (Sauer and Gold 1989). Outstanding flexibility of NATM is the main advantage of this method over conventional tunnelling techniques. In this method many different support techniques can be adopted to deal with various ground conditions.

Produced ground deformations due to urban tunnels is very important, because urban tunnels are surrounded by highways, buildings, installations and lifelines that are sensitive to deformations.

Ground deformations can be evaluated using numerical analysis methods such as finite element and finite difference. In spite of the widespread use of numerical analysis, most of the analyses used are mainly two-dimensional (2D) analyses that cannot consider for 3D situations such as entrance ramp and tunnel portal. Another issue is the modelling of the forepoles that cannot be considered in 2D modelling. Steel pipe forepoles are often used to bridge the unsupported gap as the tunnel face advances. Its action is longitudinal and therefore cannot be captured by a 2D analysis modelling just the tunnel section.

Considering a NATM tunnel as a case study, this paper tries to illustrate how 3D numerical analyses can be applied to stability analysis and to foresee the ground settlement.

2 PROJECT SPECIFICATION

The Niayesh parallel twin tunnels that are located in Tehran, connect the crowded Niayesh and Sadr highways. The north tunnel is excavated by the NATM and oval cross section with a height of about 11.5 m and a width of about 14 m at the eastern portal. The north tunnel at the eastern portal is located under a reinforced soil slop that is abut 4 to 6 storey buildings and streets.

Regarding project specifications 1 [m] diameter reinforced concrete piles were performed in vicinity of buildings and tunnel entrance. As it shown in figure 1, two lanes bored concrete piles used with 2.5 [m] spans. Stability analyses carried out for initial conditions and during and after construction conditions.

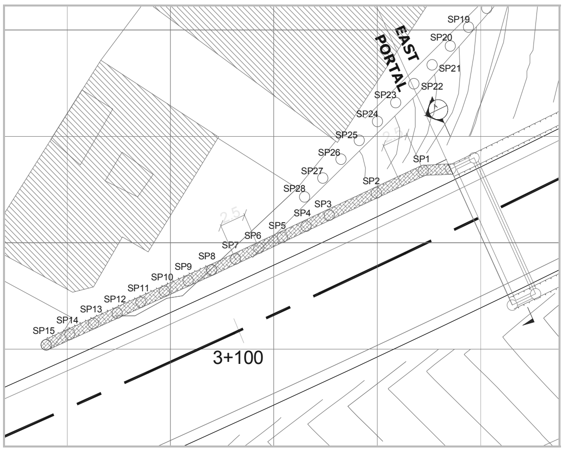

Figure 1. Plan of Niayesh east portal - north tunnel

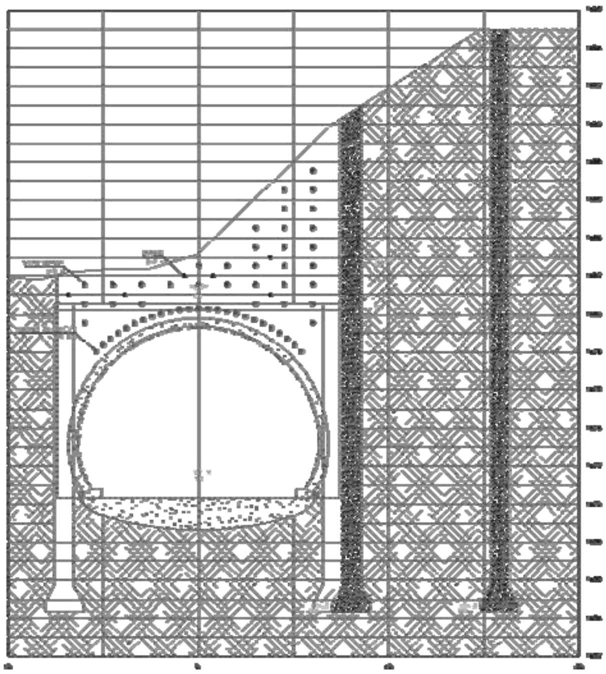

Figure 2. Section A-A, (see Figure 1)

Based on the field and the laboratory test results, subsurface conditions are described as follows:

Generally, filling material can be found to El. +1480 that is about 2 meter above tunnel. Beneath the filling soil layer, soil profile is composed of dense sandy gravels and dense clayey gravels, both contains silt and clay material. Table 1 shows the geotechnical properties of different soil materials.

Table 1.Geotechnical parameters of different layers

Elevation	To +1480	+1480 to +1475	Under +1475
Cohesion (kg/cm^2)	0.1	0.2	0.3
Poisson Ratio ν	0.32	0.3	0.3
Frictional Angle (·)	35	35	35
Natural density (gr/cm^3)	1.8	1.9	1.9
Young's Modulus (kg/cm^2)	600	650	650

3 NUMERICAL ANALYSES

3.1 *Softwares*

Numerical analyses have performed by 3D finite element software released by Plaxis company. Plaxis3D Tunnel is a finite element package specifically intended respectively for the analysis of deformation and stability in tunnel projects.

The NATM construction progress were modelled by stepped construction phases. In the applied performance method, after excavation of each stages, a 15 cm reinforced shotcrete layer, supported with lattice elements, will cover the excavated surface as an initial lining. The well-known Hardening-Soil model (Schanz et al. 1999) was used to model the soil layers.

3.2 *Input parameters*

Regarding 3 dimensional tools, Plaxis3D Tunnel can be used to analyze some non-planar problems. Therefore, eastern portal of the north tunnel is modelled by Plaxis3D Tunnel.

Construction stages are simulated in analyses and geometry of slope and material parameters were considered similar to analysis conditions described below.

The soil parameters assigned as presented in table 1. Soil nails and forepoles are modelled by geogrid elements and initial lining elements are modelled by plate elements. Geogrids are with normal stiffness but no bending stiffness. They can only sustain tensile force and no compression and plates are structural elements with bending and axial stiffness. The most important parameters of plates are flexural rigidity (bending stiffness) EI and axial stiffness EA.

Character of all the plate elements used as a interior temporary beam element which removed during the construction stages applied as internal lattice that presented in table 2 and characters of all of the plate elements used to model initial lining of the tunnel, including 15 cm reinforced shotcrete and steel lattices, applied as external lattice.

Table 2.Structural element properties

Element	EA (KN/m)	EI (KN.m^2/m)
Internal lattice	5.3E6	1.4E4
External lattice	7.4E6	3.8E4

In this section, the results of the short-term stability and performance analysis of the north tunnel under the reinforced slop are presented. The model geometry was established according to the project specifications. Considering the adjacent buildings, the distributed load of 6000 kg/m2 is applied and 2000 kg/m2is applied for the highway that abuts under the slop.

At the location of the portal, the north tunnel will be constructed in minimum depth of 7 m under toe of the reinforced slop. Regarding the stages of the construction of the tunnel, the staged construction applied in the numerical modelling.

In staged construction right top and bottom drifts, as it is shown in figure 3, are removed after left top and bottom drifts, respectively. All the stages are followed by placing initial lining elements on excavated soil face.

It should be noted that in the 3D model the portal is excavated before tunnel construction.

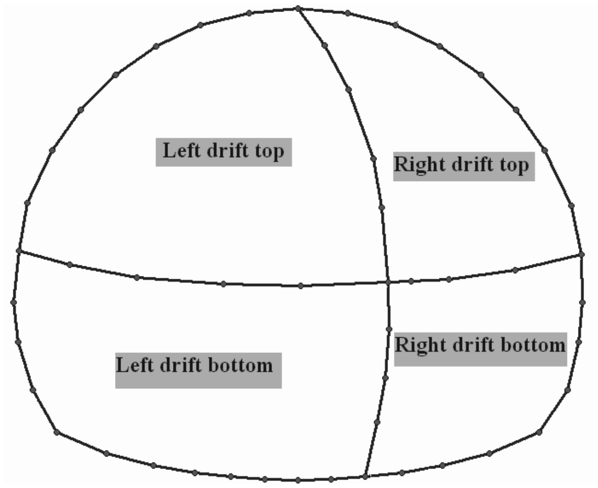

Figure 3. Stages of construction

3.3 Analyses results

In the first models, factor of safety for stability of the reinforced slop, before any excavations, was analyzed. According to analysis, the safety factor of 1.44 is obtained.

Right drift clusters are removed by two steps after removing left side clusters. Numerical analyses resulted vertical settlements up to about 44 millimetres obtained.

Figure 4 presents final vertical deformations, for after construction conditions, considering 4 steps for removing the soil clusters according to the construction. As it shown, the maximum settlements is about 44 [mm] and it accured under the foundation of the 6-storey bulding, while the factor of safety after construction is 1.39.

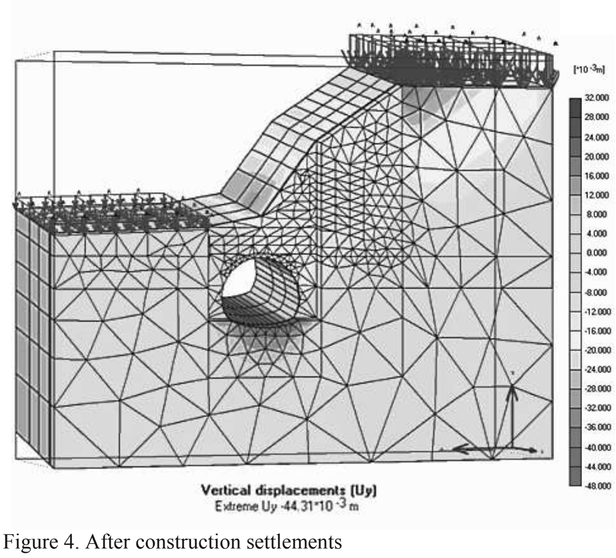

Figure 4. After construction settlements

The construction has performed and the settlements were monitored parallel to the tunnel construction from several settlement points on the 6-storey building and some convergence station in the initial lining of the tunnel. Figure 5 presents location of settlements monitoring point around the 6-storey building.

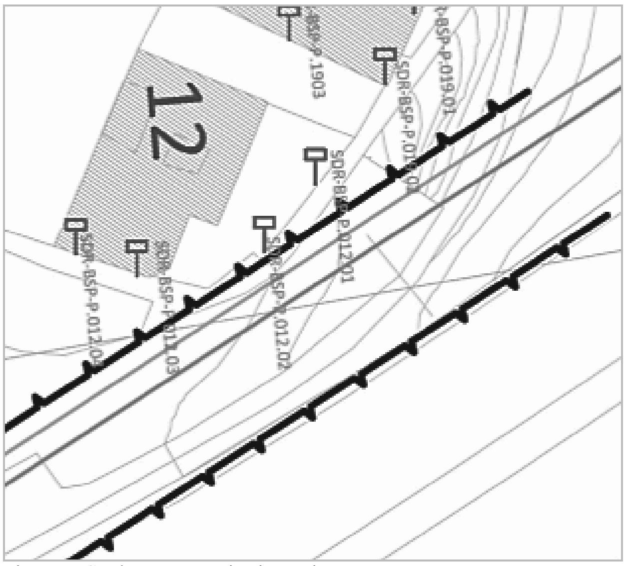

Figure 5. Settlements monitoring points

Figure 6 shows the monitored settlements during and after construction together with the 3D model results.

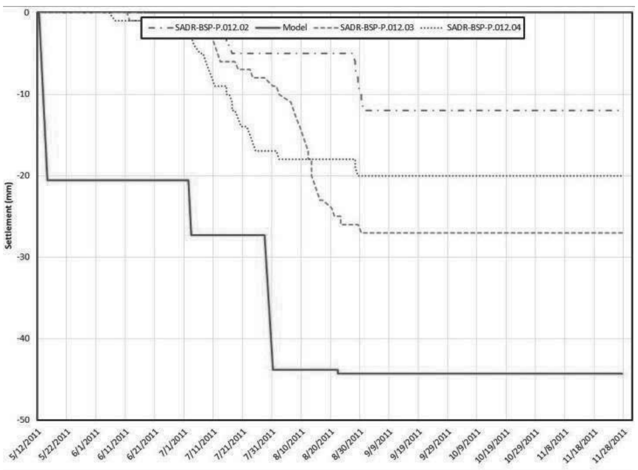

Figure 5. Settlements from monitoring and modeling

According to analysis for after construction condition, the maximum vertical deformations of foundation of 6-storey building are about 44mm.

The maximum in-situ monitored settlement on the 6-storey building was less than 27 [mm] just after construction completion which smaller than models results.

As shown in Figure 5, the maximum settlements from modeling results are greater than the monitoring results. The settlements obtained from numerical modeling are greater for all construction stages after full balancing of out-of-balance forces for each stage.

4 CONCLUSIONS

The numerical analyses have performed by using 3D finite element software to control performance and stability of the tunnel. Regarding 6-story building and the reinforced slop upon the tunnel, settlement of ground surface, was considered the main concern of ground performance.

Monitoring results shows that the maximum settlement of the building's foundation was about 27 [mm] just after construction completion which is smaller than the numerical results.

The maximum deformations and the safety factors obtained from the finite element analysis by 3D models are summarized in table 3.

Table 3. Analyses results for after construction.

Stages	Factor of safety	Max settlement [mm]
Initial lining of left drift top	1.32	20.6
Initial lining of left drift bottom	1.45	27.3
Initial lining of right drift top	1.30	43.8
Initial lining of right drift bottom	1.39	44.3

As shown in the table 3 the factor of safety for all stages during construction are acceptable. According to the Plaxis3D analyses the maximum settlement of the 6-storey building after construction is about 44 mm and the final factor of safety is about 1.39.

5 ACKNOWLEDGEMENTS

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