Numerical modeling for Selection of appropriate tunneling method in S station of Isfahan subway

enayatallah emami meybodi*[1], Jamaloddin Hajibagheri Foroshani[1], Fariba Kargaran Bafghi[1]

1- Department of Geology, Yazd University, Yazd, Iran

* Corresponding Author: *enayatemami@gmail.com*

(Received:January 2021 , Accepted:April 2021)

Keywords

Subway station
NATM
STM
Cut & cover
support systems
Numerical Modeling

Abstract

Nowadays, due to the increasing urban environments, increasing the density of surface structures and the lack of space for intra-urban transportation, the need to implement underground structures such as tunnels and subway stations in urban environments has been felt more than ever. One of the important factors in the implementation of deep underground stations in urban environments is the choice of suitable excavation methods that have a significant impact on the stability of the tunnel space during excavation, surface sinking caused by drilling, and also the long-term stability of the excavated space. In this research, considering the geotechnical characteristics of the land and the geometry of the station under study, three common methods for excavation of subway station, including NATM, STM, and cut & cover methods with support systems such as shotcrete, piles and ribs, fore polling and nailing numerically modeled and have been evaluated and reviewed for the stability of the space and tunnel wall displacement. Numerical modeling of various methods for implementing this space has been done using the finite difference method with FLAC3D software. Sensitivity analysis for changing geometric parameters of support systems was done. According to the results, the maximum displacement in the environment around the station is related to the cut & cover method and the minimum is related to the STM method with the nailing support system.

1- NTRODUCTION

The construction of large underground spaces, such as subway stations due to the large cross-section of these environments, has caused changes in the surrounding environment and, as a result, has created subsidence in the ground, which poses risks to surface and subsurface structures. Therefore, in addition to these spaces' stability, the relocation of the surrounding area should be predicted and controlled as much as possible. When excavating in urban areas, the process should be done so that the subsidence is at a minimum level, and minor damage is caused to surface and subsurface buildings [1]. One of the factors influential in stabilizing the underground excavated spaces is the division of the excavating cross-section and step excavating. In general, in this model, the total cross-section is divided into smaller sections and fronts, and the excavation operations are carried out on different fronts, with specific steps and distances from each other, so that the excavating space is minimally damaged [2]. Different experts have proposed different models to determine the excavating order in these models. These patterns can be optimized depending on the geological conditions, dimensions of the excavating section, groundwater status, overburden height, etc. The most common of these models in subway station excavation are NATM, STM, slow and push model and innovative combined models. According to the geological and geotechnical characteristics of the area, depth of the station, the concentration of surface buildings, and geometry of the space in question, the three models of excavating NATM, STM, and slurry with the nail, pile, and rib support systems (concrete arch), Umbrella Arch Model (UAM) (fore polling) and shotcrete has been examined to execute the desired space. The specifications of support systems, including design and installation pattern and mechanical specifications, were selected based on the project consultant's opinions (Zayand Ab Consulting Company) in the initial design. The model's response in terms of displacement of walls and ceiling of excavating space to changes in diameter and length of nails, change in diameter of piles, and change in diameter of piles and ribs was studied. What has been specially considered in this research is the comparison of three different models of subway station implementation technically using numerical modeling. Proper modeling based on reliable data has been able to show to a large extent the effect of the model of implementation on the amount of displacement that occurred in the structure. This research has been done due to the lack of specific design standards and the complexity of calculations to consider the support system's interaction with the ground. In this research, three-dimensional numerical modeling in a case study has been used to determine the optimal excavation methods and optimal support system parameters.

2- The Literature Review

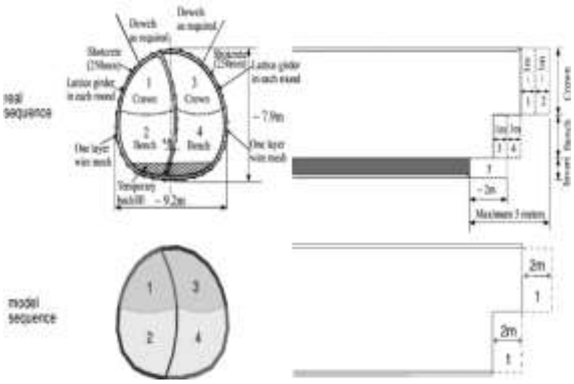
So far, various researches have been done on estimating the impact of excavating models and type of support using numerical modeling in soft soils, especially in large spaces such as subway stations and highway tunnels. The main reason for using numerical models is the complex loading conditions in multi-stage drilling and the difficulty or impossibility of analyzing the support system's interaction with the drilled structure. Sharifzadeh et al. studied the excavating model selection, drilling sequence, and optimal distance between different tunnel drilling stages by NATM model using numerical modeling using a three-dimensional finite element model in Niayesh tunnel in Tehran. Finally, the optimal values of excavating sequence and the optimal length and dimensions of excavating each section were estimated [3].Nowruzi et al. Using numerical modeling by Plaxis2D software, the temporary support system of Tehran Niayesh tunnel in NATM excavation method in one section has been evaluated using comparison of instrument data and numerical modeling output [4]. In another investigation on the surface subsidence of Niayesh tunnel using NATM excavating method and adopting finite element numerical modeling by Plaxis2D, experimental models and comparison with real data in three sections of the tunnel have been estimated [5]. In an article, Hejazi Rad et al. examined the effect of different multi-stage excavation models for implementing the Tehran X7 metro station in a surface settlement using Plaxis3D software. In this model, the support of the concrete vault and the German excavation models, and the excavation of the side galleries were investigated, and the results of the surface settlement created in the models were compared with each other [6]. In 2013, Reyhanian Zavareh et al. Estimated the optimal distance between the concrete arch and the subsidence of the ground using analytical and numerical models at Haft Tir station of Tehran Metro Line 6. In this paper, Flac2D differential element software and analytical and experimental criteria have been used to determine the optimal distance of concrete beams [7]. In 2008, okac surveyed the surface settlement using a comparison of data from experimental relationships and the actually measured subsidence on the route between the two Istanbul metro tunnel stations. In this research, the NATM drilling model has been used with and without umbrella arch support [8]. Sedghiani et al., in a study in 2010, investigated the effect of the pre-support model of the concrete arch (piles and ribs) in Tabriz metro station by adopting numerical modeling of three-dimensional finite element [9]. In 2012, stations in the Beijing Metro were excavated on the soft ground using various STM models. In a study, surface settlement due to drilling has been studied and compared by instrumentation and numerical modeling. The results have shown that the STM drilling model has a good ability to control surface settlement. Mobile Oskooi et al., in 2018 modeled the application of the STM excavation model for drilling a two-way intersection in soft soils of Shiraz subway using the numerical model of the three-dimensional differential element. The purpose of numerical modeling by FLAC3D software is to evaluate the settlement amount during execution and determine the best execution model with the least amount of settlement [11]. In 2006, Shariatmadari et al., in a study examined the displacement of the ground surface caused by slow and covered excavation in Tabriz metro station. In this research, soil properties have been obtained using real surface displacement data and modeling with Plaxis software [12]. In a 2012 article, Wang et al. analyzed the shifts and tensions around the Tianjin metro station space in China, which were drilled using the slow-cover model. They estimated the effects of excavation phases and support using numerical modeling [13]. In 2014, the convergence of a subway station's walls in Chengdu, China, which was constructed in a slow and covered manner, was examined. In this research, the structures and support required to prevent convergence have been identified [14]. In a 2014 article, Gu and Hu analyzed the numerical analysis of ground settlement resulting from a subway station's digging using the cut and cover model. In this study, a subway station in Kunming, China, was modeled using Flac3D software [15]. A 2016 study examined the displacement and failure of the Nanjing Subway Station support, a subway line in China, excavated in soft soils by the cut and cover model [16]. The Umbrella Arch Model (UAM) or forepole was introduced in 2014 in an article investigating tunnels' design and construction in difficult geological conditions such as weak rock masses. In the current study, we have tried to provide the tunnel designers with the proper selection process of umbrella arch support systems using basic concepts [17]. In 2014, a study was conducted on the design of an umbrella arch support system using numerical analysis. This research has been done due to the lack of specific design standards for fore polling and the complexity of calculations to consider this support system's interaction with the ground. In this research, two-dimensional and three-dimensional numerical modeling in a case study has been used to determine the optimal parameters of fore polling for umbrella arch design [18]. In 2016, a semi-analytical model for using umbrella arch pre-support in squeezing ground conditions was presented in a paper. This paper emphasizes that due to the complexity of loading and interaction of fore polling with the ground, the various analytical models available cannot provide a suitable criterion for the design of fore polling. Therefore, better results can be achieved by using the outputs of numerical and analytical models simultaneously [19].

3- Appropriate Excavation Methods

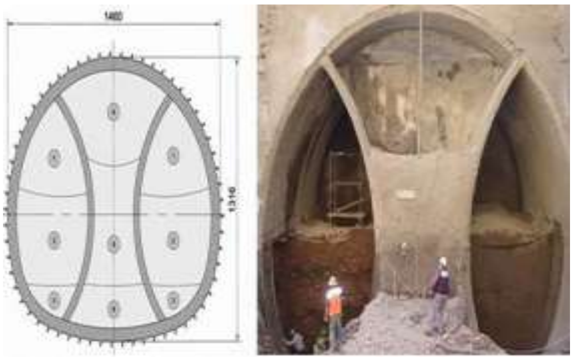
In tunnels excavation in weak and low-strength soil, especially in tunnels with relatively large cross-sections, excavating the entire tunnel cross-section is not possible in one phase possibility of landslides due to unauthorized subsidence, uneconomic operations, etc. Two standard solutions in such cases are the use of land improvement models to improve the soil resistance parameters and increase the stability and the use of excavation phases models that are used according to the conditions of one or a combination of these two models [11] .

With the development of the urban subway, its constructions will face increasing challenges such as space instability and excessive deformation at the ground level due to many factors such as complex geological conditions and limitations of adjacent structures [20].

One of the effective methods in reducing displacements and controlling instability is the NATM excavation model. This model is implemented in three different ways. As shown in Figure 1.



a)The single walls opening model



b)The double walls opening model

c) The model of opening from the upper level

Fig. 1-. Different NATM excavation models [21]

STM excavation model is another model of excavation large cross-section tunnels that was modeled on NATM excavation model in 1987 in China. This model is designed for Cut-and-cover tunnels in urban areas with a high concentration of buildings and poor soil [10].

The main difference between NATM and STM models is in the philosophy of their use. In the NATM-based model, the ground resistance is mobilized by allowing controlled deformations, while in the STM model, instead of allowing the earth to move, the subsidence of the ground should be strictly controlled [10]. In other words, STM implements the models used in NATM but does not necessarily use the NATM philosophy.

Although many structures have been constructed using this model, few articles have been published in journals [22, 10].

This excavation model has subgroups consisting of stage excavation, Middle Drift Model excavation, intermediate thrust model, and central columns. Different subgroups of the STM model are used based on different conditions of the station's dimensions and geometry. The MDA model can implement single-arc and three-arc three-span stations, as shown in Figure 2.

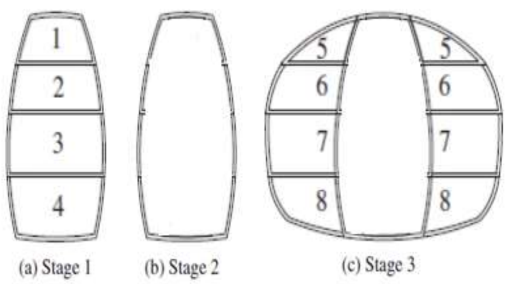


Fig. 2-. STM excavation method of MDA subgroup [10]

Another excavation method for building large subway stations is the cut and cover method. This method is mainly used in areas with a low concentration of surface structures [24, 23]. A trench of suitable width will be created from the ground level to the tunnel floor's depth, and the trench walls will be reinforced. The station's walls and roof will be built, and then it will be due to the ground level. This method is possible when there are no surface structures at the site, or their destruction is possible. On the other hand, water, sewage, electricity, gas, and telephone networks will create problems for implementing this method in urban areas. In such cases, these networks must be relocated before the tunnel is constructed [25].

4- Pre-excavation Support Systems

A group of tunnel and station support systems is those systems that are constructed before the general excavation of the tunnel or station. As a result, the final excavation and construction of the tunnel are done. One of these support systems is a concrete arch system or pile and rib. The steps of implementing this support system are as follows:

A. Initially, the primary tunnel is constructed with a small cross-section along with the underground space.

B. From the executed middle tunnel, small access galleries at certain distances are drilled transversely to both sides in the main underground space.

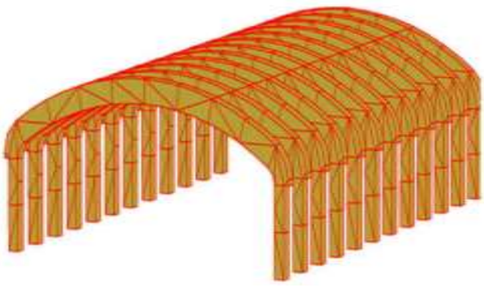
C. From the end of the created cross-access galleries, two side galleries are drilled parallel to the primary, middle tunnel and with a length equal to the main underground space.

D. From inside the side galleries, a row of piles is executed at regular intervals.

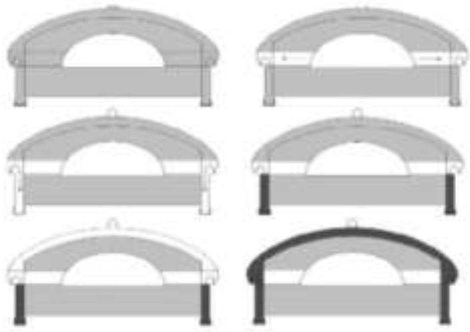
E- Also, from the top of the piles on both sides, a gallery with a horseshoe cross-section is drilled, which is a gallery to create a retaining arch that connects the two opposite piles on both sides of the main grilling area. As shown in Figure 3-(a), in this method, underground, reinforced concrete elements, including piles and arched arches (ribs), are executed around the desired underground space before excavation in order to maintain the ground during excavation. [9]. As in Figure 3- (b), the implementation of this support system is shown schematically. In this way, a row of parallel concrete arches is created in the basement, which acts as a guard structure. After implementing concrete piles and arches, the desired space is drilled in this guard structure's shelter with high safety. Figure 4 shows a view of implementing this support system in one of the Isfahan subway stations. On the left side of the figure, the pile and their connection to the ceiling ribs are marked. The propulsion system is another extensive cross-sectional underground support system that is part of the pre-containment method to protect the area that has not yet reached the excavation frontier. In this excavation method, as shown in Figure 5, first the boring machine drills holes in the tunnel arch with a slight angle of deviation from the horizon (usually between 5-10 degrees), then steel pipes or rods are placed in these holes, and the rest of the borehole space is filled with mortar. These boreholes are created in the tunnel arch to cover a space in the shape of an umbrella in the tunnel arch [8].

5- Details of the Studied Station

S Station is the 19th station on Line 2 on Zeinabieh Street, called S, located between Laleh Park and Ashegh Isfahani stations. In the initial studies, this station is defined in km: 20 + 400 with the code of level on the rail equal to + 1544 + 681 and the depth of the rail level: 17.31 [26]. Figure 6- a shows the location of the station on the aerial photograph. In Figure 6-b, the station location's rectangular reference points can be seen in terms of latitude and longitude. In the first phase of studies for designing S Station, three boreholes were excavated near the station's site. Based on excavating these boreholes, it was determined that this area is generally composed of alluvial sediments that include 13 layers. Most of these layers are made of sand, clay, weld stone, loam, dirty sand, and dirty clay. Figure 7 shows the geological section and the BH41 borehole and how the layers are positioned relative to each other [26]. The area has thirteen alluvial layers. For studies and numerical modeling of the S station, due to the low thickness of some layers and the similarity in mechanical characteristics, some layers were combined to facilitate the work, and finally, six layers were identified. Geomechanical characteristics of soil layers have been determined based on experiments performed. You can see these specifications in Table 1. According to the latest studies conducted in the study area, the groundwater level is relatively deep and is located at a depth of 21 meters above the ground.



(a) Concrete elements of piles and ribs



(b) Implementation of the pile and rib support system stages

Fig. 3-. The pile and rib support system

Fig. 4-. A view of the pile and rib support system implemented in one of Isfahan subway stations

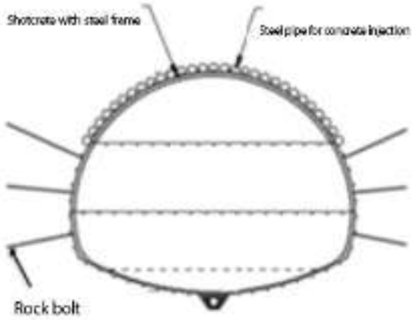


Fig. 5-. fore polling support system [8]

a)The project location based on the aerial photo

b) Longitude and latitude of quadrilateral spots of S station

Fig. 6-. Project location

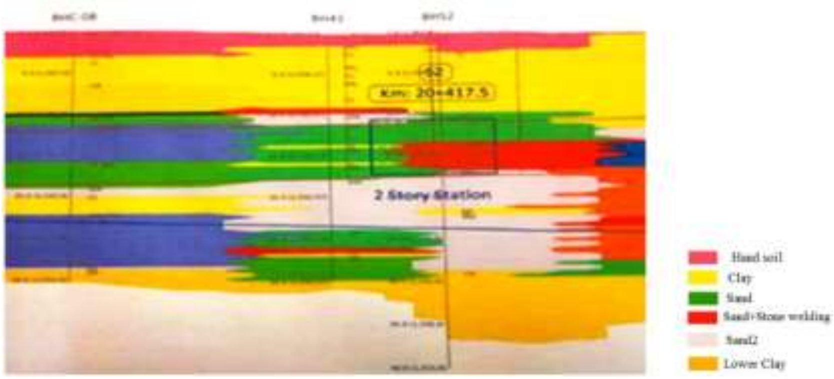


Fig. 7-. geologic profile of the project site [26]

Table 1-. Characteristics of soil layers in Mohr-Coulomb Theory [27]

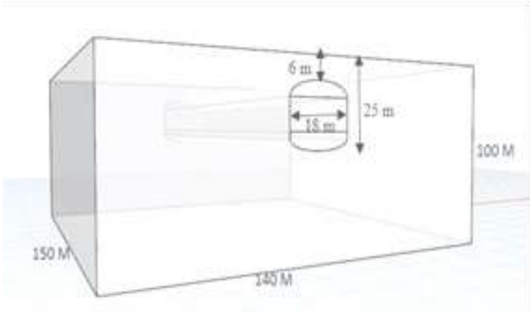
Name	Volumetric Modulus (GPa)	Shear Modulus (GPa)	Saturation Density (Kg /m^3)	Dry Density (Kg /m^3)	Poisson's Ratio	Young's Modulus (GPa)	Friction Angle (Degree)	Cohesion (GPa)	Depth (Meters)
Hand soil	1.6	0.5	2100	1800	0.35	0.015	23	0.015	0-3
Clay	2.1	0.7	2100	1660	0.35	0.019	28	0.01	3-8
Sand	2.6	0.9	2000	1600	0.35	0.024	22	0.038	8-12
Sand + stone welding	3	1	2150	1800	0.35	0.027	28	0.035	12-20
Sand	2.5	0.85	1970	1560	0.35	0.023	26	0.028	20-27
Lower clay	3.3	1.1	2000	1650	0.35	0.03	25	0.040	27-70

6- Numerical Modeling Process

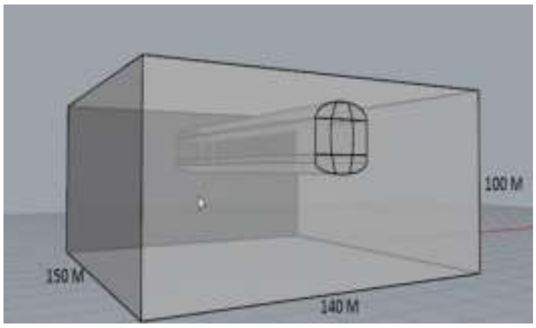
Due to the necessity of modeling the different stages of geometric modeling, excavation, and three-dimensional analysis of the problem, in this research, Rhino, Kubrix, and FLAC3D software have been used for numerical modeling. The modeling of NATM and STM excavation methods has relatively complex excavation and geometry steps. Since the dimensions and meshing methods significantly affect the output of the model, the initial geometry and meshing were performed using intermediate software such as Rhino and Kubrick so that the dimensions of the meshes were almost the same. The general dimensions of the NATM and STM excavation model are 150 × 100 × 140 meters, and the model of cut and cover method was designed with dimensions of 150 × 100 × 110 meters. After making the models in Rhino software, meshing with Kubrix software is done in FLAC3D software format.

The dimensions of the model and the excavation location were selected so that the boundary conditions did not affect the stress values and the displacement of the excavated space, and the symmetry of the model

was maintained. Figure 8 shows the dimensions and shape of these models in Rhino software. Due to the ease of modeling, the cut and cover excavation model was built directly in FLAC3D software. The general model and excavation stages are shown in Figure 9. Figure 10 shows the transition shapes to FLAC3D software and their meshing. After implementing the software models, the geomechanical characteristics of the soil layers are applied to the model. The behavioral model is considered as Mohr-Coulomb theory models. The surface load of 2000 kg / m2 was applied to the general surface above the model due to the 2-story buildings around the station site and the road's passage over the station site.



(a) NATM excavation model



(b) STM excavation model

Fig. 8-. Basic geometric model of NATM and STM excavation model in Rhino environment

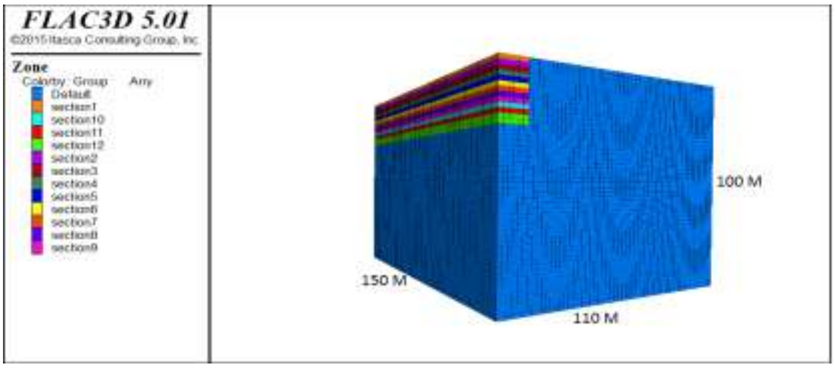
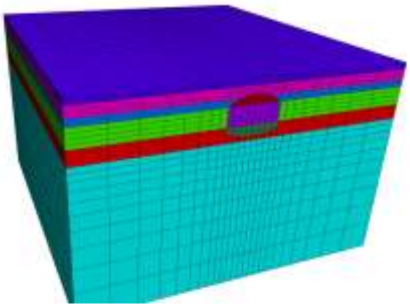
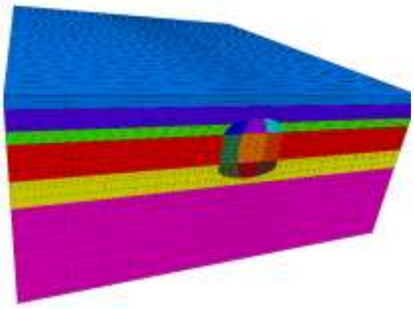


Fig. 9-. Cut and cover model in FLAC 3D environment



(a) Meshing modeling of NATM excavation method



(b) Meshing modeling of STM excavation method

Fig. 10-. Meshing with Kubrix software

6-1- Numerical Model Validation

Before performing the primary analysis, the numerical model's validation was evaluated from two aspects: the validity of the software and the second's validity. To ensure the efficiency and accuracy of the software, two models of underground excavation examples were implemented. These models were available in the software manual, and then the results were compared with the results presented in the manual, which was entirely consistent. After ensuring the software's correct operation, the tunnel's initial model was validated based on the data obtained from the instrumentation and behavior in the project. In this project, behavioral surveying is performed based on measuring the displacement at the surface of the excavation space (roof and walls) and the ground at specific points by accurate mapping cameras. These points are shown schematically in Figure 11.

In urban areas, a complete survey of surface displacement is impossible. Due to the availability of the results recorded in one of the sections of installation of behavioral points in off-road space and adjacent buildings on the ground, the same section that is almost close to the middle of the station space was used to control the displacement of the model. The results are shown in Figure 12. These results indicate that the numerical model fits well with the actual conditions.

6-2- Excavation Stages in the Numerical Model of NATM Method

In NATM excavation, the tunnel is first divided into three parts, the tunnel crown, the middle, and the lower platform. Excavation stages for this method are 5 meters. Excavation starts from the crown of the tunnel and progresses along three excavation stages. Then the middle of the tunnel is dug two steps, and in the next stage, the lower platform is dug 1 step. In the advances of the following stages, each of the three sections of the tunnel in each stage is dug evenly along with the two steps (Figure 13- (a)).

After each excavation stage, the shotcrete support and nailing system of the previous stage are performed. In the case of a pile and rib support system, first, the pile and rib support system is applied to the whole model, and then the excavation stages will be performed as in the previous part. Figure 13- (b) shows shotcrete and nail storage systems, and Figure 13- (c) shows shotcrete, pile, and rib storage systems. The fore polling support system overlaps the pipes of the previous stage by 3 meters in each section. In this way, after installing a series of pipes with a length of 12 meters in one section, with the tunnel's progress at a rate of 9 meters, the fore polling pipes of the next section will be installed. Figure 13- (d) shows the view of the fore polling support system with shotcrete.

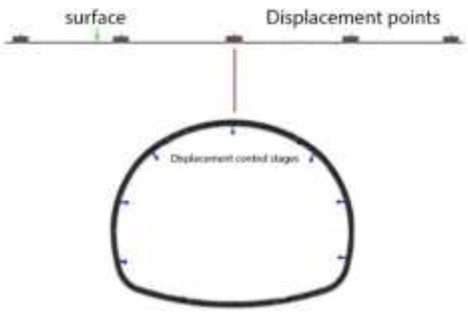


Fig. 11-. Schematic representation of displacement measurement points

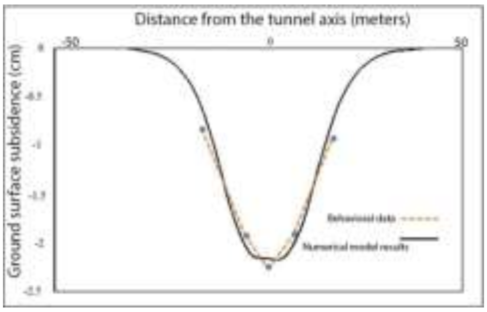
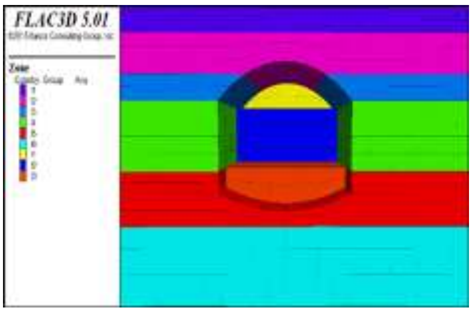
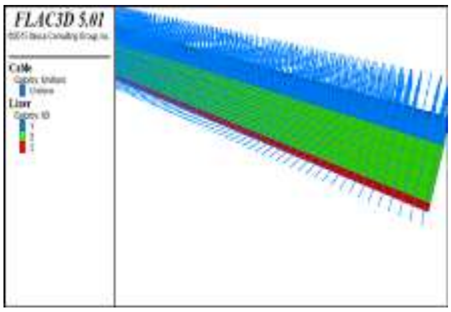


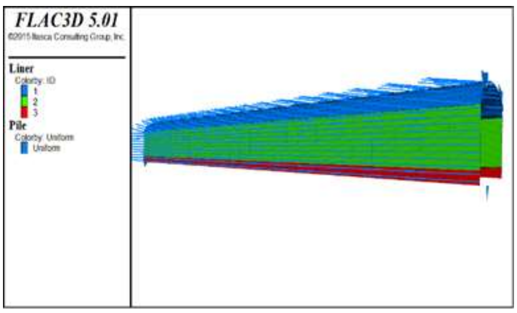
Fig. 12-. surface displacement obtained from the results of numerical analysis and behavioral data



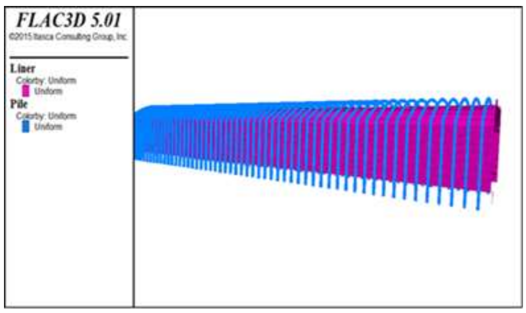
a) NATM excavation model



b) Soil nailing system with shotcrete



c) Fore polling maintenance system with shotcrete



d) Piles and rib maintenance system with shotcrete

Fig. 13-. Excavation stages by NATM model and support systems

6-3- Excavation Stages in STM Numerical Model

In the STM excavation model, the frontier is divided into nine parts. First, it is divided into three parallel tunnels with equal areas, and each of these three parallel tunnels is divided into three parts, the tunnel crown, the middle part, and the lower platform, like the NATM method. In the first stage, excavation starts from the middle tunnel, and the sequence of excavation steps is applied as in the NATM method. After excavating the central tunnel and implementing the support system, it is time to excavate the two side tunnels simultaneously and excavation steps as in the previous step, but before each excavation step, the central tunnel support system in that part of the model must be removed. Figure 14 shows the excavation steps of the STM model. After excavating each stage of the side tunnels in the STM model, the previous excavating stage's support system is performed in the tunnel. These support systems are the same as the support systems in NATM in terms of dimensions, shape, and mechanical properties. Because the final excavating shape in these two excavation methods will eventually be the same, the support systems in both methods have the same shape.

6-4- Excavation Stages in a Numerical Model of Cut and Cover Method

In the cut and cover excavation method, one of the hollow walls was examined. Vertical drilling stages are considered 2 meters in this model; the wall's final depth is 25 meters above the ground. After excavating each stage, the wall support system is run at the same time.The support system in the cut and cover model is a combination of soil nailing with piles. The horizontal distance of the nails is 1.5 meters, and their vertical distance is 2 meters. The piles are modeled with a distance of 1.5 meters from the center to the center and with diameters of 0.3, 0.5, 0.75, 1, 1.25, and 1.5 meters and a length of 32 meters according to the consultant design. Figure 15- (a) shows the excavated pit model, and Figure 15- (b) presents the support system. The soil nailing system was examined with a horizontal distance of 1.5 m and a vertical distance of 2 m and with lengths of 6 to 16 m as increasing the length by 2 m in each model and changing the diameter from 12 mm to 30 mm. Table 2 presents the mechanical properties of the nails.

Table 2-. Mechanical specifications of the nailing system [27]

Young's modulus	$200*10^9$ Pa
Tensile Yield Strength	$1*10^{10}$ Pa
Slurry cohesion	$1*10^2$ Pa
Slurry friction angle	25 degrees

The shotcrete system used in all three excavation methods is the same and has been executed with a thickness of 2 m, presented in Table 3 as the shotcrete support system's mechanical properties.

Table 3-. Mechanical Specifications of Shotcrete [27]

Poisson's ratio	0.25
Young's modulus	$10.5*10^9$ Pa
Normal Stiffness	$7.4*10^{10}$ Pa/m
Shear Stiffness	$7.4*10^9$ Pa/m

The fore polling support system of pipes with a length of 12 meters and an angle of 10 degrees to the horizon with a length of 3 meters were investigated. Table 4 shows the mechanical properties of fore polling pipes. The pile and rib support system and the piles are modeled with a distance of 1.5 meters from the center to the center and diameters of 0.3, 0.5, 0.75, 1, 1.25, and 1.5 meters. Pile and ribs properties, pile, and foreboding are the same in FLAC 3D software; Table 4 presents the mechanical specifications of pile and ribs, pile and fore polling.

Table 4-. Mechanical Specifications of fore polling, Piles, Ribs, and piles [27]

Poisson's ratio	0.3
Young's modulus	$8*10^{10}$ Pa
Shear Stiffness	$1.3*10^{10}$ Pa / m
Shear cohesion	$1*10^2$ Pa
Shear friction angle	15 Degrees
Normal Stiffness	$1.3*10^{11}$ Pa / m

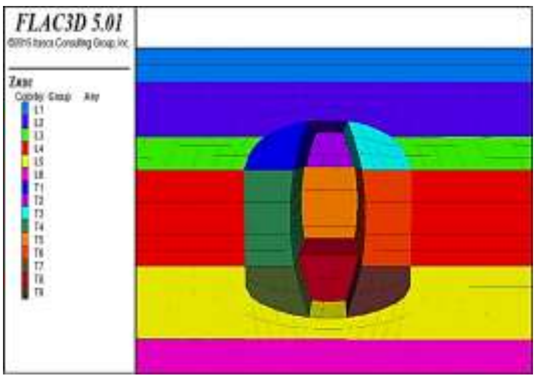
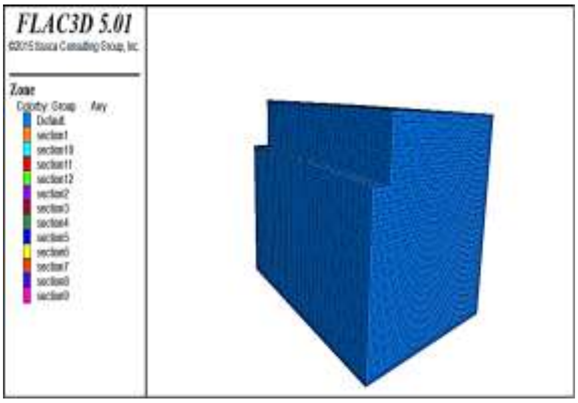
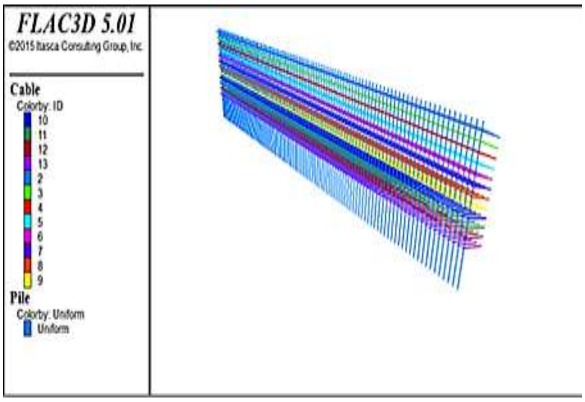


Fig. 14-. Central tunnel excavation and STM excavation scheme diagram



(a) Excavation by cut and cover model



(b) Pile support and soil nailing system

Fig. 15-. Excavation model and support system by cut and cover model

7- Comparing the results of station excavation modeling in different models

The desired space excavation has been modeled precisely according to the models presented in different methods, and the results have been studied and compared.

7-1- Displacement in the crown, wall, and floor of the tunnel in NATM excavation method

In the NATM excavation model, three systems of soil nailing, pile, rib, and fore polling were used simultaneously with shotcrete. As presented in the previous section, different lengths and diameters of piles and ribs, fore polling, and soil nails have been studied.

To evaluate the displacement results due to the change in the diameter of the nails, diameters of 12, 20, 22, 24, 26, 28, and 30 mm were investigated, and a length of 6 m for the nails was considered as the initial and fixed length of the modeling.

As shown in Figure 16- (a), the displacements decrease significantly as the diameter increases due to the increase in the nails' tensile strength. To investigate the change in the nails' length, by examining the change in diameters previously performed, a

diameter of 26 mm has been considered fixed, and the lengths of 6, 8, 10, 12, 14, and 16 meters have been examined.

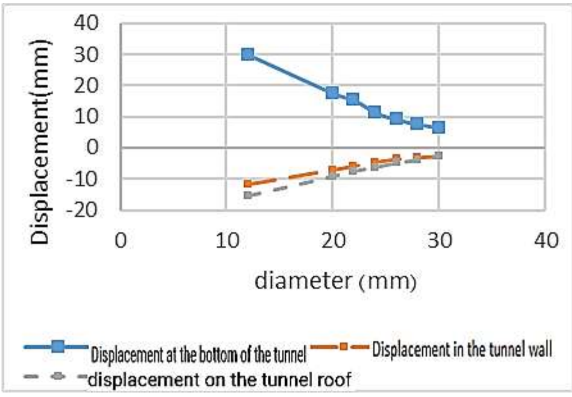
The point is that with the constant height of the tunnel over 6 meters, the length of the nails only changes in the tunnel wall and is fixed in the tunnel roof. Figures 16- (b) -16 (c) show the displacement in the wall, floor, and tunnel roof. It can be seen that increasing the nails' length did not have much effect on the displacements.

To investigate the effect of the pile and rib support system and fore polling on the number of displacements, only their diameter parameter was examined, and their center-to-center distance (number) was considered fixed. Figures 16-(d) and 16-(e) show the amount of displacement due to changes in the diameter of piles and ribs and fore polling in different parts of the tunnel, respectively. All outputs are recorded at each stage after the model reaches equilibrium.

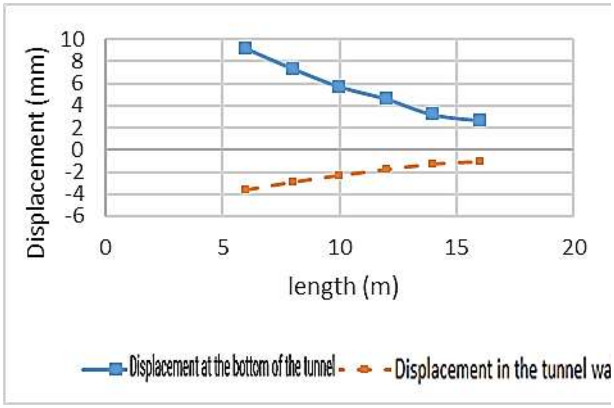
7-2- Displacement in the crown, wall, and floor of the tunnel in STM excavation method

In the STM excavation model, three soil nailing, pile and rib, and fore polling are used simultaneously with shotcrete, such as the NATM model. Changing the diameter and length of support systems is similar to the NATM model. Consequently, we avoid mentioning them again to prevent duplication. Figure 17- (a) compares the amount of displacement due to the change in the diameter of the nails, and Figures -17 (b) and 17- (c) show the amount of displacement due to the change in the length of the nails in the tunnel wall. Here the parameters under consideration are similar to the parameters of the NATM model.

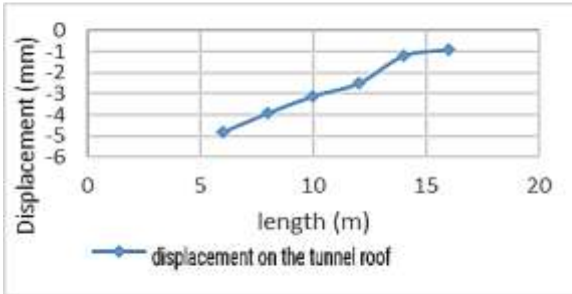
Considering that the support system's parameters in this model are the same as the NATM model, in Figure 17- (d), we can see the amount of displacement due to changes in the pile and rib diameter. In the fore polling support system, the diameter parameter was investigated, the size of the diameter variable is considered the same using the NATM model. Figure 15- (e) shows the amount of displacement due to the change in the diameter of the fore polling.



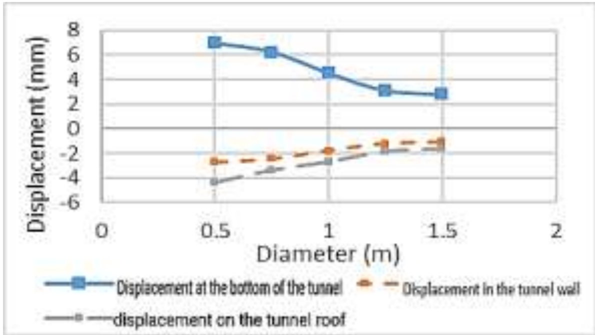
a) Investigating the effect of changing the diameter of the nails



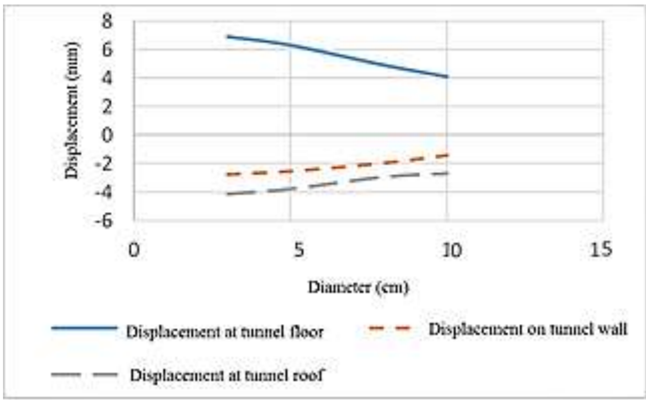
b) Investigating the effect of changing the length of the nails



c) Investigating the effect of changing the length of the nails

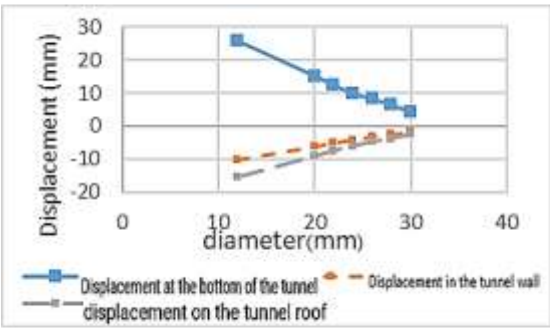


d) Investigating the effect of changing the diameter of the pile and the rib

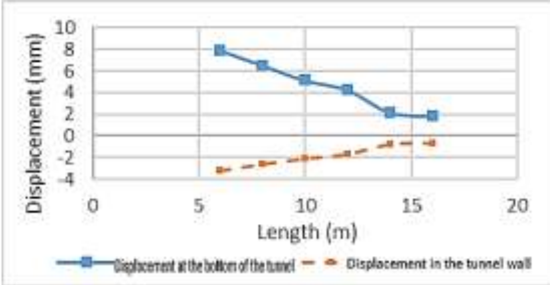


e) Investigating the effect of change in the diameter of the fore polling

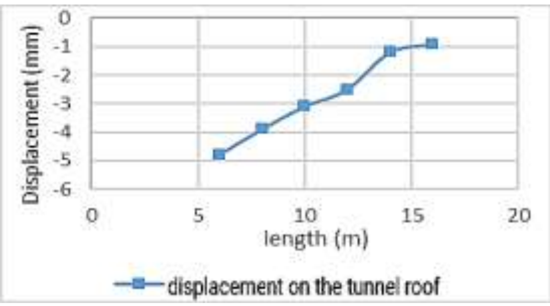
Fig. 16-. Investigation of displacements in NATM excavation method



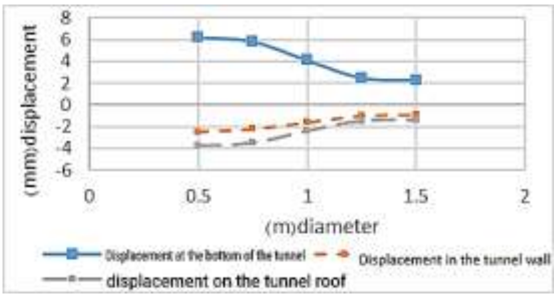
(a) Investigating the effect of changing the diameter of the nails



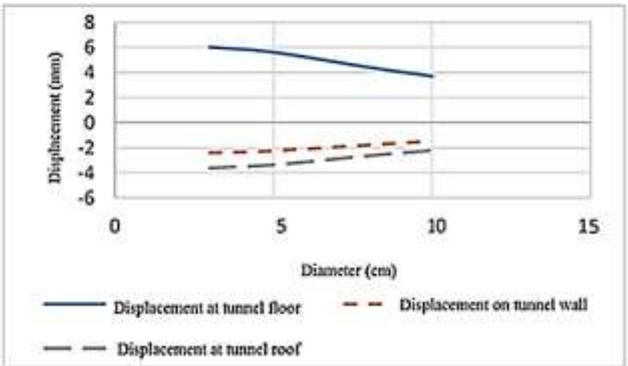
b) Investigating the effect of changing the length of the nails



c) Investigating the effect of changing the length of the nails



d) Investigating the effect of changing the diameter of the pile and the rib



e) Investigating the effect of change in the diameter of the fore polling

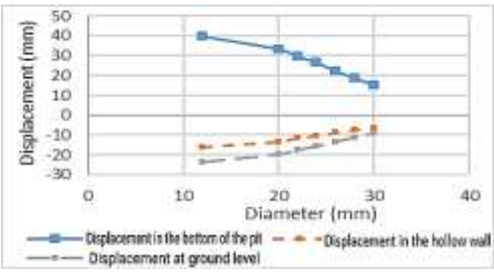
Fig. 17-. Investigation on displacements in STM excavation method

7-3- Displacement of the wall, floor, and edge of the pit on the ground in cut and cover method

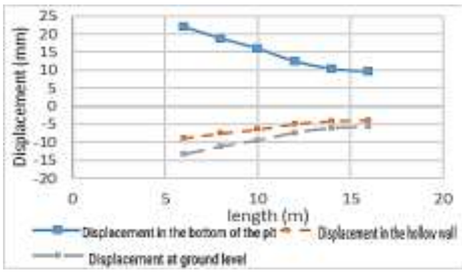
In the cut and cover excavation model, nail and pile holding systems protect the pit. The distance between the nails and their variable parameters is the same as the previous methods, and in piles, the center-to-center distance of the piles and the variable diameter parameter, such as the pile and rib system, is considered as in the previous drilling methods.

Figure 18 (a) shows the amount of displacement in different parts of the pit due to changes in the nails' diameter with an initial fixed length of 6 meters. Figure 18- (b) shows the amount of displacement due to the change in the nails' length with a fixed diameter of 28 mm.

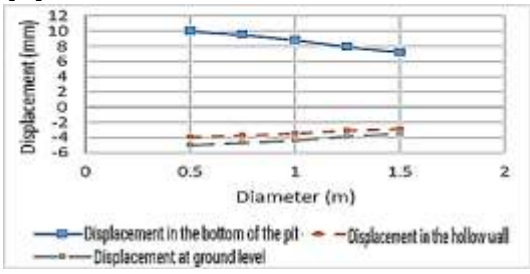
In Figure 18- (c), the amount of displacement due to the change in the piles' diameter in the pit can be seen. The piles' variable parameters are the same as the pile and rib system in the NATM and STM models.



(a) Investigating the effect of changing the diameter of the nails



b) Investigating the effect of changing the length of the nails



c) Investigating the effect of change in the diameter of piles

Fig. 18-. Investigation of displacements in the cut and cover model

8- Conclusion

Estimating the impact of excavation methods on displacement is purely technical, and the implementation of these three methods has not been compared economically. According to the studies performed in the field of using different excavation methods of large cross-section tunnels and maintenance systems for Isfahan S metro station, some of the results can be explained as follows:

1-Increasing the diameter of the nails reduces the amount of movement in different parts of the tunnel. However, this change in diameter has little effect on the movement of different parts of the tunnel. By examining the change in nails' diameter in the STM and NATM excavation models, the STM method's displacement rate was about 12% less than the NATM drilling method.

2-Changes in the nails' length had a more significant effect on tunnel displacement rate than changes in the nails' diameter. In the STM excavation model, the number of displacements with the nail length change parameter was about 32% less than the NATM excavation model.

3-The amount of displacement has significantly decreased by changing the pile and rib diameter in the excavations. In the STM excavation model, the number of displacements was about 19% less than the NATM method.

4-With the change in the diameter of the concrete pipes of fore polling, the number of displacements has decreased a lot. In the STM model, the displacements were about 10% less than in the NATM model.

5-In the cut and cover excavation model, the amount of displacements is much more than other excavation models in this research. Compared to these three excavation models, the cut and cover model had about 57% more displacement than the NATM model and about 65% more than the STM model.

6-Comparing the maintenance systems with each other and the displacement rate in the best scenario, the nailing method has about 55% less displacement than the Fore polling system and 20% less displacement than the pile and rib system, and the pile and rib system has about 35% less displacement compared to the fore polling system.

7-In this research, the STM method's effect on reducing the displacement rate was more among the excavation models. At this station, it is recommended to use the STM excavation model and nail holding system.

REFERENCES

[1] Toraño, Javier, Rafael Rodríguez, Isidro Diego, and José M. Rivas. "*Estimation of settlements due to shallow* tunnels and their effects." Tunnelling and Underground Space Technology 21, no. 3-4 (2006).

[2] Yoo, Chungsik. "Performance of multi-faced tunnelling–A 3D numerical investigation." Tunnelling and underground space technology 24, no. 5 (2009): 562-573.

[3] Sharifzadeh, Mostafa, Farshad Kolivand, Masoud Ghorbani, and Shahaboddin Yasrobi. "Design of sequential excavation method for large span urban tunnels in soft ground–Niayesh tunnel." Tunnelling and Underground Space Technology 35 (2013): 178-188.

[4] Nowruzi Bazminabadi S, Ramezanzadeh A, Karimi Andani M, Hajar M, "Evaluation of the temporary maintenance system of Tehran Niayesh tunnel based on meeting on urban lands", 10th International Congress of Civil Engineering, Tabriz, 2015. (In Persian)

[5] Khanlari Gh., Maleki M, Heidari Turkmani R, Alipour S, Naseri F, "Estimation of surface subsidence in Niayesh Highway Tunnel using experimental, numerical and real settlements methods" Journal of Engineering Geology, 9,2015. (In Persian)

[6] Hejazi Rad, S, Ganjian N, Mansouri M.R. "Study of appropriate methods of multi-stage drilling of deep underground stations - a case study of station x7 of Tehran metro line seven." Tunnel and underground spaces engineering, 2015; 4 (1): 33-52. (In Persian)

[7] Rihanian Zavareh, H., Hosseini, F and Talebinejad, A,R., "Determining the optimal distance of concrete arches and estimating the meeting in metro stations - Case study: Haft Tir station of Tehran metro line 6". Tunnel and underground spaces engineering, 2014; 2 (2): 121-132. (In Persian) doi: 10.22044 / tuse.2014.254

[8] Ocak, Ibrahim. "Control of surface settlements with umbrella arch method in second stage excavations of Istanbul Metro." Tunnelling and Underground Space Technology 23, no. 6 (2008): 674-681.

[9] Sadaghiani, Mohammad H., and Saleh Dadizadeh. "Study on the effect of a new construction method for a large span metro underground station in Tabriz-Iran." Tunnelling and underground space technology 25, no. 1 (2010): 63-69.

[10] Fang, Qian, Dingli Zhang, and Louis Ngai Yuen Wong. "Shallow tunnelling method (STM) for subway station construction in soft ground." Tunnelling and Underground Space Technology 29 (2012): 10-30.

[11] Moqbeli Oskooi A, Ajamzadeh H, Mansourzadeh Sam, Ismailpour Ghamshlour, "Application of Shallow Tunneling Method for Crossover Drilling in Poor Soils (Case Study: Shiraz Metro)", Transportation Research Journal, 2018 , 4, 60-45. (In Persian)

[12] Shariatmadari, N., P. Chaichi, and M. Moazami. "The survey of ground surface settlement caused by cut and cover tunnel excavation in Tabriz subway." Tunnelling and Underground Space Technology 21, no. 3-4 (2006).

[13] Wang, Tie Cheng, Yang Gao, and Hai Long Zhao. "Analysis of Mechanical Behavior of Subway Tunnel Constructed by Cover and Cut Reverse Method." In Advanced Materials Research, vol. 446, pp. 3623-3627. Trans Tech Publications Ltd, 2012.

[14] Zhou, Xiao Jun, Jing He Wang, Lu Lu Mao, and Rui Guo. "Design of Typical Subway Station Structure and its Enclosure with Open Cut Method in Chengdu City." In Applied Mechanics and Materials, vol. 501, pp. 1711-1714. Trans Tech Publications Ltd, 2014

[15] Guo, Yan Hui, and Ke Peng Hou. "Numerical simulation of ground surface settlement induced by open-cut subway station." In Applied Mechanics and Materials, vol. 522, pp. 1689-1692. Trans Tech Publications Ltd, 2014.

[16] Zhou, Shunhua, Honggui Di, Junhua Xiao, and Peixin Wang. "Differential settlement and induced structural damage in a cut-and-cover subway tunnel in a soft deposit." Journal of Performance of Constructed Facilities 30, no. 5 (2016): 04016028.

[17] Oke, Jeffrey, Nicholas Vlachopoulos, and Vassilis Marinos. "Umbrella arch nomenclature and selection methodology for temporary support systems for the design and construction of tunnels." Geotechnical and geological engineering 32, no. 1 (2014): 97-130.

[18] Oke, J., N. Vlachopoulos, and M. S. Diederichs. "Numerical analyses in the design of umbrella arch systems." Journal of Rock Mechanics and Geotechnical Engineering 6, no. 6 (2014): 546-564.

[19] Oke, Jeffrey, Nicholas Vlachopoulos, and Mark S. Diederichs. "Semi-analytical model for umbrella arch systems employed in squeezing ground conditions."Tunnelling and underground space technology 56 (2016): 136-156.

[20] Cao, Liqiang, Qian Fang, Dingli Zhang, and Tielin Chen. "Subway station construction using combined shield and shallow tunnelling method: case study of Gaojiayuan station in Beijing." Tunnelling and Underground Space Technology 82 (2018): 627-635

[21] Ajorloo, H. "Methods of construction of urban tunnels and related challenges, a case study: Resalat, Niayesh and Ahvaz metro tunnels", Tehran Center for Studies and Planning, 2015, Report 331.(In Persian)

[22] Xiang, Yanyong, Shaohui He, Zhijie Cui, and Suozhu Ma. "A subsurface “drift and pile” protection scheme for the construction of a shallow metro tunnel." Tunnelling and underground space technology 20, no. 1 (2005): 1-5.

[23] Hamza, M., A. Ata, and A. Roussin. "Ground movements due to the construction of cut-and-cover structures and slurry shield tunnel of the Cairo Metro." Tunnelling and Underground Space Technology 14, no. 3 (1999): 281-289.

[24] Hamza, M., A. Ata, and A. Roussin. "Ground movements due to the construction of cut-and-cover structures and slurry shield tunnel of the Cairo Metro." Tunnelling and Underground Space Technology 14, no. 3 (1999): 281-289.

[25] Grigson, R., Ho, C., LeMus, P., “Second avenue subway project: deep excavation support of a cut-and-cover station”. In: Geotechnical and Structural Engineering Congress (2016, pp. 402–415.

[26] Madani, H., "Tunnel construction (Vol. I), drilling and execution", Amirkabir University of Technology (Tehran Polytechnic), 650 pages, 2001. (In Persian)

[27] Isfahan Zayand Ab Company "Report on the review of methods and executive strategies of Oman Samani station", Iran, 2016. (In Persian)

[28] Azmoneh Foulad Consulting Engineers "Report on Laboratory and On-Site Results of Isfahan Line 2 Metro, Oman Samani Station Well"s, 2015. (In Persian).