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Interaction of Excavated Tunnels by Earth Pressure Balance Machines and Sub-surface Obstacles; Case Study: Tehran Metro Line 7

Dariush Mohammadi[1&2], Kourosh Shahriar[1*] and Davoud Parsapour[2]

1. Department of Mining Engineering, Amirkabir University of Technology, Tehran, Iran
2. Department of Civil and Environmental Engineering, Amirkabir University of Technology, Tehran, Iran

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Abstract

Tunneling in urban areas has always encountered many uncertainties, which if not considered in both analysis and design of the tunnels, will cause unexpected events during tunnel construction. Obstacles are among the most remarkable uncertainties in tunneling that affect the tunnel construction process. The obstacles in urban tunneling include municipal utilities, surface and sub-surface structures, channels, wells, storages, and unknown cavities. Tehran Metro Line 7 in Iran is no exception to the rule, and has been grappling with the obstacles. In this work, we investigate the effect of the existence of wells and unknown cavities in the zone of influence of excavated tunnels by EPBM. The innovation of this research work is in the EPB tunnel design encountering wells and cavities that are as risky as the adjacent underground structure. In this work, we use a numerical simulation of the 3D finite difference method (FDM) so a series of parametric studies based on the numerical model are examined using the well and unknown cavity geometry and their location relative to the tunnel in alluvium. According to the results obtained, a major disturbance occurs in the near field of the well–tunnel, and the interaction problem happens in front of the tunnel face. The numerical outcome indicates that the most critical state of the ground settlement by EPBM happens when the well and unknown cavity are located in the face of the tunnel. It is also proved that the ground behavior is different for each part of EPBM such as ahead of the face, cutter head, shield, and segmental lining parts.

1. Introduction

Cities have usually been developed in alluvial areas. Therefore, there is no choice for tunnel and underground space excavation except in soft ground. Furthermore, for people's rapid access, underground structures in urban areas should be constructed in lower depths from the natural surface. Thus excavation is carried out in loose and alternating zones. As tunneling projects have a larger scale compared with site investigations, it can be stated that the tunnel constructors encounter an unknown host ground. As a result, there are no definite parameters in the tunneling process, so tunneling in urban areas always faces many uncertainties.

Underground excavation causes a disturbance in the state of the stress in the ground, and creates a new stress regime in the form of a bulb around the advancing tunnel face [1]. Stress concentration and relaxation are created around an excavation zone so the stress redistribution process causes a plastic zone once the ground reaches a stable state, which may generally be accompanied by ground surface settlement or collapse [2]. The concept of the zone of influence is important in tunnel design since it may

Corresponding author: k.shahriar@aut.ac.ir (K. Shahriar).

provide a considerable simplification of the design problem. The essential idea of the zone of influence is that it defines domain of the significance of the pre-mining stress field due to excavation. It is different in near and far fields of an opening [3]. As depicted in Figure 1, the zone of influence around a circular opening of radius *"a"* occurs in the circular boundary around an excavation with a radius "*r"* as well as ahead of the opening face in the longitudinal direction [4].

The concept of the settlement originated in the mining activities in rock grounds that gradually enter the urban tunneling projects in soft grounds due to the sensitivity importance of this issue in urban areas. In the tunneling process, when the pressure-arch is created, the ground movements initiate from the opening, and spread toward the surface. The arching pressure differs in shallow versus deep tunnels. In a shallow tunnel, the pressure-arch reaches the ground surface, and has an interface with the ground; however, this is not always the case in a deep tunnel.

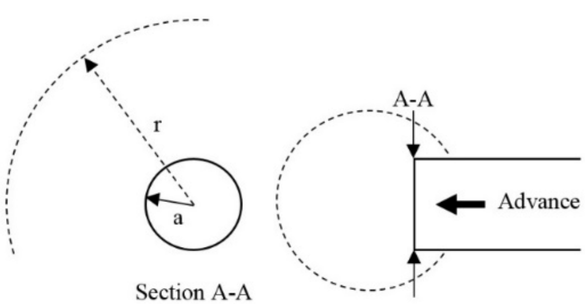

Figure 1. Zone of influence around and ahead of a circular opening.

A settlement basin happens after a shallow tunnel excavation, as shown in Figure 2. These displacements consist of two components, one in the vertical direction (*z* axis), which causes a gradual settlement, and the other in the horizontal direction (*x* and *y* axes), which causes a compression and tension condition in the longitudinal and transverse directions.

The surface and sub-surface settlement prediction approaches are divided into four categories [6]: (1) empirical and statistical method, (2) analytical method, (3) numerical method, and (4) laboratorial and physical method, in a Greenfield site case. The empirical studies that are based on a probability normal or Gaussian curve have been proposed by Peck, Oteo, and O'Reilly in order to predict the transverse direction of the surface settlement [7-9], and Romo and Attewell in order to predict the longitudinal direction (the tunnel axis) of the surface settlement [10, 11]. Sagaseta *et al.* have proposed the first analytical equation to predict the surface settlement [12], and then revised the equation (e.g. [13-15]). Recently, many researchers have used the numerical methods to predict the settlement. A series of 3D finite element models to investigate the settlement measurement and interaction problem of the Milan underground project in Italy, line 1 of Shiraz metro in Iran, and Taipei Rapid Transit System (TRTS) in Taiwan have been developed by Migliazza *et al*., Afifipour *et al*., and Chen *et al*., respectively [5- 17]. Other numerical studies have concentrated on the EPB mechanized tunneling settlement process such as face pressure [18, 19], backfill grouting [20, 21], and segmental lining [22-25].

In this research work, the problem statement in Tehran Metro Line 7 is first illustrated, and the obstacle – tunnel interaction will be discussed in detail. Then the numerical analysis will be used in order to compare different scenarios through evaluation of ground deformation. The aim of this research work is EPB tunnel design encountering wells and cavities that are as risky as the adjacent tunnel in numerical model. In this paper, we will show that the tunnel-obstacle interaction is important in the EPB tunnel design aspects in urban area, so a series of parametric studies are examined using the well and unknown cavity geometry and their location relative to the tunnel.

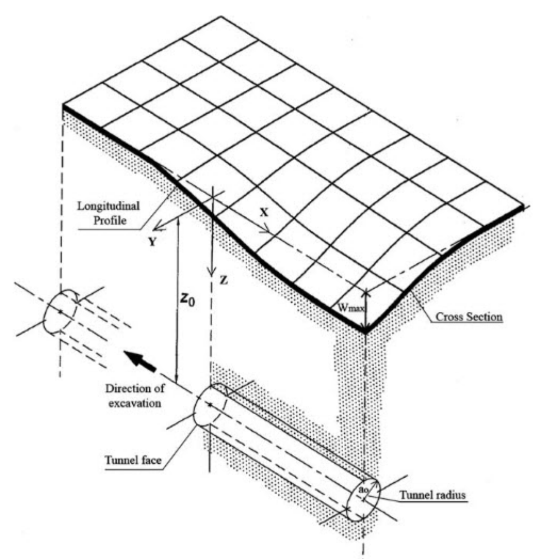

Figure 2. Settlement basin induced by a shallow tunnel excavation [5].

2. Problem statement

Generally, the route of a tunnel in urban areas is chosen to pass right under the city streets and Greenfield sites with a suitable burial depth to reduce the tunneling effect on the surface structures and infrastructures. However, the excessive ground settlements and collapses occasionally occur in the tunneling projects. The ground settlement has occurred in urban areas in the last decade due to the fact that tunneling has been one of the main crises in the developing countries. Notable tunnel failures from 1964 to 2015 in the world were reported by CEDD [26]. The obstacles such as municipal utilities, surface and sub-surface structures, channels, wells, storages, and unknown cavities can be regarded as the important reasons for ground collapse in urban tunneling. Some researchers have described the obstacle–tunnel interaction such as building and surface structures [27, 28], underground structures [29-31], foundation excavation [32], and municipal utilities [33]. However, Line 7 of Tehran Metro mechanized tunneling group reports indicate that the wells and cavity have been a contributing factor to the huge collapse. Thus tunnel–well and tunnel-cavity interaction has received less attention in CEDD [26] and other reports [27-33]. Tunnel-well interaction in Istanbul metro project, Turkey, was reported by Ayaydin [34]. Also Siow [35] in the smart tunnel project, Malaysia, Lyu et al. [36], and Ou et al. [37] have approved the tunnel–cavity interaction.

This research paper focuses on the tunnel–well and tunnel–cavity interaction, less discussed in the literature, especially the EPB tunnel–obstacle interaction, and describes the unexpected events during the tunnel construction when the tunnel construction process faces the obstacles. The innovation of the research work is in the EPB tunnel design encountering wells and cavities, especially on the surface settlement and plastic points. Thus well and cavity are as risky as the adjacent underground structure.

In a tunnel project, the obstacles are usually identified in the initial and final phases, and their risk is investigated during the construction process. Figure 3 shows the obstacle classification in urban tunneling. According to this figure, the obstacles in urban tunneling are divided into the two categories of surface and sub-surface with linear and point structures. Some obstacles are located on the surface so they are easier to identify; others are covered by soil and asphalt, and are hidden from the view so their risk during tunnel operation increases. In other words, it can be stated that the obstacles in urban tunneling are divided into two definite and probable types.

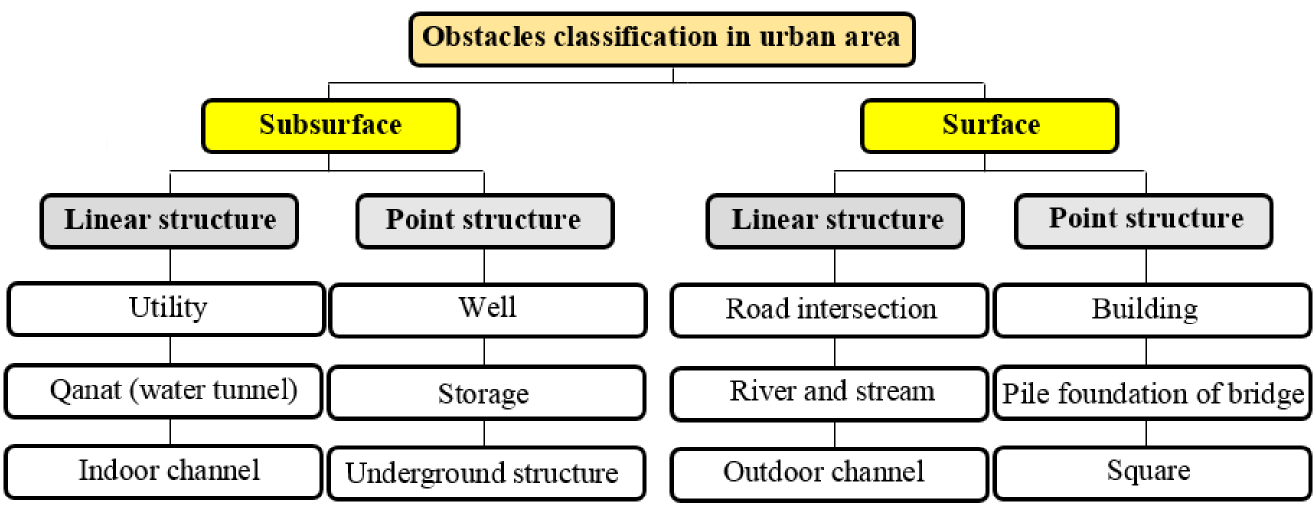

Figure 3. Obstacle classification in urban tunneling.

Tehran Metro Line 7 (Iran) is not an exception to the rule, and has been grappling with the obstacles since its construction began. This rail tunneling project is 27 km long with 22 stations, which connects SE of Tehran to its NW. For the construction of Tehran Metro Line 7, two 9.16 m diameter EPBMs were used in the soft ground. In the north section of the project, the tunnel is passing through a saturated host ground and a high groundwater level. Therefore, as shown in Figure 4, in order to build the W7 Station in this area, there was no choice but to construct the station using a diaphragm wall (slurry wall) method in a shallow depth. The tunnel rail level is supposed to reach the station rail level so the tunnel should pass through an overburden with -7.5 m depth at a chainage of 21 + 700 to 22 + 150. Under these conditions, the ratio of the overburden to tunnel diameter (O/D) is lower than 1, the risk of which is unacceptable in the world, and is almost impossible scientifically.

Figure 4. Aerial photograph of the studied area (location of San'at Square and line 7 of Tehran Metro) and field observation.

On March 8, 2015, when EPBM was digging the tunnel right below the Sheikh Fazlollah Nouri EXPY and San'at Square, the settlement signs were observed at a chainage of 21 + 100 to 21 + 110, as illustrated in Figure 4. Field observation and monitoring operation approved settlement expansion from 1:00 PM (12 mm on the tunnel axis based on the monitoring point) to 9:00 PM (29 mm on the tunnel axis based on the monitoring point) and surface crack according to Figure 5.

Finally, on March 9, 2015, at 2:00 AM, a crater with 6 m length, 3 m width, and 3.5 m depth was created in the San'at Square. No one was injured in this incident. The crater was filled by aggregate and concrete (Figure 6).

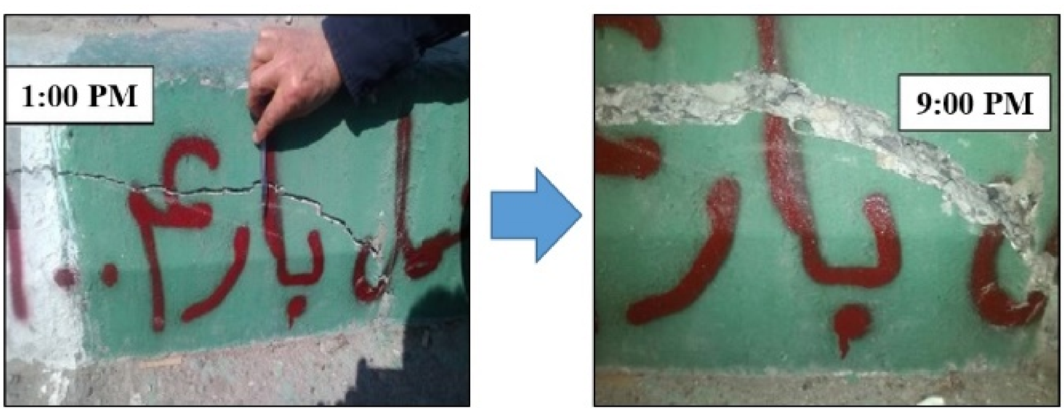

Figure 5. Settlement sign and crack expansion from 1:00 PM to 9:00 PM.

Figure 6. Filled crater by aggregate and concrete.

Subsequently, site investigations were focused on the collapsed area, tunnel face, and cutter head. Based on these investigations, it was confirmed that the masonry materials existed in the cutter head section (Figure 7). As a result, the existence of an abandoned well was confirmed above the tunnel.

According to Figure 8 (Step 1), a filled well with loosely materials is covered with asphalt. When EPBM was approaching the well, it came into the zone of influence of the tunnel [38]. Consequently, the wall of the well got loose (Figure 8, Step 2), and when the soil reached a plastic state, the ground around the well collapsed (Figure 8, Step 3). Reviewing the ground settlement and collapse history in Line 7 of Tehran Metro, it can be observed that the collapse incidents have happened in the pre-, mid-, and post-excavation stages. The EPBM functioning can also be divided into four categories based on the ground behavior: (1) ahead of the tunnel (zone 1), (2) cutter head (zone 2), (3) shield (zone 3), and (4) segmental part (zone 4), as depicted in Step 3 of Figure 8. The ground behavior is different in these four parts.

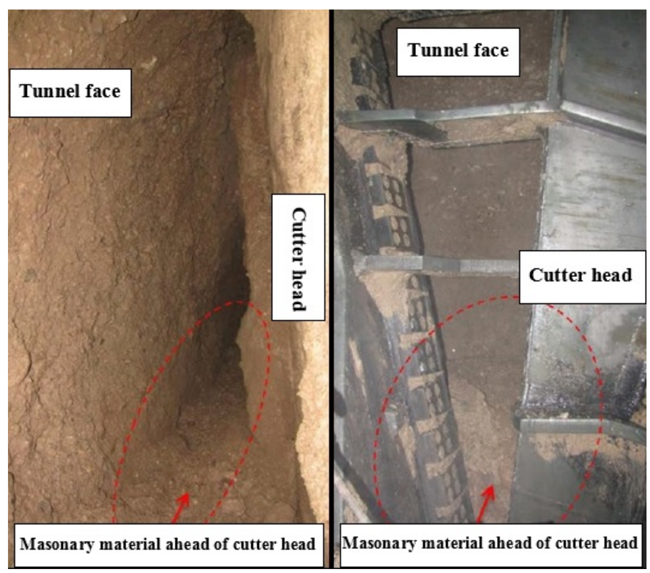

Figure 7. Masonry materials ahead of the cutter head and tunnel face.

It was also found that facing with unknown cavities was the main reason of the collapse. In the coarse-grain alluvial areas, the groundwater resources are extracted in order to compensate for a shortage of surface water resources. A continuous extraction beyond the capacity of the groundwater resources causes their drying up as a consequence. When these water resources are dried up, the underground caverns will be created within the alluvial areas.

3. Geological and geotechnical specifications

Tehran is located on Quaternary alluvium according to the geological classification of Rieben [39]. The city is located at the foot of the Alborz Mountain Range, which is basically composed of Eocene pyroclastic deposits (green tuff) and other volcanic rocks. The geology and the morphology of the Tehran region are similar to those of the other cities located at the foot of mountains. The Alborz

Mountain Range is steep, and mainly consists of tuff, limestone, and dolomite. The area experiences heavy rains in some seasons, and is seismically active. As a result, the non-uniform soil layers have been formed [39, 40].

The appropriate separation of the soil type is one of the most important activities that should be considered in the geotechnical studies of mechanized tunneling. For this purpose, investigations are carried out at the laboratory and field levels. The Line 7 of Tehran Metro passes through a host ground that can be divided into 6 geotechnical categories, namely ET-1 to ET-6. Based on the borehole (BH) and test pit (TP) results, the soil type from chainage 21 + 400 to W7 Station was determined to be of ET-5 type (Clayey silt and Silty clay with sand very sandy clay (or silt)), as illustrated in Figure 9.

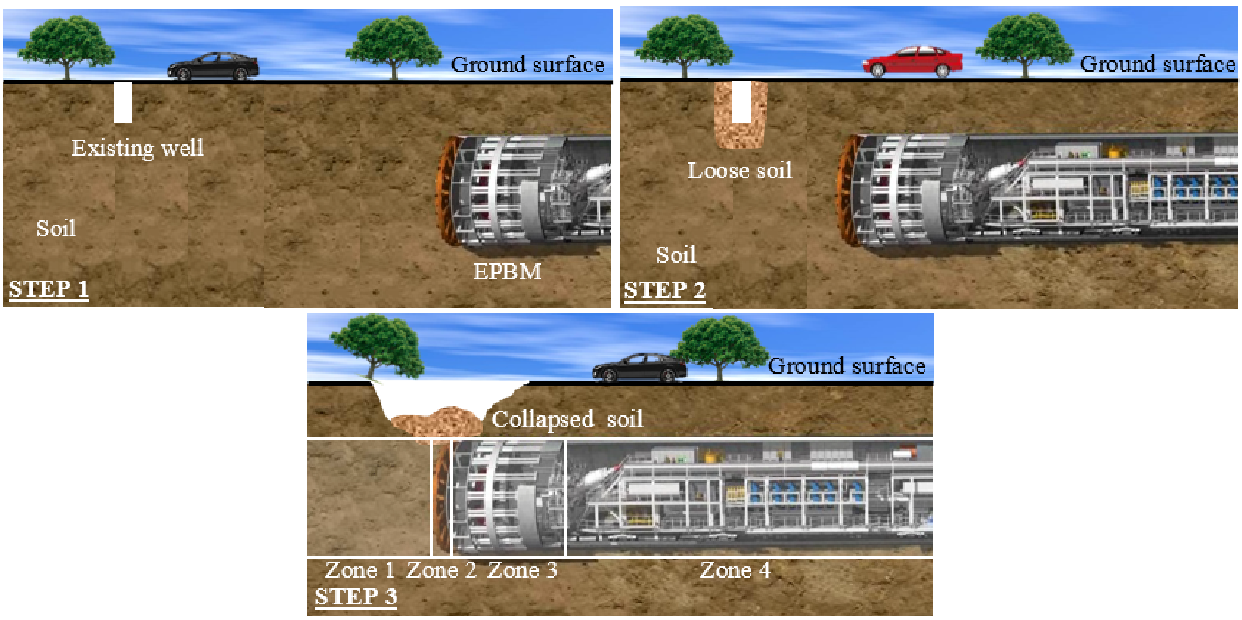

Figure 8. The EPBM–well interaction scenario.

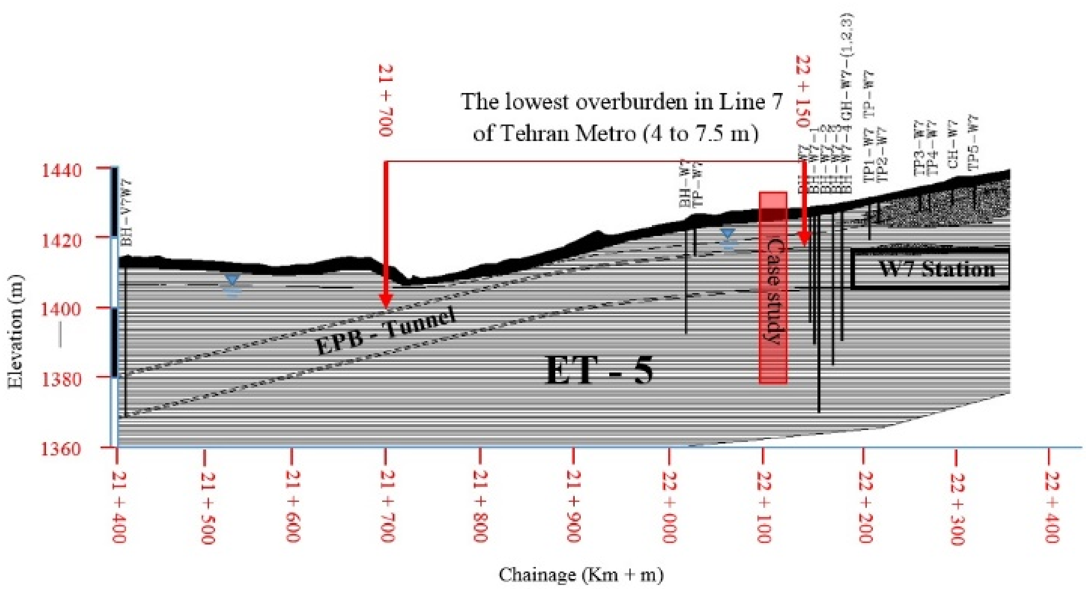

Figure 9. Geotechnical profile in the lowest overburden at line 7 of Tehran Metro and case study area.

The geotechnical parameters of ET-5 soil type are presented in Table 1. The groundwater level is 2-4 m based on the latest measurements. The groundwater table is higher than the tunnel crown level. The effect of the existence of water was considered in the numerical model.

Table 1.Geotechnical parameters of ground layers.

Soil type	Layer thickness (m)	Wet density (KN/m^3)	friction angle (degree)	Cohesion (KN/m^2)	Elastic modulus (KN/m^2)	Poisson ratio	$K_0 = 1 - \sin\varphi$
Man filled	0-1	16	22	25	15000	0.40	0.63
ET-5	>1	17	27	40	35000	0.35	0.55

4. Numerical model

The numerical method was used based on the field data, as described in Section 2, so as to investigate the existence of well and cavity on tunneling process. The proposed method can be considered in the EPB tunnel design encountering the obstacles, the risk of which must be recognized in the design and construction phase, consequently. The parametric studies on the geometry of the current obstacles and their location relative to the tunnel is important to accept their risk.

4.1. Finite difference method (FDM)

The basis for the numerical method is the transformation of a problem with an infinitive degree of freedom to a limited number of grid points. FDM is one of the oldest numerical methods used for solving differential equation systems, which is still widely used in solving the engineering problems.

The zone of influence around and ahead of the tunnel was considered 10 and 4 times the radius of the tunnel, respectively, and therefore, the numerical model geometry has 48 m width, 60 m height and 45 m length, as shown in Figure 10. Consequently, the boundary conditions of the model have no impact on the analysis. The model was pinned in the bottom boundary; meanwhile, it was also fixed in the horizontal direction on each side, and the top boundary was free in both directions. Due to the symmetry of the model and excavation steps, it was enough to develop half of the model to save the calculation time.

According to constitutive modeling, the soil layers and structural elements were modeled as Mohr-Coulomb and linear elastic material, respectively. The monitoring paths were selected in the transverse direction in the middle of the model at levels of 0, 2, 4, and 6 m below the ground surface and in a longitudinal direction on top of the tunnel axis (Figure 10). A well with 1 m diameter and 4 m depth was simulated symmetrically at the top of the tunnel. The traffic load was considered 20 KN/m^2 (uniform distributed load) at the top boundary.

4.2. Verification of numerical model

Tunnel construction causes disturbance in the ground equilibrium so the numerical model must be solved after each stage construction, similar to what happens in reality. According to Figure 11, representing the EPBM tunneling process in the numerical model, in the first step, the face pressure is applied to the tunnel face during excavation, and then the shield gradually enters the excavated zone with the over cut around it by trust force. When EPBM excavates the tunnel, segments are erected in each ring, and then grouting is implemented behind the erected segments. The backfill grouting and its pressure can contribute to the deformation behavior of ground in a shallow overburden depth, especially. In this model, the grouting pressure was applied behind the segment. Table 2 shows the specifications of EPBM, and Table 3 depicts the properties of the structural elements of the tunnel.

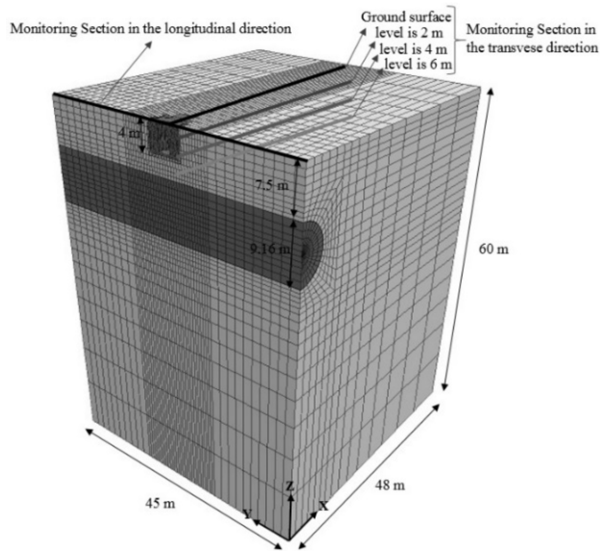

Figure 10. Finite difference model of tunnel of Line 7 of Tehran Metro around the San'at Square.

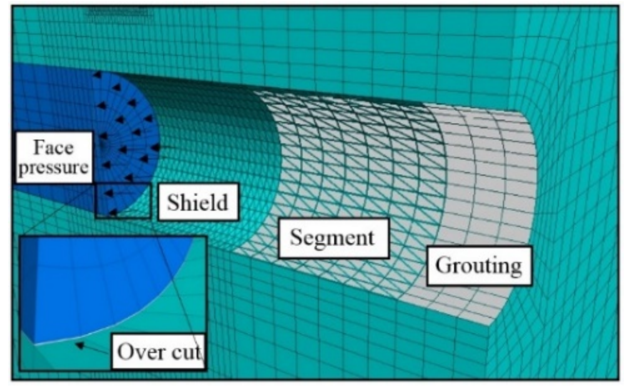

Figure 11. View of EBP tunneling process in numerical model.

Table 2. Specifications of EPBM in Line 7 of Tehran Metro.

Type of machine	Overburden (m)	Excavator diameter (m)	Over cut (m)	Length of shield, (m)	Excavation round (m)	Face pressure (KN/m^2)	Grout pressur, (KN/m^2)
EPBM	7.5	9.16	0.02	10.5	1.5	60	150

Table 3. Specifications of structural elements of the tunnel and EPBM.

Structural elements	Type of material	Model behavior	Thickness (m)	Elastic modulus (KN/m^2)	Poisson ratio	Density (KN/m^3)	Compressive strength (KN/m^2)
Shield	Steel	Elastic	0.15	200 * 10^6	Rigid	87.5	-
Segment (6+1+1 segments in each ring)	Concrete	Elastic	0.35	30 * 10^6	0.20	25	40 * 10^3

The 3D modeling of tunneling project with the FLAC software is compared with an empirical equation by Peck according to Equation 1.

$$S_{(x)} = S_{max}\, exp\left(-\frac{x^2}{2i^2}\right) \quad (1)$$

where x is the distance from the tunnel centerline, $S_{(x)}$ is the settlement value at x distance from the tunnel centerline, S_{max} is the maximum value of settlement that occurs on tunnel axis, and i is the distance of the turning point to the tunnel central line that is calculated from Equation 2.

$$i = R\left(\frac{z}{2R}\right)^{0.8} \quad (2)$$

where R and z are the tunnel radius and the tunnel axis depth, respectively. The surface settlement trough in the Greenfield site (without well) and the empirical equation were used for comparison, calibration, and verification. The results in Figure 12 show a good agreement of these numerical analyses.

5. Analysis of results

5.1. Well scenario

In the San'at Square case study, the vertical displacement contours ahead of the tunnel were compared between a Greenfield site and a condition with the existence of an anomaly ahead of tunnel face like a well (the well is 4 m in depth and 1 m in diameter). This comparison indicates that the deformation contours are compressed when there is a well above the tunnel, as shown in Figure 13.

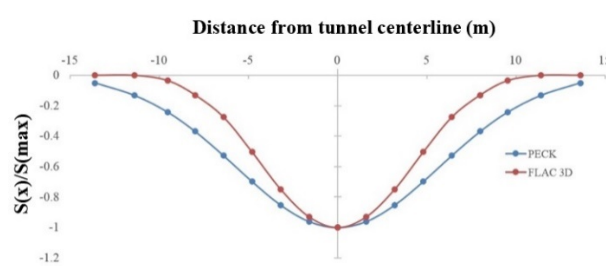

Figure 12. Result of surface settlement of numerical model and Peck's equation.

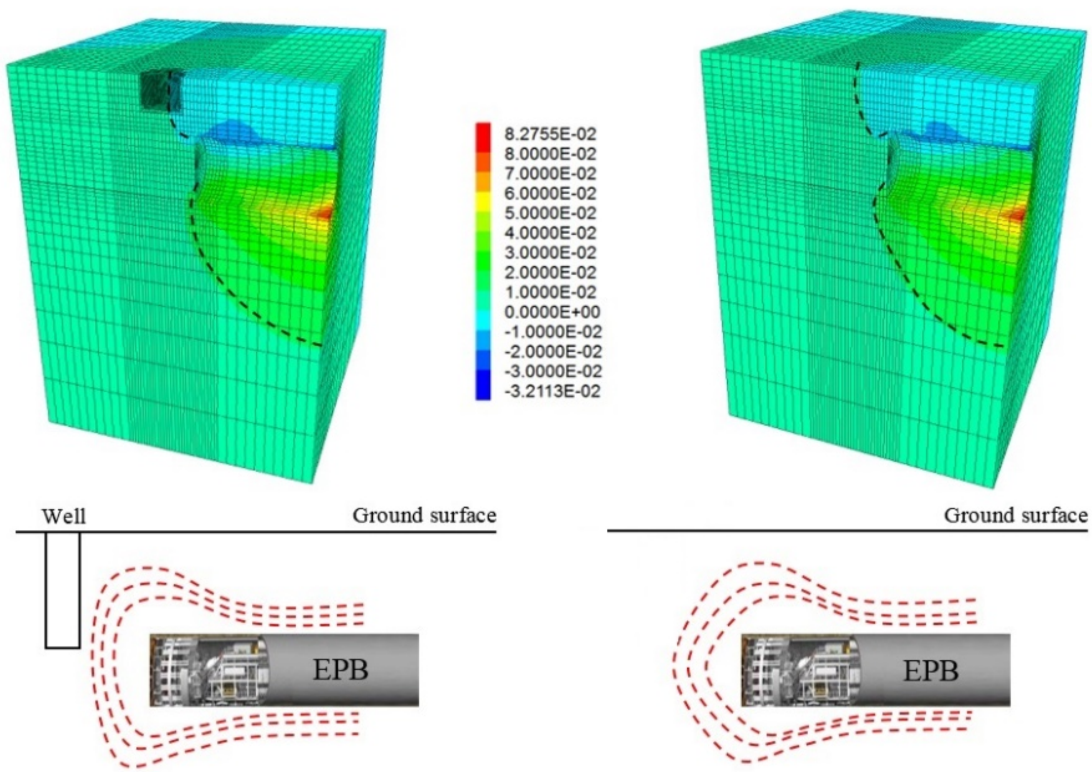

Figure 13. Comparison vertical displacement contour in the Greenfield site and the existence of well (unit is meter).

Figure 14a indicates the disorderliness of the vertical displacement ahead of the tunnel (*D/2* is the farther away face, where *D* is the tunnel diameter). It shows more deformation in the Greenfield (GF) site than in the site with a well of 4 m depth. The numerical outcomes based on Figure 14a approve the results of Figure 13. The well causes disturbance in the deformation path around the tunnel face and the stress concentration on the wall of the well, therefore, ground settlement due to the well mainly govern by the progressive failure of well. EPBM tunneling in a shallow depth will be governed by the invert-arching, not by pressure-arching. As a result, it has an interface with the ground surface so the crown deformation location is less than the ground surface deformation ahead of the tunnel. Hence, the transverse surface settlements show a larger value than sub-surface settlements ahead of the shallow tunnel in a GF site and in case of the existence of a well.

When the cutter head arrives under the well, as shown in Figure 14b, there is no interaction effect. The maximum surface settlement in the GF site, which is 3 mm, is less than the case with a well which is 7.6 mm. It must be accepted that with the advance of EPBM, the vertical deformation gradually moves up. This deformation in the middle shield and segmental parts are presented in Figures 14c and 14d, respectively. The maximum surface settlement is 13.4 mm and 20.3 mm in the middle shield and the segmental parts in case of the existence of well, respectively. As expected, the surface and sub-surface settlements in the GF site is less than the case of the existence of well when the tunnel is constructed. The numerical results showed that the plastic point occurred in the wall of the well, which proved the well collapse.

A series of parametric numerical analysis on the well depth and its location relative to the tunnel was examined. In addition to a 4 m well in the San'at Square, which was located totally above the tunnel, two other wells with 12 m and 20 m depths were considered in two separate models in a way that the bottom of the former was located on the tunnel face and the bottom of the latter was located lower than the tunnel bench. It is notable that the diameter of the wells was considered as 1 m.

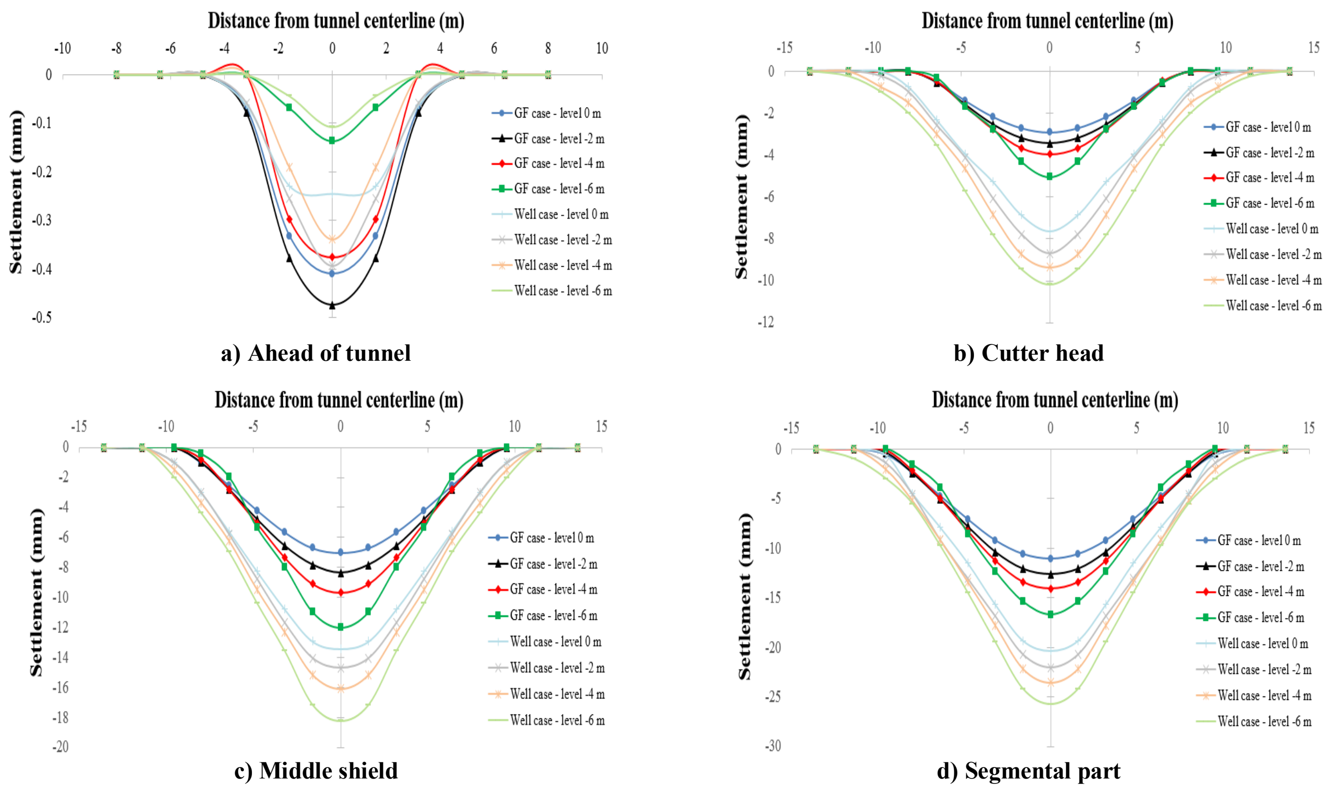

Figure 14. Transverse settlement in level 0 m, 2 m, 4 m, and 6 m below the ground surface (GF and well existence mode).

As demonstrated in Figure 15a, the transverse surface settlement *D/2* farther away from the tunnel face in the deepest well scenario is similar to that of a GF site so the stress distribution around the tunnel and a deep well is more regular than in the middle and shallow wells. A well in the face of an EBP tunnel causes turbulence in the tunneling process and faces pressure when the cutter head is exactly under the well, as clearly observable in Figure 15b. The wells with 12 m and 20 m depths have the most critical state and as the face is grappling with the well, an irregular state is created. Thus the maximum vertical displacement is 10.0 mm in this condition. The transverse surface settlement of a well with 4 m depth and that of a GF site are 7.6 mm and 2.9 mm, respectively.

The trend in Figure 15c is not similar to that in Figure 15b. In the middle shield location (Figure 15c), a well with 4 m depth shows more surface settlement of 13.4 mm relative to a GF site and wells with 12 m and 20 m depths after tunnel excavation. Finally, the segmental part, as depicted in Figure 15d, shows a maximum transverse surface settlement of 20.3 mm and a minimum of 18.1 mm in the wells with 4 m and 20 m depths, respectively. Therefore, the deepest well shows less settlement than the shallowest one compared to a Greenfield site. Since the well with 20 m depth crosses from the entire diameter of the tunnel and the uniform state exists on the tunnel face, a well with a 20 m depth shows less settlement than the one with a 4 m depth.

The longitudinal displacement profile (LDP) in Figure 16 substantiates this view with evidence. After the application of grouting and pressure to the numerical model, a smaller heave occurred in the settlement basin.

5.2. Unknown cavity scenario

Based on the collapse history of Line 7 of Tehran Metro, the cavities are a usual obstacle in the tunneling process. Thus a cavity with a similar volume to the San'at Square well and sphere shape was defined in three separate models: (1) right on top of the tunnel, (2) in the face of the tunnel, and (3) at the bottom of the tunnel. Figure 17a shows the transverse surface settlement with a distance of *D/2* ahead of the tunnel face in the cavity scenarios. A Greenfield site has the minimum surface settlement, and a cutting face cavity is the most critical state, which induces disturbance to the face pressure balance.

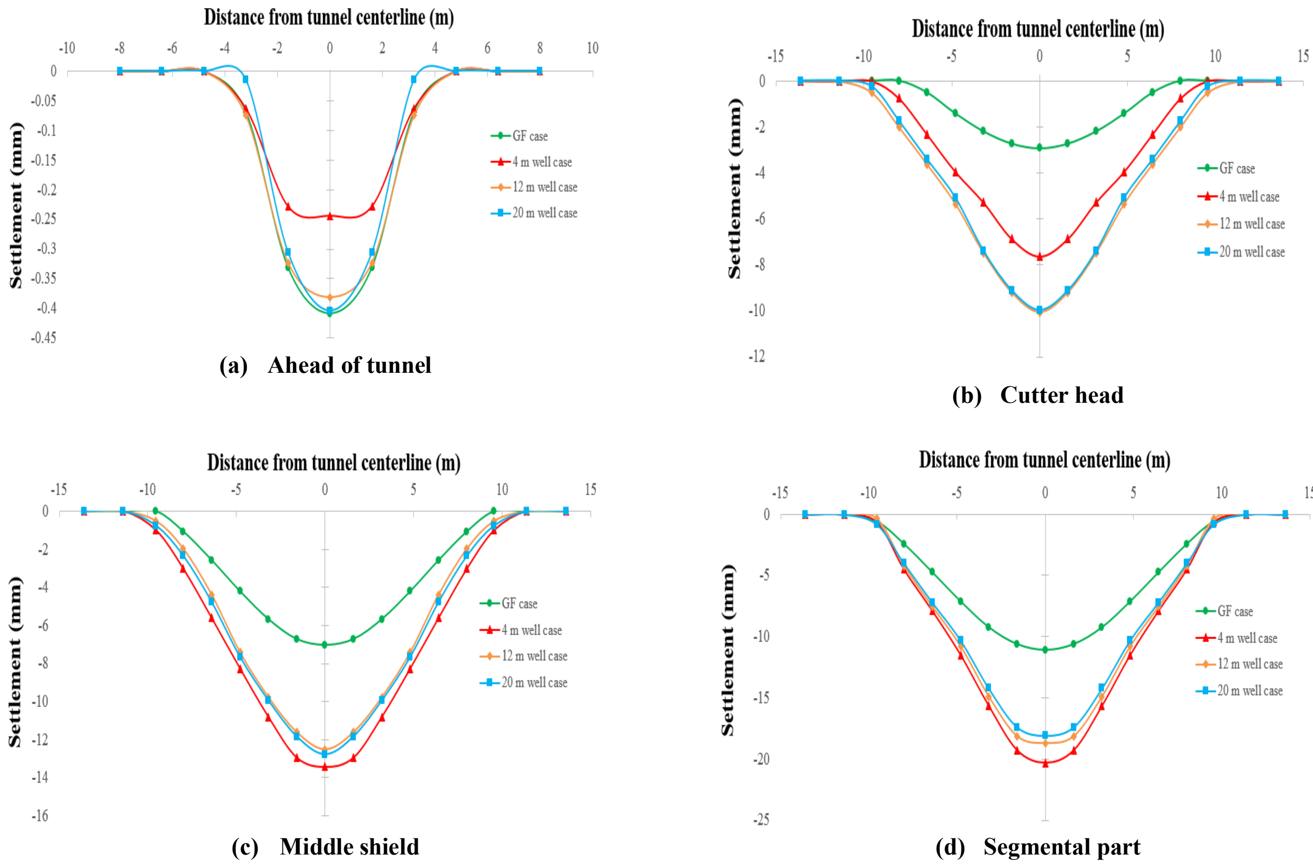

Figure 15. Transverse surface settlement in GF site and well existence different scenarios.

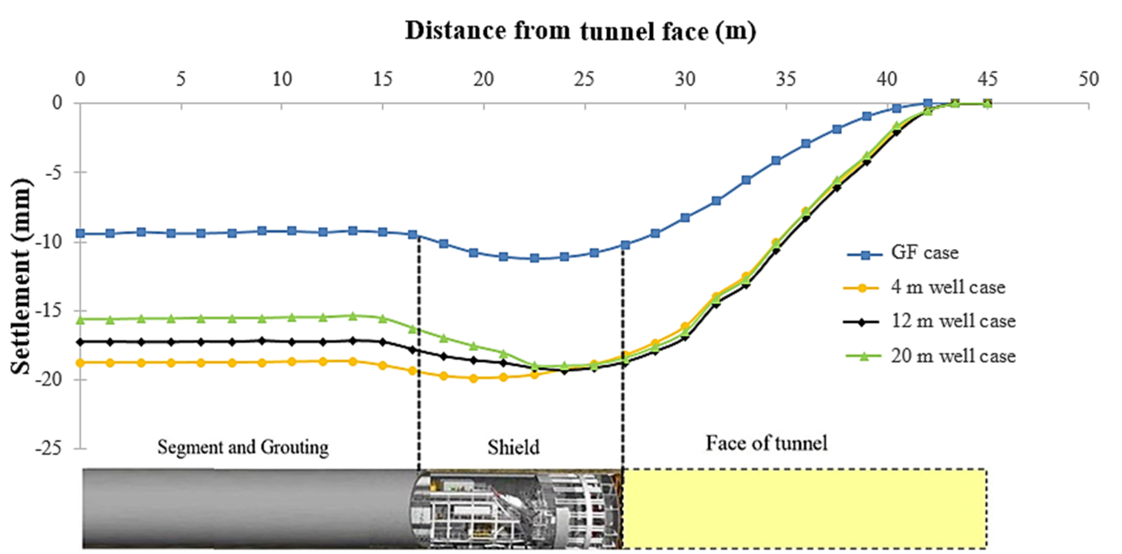

Figure 16. Longitudinal displacement profile (LDP) of GF site and well existence different scenarios.

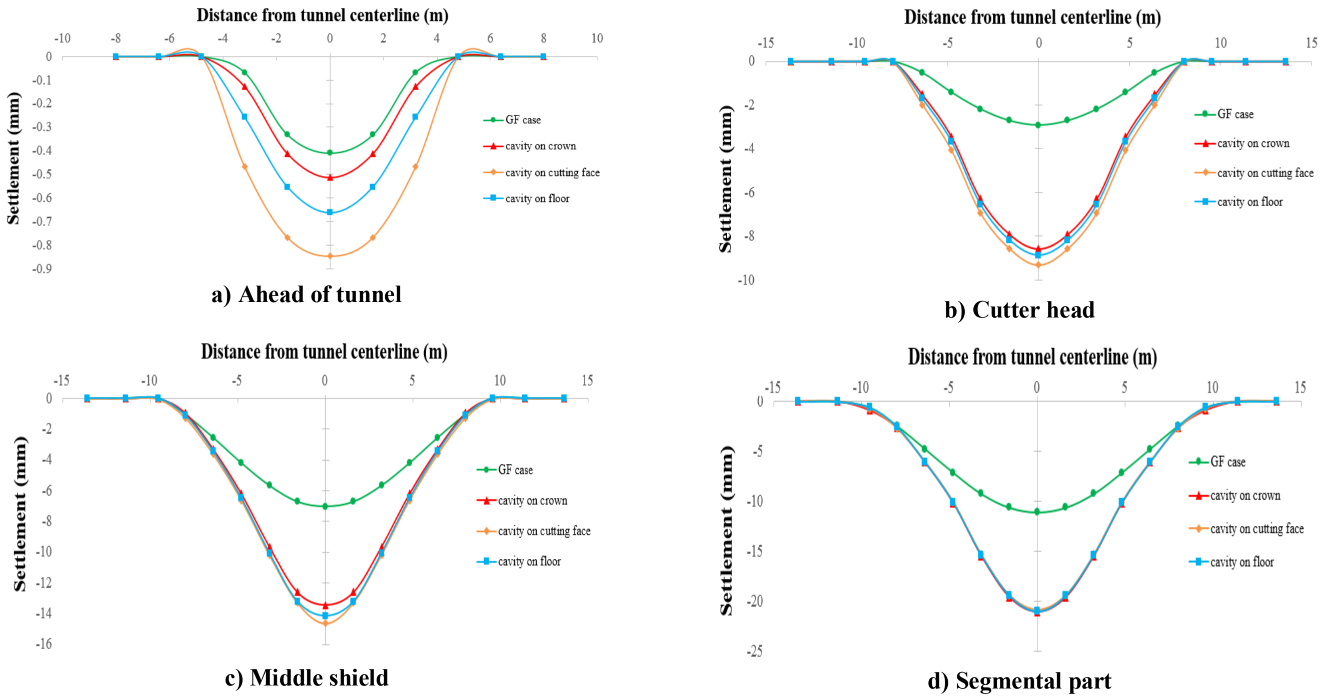

Figure 17. Transverse surface settlement in GF site and cavity existence different scenarios.

Comparing Figures 15a and 17a, one can find out that a cavity scenario shows more transverse surface settlement than a well scenario farther from the EPBM cutter head. The comparison of Figures 17a and 17b reveals that when the cutter head reaches the cavity, the vertical deformation gradually moves up with a similar trend in all scenarios.

As seen in Figures 17c and 17d, generally, the transverse surface settlement value in a Greenfield site is less than that of a cavity scenario. For instance, the maximum surface settlement value in the segmental part is about 21 mm and 11.1 mm in the cavity scenario and the GF site, respectively. This is depicted in the longitudinal displacement profile (LDP) in Figure 18. According to the diagrams in the cavity scenario, when the cavity is located in the tunnel face, which is going to be excavated by an EPBM, the most critical case will happen.

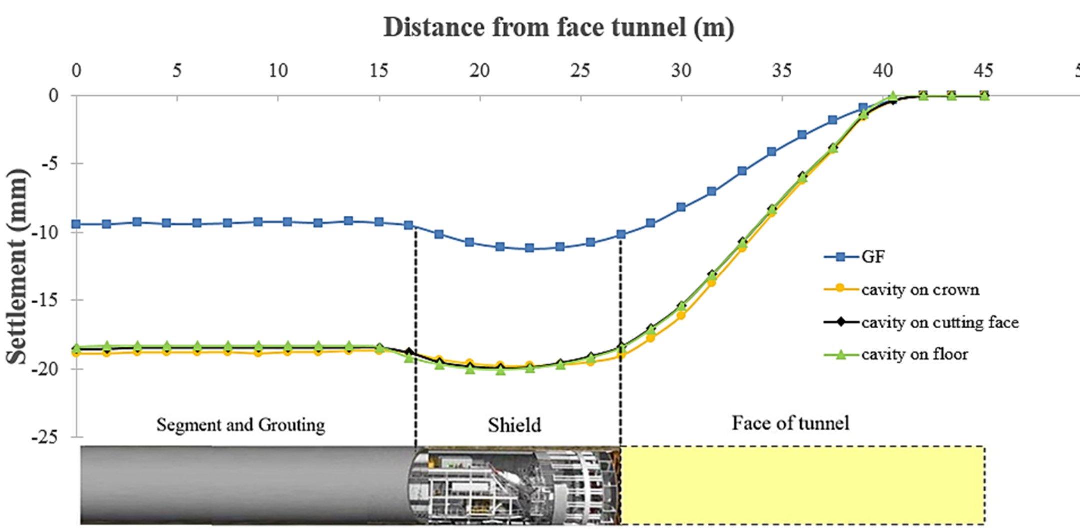

Figure 18. LDP of GF site and cavity existence different scenarios.

6. Conclusions

Obstacles are among the most important uncertainties in the tunnel construction process. Facing these obstacles (such as municipal utilities, cavities, wells, and channels), influences the tunnel construction process. In this project, we focused on the effect of the existence of a well and an unknown cavity located in the zone of influence of excavated tunnels by EPBM. Also a series of parametric studies were carried out on the well and unknown cavity geometry and location relative to the tunnel. Accordingly, a 3D FDM model was utilized, and the monitoring paths in this numerical model were chosen in accordance with the ground settlement and collapse history of Line 7 of Tehran Metro. The numerical modeling results obtained were in good agreement with the Peck's equation. The main results of this work are as follow:

- The obstacles such as the municipal utilities, surface and sub-surface structures, channels, wells, storages, and unknown cavities are a key reason for the ground collapse in urban tunneling.
- Encountering the wells and cavities in the EPB tunneling process must be considered in the tunnel design since they are as risky as the adjacent underground structure.
- When an EPBM approaches a well, the well enters the zone of influence of the tunnel, and the wall of the well becomes loose. When the soil of the wall reaches a plastic state, the ground around the well will collapse.
- It was found that the ground behavior was different for the ahead, cutter head, shield, and segmental parts of EPBM.
- In the San'at Square case study, the comparison of vertical displacement contours ahead of the tunnel between a Greenfield site and a site containing a well (4 m in depth and 1 m in diameter) shows that the deformation contours are compressed when there is a well above the tunnel; this occurred just ahead of the tunnel.
- With the advancement of EPBM, the vertical deformation gradually moves up, which is obvious in the middle shield and the segmental parts. The most critical state of the ground settlement by EPBM occurs when the cavity is located in the face of the tunnel.
- In the segmental part, the deepest well shows less settlement than the others.
- The transverse surface settlement *D/2* ahead of the tunnel face shows that the smallest value for the surface settlement occurs in a Greenfield site relative to a site with a cavity. The cutting face cavity is the most critical state, and shows disturbance to the face pressure balance.
- In the segmental part, the maximum surface settlement in the cavity scenario is more than that of the Greenfield site, almost double.

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اندرکنش بین تونل‌های حفاری شده با ماشین‌های فشار تعادلی زمین و معارضین زیرسطحی؛ مطالعه‌ی موردی: خط ۷ متروی تهران

داریوش محمدی[۱و۲]، کوروش شهریار[۱*] و داوود پارساپور[۲]

۱- دانشکده مهندسی معدن، دانشگاه صنعتی امیرکبیر، تهران، ایران
۲- دانشکده مهندسی عمران و محیط زیست، دانشگاه صنعتی امیرکبیر، تهران، ایران

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* نویسنده مسئول مکاتبات: k.shahriar@aut.ac.ir

چکیده:

تونلسازی در محیط‌های شهری، همواره با عدم قطعیت‌های بسیاری روبرو است. در صورتی که این مهم، در تحلیل و طراحی تونل‌ها نادیده گرفته شود، موجب وقوع اتفاقات غیر منتظره و خسارات جانی و مالی در زمان اجرا خواهد شد. معارضین در تونلسازی شهری یکی از برجسته‌ترین عدم قطعیت‌ها است؛ به عبارتی دیگر، برخورد با چنین موانعی بر روند حفاری تونل تاثیرگذار است. معارضین در تونلسازی شهری شامل تاسیسات شهری، سازه‌های سطحی و زیرسطحی، کانال‌ها، چاه‌ها، انباره‌ها، قنات و حفره‌های ناشناخته اشاره کرد. پروژه‌ی خط ۷ متروی تهران نیز از این قاعده مستثنی نبوده و با این معارضین دست و پنجه نرم کرده که در مواردی باعث تغییر مسیر تونل و ماشین حفار شده است. در این مقاله، به بررسی اثر وجود چاه و حفره‌های ناشناخته‌ای که در محدوده شعاع تاثیر تونل‌هایی که با ماشین فشار تعادلی زمین حفاری می‌شوند، پرداخته شده و مسئله‌ی اندرکنش تونل-معارض براساس تاریخچه‌ی تغییرشکل‌های غیرمجاز و ریزش‌های رخ داده در این خط و پروژه‌های مشابه در سرتاسر جهان، مورد بحث قرار گرفته است. در همین راستا، تعدادی مطالعه‌ی پارامتری بر روی هندسه و موقعیت چاه و حفره نسبت به تونل، مقایسه‌ی نشست سطحی و زیرسطحی و درنهایت روند تغییرات شعاع تاثیر تونل در سناریوهای مختلف انجام شد. در این تحقیق از مدلسازی عددی سه بعدی تفاضل محدود استفاده شده است. خروجی نتایج نشان می‌دهد که آشفتگی عمده در میدان نزدیک چاه-تونل به وجود می‌آید که بحرانی‌ترین حالت نشست در حفاری با ماشین هنگامی رخ می‌دهد که چاه و حفره در جبهه‌کار تونل قرار دارد. همچنین مشخص شد که رفتار زمین در هر ناحیه از ماشین شامل جلوتر از سینه‌کار، کله حفار، سپر و لاینینگ سگمنتال متفاوت است.

کلمات کلیدی: ماشین فشار تعادلی زمین (EPBM)، معارضین زیرسطحی، ریزش زمین، نشست، ناحیه تاثیر تونل.