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Interaction of Underground Cavities with Stabilized Urban Excavation by Nailing and Anchorage

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ABSTRACT

One of the most important geotechnical issues is the stabilization and deep excavation of the city, which many research has been done about it., especially in recent decades. One thing that add to the complexity and challenge of such projects is the existence of cavities and empty spaces in the vicinity of the excavation. Therefore, careful study and in-depth analysis play a crucial role in such projects. In this research, we try to examine this issue from different aspects and its practical result use in future projects. Due to the fact that the two methods of anchorage and nailing are the most widely used methods in strengthening and stabilizing the excavations, these two methods were selected also interaction of excavation-underground cavities were investigated. parameters such as the cavity depth, the distance of the cavity from the excavation, the diameter of the cavity, and the thickness of the cavity cover, have been investigated in this research. In this research, for analysis and modelling, PLAXIS 2D finite element software has been used with the assumption plain strain and hardening soil model which is suitable for drilling. The results of the analysis showed that the horizontal displacement of the excavation increases due to the presence of cavities and the sensitivity of the cavities stabilized with the anchorage method is greater than the nailing method. The greatest effect of the cavity on the behaviour of excavation on the one hand is at special critical distances and depths. Studies have also shown that the field of soil deformation changes despite the cavity, but it will not have a significant effect on the forces created in consolidating elements. On the other hand, drilling operations near cavities can lead to changes in the internal stresses of the cavity covering elements that must be considered in the design.

Keyword: Nailing, Anchorage, Cavity, Interaction

INTRODUCTION

Deep urban excavations are one of the most important and challenging issues in the field of geotechnics, which has been studied by many researchers, especially in recent decades. Due to limited space in cities, excavation and drilling in the vicinity of structures and facilities will be inevitable.

Therefore, it is very important to pay attention to the choice of stabilization and drilling methods. If you do not pay attention to this, the occurrence of excessive displacement, rupture or cracks in the structures and facilities adjacent to the pit will not be far from the mind. Nationwide, we are witnessing a high volume of excavations for the construction of various structures, and every year, due to the use of inappropriate methods for stabilization, we are witnessing the collapse of many excavations, which cause a lot of human and financial losses. For this reason, there will be a need for methods to ensure the stability and safety of the pit. Various methods such as the use of weighted concrete walls, diaphragms and shields, piles, etc. are available for the stability of the pits. One of the most widely used and popular methods in Iran is the anchorage and nailing method. On the other hand, in urban environments, the presence of underground cavities such as aqueducts, subway tunnels or traffic tunnels will be expected. Excavation in the vicinity of these cavities can lead to a dual excavation-underground cavity interaction. So that the behavior of the pit will be different with or without the hole. Excavation will also affect the behavior of the cavities and can change the internal stresses of the cavities or increase their displacement.

Most previous studies have considered the interaction of surface structures with cavities and little attention has been paid to the interaction of cavities with excavations. Among the somewhat related studies, we can mention the analysis of the interaction of the concrete frame based on the pile group with the tunnel by Marvieh and Shahroor [1]. Their numerical analysis showed that at a distance of 3 times the diameter of the pile from the drilling front, the analysis results will be close to the values obtained assuming a flat strain. The comparison of the displacements that occurred in the piles showed that the displacement values will be small until the drilling front reaches the place of the piles. However, as the tunnel is drilled through the piles, the amount of pile displacement will increase due to the movement of the soil. Another similar study was conducted by Parvari et al. [2]. Using a finite element three-dimensional model, they studied the parametric effect of drilling twin tunnels on how to change the internal forces of adjacent piles. The candles are lit. Basil studied the interaction of tunnels and piles with a two-stage method in which the motion of the earth without considering the pile by the finite element and the response of the pile group by the boundary element method were modeled [3]. In this study, it was observed that the tunnel effect on the pile group is in the same horizontal distance from the tunnel compared to the single pile, reducing the bending moment and the axial force in the pile group piles that are under higher load. Hong et al. Studied the deposition and charge transfer mechanism of the pile group exposed to the twin tunnel below the pile group tip using the TT centrifuge model experiment and finite element inverse analysis [4]. It was found that the soil deformation caused by each tunnel starts mainly in a 61-degree wedge (slope with horizon) from the line of the junction of the tunnel crown and the tunnel wall and continues to the ground level. Twin tunnels occur in each experiment, with most of the pile anchorage occurring after the advance of the first tunnel.

Netzel and Kalberg performed three-dimensional analysis of the Amsterdam metro twin tunnels and the pile-based surface structure using Diana finite element software[5]. The analyzes showed that as the drilling machine progresses in the tunnel, the affected structures will twist, because part of the structural block is affected by the subsidence resulting from the tunnel and part is not affected. Tunnel drilling can also increase induced stresses in substructure piles, so this issue should also be considered in analysis and design. In another study, Lee et al. Showed that by increasing the horizontal distance of the tunnel from Piles, the amount of pile settling can be more or less from the surrounding soil [6]. In another study, Pang investigated the effect of mechanized tunnel drilling on deep foundations. Increasing the drilling speed of the tunnel and at the same time maintaining the pressure of the drilling front, reduces settling in piles and surface structures. However, the hardness of the tunnel cover and the injection pressure behind the tunnel will have little effect on these parameters [7]. Examining the position of the tunnel and deep foundations, Yang et al. Also stated that if the piles are located in a triangular environment from the front of the tunnel, tunnel drilling can lead to a severe reduction in stress at the pile tip, resulting in reduced bearing capacity and increased subsidence. Candles are crafted [8]. Chen et al. Have investigated the interaction of deep-twin subway tunnels in soft soils [9]. To investigate this interaction, the numerical model in Plexis software showed that considering the existence of tunnel cavities in the pit analysis has led to an increase in surface subsidence in the excavation. Jamali et al. Studied the interaction of reinforced excavation by nailing and adjacent tunnel in two dimensions with Plexis software and observed that increasing the distance between the tunnel and the pit significantly reduces the bending moment, shear force and force. The axis enters the tunnel lining. The presence of surface excavations in the area affected by the tunnel can also lead to rupture of the tunnel cover element. This case was investigated by Zang et al. And stated that if surface drilling leads to a 20 mm increase in displacement in the coverage of subway tunnels, it is possible to exit the operation of these tunnels. Therefore, in addition to the behavior of surface excavations, the function of urban tunnels should also be considered [10]. Jamali et al. Have investigated the interaction of reinforced excavation by nailing and adjacent tunnels [11]. The analyzes were performed in two dimensions with Plexis software. The ground is assumed to be in two layers, with the first 1 m containing organic disturbed soil and then the sandy clay continuing to the end of the model boundary. The depth of the tunnel and the distance from the nailed wall were examined in the concrete cover at different times. It was observed that the horizontal displacement of the tunnel was for all cases towards excavation. Increasing the distance of the tunnel from the excavation site reduces the horizontal displacement of the tunnel. It has been identified that there is a critical area around the excavation where excavation has a significant impact on the tunnel. In addition, the horizontal displacement increases with decreasing tunnel diameter. Also, with increasing the depth of the tunnel, the horizontal displacement of the tunnel due to excavation decreases.

Due to the use of two methods of anchorage and nailing in the country, so far, no studies have been conducted on the interaction of excavations reinforced with these two methods and underground cavities. Therefore, in this paper, the interaction of underground cavities and adjacent excavations reinforced by anchorage and nailing method on each other as well as the effects of the type of excavation stabilization system (active or inactive) on the results of determining the effects of coating for We deal with the hole in the hollow behavior. The effects of cavity distance, depth and droplet on excavation displacement and stresses of reinforcement elements have been investigated. Numerical modeling is performed in two dimensions (flat strain) with Plexis finite element software.

MATERIAL AND METHOD

Modeling (model geometry)

According to the purpose of this study, which is to investigate the effect of the presence of holes on two walls stabilized with nails and anchors, the wall with a height of 15 meters was selected to examine both nailing and anchorage methods at a constant height. For this wall, nailing and anchoring design was done according to FHWA guidelines [12, 13].

Then, with the initial design, the wall was obtained in the model of geo-style limit equilibrium software and its stability coefficient. The stability coefficient of both walls has been selected to be approximately 1.5, which indicates that they are stable as a permanent wall. The rupture mechanism obtained in the case of nails and anchors is shown in Figure (1) and Figure (2). The nail-stabilized wall consists of 7 rows of nails, the first of which is 2 meters from the ground. The horizontal and vertical distances of the nails are considered to be two meters. For stability, reinforcements with a length of 10 meters and an angle of 15 degrees have been used. The anchor stabilized wall consists of 4 rows of anchors, the first row of which is 2 meters from the ground. The horizontal and vertical distances of the anchors are three meters and 3.5 meters, respectively.

For stability, two-strand strands are used with a 15-degree angle and a band length of 4 meters. The total length of the first-row anchors is 12 meters, the second-row anchors are 10 meters and the third and fourth row anchors are 9 meters.

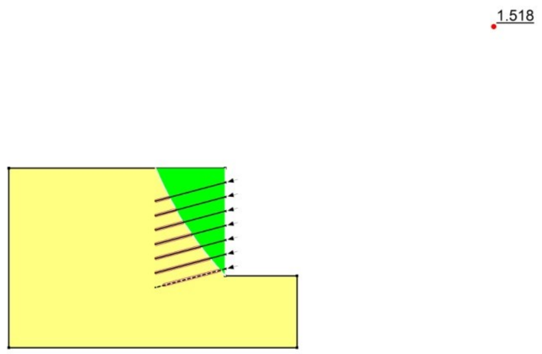

Figure. 1: Reliability of a wall reinforced with nails

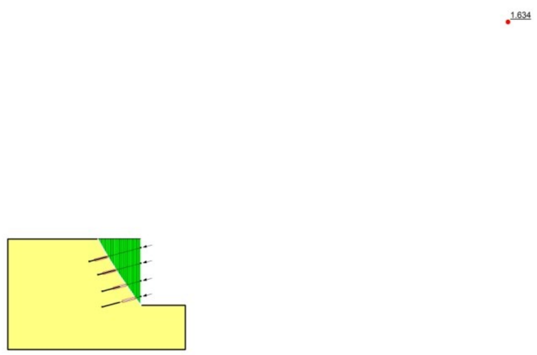

Figure. 2: Reliability of a wall reinforced with anchors.

DIMENSIONS OF MODEL, MESH AND ELEMENTS USED

In numerical models, the lateral boundaries of the model should be in a position that does not affect the results of the numerical model. Therefore, considering the height of 15 meters of the assumed wall, the total length of the model was 100 meters and its height was 40 meters. The geometry of the nailed wall model with the tunnel can be seen in Figure (3). In numerical modeling of geotechnical structures, mesh size is important. The smaller the dimensions of the model mesh, the more accurate the modeling as well as the analysis time. Therefore, it is appropriate to concentrate the muscles in areas where there is a higher concentration of stress and strain, and in other areas; Use larger nets to reduce analysis time, such as near borders. For this reason, the meshes used around the excavation wall and the adjacent tunnel are fine and selected in other larger areas. Figure (4) shows the lattice model used in the analyzes.

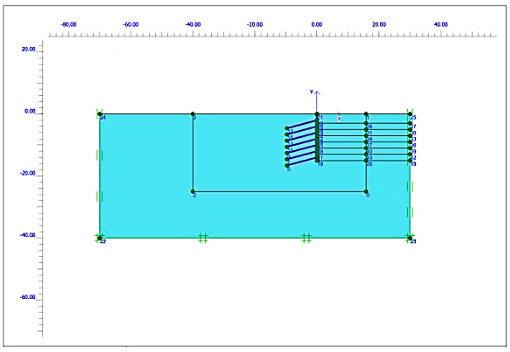

Figure. 3: Geometric model made for nailed wall

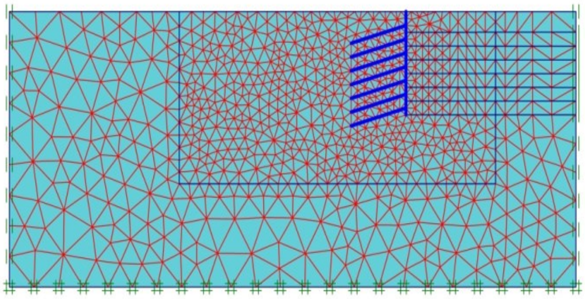

Figure. 4: mesh of the nailed wall model

PARAMETERS USED

To model the retaining walls, it is better to use a model in which the stiffness depends on the stress and its value in the loading path is different from the loading path. Therefore, in this study, the behavior model of hardening soil has been used in Plexis software [14]. To select the appropriate parameters of the hardening soil behavioral model, the results presented by Islami et al., Which are the result of studies of a real excavation project in Tehran [15]. Accordingly, the soil mass parameters are described in Table (1).
To model the nails, a plate element is used that has the ability to withstand axial force and bending. Also, a combination of geogrid element was used for the anchor restrained part and anchor element for the anchor free part. These two elements have a central behavior. For the geogrid element and the plate, the third-dimension distance of the anchors and nails is considered by correcting the axial properties of the elements. But the third-dimension distance in the free part as a material property is applicable to the model. The properties of these elements are presented in Table (2) and Table (3).

Table. 1: Characteristics of soil materials considered in the analyzes

$\gamma\left(\frac{kN}{m^3}\right)$	$E(kPa)$	$E_{oed}(kPa)$	$E_{ur}(kPa)$	m	C	$\varphi(deg)$	$\psi(deg)$
20	40000	40000	120000	0/5	30	35	5

Table. 2: Characteristics of raw materials in analyzes

parameter	Unit	Value
Elastic nail module	GN/m^2	200
Elastic grout modulus	GN/m^2	22
Axial stiffness	KN/m	214000
Bending stiffness	KNm^2/m	162

Table. 3: Characteristics of anchor materials in analyzes

parameter	Unit	Value
Elastic modulus of strands	GN/m^2	200
Strain force	kN	300
Axial stiffness-free section	KN/m	5.724
Axial stiffness - restrained section	KNm^2/m	1.914

VALIDATION

In order to validate the modeling process in this research, aesthetic and seedling study has been used [7]. In this paper, a parametric study of the factors affecting the interaction of urban tunnels and stabilized excavations has been done by nailing method. A nailed wall is considered to be 10 meters high and is reinforced with 6-meter-long nails that are placed at a 15-degree angle to the wall. Adjacent to this pit is a tunnel with a diameter of D, at a distance of H from the ground and at a distance of X from the wall. These parameters are assumed to be variable in the analyzes. Figure (5) presents the assumed geometry and parameters mentioned. In these analyzes, the impact of drilling on the tunnel has been considered. Therefore, the effect of different parameters on tunnel behavior before and after wall excavation has been investigated. The wall was drilled in 4 stages with a height of 2.5 meters in each stage. It also enters the earth at a massive load of 20 kPa.

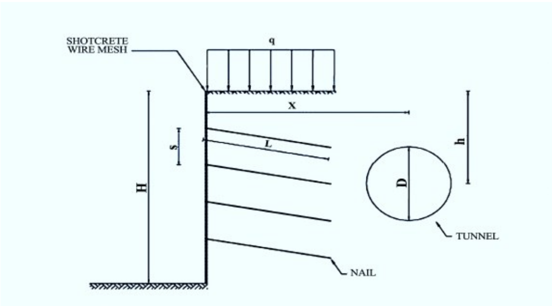

Figure. 5: Assumed geometry in the validation paper

In the analysis performed in this study, in order to validate the tunnel with a diameter of 4 meters was selected and assumed at different distances from the wall. The depth of the tunnel from the ground was assumed to be 5 meters. In order to evaluate the accuracy of modeling with the reference paper, the rate of increase in horizontal displacement of tunnel lining due to drilling resulting from this modeling and presented in the reference paper is presented in Figure (6). The red line indicates the result of the article and the blue line represents the result of modeling in this research. It is observed that with increasing X, the rate of increase in horizontal displacement decreases, which indicates a decrease in the impact of the pit on the tunnel. The trend of changes and the values obtained in this research and presented in the reference article are consistent with each other, which indicates the accuracy of the modeling performed. Also, for further investigation, the rate of increase of vertical displacement of concrete lining is presented in Figure (7). In these two figures, a good agreement is observed, which shows the accuracy of modeling.

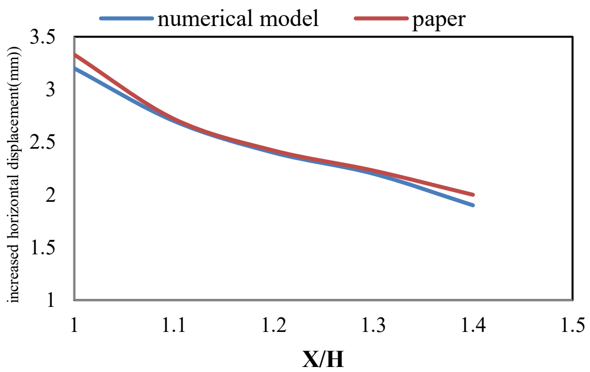

Figure. 6: Increased horizontal displacement of lining due to drilling

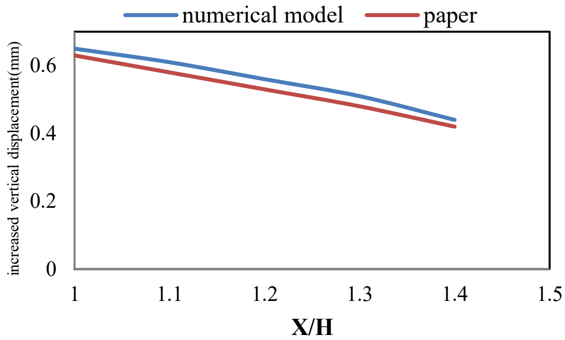

Figure. 7: Increased vertical displacement due to drilling

DISCUSSION

Parameters examined

In this study, the effect of tunnel distance from the wall, tunnel depth and tunnel diameter on the behavior of anchored and nailed retaining walls has been investigated. The values under consideration are shown in Figure (8) that the height of wall H is the depth of the center of the tunnel from ground level D and the distance of the tunnel from wall X.

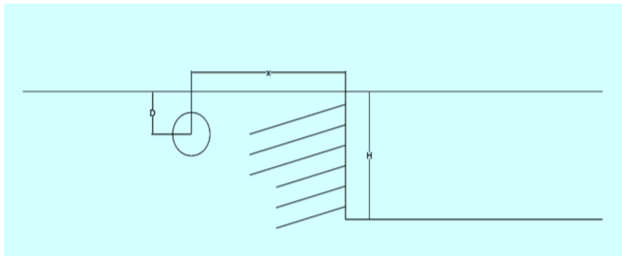

Figure. 8: Introduction of the parameters considered in the research

EFFECT OF CAVITY DISTANCE FROM THE WALL

Investigation of the effect of tunnel distance from the wall in the values of $X/H = 1{,}1.5{,}2$ where the tunnel diameter and lining thickness are assumed to be 8 m and 40 cm, respectively.

In Figure (9) and Figure (10), the horizontal and vertical displacement of the edge of the pit in the absence of the tunnel, as well as the different position of the tunnel relative to the wall in the two states of consolidation with nails and anchors are shown. In the case of a nailed wall, the horizontal displacement of the edge of the pit is observed, when the tunnel is closest to the wall, there is a significant increase compared to the case where the tunnel is not considered. So that the horizontal displacement increases from 18 mm to 25.5 mm. As the distance from the center of the tunnel to the wall increases, we will see a decrease in horizontal displacement, which indicates a decrease in the impact of the tunnel on the pit. But even with $X/H = 2$, the horizontal displacement of the pit is about 3 mm larger than without the tunnel. Comparison of vertical displacement shows that at $X / H = 1$, the edge of the pit is reduced by about 2 mm compared to the case without the tunnel. The reason for this behavior is the uplift caused by tunnel excavation.

Due to the superficiality of the tunnel, the uplift reaches the ground level and leads to a decrease in subsidence. As the distance between the tunnels increases, the effect of inflation decreases and the subsidence of the earth's surface increases. Changing the distance of the tunnel from the nailed wall at $X / H = 2$ to $X / H = 1$ has led to an increase in horizontal displacement from 15% to 40%. Similarly, vertical displacement first shows a decrease of 20% and then an increase of up to 15%. The trend observed in the anchorage wall is similar. Comparison of the vertical displacement of the anchorage wall shows that at $X / H = 1$ the depression of the edge of the pit decreases by about 4 mm compared to the case without the tunnel. The reason for this behavior is the uplift caused by tunnel excavation. As the distance between the tunnels increases, the effect of inflation decreases and the subsidence of the earth's surface increases. It can be seen that changing the tunnel distance from $X / H = 2$ to $X / H = 1$ has led to an increase in the horizontal displacement of the anchorage wall from 11% to 50%. Similarly, vertical displacement shows a change of up to 60% due to the increase in inflation effect by reducing the tunnel distance. In general, the percentage of increase in displacement in the anchorage is higher than the nail wall, which indicates that the anchorage system is more sensitive to the presence of underground cavities than the nailing system.

Figure (11) and Figure (12) show a comparison of the axial force created in the nails and anchors with the distance of the hole from the wall, respectively. It is observed that the forces created in the structural elements do not change with changing the cavity distance.

In Figure (13) and Figure (14), respectively, the change of axial force and flexural anchor of the hole cover element with the distance of the tunnel from the wall is nailed and anchorage is presented. The axial force created by changing the hole distance is almost constant, but the bending moment in the borehole state increases sharply compared to the non-borehole state. As the distance between the tunnel and the wall increases, the rate of increase of the bending anchor decreases, but in each case, it is greater than the amount without holes. The anchorage rate of the cavity cover element in the anchorage system is higher than the nailing system.

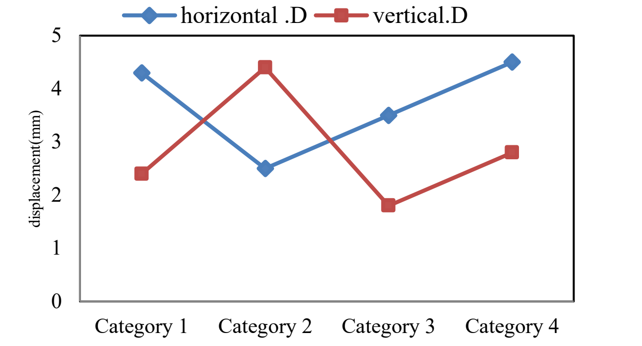

Figure. 9: Horizontal and vertical displacement of the nailed edge by changing the tunnel distance

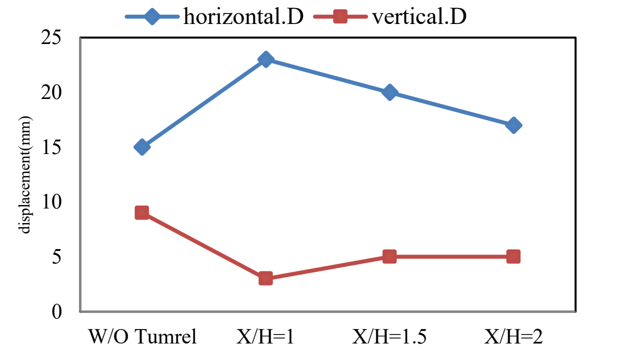

Figure. 10: Horizontal and vertical displacement of the anchored pit edge by changing the tunnel distance

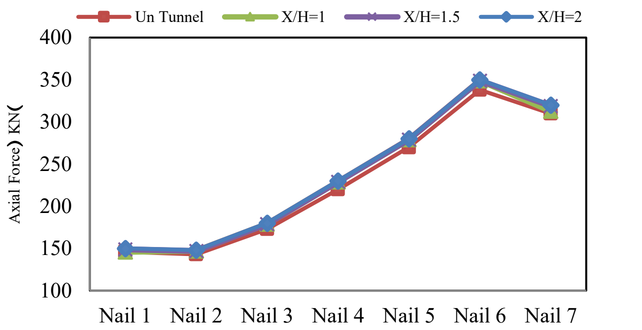

Figure. 11: Changing the axial force of the nails by changing the distance of the tunnel

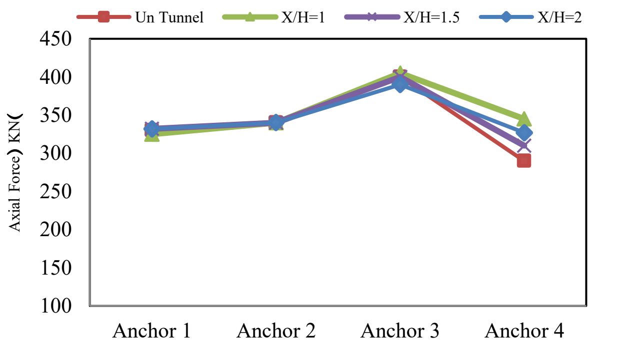

Figure. 12: Changing the axial force of the anchors by changing the tunnel distance

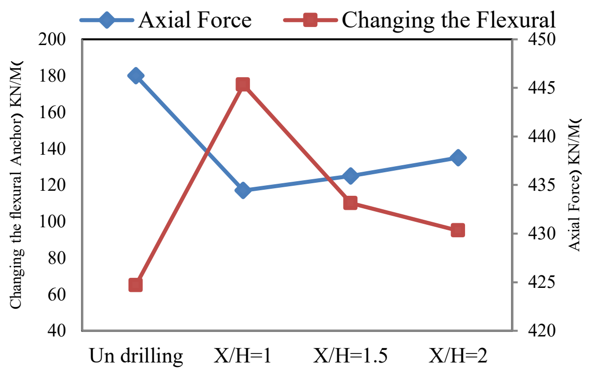

Figure. 13: Changing the flexural anchor and axial force of tunnel lining in the stud restrained by changing the tunnel distance

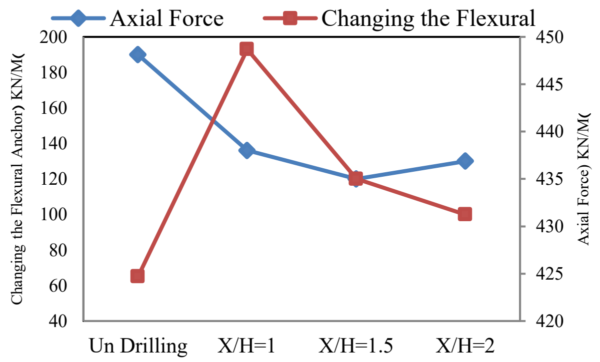

Figure. 14: Changing the flexural anchor and axial force of the tunnel lining in the anchor-restrained pit by changing the tunnel distance

EFFECT OF CAVITY DEPTH FROM GROUND LEVEL

Investigation of the effect of tunnel depth from the ground in the values of D/H = 0.3,0.5,0.75 where the tunnel diameter and lining thickness are assumed to be 8 m and 40 cm, respectively. Figure (15) shows the horizontal displacement of the frame and the edge of the pit reinforced with nails by changing the depth of the tunnel. It is observed that with increasing the depth of the tunnel from the ground to a depth of 0.5 h, the horizontal displacement of the pit increases. But with more depth; The effect of the tunnel on the excavation is reduced and the displacement is decreasing. Comparison of vertical displacement shows that as the depth of the cavity increases, the subsidence also decreases continuously. This behavior is due to the uplift of the tunnel. Due to the superficiality of the tunnel, the uplift reaches the ground level and leads to a decrease in subsidence.
Examination of the horizontal and vertical displacement of the anchorage pit by changing the depth of the tunnel as seen in Figure (16) shows that the horizontal displacement of the pit edge increases with increasing tunnel depth from the ground to a depth of 0.5 h and then decreases finds.
This behavior indicates the existence of a critical depth in both methods in which the tunnel has the greatest impact on the horizontal displacement of the wall. The percentage of increase in horizontal displacement to critical depth will be higher in the anchor system and then higher in the nailing system. This depth is obtained in the range of analyzes equal to 0.5H.
In this case, the analysis of comparing the axial force created in the nails and anchors with the depth of the hole from the ground showed that the forces created in the structural elements do not change with changing the depth of the hole. Therefore, their diagrams are omitted. Due to the fact that the tunnels were located at different depths, it is expected that due to different overhead, the amount of axial force and bending moment created in the cover will also be different. Therefore, in order to investigate the effect of drilling on the coating behavior, the difference between the structural efforts of the coating before and after drilling was considered. The axial force and flexural anchor changes of the tunnel cover at different depths are shown in the nail holder in Figure (17) and in the anchor holder in Figure (18). It can be seen that drilling in all cases leads to an increase in the bending moment while the axial force of the cover element remains almost unchanged.
The highest increase in flexural anchorage was obtained in both maintenance systems at a depth of 0.5 h, which indicates that this depth is critical from the point of view of structural efforts of the cavity cover element. In these analyzes, the change of bending anchor of the cover element in the anchorage system is more than the nailing system, which indicates that this system is more sensitive to the homogeneity of its surroundings.

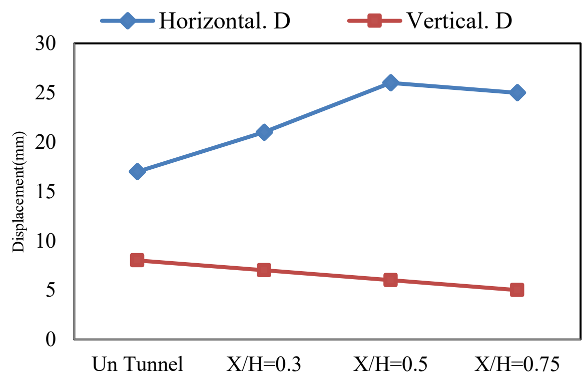

Figure. 15: Horizontal and vertical displacement of the nailed edge by changing the depth of the tunnel

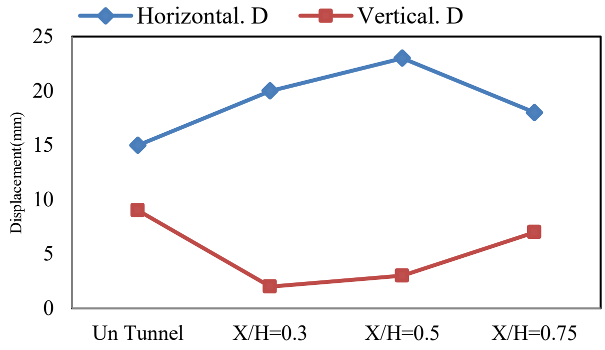

Figure. 16: Horizontal and vertical displacement of the anchored pit edge by changing the depth of the tunnel

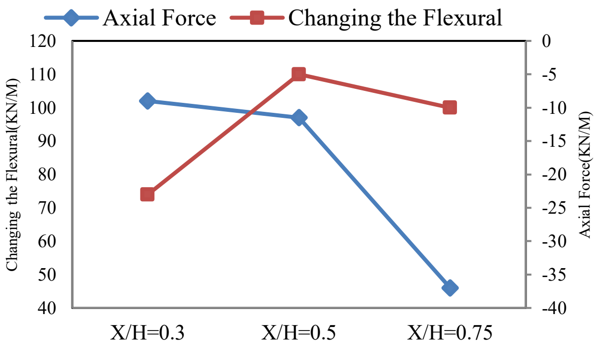

Figure. 17: Changing the flexural anchor and axial force of tunnel lining in the nail-restrained pit by changing the tunnel depth

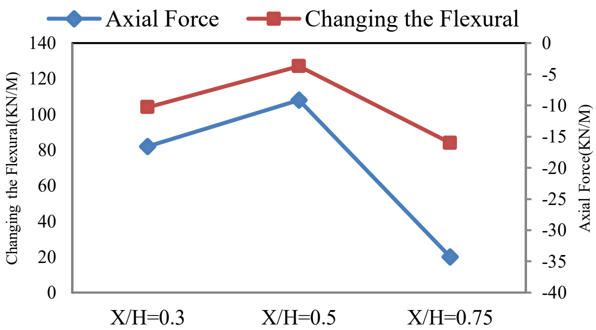

Figure. 18: Changing the flexural anchor and axial force of the tunnel lining in the anchor-controlled pit by changing the tunnel depth

EFFECT OF CAVITY DIAMETER

Investigation of the effect of tunnel diameter in the values of 4, 6, 8 meters that the thickness of lining, distance and depth of the tunnel are equal to 40 cm, $X / H = 1$ and $D / H = 0.5$, respectively, which are the most critical responses of the pit and tunnel Has created.

Regarding the wall reinforced with nails, according to Figure (19), it can be seen that the horizontal displacement of the edge of the pit increases continuously with increasing the diameter of the tunnel. Comparison of vertical displacement shows that as the diameter of the cavity increases, the subsidence also decreases continuously. This behavior is due to the uplift of the tunnel.

Due to the superficiality of the tunnel, the uplift reaches the ground level and leads to a decrease in subsidence. The larger the diameter of the tunnel, the greater the volume of drilling, resulting in more uplift. Changing the diameter of the tunnel from 4 to 8 meters leads to an increase in horizontal displacement from 5% to 40% and a decrease in vertical displacement from 10% to 25%.

In the case of anchor-restrained wall, where the changes in the settlement and horizontal displacement of the wall crown with the tunnel diameter are shown in Figure (20), it can be seen that the horizontal displacement of the pit edge increases continuously with increasing tunnel diameter.

Changing the diameter of the tunnel from 4 to 8 meters leads to an increase in horizontal displacement from 6% to 50% and a decrease in vertical displacement from 40% to 65%.

In this case, too, the anchorage method is more sensitive to the presence of holes than the nailing method.

The study showed that the change in tunnel diameter did not lead to a significant change in the axial force created in the nails and anchors. Therefore, their diagrams are omitted.

Due to the fact that the diameter of the tunnels in this case is different, so it is expected that the values of axial force and flexural anchor created in the cover are also different. Therefore, in order to investigate the effect of drilling on the coating behavior, the difference between the structural efforts of the coating before and after drilling was considered.

Changes in the flexural anchorage and axial force of the cavity cover element in different diameters before and after nailing are shown in Figure (21) and after anchoring in Figure (22). Due to these problems, it is observed that the difference of bending anchor before and after drilling the pit also increases.

The trend of changes in the flexural anchor is similar to the trend of horizontal displacement changes with depth and completely follows it. The reason for the low impact of excavation on the axial force of the tunnel cover is that the axial force is more affected by perpendicular shifts along the tunnel.

Examination of the diagram shows that in this case the nailing system will have a greater effect on the flexural anchor of the cover. In a way, the rate of increase of the anchor in the nailing system is more than the anchoring system.

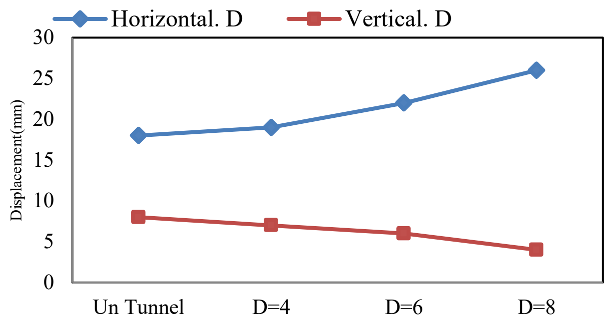

Figure. 19: Horizontal and vertical displacement of the nailed edge by changing the diameter of the tunnel

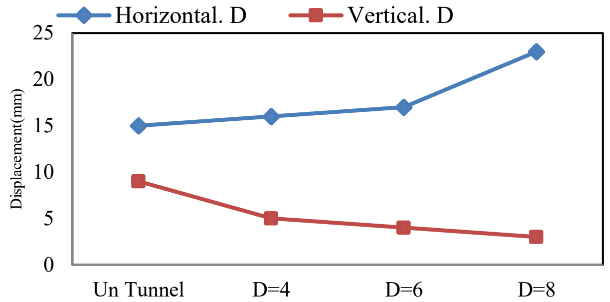

Figure. 20: Horizontal and vertical displacement of the anchored edge by changing the nature of the tunnel

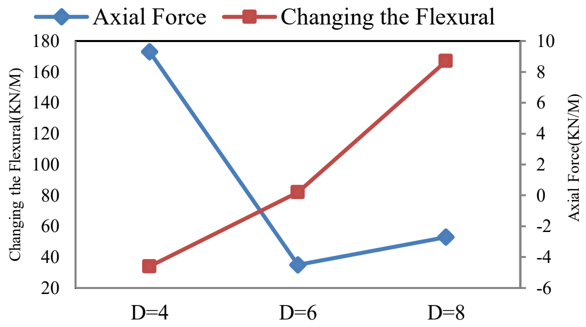

Figure. 21: Changing the flexural anchor and axial force of tunnel lining in the nail-restrained pit by changing the tunnel diameter

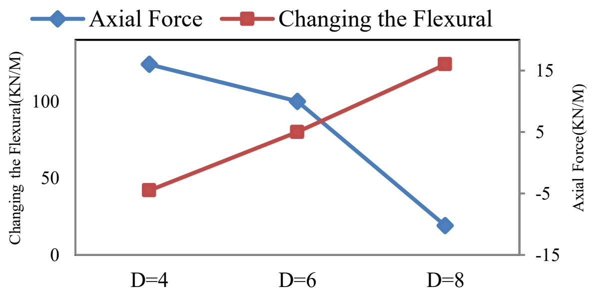

Figure. 22: Changing the flexural anchor and axial force of the tunnel lining in the anchor-restrained pit by changing the tunnel diameter

CONCLUSION

In this study, the interaction of underground cavities with urban excavations was investigated. The most important results are:

1- The presence of underground cavities around the excavation will change the behavior of the excavation. In the studies, the distance of the hole up to twice the height of the pit, the depth of the hole up to 3.4 of the height of the pit and the diameter of the hole as much as 4 meters are effective on the behavior of the pit.

2- By increasing the distance of the cavity from the excavation wall, its effect on horizontal displacement decreases. Although the horizontal displacement of the anchor system is less than that of the nail, the rate of increase in horizontal displacement through the tunnel is greater than in the case where there is no tunnel. In other words, the horizontal displacement of the anchorage system is more sensitive to cavities than to nailing.

3- With increasing the depth of the hole from the ground, first we see an increase in its effect on horizontal displacement and then a decrease. So there is a critical depth at which the most critical effect of the cavity on the horizontal displacement of the pit is obtained. In the range of studies, this depth is equal to half the height of the pit.

4- Increasing the diameter of the tunnel leads to increasing the horizontal displacement and increasing the thickness of the cover leads to reducing it.

5- The axial force of the tunnel cover is not affected by the excavation of the pit. But the bending anchor in it is highly dependent on excavation. In two factors, the distance of the hole from the excavation and the depth of the hole, the effect of the anchor system on the bending anchor of the cover was greater and in the tunnel diameter parameter, nailing had a greater effect on the bending anchor of the cover.

6- Studies have shown that although the horizontal settling and displacement of the anchorage system is less than nailing in all analyzed cases, but the response of the anchorage system to nailing is more sensitive to the presence of cavities.

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