Investigation of surface settlement of ground caused by cut-and-cover tunneling in Urmia Interchange

Chiya Gharakhan, Hajir Mohammad Eisa, Masoud Hajialilue Bonab

Abstract— **Earth's surface settlement is one of the most important tunnel drilling circumstances that has been studied by many international investigations to control its effects. This paper investigates the effect of cut-and-cover tunnel construction at the ground level adjacent to the non-surface interchange of the Urmia city, Iran. At the beginning of this research, the measurement of the Earth's ground settlement at some section of the non-surface interchange that is obtained from local surveys is provided. At the next step, it is compared with the analytical results of PLAXIS 3D and local data and soil parameters. The exact surface, obtained from the regional organization, was used to measure the Earth's ground settlement. According to the results obtained from the measurements, the maximum settlement is 9.95 mm. The calculated subsidence value of numerical modelling is lower than the results of local surveys, which may be due to the accuracy of soil laboratory parameters. At the end of the research, the actual soil parameters were obtained using recursive analysis. The measured session values are within the range of the results of other researchers.**

Index Terms: **Cut-and-Cover Tunneling, Sliding, Numerical Modeling, PLAXIS 3D.**

I. INTRODUCTION

Tunnels are one of fundamental structures utilized in many countries. From structural viewpoint, they could be constructed with various geometry and materials which each of these factors can influence dominant behavior of structures, [1], [2]. One of the main differences of tunnels with other structures is their structural restraints. In most of the building structures, the supports of the structure are in discrete points and their configuration can play significant role in the overall behavior of the structure,[3]. However, tunnels have continues supports in the ground. The interaction between the tunnel and the soil buried in is mostly the result of the geotechnical properties of the soil. Nowadays, with increasing demand for in-city trips, there is an urgent need for shallow and easy-to-installation tunnel. From geometrical viewpoint, understanding the ground's response to tunnel drilling is essential for creating safe and affordable construction. This response, which appears as stress field changes and displacement of the soil mass around the tunnel, depends on various factors including geology, geotechnical properties, drilling method as well as tunnel maintenance and equipment facilities. A precise understanding of this can be achieved through local measurements such as those in this article.

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Adequate attention and study of the interaction between drilling and its surrounding soil is an essential prerequisite for providing a valid prediction regarding the excavation of surface tunnels based on numerical analysis. On the other hand, the safety and resistance of structures in front of various hazards and loads are vital for the economy and industrial improvement, and they should be included in the designing of the structures as well [4]. This discussion presents an investigation of the behavior and deformation of the land surface due to drilling and construction in urban areas based on numerical modeling in tunneling.

II. BORING THE TUNNEL

In general, tunnel drilling is done in two ways: open front and closed front. The following is a summary of each of these two methods.

A. *Open-front Tunneling Method*

Open-front tunnel construction includes tunneling techniques without the use of permanent maintenance for the drilled tunnel front. Shielded mechanized tunneling can also be used as open-front tunneling. In this case, the main factors of the meeting are:

1- Move the earth toward a part of the tunnel that is not maintained

2- The radial motion of the earth towards the deformed cover

3- The radial motion of the earth towards the cover thus consolidates

The initial case of the meeting can be reduced by reducing the length of the tunnel not maintained by restraint on the work front. The latter is usually high, which is why primary shotgun coating is used for primary maintenance. Various additives are used to accelerate the hardening of concrete, allowing the drilling speed to increase. When tunneling is done on low-permeability soils, some consolidation may occur after tunneling. In cases where the completed tunnel acts as a drain or impedes further consolidation to the surrounding soil, delayed radial movement may occur. In lands, with high permeability, the drainage pressure drops and consolidation phenomena occur in front of the tunnel front, and ground movement may occur rapidly during consolidation [5].

B. *Closed Front Tunnel Method*

This tunneling method involves continuous maintenance of the tunnel front. In contrast to open-frontal tunneling, land deformation is less common in this method. This issue is particularly important in urban and shallow areas. There is a great deal of variability in the maintenance tool in this method, and so in unstable terrain, the workflow can be sustained by mounting restraint or nail soil after each maintenance sequence.

In some cases, the use of compressed air can cause tunneling with a closed work surface. Along with the use of shotcrete and containment, fast closing of the loop helps greatly stop the deformation of the ground. The small deformation of land that results in closed-loop tunneling results in high tunnel cover forces, but if the tunneling is shallow in urban areas, the loads on the cover are relatively small. Meyer and Taylor expressed their idea of deformation associated with shield tunneling as follows:

1- Moving the earth toward the work front, thereby releasing tension
2- The radial motion of the Earth towards the shield, as a result of tunnel pre-drilling
3- The radial motion of the earth toward the endless space, thereby creating a gap between the shield and the cover
4- The radial motion of the ground towards the coating, thereby deforming the coating
5- The radial motion of the earth toward the cover, which results in consolidation

One of the methods of tunnel excavation is the closed-loop method. In this method, the trenches from the surface are drilled to the desired depth and width so that the floor of the trench will be tuned to the floor of the tunnel. Then install the desired facility in the tunnel and wall it with maintenance equipment and embark on it to the ground level. This method is possible in cases where there are no surface structures or damage to the site in question. According to the experiences in different cities of the world, in general, it can be said that in case of deeper tunnels from 10 to 14 meter, the method of sputtering is cheaper and easier than other methods and the construction of subway tunnels to the depth of 18 meters is also quite practical and affordable.

C. Types of cut-and-cover tunneling methods

Depending on the type of execution, the slower method is categorized as follows:

1- Side piles as retaining wall
2- Side piles as soil retaining wall and pillar instrumentation
3- Side and middle pillar piles and ceiling in insitu fills
4- Piles for side and middle columns and prefabricated ceiling

III. Investigations in the Tunnel Surface and Excavation

The adverse effects of drilling operations on the construction of a tunnel or ditch on land surface structures led researchers to conduct extensive research to develop and develop methods for estimating and evaluating land surface meetings. In this context, not only the size of the final meeting was examined, but also the amount of the meeting at various stages in the preparation of a meeting procedure. Also, the question of which surface structures will be affected by drilling operations and to what extent this will be affected has been one of the major issues raised by many researchers. Past tunneling research can be divided into four main groups: experimental research, analytical research, laboratory research, and numerical research.

IV. Numerical Methods

The use of the finite element method as one of the methods for geotechnical engineering began in the year 1966 and proved to be a robust method for analyzing the behavior of different structures in civil engineering using different software such as ABAQUS, PLAXIS, PFC2D, and so on [6]. By using these software, the user could use this kind of analysis to be simple and quick for two- dimensional and three-dimensional structures as well [7]. Clough and wood ward [8] used this method to characterize stresses and displacements in the embankments, and Deer and Reyes explained its use for analyzing tunnels and underground excavations in rock. Cho in 1994 in his doctoral dissertation "Predicting Surface Occurrence as a result of Tunneling in Soft Lands," he used two-dimensional finite element analysis to investigate the impact of different soil behavioral models on the shape of the subsidence pit. Fowell and Karakus in their paper [9], investigates the effects of drilling on the amount of subsidence using the finite element method. Underground structures are one of the most important ways of dealing with traffic in big cities today. Important underground structures in the cities can be pointed to the tunnels built and covered method. Fowell and Karakus [9], in this research, the static analysis of tunnels in coarse-grained wetlands using numerical modeling of discrete elements (DEM) and PFC2D software has been investigated, and the effect of tunnel depth on land surface profile has been investigated. Meanwhile, these underground structures could affect the performance of the over pavement as well. In this regard, investigation on the methods of reinforcing/stabilization of pavement layers illustrated that reinforcement and increasing the resilient modulus of pavement layers leads to reducing the permanent deformation (rutting) of flexible pavement, especially for the pavement constructed over weak subgrades layers [10] and in continue developed a step-by-step framework and general guidelines for the process of project evaluation of existing pavement conditions following the proposed six steps and developed the methods for the selection of feasible maintenance/rehabilitation alternatives for the pavement [11]. In addition, For performed finite element studies in this field, the results of the analysis software are compared with the analytical solution, FEM, and PLAXIS solution [7]–[10], [12]–[15].

Mahmoud Vafaian et al. [16] in 2001 comparison of Mohr-Coulomb Behavior Models and Hardened Soils to Estimate Maximum Surface Settlement and Survey of Underground Stability in Shallow Tunnels Using PLAXIS Software. If the Mohr-Coulomb behavior model is used, the maximum surface subsidence will increase with increasing tunnel depth, which may not be acceptable in some cases, but in the advanced hardened soil model with increasing depth of drilling depth, the maximum surface subsidence and stability factor the tunnel decreases and increases in order, which is acceptable.

V. Study of Urmia Interchange

A. Geotechnical studies of the area

The geological and geotechnical information of the study area is based on the Stocklin segmentation of the project site in Alborz Zone. The Alborz Mountains in the east connect to the Pamir Mountains through the Hindu Kush. But the western and northwestern stretches of the mountains or the Libs, are ambiguous. Looking at the geological map of Azerbaijan, we observe that sedimentary, volcanic rocks cover much of it. Also, in some places, such as Tabriz and Maku, igneous rocks are exposed in and need such as syenite. Fig. 1 shows the location of the project study area.

To determine the engineering parameters of each layer, the results of laboratory and field experiments were analyzed based on the location of each layer. Then based on the analysis of the proposed values of each parameter is presented. To select the engineering parameters of each layer, the data is scattered, and the results are far from realistic.

Soil at the project site from the ground level up to a depth of 1.5 meters from the loam soil, from 1.5 m to 3 m deep clay with sand (CL), from 3 m to 11 m deep gravel with clay (GC), from 11 m to 15 m deep clay with sand (CL), from 15 m to 22 m deep gravel with clay (GC), from 22 m to 27 m deep clay with sand (CL), and from 27 m to 30 m deep gravel with clay (GC). Based on the results of field and laboratory experiments and engineering judgments, the necessary parameters for determining the permissible soil strength and estimating the subsidence of the foundations are suggested in Table 1.

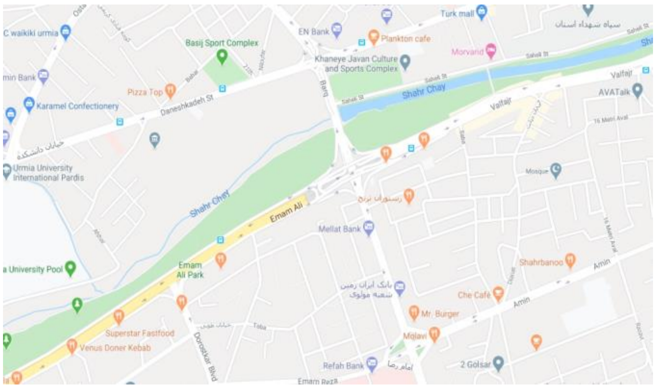

Fig. 1. Locating the study area

Table 1. Soil properties

Soil type based on its class	GC	CL	Peat Soil	unit
Number of SPT blows identifier of soil	43	22	-	Number of blow
Natural unit weight γ_{wt}	2.03	1.81	0.8	gr/cm^3
Effective internal friction angel of soil based on effective stress (φ')	33	28	25	degree
Effective cohesion of soil based on effective stress (C')	0.03	0.12	0.1	kg/cm^2
Friction angle of soil based on ultimate stress (φ_u)	-	25	23	degree
Cohesion of soil based on ultimate stress (C_u)	-	1.05	0.09	kg/cm^2
Soil compaction factor (C_c)	-	0.137	-	-
Soil inflation factor (C_s)	-	0.031	-	-
Soil Poison ratio (ϑ)	0.36	0.4	0.35	-
Soil Young Modules	600	320	150	kg/cm^2

B. Dimensions and specifications of retaining wall

Drilling width and depth of 28 meters (with two 14 m space) drilling in the study area is about 5.5 m. The temporary structure was carried out using pile running piles to retrieve the pit before drilling following Fig. 2 and 3. In such a way that piles with 1-meter diameters (side piles) and 1.5 meters (intermediate piles) and 15.5-meter height with 3 meters distance from each other, are executed at the project site. The drilling process is such that three rows of piles like Fig. 4 the shape of the pile are ground in fine grit and then drilled by a shovel and loader.

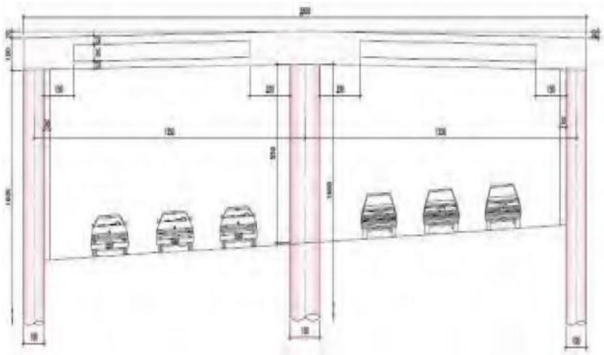

Fig. 2. Drilling section

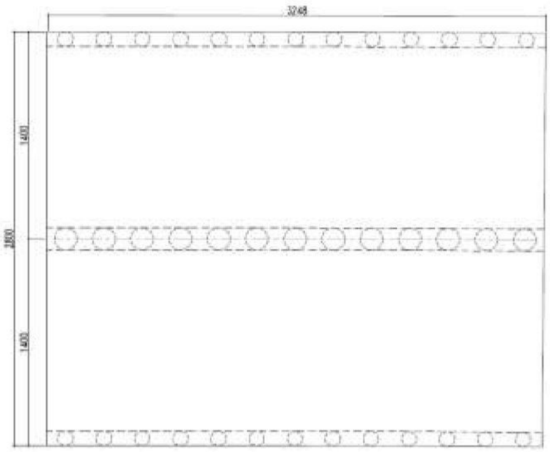

Fig. 3. The position of the piles

C. Settlement measurement

The precision level obtained from the province's survey organization was used to measure the ground settlement. Totally 28 points were selected that 6 pinots were lost during drilling of point data. The total length of 80 m, according to fig. 4 and table 2. Points that selected were at 10 m from each other, and settlement was measured in four steps. The surveillance camera was used to measure the meetings, which were read at the mapping station created at the project site.

Table 2. Distance between desired points from drilling edge

Point	Distance from excavation edge (m)	Point	Distance from excavation edge (m)
E	3	**B**	10
A	5	**N**	20
C	6	**M**	30

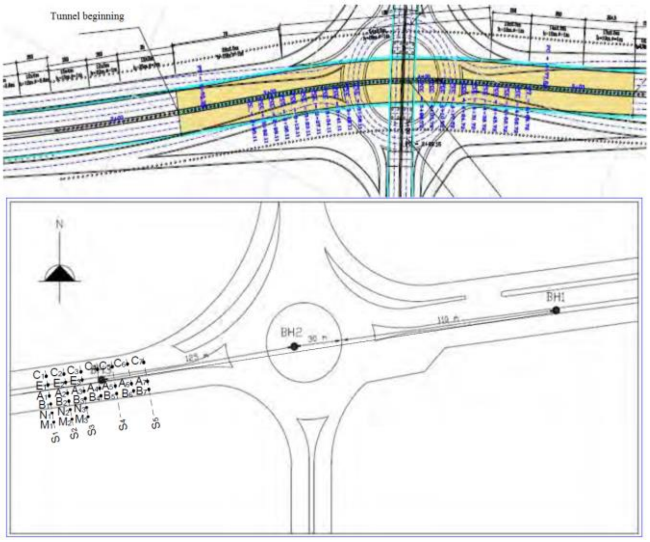

Fig. 4. Study area and location of meeting points for measurement

D. *Discussion of results*

As mentioned, the points of displacement at various stages of drilling were read using a surveying camera. To investigate the results obtained, the five profiles of transverse seating profiles were plotted at different stages, and in the axis, the direction shown in fig. 5 to 9. As these profiles show, by decreasing the edge of the hole, the subsidence decreases and tends to zero. Also, as the depth of digging increases, the number of subsidence increases. According to the results obtained from the measurements, the maximum sum of points taken at the nearest point to the drilling edge is 3 m from the drilling edge, which was 9.95 millimeters. In the mentioned fig., series 1 related to 2m depth, series to related to 3.5m depth, and series 3 related to 5.5m depth.

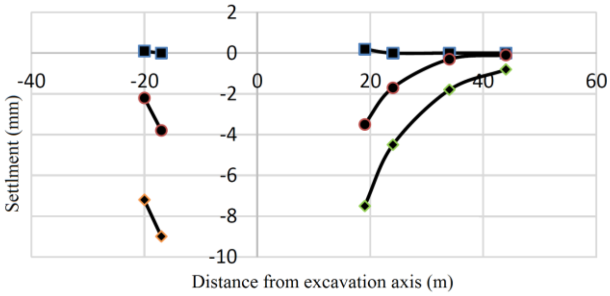

Fig. 5. Vertical displacement of points S1 due to the distance from the axis

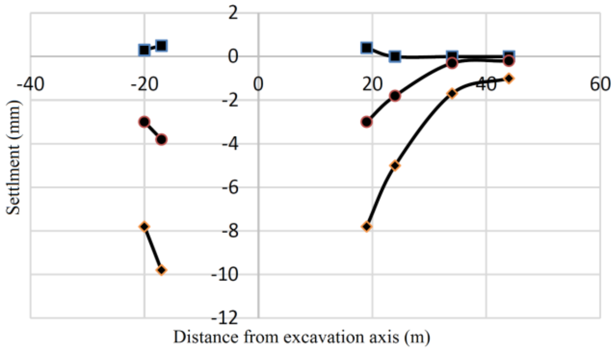

Fig. 6. Vertical displacement of points S2 due to the distance from the axis

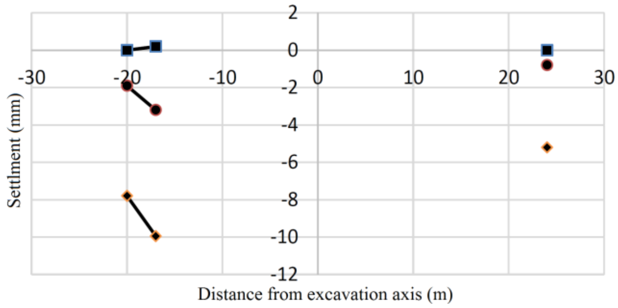

Fig. 7. Vertical displacement of points S3 due to the distance from the axis

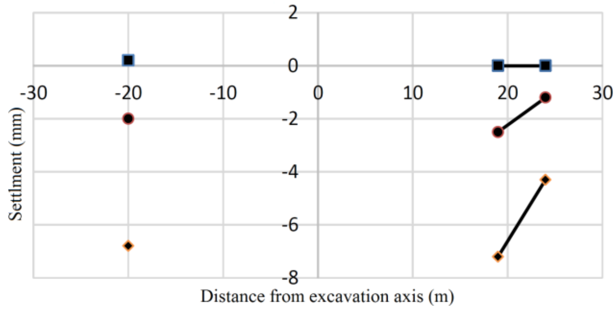

Fig. 8. Vertical displacement of points S4 due to the distance from the axis

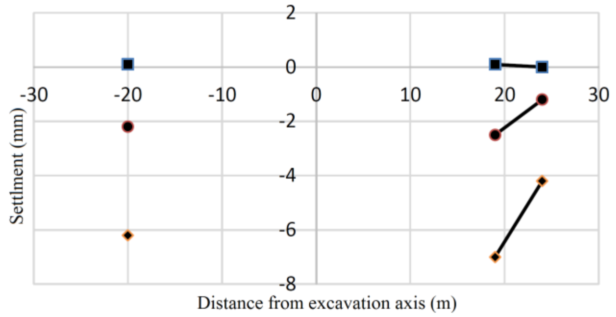

Fig. 9. Vertical displacement of points S5 due to the distance from the axis

VI. NUMERICAL MODELING

A. *General Model Specifications*

As mentioned before, to verify the results of numerical modeling, the drilling situation of the cross-section in the point of 12+600 Km is modeled with Plaxis 3D in a realistic space, and finally, the results of numerical modeling will be compared with the results obtained from the mapping readings.

B. *Results of numerical modeling of the desired well*

Fig. 10 to 14 represent how to settle on the ground for the time after the piles are placed in the soil after 2 m, 3.5, and 5.5 m, respectively. Fig. 14 shows how the orbitals are changed in the piles. As represented in fig. 10 to 14, the maximum land surface settlement occurs at the edge of the pit and the depth of 5.5 m the drilling meter. According to the diagram, the maximum meeting is 7.1 mm, which is a good estimate compared to the one observed during drilling. The diagrams also show that by dropping off the drilling edge, the number of subsidence decreases, and as the depth of digging increases, the number of subsidence increases. It is also well-visible in this form of the rising floor phenomenon, which is one of the causes of corrosion. The amount of this elevation increases with increasing excavation so that the amount of 16 millimeter reaches the end of the excavation. It should be noted, however, that this value would be reduced if modeled with the hardened soil model (HS).

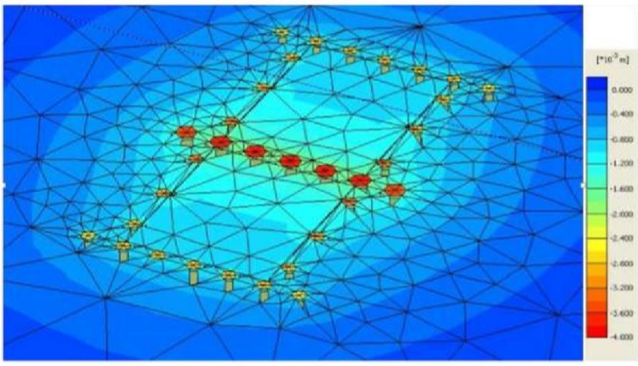

Fig. 10. Shift the ground level after placing the piles

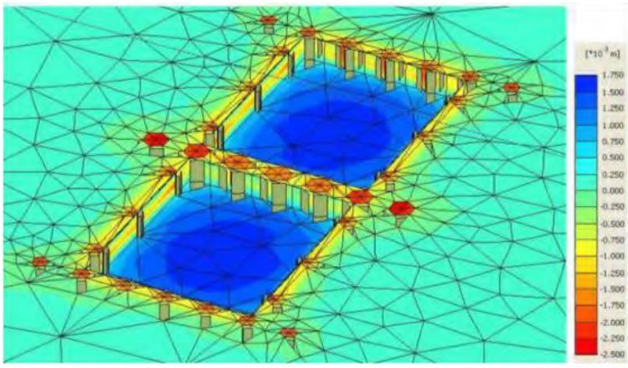

Fig. 11. settlement after 2 meters of drilling

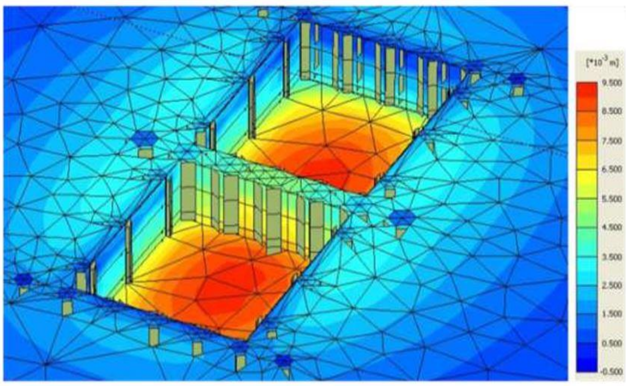

Fig. 12. settlement after 3.5 meters of drilling

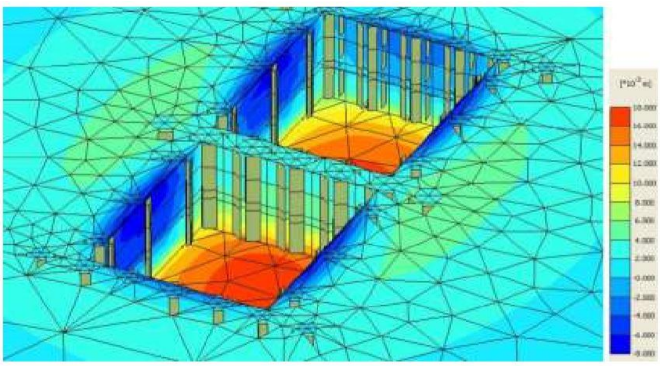

Fig. 13. settlement after 5.5 meters of drilling

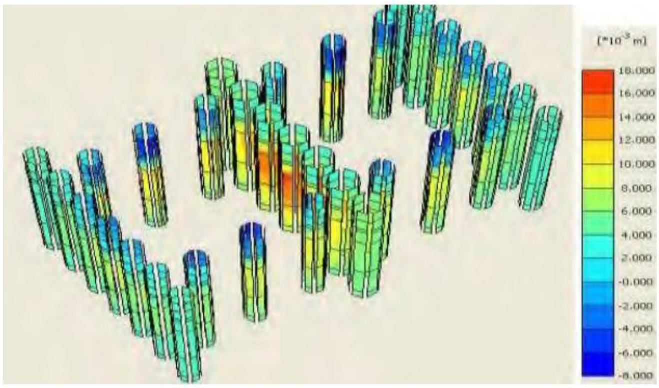

Fig. 14. How to change the vertical position along with the piles

VII. COMPARISON OF MAPPING RESULTS WITH PLAXIS

In the early phase of drilling, the results of the modeling study were more than those measured at the site, which would be found by moving away from the edge of the drilling rig. In the second step, the measured subsidence value is higher than the analysis, which may be due to the effect of the Mohr-Columbus model. In the third stage, the drilling session was further analyzed, and this may be due to the inaccuracy of the soil parameters obtained from the laboratory.

VIII. DETERMINE THE ACTUAL SOIL PARAMETERS

To improve the results of the modeling and prediction of drilling-induced sedimentation, we introduce some variables that are relevant to soil parameters that can bring us closer to the results of laboratory testing. Table 3 shows the range of soil parameters. From the results obtained, it is clear that the changes in friction and cohesion have a greater impact on the settlement and elastic modulus changes and have a very limited effect on them. The main parameters of the project sandstones are the elastic modulus 40,000 KN/m^2, friction angle 38, and cohesion 11 KN/m^2.

Table 3. Actual soil parameters

Parameter	E (KN/m^2)	C (KN/m^2)	φ
Appropriate sand range	40000-70000	8-15	35-38

IX. CONCLUSION

In this paper, we compare the results of numerical modeling and local measurements of soil parameters. The exact level of the land, obtained from the Provincial Research Organization, was used to measure land settlement. The surveillance camera was used to measure the meetings, which were read at the mapping station created at the project site. To investigate the results obtained, the profile of transverse subsidence profiles is plotted at different stages along the drill axis. By examining the graphs, it is clear that:

1- Moving away from the edge of the cavity, the amount of subsidence decreases and tends to zero

2- As the depth of excavation increases, subsidence increases

3- According to the results obtained from the measurements, the maximum meeting point at the nearest point to the drilling edge is 3 m from the drilling edge, which is in 9.95 millimeters.

By modeling the desired problem in Plaxis 3D software after 2, 3.5, and 5.5 drilling shows that:

1- The maximum land surface subsidence occurs at the edge of the pit and the 5.5 depth of drilling. The maximum meeting with the diagram is 7.1 mm, which is a good estimate compared to the one observed during drilling.

2- The diagrams also show that by dropping off the drill edge, the number of subsidence decreases, and the subsidence rate increases with increasing depth of digging.

3- The results obtained from the numerical modeling of the bottom floor elevation phenomenon, which is one of the causes of corrosion damage, are well visible. The amount of this elevation increases as the number of excavations increases so that at the end of the drilling, it reaches a 16 millimeter.

It should be noted, however, that if modeled with a hardened soil model (HS), this value would decrease

4- In the early phase of drilling, the modeling results of this study were more than those measured at the site, which was reduced by moving away from the drilling edge. In the second stage of drilling, the measured subsidence value is higher than the analysis, which may be due to the effect of the Mohr-Columbus model. In the third stage, the drilling session was further analyzed, and this may be due to the inaccuracy of the soil parameters obtained from the laboratory.

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