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An Investigation on the Behavior of Retaining Structure of Excavation Wall Using Obtained Result from Numerical Modeling and Monitoring Approach. (A Case Study of International "Narges Razavi 2 Hotel", Mashhad)

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Abstract

With the growing population and density in metropolitan areas, higher tendency to live in high-rise buildings, and increasing demand for parking lots, it seems necessary to excavate soil to construct underground spaces. During excavation work, as the height of the wall increases, special care should be taken to the wall stabilization to avoid any consequent damage including extensive property damage or loss of life. Different methods such as performing steel or concrete pile, sheet piling, reciprocal anchorage, diaphragm wall, soil nailing, and soil anchorage can be utilized to stabilize excavation wall. As all of these methods have their own advantages and disadvantages, it is important to know the limitations and differences of each method. Besides providing more work space in the wall, using novel methods of stabilization may lead to considerable savings in cost and time. By examining the behavior of retaining structure and also predicting the value of wall displacement, resulting from existing loads such as adjacent structures of the wall, service loads, and vehicle live load, a big step can be taken to prevent any probable damage. Currently, due to the development of high speed digital computers, finite element method (FEM) can be applied to predict the behavior of retaining structure. In this paper, as a case study, the behavior of retaining structure of excavation wall of Narges Razavi 2 International Hotel, Mashhad, stabilized using steel pile and soil anchorage, has been investigated. For this purpose, the results obtained from finite difference software, FLAC2D, and finite element software, PLAXIS2D, have been compared with those obtained from the monitoring of excavation wall. It was found that there is a good consistency between the results.

Keywords: Retaining Structure, Soil Anchorage, Numerical Modeling, FLAC2D Software, PLAXIS2D Software

1. Introduction

Different types of surcharges, adjacent structures around the wall, limitations in using equipment, project location, properties of materials, and construction cost limit types of stabilization methods of excavation wall [1]. Stabilization of excavation wall using steel pile and soil anchorage is characterized as one of novel methods implemented corresponding to the progress of excavation operation. This method which is on the basis of reinforced soil concept improves the strength of soil mass. The mechanism of the method is based on nailing the soil behind the wall by a number of steel tensile anchors from top to the bottom of the wall. The following are some of the advantages of the soil anchorage method:

- Flexibility, high speed and of simplicity
- Not taking up too much working space in the excavation areas
- Applicable in the rural zones
- Improvement in the geotechnical properties of soil

Among researchers who have worked in this field, reference can be made to Hanna & Matallana, 1970, James & Phillips, 1971, Plant, 1972, Liu & Dugan, 1972, Hanna & Kurdi, 1974, Anderson & Hanna, 1977, Matlock, 1981, Fernandes & Falcao, 1988, Lim & Briaud, 1996, Briaud & Lim, 1999, Dawkins, 2001, Krabbenhoft

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et al., 2005 and Tan & Paikowsky, 2008. One important issue in the design of excavation wall stabilization is to decrease the lateral displacement of wall. This is becausehigh lateral displacement indicates lack of stability and is followed by collapse of soil into the wall. The consequences of an unstable wall are financial and human damages to the surrounding wall area. Therefore, the wall displacements should be carefully controlled to prevent any damage [1]. In order to predict and determine the horizontal displacements, finite element difference software, FLAC2D, and finite element software, PLAXIS2D, have been employed. The software based on the plane strain theory can determine the horizontal and vertical displacements and the behavior of retaining structure as well.

For the sake of accuracy, the results of numerical modeling have been compared with the monitoring results and actual behavior of the wall. This paper is aimed at investigating the behavior of retaining structure of excavation wall. For this purpose, as a case study, International Hotel Narges Razavi 2, Mashhad, stabilized using soil anchorage and steel pile, was studied.

2. Stabilization of Excavation Wall Using Soil Anchorage and Steel Pile

Stabilization of excavation wall by soil anchorage is similar to soil nailing to some extent [2]. This multi-stage approach performed from top to bottom employs steel or concrete pile to decrease lateral displacement of the wall. For this purpose, pile locations were first excavated to the required depth. Afterwards, in the case of using steel pile, the designed profile is placed at the excavation and if concrete pile is used, the reinforcement mesh is placed and then concreting is started [3]. It should be mentioned that in the current study, stabilization was conducted using soil anchorage and steel pile. The pile had a structural concrete with cement content of 350 kg/m^3 at the embedded part and plastic concrete with cement content of 60 to 100 kg/m^3 at the top part. After installing the surrounding steel piles of the wall, excavation operation was carried out at the depth of 2 to 3 m corresponding to geotechnical parameters of soil profile. Then, some boreholes were formed in the excavation wall with definite length, diameter and angle obtained from numerical modeling and designs. Anchors consisted of cables with yielding strength of 18500 kg/cm^2 and each cable was comprised of 7 strands with diameter of 1.524 cm. To apply high tension to the anchors, according to the obtained results, one or more cables were placed at each borehole.

In addition to stabilizing the wall and meeting required safety factor, anchors are responsible for preventing any deformation in the adjacent structures resulting from prestressing forces. Each anchor is composed of restrained and unrestrained parts and spacer and centralizer were installed to provide sufficient cover for the cables. After installing anchors, the end of the borehole was filled by a cement mortar with a weight ratio of water to cement (w/c) of 0.4. This provides a support at the end of anchors to apply the tensile force.

Tensile forces transferred to concrete pile, steel pile or concrete block through load- bearing plates. Based on the results of design process, the location of concrete block in the wall was first excavated and then meshing and concreting were implemented. Dimensions of concrete support and its reinforcement details vary according to the applied tensile force to the anchor. Like spread footing, concrete blocks act as a two-way slab. Concrete blocks should have sufficient strength against punch shear and bending shear forces.

After injection, under pressure, and setting mortar at the restrained part, a filling mortar was inserted into the unrestrained part. After finishing the injection into the borehole, performing concrete block, and setting mortar, the tensile force was applied to the anchor by a specific hydraulic jack. Finally, the excavated area, with a depth of 2 to 3 m, was prepared for meshing and shotcreting with a thickness of 10 cm and content of 400 kg/cm^2.

Shotcrete, as a permanent facing for the walls, are utilized to provide local stability among piles or blocks and to protect soil surface from weathering and environmental effects. Therefore, following the above procedure and performing the first stage of excavation safely, we can move on to the next stages. An example of wall stabilization by anchorage method is shown in Figure 1.

Figure 1. A view of stabilized wall by soil anchorage and steel pile

3. Project Introduction

As shown in Figure 2, International hotel Narges Razavi 2, Mashhad, is located at the intersection of Imam Khomeini Street and Pasdaran Street, next to the Provincial Tax and Revenue Agency. The project will be constructed over an area of 8900 square meters with 5 underground floors and totally 24 floors. In order to provide the underground space and also to reach foundation level, it is necessary to stabilize wall excavation.

Some of the advantages of soil anchorage method are preventing the sliding of soil mass, limiting deformation of excavation wall, protecting adjacent structures, providing the possibility of vertical excavation, and creating space for constructing foundation and structure. In the current study, the soil anchorage method has been used in conjunction with concrete block and steel pile in the vicinity of traffic and structural surcharges respectively.

Due to the existing surcharges and structures, limitation in anchors length, and also improvement in the performance of stabilization system, five different types were used in the design of retaining structure. The differences between them lie in soil anchorage system by concrete block or steel pile, number, length, and angle of anchors to the horizon.

It should be mentioned that this paper is aimed at investigating the behavior of retaining structure at the south west side (Type3). This 24-meter-deep wall is adjacent to a six-story building and is stabilized by soil anchorage and steel pile. The project plan, surrounding surcharges, and types of retaining structure are cited in Figure 2.

At the south west side of the project, stabilization system (Type 3) is steel pile with 2IPE400 section and seven rows of anchors with the lengths 14 to 23 m horizontal and vertical distances of 2.6 m. The anchors, depending on the designed forces, include 4 to 6 high-strength cables with bonded length of 8 m. According to the geotechnical parameters of soil profile and elevation level of each anchorage row in the designs, excavation was implemented in 8 stages. At the end of each stage, steel mesh and a 10-cm thick Shotcrete were implemented. Figure 3 shows a view of Type 3 stabilization system at the south west side of the project [4].

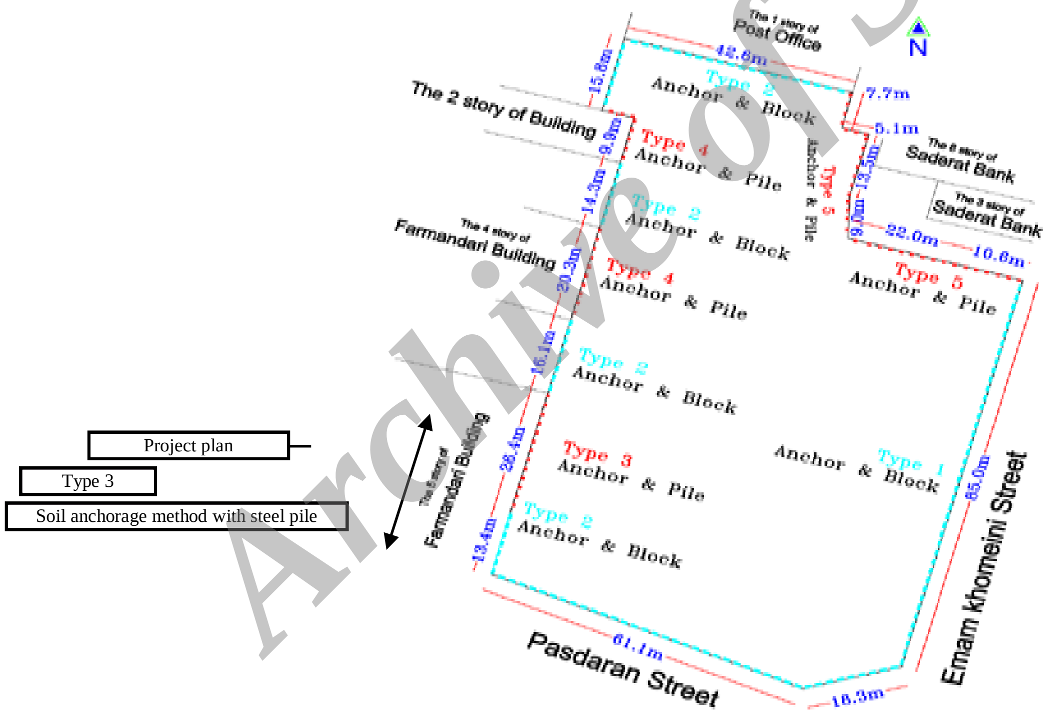


Figure 2. Project plan, surrounding surcharges and types of retaining structure

Due to the importance of horizontal displacements, some reflectors were installed on the edge of different walls to record the displacement of the walls within a one-year interval. Reflectors were read by the surveying instrument at definite time intervals. The coordinate of each reflector is based on the bench mark and accordingly the relative displacement of each reflector compared to the previous reading was obtained. The obtained displacement values from monitoring bench marks M16 and M17 located at the south west side of the project, are cited in a ten-month interval at Figure 4 corresponding to the progress of excavation operation within 38 weeks. It should be noted that the record of reflectors had a sensitivity of 0.01 mm [5, 6].

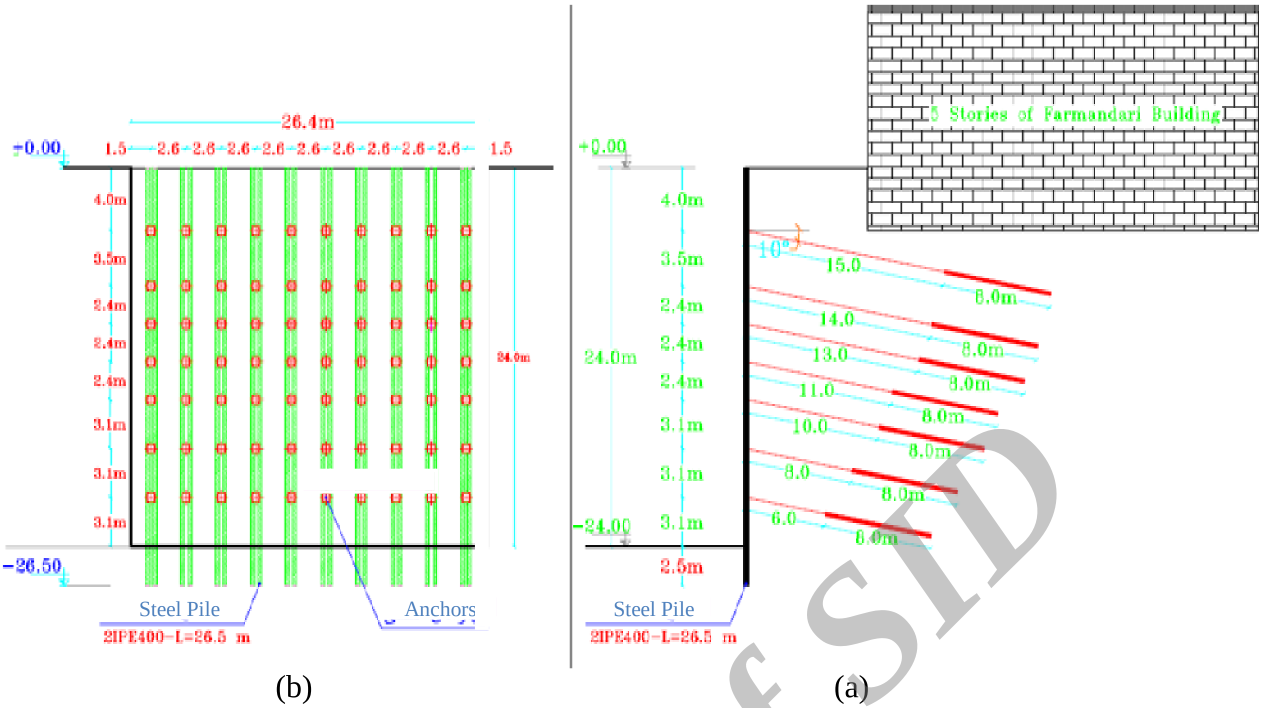
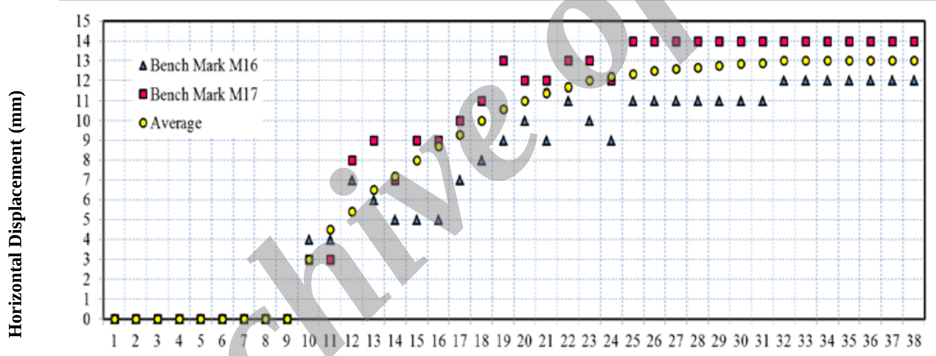


Figure 3. View of type 3 stabilization system at the south west side of the project: a) Section of type 3 b) view of type



Reading of bench marks M16 and M17 corresponding to excavation operation in 38 weeks and 10-month interval

Figure 4. The obtained displacement values from monitoring at the south west side of the project in a one-year interval

4. Used Software

FLAC2D and PLAXIS2D Software which are based on the finite difference method and finite element method, respectively, have wide applications in solving numerical geotechnical problems such as determining the excavation wall behavior [7]. In the finite element method, first, the differential equations are written separately for each node and the derivative terms are substituted by difference equations; then, the results are presented in the form of simultaneous linear equations. On the other hand in the finite element method, differential equations are solved by interpolation functions and the governing equation of each element is derived. Through the integration of equations of each element, the governing equations on the numerical model can be obtained, and finally, these equations are substituted by a system of linear or non-linear equations.

4.1. FLAC2D Software

FLAC2D software based on the finite difference method is capable to simulate the behavior of structures on the soil, rock, and other materials when they reach yielding limit and then enter into plastic flow. In this software, materials are defined by elements and meshes. Also, materials are allowed to reach yielding limit and enter plastic region, therefore, the obtained mesh can deform. FLAC2D has a high capability in the modeling of plates along which overlap or separation occurs. Other applications of the software are modeling plane strain, plane stress, axial symmetry, underground water, rock bolt, pile, dynamic analysis of materials, and viscoelastic and viscoplastic conditions. In FLAC2D, an element reacts against applied forces according to the predefined stress- strain principals [8].

Table1. Physical parameters of layers of soil profile

Soil Layer	Depth (m)	Unit Weight (kN/m^3)	Elasticity Modulus (MPa)	Poisson ratio	Cohesion (kPa)	Angle of Internal Friction (°)
Top layer	0-9	18	50	0.3	30	30
Bottom layer	9-43	19	70	0.3	40	32

4.2. PLAXIS2D Software

PLAXIS2D is a robust simulator of geotechnical problems which works on the basis of finite element method. This software is capable of solving a wide range of problems, from simple linear analysis to highly complex nonlinear simulation, particularly, through considering the effect of soil-structure interaction [9]. The software enables modeling different types of soil model in a simple graphical environment with the possibility of stage construction so as to reflect more realistic conditions of the problem. Finite element method is a powerful tool for the analysis of interaction of anchorage, soil, and structure. The advantage of this method lies in its capability to analyze elements of anchored wall, soil, and their interaction considering the effects of parameters. Moreover, using finite element method, it is possible to study any two-dimensional soil profile under plane strain theory. It should be mentioned that one of the reasons for the success of finite element method in the analysis of problems is the use of different behavioral models of soil considering a wide range of strains, effects of loading speed, effects of stiffness decrease, etc. [9,10].

5. Used Materials

5.1. Soil

One of the most important parameters in the numerical modeling FLAC2D and PLAXIS2D Software is properties of soil profile. To determine the parameters of soil profile, it is required to conduct geotechnical studies. Therefore, in the current research, the results of both field and laboratory studies have been employed. While field studies include excavation of four 50 m deep boreholes, Standard Penetration Test (SPT), density, plate loading, and pressure meter tests, laboratory studies include grading, hydrometric, Atterberg Limit, water content, consolidation, direct shear, uniaxial shear, and triaxial shear tests. After examining the field and laboratory studies, soil profile was classified into two layers according to Table 1 [11].

5.2. Steel Pile

Based on the results obtained from numerical modeling and designs, the steel pile was assumed to be 2IPE400 profile with the length of 26.5.The list of parameters used for the steel pile in the numerical modeling is presented in Table 2.

Table 2. Used parameters for the steel pile in the numerical modeling

Steel Profile of Pile	Length	Elasticity Modulus (MPa)	Poisson Ratio	Area section (cm^2)	Moment of Inertia (cm^4)
2IPE400	26.5	206	0.2	169	46260

5.3. Anchor

According to the stabilization mechanism of excavation walls by soil anchorage and steel pile, the intended force was applied by anchors including high-strength cables with two restrained and unrestrained parts. The used parameters for anchors in the numerical modeling are listed in Table 3.

Table 3. Used parameters for anchors in the numerical modeling

Anchor	Elasticity Modulus (MPa)	Area Section (cm^2)	Ultimate Failure Strength (MPa)
Strand 0.6”	200000	140	1860

5.4. Shotcrete

As stated earlier, shotcrete, as a permanent facing for the walls, are utilized to create local stability among piles or blocks and to protect soil surface from weathering and environmental effects. Based on the values obtained from design procedure, the used parameters for the shotcrete in the numerical modeling are given in Table 4.

Table 4. Used parameters for the shotcrete in the numerical modeling

Height (m)	Thickness (cm)	Unit Weight (kN/m^3)	Elasticity Modulus (MPa)	Poisson Ratio
24	10	24	2.4	0.2

6. Numerical Modeling

In order to evaluate the behaviour of retaining structure at the south west side of the project, the results obtained from numerical modeling have been compared with those obtained from monitoring process. Furthermore, stability analysis and actual modeling of the problem have been performed using FLAC2D and PLAXIS2D Software through considering the effect of shotcrete, and anchorage-soil interaction. It is worth mentioning that the modeling was implemented according to the soil profile, surcharges around the wall and two-dimensional arrangement of steel piles, anchors wall and under plane strain theory and stage construction of the wall. The numerical model consisted of soil, steel pile, anchor, and shotcrete. It should be mentioned that, to neglect the effects of boundary conditions, the soil mass was considered as a 70m× 43m×1m rectangular cube, according to the position of steel pile and anchors.

Figure 5 and 6 show the dimension and type of meshing of the soil mass in the FLAC2D and PLAXIS2D Software, respectively. Due to the difference in the principles of modeling, meshing was performed differently for each software. Furthermore, both models employ Mohr-Coulomb elasto-plasticity for the behaviour of soil profile.

In order to analyse the numerical model by finite element method, the model geometry was meshed using 15-node triangular elements. The reason for using triangular element in the finite element method is the simplicity of the application and also favourable compatibility with irregular boundaries of different geometric shapes. Also for the sake of the accuracy of numerical modeling, the adjacent regions to the anchors, steel pile, and shotcrete were again meshed to consider the effect of soil-structure interaction. It should be noted that the mesh size depends on the project importance, expected accuracy, CPU power, and computational time of modeling. In order to improve the accuracy of numerical model and also to simulate the construction sequences of excavation properly, the process of modeling was made in 8 stages.

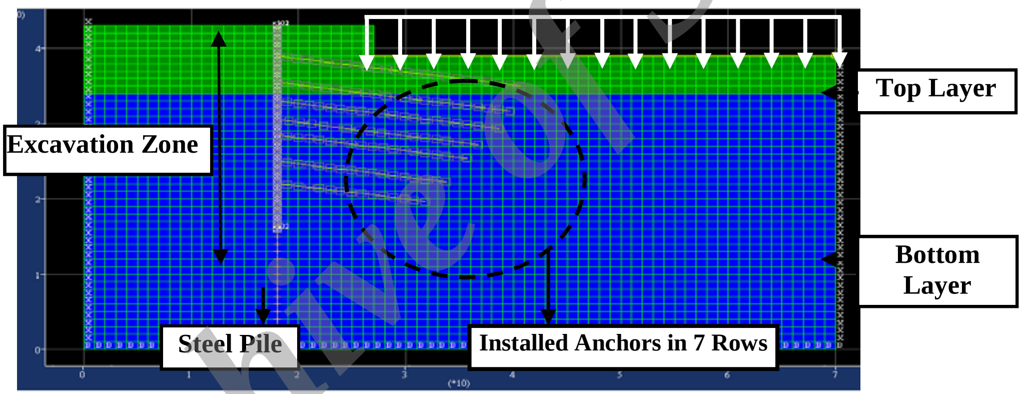


Figure 5. A schematic view of model at FLAC2D software

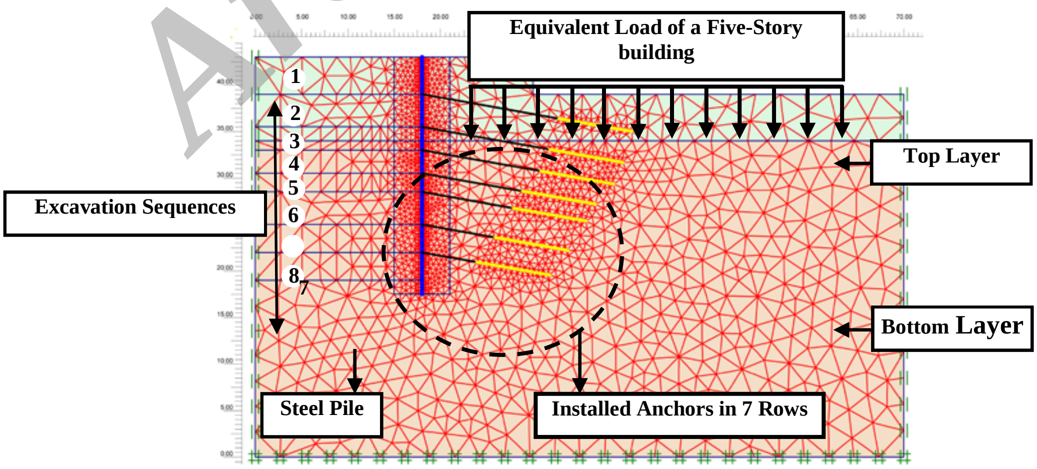


Figure 6. A schematic view of model at PLAXIS2D software

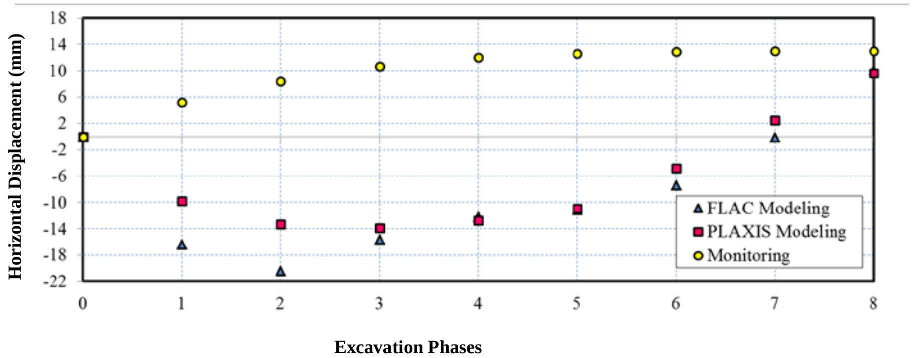


Figure 7. Comparison the results of numerical modeling and monitoring values of horizontal displacement relative to excavation operation

In order to evaluate the accuracy of numerical modeling, the obtained values from numerical modeling have been compared with the monitoring values. Monitoring was implemented at the top levels of the wall by two reflectors (M16 and M17) installed on the south west wall. Comparison of numerical modeling and monitoring values, as shown in Figure 7, indicated that despite the existing complexity in the soil profile and limitation in the numerical modeling, there is a good consistency between the numerical results and lateral deformation values. Figure 7 compares the results of numerical modeling and monitoring values of horizontal displacement relative to excavation operation including 8 phases.

7. Conclusions

1) Comparison of numerical modeling and monitoring values from lateral deformation of wall indicated that despite the existing complexity in the soil profile and limitation in the numerical modeling, at the end of excavation there is a good consistency between the numerical results and lateral deformation values.
2) It was found that finite difference software, FLAC2D, and finite element software, PLAXIS2D is powerful tools for investigating the behaviour of a stabilized wall by soil anchorage and steel pile.
3) With increase in the excavation depth, lateral deformation of the wall will increase. The increasing rate compounds with the progress of the excavation operation.
4) Due to the complexity in the soil profile, Mohr-Coulomb behavioural model was found to be an appropriate model to predict the behaviour of an excavation wall stabilized by soil anchorage and steel pile.
5) Comparison of the obtained results from numerical modeling and monitoring lateral displacement indicated that in, all cases, monitoring exhibited more conservative results.
6) At the end of excavation operation and implementing the retaining structure, the actual lateral displacement of the wall was 12.97 mm, while, FLAC and PLAXIs Software predicted it to equal 10 and 9.68 mm, respectively.

8. Acknowledgments

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