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# Seismic Performance of Deep Excavations Restrained by Anchorage System Using Quasi Static Approach

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## ABSTRACT

*Soft grounds amplify the earthquake motions and the peak ground acceleration increases when passing through them. Thus, the response of structures constructed on such sites would be more severe than others. The deep excavations are one of the most vulnerable geotechnical structures during earthquakes particularly when performed in soft grounds. Hence, they have to be stabilized and restrained for these circumstances. Using the anchorage system is one of the most common methods to stabilize such excavations. The influence of different factors such as soil characteristics, and anchors' geometry and properties on seismic response of so-called restrained deep excavation is an important issue that needs to be focused on. In the present paper, the results of quasi-static finite element analyses of deep excavations performed in soft and stiff grounds during earthquake loadings have been presented, compared and discussed. The results show that considering adequate values for the anchor parameters (such as; angle, length and distance between the anchors and the amount of pre-stress force in them) leads to accurate and satisfactory design safety and deformation controls of the excavation.*

**Keywords:**
Anchorage; Quasi static seismic analysis; Finite element method; Deep excavation

## 1. Introduction

The Pseudo-static method is the first method used for seismic design. The theoretical basis of this method is the principle of De Allembert, which states that when a structure in the amount of A is accelerated, the effects of this vibration on the upper structure are $(A/g)\times W$ in the opposite direction of acceleration. Therefore, the quasi-static coefficient $K$ is equal to $(A/g)\times W$. The value of the pseudo-acceleration coefficients in horizontal and vertical directions ($k_h$ and $k_v$) is determined both as a coefficient of gravity acceleration, and their direction is determined in such a way as to create the most critical state. The reason for naming the quasi-static method is that instead of applying the cyclic earthquake load to the model, It is removed and the forces of the earthquake as static forces $K_W$ (which $K$ is the seismic coefficient and $W$ is the weight of the structure) in two horizontal and vertical directions and in the form of vertical inertia forces ($F_h = k_h\times W$ and $F_v = k_v\times W$) is applied on centre of the failure wedge and the problem in the form of statically is considered. The similarity of the quasi-static method with equilibrium analysis (static method) used by geotechnical engineers causes it easy to understand and perform its calculations. An earthquake can put the slipping mass under the influence of both horizontal and vertical quasi-static forces, but because in most earthquakes the maximum vertical acceleration is less than the maximum horizontal acceleration therefore $k_v < k_h$ and as a result $F_v < F_h$ and the vertical quasi-static force will have less effect on the stability coefficient, which is why, in quasi-static analyzes, the vertical acceleration is usually neglected. Pseudo-static method for stability and determination of coefficient of reliability (factor of safety) of circular and non-circular linear sliding surfaces of trenches is used. The trenches tend to move downward (slide) after excavating and breaking tension balance. From the static point of view, slip occurs when active forces overcome the resistance forces (on the sliding surface) that derive from the shear strength of the soil at the sliding surface [1]. In controlling the safety and stability of the trenches, the shear stresses created along the most critical and most likely slip surface should be calculated and compared with the shear strength. There are various methods to stabilize trench wall and excavation which the anchorage method can be very effective in reducing displacement of trench wall [2] and that often widely is used in excavations of the urban districts. In the anchorage method, after the placement of the Soldier piles inside the wells embedded in the soil beforehand, excavation is done step by step and from top to bottom of the trench. After each stage the excavation (the depth of the excavation in each step depends on the type of soil and distance between the wells of the Soldier piles that is usually 2 to 3 m), with the help of special drilling machines, wells horizontally or angled in the wall is drilled. Then, inside these wells, prestress cables (anchors) that are made of rebar or strands are placed, and these cables are completely fixed in the soil by injection of concrete at the end of the wells. Then the cables are tensioned by special jacks and the ends of the cables are fixed on the wall surface by bolt and nut. This will cause the pre-stress force in the cable compress the soil of behind wall and, at the same time, the total active force of the soil in the trench wall is transferred to the soil in the body of the wall and soil acts as a guard structure. In this method, in addition to the slope and geotechnical characteristics of the soil, other factors such as the angle of placement, the length and spacing between the anchors, impact on the stability and deformation of retaining walls that are restrained by this method. The first, stability of the trenches was investigated by Flennius [3], and then the stability of those in different methods, including the equilibrium method, the boundary element method [4], finite element method [5], and other methods was investigated. Among the proposed methods, the finite element method is more widely used than other methods due to its ease of use and execution. In the present study, by studying a case study and using finite element method, effects of factors such as the angle, length and distance of between anchors and the amount of pre-stress force in them, on stability and deformation of the retaining wall by Anchorage system has been investigated and the results have been discussed.

## 2. Soil and Anchorage System Specifications

In this study, quasi-static behavior of retaining wall with horizontal acceleration 0.15 g in an excavation built-in Tehran city and with a height of 21 m and with two different soil types (dense and loose soil) has been investigated. The proposed parameters have been considered for modeling according to Table (1).

## 3. Finite Element Modeling

In the present study, PLAXIS 2D finite element software for the analysis of soil deformation and stability has been used. The general geometry considered in this paper is shown in Figure (1). The plain strain condition has been used to analyze the

**Table 1.** Parameters used for software modeling.

| Parameters of Two Types of Soil | Value |
|---|---|
| Horizontal Acceleration Coefficient of the Earthquake ($K_h$) | 0.15 g |
| Cohesion $c$ (kN/m$^2$) | 32, 27.5 |
| Modulus of Elasticity $E$ (kN/m$^2$) | $8.79\times10^4$, $5.5\times10^4$ |
| Friction Angle $\phi$ | 38.3°, 28° |
| Dilation Angle $\psi$ | 8°, 0° |
| Unit Weight $\gamma$ (kN/m$^3$) | 19.5, 17 |
| Poisson's Ratio $\nu$ | 0.2 |
| Horizontal Distance (m) between Anchors $S_h$ | 2.75 |
| Vertical Distance (m) between Anchors $S_v$ | 3 |
| Length of Anchors $L$ (m) | 19, 18, 17, 16, 14, 13, 12.5 |
| Normal Stiffness of Anchors (Bound Length) $EA$ (KN) | $1.319\times10^5$ |
| Normal Stiffness of Anchors (Unbound Length) $EA$ (KN) | $1.4\times10^5$ |
| Normal Stiffness of Shotcrete Coated Wall $EA$ (KN) | $2.1\times10^3$ |
| Flexural Rigidity of Shotcrete Coated Wall $EI$ (kN.m$^2$) | 1750 |
| Poisson's Ratio of Shotcrete Coated Wall $\nu$ | 0.2 |
| Building $Q$ (kN/m$^2$) Adjacent Surcharge | 30 |
| Height of Trench Wall $H$ (m) | 21 |

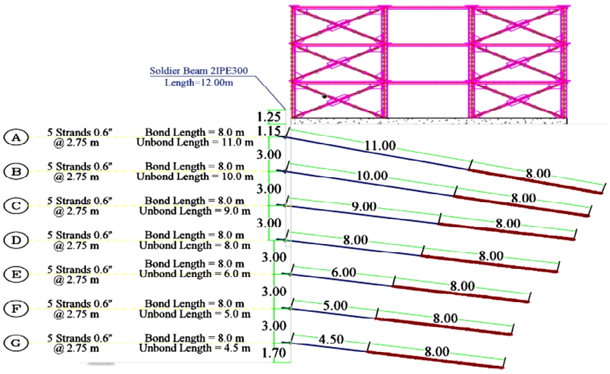


**Figure 1.** General geometry of numerical models constructed in the present study.

deformations. Soil elements have been considered as triangular and 15 nodes. The hardening behavioral model has been used for soil, whose parameters are given in Table (1). The dilation angles ($\psi$) of soils have been estimated based on the equation of $\psi = \phi - 30^{\circ}$ [6]. A shotcrete coated wall with 10 cm thickness and elastic behavior model has been used for protecting the excavation face. For the anchors in the unbound length and as well as anchors bond length, the elastoplastic behavior model has been used. The ?nite element mesh in the models made for this study has been shown in Figure (2). According to the recommendation of Lees [7], the minimum horizontal distance between the vertical edges of the trench should be four times of its height so that the effects of the boundaries of the model on the results to be minimized. This recommendation is used for the distance between the vertical and lower bounds of the model. According to the obtained displacement and stress contours, the selected distance is sufficient. The lower boundary of the model has been fixed against horizontal and vertical movements and lateral boundaries have been fixed against horizontal

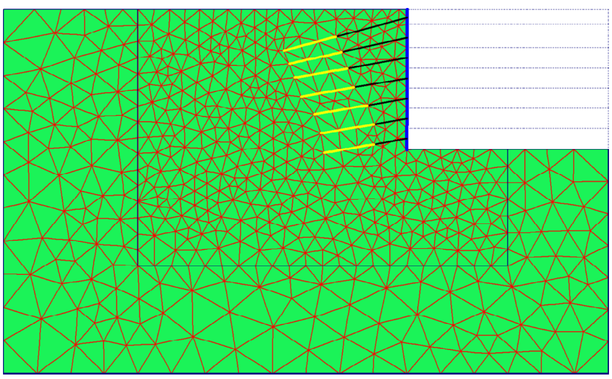

**Figure 2.** The Finite Element mesh in the numerical modelling.

movements. A surcharge of $Q = 3$ (t/m$^2$) is applied to the ground for modeling a three-storey building. In the next step, the initial displacement is considered to be zero, and then the stages of modeling of the excavation and installation of the anchors in seven stages, each stage including excavation, execution of the shotcrete, installation and pre-stressing of the anchors (5 Strand 0.6") under the force of 272.7 kN, is fully modeled by the finite element software. In the next step, the quasi-static analysis has been performed using the acceleration coefficient of 0.15 g and the stability coefficient (safety factor) of the wall was evaluated in the final step.

## 4. Verification of the Numerical Model

Prior to parametric studies for evaluating the influences of different factors on seismic performances of the deep excavation, the numerical model has to be verified and checked for reliable estimation and results. To assess the accuracy and validity of the model, the field data from surveying of a real deep excavation in city of Tehran were used. The data consisted from horizontal displacements of a trench measured by surveying method from top to the bottom. The results of numerical analyses for the same trench were obtained and compared with the field data. In Figure (3) the horizontal displacements of the above trench estimated from numerical model and measured by surveying technic are illustrated in the same coordinates. As can be seen in the figure, in spite of some differences between the results from the two methods, the general trend and variations of the horizontal displacement from top to bottom of

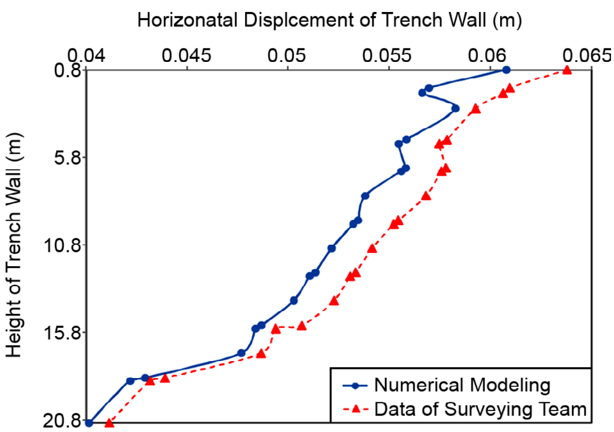


**Figure 3.** Comparing the displacements of a real trench wall in Tehran resulting from different methods.

the trench are in good agreement and the numerical modeling shows a relatively reliable and acceptable result for parametric studies in the present research.

## 5. Parametric Studies of the Restrained Deep Excavation

In this section, the effect of the geometric parameters of anchors (i.e. angle, length and distance between the anchors) and the effect of the change in the amount of pre-stress force in the anchors on the following items are evaluated:

1. Horizontal displacement.
2. Vertical displacement (including the settlements caused by the excavation at the adjacent ground level of the trench and the swell in the excavation bottom).
3. The force created by the deformation of the wall in the anchors.
4. The safety factor of the vertical trench.

During these analyses, by changing the values of each parameter and keeping the other unchanged, the effect of the changed parameter on the horizontal and vertical displacements are studied and also the coefficient of reliability have been evaluated and discussed.

### *5.1. The Effect of Anchors Geometry on Stability and Deformations*

In this part of the present study, using a quasi-static analysis in two sites with loose and dense soil and taking into account changes in length and angle and also distances between the anchors, the effect of various geometric parameters of anchors on the stability and deformation of the restrained deep excavation by anchorage method is investigated.

#### 5.1.1. The Effect of Anchors' Angle on Stability and Deformations

As the angle of the anchors increases, the amount of deformations decreases, which can be due to the increase in the force of the anchors due to the slope increase. As shown in Figure (4), in both sites with loose and dense soil, with an increase in angles of anchors from 5 to 14 degrees, the horizontal displacement of the trench wall decreases and by changing the angle from 14 to 20 degrees the horizontal displacement of the wall will increase. However, it is evident that the amount of deformations in soft ground (loose soil) is always more than that of the stiff ground (dense soil). Based on the analyses results, the optimum angle of anchors to get the minimum deformations of the vertical trenches during earthquake loadings may be recommended for 14 degrees. This fact is in agreement with similar previous studies [8-9].

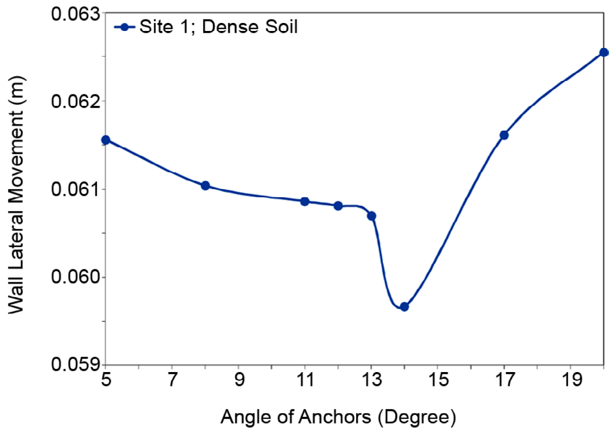


**Figure 4.** Effect of change in the angle of anchors on the horizontal displacement of the trench wall.

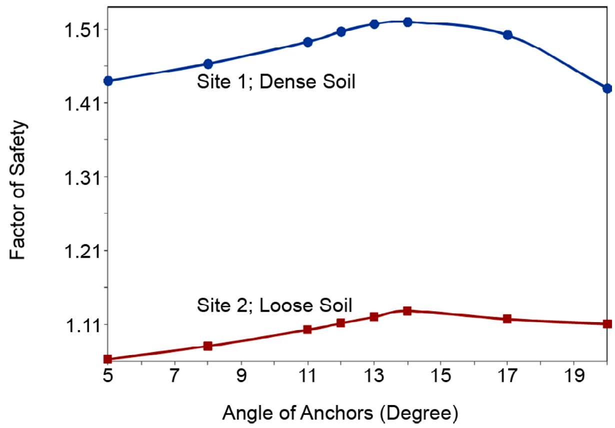


**Figure 5.** Eeffect of change in the angle of anchors on the safety factor.

As shown in Figure (5), with increasing angles of anchors from 5 to 14 degrees, the safety factor of the vertical trench will increase, and then will decrease. It is thus recommended to use anchors at a 14-degree angle to achieve the maximum amount of factor of safety. It can also be observed that the safety factor of the deep excavation restrained by anchors in dense soils is always greater than that of similar trench in loose soil during earthquake loadings.

In Figure (6), the effect of change in the angle of anchors on the vertical settling caused by the excavation at the ground level in the vicinity of the excavation, for a new construction, is observed. It is clear that by increasing the angles of the anchors in

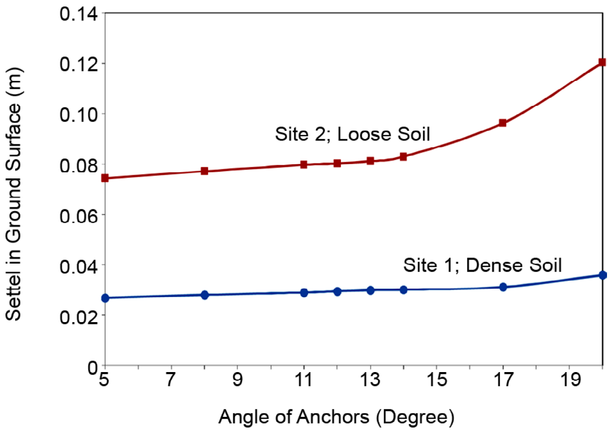


**Figure 6.** Effect of change in the angle of anchors on settling caused by the excavation at the ground level in the vicinity of the excavation.

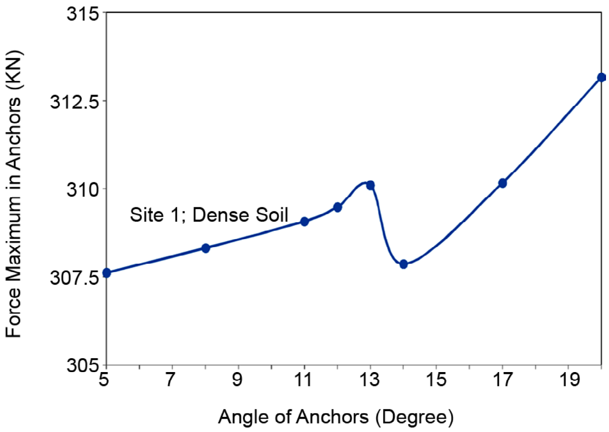


**Figure 8.** Effect of change in the angle of anchors on the maximum force induced in them by the deformation of the wall.

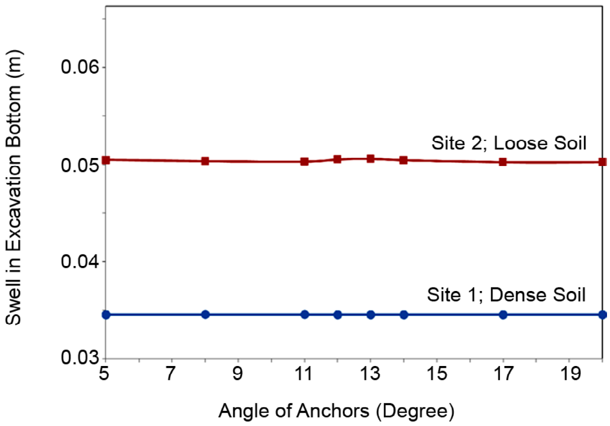


**Figure 7.** Effect of change in the angle of anchors on the swelling in the bottom of the excavation.

both loose and dense sites, the rate of the vertical deformation (settlement) will be incremental. Again, in the site with loose soil, the settling response will be much more than that occurs in the site with dense soil. Moreover, by increasing the angle of anchors from 14 to 20 degrees the rate of the vertical settling increases particularly in the loose soil. Nevertheless, as shown in Figure (7) changing in the angles of the anchors in both sites with loose and dense soil has no effect on the swelling in bottom of the excavation despite the fact that in the site with loose soil, the amount of swelling is much more than that in the dense site.

#### 5.1.2. The Effect of Anchors' Angle on the Force Induced by Wall Displacement

As shown in Figure (8), by increasing the angles of the anchors from 5 to 13 degrees, the maximum force induced in anchors by the deformation of the wall during earthquake loadings will be incremental, while further increase in the angle from 13 to 14 degrees, will cause the induced forces to decrease. However, continuing the increase of the angle from 14 to 20 degrees, leads to re-increasing the amount of forces induced within the anchors. It is also evident that the amount of forces induced in the anchors performed in the loose soils is always greater than those induced in the anchors performed in the dense soils.

#### 5.1.3. The Effect of Anchors' Length on Stability and Deformations

In the technique of anchoring, part of the length of the anchor is not injected (unbound length). In order to examine this length, all of the effective parameters in the modeling, including geotechnical characteristics of the soil, excavation depth, strands (anchors) characteristics, spacing of the anchors from each other and the length of the injected area are considered to be constant and the unbound length of anchors is changed. For evaluating the effect of unbound length on the response of the excavated trench during an earthquake, the length of the anchors had been changed in four increasing steps (+0.25m each step) and also in four decreasing steps (-0.25 m each step) while the bonding length has been constant in all analyses. The results of analyses are shown in Figures (8) to (12). As can be seen, it is evident that using anchors of greater length, causes the axial stiffness to decrease and the contribution of the tensile forces, induced by the deformation of the trench, to decrease. It will make the response of the trench more satisfactory (i.e., the deformations will decrease and the factor of safety will increase).

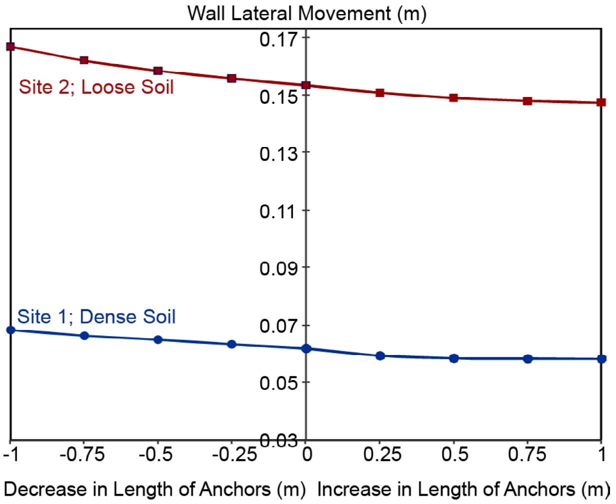


**Figure 9.** Effect of change in the anchors' length on the horizontal displacement of the trench wall.

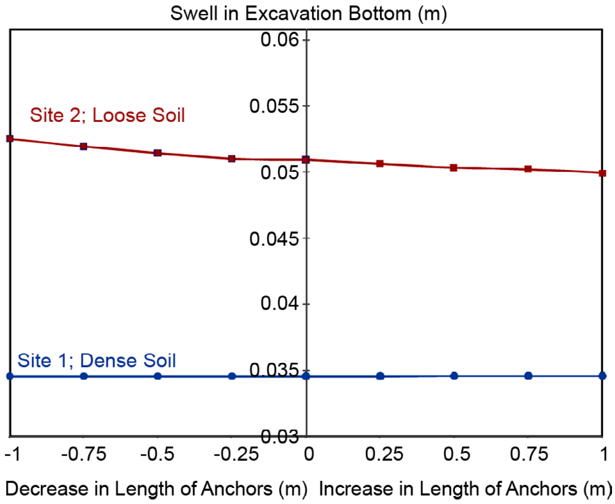


**Figure 12.** Effect of change in the anchors' length on the swelling in the bottom of the excavation.

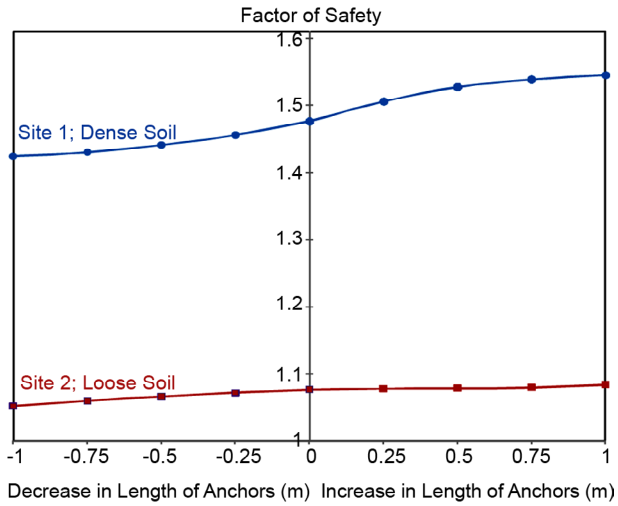


**Figure 10.** Effect of change in the anchors' length on the safety factor.

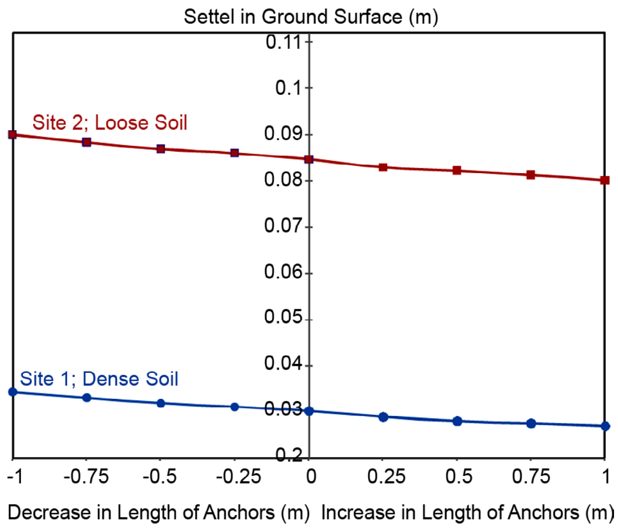


**Figure 11.** Effect of change in the anchors' length on settling caused by the excavation at the ground level in the vicinity of the excavation.

In Figure (9), it can be found that in both sites with loose and dense soil, the use of anchors with a longer length in the total height of the wall (increase anchor length) to a certain limit will reduce the horizontal deformation of the trench wall. As it is seen, in walls with loose soil, the response of the wall (horizontal displacement in the wall) is much more than that happens in the site with dense soil.

As can be seen in Figure (10), in both sites with loose and dense soil, increasing the length of all anchors in the trench wall, would increase the factor of safety. Moreover, it is also clear from the figure that in sites with loose soil, the safety factor is less than that in the sites with dense soil. In Figure (11), it can be seen that with increasing the length of the anchors, the settling of the ground (due to the adjacent excavation for a new building) is reduced. In addition, in the looser soil the amount of settlement would be much more than that occurs in the sites with dense soil. Although the increase or decrease in the length of anchors in the sites with a dense soil has not a great effect on the swell in the bottom of the excavation (Figure 12), increasing the length of the anchors in the loose soils would cause the amount of swell in the bottom of the excavation to decrease slightly.

### 5.1.4. The Effect of Anchors' Length on the Force Induced by the Wall Displacement

As can be seen in Figure (13), in sites with dense soil, increasing the length of the anchors would cause As can be seen in Figure (13), in sites with dense

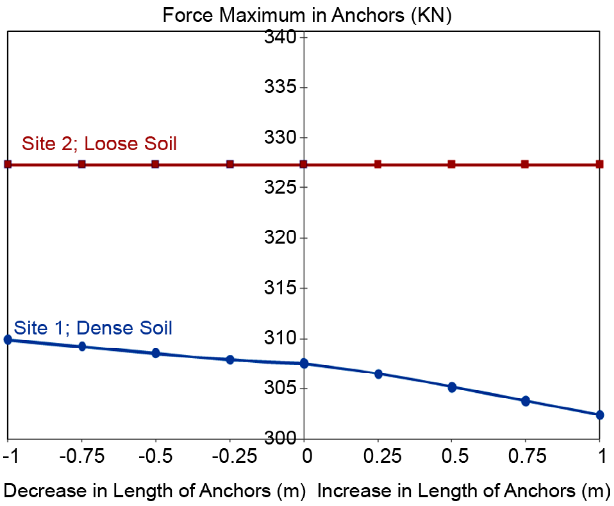


**Figure 13.** Effect of change in the anchors' length on the maximum force induced in them by the deformation of the wall.

soil, increasing the length of the anchors would cause the maximum amount of force resulting from the deformation of the trench wall to decrease, while, in a site with a loose soil, the force generated in the anchors does not show any changes. However, the amount of force developed in the anchors in loose soil is quite greater than that induced in dense soil. Considering the elastoplastic behavior for the anchors, it can be noted that in the latter case they have reached their maximum tensile strength and the maximum force in them have been fixed (anchors are about to yield).

### 5.1.5. The Effect of Anchors' Length of the Semi-Upper and Lower Parts of the Wall on the Stability and Deformations

Due to much deformation of the trench at its top than its bottom, use of anchors with short length in the upper part may cause big forces to be developed in them, but using anchors with greater length makes the axial stiffness to decrease and the con-tribution of the tensile forces induced by the deformation of the trench to decrease, hence the deformations will decrease and the factor of safety of the trench will increase.

In Figure (14) it is seen that in a site with dense soil, increasing the length of anchors in the semi-upper half of the trench the horizontal displacement will decrease. On the contrary, decreasing the length of anchors in this part will cause the horizontal displacement to increase. Similarly, in the site with loose soil, the same the trend can be seen for the deep excavation restrained by anchors.

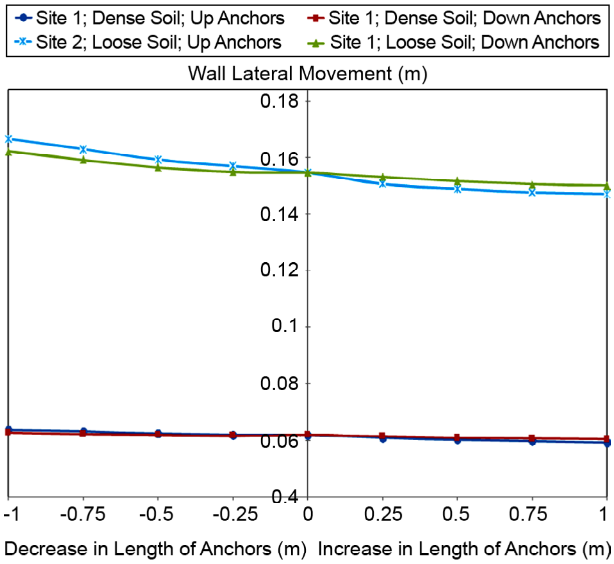


**Figure 14.** Effect of change in the anchors' length of the semi-upper and lower parts of the wall on the horizontal displacement of the trench wall.

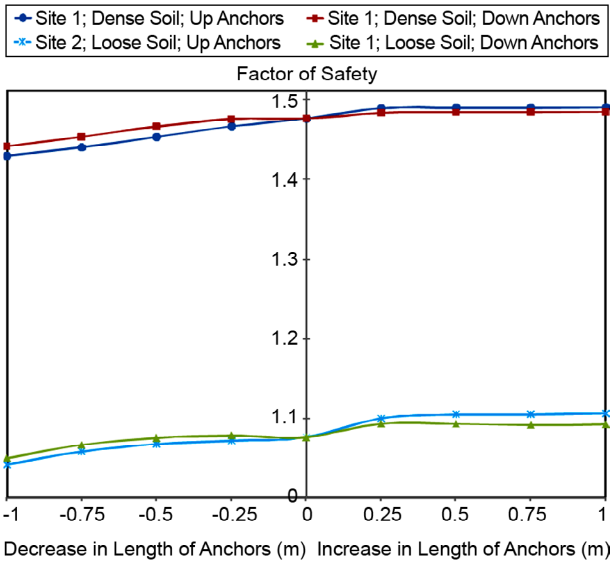


**Figure 15.** Effect of change in the anchors' length of the semi-upper and lower parts of the wall on the safety factor.

As shown in Figure (15), in the dense soil site, the increase in the length of the upper half of the anchors will result in the safety factor of the trench to increase. Conversely, by decreasing the length of the upper half of the wall anchors, the factor of safety will decrease. Similarly, in the site with loose soil, the same trend can be seen for the deep excavation restrained by anchors.

In Figure (16), it is observed that in a site with loose soil, an increase in the length of anchors located in the upper half of the trench will cause the settlement of the earth surface to decrease. However, in the dense site, increasing or decreasing

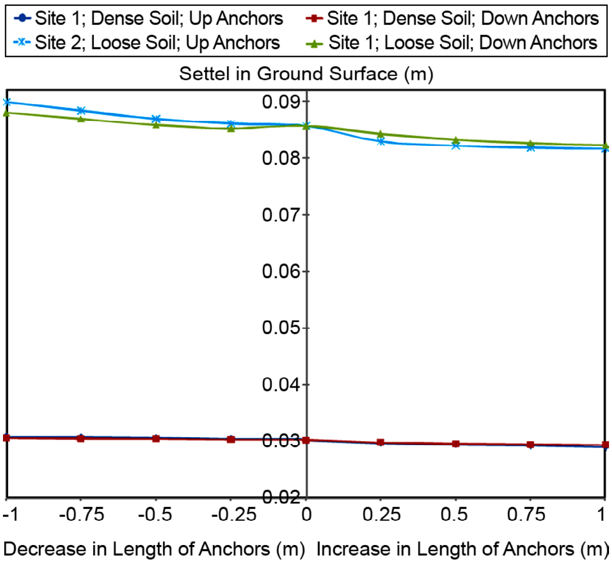


**Figure 16.** Effect of change in the anchors' length of the semi-upper and lower parts of the wall on the settling caused by the excavation at the ground level in the vicinity of the excavation.

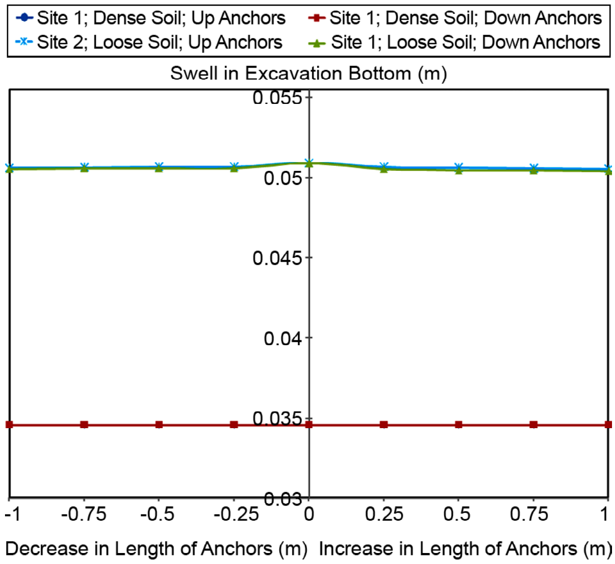


**Figure 17.** Effect of change in the anchors' length of the semi-upper and lower parts of the wall on the swelling in the bottom of the excavation.

the length of anchors in the upper half or in the bottom half of the wall has no significant effect on the settlement of the Earth's surface.

According to Figure (17), in sites with dense and loose soil, increasing or decreasing the length of the anchors in the upper or bottom half of the wall, no influences on the swell in the bottom of the excavation can be observed.

### 5.1.6. The Effect of Anchors' Length of the Semi-Upper and Lower Parts of the Wall on the Force Induced by the Wall Displacement

Referring to Figure (18), it can be found that in a site with loose soil, increasing or decreasing the anchors' length in the upper or lower half of the wall, no significant changes in the maximum force generated in the anchors happen. In the site with dense soil, increasing in anchors' length at the upper half of the wall, the maximum force in the anchors due to deformation of the trench would decrease and vice versa. However, in the site with dense soil, for the anchors in the lower half of the wall, opposite trend occurs in the maximum forced induced in the anchors.

### 5.1.7. The Effect of Anchors' Distance on the Stability and Deformations

By reducing the horizontal distance between the anchors, due to more confinement the stability of the trench wall increases and the trench displacements will decrease. Also, the forces induced in the anchors would decrease and the performance of the trench wall would improve accordingly.

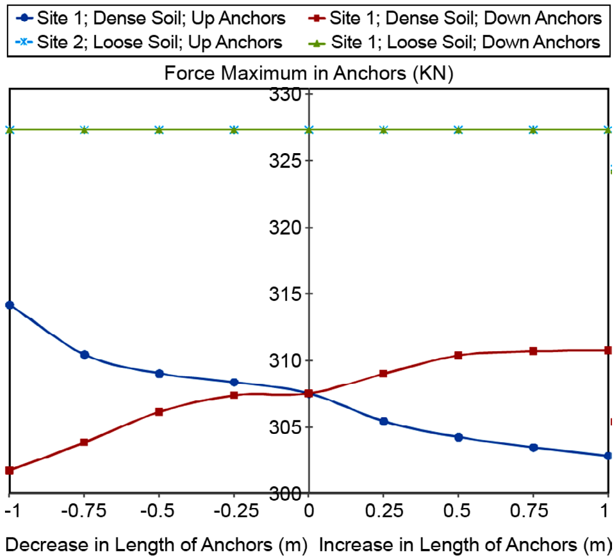


**Figure 18.** Effect of change in the anchors' length of the semi-upper and lower parts of the wall on the maximum force induced in them by the deformation of the wall.

Based on the Figure (19), increasing the horizontal distance between the anchors would increase the horizontal displacement of the trench wall which its rate is much more evident in site with loose soil.

As shown in Figure (20), the stability of the trench (safety factor) would decrease with increasing the horizontal distance of the anchors. This decrement for trench in loose soil would be much more appreciable than that for trench in dense soil.

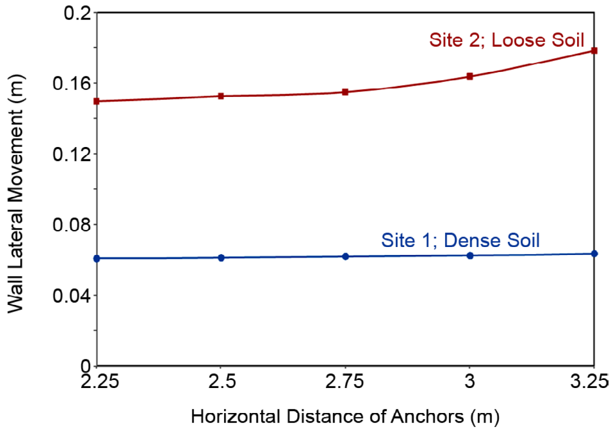


**Figure 19.** Effect of change in the anchors' distance on the horizontal displacement of the trench wall.

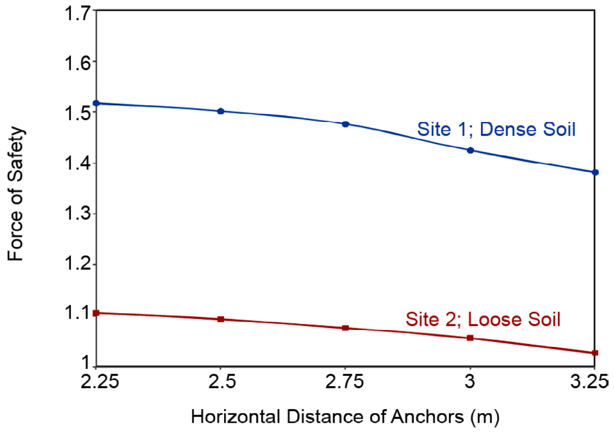


**Figure 20.** Effect of change in the anchors' distance on the safety factor.

From Figure (21), it is clear that in both sites with loose and dense soil, increasing the horizontal distance between anchors, would cause the surface settlement of the ground to increase due to the adjacent ground excavation. The rate of increment in ground settlement for trench in loose soil would be more than that for trench in dense soil. However, in sites with dense and loose soil, the increase in the horizontal distance of the anchors does not have significant effect on the swelling in the bottom of the excavation (Figure 22).

## 5.1.8. The Effect of Anchors' Distance on the Force Induced by the Wall Displacement

With respect to Figure (23), it can be seen that by increasing the horizontal distance of the anchors, the maximum force generated in the anchors decreases, and in sites with loose soil, the intensity of the force generated in the anchors is much more than that in site with denser soil.

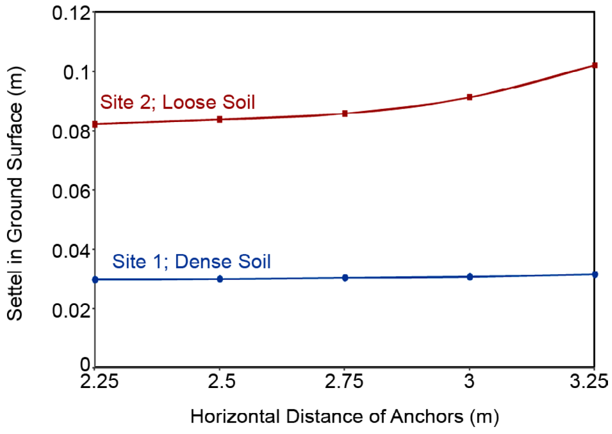


**Figure 21.** Effect of change in the anchors' distance on the settling caused by the excavation at the ground level in the vicinity of the excavation.

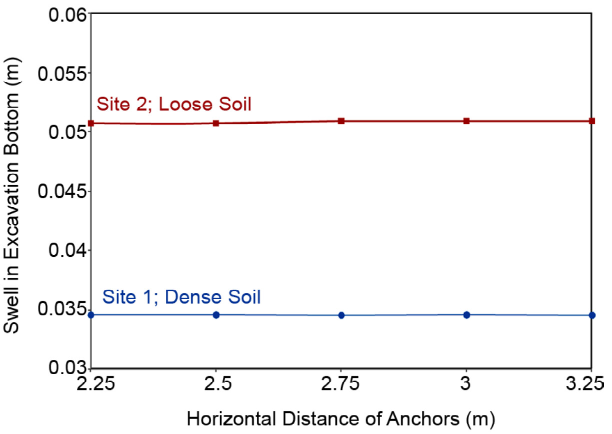


**Figure 22.** Effect of change in the anchors' distance on the swelling in the bottom of the excavation.

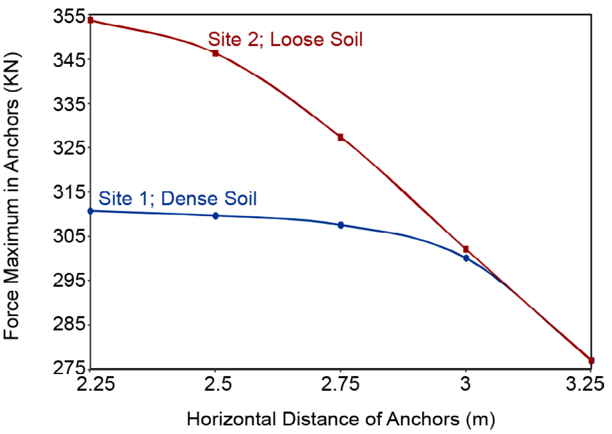


**Figure 23.** Effect of change in the anchors' distance on the maximum force induced in them by the deformation of the wall.

## *5.2. The Effect of Anchors' Pre-Stress Force on Stability and Deformations*

Increasing the pre-stress forces in anchors would increase the confinement and shear strength parameters of the trench soils and the stability of the excavated wall will increase accordingly.

It is seen in Figure (24) that with increasing the amount of pre-stress force in the anchors, the horizontal displacement in the trench wall decreases and the wall response (horizontal displacement) in the site with looser soil is much more than that in the site with denser soil.

As shown in Figure (25), with increasing pre-stress in anchors, the safety factor (FOS) of the trench increases, and the response of the site to the dense soil (FOS) is more than that in the site with the looser soil. Moreover, increasing the pre-stress in the anchors, the amount of settling decreases in the adjacent ground of the wall, and the amount of settling in the site with loose soil is more than that in the site with the dense soil (Figure 26).

As can be seen in Figure (27), in a site with dense soil, increasing pre-stress forces in the anchors, the amount of swelling on the bottom of the excavation would reduce; however, in the looser soil, the increase in pre-stress in the anchors do not have a significant effect on the swell.

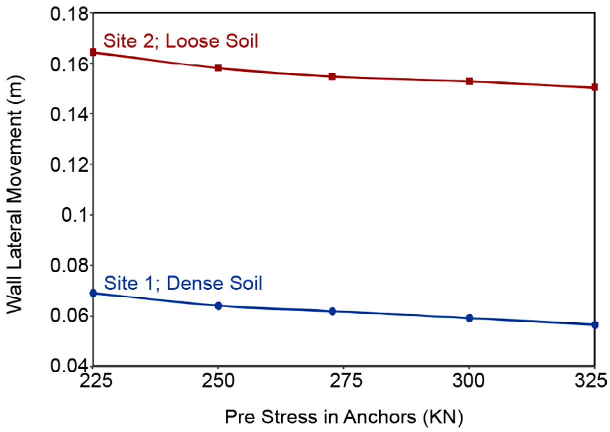


**Figure 24.** Effect of change in the anchors' pre-stress force on the horizontal displacement of the trench wall.

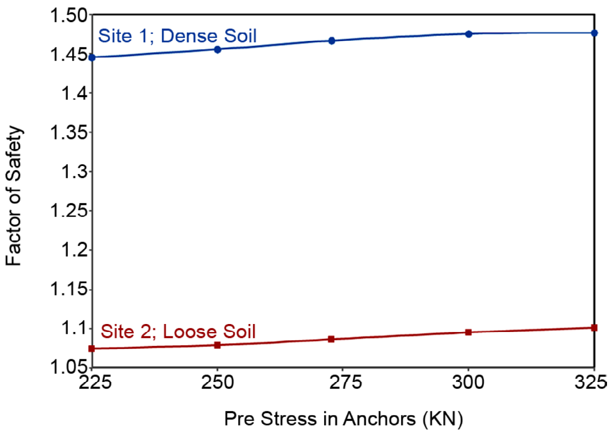


**Figure 25.** Effect of change in the anchors' pre-stress force on safety factor.

### *5.3. The Effect of Anchors' Pre-Stress Force on the Force Induced by the Wall Displacement*

With regard to Figure (28), it can be seen that by increasing the amount of pre-stress forces in the anchors, the maximum force generated by the

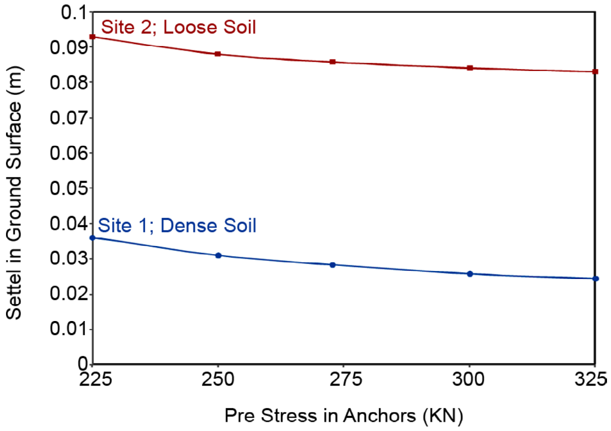


**Figure 26.** Effect of change in the anchors' pre-stress force on the settling caused by the excavation at the ground level in the vicinity of the excavation.

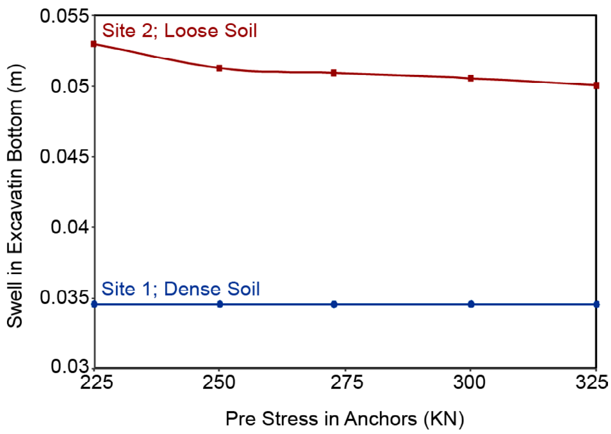


**Figure 27.** Effect of change in the anchors' pre-stress force on the swelling in the bottom of the excavation.

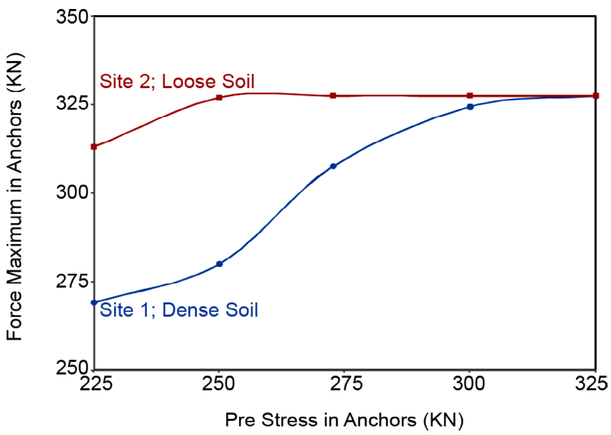


**Figure 28.** Effect of change in the anchors' pre-stress force on the maximum force induced in them by the deformation of the wall.

deformation of the wall in the anchors will increase. Also, in the site with loose soil, the induced forces in the anchors are more than those in the site with dense soil.

## 6. Conclusions

The response of deep excavations, restrained by anchors, during earthquake loadings was investigated using quasi-static method. A numerical model of the excavation was made and analyzed for two types of site (in loose and dense soils) by PLAXIS-2D software. The numerical modeling was calibrated using field displacements of a trench in Tehran measured by surveying. Parametric studies were carried out in which the influences of anchors geometry and set-up (i.e. length, angle, and distances) as well as the applied pre-stress forces on the seismic stability and displacements of the excavation were evaluated and discussed. The main and most important results of the present study are as follows:

In both sites with dense and loose soils, the minimum displacement and the maximum stability of the trench wall as well as the minimum forces induced in anchors are obtained when using anchors with an angle of 14 degrees toward horizontal. However, using anchors by angles more than that the displacements and induced forces would increase and the stability of the trench would decrease.

- In both sites (i.e., with loose and dense soil), increasing the length of the upper half of the anchors, leads to decrease the horizontal displacement of the trench wall.
- In the site with loose soil, increasing the length of anchors at the upper half of the trench wall would cause the settling of the adjacent ground of the trench wall to be reduced.
- In the site with dense soil, increasing the length of anchors located in the upper half of the trench, results in decreasing the maximum force created in the anchors due to deformation of the trench. However, in the site with a loose soil, the increase or decrease in length of anchors may cause only a slight change in the maximum force created in anchors.
- In the site with soft soil, increasing the pre-stress forces in anchors, may cause the swelling in the bottom of the excavation to be reduced, nevertheless, in the site with dense soil, pre-stressing the anchors is nearly ineffective.

## References

1. Bayoumi, A., Bobet, A., and Lee, J. (2008) Pullout capacity of a reinforced soil in drained and undrained conditions. *Finite Elements in Analysis and Design*, **44**, 525-536.

2. Blanco-Fernandez, E., Castro-Fresno, D., Del Coz Diaz, J.J. and Diaz, J. (2013) Field measurements of anchored flexible systems for slope stabilization: Evidence of passive behavior. *Engineering Geology*, **153**, 95-104.

3. Fellenius, W. (1936) Calculation of stability of earth dams. *Transactions, 2nd International Congress on Large Dams. Int. Committee on Large Dams*, 445-462.

4. Jian, Y.S. (1990) *Slope Analysis Using Boundary Elements*. New York, Springer-Verlang Publisher.

5. Matsui, T. and San, K. (1992) Finite element slope Stability analysis by shear strength reduction technique. *Soils and Foundations*, 59-70.

6. Bolton, M.D. (1986) The strength and dilatancy of sands. *Geotechnique*, **36**(1), 65-78.

7. Lees, A. (2016) *Geotechnical Finite Element Analysis*. ICE Publishing, London.

8. Maleki, M., Shamloo, S., and Kazemi, A.R. (2018) A case study of effective factors on the displacement of the trench wall by anchorage system. *6th National Congress on Civil Engineering, Architecture and Urban Development*, Tehran, Iran.

9. Maleki, M. and Nabizadeh, A. (2019) Investigation of seismic behavior in restrained deep excavation by the nailing system by finite element method. *3rd International Conference on Applied Researches in Structural Engineering and Construction Management*, Sharif University of Technology, Tehran, Iran.