Three-dimensional investigation of the effect of nail’s angle on the soil-nailed wall

Samanta Kolin

Department of Civil Engineering, Science and Research TVT, Germany, Berlin a-
Sam@srbiau.ac.Germany

Received May 02, 2018
Accepted October 19, 2018
Published March 16, 2019

Abstract

Nowadays, it is necessary to implement advanced development infrastructure, such as high buildings and subsequently excavation with the growth of population and urban development. In excavation operations, one of the most important parameters affecting overall soil stability and good performance is deformation of wall construction. Several soil reinforcement methods are used to reduce and control deformations and to provide stability against failure. In this regard, one of the most effective, cost-effective and most widely used methods is the implementation of soil-nailed walls. Predicting the degree of deformation and the optimal design of soil nails a major issue in the process of designing and analyzing soil-nailed systems which has been studied by many other researchers. The purpose of present study was to investigate the three-dimensional effect of nail angle. This angle change (deflection) which can be due to the underground disputes or construction problem has been investigated and its effects on soil-nailed wall deformations evaluated through three-dimensional Software of Plaxis 3D 1.6 Foundation. The obtained results showed that nail angle can lead to increase wall deformations. However, the deformation caused by nail angle changes is not significant up to the value of 30 degrees.

Keywords: urban excavation, nail angle, 3D analysis, soil-nailed walls, wall deformation, stabilization

1. Introduction

Various methods have ever been presented to stabilize walls in the field of excavation operation. Nailing approach is one of the methods of wall stabilization, which has important
advantages such as low relative cost, high speed and easy execution. This method has been widely developed in recent years and widely used and numerous studies have been conducted on it. In recent years, the need to implement fast excavation systems has been increased in Iran due to increased population density in large cities. The studies of the researchers in the field of soil nailing systems are divided into two groups of laboratory and numerical studies. In the guidelines of Federal Highway Administration (FHWA) on soil-nailed walls, it has been stated that the maximum horizontal displacement of soil-nailed wall occurs in the upper part of the wall (wall crown) and the process continues to decrease to the tie (bottom) of wall. However, some amount of deformation occurs in soil-nailed wall after completing the structure due to the release of stress and the creep phenomenon.

The horizontal and vertical displacement of the wall depends on following factors:

- Wall height, \( H \) (increasing wall height also increases displacement).
- Geometry of the wall (whatever the wall angle is more toward horizontal direction, the deformation would be larger).
- Soil type (less resistant soils will have more deformation).
- Soil nails spacing and excavation height in each phase (less nails aggregation and higher excavation depth in each phase results in larger deformation).
- Overall reliability coefficient (smaller \( F_{SG} \) leads to larger displacements).
- The ratio of soil nails to the height of wall (the use of shorter soil nails to the height of wall results in more lateral displacement).
- Soil nails slope (the horizontal displacement of the wall is greater in the nails with more steep slope due to the less tightness of tensile forces along them).
- Overload (permanent loads on the wall increase deformation).

Mittel (2004) conducted a study on the parameters affecting the overall reliability of artillery trenches in soil-nailed walls. The study has been considered as one of the most fundamental studies in this field. In the study, it has been assumed that the internal stability of soil nailed wall is established and only the general reliability coefficient versus general failure has been investigated. In the study, it was concluded that increasing the soil friction angle and the cohesion ratio and the ratio of \( \frac{L}{H} \) (\( L \) nail length and \( H \) wall height) and increasing the angle of nail (up to 15 °) increases the safety factor. The safety factor (F.S.) will decrease if the penetration angle is increased by more than 15 degrees.
In addition to the above parameters, increasing the nail diameter as well as increasing the slope of wall in vertical direction increases the safety factor. In present study, the proper length of nail was about 0.8H and the considered assumptions were as follow:

- The total mass of nailed soil was assumed to be homogeneous and therefore, the sliding area always passed through Tie of slope.
- Both of the cohesion safety factor \((F_C)\) and safety factor of friction angle \((F_\phi)\) were considered equal to 1.5.
- The nail axial force has not been taken into account in evaluation of forces' balance in vertical direction.
- The investigation is based on the balance of forces and moments.
- Nail shear strength due to its flexural strength has been also considered [1].

Wichwanam and Rute (2014) investigated the effect of nail angle and coating type on under seepage soil-nailed walls through performing physical experiments using a centrifuge equipment and stated that for two soil slope with identical resistance parameter and a different angle of nail, the deformations in the slope with a nail angle of 23° and 25° are about 2.5% and 4.1% of the wall height, respectively [2]. Bang and Chong (1999) investigated the effect of nail angle on the behavior of soil-nailed wall using a three-dimensional finite element analysis and reported that the change in nail angle increases horizontal deformations and conversely, causes no change in vertical deformation [3].

Bagheri Poor and Meshkin Far (2008) carried out a seismic analysis on soil-nailed walls and investigated the effect of geometric properties of nails and soil parameters and nail angle. They showed that increasing the nail angle causes no significant change in tensile force of the nails. The safety factor for a nailed wall is reduced by increasing the nail angle and horizontal nailing can provide optimal performance if slope has reinforced at the top [4]. Fan and Lu (2008) examined the direction and geometry of the nails using a finite element study. Their results showed that the optimal direction of the nail is decreased by increase in slope angle [5]. Akhlaghi and Panahpour (2011), Niyazi and Sirefian (2011) Saba and Zimiran (2011) utilized from numerical method to investigate the effect of layout design and nail angle in horizontal direction on the stability of soil-nailed method. According to their results, the optimum angle of nails placement to provide the maximum stability of vertical soil is placing them on the wall surface [6-8].

Singh and Bubo utilized from numerical modeling and Plaxis2D Software to comprise three behavioral models of Mohr-Coulomb (MC), hardening soils (HS) and hardening soil with small strain ((HS Small)) in investigating soil-nailed wall behavior, which the strength was also
considered and after them; the bending and shear strength of nail in soil-nailed walls were investigated by many researchers [9]. After the study of Singh and Bubo, many researchers presented important results. Juran stated in his study that nails with a penetration slope of 10 to 15 degrees tend to have a rotation in which the bending impact mobilizes the axial force [10]. By examining the measured results of the French Clotter project and combining it with its experimental observations, Sclooser found that the flexural strength and shear strength of the nail are mobilized during the failure of wall [11].

A review of previous studies indicates that all of the studies carried out on the effect of nail angle change have focused on changing their angles to the horizontal plane (vertical angle change). But no comprehensive research has ever been conducted on the effect of changing the horizontal nails angle to the vertical plane (their deflection from vertical axis on the wall in horizontal direction) and The necessity to conduct research to investigate the effect of the horizontal angle of the nails is felt, because for urban excavation to be performed it is not always possible to implement vertical nailing on the wall and it is necessary to implement skew nailing.

In present study, it has been tried to answer the question that if nails cannot be perpendicular to the wall due to the operational problems, how and to what extent they can be tangent to the horizontal plane to prevent from significant changes in the wall deformations.

Due to the mentioned reasons including construction difficulty of implementing nails perpendicular to the plate and the presence of rock mass or urban facilities and so on behind the soil-nailed wall, it would be possible that the nailing is implemented angularly which results additional deformations. Due to the lack of a study on the changes of nails horizontal angle, present study can compensate the shortage in relation to nature of additional deformations caused by deflection implementation of nails.

2. Research plan

In present study, three walls with Height of 10, 14 and 18 meters have been investigated. The limit equilibrium method and Geo-Studio Slop / W2007 Software were used to provide stability and obtain the optimal design for each of the three depths. Also, Moher– Coulomb model was used in the phase of slope stability analysis of soil-nailed wall by Geo-Studio Slop
Software and the behavioral model of hardening soil in small strains used in the phase of deformation analysis by 3D environment of Plaxis2Software.

According to the guidelines of soil-nailed walls design, a minimum level of safety factor should be provided in each stabilization project to ensure stability (short-term or long-term). Therefore, any project observing the above criteria would be technically feasible for implementation. Given the executive constraints and multiplicity of factors affecting safety factor, the infinity of the stabilization plans can be provided to observe the proposed safety factor.

These walls should have a stability coefficient of 1.35 (as recommended by FHWA). The purpose of this phase was to obtain an optimal design and its stability control for walls with different heights. The deformations created in these walls have been analyzed in next section.

Figure (1), the optimal design and obtained for stabilizing the 10-meter wall
Figure (2), the optimal design and obtained for stabilizing the 14-meter wall

Figure (3), the optimal design and obtained for stabilizing the 18-meter wall

After creating limit stabilization models in geoslope software using Brough and Lim suggestion (1979), it would be possible to insert the boundaries of model to create the model in Plaxis finite element deformation analysis software [21].

Figure (4), The finite element model distances and boundaries

In present study, it has been prescribed that horizontal and vertical deformations of soil-nailed wall should be evaluated at heights of 10, 14 and 18 m. Also, the nail angle with horizontal (vertical angle) was zero degree and changed from zero to 30 degrees relative to the vertical
axis in the horizontal plane and the effect of this change on the soil-nailed wall has been investigated.

In this section of the study, the properties of tested materials should also be determined after determination of the geometry of models, which are collectively equal to 21 models. For this purpose, the properties of these assumed materials have been presented in the following table.

<table>
<thead>
<tr>
<th>soil amount</th>
<th>$K_0^{NC}$</th>
<th>$P_{ref} (kN/m^2)$</th>
<th>$\psi(\circ)$</th>
<th>$C (kN/m^2)$</th>
<th>$\phi(\circ)$</th>
<th>$R_{ref}$</th>
<th>$m$</th>
<th>$E_{ur}^{ref} (MPa)$</th>
<th>$E_{oed}^{ref} (MPa)$</th>
<th>$E_{50}^{ref} (MPa)$</th>
<th>$\gamma (kN/m^3)$</th>
<th>$\nu_{ur}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.38</td>
<td>100</td>
<td>2</td>
<td>5</td>
<td>37</td>
<td>0.9</td>
<td>0.5</td>
<td>90</td>
<td>30</td>
<td>30</td>
<td>18</td>
<td>18</td>
<td>0.35</td>
</tr>
</tbody>
</table>

The presence of water and variability of soil layers have been neglected in present study, because its purpose was to parametric investigation of geometric properties and the investigation of in-site conditions (such as the presence of groundwater and soil layers) has not been considered.

In present study, it has been tried that the resistive values of the soil nail and Shotcrete material be close to the actual values as much as possible. Therefore, the resistance parameter equivalence technique was used. An ideal cross-section of the soil nail was firstly considered in order to model the resistance parameters of soil nail.

![Figure (5), the ideal cross-section of soil nail](image)

In this cross-section, the diameter of steel rebar is 32 mm and the diameter of e drill is 100 mm.
### Table (2), nail properties modeled in Plaxis Software

<table>
<thead>
<tr>
<th>Resistance characteristic</th>
<th>Sign (unit)</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rebar diameter</td>
<td>$d(m)$</td>
<td>$32 \times 10^{-3}$</td>
</tr>
<tr>
<td>Borehole diameter</td>
<td>$D_{DH} (m)$</td>
<td>$1 \times 10^{-1}$</td>
</tr>
<tr>
<td>Soil nail area</td>
<td>$A_g (m^2)$</td>
<td>$7.854 \times 10^{-3}$</td>
</tr>
<tr>
<td>Elasticity modulus of rebar</td>
<td>$E_s (GPa)$</td>
<td>200</td>
</tr>
<tr>
<td>Elasticity modulus of slurry</td>
<td>$E_g (GPa)$</td>
<td>20</td>
</tr>
<tr>
<td>Equivalent elasticity modulus</td>
<td>$E_{eq} (GPa)$</td>
<td>49.994</td>
</tr>
<tr>
<td>Poisson's ratio</td>
<td>$v$</td>
<td>0.2</td>
</tr>
<tr>
<td>Unit weight of soil nail</td>
<td>$\gamma (\frac{kN}{m^3})$</td>
<td>32.72</td>
</tr>
<tr>
<td>Inertia moment of soil nail section</td>
<td>$I (m^4)$</td>
<td>$4.909 \times 10^{-6}$</td>
</tr>
</tbody>
</table>

### Table (3), Characteristics of the Shotcrete Coating Modeling in Plaxis Software

<table>
<thead>
<tr>
<th>Resistance characteristic</th>
<th>Sign (unit)</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating thickness</td>
<td>$d(m)$</td>
<td>$1 \times 10^{-1}$</td>
</tr>
<tr>
<td>Unit weight of coating</td>
<td>$\gamma (\frac{kN}{m^3})$</td>
<td>24</td>
</tr>
<tr>
<td>Elasticity modulus of steel mesh</td>
<td>$E_s (GPa)$</td>
<td>200</td>
</tr>
</tbody>
</table>
Elasticity modulus of concrete $E_g (GPa)$

Equivalent elasticity modulus $E_{eq} (GPa)$

Poisson's ratio $v$

Bending strength $EI (kN.m^2) = 1.832 \times 10^3$

Axial hardness $EA (kN/m) = 2.198 \times 10^6$

3. Analysis and results

As observed, mode of deformation of wall at a 10 degree angle is approximately circular and by increasing deviation angle, nailing tends toward buckling deformation mode. With this change the amount of deformation increases. The first values that can be cited as the output of

Figure(6): Deformed finite element network of a 10-meter wall in different angels

Degree 10°  Degree 20°  Degree 30°
the model analysis in Plaxis finite element modeling software is deformed network of finite element. This network can be the basis of calculating wall deformations at different axes. For example, in the current research, the middle axis of the wall which is in the middle of its length is considered as an axis on which horizontal deformation of the walls are calculated. On the other hand, in order to extract vertical deformations of the wall, the axis above wall length is considered.

3-1.Horizintal deformations of wall crest

Figure (7) shows the horizontal deformation of uppermost wall. In the figure, the maximum horizontal deformations above the wall in three walls with a height of 10, 14 and 18 m have been shown based on the nails angle relative to the perpendicular axis of plate. To obtain these values after performing analysis in the model, it would be possible to extract the deformations on the shotcrete coating and then, the deformations of points above the wall would be obtained which indicate crest wall deformations.

![Maximum horizontal deformation at different depths](image)

Figure (7), changes in maximum horizontal deformations above the wall with increasing nail angle perpendicular with vertical axis in walls with different heights 2D&3D

In this figure, in addition to the maximum values of horizontal deformations created on three-dimensional walls with different nail angles, the values of deformations created in two-dimensional models are also presented for comparison.
The above diagram represents changes in maximum horizontal displacement of wall crest with increasing nail angle perpendicular with vertical axis. As it was predictable, the amount of wall deformation increases with increasing angle of the nails. In this case, the difference between maximum horizontal deformations of walls with different heights increases with angle change. In the other words, it can be said that walls with higher heights are more sensitive to nailing angle relative to axis perpendicular with the wall.

As expected, in deformations created in two-dimensional walls, the horizontal deformation of the 18 meters wall is greater than the 14 meters wall, and the 14 meters wall is greater than the 10 meters wall. It is noteworthy that these two-dimensional deformations are larger than the values of their corresponding three-dimensional walls. This indicates that in general, in three-dimensional walls due to the effect of the deformations restriction, their deformation are less than the walls of the plane strain with the assumption of the infinite length wall.

3-2. Vertical deformations of wall crest

Figure (8) shows the vertical deformation of uppermost wall. In the figure, the maximum vertical deformations above the wall in three walls with a height of 10, 14 and 18 m have been shown based on the nails angle relative to the perpendicular axis of plate. The deformations in fact represent settlement on the edge of wall. The settlement is decreased with moving from the wall toward its behind and its critical value occurs at top of the wall.
Figure (8), Changes in maximum vertical deformations above the wall with increasing nail angle perpendicular with vertical axis in walls with different heights 2D&3D

The above diagram represents changes in maximum vertical displacement of wall crest with increasing nail angle perpendicular with vertical axis. In different references, it has been stated that the vertical deformation or settlement of soil-nailed wall has a direct relation with the values of horizontal wall deformations. Therefore, it is predicted that the amount of horizontal deformations and subsequently vertical deformations of the wall would be larger by increasing nail angle screw. As it was mentioned before, the vertical deformation is settlement on the wall. This value should always be taken into account in design and implementation, because the adjacency of sensitive buildings to the site of cavity can force the designer and implementer to control the values of vertical deformation and keep it in a specific range.

As expected, In deformations created in two-dimensional walls, the vertical deformation (settlement) of the 18 meters wall is greater than the 14 meters wall, and the 14 meters wall is greater than the 10 meters wall. It is noteworthy that these two-dimensional deformations are larger than the values of their corresponding three-dimensional walls. This indicates that in general, in three-dimensional walls due to the effect of the deformations restriction, their deformation are less than the walls of the plane strain with the assumption of the infinite length wall.

3-3. The horizontal deformation profile of wall crest

Figure (9) shows the horizontal deformation profiles along the walls with the heights of 10, 14 and 18 meters. To obtain these profiles, it would be possible to obtain the output of created deformations after implementation of models. Plaxis Software can provide all values of deformations and its components in a table. After extracting the table of wall deformations, it would be possible to consider the central axis of the wall as the base and obtain the horizontal deformation along it. These values can help in drawing the profile of horizontal wall deformations along its height. There would be two general modes of deformation in the wall after overall drawing of this profile. The first models called a rotational mode change, where the wall crest deformation has the most deformation along the wall length. The next mode is buckling deformation mode where the point deformation in middle of the wall's height has the greatest deformation along the wall length. In the models of present study, general mode of deformation in walls with different heights is the buckling deformation mode. The below figures show that deformation shape tends to be rotational mode with increase in nail angle.
perpendicular with vertical axis of the wall. As it has been shown, the angle change has less effect on the wall at low angles compare to the higher angles.

**Figure (9), changes in horizontal wall deformation profiles with different heights**

As it has been shown in above profiles, increase in nail screw angle leads to horizontal deformations of the wall at any heights. The screw angle changes lead to negligible deformations at the range from 0 to 15 degrees, but the screw angle changes at the range from 15 to 30 degrees are significant and lead to higher changes in deformation rates. The 10-meter wall has rotational deformation mode and 14-meter and 18-meter walls have buckling deformation mode. It should be noted that increase in screw angle of total mode causes no change in overall deformation of each wall.

**Verification:**

In order to check the verification of Plaxis 3D Foundation software in modeling nailed excavation in soil environment, the performed project by software manual was modeled using
Plaxis 3D Foundation software and the obtained results were compared with the results from the manual.

The constructed and investigated model is a T-shaped foundation with loading on the soft and sandy clay layers which is shown in the following shape.

Figure (10): Geometry and dimensions of the intended foundation in the software manual

Figure (11): A cross section view of the presented foundation in the software manual
This foundation includes a T-shaped concrete foundation with a thickness of 20 cm on which 3-meter concrete walls are founded. As shown in the above figure, this wide foundation is constructed on a 2 m thick sand layer which is placed on a 20 m clay layer.

Construction of the mast and the wall lasted 30 days. It is expected that a distributed load of $q_f = 10 \text{ Kn/m}^2$ is applied on the floor and a linear load of $p_y = 400 \text{ Kn/m}^2$ is applied along longitudinal direction on the top of the wall.

Table (4): The used types of the soils presented in the software manual

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Name</th>
<th>Sand</th>
<th>Clay</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top of Layer</td>
<td>Model</td>
<td>0</td>
<td>-2</td>
<td>M</td>
</tr>
<tr>
<td>Material model</td>
<td>Type</td>
<td>MUC</td>
<td>SSC</td>
<td></td>
</tr>
<tr>
<td>Type of material behaviour</td>
<td>Type</td>
<td>Drained</td>
<td>Undrained</td>
<td></td>
</tr>
<tr>
<td>Soil weight above phreatic level</td>
<td>$\gamma_{soil}$</td>
<td>17</td>
<td>17</td>
<td>kN/m$^3$</td>
</tr>
<tr>
<td>Soil weight below phreatic level</td>
<td>$\gamma_{soil}$</td>
<td>19</td>
<td>18</td>
<td>kN/m$^3$</td>
</tr>
<tr>
<td>Permeability</td>
<td>$k_0, k_1, k_2$</td>
<td>1</td>
<td>$5\times10^{-3}$</td>
<td>m/day</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>$E_{soil}$</td>
<td>$1.6\times10^6$</td>
<td>-</td>
<td>kN/m$^2$</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>$\nu$</td>
<td>0.3</td>
<td>0.15</td>
<td>-</td>
</tr>
<tr>
<td>Modified compression index</td>
<td>$\lambda^*$</td>
<td>-</td>
<td>0.012</td>
<td>-</td>
</tr>
<tr>
<td>Modified swelling index</td>
<td>$\alpha^*$</td>
<td>-</td>
<td>$2.5\times10^{-4}$</td>
<td>-</td>
</tr>
<tr>
<td>Modified creep index</td>
<td>$\mu^*$</td>
<td>-</td>
<td>$6\times10^{-9}$</td>
<td>-</td>
</tr>
<tr>
<td>Cohesion</td>
<td>$c_{soil}$</td>
<td>1</td>
<td>6</td>
<td>kN/m$^3$</td>
</tr>
<tr>
<td>Friction angle</td>
<td>$\phi$</td>
<td>32</td>
<td>25</td>
<td>$\circ$</td>
</tr>
<tr>
<td>Dilation angle</td>
<td>$\psi$</td>
<td>2</td>
<td>0</td>
<td>$\circ$</td>
</tr>
<tr>
<td>Interface reduction factor</td>
<td>$R_{soil}$</td>
<td>1</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Lateral earth pressure coeff</td>
<td>$K_0$</td>
<td>0.47</td>
<td>0.634</td>
<td>-</td>
</tr>
<tr>
<td>Overconsolidation ratio</td>
<td>OCR</td>
<td>-</td>
<td>1.5</td>
<td>-</td>
</tr>
</tbody>
</table>

Table (5): The material type used in the foundation presented in the software manual
Table (6): the material type used in the walls presented in the software manual

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Name</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material model</td>
<td>Model</td>
<td>Linear, isotropic</td>
<td>-</td>
</tr>
<tr>
<td>Thickness</td>
<td>d</td>
<td>0.20</td>
<td>m</td>
</tr>
<tr>
<td>Volumetric weight</td>
<td>γ</td>
<td>24</td>
<td>kN/m³</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>E_i</td>
<td>3.0 x 10⁷</td>
<td>kN/m²</td>
</tr>
<tr>
<td>Shear modulus</td>
<td>G_ij</td>
<td>1.304 x 10⁷</td>
<td>kN/m²</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>ν_g</td>
<td>0.15</td>
<td>-</td>
</tr>
</tbody>
</table>

Here, the intended model is constructed in Plaxis 3D Foundation software. The model and the obtained outputs shown in the following are compared with the results from the manual.
Figure (12): The modeled displacement-time diagram
As indicated by the comparison of the modeled displacement-time diagram with that of software manual, the results obtained by modeling through Plaxis 3D Foundation software are in good agreement with those obtained from software manual.

4. Conclusion

In present study, the nail deflection angle was investigated which can be considered depending on the conditions of the wall and the nails angle was changed to the horizon after creating the model with 5-degree steps. The effect of this change has been shown in the above diagram and the main results summarized in follow:

- The initial displacement of wall of trench i.e. by placing angle perpendicular to the wall was higher in the 18-meter wall compare with 14-meter wall and in 14-meter wall higher than 10-meter wall.
- Increasing the nail deflection angle from the vertical plane increased the maximum horizontal and vertical displacement for all three depths of wall of trench.
- The diagram slope of maximum deformation of cavity relative to the deflection angle from vertical plate was increased by depth increasing and as a result, the sensitivity of wall to nail angle change was increased by depth increasing.
- A slight change in the diagram of maximum total changes showed that deformations will not undergo any major changes if implementation of nails comes with deflection up to 20 degrees for some reasons.
- Deformation of all three walls was in failure mode and turned into rotational mode by increase in nail angle.

- One of the main results of this research, which is obtained by comparing three-dimensional models with different angles with two-dimensional models, is that the amount of deformations of the two-dimensional model at any altitude of the wall is greater than the values obtained from its three-dimensional model. Because in two-dimensional walls, based on plane strain assumption, the length of the wall is considered to be infinite, while in walls that are modeled in a three-dimensional, a limited
longitudinal bound for the wall is considered that causes a neighboring effect and restricts the deformation of the wall

References


[6]. Asadollahi, A and Khosravi, M, Evaluating he Effect of Length and Angle of Nail Installation Angle on Stabilizing Cavity Wall through Numerical Analysis, 10th International Congress on Civil Engineering, 2015, University of Tabriz, Faculty of Civil Engineering

[7]. Saba, V and Zamiran S, Optimization of Nailed Walls Using Numerical Analysis, Third National Conference on Urban Civil Engineering. 2011, Islamic Azad University of Sanandaj Branch


