

INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

<https://www.issmge.org/publications/online-library>

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

Numerical Analysis of Soil Nail Shearing Behavior during Pullout & the Effect of Overburden Pressure on Pullout Resistance Using Finite Element Method

Amir Reza Behzadian

M.Sc. in Geotechnical Engineering, Civil Engineering and Environment Faculty, Tarbiat Modares University, Tehran, Iran

Mohammad Oliaei

Assistant Professor of Geotechnical Engineering, Civil Engineering and Environment Faculty, Tarbiat Modares University, Tehran, Iran

Ali Komak Panah

Associate Professor of Geotechnical Engineering, Civil Engineering and Environment Faculty, Tarbiat Modares University, Tehran, Iran (a-panah@modares.ac.ir)

Mansour Mosallenejad

Assistant Professor of Geotechnical Engineering, Civil Engineering and Environment Faculty, Shiraz University, Iran

ABSTRACT: Nowadays, as a result of development of constructions in urban areas, confronting with lack of sufficient ground for construction purposes is inevitable. Beside, providing required space for parking and mechanical installations is indispensable for the majority of urban buildings. In such situation implementation of deep excavation is the solution. One of the most common systems for stabilizing the excavations in Iran, due to economical privileges & proper behavior, is soil nailing. The important key parameter in designing process of such system is the soil-nail bond resistance and so its pullout strength. The ahead research has been performed using three dimensional finite element method in order to model a nail in the passive zone. The numerical model has been verified with experimental results. Shearing behavior of the nail during pullout & the effect of different overburden pressures on the pullout resistance are the major topics which is going to be probed in this article.

Keywords: Nailing, Pullout resistance, Finite element method, Overburden pressure

1 INTRODUCTION

Given the growth of urban life and increased volume of construction in highly populated areas as well as the necessity of meeting criteria set by municipalities for supply of parking lots and proper spaces for mechanical installations, vertical drilling and excavation have become integral and essential parts of most projects. As a result of excavations, especially deep excavations, the primary soil equilibrium is disturbed and the soil stress tensor changes. The new soil stress state and variations of boundary conditions (such as elimination of lateral stresses on deep adjacent wall elements) can disturb the primary soil equilibrium and result in loss of soil cohesion and soil mass failure [1].

Engineering and special measures are required to prevent such hazards to ensure stability and safe operation of the excavation system and reduce the effects of subsequent settlements on adjacent structures. Some of the methods for achievement of deep excavation stability include the truss construction, reciprocal support, and soldier pile methods. One of the new and common excavation stabilization methods that have attracted considerable attention especially in urban areas due to its economic advantages and ease of implementation is nailing.

In nailing, passive (non-prestressed) elements are used in soil mass to sew the zone prone to failure to a stable soil mass beyond the failure line. With slight movement of the instable zone, the nail elements are activated, bear load, and contribute to stability of the soil mass prone to failure.

In the design of nailing systems the limit equilibrium method is used to estimate the excavation stability factor of safety [2]. In this process, the accurate estimate of the nail pull-out capacity is the most important parameter influencing the design. This estimate is obtained mainly considering the values mentioned in reputable codes such as FHWA, and the initial estimate is validated through pull-out field tests. In this method, the load-bearing mechanism, load transfer, and ultimate strength of nails are basically influenced by the intersection between soil and the grouting mortar. Hence, nail pull-out resistance is a function of different factors such as the applied overburden pressure, grouting pressure, ambient moisture, grouting matrix, and drilling method [3].

Chu et al. (2005) carried out experiments to compare results of nail pull-out tests and results of the direct shear test [4]. They found a satisfactory correlation between results of both experiments under equal overburden pressure effects and similar experiment conditions. In another study, Su et al. carried out a series of experiments to assess nail pull-out resistance in Hong Kong soil [5]. They used the pull-out devices made in Hong Kong University to observe and study the effect of different overburden pressures on nail pull-out resistance. It was found that with an increase in the overburden pressure the nail pull-out resistance increased slightly. Simulation of the nail pull-out process has attracted the attention of different researchers such as Franzen et al. [6], Pradhan et al. [7], Zhu et al. [8], and Chai et al. [9].

2 PROBLEM SOILVING METHOD

Similar to all of the existing civil engineering designs, several parameters influence nailing design, and the effects of these parameters cannot be differentiated. However, it is necessary to consider the concurrent effects of these factors. One of the factors to be studied is the effect of overburden pressure on nail pull-out resistance.

Theoretically, with an increase in overburden pressure and the soil pressure exerted on nail, the nail pull-out resistance increases. However, the extent of the increase and the effect of the increase in overburden pressure on nail pull-out resistance under different conditions are of importance.

In this research, to study the effect of overburden pressure on nail pull-out resistance under different conditions, numerical modeling was carried out. Numerical modeling was carried out in the powerful ABAQUS finite element software, and to increase precision of results, the numerical modeling results were compared to results of the experiments on samples.

3 NUMERICAL MODELLING

For the numerical modeling data reported by Su et al. were used. In their research, the effect of different overburden pressures on pull-out resistance was experimentally examined.

3.1 Model Geometry and Meshing

The study numerical model was a soil mass with a width and height of 0.8 m, with a unit third dimension. It is worth stating that the aforementioned dimensions exactly matched the dimensions of the experimental sample in the research by Su et al. [10].

The nail in the modeling had a diameter of 10 cm and a length of 1.1m. In the nail pulling-out operation, the pull-out length was equal to 10% of the overall length, i.e. 10 cm. Moreover, since the nail has to be always in the soil during the pulling-out operation and contact its surface, the nail length was set to 1.1m. In addition, the nail central axis was at a 0.35-m distance from the model floor. In the numerical model, thickness of the nail-soil interaction zone was set to 4 mm, and materials with a different behavioral model than soil and nail were used. Considering the behavior of the study problem and the state and direction of loading, it was possible to build and analyze a numerical symmetrical model. In addition, the standard 3D (three dimensional) stress element in the form of an 8-node reduced integration was used to mesh the model. This element is called the C3D8R in ABAQUS. Figure 1 depicts the geometry of the study model and its meshing.

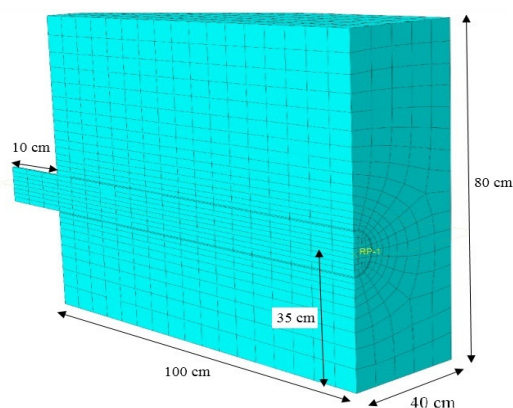


Figure 1. Model's geometry and its meshing

3.2 Boundary Conditions

Under actual conditions the soil environment is vast and taking soil dimensions into account is significantly important in pulling out nails for minimizing its effect on the results. On the other hand, given the nature of loading while pulling out the nails it is not necessary to consider far-nail areas in the modeling because it significantly increases the time required for the analysis. The boundaries of the numerical model floor are restrained in all of the three main directions. Moreover, lateral

boundaries are only restrained along the horizon to allow for changes along the direction perpendicular to this soil.

3.3 Behavioral Model and Material Specifications

The behavioral model selected for this research was a behavioral model with the Mohr-Coulomb yield criterion. In the linear elastic model the parameters determining soil behavior are density, modulus of elasticity, and the Poisson ratio of materials, which was constant in the analysis.

The linear elastic behavior model with the Mohr-Coulomb yield criterion is completely similar to the linear elastic behavioral model except that the principal stresses in all elements are calculated, and when the stress condition in each element equals the critical stress condition in terms of the Mohr-Coulomb criterion, it is considered yield stress and materials demonstrate plastic behavior. Therefore, the elastic behavioral model with the Mohr-Coulomb yield criterion displays a completely elasto-plastic behavior. In addition to parameters of the linear elastic model, the parameters required in this model include internal angle of friction, cohesion, and materials dilation angle. The selected soil specifications are presented in Table 1 based on the paper by Su et al. It is worth stating that argillaceous sand was modeled using the values used in the research by Su et al. [10], and for the clay soil models the clay soil specifications resulted from experiments were used.

Table 1. Model Parameters

| Clay | Clayey Sand | Unit | Parameter | |
|------|-------------|--------------------|---------------|------|
| 1.55 | 1.668 | gr/cm ³ | Density | Soil |
| 12.5 | 27.5 | - | Young Modulus | |
| 0.4 | 0.35 | MPa | Poisson Ratio | |
| 20 | 34 | Degree | Friction | |
| 0 | 8.2 | Degree | Dilation | |
| 40 | 27 | kPa | Cohesion | |

3.4 Loading Phases

One of the valuable features of ABAQUS is the possibility of defining different phases of the analysis process, which allows for considerable improvement of precision of modeling. The different phases of analysis used in this research are summarized into the following 3 phases.

In-situ stress development (in-situ stress phase):

This phase, which is referred to as the geostatic phase in geotechnical science, is the first phase to be taken into account in soil problems. In this phase, soil is influenced by gravity, as a result of which in-situ stress develops and the model reaches the state of equilibrium. Figure 2 shows the vertical stress field in this state for an overburden pressure of 300 kPa.

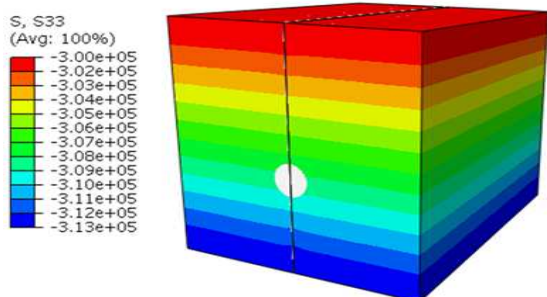


Figure 2. Contour of vertical stresses for the 300 kPa overburden

Nail position boring (drilling phase):

Following the geostatic analysis and stabilization of in-situ stresses drilling is carried out in the soil. As a result of the drilling operation, stress is released in the drilled region, figure 3. The release of stress definitely affects the results and its exclusion from calculations leads to a considerable level of calculation error.

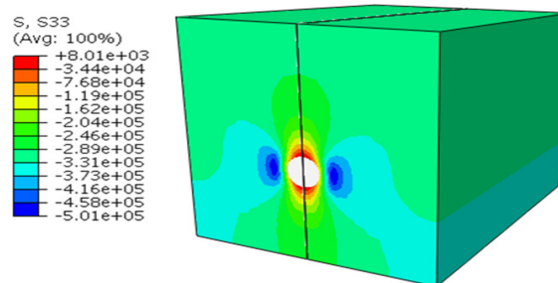


Figure 3. Drilling phase

Nail pull-out phase (loading phase):

In this phase, the nail is placed in its position following the drilling. It is worth stating that the nail is installed with a contact layer. After placement, the pull-out force is applied to the nail head and the nail is pulled out under a certain load. figure 4 shows the Mises stress contours at the maximum resistance level.

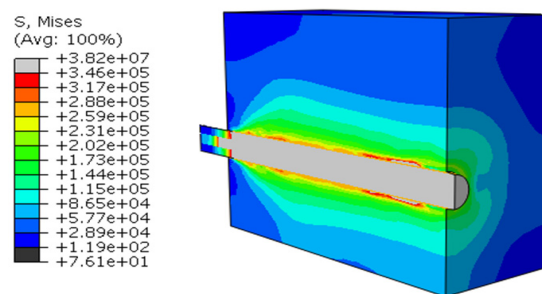


Figure 4. Mises stress contour at the maximum resistance level

3.5 Results Validation

Based on the diagrams provided by Su et al., the mean nail pull-out shear stress on the grout wall was calculated based on variations of displacement using the numerical model, figure 5. In this figure, the above diagram was compared to the results of experiments to validate the numerical model. As seen in this figure, the numerical model predicted results similar to the experimental results with satisfactory compliance. However, this numerical model was designed and tested for the 300 kPa overburden pressure state.

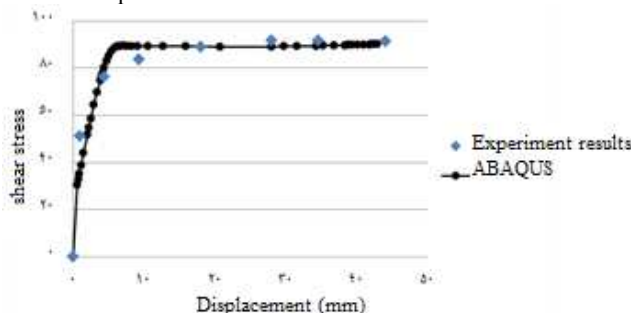


Figure 5. Validating results of the numerical modeling against the values reported by Su

4. RESULTS

Figure 6 shows the mean pull-out shear stress and variations of the axial load applied to the nail (over time), which is divided by the lateral grout surface area, in terms of displacement. As seen, the nails pull-out force increased for only app. 3% as the upper overburden pressure increased from 40 kPa to 120 kPa. As the upper soil overburden pressure increases from 40 kPa to 300 kPa, the increase in the nails pull-out resistance increased for 10%. In addition, the increase in nails pull-out resistance reaches 28% from 40 to 700 kPa. The slight increase in the nail pull-out force with the increase in the soil upper overburden pressure can be attributed to the full release of stress in the drilling phase. In the nail cavity drilling phase, release of stress does not occur completely and considerable vertical stress is transferred from the soil mass to the grout wall and the surface area increases. As the soil overburden pressure rises, the vertical stress increases and the effect of overburden pressure on the nail pull-out resistance escalates.

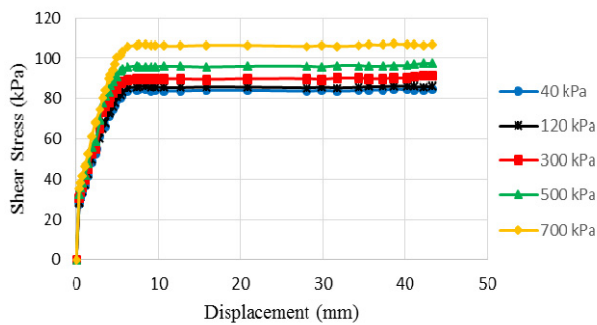


Figure 6. Effect of different overburden pressures on the pull-out resistance

To study the effect of soil cohesion on the nail pull-out resistance, two models with clay soil were analyzed. In these models, cohesion is set to 40. Results of this analysis are shown in Figure 7. Based on these results, the nails pull-out resistance decreases as the soil becomes argillaceous. In other words, the nails pull-out resistance is higher in granular soils than cohesive soils. This result is explained given the higher penetration of cement into soil in granular soil as compared to clay soils. In both of the argillaceous sandy soil and clay soil the overburden pressures of 40 and 300 kPa were used to determine the effect of the overburden pressure in both states. After examining the above diagrams it was found that in granular soils the effect of overburden pressure is larger in granular soils than clay soils. Analysis of results of different diagrams revealed that the increase in the nail pull-out resistance in clay soil was approximately 45% of that of the argillaceous sandy soil.

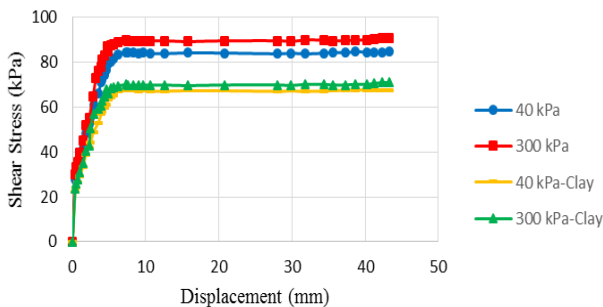


Figure 7. Effect of overburden pressure on granular and cohesive soils

2 CONCLUSION

In this research, through numerical modeling in ABAQUS, studies were carried out on the effect of the overburden pressure on the nails pull-out resistance and the following results were obtained.

1. The nails pull-out resistance increases with an increase in overburden pressure. However, the increase is not significant, which can be mainly attributed to the release of pressure during drilling.
2. The effect of the increase in overburden pressure on the pull-out resistance was slight before the peak point of the stress-displacement curve, and the difference in the pull-out resistance was caused by variation of overburden after the maximum resistance point.
3. In the linear region of the stress-displacement curve, which shows the elastic behavior range, the increase in overburden pressure almost does not affect the pull-out behavior.
4. The effect of overburden pressure on the nails pull-out resistance is higher in granular soils than cohesive soils.

3 ACKNOWLEDGEMENTS

We hereby express our deepest gratitude to the support and assistance provided by Gohar Zamin Iron Ore Company, a pioneer corporation in the field of iron ore industry in Iran.

4 REFERENCES

- [1]. Lazarte, C.A., et al., Soil Nail Walls Reference Manual. 2015.
- [2]. Elias, V. and I. Juran, Soil nailing for stabilization of highway slopes and excavations. 1991.
- [3]. Ou, C.-Y., Deep excavation: theory and practice. 2006: CRC Press.
- [4]. Chu, L.-M. and J.-H. Yin, Comparison of interface shear strength of soil nails measured by both direct shear box tests and pullout tests. *Journal of geotechnical and geoenvironmental engineering*, 2005. 131(9): p. 1097-1107.
- [5]. Su, L.-J., et al. Numerical simulation of pressure grouting in soil nail pull-out tests. in *Key Engineering Materials*. 2007. Trans Tech Publ.
- [6]. Franzén, G., Soil Nailing. A Laboratory and Field Study of Pullout Capacity. 1998: Chalmers University of Technology.
- [7]. Pradhan, B., et al., Soil–nail pullout interaction in loose fill materials. *International Journal of Geomechanics*, 2006. 6(4): p. 238-247.
- [8]. Zhou, W.-H., J.-H. Yin, and C.-Y. Hong, Finite element modelling of pullout testing on a soil nail in a pullout box under different overburden and grouting pressures. *Canadian Geotechnical Journal*, 2011. 48(4): p. 557-567.
- [9]. Chai, X., S. Hayashi, and Y. Du. Du Y J. Contribution of dilatancy to pull-out capacity of nails in sandy clay. in *Int' l Conference on Soil Nailing and Stability of Soil and Rock Engineering*. 2004. Nanjing:[sn].
- [10]. Su, L.-J., et al., Influence of overburden pressure on soil–nail pullout resistance in a compacted fill. *Journal of geotechnical and geoenvironmental engineering*, 2008. 134(9): p. 1339-1347.