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Investigation of corner effects of deep excavations using the combination of soil nailing and ground-anchors methods

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ABSTRACT: Increasing population growth and economic growth have increased land prices in metropolitan areas. Soil nailing and ground anchor are common methods of deep excavation stabilization in Iran. The presence of a convex corner causes complexity in stabilization. In this paper, three-dimensional modeling of the convex corner has been carried out in combination of soil nailing and ground-anchor methods by ABAQUS 3D. Particularly, the effect of using the soil nail and ground anchor combination on the vertical and lateral displacement of the excavation was investigated. The variables include: the angle of the ground anchors (90 and 60 degrees), the angle of the soil nails (90 and 60 degrees) and the configuration of nails and ground-anchors. In addition, the different combination of soil and anchors layout was modelled. Based on the results, the optimum design was presented regarding the location and configuration of soil nails and ground-anchors for a deep excavation with a convex corner and 20 meter depth.

1 INTRODUCTION

Construction of high rise buildings is increased in Iran during the last decade due to increase in population and high price of lands. Additionally, the requirement of providing a parking space for each new unit either commercial or residential led to the design and construction of deep excavations in large cities such as Tehran and Mashhad. There are different types of supporting system can be used for deep excavations. Soil nailing and ground anchors are most common methods for temporary/permanent support of these type of excavations in Iran as it causes less congestion in the excavation and the installation of nails/anchors is relatively fast.

The common practice to design of soil nailing/ground anchors is using two-dimensional analysis considering plane strain situation. This assumption does not consider the effect of corners on the evaluation of lateral displacement as well as settlement. Ou and Shiau 1998 conducted 2D & 3D numerical analysis for an excavation with 90° concave corners enhancing three-dimensional non-linear finite element program. They considered the top-down method for the support of the exaction. The field data was used for the verification of the three-dimensional modelling results. Based on the conclusion, the wall displacement decreases with decreasing distance from the corner. In 1998, Lee et al. investigated the effect of corners on wall deflections and ground movement around multi-strutted deep excavations. Field data revealed that the corners can decrease the lateral movement and settlement significantly. In addition, the results indicated the length to depth ratio of excavation, the stiffness of struts and the depth to the stiff layer are the main factors related to the corner's effects.

Zdravkovic et al. 2005 performed the three-dimensional modelling of a square and rectangular retaining wall with a finite element program. They found that for rectangular excavation with length to width ratio of 4, the condition in the longer side of the wall still not satisfied the plane strain assumption with regards to the horizontal and vertical movements of the wall. However, for a shallow depth of foundation, the difference between the real condition and plane strain assumption will be negligible. For length to width ratio of 2, the effects of depth would be significant.

In order to get a better understanding about the approximation of using plane strain instead of a three-dimensional condition, Wu et al. 2010 introduced a new parameter as plane strain ratio (PRS). PRS defined as the maximum horizontal displacement in the three-dimensional analysis to the maximum horizontal displacement in the two-dimensional analysis. Higher PSR represents sections that are less affected by the corners. Based on different PSR values, the aspect ratio for excavation geometry and distance from the corner, they produced a chart which indicated that if the PSR is close to the value of 1, the effects of corners on lateral displacements are negligible.

Hsieh et al. 2013 compared the numerical modelling prediction with four case study monitoring results. Based on their study, the lowest horizontal displacement will occur close to the concave corners. Law et al. 2014 used hardening soil as a constitutive soil models in PLAXIS 3D for modelling of a deep excavation in Kenny Hill and the results show that selection of the soil parameters for 2D and 3D analysis for advanced constitutive models are as import as the corner effects consideration in the modelling to predict the displacement more accurately. Zad and Farnegin 2017 carried out the parametric study using PLAXIS 3D A.E. 2015 for modeling of 15m deep excavation by using soil nailing method for supporting system. The location, horizontal and vertical distance of nails and the type of constitutive soil models are varied. Based on their results, the soil nail distance can be increased around the concave corners considering three-dimensional effects of corners which can result in the optimum design of soil nailing method.

ABAQUS 3D was used in this paper to evaluate the convex corner effects of a 20 m deep excavation using the combination of soil nailing and ground-anchors methods to find out the optimum design for the support system.

2 NUMERCIAL ANALYSIS

Drucker Prager Cap Model was used for the modelling of the soil. The properties of the soil are summarized in Table 1. Figure 1 displays the geometry and boundary of the model with 80*80*30 meter. The depth of the excavation was 20 meter with 20 meter length in the plan.

Table 1. Soil properties

Parameter	Value
Friction angle β (Degree)	50
Cohesion d (kPa)	62
Unit weight γ (kN/m^2)	19
Modulus of elasticity E (MPa)	50
Poisson's ratio ϑ	0.3

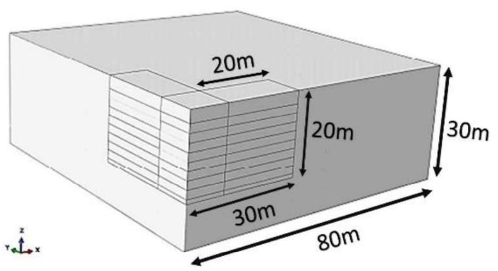


Figure 1. Geometry of the numerical model

Mesh sensitivity analysis was carried out to find the adequate size of the mesh in term of the accuracy of the result in addition to the optimum time for calculation regarding element size and numbers as shown in Figure 2.

In the numerical analysis 3d bock element was selected for the soil, plate element for shotcrete, beam truss for the modelling for the nails and ground-anchors. The properties of soil nails, ground-anchors and concrete pad are displaced in table 2, 3 and 4 respectively. Table 5 summaries the different types of soil nails/ground anchors arrangement. In addition, figure 3 presents the plan of different configurations for the supporting system.

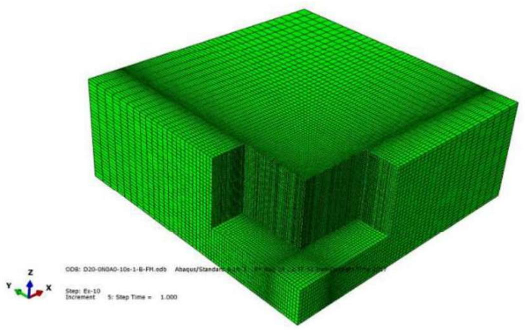


Figure 2. Mesh size for the model

Table 2. Soil nails properties

Parameter	Value
Type	A1-32
Unit weight/Length (kg/m)	6.31
Area (mm^2)	804
Modulus of elasticity E (GPa)	200

Table 3. Ground-Anchors properties

Parameter	Value
Type	4strand-0.6
Unit weight/Length (kg/m)	4.48
Area (mm^2)	560
Modulus of elasticity E (GPa)	200
Ultimate capacity (kN)	1040
Tendon capacity (F_u) (kN) for 0.6	624
Tendon capacity (F_u) (kN) for 0.7	728
Tendon capacity (F_u) (kN) for 0.8	832
Modulus of elasticity-Bound E (GPa)	28
Area-Bound (cm^2)	121
Poisson's ratio-Bound	0.16

Table 4. Concrete pad properties

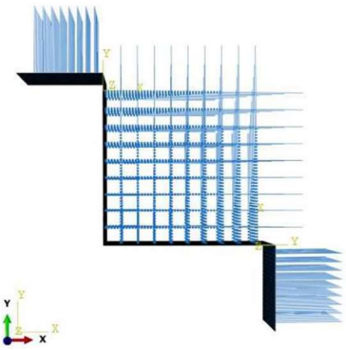
Parameter	Value
Thickness (m)	0.35
Area (m^2)	0.48
Modulus of elasticity E (GPa)	21

Table 5. The configuration of different types of numerical models

Model No.	Support system	reinforced length		reinforced angle	
		Anchor	Nail	Anchor	Nail
1	Anchor	20	0	90	0
2	Anchor	20	0	60	0
3	Anchor&Nail	14	6	90	90

4	Anchor&Nail	14	6	60	90
5	Anchor&Nail	14	6	90	60
6	Anchor&Nail	14	6	60	60

Figure 4 displays the targeted path for the lateral and vertical displacement. Total displacement includes the resultant of the displacements in x, y and z direction.



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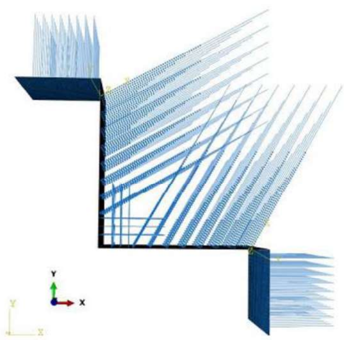

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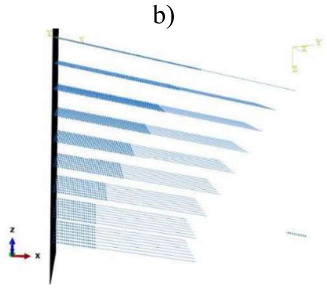

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Figure 3. The plan and cross section of different types of configurations a) ground-anchors with 90 degrees b)combination of ground-anchors with 90 degrees with soil nails with 60 degrees c)cross section of the wall supported by ground-anchors

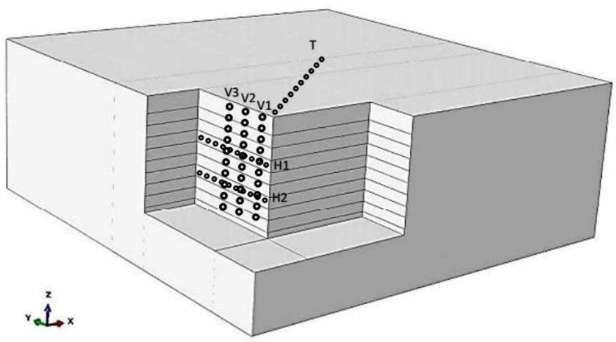


Figure 4. The target path for the lateral and vertical displacement.

3 NUMERICAL RESULTS

Figure 5 displays the vertical displacement towards the T path. As it can be seen, with the change of angle ground-anchor's angle from 90 to 60 degrees, the vertical displacement will increase by 37%. This might relate to the less coverage of ground-anchors with 60 degree inclination. The maximum vertical displacement will occur around 4 meters from the corner for all of the different numerical models. Using soil nailing will decrease the value of vertical displacement especially in combination of ground-anchors.

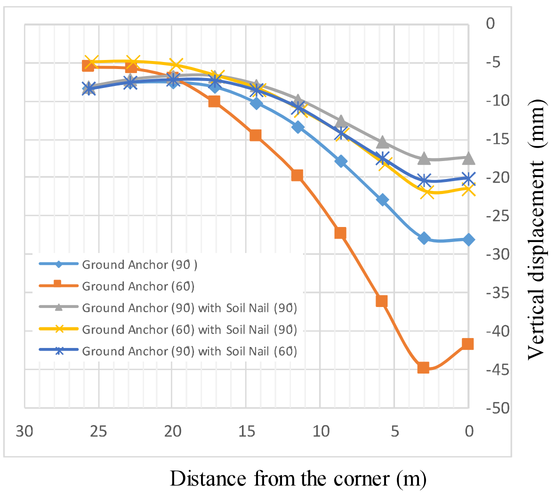


Figure 5. The vertical displacement towards T path

Figure 6 plots the lateral displacement towards T path which indicates supporting system including ground-anchors with 60 degrees angle and soil nailing with 90 degrees angle will result in lowers value of lateral displacement in comparison to other types of configurations.

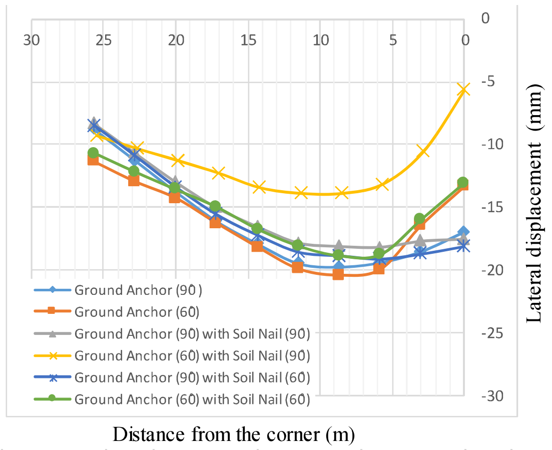
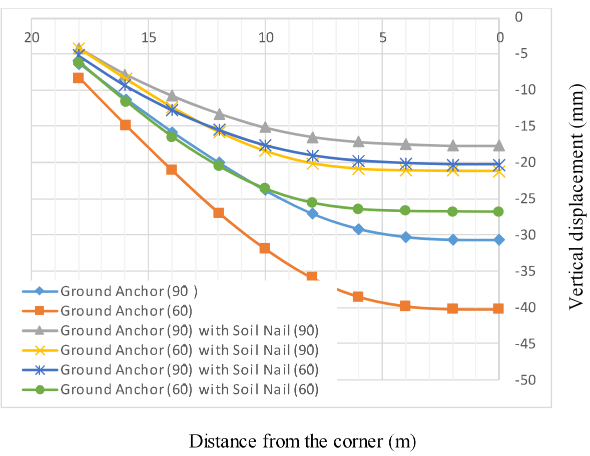


Figure 6. The lateral displacement towards T path

Figure 7 represents the vertical displacement towards V1 and V3 path located 1 meter and 10 meters from the corner, respectively. Based on the results, the maximum vertical displacement occurs at the top of the wall. Additionally, the maximum later displacement belongs to the numerical model using ground-anchors with the angle of 60 degrees. By using the combination of soil nails and ground-anchors with the angle of 90 degrees, the vertical displacement will decrease significantly.



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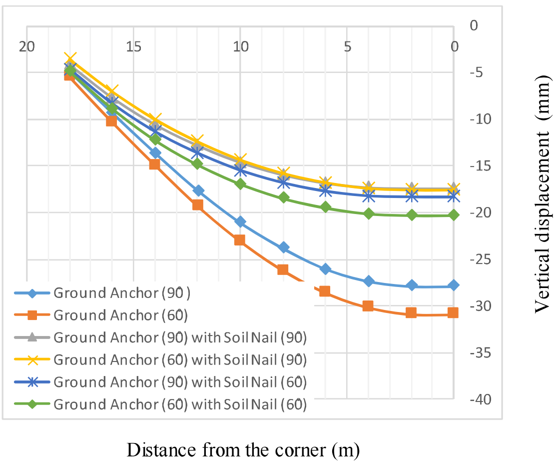

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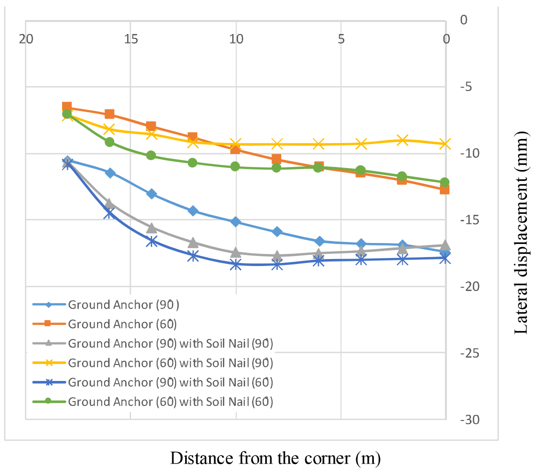
Figure 7. The vertical displacement towards a) V1 path b)V3 path

Figure 8 plots the lateral displacement towards V1 and V3 path. As it can be seen 60 degrees of inclination for either soil nails or ground anchors will reduce lateral displacement towards the V1 path which located 5 meters from the corner. However, by moving from V1 to V3, the corner effects will dissipate and the amount of lateral displacement will be fairly similar for most scenarios. The minimum values for belong to the combination of the ground-anchor with 60 degrees with soil nails 90 degrees. The ground-anchors and/or nails with 90 degrees indicate less value for the lateral displacement in comparison to the 60 degrees.

4 CONCLUSION

In this paper the effect of using soil nailing and ground-anchors system for support of a convex corner of a 20 m deep exaction was investigated. Six different configuration for support system was modelled in 3D finite element program with installation of 60 and 90 degrees for the reinforcements. Based on the numerical results:

1- With the change of angle ground-anchor's angle from 90 to 60 degrees, the vertical displacement will increase by 37%. This might relate to the less coverage of ground-anchors with 60 degree inclination. The maximum vertical displacement will occur around 4 meters from the corner for all of the different numerical models.
2- Using soil nailing will decrease the value of vertical displacement especially in combination of ground-anchors
3- As it can be seen 60 degrees of inclination for either soil nails or ground anchors will reduce lateral displacement towards the V1 path which located 5 meters from the corner.
4- By moving from the corner toward the middle of the wall, the corner effects will dissipate and the amount of lateral displacement will be fairly similar for most scenarios. The minimum values for lateral displacement related to the combination of the ground-anchor with 60 degrees with soil nails 90 degrees. The ground-anchors and/or nails with 90 degrees indicate less value for the lateral displacement in comparison to the 60 degrees.



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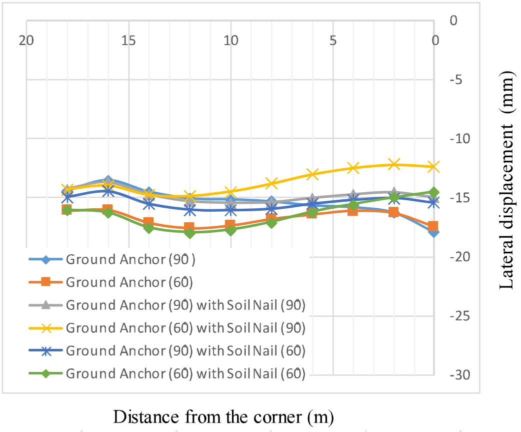

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Figure 8. The lateral displacement towards a) V1 path b)V3 path

REFRENCES

Lazarte, C.A., Robinson, H., Gomez, J.E., Baxter, A., Caden, A. and Berg, R. 2015. Geotechnical Engineering Circular No. 7 Soil Nail Walls-Reference Manual, Report No. FHWA-NHI-14-007 Federal Highway Administration, Washington, DC 20590.

Ou C.U. and Shiau B.Y. 1998. Analyis of The Corner Effect on Excavation Behaviors. *Canadian Geotechnical Journal* 35 (3), 532-540.

Lee, F.H., Yong, K.Y., Quan, K., and Chee, K.T., 1998. Effect of Corners in Strutted Excavations: Field Monitoring and Case Histories. *Journal of Geotechnical and Geoenvironmental Engineering* 124 (4), 339-349.

Zdravkovic, L., Potts, D. M., and John, H. D., 2005. Modelling of a 3D Excavation in Finite Element Analysis, *Géotechnique* , 55(7), 497–513.

Wu, Chao-Hui; Ou, Chang-Yu; Tung, Ningchien, 2010. Corner Effects in Deep Excavations-Establishment of a Forecast Model for Taipei Basin T2 Zone, Journa*l of Marine Science and technology*, 18 (1), 1-11.

Hsieh, Pio-Go; Ou, Chang-Yu; Lin, Yi-Lang, 2013. Three-Dimensional Numerical Analysis of Deep Excavations with Cross Walls, *Acta Geotechnica*, 33-48.

Law, K.H.;Roslan, H ;Zubaidah, I, 2014. 3D numerical analysis and performance of deep excavations in Kenny Hill formation, *Journal of Numerical Methods in Geotechnical Engineering*, 2 ,759–764.

Ernst, S., 2003. Recommendations on Excavations-3rd Edition, Published by German Society for Geotechnics, the University of Michigan.

Zad, A. A. and Farnegin M., 2017. Three dimensional analysis of corner effects of deep excavations using soil nailing method, Proceedings of the 19th International Conference on Soil Mechanics and Geotechnical Engineering, Seoul, South Korea.