Determination of vertical displacements behind the excavation support systems

Zafer Çetin
Geophysics & Msc Civil Engineer, Tülomsaş, Eskisehir, Turkey, ctnzfr@gmail.com

M. İnanç Onur
Res. Assistant, Anadolu University, Eskisehir, Turkey, mionur@anadolu.edu.tr

Mustafa Tuncan
Prof. Dr., Anadolu University, Eskisehir, Turkey, mtuncan@anadolu.edu.tr

Ahmet Tuncan
Prof. Dr., Anadolu University, Eskisehir, Turkey, atuncan@anadolu.edu.tr

KEYWORDS: Deep Excavation, Vertical settlement, Plaxis 3D

ABSTRACT: Types of vertical displacement on soil surface behind the excavation support systems usually form like concave or spandrel type. In this study, vertical displacements behind the different excavation support systems were analyzed. Relationship between soil types and relative displacements examined for deep excavations by using different relative densities for sandy soils and different consistency degrees for clay soils on the models. Steel sheet pile and reinforced concrete wall elements were chosen for support systems. Plaxis 3D Foundation software was used for calculations. Concave or spandrel types of vertical displacements on soil surface behind the excavation support system were found at the end of the analyses. At the end of the study; vertical deformation changes due to different excavation support systems for different clay and sandy types of soil were presented by using various graphs.

1 INTRODUCTION

Deep excavations are commonly chosen for basements of multi-storey buildings in developed countries due to inadequate construction areas. Many of them are constructed nearby existing constructions so support systems should preserve the stability and control displacements next to the excavation. Settlement prediction is usually made by empirical methods and also by numerical modeling in recent years. The vertical displacement profile resulting from the deep excavation is usually two types (Fig. 1). One of them is spandrel type, and second one is concave type (Hsieh & Ou 1998). The maximum vertical displacement at spandrel type occurs nearby retaining wall, and displacement profile is convex. At the concave displacement type, the maximum soil displacement occurs at a certain distance from the wall, and displacement profile is concave.

Typical wall deflection and ground movement induced excavation can cause differential settlements, tilting and cracks on the existing structure. Damages can be prevented by estimating soil movement and applying appropriate engineering solutions. In literature, empirical models were given for settlement estimating by Hsieh & Ou (1998). Then some approaches based on finite element methods were given by many researchers (Schweiger et al. 2009), (Sevencan et al. 2010), (Tunca &

Berilgen 2011). Finite element method has not able to estimate certain settlements, yet but finite element method is able to predict distribution of the horizontal displacement and superficial settlement (Santos et al. 2008).

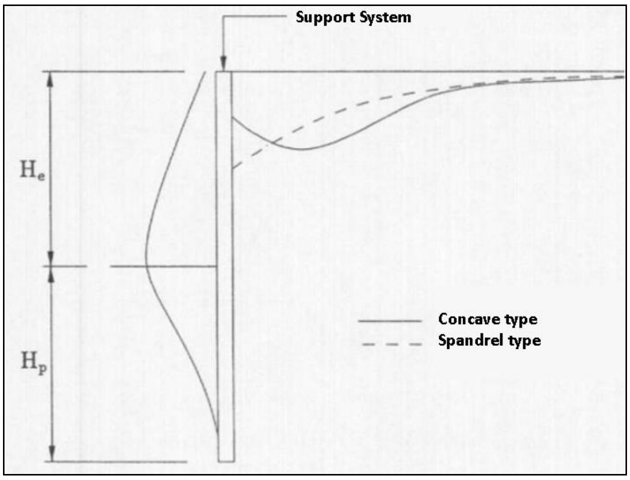

Figure 1. Vertical displacement types behind the wall of excavation (Hsieh and Ou 1998)

In this study, vertical displacements behind the different excavation support systems were analyzed. Steel sheet pile and reinforced concrete wall elements were chosen for support systems. Relationship between soil types and relative displacements examined for deep excavations by using different relative densities for sandy soils and different consistency degrees for clay soils on the models.

2 MODELING AND METHOD

In this study Plaxis 3D Foundation software was performed for calculations. Plaxis is a commercially available finite element program which is used commonly in geotechnical engineering for the deformation and stability analysis. The software can make numerical solutions based on the finite element method (Brinkgreve and Broere 2004). The software can solve the problems with 2D or 3D analysis by separete modules. For this study, 3D analysis was chosen for considering all factors and example screens of the models can be seen in Fig. 2.

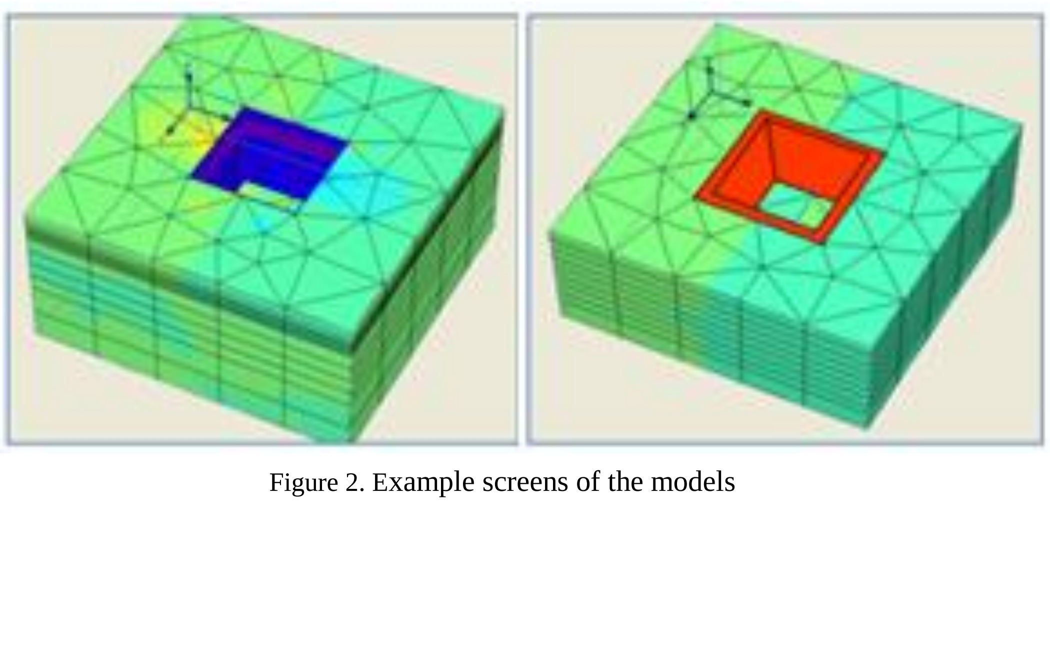

Figure 2. Example screens of the models

2.1. Material Properties

For support element systems, steel sheet pile and reinforced concrete wall elements were chosen. Sheet pile walls and reinforced concrete elements are retaining walls constructed to retain earth, water or any other fill materials. Sheet pile walls are thinner in section but more expensive as compared with reinforced concrete walls. Both of them are commonly used for excavation support systems by contractors. Some parameters of support systems are given in Table 1 and Table 2.

Table 1. Parameters of steel sheet pile elements

Material Type	**Thickness (d)**	**Unit Weight (γ)**	**Elastic Modulus (E)**	**Poisson's Ratio (ν)**
	cm	kN/m^3	kN/m^2	-
Linear Elastic	10.00	77.00	2E+8	0.3

Table 2. Parameters of reinforced concrete wall

Material Type	**Thickness (d)**	**Unit Weight (γ)**	**Elastic Modulus (E)**	**Poisson's Ratio (ν)**
	cm	kN/m^3	kN/m^2	-
Impermeable	100.00	24.00	3E+7	0.18

Soil models were grouped as sandy and clay soils under two main headings in the analyses. Sandy soils were classified as very loose sand, loose sand, medium dense sand, dense sand and very dense sand. Clay soils were classified as very soft clay, soft clay, medium clay, stiff clay, very stiff clay and hard clay. Some parameters of soil models are given in Table 3 and Table 4. The groundwater level is considered on the deep for all soil models and ineffective to the excavation conditions due to eliminate pore water effects.

Table 3. Properties of sandy soil models

Soil Type	**Material Type**	**γ_{dry} (kN/m^3)**	**γ_{sat} (kN/m^3)**	**ν**	**E (kN/m^2)**	**c (kN/m^2)**	**φ (°)**
Very loose sand	Mohr-Coulomb, drained	11	12	0.20	10350	0.01	26
Loose sand	Mohr-Coulomb, drained	14	15	0.23	15000	0.01	28
Medium dense sand	Mohr-Coulomb, drained	17	18	0.25	20000	0.01	32
Dense sand	Mohr-Coulomb, drained	20	21	0.27	35000	0.01	37
Very dense sand	Mohr-Coulomb, drained	22	23	0.30	50000	0.01	43

Table 4. Properties of clay soil models

Soil Type	Material Type	γ_{dry} (kN/m³)	γ_{sat} (kN/m³)	ν	E (kN/m²)	c (kN/m²)	φ (°)
Very soft clay	Mohr-Coulomb, un-drained	10.00	11.50	0.20	2070	10	1
Soft clay	Mohr-Coulomb, un-drained	11.50	13.00	0.25	4000	20	1
Medium clay	Mohr-Coulomb, un-drained	13.00	14.50	0.30	5180	30	1
Stiff clay	Mohr-Coulomb, un-drained	16.00	17.50	0.35	8500	75	1
Very stiff clay	Mohr-Coulomb, un-drained	17.00	18.50	0.40	10350	150	1
Hard clay	Mohr-Coulomb, un-drained	19.00	20.50	0.45	25000	250	1

3 ANALYSIS AND RESULTS

3.1. Determination of the Relationship between Vertical Displacement and Distance Supported by Steel Sheet Pile for Clay Soils Supported by Steel Sheet Pile

Vertical displacements occurred behind the steel sheet pile have been analyzed depending on the distance in clay soils. For each model, vertical displacement/excavation depth (%) ratio varied with the distance from the excavation support wall. For clay soils, results showed that this change increases by distance and demonstrated concave type displacement (Fig. 3a). Firstly, vertical displacements increase and start to decrease after reaching the maximum level at a particular position for this type of displacement profile. For this soil profile vertical displacement/excavation depth (%) ratios are obtained almost equal values by different excavation depths. This shows that the excavation depth doesn’t have substantial effect on this ratio (Çetin 2012).

3.1.1. For Sandy Soil Supported by Steel Sheet Pile

Vertical displacements occurred behind steel sheet pile have been analyzed depending on the distance in sandy soils. Result of the analysis showed a decrement on the vertical displacement / excavation depth ratio (%) by distance (Çetin 2012). These results demonstrated spandrel type displacement. Figure 3b shows the results of analyses for sand soils supported by steel sheet piles.

3.2. Determination of the Relationship between Vertical Displacement and Distance Supported by Reinforced Concrete Wall for Clay Soils Supported by Reinforced Concrete Wall

It is found that vertical displacement/excavation depth (%) ratio increased by distance from the excavation support wall for each model. Displacement demonstrated concave type movement. For this soil profile vertical displacement/excavation depth (%) ratios were obtained almost equal values by different excavation depths (Fig. 4a). This shows that the excavation depth doesn’t have substantial effect on this ratio (Çetin 2012).

3.2.1. For Sandy Soils Supported by Reinforced Concrete Wall

Results of the analysis showed that vertical displacement behind the reinforced concrete wall was very low for sandy soil type models. Result of the analysis showed a decrement on the vertical displacement / excavation depth ratio (%) by distance (Çetin 2012). These results demonstrated spandrel type displacement. Figure 4b shows the results of analyses for sand soils supported by reinforced concrete wall.

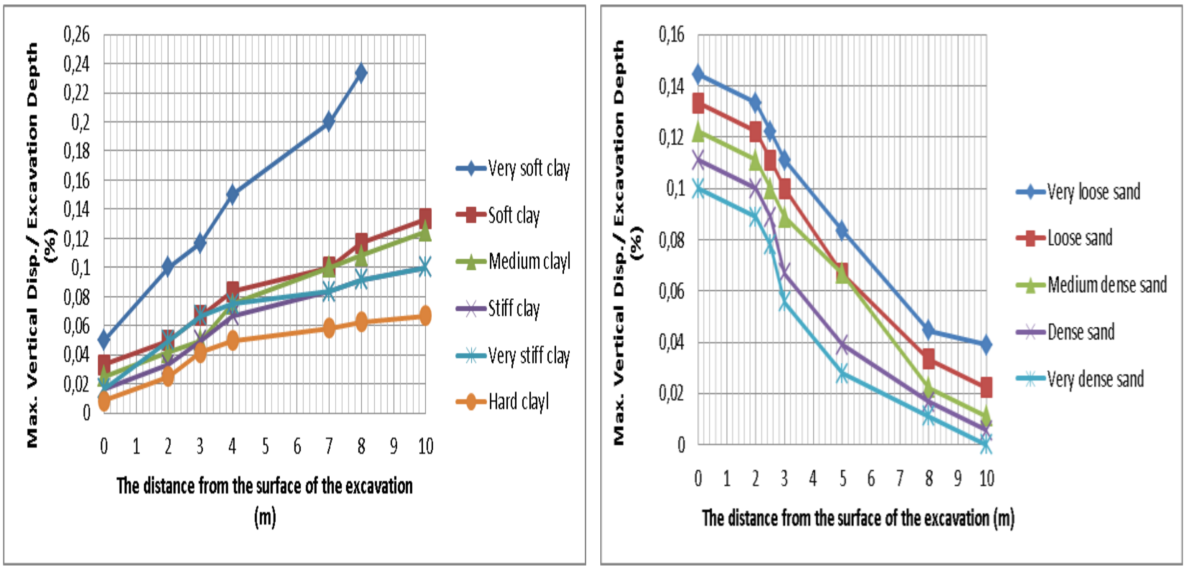

Figure 3. Model results supported by steel sheet piles (a) for clay soils (b) for sandy soils

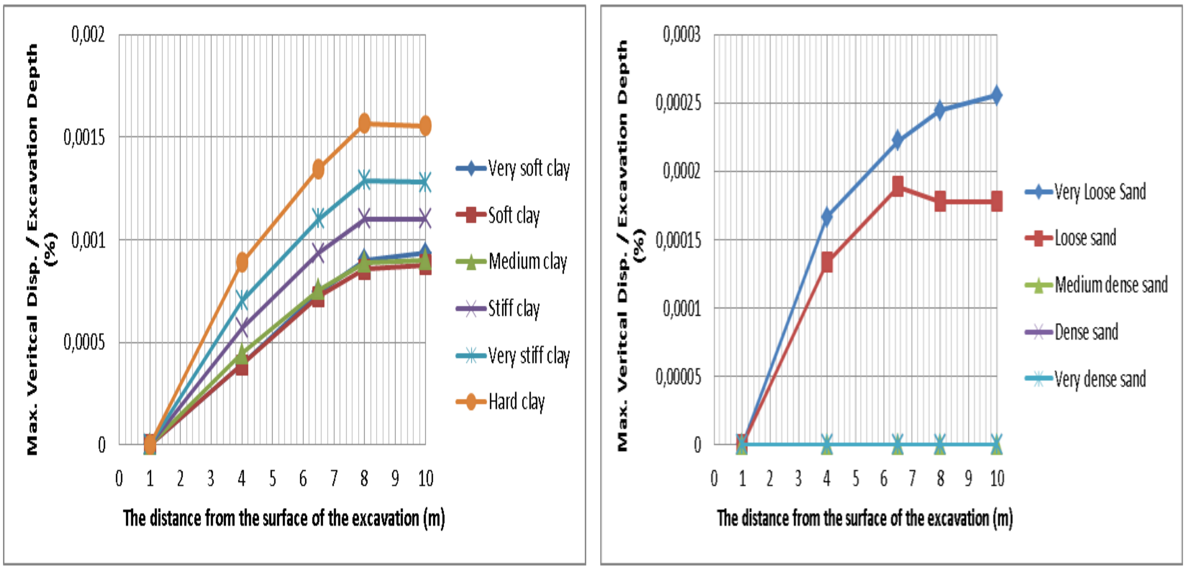

Figure 4. Model results supported by reinforced concrete walls (a) for clay soils (b) for sandy soils

4 CONCLUSIONS

In this study, vertical deformations induced deep excavations for clay and sandy types of soil were analyzed with the software Plaxis 3D Foundation. When the variation of vertical displacements in the soil behind excavation support walls was examined, less movement was observed in the soil behind the reinforced concrete wall than the soil behind the steel sheet pile wall. The results showed that reinforced concrete wall creates relatively stable effect than steel sheet pile wall. On the other hand, the vertical displacement types, occurred behind the support system, are concave for clay soils and spandrel for sandy soils.

REFERENCES

Brinkgreve, R.B.J., Broere, W. (2004), "Plaxis 3D Foundation reference manual, version 1", Delft University of Technology & PLAXIS bv, The Netherlands.

Çetin, Z. (2012). The Analysis Of Finite Element Models Of Supporting the Deep Excavation Surface. Msc Thesis, Anadolu University, Turkey.

Das, B.M. (1990). "Principles of Geotechnical Engineering. 2th. edition, USA.

Hsieh, P.G., Ou, C.Y. (1998). Shape of Ground Surface Settlement Profiles Caused by Excavation. Canadian Geotechnical Journal, 35(6), 1004-1017.

Santos, M.D., Danziger, B.R., & Sieira, A.C.C.F., (2008). A case of Numerical Analysis of Settlements due to Excavation on Nearby Structures. Proceedings, The 12 th Int. Conference of Int. Association for Computer Methods And Advances in Geomechanics, India, 3849-3857

Schweiger, H.F., Scharinger, F. & Lüftenegger, R. (2009), "3D finite element analysis of a deep excavation and comparison with in situ measurements", Taylor & Francis Group, U.K.

Sevencan, O., Özaydın, K., Kılıç, H. (2010). Numerical Analysis of Soil Deformations at Deep Excavations. Proceedings, 13 th Soil Mechanics And Foundation Engineering National Congress, Turkey, 421-440

Tunca, M., Berilgen, M. (2011). Investigation of Soil Settlements Due to Deep Excavation by Numerical Analysis. Proceedings, 4 th National Geotechnical Symposium, Turkey, 419-428.