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The Effect of Combined Systems on the Displacement and Safety Factor of the Pit Stability

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Abstract: *Regarding the excavation process in urban areas, due to improper and non-standard support of the walls, the walls collapse with the destructive effects on the trench and adjacent structures. Therefore, the aim of this research was to investigate the effect of utilization of the combined nail, anchor and piling system on the displacement and safety factor of the deep and semi-deep pits. The modeling was performed using the numerical method and utilizing the PLAXIS software. For the modeling, three pits of shallow with the depth of 10 m, semi-deep with the depth of 20 m and deep with the depth of 30 m were used. For each studied depth, according to the used reinforcing system, the safety factor and displacement of the pit wall was obtained. The results showed that the maximum displacement of the wall was in the condition that the reinforcement was performed by nailing. The maximum displacement control would be time the piling element was also added to the anchor actuator system. In deep pits, the utilization of the nailing along with the anchor resulted in the increase of the horizontal displacement of the wall. When the anchor element (strands) was used, due to the anchor actuator system operation in decreasing the displacement, the horizontal displacement of the wall was drastically reduced.*

Keywords: *Deep and semi-deep pits, Nailing, anchoring and piling systems, Pit displacement amount*

INTRODUCTION

The excavation process and procedure and consequently the pit stabilization can be somehow dangerous and troublemaking. In these conditions, it's necessary that the designer, supervisor and the executor perform the excavation by considering special arrangements and provisions.

Regarding many construction projects, it's necessary that the earth is excavated in such a way that its walls be or nearly be upright. This could be performed for various goals. In the execution process of these upright walls, the lateral pressure on these walls, that are one of the main reasons for its stability condition, is because of the earth pressure caused by soil weight and also probable surcharge loading on the soil beside the hollow.

In order to prevent the instability of the slope or presenting a stable slope, three methods could be considered including the displacement of the plan location, reducing the earth pressure forces (driver) and reinforcing the resistant forces against the displacement. But, finding a method that provides maximum safety and stability in each project needs accurate and comparative study of each pit stabilization method uniquely in each project. Since each project should be thoroughly studied due to the soil type condition and geotechnical parameters, geometrical parameters, loading and execution conditions.

In recent years, there have been some papers presented about the stabilization methods of pits and related calculations. Jinyuan Liu and Arash Olia (2011) in a paper studied the "Numerical investigation of soil nail wall during construction" and the results showed that the two-dimensional finite element method could present an acceptable result of the actual performance (three-dimensional) of the nailed walls (Olia and Liu, 2011). Vikas Pratap and Sivakumar Babu (2010) concluded in their research that the more advanced soil models present more realistic results of the soil condition. Moreover, it was important to consider the effect of nails bending strength on the surficial and internal rupture of the wall (Pratap Singh and Sivakumar Babu, 2010). Jung Lee et al. (2010) in their study concluded that the utilization of the double soldier-piled walls resulted in the improvement of the retaining wall performance. This improvement was observed both in the safety factor and wall displacement control sections (Lee et al., 2010). Hong Sze Han in 2002, has presented some deficiencies for the two-dimensional geometrical modeling compared to the three-dimensional modeling. In the Ömer Bilgin research (2010), it was concluded that the natural methods of stabilization of the bending moment amount and the deformation of the wall is more than the case where the staunching is used in the wall stabilization. KeshtkaarZaadeh et al., (2014) showed that with the increase of the anchors angle, the displacement increases and the safety factor improves. Also, Dalir and Sharafi (2016) conducted research indicating that with the increase of the piles burying height in the gable, the stability increases in such a way that with the decrease in the displacement and weight, there would be a probable fracture. When investigating the effect of the number of piles on the gable behavior, the following result was obtained that the increase of the numbers of the piles can be somehow effective on the displacement and fracture reductions. In the research of Daniari et al., (2014) it was concluded that the nailing is the most proper method for stabilization of the pits in the urban areas. Furthermore, some papers like "An investigation on the effect of deep excavation on the buried pipelines adjacent to the hollow" by Sadeghian et al. (2013), "An investigation on the effect of excavation on adjacent structures" by Hashemi Shahraki et al., (2010), "Modeling the diagonal beam method in excavation" by Khatami et al., (2009), "An investigation on the most common methods of stabilization of the urban pits" by Mahmoudi et al., (2008) could be addressed.

According to the problems in the excavation of urban areas, it could be stated that one of the most important scientific and technical activities related to the pit stabilization is the comparative study and selection of one proper method for safety and stability of the pit wall. This is performed by investigation of the specific condition of each project, each possible stabilization methods, and selection of the optimum method. The importance of this research is the comparison of various pit stabilization methods in each specified project and selection of the proper method for soil stabilization. The aim of this research was to study the effect of utilization of combined systems of nail, anchor and pile on the amount of displacement and safety factor of deep and semi-deep pits stability, using the numerical methods and modeling in the PLAXIS software and finding the best technical condition for stabilization of each pit according to the pit depth.

This research has been prepared in four sections that in the first section, general terms are provided, in the second section the research methodology is provided. Regarding the third section of the research, the outputs and the analysis of the findings is carried out and the fourth section includes the conclusion.

Research Methodology

In this research, the effect of utilization of combined systems of the nail, anchor and pile on the amount of displacement and safety factor of deep and semi-deep pits stability have been modeled and studied using the numerical methods and PLAXIS software.

After determination of the soil parameters according to the available projects and selecting three depths for modeling i.e. shallow with the depth of 10 m, semi-deep with the depth of 20 m and deep with the depth of 30 m, and using the valid standards of design and analysis of nail, anchor and pile systems, the stabilized soil pits with various stabilization methods were precisely modeled using the software. Moreover, the most proper combined reinforcing system for each excavation depth was extracted according to the technical results.

In other words, for each studied depth, according to the utilized reinforcing system, the stability safety factor and displacement of the pit wall was extracted from the PLAXIS software. After that, according to the results of the safety factor and existing displacement in each model and used combined system, a system with proper technical performance and considering unreasonable not-being heavy, the stabilization system of each model was extracted and proposed. In these studies, the related valid regulation has been considered.

Table 1: The specifications of the pit wall

The equivalent load of the surcharge loading (kPa)	Existing surcharge loading	Trench depth (m)
10	Street	10
10	Street	20
10	Street	30

Table 2: The specification of the project soil

Elastic modulus (kPa)	Friction angle (Degrees)	Adhesion (kPa)	Specific weight (kN/m^3)
50000	36	15	21

Table 3: The specification of the used reinforcing elements

Element type	Bending strength	Axial strength (kN)
Pile: 2IPB270	1340000	5240000
Pile: 2IPB200	789000	3120000
Anchor: Strand 3	-	84000
Anchor: Strand 5	-	140000
Nail: T32	-	160000
Wall: Shutcerete 10 cm	1950	2339280

Table 4: The details of the specification of the used reinforcing elements

Reinforcement	Cross section (mm^2)	Yield strength (kN)	The amount of allowable pre-stressing (kN)	Grouting pressure during implementation (bar)
Three strings anchor strands	420	782	469	2.5
Five strings anchor strands	700	1304	782	2.5
Nail and Monobar 32	800	320	192	1.5

Findings

The investigation of the horizontal and vertical displacements and stability safety factor of the 10 m wall reinforced with nailing:

The output image of the software could be observed in the following:

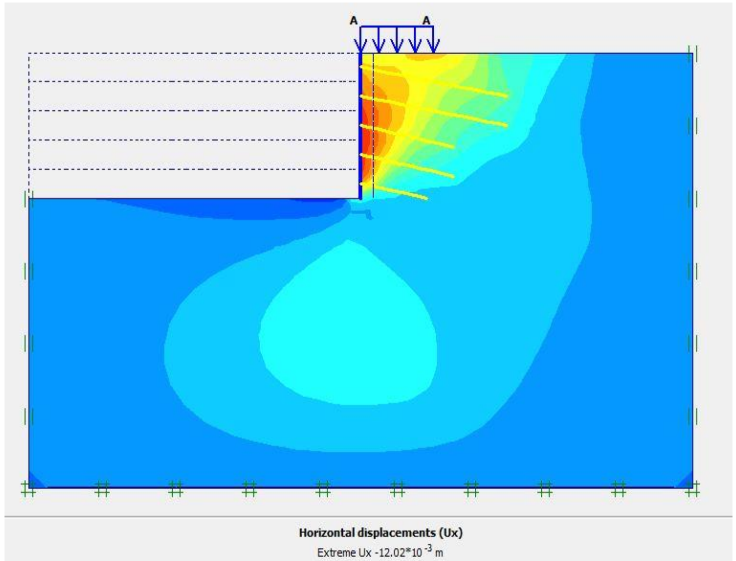

Figure 1: Results of the displacement of the model developed with piling

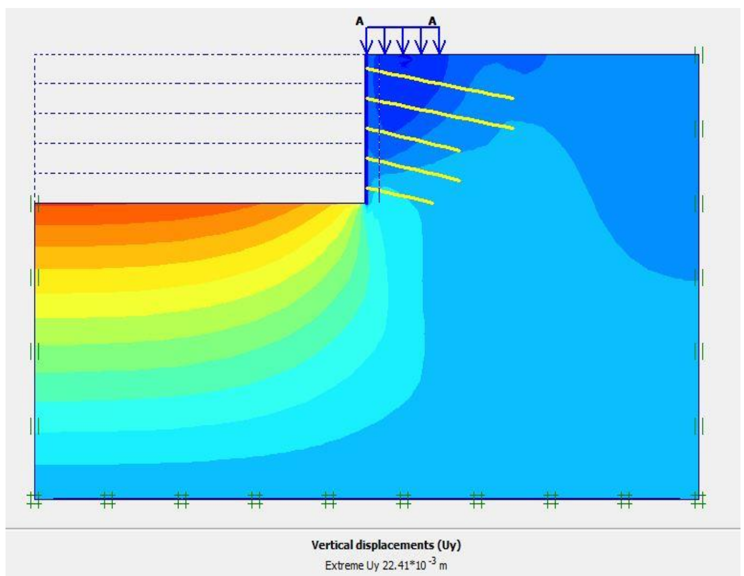

Figure 2: Results of the displacement of the model developed with piling

As could be seen in the software output images, the amount of horizontal displacement of the reinforced wall with nail and shotcreting wall was equal to 12 mm that was in the allowable range of the regulation. Also, the amount of vertical displacement of the wall was about 2 mm indicating that this displacement was in the allowable range stated by the regulation. The amount of tucking of the pit floor was about 22 mm that didn`t have any effect on the wall stability.

According to the FHWA regulation, the amount of allowable horizontal and vertical displacement of the pit wall was calculated to be about 20 mm. According to the mentioned amount, this amount had relative consistency with the calculated amount by the software (12 mm). Therefore, the amount of the wall displacement was in the allowable range. The safety factor obtained for the 10 m wall stabilized with nailing and shotcreting was equal to 2 that according to the regulation was in the allowable range.

The investigation of the horizontal and vertical displacement and stability safety factor of the 20 m wall reinforced with nailing:

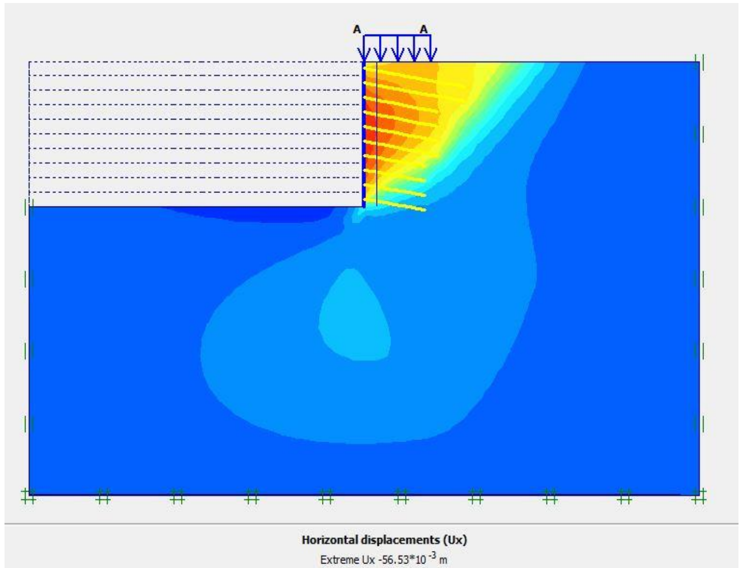

Figure 3: Results of the displacement of the model developed with piling

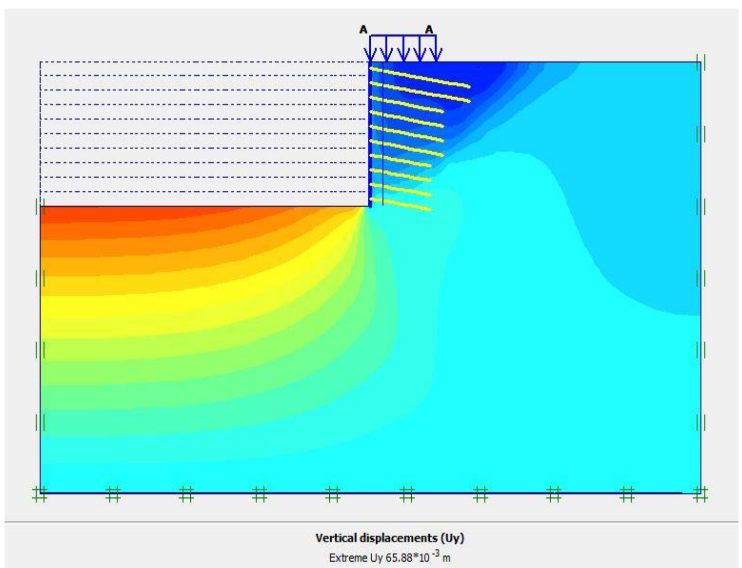

Figure 4: Results of the displacement of the model developed with piling

As could be seen in the output image of the software, the amount of horizontal displacement of the reinforced wall with nail and shotcrete wall was equal to 57 mm that was out of the allowable range of the regulation and this reinforcing system was not acceptable. Also, the amount of the vertical displacement of the wall was equal to 11 mm, which was in the allowable range of the regulation.
The amount of the horizontal and vertical allowable displacement of the pit walls in the condition of the rotation of the adjacent structure foundation was calculated to be about 40 mm. According to the mentioned amount, this amount didn`t have consistency with the displacement calculated by the software (57 mm), so the displacement of the pit wall was not in the allowable range of the

regulation. The amount of the obtained safety factor for the 10 m stabilized wall with nailing and shotcrete wall was equal to 1.78 mm that according to the regulation was in the allowable range.
According to the amounts and mentioned results, due to incompatibility of the horizontal displacement of the wall by the allowable amounts of the FHWA regulation, the reinforcement of the 20 m wall with the nailing system was not acceptable.

The investigation of the horizontal and vertical displacement and stability safety factor of the 20 m wall reinforced with nail and anchor:

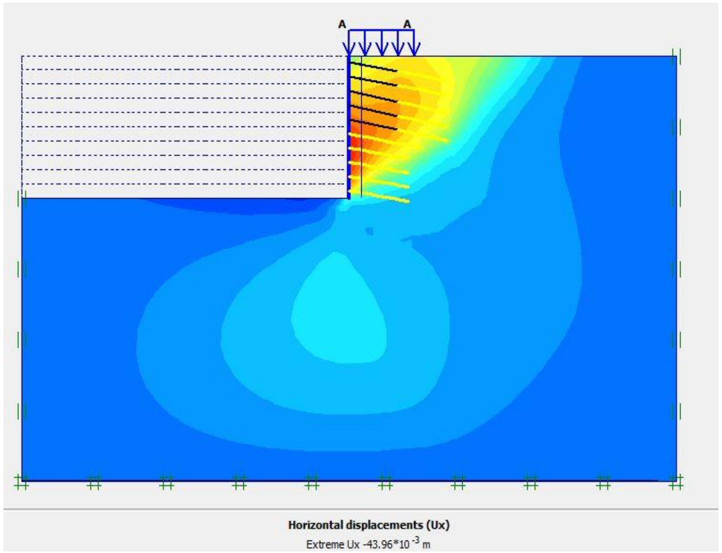

Figure 5: Results of the displacement of the model developed with piling

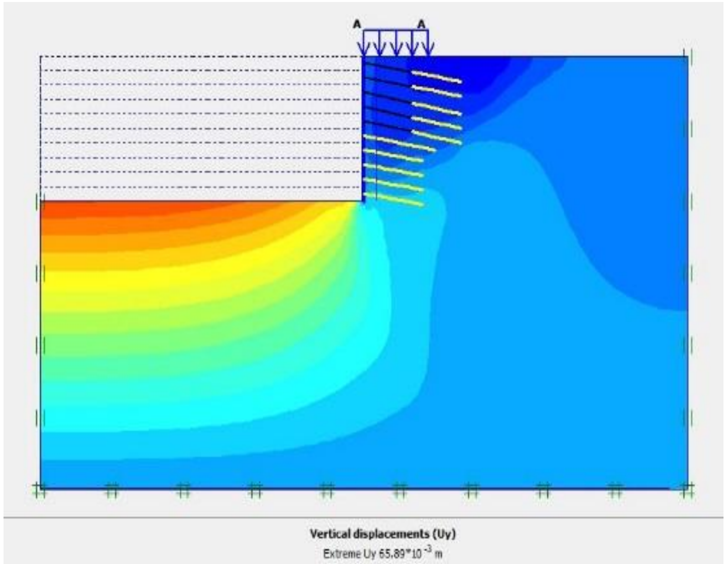

Figure 6: Results of the displacement of the model developed with piling

As could be seen in the output image of the software, the amount of horizontal displacement of the reinforced wall with nail and anchor and shotcrete wall was equal to 44 mm that was more than the allowable range of the regulation and this reinforcing system was not acceptable.
Also, the amount of the vertical displacement of the wall was equal to 5 mm that this displacement was in the allowable range of the regulation. The amount of the horizontal and vertical allowable

displacement of the pit walls was calculated to be about 40 mm. According to the mentioned amount, this amount didn`t have consistency with the displacement calculated by the software (44 mm), so the displacement of the pit wall was not in the allowable range of the regulation.
Although, by utilization of the anchoring system and due to the application of the pre-stressing forces of the anchor to the wall, the horizontal displacement of the wall showed a significant decrease compared to the reinforced with nail condition. In other words, the utilization of the anchorage, despite the high costs of the implementation, resulted in the increase of stabilization system safety.

The investigation of the horizontal and vertical displacement and stability safety factor of the 20 m wall reinforced with nail, anchor and pile:

The output of the software is shown in the following:

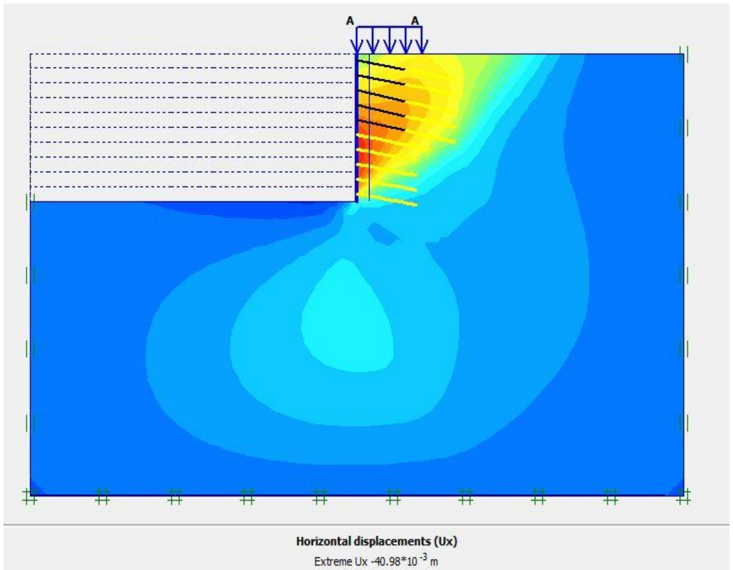

Figure 7: Results of the displacement of the model developed with piling

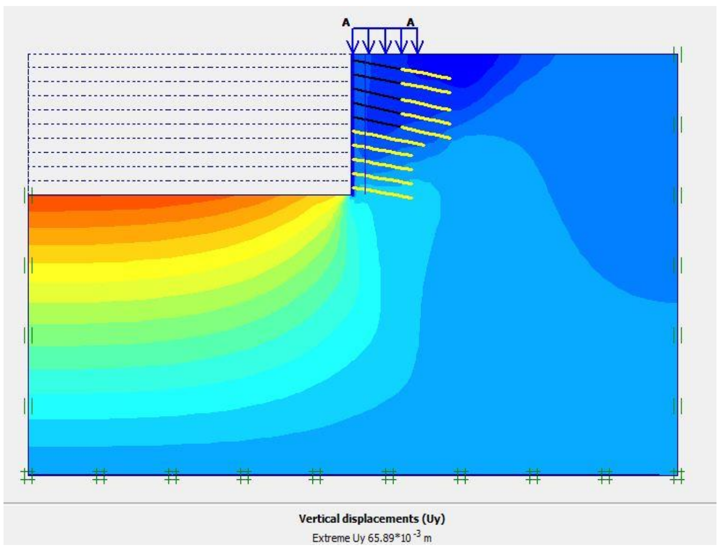

Figure 8: Results of the displacement of the model developed with piling

As could be seen in the software output image, the amount of horizontal displacement of the wall reinforced with nail, anchor and pile and shotcrete wall was about 40 mm that was in the allowable range of the regulation.

Also, the vertical displacement of the wall was about 4 mm that this displacement was also in the allowable range of the regulation.

The obtained safety factor for the 10 m wall stabilized with nailing and shotcrete wall was equal to 2.1 that according to the amounts in the regulation was in the allowable range.

The investigation of the horizontal and vertical displacement and stability safety factor of the 30 m wall reinforced with nail, anchor and pile with medium strength:

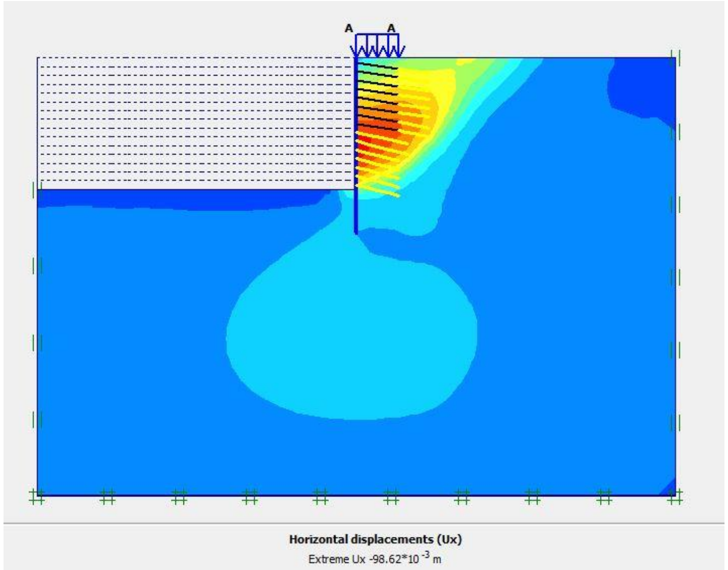

Figure 9: Results of the displacement of the model developed with piling

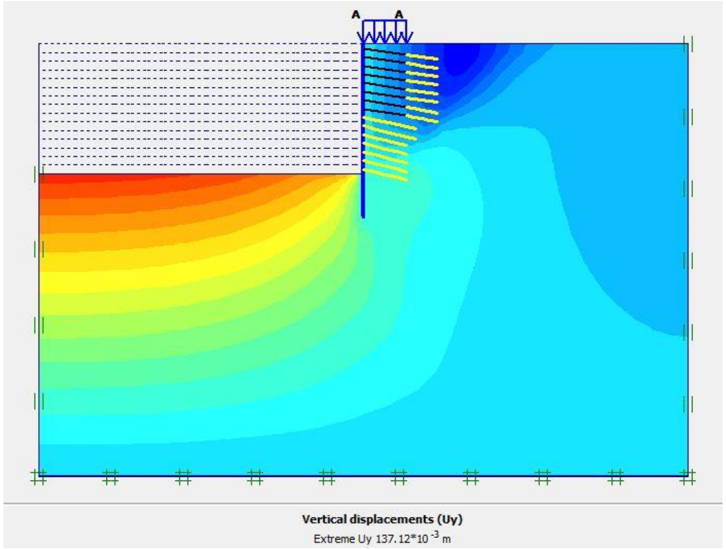

Figure 10: Results of the displacement of the model developed with piling

As could be seen in the software output images, the amount of the horizontal displacement of the wall reinforced with strand, nail and pile and shotcrete wall was equal to 98.6 mm that was higher than the allowable range and was not in the allowable range of the regulation.
Also, the vertical displacement of the wall was about 26 mm that this displacement was in the allowable range of the regulation.

The investigation of the horizontal and vertical displacement and stability safety factor of the 30 m wall reinforced with strand and pile with medium strength:

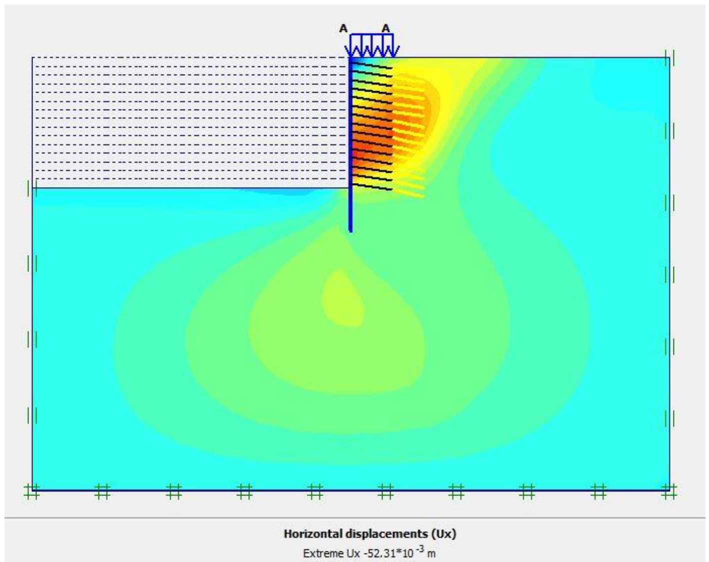

Figure 11: Results of the displacement of the model developed with piling

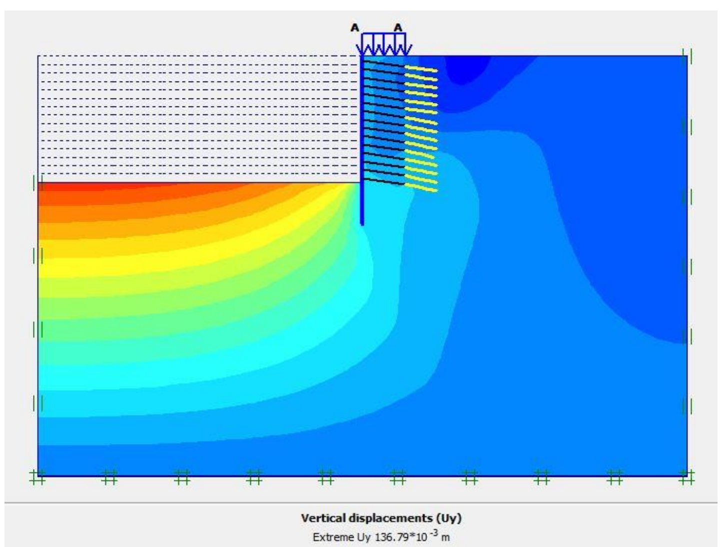

Figure 12: Results of the displacement of the model developed with piling

As could be seen in the software output image, the amount of horizontal displacement of the wall reinforced with strand and medium pile and shotcreting wall was equal to 52.3 mm that was in the allowable range of the regulation and this reinforcing system was acceptable for this wall.

Also, the vertical displacement of the wall was about 28 mm that this displacement was also in the allowable range of the regulation. According to the amounts and mentioned results, the utilization of this reinforcing system, due to all the results being in the allowable range, was acceptable.

The investigation of the horizontal and vertical displacement and stability safety factor of the 30 m wall reinforced with nail, anchor and pile with high strength:

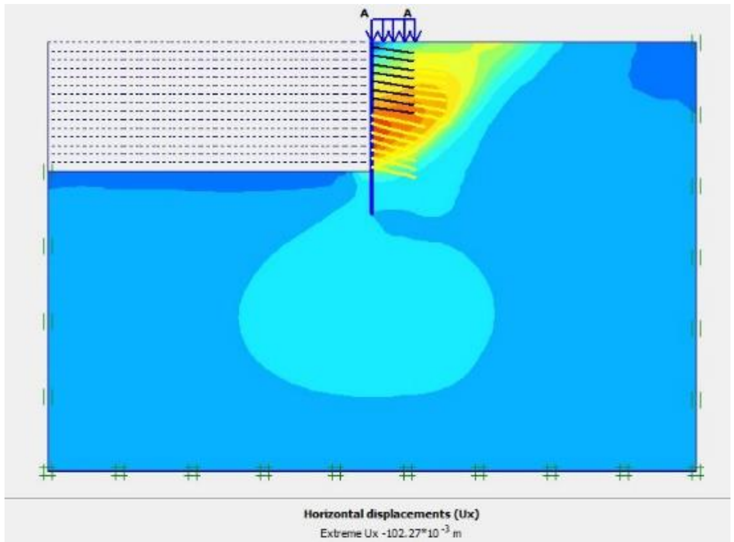

Figure 13: Results of the displacement of the model developed with piling

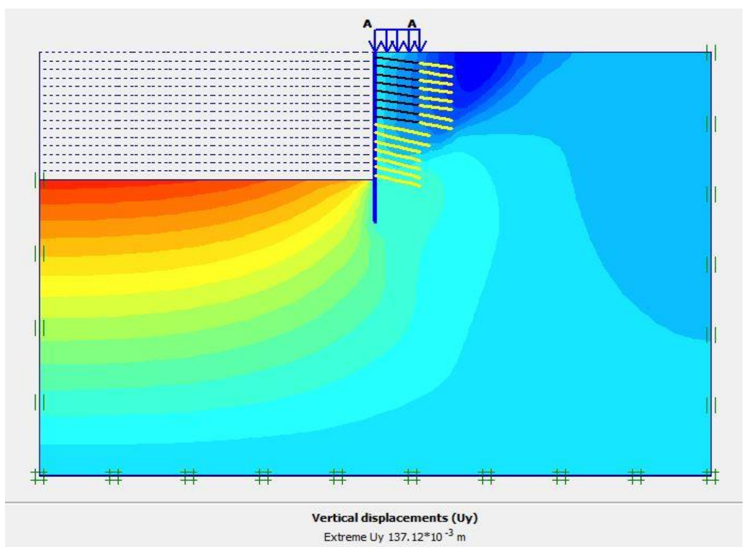

Figure 14: Results of the displacement of the model developed with piling

As could be seen in the software output images, the amount of the horizontal displacement of the wall reinforced with strand, nail and strong pile and shotcrete wall was equal to 102 mm that was higher than the allowable range thus was not in the allowable range of the regulation.

Also, the vertical displacement of the wall was about 25 mm that this displacement was in the allowable range of the regulation.

It could be seen that in the fixed nail and anchor condition, the change of the pile from 2IPE200 to 2IPE270 didn`t have any effects on the displacement of the wall. The obtained safety factor for the

30 m wall stabilized using nailing and shotcrete wall was equal to 1.7 that according to the regulation was in the allowable range.

The investigation of the horizontal and vertical displacement and stability safety factor of the 30 m wall reinforced with anchor and pile with high strength:

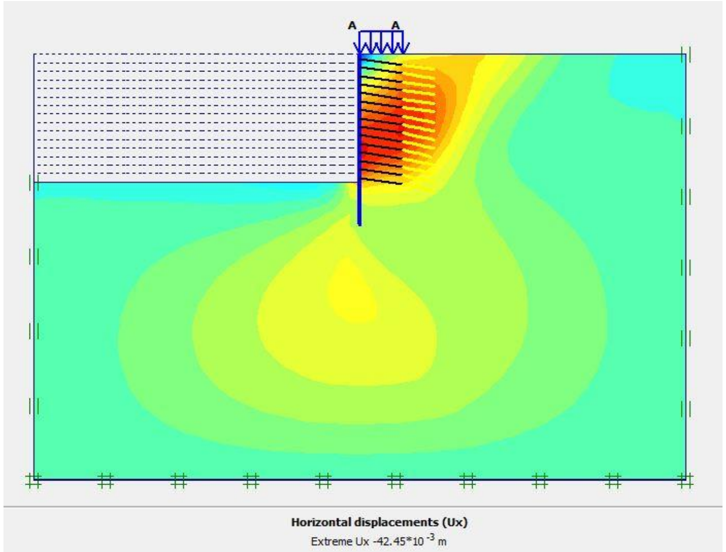

Figure 15: Results of the displacement of the model developed with piling

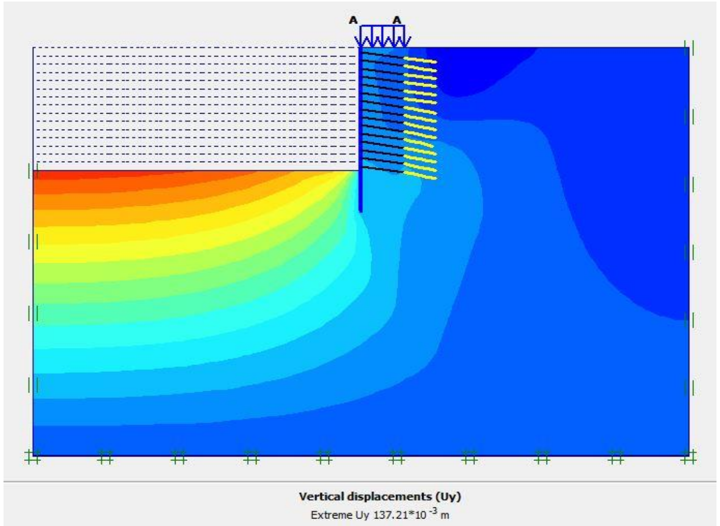

Figure 16: Results of the displacement of the model developed with piling

As could be seen in the software output image, the amount of the horizontal displacement of the wall reinforced with strand and medium pile and shotcrete wall was equal to 42.5 mm that was in the allowable range of the regulation and this reinforcing system was acceptable for this wall.

Also, the amount of the vertical displacement of the wall was equal to 25 mm that this displacement was also in the allowable range of the regulation. The obtained safety factor for the 30 m wall stabilized with nailing and shotcrete wall was equal to 1.851 that according to the regulation was in the allowable range.

Conclusion

According to the obtained results from the software and mentioned numbers, the amount of displacement of the critical pit wall according to the reinforcing system could be observed in Table (5):

Table 5: The results of the displacement and safety factor of the wall with various utilized reinforcing system

The wall depth	Reinforcement type	Stability safety factor	The maximum horizontal displacement of the wall
10 m	Nail 32	2.01	12 mm
20 m	Nail 32	1.78	56.5 mm
20 m	5*Anchor 32 5*Nail 32	1.86	44 mm
20 m	2IPB200@3m 5*Anchor 32 5*Nail 32	2.1	40 mm
30 m	2IPB200@3m 8*Strand 3 7*Nail 32	1.6	98.6 mm
30 m	2IPB200@3m 8*Strand 5 7*Strand 3	1.84	52.3 mm
30 m	2IPB270@3m 8*Strand 3 7*Nail 32	1.7	102 mm
30 m	2IPB270@3m 8*Strand 5 7*Strand 3	1.86	42 mm

In Figure (17), the graph of the displacement of the 20 m wall with three different reinforcement types could be observed:

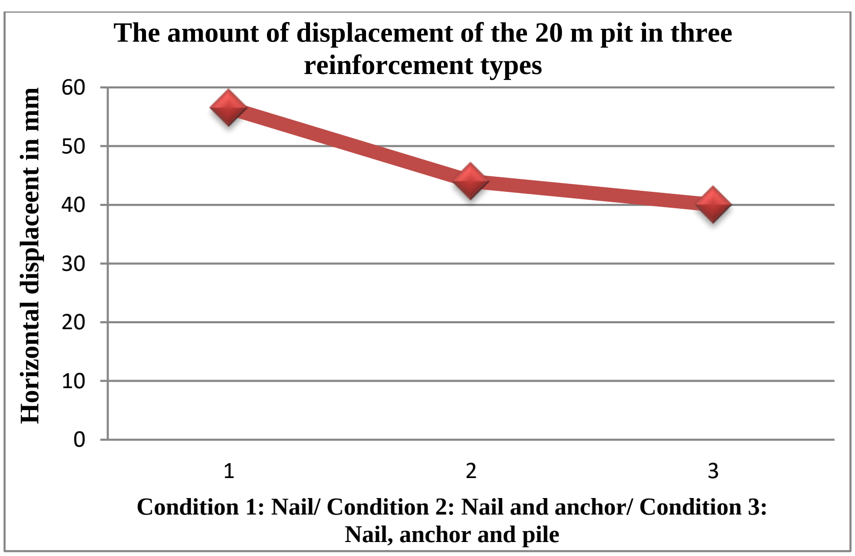

Figure 17: The comparison of the wall displacement with various reinforcement systems

The maximum displacement of the wall in the condition that the stabilization was performed by nailing could be seen in the above diagram. Nailing, due to its non-stimulating performance and its forces` dependence to the primary displacement of the soil results in the maximum displacement. Although in case placing the displacement amount in the allowable range, like the 10 m studied pit in the previous section, its utilization would have no problem.
The utilization of the pre-stressed anchor system resulted in the displacement amount decrease that this could be due to the performance of the anchor element driver. The maximum displacement control amount would be the time the piling element is added to the anchor driver system. The simultaneous bending strength and the axial pre-stressing system would result in the decrease of the wall displacement. These points are clearly observable in the above diagram.
Also, in Figure (18), the graph of the displacement of the 30 m wall with four different reinforcement types could be observed:

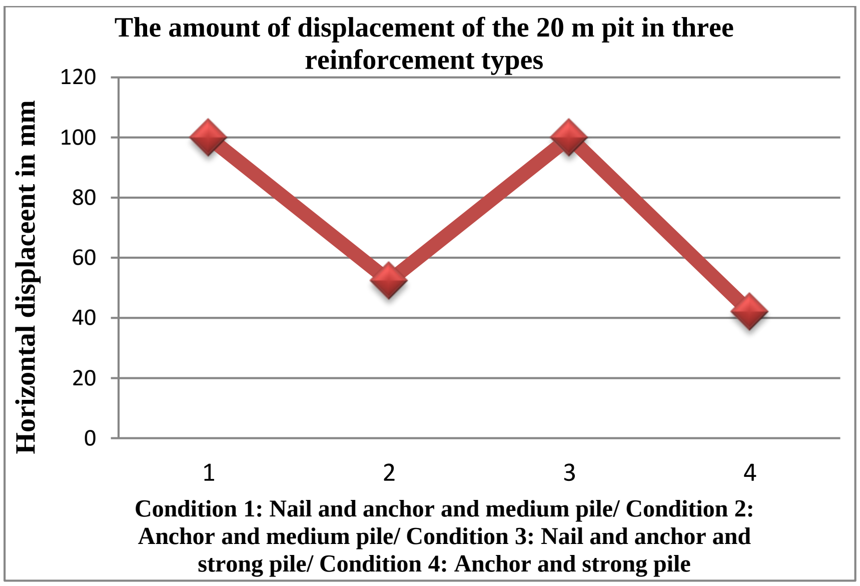

Figure 18: The comparison of the wall displacement with a combined system of pile and anchor

By studying the above diagram, it could be observed that in the deep pits, the utilization of the mail, even with the anchor, resulted in the horizontal wall displacement increase and the aggregation of the horizontal stresses and insufficiency of the produced forces in the nails in deep trenches caused the lack of required stability.
In these conditions, even reinforcing the pile profile cross-section could not be a good help for the decrease of the displacement amount. Because due to the non-stimulating performance of the nail and the nail forces reaching to the maximum allowable amount, the increase in the pile cross section caused the wall to get heavier and the impossibility of higher loading of the nails and the displacement would be constant or even might increase a little.
However, when the anchor element (strand) was used, due to the anchors` driving function in decreasing the displacement amount, the horizontal displacement of the wall was decreased drastically. In other words, the effect of pre-stressing of the elements was very higher than the effect of the increase of pile cross section. It is obvious that in case of utilization of the anchor pre-stressed elements, the increase of the pile cross section could help the wall displacement and the wall displacement could be decreased with the increase of the pile cross section.

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