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Investigating the Effect of Wide Surcharge and Inclination Angle of Nails in Excavation (A Case Study: Central District of Isfahan City)

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Abstract

Maintenance of excavation, especially in urban areas, is essential and crucial in order to avoid risks resulted from the excavation on the adjacent buildings. So, this study tries firstly to investigate various methods used to maintain and stabilize the excavations, then deals with the factors affecting the stability of excavations trussed by nailing system. Applying the existed numerical methods, the study performs a modelling of excavation behaviours in the central district of Isfahan city, and then a comprehensive analysis of such structures' performance. Thus, the factors influencing the excavation are studied, gathering the data related to geo-technique studies on the central district of Isfahan city. The various factors such as inclination angle of nails, wide surcharge over the excavation are studied more exactly by performing the reliability coefficient analysis on extended models of excavations.

Key words: Trussed excavation, Nailing system, EEM, Reliability, Wide surcharge

1 Introduction

In most of masonry projects, it is necessary to excavate the land before implementing the main structure. Conservation systems for excavation are usually retaining (support) structures providing the vertical or nearly vertical excavations. Because of the limitation of land dimensions in urban areas, most of excavations are implemented vertically and more often the stable slope is not considered for excavation walls. Although inclined excavations are possible in suburbs or outskirts of a city, however the vertical excavation encounters the problem of the walls' stability. So, it is necessary to consider some strategies to prevent the walls from being collapsed, such considerations are called the retaining (support) structures. This study aims to evaluate the behavior and performance of such structures affected by various parameters, using the case studies of excavations implemented in the central district of Isfahan city. To do that, it is offered firstly a summery of various methods applied to stabilize the excavations, and finally the effective factors, such as the inclination angle of nail to the horizon and the increase in the mat surcharge over excavation, on the stability of excavated structures retained by the nailing system. To do that, it is evaluated suitably the stratification of soil in the studying district, using the geo-technical studies. A set of analyses can be achieved by determining the profiles of the soil in the district, applying two dimensional models by the software Plaxis2D. Using the finite element method, these analyses are performed to evaluate the factors affecting the excavation performances. The results from the numerical analyses and the corresponding field (desert) measures are indicating the fairly accepted compatibility between them. Being assured of the accuracy of the models' performance, it is considered the impact of other factors, such as inclination angle of nails, mat surcharge over excavation.

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2 Geo-Technical Properties of the Soil in the Region (Central District of Isfahan City)

It is essential to gain access to the geo-technical data and properties of the local soil in order to study precisely the performance of excavations reinforced by nailing system in the central district of Isfahan city. Studying the present geo-technical report on the local soil, the data was evaluated and based on such data and using the software methods (Rockwork) and statistical techniques, it was achieved a proper stratification profile of the local soil. In the geo-technical process, subsurface off-takes were performed by drilling several machined boreholes in determined places in concordance with the project employer. The depth of boreholes is approximately 30 meters, and considering the high number of boreholes in this region, the depth of boreholes altogether was 630 meters. It could be achieved a three-dimensional representation from the soil layers in the considered route, using both geo-statistical techniques and the geo-technical data related to the drilled boreholes in the square Imam Ali and its surrounding streets. It was applied some kind of geo-statistical technique (KRIGING). The various profiles were determined in different places to specify the soil layers. Finally, the data needed for soil layers were obtained and summarized in table (1), using proper geo-technical profile.

Table 1: Geo-technical properties of the soil from the studied district

Coarse soil layer	Fine soil layer	parameters
$2.5\times10^4\ kPa$	$2\times10^4\ kPa$	E (kPa)
0.3	0.4	υ
0	11 kPa	C (kPa)
33^o	23^o	φ
0	0	ψ
18.2	18.2	γ_{wet}

Table 2: Parameters of utilized nail and concrete

Nails		Concrete	
EA (kN/m/m)	138×10^5	EA (kN/m/m)	2×10^6
EI (kN/m^2/m)	7.29	EI (kN/m^2/m)	1067
w (kN/m/m)	0.072	w (kN/m/m)	1.96
ν	0.15	ν	0.2
M_p (kN/m/m)	1.710	M_p (kN/m/m)	-
N_p (kN/m)	277	N_p (kN/m)	-

3 Geometric Properties of Excavation and Elements Used in Trussing a Nailed Excavation

The purpose of the present study is to investigate the various factors affecting the stability of the walls, studying the wall behaviours of excavation in the central district of Isfahan city. So, the walls of excavations in the districts were investigated, using the data on geo-technique properties from the central district of Isfahan city and numerical methods from modelling the soil of the considered region. Since the models analyses are of parametric ones, one of the present parameters in soil, nails, or model geometry in each part of the studies will be in certain and defined range. Thus, the effect of such changes on the stability of excavations trussed by nailing is investigated. Also, the amount of tensile forces in nails, which is of important factors in such excavations, is considered in studying the static behaviour of structures. The effect of surcharge is considered as a parameter affecting the tensile forces in nails and their inclination angle. In the studies, the slope angle of excavation is perpendicular toward the horizon. The excavation and then the nailing processes are performed in six stages. In other words, to model an excavation and then trussing with nailing system, an elevation of six meters is excavated in six steps, and in software modelling, elimination of soil elements are performed in six one-meter steps in each stage.

4 Allowable Depth and Slop of Excavation

Before initiating the excavation process, it should be assured that the depth of excavation would be so that the relative stability of the soil mass of the excavation wall is warranted. Accordingly, it is essential to evaluate the allowable depth of excavation without the needed reinforcing system, considering the type of local soil, the width of excavation, and the relevant methods. Thus, this paper investigates a case study on the stability of an implemented excavation in the square Imam Ali in order to determine the allowable depth and slop of excavation, considering geo-technical properties of the local soil. Considering the geo-technical data from the soil, there are various methods such as Limit Equilibrium, which are used to determine the allowable slope of excavation, as well as so-called numerical methods to find out the reliability coefficient for the stability of slops. To analyse the stability, the software Mathematica was used by the limit equilibrium method. In such application, limit equilibrium equations related to the given rupture wedge were written by programming language, and also, based on the equilibrium of forces on the wedge, the reliability coefficient was achieved for the stability of excavation slop. Several models were created for some excavations by the software PLAXIS3D- Tunnel and the reliability coefficient was calculated for the stability of different widths of excavations. It is necessary to state that it was modelled two different widths of excavations to investigate the effect of sensitivity of the excavation width on the results from the reliability coefficient for the stability of excavation.

5 Parametric Analyses

5.1 General steps in creating analytic models in PLAXIS software

A primary sketch is needed to be drawn of the excavations retained by the nailing system before modeling, which is performed through the common limit equilibrium methods.

Regarding the general stability of the excavation wall, the sliding soil mass is assumed as solid block on which the forces and anchors should be equilibrated, according to the principles of limit equilibrium (two-dimensional) methods. The forces and anchors exerted on the soil mass are calculated, considering the soil properties (including internal friction angle, specific gravity, and soil viscosity), the nail properties (including rupture force and nail dimensions), and the excavation dimensions (excavation elevation). Thus, the stability of the excavation walls is investigated in order the resulted reliability coefficient to be approached to the critical amount, considering the desirable different rupture levels. Then, regarding the conditions of load transition from the soil mass supported by nailing system, the length needed for the nails is calculated and their dimensions are studied. Also it is assumed that the present stresses (tensions) are created because of the weight of soil mass supported by nailing system and there is no surcharge over excavation.

5.2 Effect of inclination angle of nails

In order to perceive the excavations supported by nailing system more precisely, here is examined the effect of inclination angle of nails on the performance of a nailing-supported excavation in the central district of Isfahan city. So, a series of finite element analyses are conducted on some of excavation walls reinforced by the nails in order to study the effect of the inclination angle of nails to the horizon and the general stability of the excavation reinforced walls. The other geometric properties of the excavations reinforced by nailing system including the inclination angle of excavations' slope and also, the length of nails are assumed invariable in such examinations. Considering the fact that the axial performance of nails is always very determining in stabilizing the excavations, so it is applied only the nails sustaining the axial forces in such examinations. Thus, these elements have only the normal (axial) solidity, with no considerable bending solidity; as a result, they wouldn't tolerate any bending movement and shear forces.

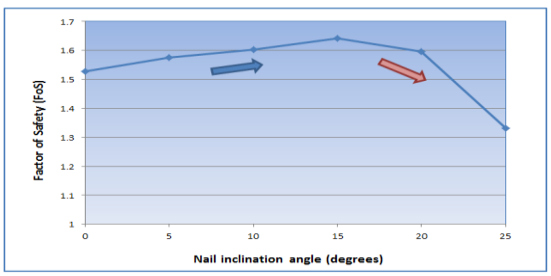


Fig. 1) The effect of the inclination angle of nails to horizon on the stability of excavation walls reinforced by nailing system

As shown in the figure (1), the reliability coefficient of reinforced excavation is increasing by the increase in the inclination angle of nails to horizon from 5○ to 15○, but the decreasing trend is initiating by passing the optimized inclination angle, i.e. the inclination angle between 15○ to 20○. According to such observations and analyses, it can be concluded that the inclination angle between 15○ to 20○ would be the best inclination angle for the nail to possess the maximum stability.

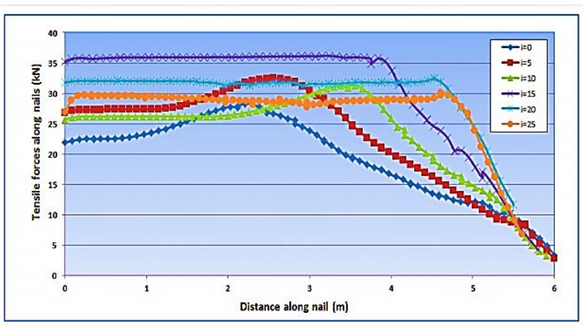


Fig. 2) Distribution of tensile forces extending in the first nails row for the different inclination angles of nails to the horizon.

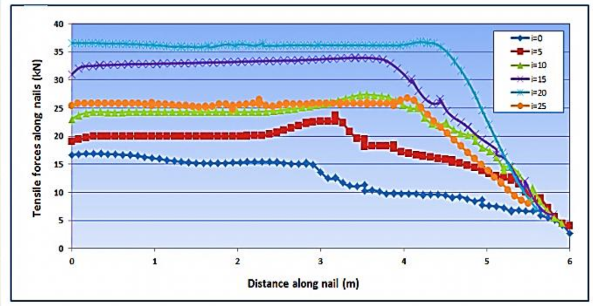


Fig. 3) Distribution of tensile forces extending in the second nails row for the different inclination angles of nails to the horizon.

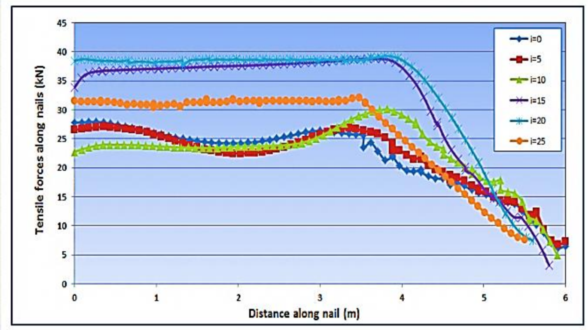


Fig. 4) Distribution of tensile forces extending in the third nails row for the different inclination angles of nails to the horizon.

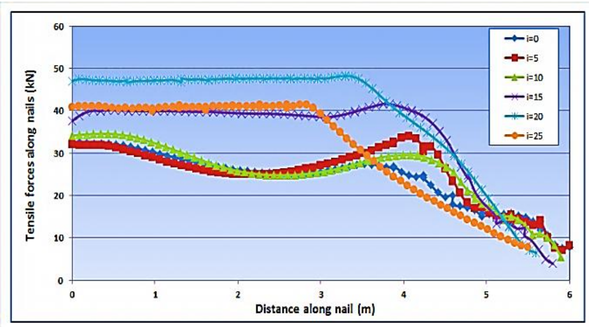


Fig. 5) Distribution of tensile forces extending in the fourth nails row for the different inclination angles of nails to the horizon.

According to the figures 2 to 7, it is seen that the tensile forces extended in the nails are increased to the optimized level by increasing the inclination angle of nails to the horizon, and then they will decrease, passing the optimized level. According to such fluctuation in the tensile forces extended in the nails, it is justified the increase and decrease in the stability of the reinforced excavation wall.

On the horizontal displacement of the excavation mask Figure 8 shows the changes in the maximum tensile forces in the nails in the depth of excavation to the changes in the inclination angle of nails. Figure 9 shows also the changes in the horizontal excavation mask for the different inclination angles. As shown, until when the nails serve as a factor in increasing the stability of excavation wall, the changes in the horizontal places of the mask will decrease considerably.

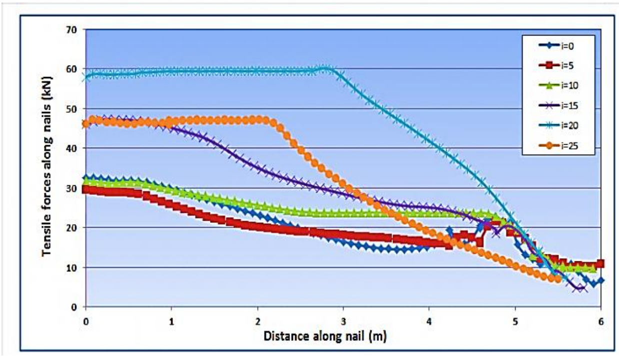


Fig. 6) Distribution of tensile forces extending in the fifth nails row for the different inclination angles of nails to the horizon.

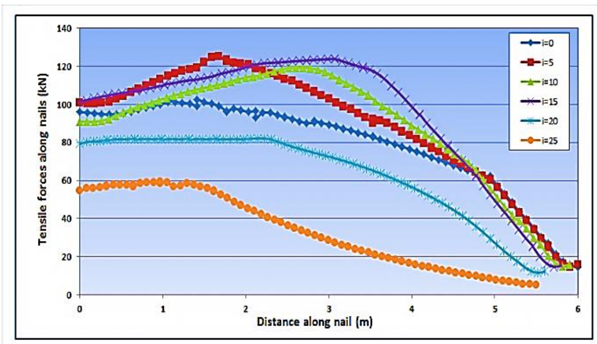


Fig. 7) Distribution of tensile forces extending in the sixth nails row for the different inclination angles of nails to the horizon.

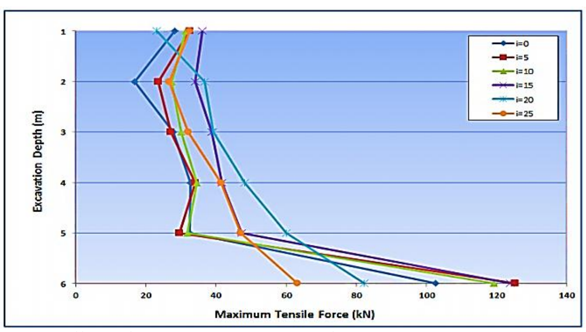


Fig. 8) Effect of the inclination angle of nails to the horizon on the maximum of tensile forces extended in the nails

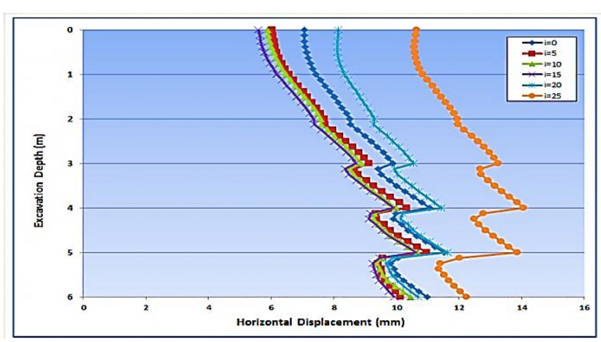
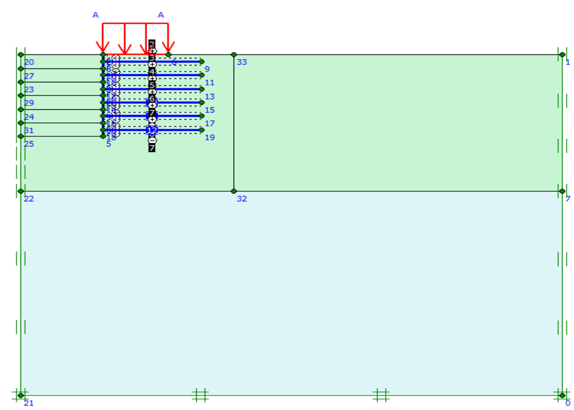


Fig. 9) Effect of the inclination angle of nails to the horizon

The decrease in the changes in horizontal places of the wall mask will continue to the optimized inclination angle, and then the stability of excavation will decrease while the inclination angle of nails increases, also the changes in horizontal places of the wall mask will increase considerably. In other words, because the nails don't serve in stabilizing and optimizing the performance of reinforced excavation wall and have insignificant effect in strengthening it, it can be seen in very sharp inclination angles of nails that the changes in horizontal places of the excavation mask will increase.

5.3 Effect of mat surcharge over excavation

In this section, the effect of mat surcharge over the excavation is investigated. If it is assumed that the weight of surface unit for a ranch house (a one-story building) is equal to 10 KN/M2, then it will be equal to 60 KN/M2 for a six story building. Considering the prevailing trend for the excavations in the urban districts, it is essential to investigate the effect of dead surcharge from the adjacent buildings on the excavation performance. Therefore, it is considered three surcharges of 20, 40, and 60 KN/M2 on the excavation performance in this study. In fig. (10), it is shown the model used to investigate the effect of mat surcharge over the excavation on its performance.


Fig, 10) Model used to investigate the effect of mat surcharge over the excavation.

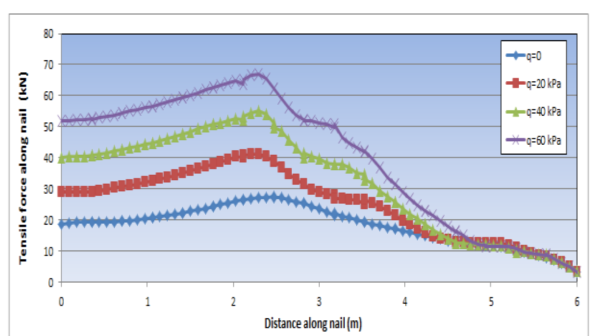


Fig. 11) Distribution of tensile forces extending in the first nails row for the different mat surcharge over the excavation.

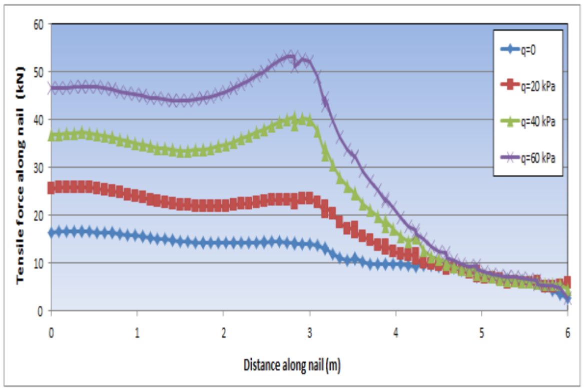


Fig. 12) Distribution of tensile forces extending in the second nails row for the different mat surcharge over the excavation.

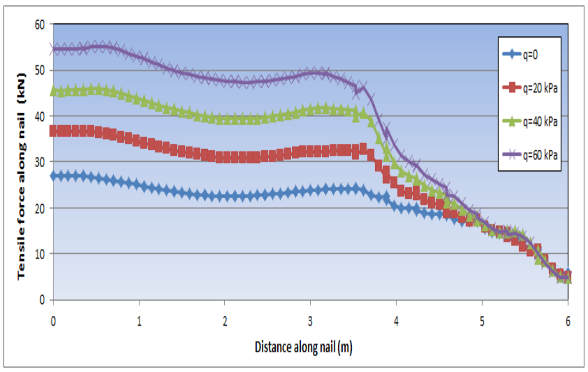


Fig. 13) Distribution of tensile forces extending in the third nails row for the different mat surcharge over the excavation.

As it is considered in the figures 11 to 16, the increase in the mat surcharge over excavation results in the tensile forces mobilized in the nails. Considering that the increase in the mat surcharge serves as a factor increasing the driving force in the rupture occurred in the soil mass, so more tensile forces are needed to overcome the shear tension (stress) developed in the soil mass. Thus increasing the mat surcharge will result in the increase in the tensile forces in the nails.

The reliability coefficient of walls is decreasing due to the increasing mat surcharge over excavation, and as it is considered, the highest reliability coefficient is related to the state where the inclination angle of nails are between 15○ to 20○. Figures 22 to 25 show the rupture surface developed in the models created with different inclination angles for nails.

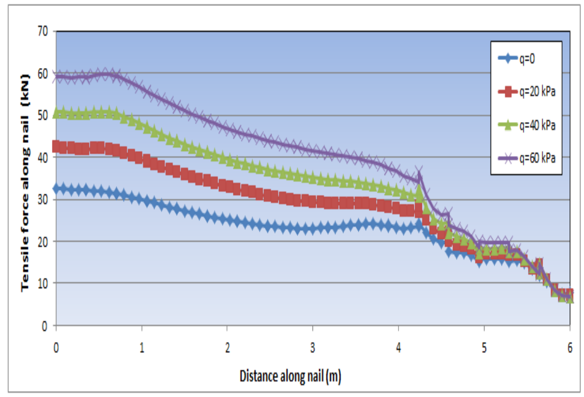


Fig. 14) Distribution of tensile forces extending in the fourth nails row for the different mat surcharge over the excavation.

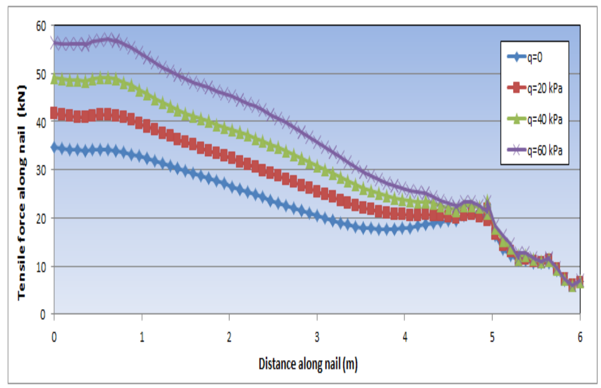


Fig. 15) Distribution of tensile forces extending in the fifth nails row for the different mat surcharge over the excavation.

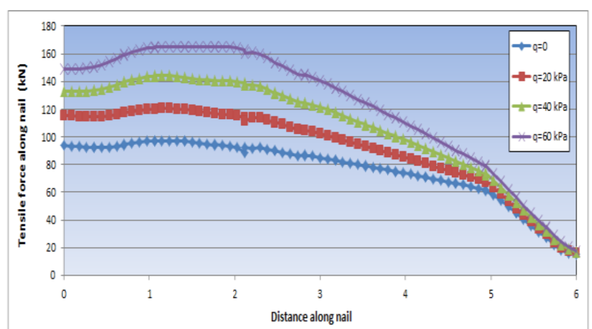


Fig. 16) Distribution of tensile forces extending in the sixth nails row for the different mat surcharge over the excavation.

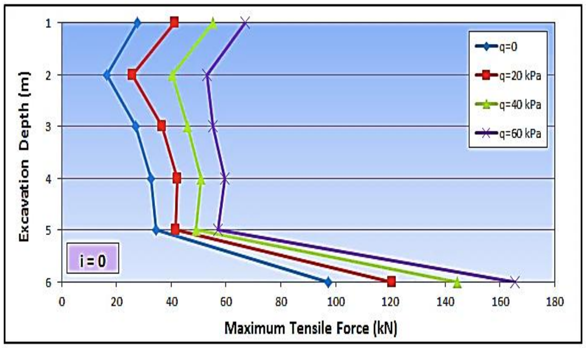


Fig. 17) Effect of the mat surcharge on the maximum of tensile forces developed in the nails with the inclination angle of zero to the horizon

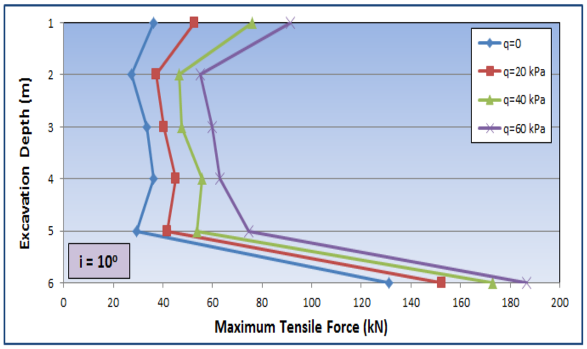


Fig. 18) Effect of the mat surcharge on the maximum of tensile forces developed in the nails with the inclination angle of ten to the horizon

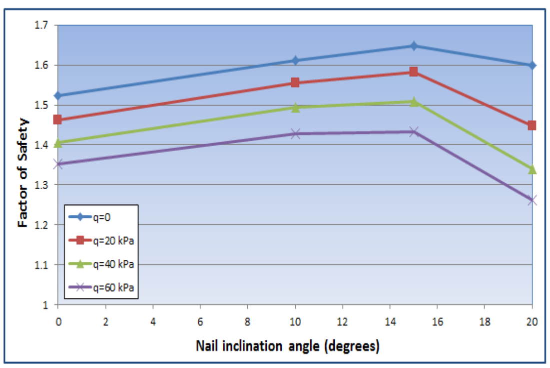


Fig. 19) Effect of the mat surcharge on the maximum of tensile forces developed in the nails with the inclination angle of 15 to the horizon

It is shown in figures 17 to 20 the effect of the mat surcharge over excavation on the maximum of tensile forces developed in the nails for different inclination angles. As it is considered, the increased surcharge over excavation will increase the tensile forces in the nails due to the increase in the inclination angle of nails to the optimized amount. The trend of the increasing tensile forces in the nails is considered till the optimized inclination angle of such excavation, i.e. an angle in the range of 15○ to 20○. After that angle, the increase in the inclination angle of nails will reduce the tensile forces.

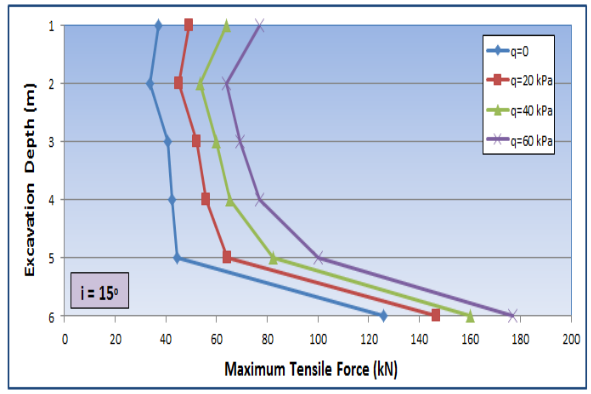


Fig. 20) Effect of the mat surcharge on the maximum of tensile forces developed in the nails with the inclination angle of 20 to the horizon

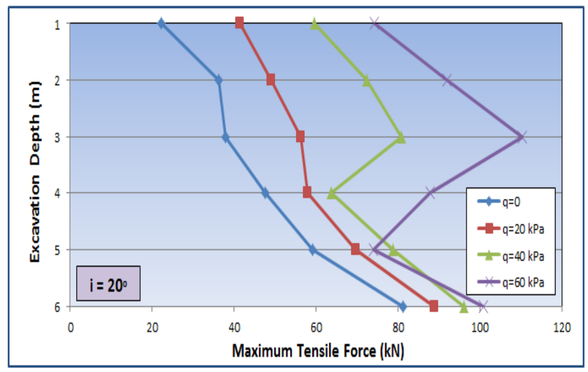


Fig. 21) Changes in the reliability coefficient of reinforced excavation to the inclination angle of nails with the increase in mat surcharge over excavation

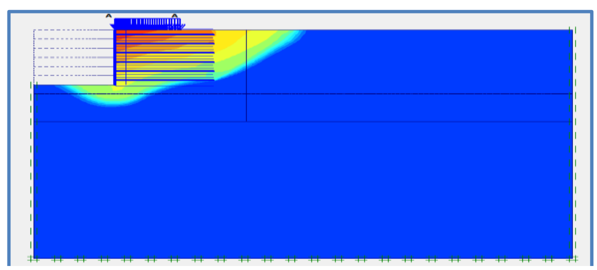


Fig. 22) Rupture surface developed in the model used in examining the effect of surcharge of 60 KN/M2 on performance of excavation reinforced by horizontal nails

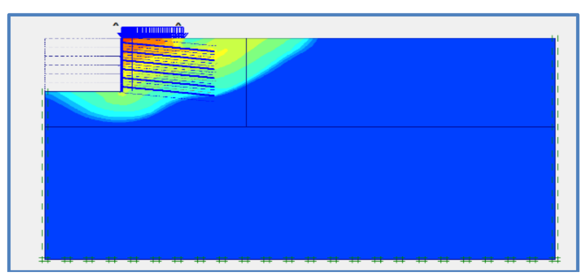


Fig. 23) Rupture surface developed in the model used in examining the effect of surcharge of 60 KN/M2 on performance of excavation reinforced by nails with inclination angle of 10°

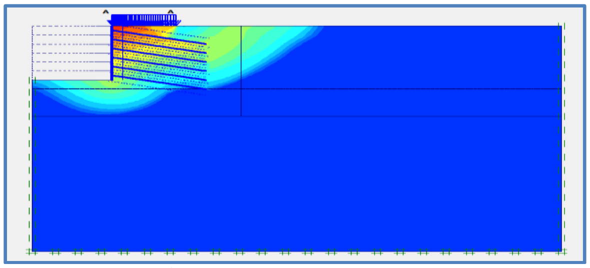


Fig. 24) Rupture surface developed in the model used in examining the effect of surcharge of 60 KN/M2 on performance of excavation reinforced by nails with inclination angle of 15°

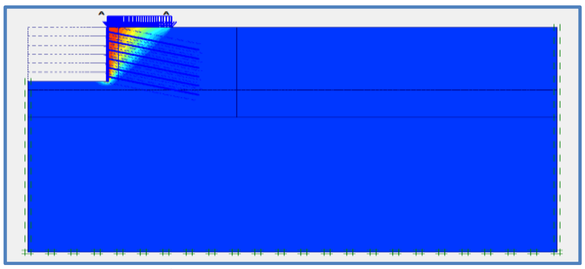


Fig. 25) Rupture surface developed in the model used in examining the effect of surcharge of 60 KN/M2 on performance of excavation reinforced by nails with inclination angle of 20°

6 Conclusions

The investigation of the inclination angle of nails concluded that by the increase in the inclination angle of nails to the horizon, the performance of reinforced excavation wall is firstly improved and its stability is increased, but passing the optimized amount, the increase in the inclination angle of nails to the horizon results the wall performance to be weakened and its stability to be reduced. In other words, by increasing the inclination angle of nails to the horizon, at first, the reliability coefficient will increase and then decrease by achieving its optimized amount. The results from the analyses showed that by increasing the inclination angle of nails to the horizon by 0○ to 15○, the reliability coefficient of the reinforced excavation walls will increase, but by passing the optimized amount, the inclination angle, i.e. the inclination angle between 15○ to 20○, the reliability coefficient of excavation is beginning to decrease.

The effect of surcharge over excavation was investigated and it was considered that the increase in the mat surcharge over excavation will increase the tensile forces mobilized in the nails. Considering the fact that the increased mat surcharge is serving as a factor increasing the driving forces for the occurrence of the rupture in the soil mass, so it is needed more tensile forces to overcome the shear tension (stress) developed in the soil mass, therefore, the increased mat surcharge will increase the tensile forces in the nails. Moreover, further investigations showed when the nails, applied to retain the excavation, are inclined relative to the horizon, they mobilize more tensile forces in them by the increased mat surcharge. The trend of increasing tensile forces in the nails was observed till the optimized inclination angle, i.e. an angle of 15○ to 20○. After that, by the increasing inclination angle of nails, the amount of tensile forces will reduce.

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