Numerical study of pile reinforced slope-A case at Khe Cham coal preparation construction site project (Vietnam)

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Abstract. Within the framework of Khe Cham coal preparation construction site project, evaluation of slope stability and solution of slope reinforcement are essential. A site investigation was performed first along a slope located in Khe Cham coal preparation construction site. The slope reinforcement was recommended due to a group of joints and cracks observed along slope surface. The main purpose of this study is to confirm the stability condition of the unreinforced slope and optimize the pile reinforcement (i.e., pile position, pile spacing). A numerical modeling software, Flac program, was used for this investigation. Soil properties using in the simulation model were obtained by the site investigation. Groundwater table, which was assumed to be in the top of the slope, was also considered in the model. The safety factor based-optimization analysis was performed with respect to pile position and pile spacing. Shear strength reduction method was established to determine the safety factor of the slope. As a result, the same conclusion as site investigation was found for the unreinforced slope, that is, the slope should be reinforced for the long-term stability. In addition, the sensitivity of the slope safety factor on pile position and pile spacing was discovered. Eventually, the optimization of pile reinforced slope was chosen and proposed based on the sensitivity of safety factor.

Keywords: Numerical study, pile reinforced slope, Khe Cham project.

1 Introduction

Khe Cham coal preparation construction site is a key ongoing project of the coal industry planning to 2020. This project has been building up for the purpose of coal preparation in Khe Cham and Cao Son areas before supplying to Mong Duong Thermo-electric Center. During the construction, evaluation of slope stability and solution of slope reinforcement are essential. With the subject of reinforcing slope, there have been a number of theories suggested for the evaluation. Among them, the limit equilibrium method (LEM), finite element method (FEM), and finite difference method (FDM) were the most widely used approaches in the literature. The advantages of using LEM are simple and easy ways for the analysis. However, the limit equilibrium method has been claimed to be inaccurate due to many assumptions. On the other

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hand, FEM and FDM are considered more accurate and over limit equilibrium methods without assumptions of shape or location of the failure surface, slice side forces and their directions.

In this study, a Finite Difference Method program, Flac 2D, was adopted to simulate the pile reinforced slope. Soil properties with the groundwater table using in the simulation model were obtained by the site investigation. A total of 16 sensitive simulation case studies were performed to determine FOSs of slope with respect to the pile positions (i.e., piles at the toe, middle, and top of slope) and pile spacing (i.e., 1 m, 2 m, 3 m, 5 m, and 8 m). The FOSs of slopes were determined based on the shear strength reduction method coupling in Flac program. Eventually, an optimization analysis for the actual slope was accomplished based on the determined FOSs.

2 Methodology

2.1 Site descriptions

The actual slope simulated in this study is located in Mong Duong, Cam Pha, Quang Ninh, Vietnam (Fig. 1). The slope was constructed as part of Khe Cham coal preparation construction site. The slope consists of thick layers (up to 30 m) of sandy soil and silty soil extending to the sandstone layer, which is beneath the surface ground of the coal preparation construction site.

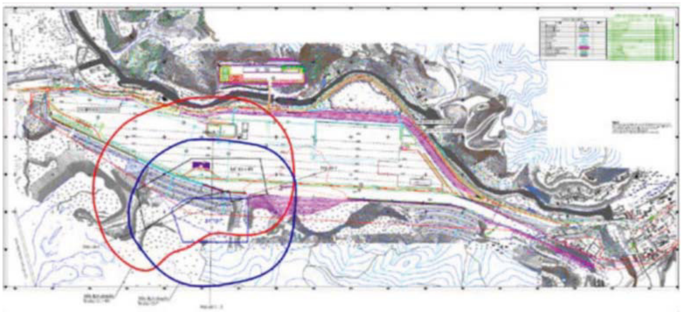

Fig. 1. Location of the actual slope (Khe Cham coal preparation construction site)

Fig. 2. Joints and cracks along the surface of the actual slope

The site investigation found some joints and cracks systems observed locally along the slope surface (Fig. 2). In this sense, the stability of the actual slope could be in doubt and the reinforcement should be executed before the further construction works of the coal preparation construction site. Based on the site investigation and slope condition (i.e., lateral movement-induce joints and cracks), the pile reinforced slope (i.e., 45 m of pile length) was recommended. The pile reinforced slope method have been widely applied for unstable slopes with lateral soil movements [1-4]. In this reinforce system, the piles are fixed firmly and deeply into bedrock or a stable layer [5].

2.2 Slope stability analysis using numerical modeling

In general, geotechnical engineers primarily conduct slope design based on the calculated factor of safety values. In this study, the shear strength reduction method was established to determine the safety factor of the slope. This method can simulate the coupled pile-slope interaction and then calculate FOSs. In this technique, cohesion (c) and internal frictional angle (ϕ) values of the slope materials are reduced until the failure occurs and with the assumption that the failure mechanism of slope is directly related to the development of shear strain. Totally, six blocks were generated for the full slope model. The toe of the grid was pinned, and its lateral boundaries were supported by rollers as shown in Fig. 3. A relatively fine mesh was applied near the slope and the mesh modeling became coarser further away from the slope. The row of piles reinforcing slope was modeled by pile elements available in Flac 2D program. The piles were all created with 10 segments per pile.

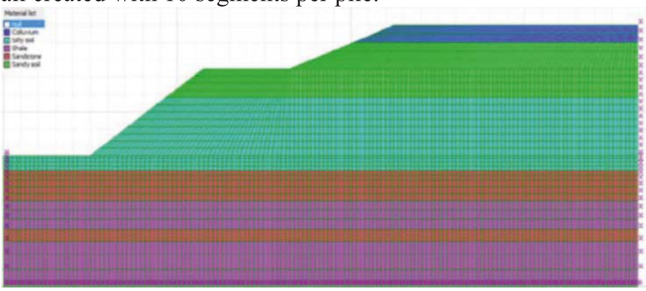

Fig. 3. Boundary condition and finite difference mesh of the actual slop

Table 1. Input parameters for numerical analysis

Parameters	Colluvium	Sandy soil	Silty soil	Sandstone	Shale	Unit
Unit weight	20	2.65	2.62	2.72	2.67	kN/m^3
Young's modulus	21.6	34	30	20000	24000	MPa
Poisson's ratio	0.26	0.25	0.26	0.25	0.22	-
Internal friction angle	30	37	28	38	40	degree
Cohesion	30	40	36.2	10000	13000	kPa

3 Results and analysis

From the computed results with Flac 2D program, The factor of safety (FOS) of the unreinforced slope was found to be 1.21, (i.e., lower than the critical FOS of 1.25, which is the FOS requirement for a safe slope as reported in TCVN [6]. In this sense, the same conclusion as site investigation was found for the unreinforced slope, that is, the slope should be reinforced for the long-term stability (i.e., pile reinforcement was recommended by the investor). The slip surface of the actual slope can be clearly seen in Fig. 4.

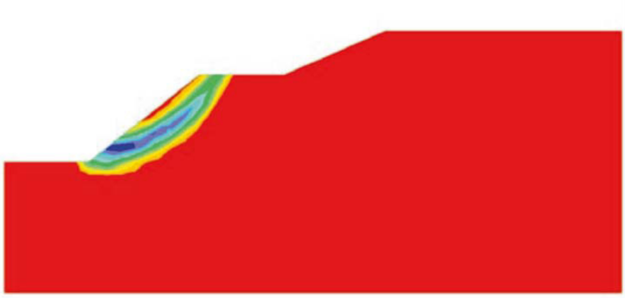

Fig. 4. Slip surface of the unreinforced slope

The further works are to optimize the pile reinforcement for the actual slope with respect to the pile positions (i.e., piles at the toe, piles at the middle, and piles at the top of slope) and pile spacing (i.e., 1 m, 2 m, 3 m, 5 m, and 8 m). The pile location plays a key role in the reinforced slope analysis. While Ito, Matsui [1], Poulos [2] recommended the piles at the middle of the slope, Lee, Hull [7], Nian, Chen [8] had a different suggestion as piles at the toe. However, the optimal pile position depends on various factors of slope such as dimension, soil profiles, and the groundwater table. Therefore, it is essential to investigate for the optimal pile position for every actual slope. The safety factor based-optimization analysis (i.e., pile position) is shown in Fig. 5. As a result, the safety factors of the actual slope were highest as the pile installs at the middle of the slope, regardless of the pile spacing. In the case of the pile installed at the upper top of the slope, the safety factor was slightly higher than that of the unreinforced slope. More interestingly, there was no change in the safety factor (i.e., same FOS as that of the unreinforced slope) in the case as piles installs at the toe of the slope. This observation can be explained by the lateral movement of piles as shown in Fig. 6. A significant horizontal sliding of the piles can be observed when piles are placed at the middle of the slope. This movement becomes smaller as piles install at the upper top and toe of the slope. Based on these findings, the suggestion was made, that is, the optimal pile position for the actual slope in this study is in the middle.

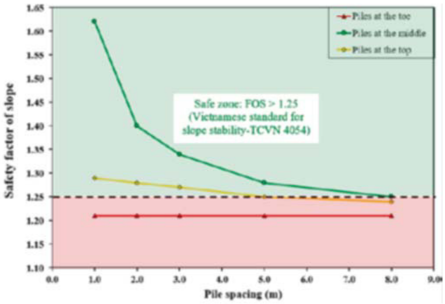

Fig. 5. The safety factor based-optimization analysis for the reinforced slope

In addition, the effect of pile spacing on the safety factor of slope was discovered in this study (Fig. 5). The safety factor decreased as the pile spacing increased (i.e., a significant decrease in the case of pile at the middle and a slight decrease in the case of pile at the upper top), except for the case pile at the toe. As to the recommended case (i.e., piles at the middle of slope), FOSs reduced from 1.62 to 1.40; 1.34; 1.28; and 1.25 as the pile spacing increased from 1 m to 2 m; 3 m; 5 m; and 8 m, respectively. It should be noted that the safety factor of the slope was higher than the critical FOS of 1.25 even in the case of 8 m pile spacing. However, the pile spacing of 5 m (i.e., FOS=1.28) was recommended for the slope in this study.

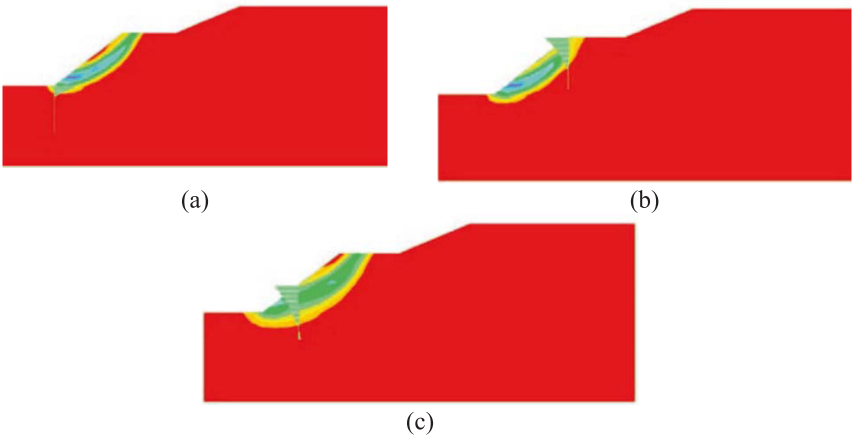

Fig. 6. Pile reinforced slope at the toe (a), upper top (b) and middle (c)

4 Conclusions

A 2D numerical study has been used to evaluate the stability condition of the unreinforced slope and optimize the pile reinforcement for the actual slope belonging to Khe

Cham coal preparation construction site. On the basis results of this study, the following conclusions can be drawn:

1. The factor of safety (FOS) of the unreinforced slope was found to be 1.21, lower than the critical FOS of Vietnamese standard for slope stability TCVN 4054 (FOS>1.25). It is recommended that the actual slope should be reinforced for long-term stability. This finding agreed with the site investigation.
2. The safety factor of the reinforced slope was sensitive to the pile position. The target FOS could not be reached in the case of the pile at the toe. However, locating the piles at the upper top and especially at the middle represented a favorable condition for the slope. The safety factors of the slope in these cases improved relatively.
3. The safety factor of the reinforced slope significantly depended on the pile spacing, especially when piles are located at the middle of the slope. The safety factor decreased as the pile spacing increased, except for the case pile at the toe. Based on the parametric study on pile spacing, the optimal pile spacing was found to be 5 m to achieve the critical FOS of higher than 1.25.

Acknowledgment

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