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SLOPE STABILITY ANALYSIS USING MINI PILE: A CASE STUDY IN CIGEMPOL RIVER, KARAWANG, WEST JAWA

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ABSTRACT: Several slope failures have occurred in the Cigembol River, Karawang, West Java. The problem could be tackled by increasing the slope using appropriate slope countermeasures and analysis. For this study an installation of mini piles was selected. The purpose of this study was to compare the safety factor of the slope before and after installation of such mini piles using soil revetment. The analysis was carried out with the finite element method. For the purpose of this analysis, the only loads considered were those of self-weight. The results show that the safety factor of the existing slope is 1.068. After installation of the mini piles, the safety factor increases to about 1.295–1.982. For the piles revetment, the optimum dimension, depth, and spacing of piles was 25 × 25 cm, 10 m, and 2 m respectively. The stability analysis of the some configuration of mini pile demonstrate that the installation of the mini pile may cause increasing the safety factor, and show there was optimum configuration mini pile model.

Keywords: *Finite Element Method*, *Mini Pile*, *Self Weight*, *Slope Stability*.

1. INTRODUCTION

Soil or rock is generally in an equilibrium condition. This condition could be disturbed by some activities, such as soil excavation, cut and fill, soil erosion, etc. Thus, the soil tends to reach a new equilibrium condition. Slope failure or a landslide is the common way for soil to reach the new equilibrium condition. Slope failure is a geological phenomenon causing many casualties and economic loss [1].

Due to site-specific conditions, slope failure analysis and prevention work are very complicated. Various slope failure prevention works have been applied to increase its stability, i.e. soil nailing, retaining wall, etc. [2,3,4]. Recently, piles have been adopted as a slope failure countermeasure. Their friction capacity can prevent movement of the ground [9,5,6,8].

Several locations around the Cigembol River in Karawang, West Java, Indonesia have experienced slope failure. Thus, applications of soil reinforcement are expected to improve the stability of the slope. Sheet piles have been chosen as reinforcement of the slope. In this study, the piles revetment as an alternative for slope reinforcement will be analyzed to obtain the optimum configuration of the piles.

2. RESISTANCE FORCE OF PILE IN THE SLOPE STABILITY ANALYSIS

The friction of a pile surface produces a resistance force against the driving force of a slope. The pile installed in the slope suffers from lateral force, thus it is called a passive pile. Forces working at the soil-pile interaction are shown in Fig. 1. Lateral force can be calculated using Eq.1.

$$P_i = W_i sin \propto_i - \left[\frac{c_i l_i}{F} + (W_i sin \propto_i - u_i l_i)\frac{\tan \emptyset_i}{F}\right] + k_i R P_{i-1} \mathrm{P_i} = \mathrm{W_i sin} \propto_\mathrm{i} - \left[\frac{\mathrm{c_i l_i}}{\mathrm{F}} + (\mathrm{W_i sin} \propto_\mathrm{i} - \mathrm{u_i l_i})\frac{\tan \emptyset_\mathrm{i}}{\mathrm{F}}\right] + \mathrm{k_i R P_{i-1}} \mathrm{P_i} = \mathrm{W_i sin} \propto_\mathrm{i} - \left[\frac{\mathrm{c_i l_i}}{\mathrm{F}} + (\mathrm{W_i sin} \propto_\mathrm{i} - \mathrm{u_i l_i})\frac{\tan \emptyset_\mathrm{i}}{\mathrm{F}}\right] + \mathrm{k_i R P_{i-1}} \quad (1)$$

where, c_i = cohesion (kN/m^2); F = safety factor; u_i = pore pressure (kN/m^2); k_i = coefficient, R = factor of reduction. Coefficient k_i and factor of reduction R are shown in Eqs. 2 and 3, respectively.

$$k_i = \cos(\alpha_{i-1} - \alpha_i) - \sin(\alpha_{i-1} - \alpha_i)\frac{tan\emptyset_i}{F} \quad (2)$$

$$R = \frac{1}{\frac{s}{d}} + \left(1 - \frac{1}{\frac{s}{d}}\right) R_P \quad (3)$$

where, s/d = distant and diameter of pile ration, R_p = soil pressure percentage within pile.

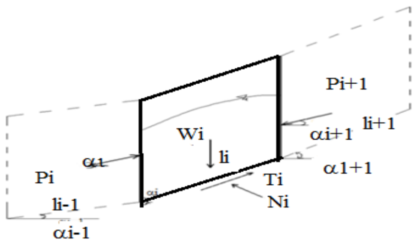


Fig.1 Forces working at the pile [4].

The internal friction angle can be obtained using Fig. 2 [4].

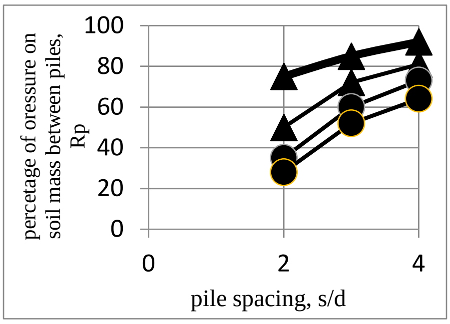


Fig.2 Internal friction angle [4].

Additional resistance force of pile (P_p) can be obtained using Eq 4.

$$P_p = {}^{P_i}/_{D_i} \tag{4}$$

Reduced additional force P_m and safety factor F can be calculated using Eq. 5 and Eq. 6, respectively.

$$P_m = \frac{P_p}{c_o} \tag{5}$$

$$F = \frac{Retaining\ force + P_m}{Propulsive\ force} \tag{6}$$

3. RESEARCH METHOD

A slope geometry model, layering the soil, and properties of the pile were used in this study in accordance with the existing data. The geometry model of the slope was made in accordance with a cross-section drawing of the study site (Figure 3). The safety factor analysis was made using phi/c reduction as the type of calculation. The slopes were considered safe when the safety factor was more than 1.5. Variations of the pile model are the depth, dimension, and the distance between the pile. All data used are secondary data

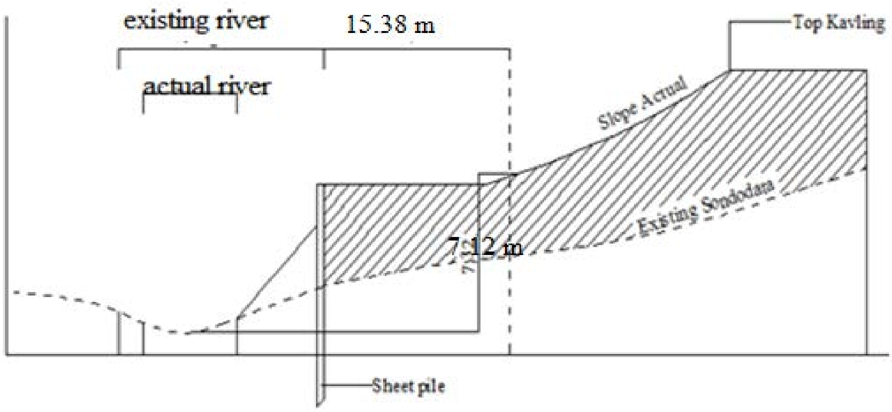


Fig.3 Cross-section of actual slope.

Fig. 3 shows the cross-section of the existing slope, whereas Fig. 4 shows the model geometry of the slope.

Pile dimensions refer to the dimensions of the cross-section minipile adapted to the slopes.

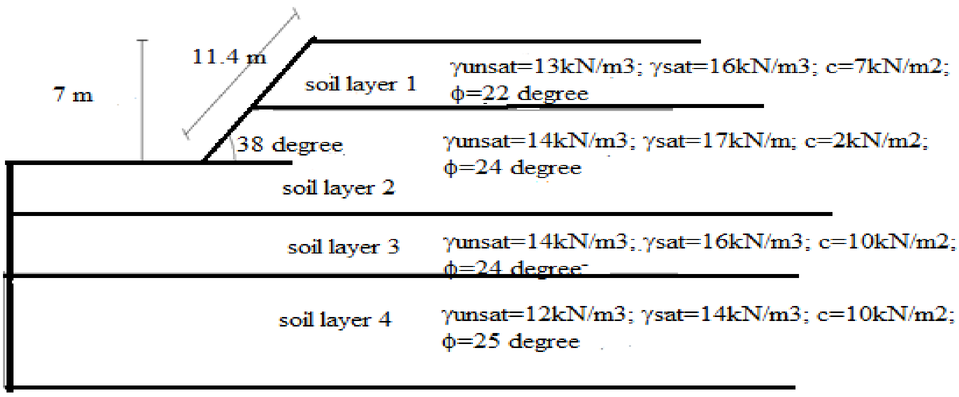
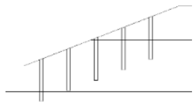
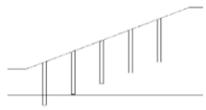
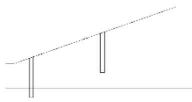
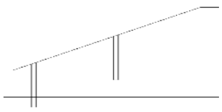
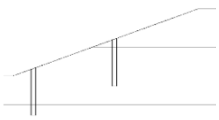


Fig. 4 Cross-section of the model slope

Pile configuration, soil data, and pile properties are shown in Table 1, 2, and 3 respectively. The depth of the pile is function *h*, where *h* is the depth of biggest slip surface on the slope without reinforcement. The configuration pile was arranged so that it penetrates all layers of the soil.

It was feared that a pile that was too large would weigh on the slopes. The distance installing between the pile was 2.0 m and 5.0 m. The length of the slope models was 11.4 m. The distance installing election is considered relatively ideal to represent the behavior of the slope after reinforced pile.

Table 1. Configuration pile.

Pile distance (m)	Dimension (cm)	depth (m) *f(h)*	depth (m) Nilai	Configuration Pile
2	25 × 25	*h*	5	
		h + 1/4h	6.25	
		h + 1/2h	7.5	
		2h	10	
	30 × 30	*h*	5	
		h + 1/4h	6.25	
		h + 1/2h	7.5	
		2h	10	
	40 × 40	*h*	5	
		h + 1/4h	6.25	
		h + 1/2h	7.5	
		2h	10	
5	25 × 25	*h*	5	
		h + 1/4h	6.25	
		h + 1/2h	7.5	
		2h	10	
	30 × 30	*h*	5	
		h + 1/4h	6.25	
		h + 1/2h	7.5	
		2h	10	
	40 × 40	*h*	5	
		h + 1/4h	6.25	
		h + 1/2h	7.5	
		2h	10	

h = maximum depth of sliding surface of existing slope

Table 2 Soil data

	γ_{unsat} (kN/m^3)	γ_{sat} (kN/m^3)	k_x	k_y	v	E_{ref} (kN/m^2)	$\boldsymbol{c_{ref}}$ **(kN/m^2)**	$\boldsymbol{\phi}$ **(°)**
Layer 1	13	16	0.001	0.001	0.35	1560	7	22
Layer 2	14	17	0.001	0.001	0.35	4335	2	24
Layer 3	14	16	0.0001	0.0001	0.33	5000	10	24
Layer 4	12	14	0.001	0.001	0.35	5000	12	25

Table 3. Pile properties

Dimension (cm)	*EA* (kN/m)	*EI* (kNm^2/m')
25 × 25	367187.5	1912.435
30 × 30	634500	4758.750
40 × 40	1504000	20053.333

4. RESULT AND ANALYSIS

The safety factor of the existing slope is 1.068, while the safety factors of the reinforced slope using pile are shown in Table 4. Figs. 5 and 6 show the behavior of the safety factor with respect to the depth in the distance of piles of 2 m and 5 m, respectively. The relationships of SF with pile dimensions in the pile depths are presented in Figs. 7–10.

Table 4. Safety factor of the reinforced slope using piles.

Spacing of the *Pile* (m)	Pile dimension (cm)	depth (m)	*SF*
2	25 × 25	5	1.338
		6.25	1.476
		7.5	1.649
		10	1.982
	30 × 30	5	1.326
		6.25	1.464
		7.5	1.635
		10	1.972
	40 × 40	5	1.295
		6.25	1.436
		7.5	1.605
		10	1.945
5	25 × 25	5	1.323
		6.25	1.455
		7.5	1.611
		10	1.946
	30 × 30	5	1.322
		6.25	1.456
		7.5	1.614
		10	1.947
	40 × 40	5	1.316
		6.25	1.453
		7.5	1.621
		10	1.947

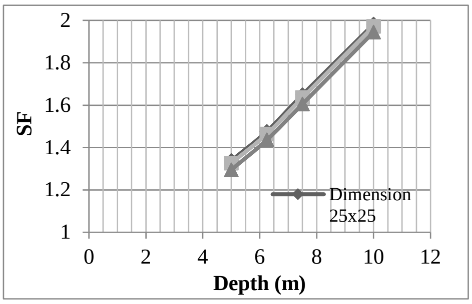


Fig. 5. Depth-safety factor relationship (pile spacing = 2 m).

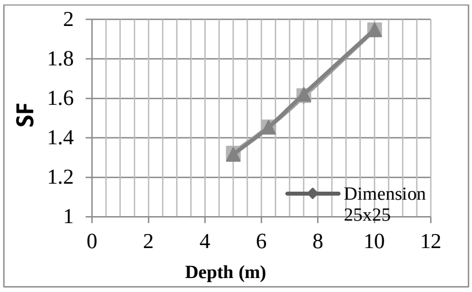


Fig. 6. Depth-safety factor relationship (pile spacing = 5 m).

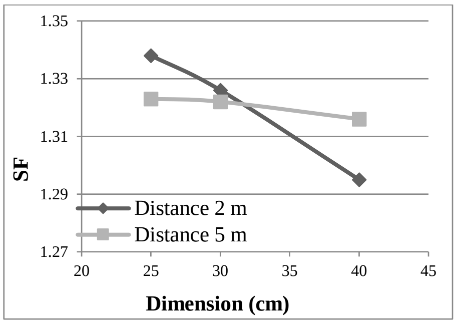


Fig. 7. Pile dimension pile-safety relationship (depth = 5 m).

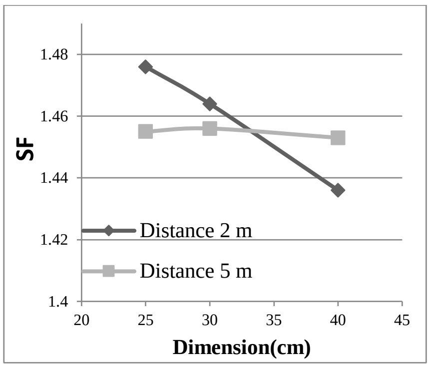


Fig. 8. Pile dimension pile-safety relationship (depth = 6.25 m).

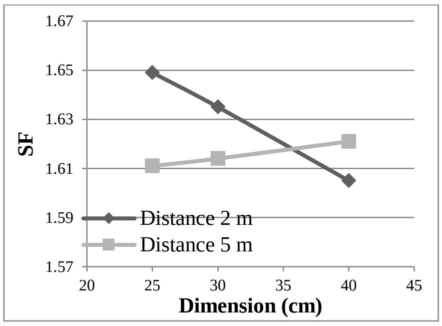


Fig. 9. Pile dimension pile-safety relationship (depth = 7.5 m).

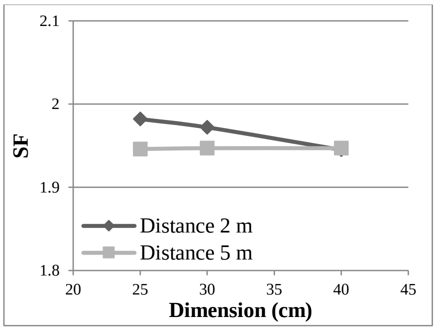


Fig. 10. Pile dimension pile-safety relationship (depth = 10 m).

Figs. 5 and 6 show that with a deeper pile installed, the safety factor is greater. The safety factor tends to be higher with respect to the increase of resistance force of the pile. Figure 7 to Figure 10 shows that the safety factor changes for the variables, i.e. dimensions, spacing, and depth of pile. A distance installing between of pile 2.0 m with greater dimensions tends to decrease the safety factor, but this condition does not occur at a distance of 5.0 m pile installation. There is a decrease in the safety factor caused by slopes that are impaired by penetration dense pile. Figure 7 to Figure 10 show the same safety factor at a distance of 2.0 m and 5.0 m. At a depth of 10.0 m pile there are relatively no changes in the safety factor. These conditions show the need for optimization prior to application in the field in order to obtain an efficient configuration.

5. CONCLUSION

1. The safety factor of the existing slope is 1.068, After the slope is reinforced using piles, it increases to 1.295–1.982.
2. The deeper the pile is installed, the greater the safety factor. Penetration depth of pile 5.0 m to 10.0 m results in a safety factor from about 1.295 to 1.982.
3. The spacing of the pile is the determinant parameter affecting the safety factor, while pile depth has no influence.

6. REFERENCES

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