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Safety Factor on Slope Modeling with Composite Bamboo Pile Reinforcement

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ABSTRAC

Landslide phenomenon especially on slopes always become interesting issues to be discussed. Last few years, composite bamboo pile is one of the innovative slope reinforcement methods to increase slope stability. Slope modeling with composite bamboo reinforcement was using an experiment box with 1,50 m as length; 1,0 m as width and 1,0 m as height. It used sand soil with fine gradation and composite bamboo pile with various diameters and space between piles. The load has modeled as a strip footing with continuous increases load by load cell until the limit load reached. The problem that occurred in laboratory has analysed with Finite Element Method. It changed 3D slope modeling to be 2D modeling. Composite bamboo pile has choosen as a new utilization innovation of bamboo to be pile reinforced and a positive value to optimize bamboo local material to be a steel reinforced replacement material. The result of experiment shown that utilizing of pile reinforcement on slope has increased slope stability. It shown with significally increase of safety factor, bearing capacity improvement and maximum limit load that able to reached on slope.

Keyword - Bearing capacity improvement, Composite bamboo pile, Finite element method, Slope reinforcement, Slope stability

1. INTRODUCTION

When a shallow footing placed on slope surface, not only bearing capacity of footing but also slope stability will be significally decreased, depend on location of the footing to slope inclination. For solve that problem, it is used a reinforced system with install the composite bamboo pile. The method to install pile at the top of slope has a function as a resistant element and at once to resist all lateral forces that work. It work with reduced that lateral forces by transfer of the force to composite bamboo pile reinforcement that installed on some distance at slope.

Some researches has been done to researched the slope stability with pile reinforcement (De Beer and Wallays, 1970; Ito and Matsui, 1975; Ito et al, 1981; Viggiani, 1981; Ito et al, 1982; Poulos, 1995; Lee et al, 1995; Hong da Han, 1996; Chen et al, 1997; Hassiotis et al, 1997; Ausilio et al, 2001; Hull and Poulos, 1999; Cai and Ugai, 2000; Won et al, 2005; Eng Chew Ang, 2005; Lee and Wang , 2006; Wei and Cheng , 2009). One of the most important things on evaluating slope stability with pile reinforcement is limit soil pressure which mobilized on pile-soil interface. There are two system analysis on slope stability with pile reinforcement, which are pile stability and slope stability

2. SLOPE STABILITY WITH PILE REINFORCEMENT

2.1 Bearing Capacity Improvement Analysis (BCI)

Bearing capacity improvement factor is factor that explain the differences of limit load before and after pile reinforcement. The increasing of BCI values shows the increasing of slope stability as seen on greater limit load. BCI values can be wrote as equation 1:

$$BCI_u = \frac{q_u(R)}{q_u} \quad (1)$$

Where :

q_u (R) = ultimit bearing capacity with reinforcement

q_u = ultimit bearing capacity without reinforcement

2.2 Slope Stability Analysis

The result from earlier research showed global safety factor for slope stability with pile reinforcement estimated from limit equilibrium or finite element method. Duncan (1990) explained, slope stability with pile reinforcement can adopted from same method for slope stability without reinforcement. Ito et al (1979) suggested, slope stability with pile reinforcement analysis to resist shear moment. Safety factor of slope stability with reinforcement can be wrote as equation 2:

$$FS_{lereng} = \frac{M_r}{M_d} = \frac{M_{rs}+M_{rp}}{M_d} \quad (2)$$

Where :

M_r = resistance momen

M_d = driving momen

M_{rs} = resistance momen along critical circle

M_{rp} = additional resistance pile reinforcement momen

2.3 Safety Factor Analysis Using Finite Element Method

This research used PLAXIS 8.2 as a finite element method program to analize safety factor on slope with non-reinforcement and safety factor on slope with pile reinforcement. PLAXIS 8.2 is used 2D modeling which very different with laboratory modeling that was a 3D modeling. To find the effect for diameter and space between piles, it cannot enter the material value directly into initial input. The quantities of diameter and space between piles must be changed into EI and EA form. Furthermore, they have to be transformed into equivalent EI form. The previous research has been done the plane strain analysis with equivalenting pile that used in the modeling to sheet pile which has same stiffness to average stifness from row of piles and soil, as shown on Fig. 1. Thereby, it can be analyze using the transformation value between piles and soil to EI equivalen form.

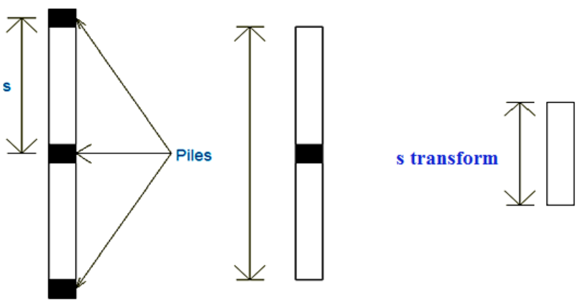


Figure 1. EI and EA transformation value between piles and soil

PLAXIS modeling in this case, used Mohr-Coloumb method model. Mohr-Coloumb model is very popular as initial approximation to understand about general soil behaviour. Parameters on this model are; Modulus Young (E), Poison ratio (v), cohession (c), friction angle of soil (φ) and dilatation angle (ψ). Table 1 shows the parameters that used on this model.

Table 1. Soil Parameters for PLAXIS

Parameter	**Unit**	**Value**	
		Dr 74%	**Dr 88%**
E soil	kN/m^2	311	2427
v		0,3	0,3
C	kN/m^2	0,5	0,5
ϕ	°	34,40	38,68
ψ	°	3,2	7,5

3. MATERIALS AND METHODS

3.1 Box Model and Footing

Prime element that used is box, made of fiber glass with length : 1,50 m; width : 1,0 m and height : 1,0 m. Base of box using sheet steel with thickness 1,2 cm. The box made to be rigid enough for maintain strain plane condition. Fiberglass used on box to make observation more easier in laboratory. The experimental box presented in Fig. 2.

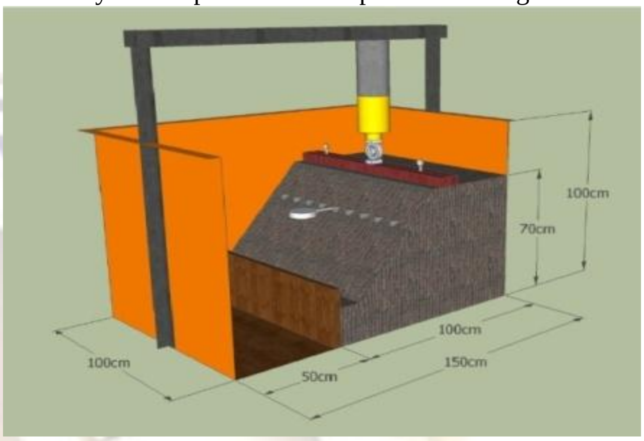


Figure 2. Experimental box

Reinforcement system consist of hydraulic jack that manually operated with 10 tons capacity and load cell that has been calibrated as a load gauge which occured in proving ring reading. A continuous footing with length 100 cm, width 10 cm and height 10 cm located on slope surface that directly linked with hydraulic jack. Upper end from hydraulic jack linked to a rection beam that restraint on steel primary framework. Load increment process used stress control that connected with two dial gauges for measuring footing settlement.

3.2 Sand Soil Test

Sand soil that used in this research is sand soil with fine gradation. Specific gravity of sand soil's particles determined with standart procedure based on ASTM standart. Mechanical parameters can be determined using direct shear test with sample that took directly from slope experimental model at desirable density. For determine grain size distribution, it is using sieve analysis. The result of grain size analysis can be shown on Fig. 3. Physical and mechanical parameters presented in Table 2.

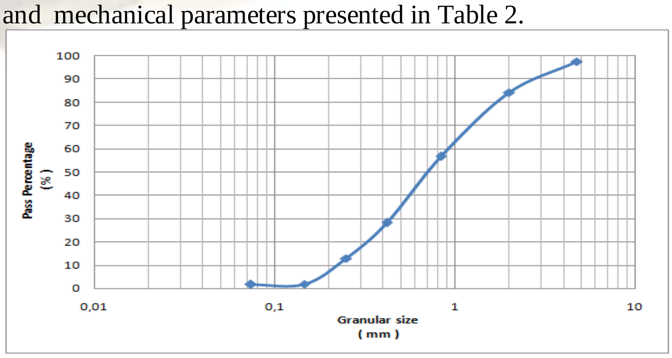


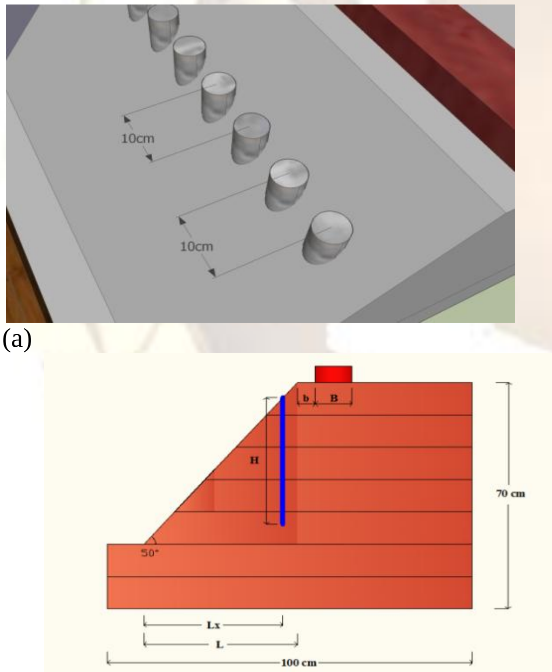
Figure 3. Grain size analysis

Table 2.Sand Soil Characteristics

Explanation		Value		Unit
		Dr 74%	Dr 88%	
Specific Gravity	Gs	2,69		-
Dry volume gravity	γ_d	13,2	16,1	kN/m^3
Cohesion	c	0,4	0,5	kN/m^2
Friction angle	Φ	34,4	38,68	o

3.3 Procedure and Experimental Program

Sand soil model compacted every layer with height 10 cm using standart proctor until reached the desirable density. After that, it shaped to a slope with desirable inclination angle (50^o). Composite bamboo pile reinforcement installed in specific position. Variables that used are; diameter of composite bamboo pile which symbolized with D and space between piles that symbolized with D_1. Space between center of piles (D_1) and pile parameters presented in Fig. 4.



(a)

(b)

Figure 4.(a) Space between piles (D_1), (b) Pile section.

This research used composite bamboo piles with 4 bamboo sticks as reinforced that installed in composite piles on circle line as shown in Fig. 5.

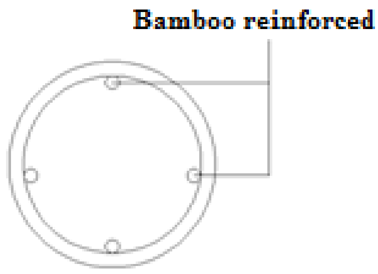


Figure 5. Bamboo reinforced position in composite pile reinforcement

Variation of diameter (D) that used are; 1,27 cm; 1,905 cm; 2,54 cm and 3,175 cm. For space between piles (D_1), it divided into 4 variations; 7,5 cm; 10 cm; 12,5 cm and 15 cm. Whereas for pile location, it used Lx/L ratio with Lx is a distance from sub-slope to pile location and L is a slope horizontal length. Pile reinforcement variations that used in this research can be shown in Table 3.

Table 3. Variables in Slope Model Test

No	Constant parameters	Independent variable	Exp.
1	Non reinforcement	b = 0,5 B Dr = 74%; 88%	-
2	H/B = 4 Lx/L = 0,452	D/B=0,127;0,1905;254; 0,3175 D_1/B= 0,75; 1; 1,25; 1,5 Dr=74%; 88%	row

This experiment produced load and settlement data. From those data, safety factor and BCI value can be proceed as final results.

4. RESULT AND DISCUSSION

4.1 Effect of Pile Diameter to Safety Factor on Slope with Pile Reinforcement

To find effect of pile diameter to safety factor on slope with pile reinforcement, the experiments must be done using pile reinforcement with 4 variation of diameters, there are; 1,27 cm; 1,905 cm; 2,54 cm and 3,175 cm that located on middle of slope (Lx/L = 0,452) with length of pile 40 cm. Result of experiment shows that greater pile diameter brings greater BCI and SF as shown on Fig. 6,7 and 8.

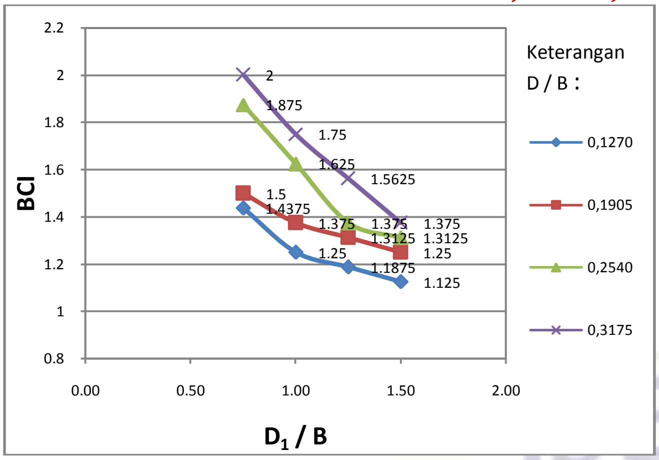


Figure 6. Relation between BCI and ratio pile spacing – foundation width with different pile diameter

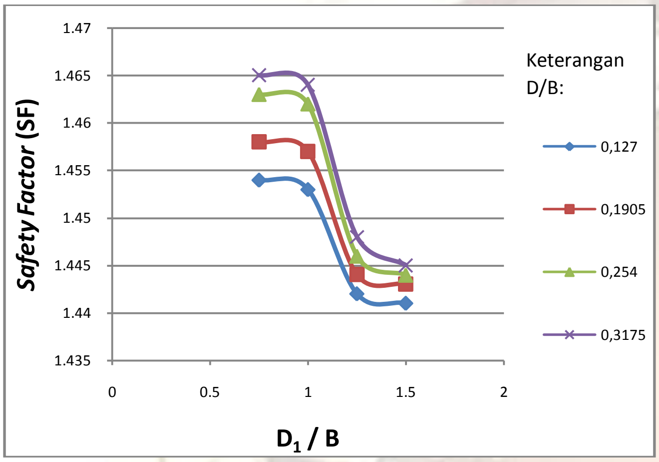


Figure 7. Relation between SF and ratio pile spacing – foundation width with different pile diameter on second condition

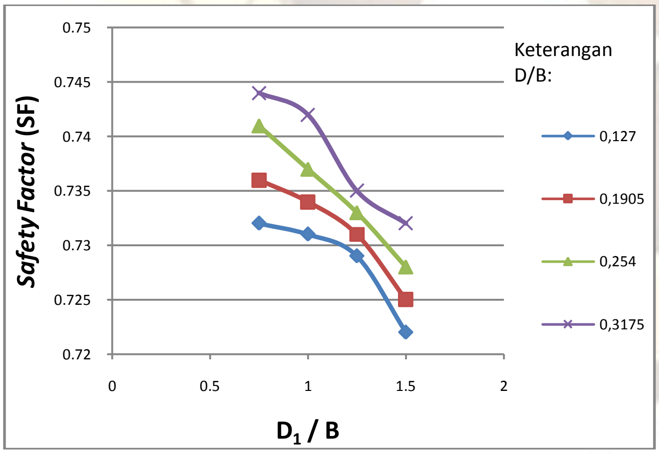


Figure 8. Relation between SF and ratio pile spacing – foundation width with different pile diameter on fourth condition

4.2 Effect of Space Between Piles to Safety Factor on Slope with Pile Reinforcement

To find effect of space between piles to safety factor on slope with pile reinforcement, the experiments must be done using pile reinforcement with 4 variation of spaces, there are; 7,5 cm; 10 cm; 12,5 cm and 15 cm that located on middle of slope (Lx/L = 0,452) with length of pile 40 cm. Result of experiment shows that fewer space between piles brings greater BCI and SF as shown on Figure 9,10 and 11.

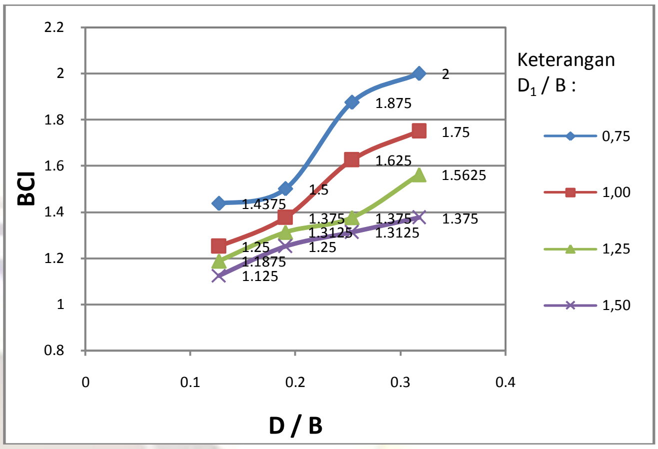


Figure 9. Relation between BCI and ratio pile diameter – foundation width with different space between pile

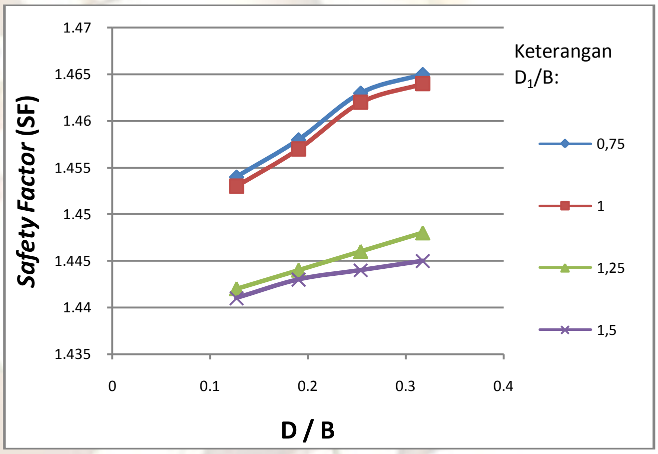


Figure 10. Relation between SF and ratio pile diameter – foundation width with different space between pile on second condition

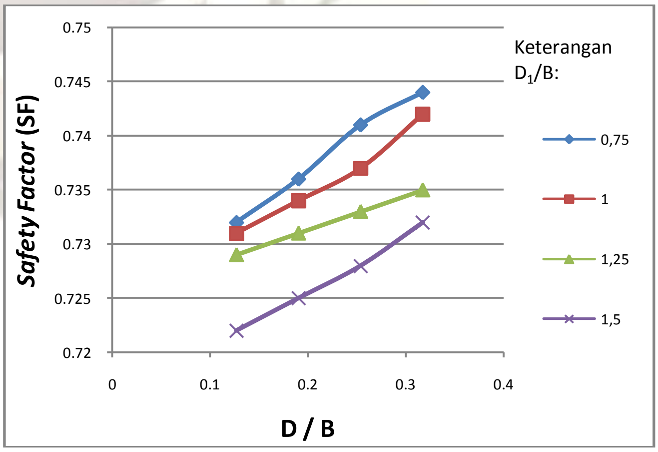


Figure 11. Relation between SF and ratio pile diameter – foundation width with different space between pile on fourth condition

5. CONCLUSION

1. Slope reinforcement with pile reinforcement has a significant effect to increase safety factor of slope stability
2. On various pile diameter, SF and BCI reached the maximum point on 2,54 cm as pile diameter.
3. On various space between piles, SF and BCI reached the maximum point on 7,5 cm as space between piles.

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