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Research Article

Bearing Capacity of Continuous Footing on Slope Modeling with Composite Bamboo Pile Reinforcement

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Abstract

The footing that placed on slope surface will decrease bearing capacity of soil. The function of using composite bamboo pile is to increase bearing capacity of footing on slope and that is one of the innovative slope reinforcement methods which necessary for last few years. 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 was modeled as a strip footing with continuous increasing load by load cell until the limit load has been reach. The problem occurred in laboratory has been analyzed with Finite Element Method. It changed 3D slope modeling to be 2D modeling. Composite bamboo pile has been chosen as a new utilization innovation of bamboo as reinforced pile and that's a positive value to optimize bamboo local material as steel reinforced replacement material. The result of experiment using composite bamboo as pile reinforcement on slope has increased slope bearing capacity. It shown with significant increasing of bearing capacity and maximum limit load can be reached on slope.

Keywords: *bearing capacity improvement, bearing capacity on slope, composite bamboo pile, finite element method, slope reinforcement.*

1. Introduction

When a shallow footing has placed on slope surface, bearing capacity of footing will significantly decrease, depend on location of the footing to slope inclination. To resolve this problem, it used a reinforced system using composite bamboo pile. The method of installing piles at top of the slope has function as a resistant element and at once to resist all lateral forces that is working. They worked with reducing lateral forces by transferring the force to composite bamboo pile reinforcement which is installed with various distance on slope.

Some researches has done researching the soil bearing capacity on slope, both by analysis, experiments and numeric. Osamu Kusakabe et al (1981) has been researched about bearing capacity of clays on slope that are being given a continuous load using upper bond theorem as analysis method. Kunimoto Narita et al (1990) has been researched about soil bearing capacity on slope with analytical approach using log spiral method that is compared to upper bond method. Azzam et al (2010) started a research using skirted strip footing reinforcement, that is compared to soil bearing capacity on sand slope with experimental and analytical approach. Anil Kumar et al (2009) done the research using sand soil and geogrid reinforcement, with experimental and numerical approach. Huang et al (1994) started a research using geotextile reinforcement and it explained about failure mechanism on sand slope. Sawwaf (2004) done the researched with using pile reinforcement on sand slope. The effects from reinforcement for increasing ultimate soil bearing capacity is presented in non-dimensional form that called BCI. J. Thanapalasingam and C. T. Gnanendran (2008), E. C. Shin and B. M. Das (2000), M. J. Kenny and K. Z. Andrawes (1997) also P. K. Haripal et al (2008) said that bearing capacity improvement (BCI) is a rasio which explain the comparation between ultimate soil bearing capacity with reinforcement to ultimate soil bearing capacity without reinforcement. A. Zahmatkesh et al (2010) said that BCI is a rasio which explain the comparation between soils bearing capacity with reinforcement to soil bearing capacity without reinforcement in same settlement level. S. M. Marandi et al (2008) used BCI based on; ultimit bearing capacity base and same settlement level base.

2. Soil Bearing Capacity of Continuous Footing on Slope

2.1 Bearing Capacity Improvement (BCI) Analysis

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Bearing Capacity Improvement (BCI) can be determined based on two things; bearing capacity at ultimate point (BCI_u) and bearing capacity at same settlement level (BCI_s). BCI is a ratio between bearing capacity with reinforcement to bearing capacity with non-reinforcement. Increasing value of BCI shows that slope bearing capacity has been increased after using reinforcement. BCI can be written as equation 1:

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

In which $q_u(R)$ = ultimate bearing capacity with reinforcement, q_u = ultimate bearing capacity without reinforcement; q(R) = bearing capacity with reinforcement at "s" level settlement; q = bearing capacity without reinforcement at "s" level settlement.

2.3 Bearing Capacity Analysis Using Finite Element Method

This research is using PLAXIS 8.2 as a finite element method program to analyze slope bearing capacity with non-reinforcement and slope bearing capacity with pile reinforcement. PLAXIS 8.2 use 2D model which is very different from actual condition in the laboratory modeling that was a 3D modeling. To find the effect of diameter and space between piles, material value cannot be entered directly on 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 treat the same pile that is used in modeling to sheet pile which has same stiffness to average stiffness 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 equivalent form.

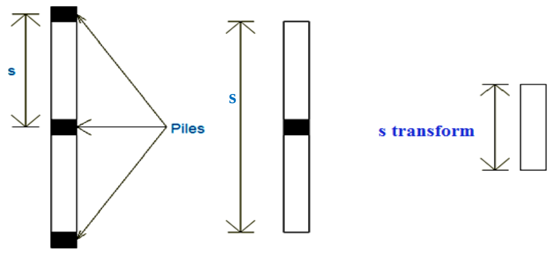


Figure 1: EI and EA transformation value between piles and soil

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.

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 shown in Fig. 2.

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

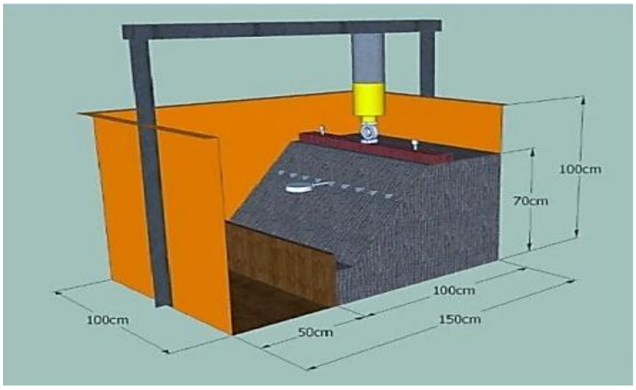


Figure 2: Experimental box

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 contacted to 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 measure footing settlement.

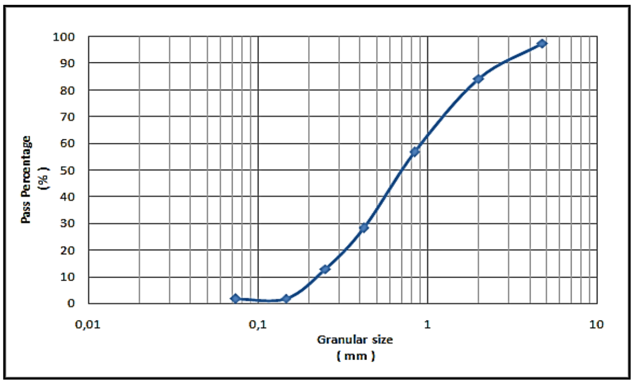


Figure 3: Granular size analysis

3.2 Sand Soil Test

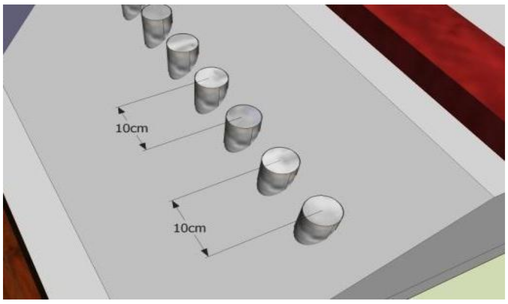
Sand soil that was used in this research are sand soil with fine gradation. Specific gravity of sand soil particles determined with standart procedure based on ASTM standart. Mechanical parameters can be determined using direct shear test with sample that took directly from slope experimental model at desirable density. To determine granular size distribution, they use sieve analysis. The result of granular size can be shown on Fig. 3. Physical and mechanical parameters presented in Table 1

Table 2: Sand Soil Characteristics

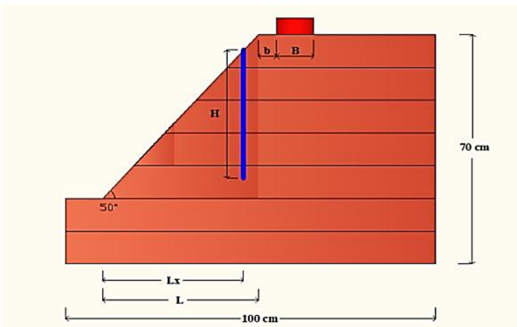
Explanation		**Value**		**Unit**
		Dr 74%	**Dr 88%**	
Specific Gravity	Gs	2,69		-
Dry volume gravity	γ_d	13,2	16,1	kN/m^3
Cohesion	c	0,4	0,5	kN/m^2
Friction angle	Φ	34,4	38,68	^{o}

3.3 Procedure and Experimental Program

Sand soil model compacted every layer with height 10 cm using standart proctor until they 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 using composite bamboo piles with 4 bamboo sticks as reinforced that installed in composite piles on circle line as shown in Fig. 5.

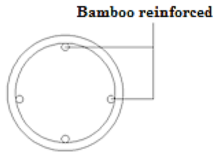


Figure 5: Bamboo reinforced position in composite pile reinforcement

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

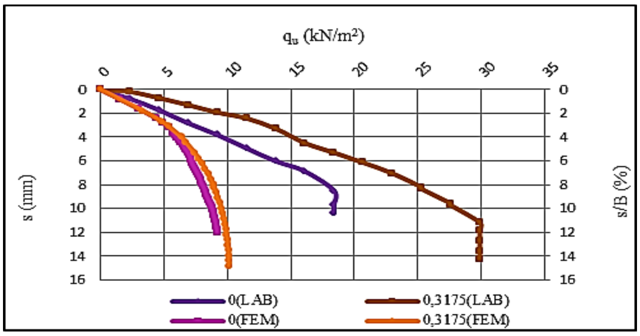
No	Constant parameters	Independent variable	Exp.
1	Non reinforcement	b = 0,5 B Dr = 74%; 88%	-
2	H/B = 4 Lx/L = 0,452	D/B=0,127;0,1905;254; 0,3175 D_1/B= 0,75; 1; 1,25; 1,5 Dr=74%; 88%	row

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

4. Result and Discussion

4.1 Pile Diameter Effect to Bearing Capacity on Slope

To find pile diameter effect on slope bearing capacity, 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). Relation between bearing capacity (q_u) and settlement (s) for non-reinforcement slope (D/B = 0) and reinforcement slope with maximum diameter (D/B = 0,3175) shown in Fig. 6.



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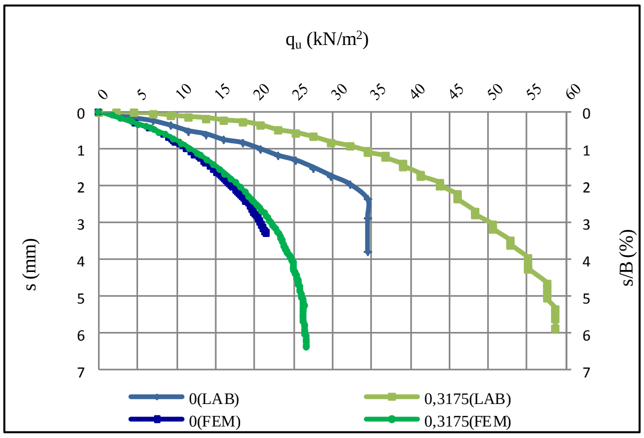
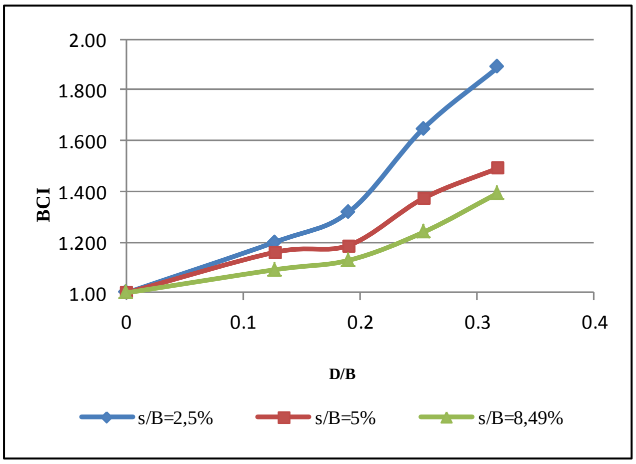


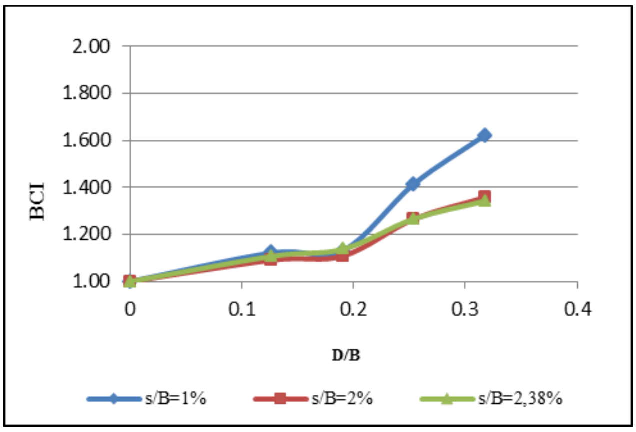
(b)

Figure 6: Relation between bearing capacity and settlement using pile's diameter variation (a) Dr 74% (b) Dr 88%

The experiment result which has been done in laboratory and result from analytical with FEM (PLAXIS) show that more wider diameter of pile, then BCI value became more increasely. Incrementation of BCI presented in Fig. 7.



(a)



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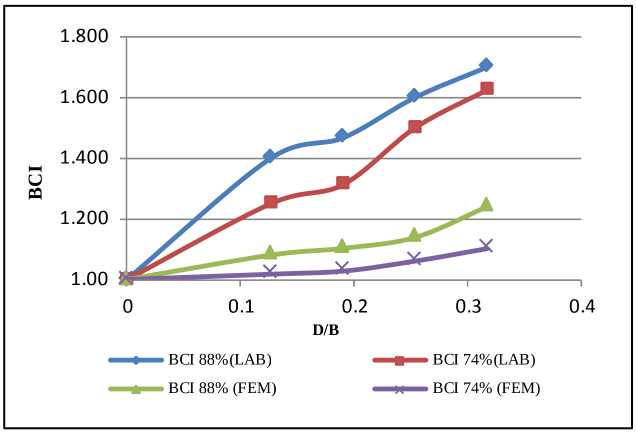
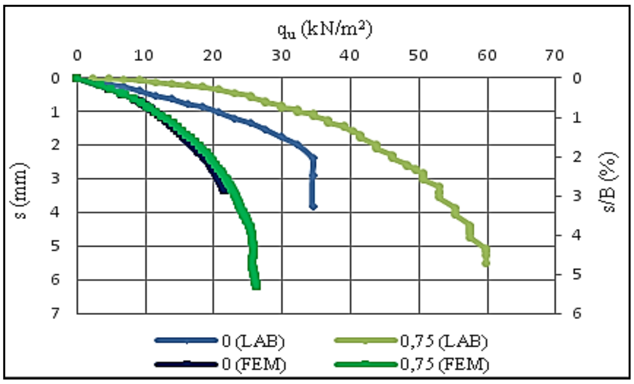


(c)

Figure 7: Relation between BCI and various diameter of pile.(a) BCI_u for every Dr, (b) BCIs Dr 74%, (c) BCI_s Dr 88%

4.2 Effect of Space between Piles with Bearing Capacity on Slope

To find space between piles effect on slope bearing capacity, 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). Relation between bearing capacity (q_u) and settlement (s) for non-reinforcement slope ($D_1/B = 0$) and reinforcement slope with maximum diameter ($D_1/B = 0,75$) shown in Fig. 8



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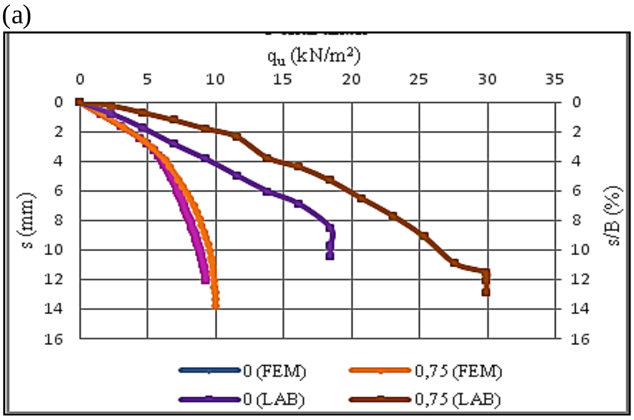
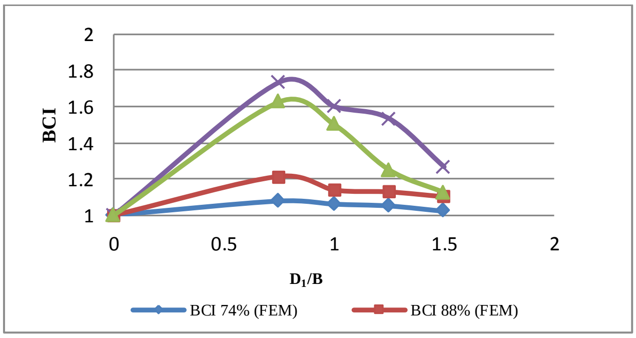


(b)

Figure 8: Relation between bearing capacity and settlement using space between piles variation (a) Dr 74% (b) Dr 88%

The experiment result which has been done in laboratory and result from analytical with FEM (PLAXIS) show that more closer the distance between piles, then BCI value became more increasely. Incrementation of BCI shown in Fig. 9.



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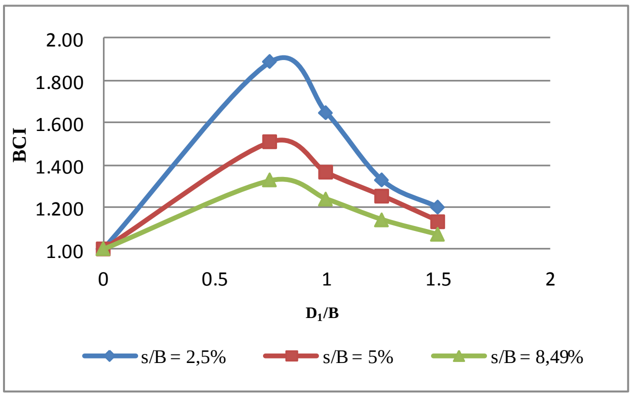

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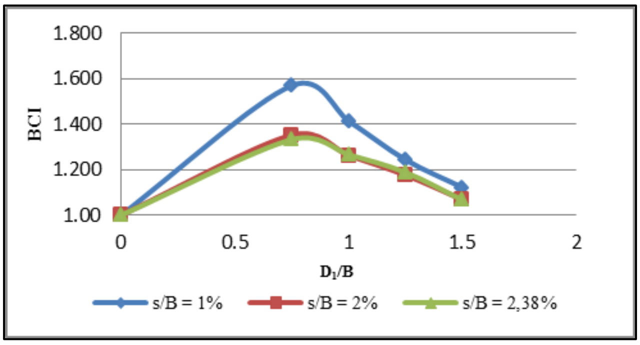
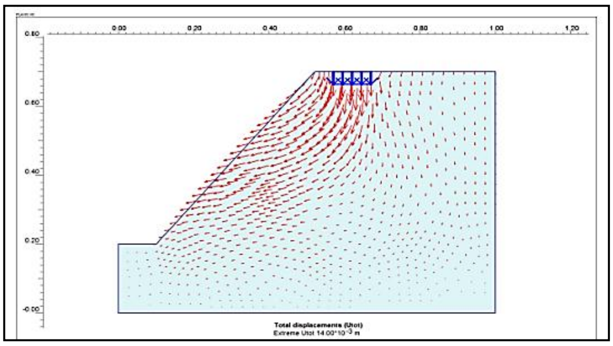


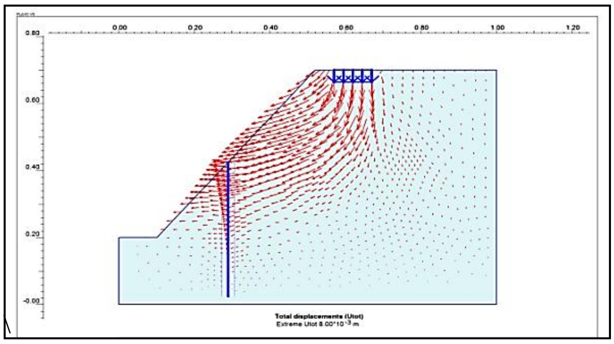
(c)

Figure 9. Relation between BCI and various space between piles.(a) BCIu for every Dr, b) BCIs Dr 74%, c) BCIs Dr 88%

Fig. 10 shows slope displacement vectors for non-reinforcement slope and slope with pile reinforcement for Dr 74% and Dr 88% that obtained from PLAXIS 8.2.



(a)



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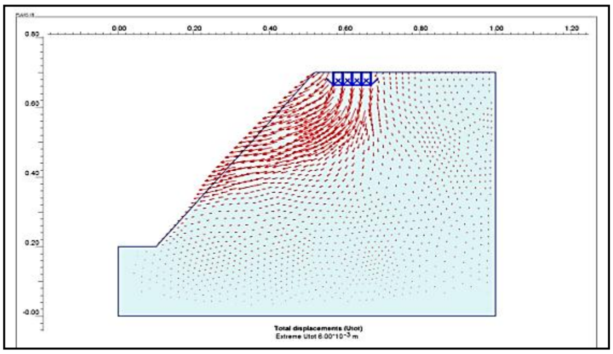

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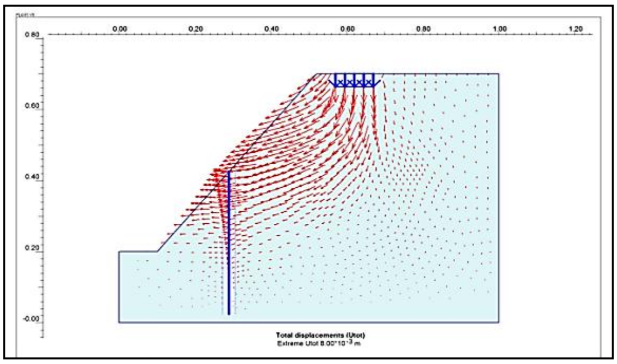

(d)

Figure 10: Displacement vector; (a) Non-reinforcement with Dr 74%, (b) Using pile reinforcement with Dr 74%, (c) Non-reinforcement with Dr 88%, d) Using pile reinforcement with Dr 88%.

5. Conclusion

- Slope reinforcement with pile reinforcement has a significant effect to increase bearing capacity of continuous footing.
- On various pile diameter, BCI reached the maximum point on 2,54 cm as pile diameter.
- On various space between piles, BCI reached the maximum point on 7,5 cm as space between piles.

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