Numerical Simulation of Slope Stability for Soil Embankment Reinforced with Inclined Bamboo Piles

by Ngudiyono Ngudiyono

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Abstract Slope stability is an important parameter when designing for the embankment. Poor-quality and degradation properties of soil material became triggers slope failure. Bamboo culm (*Dendrocalamus asper*) provided a diameter of 6–15 cm and high tensile strength parallel to the grain, and it was suitable for slope stabilizing. Slope stabilization by bamboo pile is a passive technique in which soil displacements require to activate pile forces. In this manuscript, two-dimensional (2D) model slope reinforcement with bamboo pile with the shear strength reduction (SSR) finite element method (FEM) by using ABAQUS SE software has simulated. The bamboo piles with 5 m length and 6 cm, 10 cm, 15 cm for diameter were placed two in the edge, one in the middle, and inserted perpendicular to slope plane embankment with the inclination of 33.69°. The model of the slope was analyzed, its influence on bamboo piles soil interaction by evaluating the safety factor (FOS). The result has shown that reinforced embankment slope with inclined bamboo piles had increased slope stability, the safety of factor (FOS) increase to 1.515. The shear strength reduction (SSR) finite element method (FEM) can be used as an alternative for slope stability analysis.

Keywords Slope stability · SSR · FEM · Reinforcement · Bamboo pile

1 Introduction

Slope stability is an important parameter when designing embankment roads, highways, dams, and other civil engineering structures. The problem of poor-quality soil material and degradation properties of soil material became sometimes triggers slope failure. Several slope reinforcement techniques widely applied are geosynthetic, soil

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nailing, concrete or steel mini-pile, concrete block, etc. The technologies that require skilled labor are relatively expensive.

Bamboo is a natural material widely available globally, especially in Asia, and has been widely used as a traditional and modern building material. Bamboo also green building material, renewable, sustainable, typically be harvested in less than three years to four years, and relatively inexpensive. Bamboo culm (*Dendrocalamus asper*) provided with diameter 6–15 cm, tensile strength parallel to grain 228 MPa, flexural strength 134.97 MPa, and modulus of elasticity 12,888.48 MPa [1, 2] that make it suitable for slope stabilizing. Bamboo piles inserted in a soil mass can provide stability by adding the reactive portion to the resistant forces contrary to the ground. Slope stabilization by bamboo pile is a passive technique in which soil displacements require to activate pile forces [3, 4].

Using bamboo piles as material for reinforcement of slope sandy soil was carried out by Munawiret al. [5, 6]; the result of the experiment and numerical by using PLAXIS showed that pile reinforcement applied on the slope had improved the stability of the slope. It had indicated by the significant increase of safety factor and bearing capacity. Wahhab and Ramadhan were used bamboo as soil reinforcement to landslide in Kali Wungu–Boja road, Darupono Village, Kendal District, two varieties of bamboos with a diameter of 20 and 15 cm were analyzed. The safety factor was analyzed by using PLAXIS and SLOPE/W software. The result showed that of safety factor was give the illustration that bamboo could use as an alternative material to slope reinforcement [7]. Using the *Dendrocalamus Giganteus* species bamboo-pile for slope stability using the finite element method (FEM) analysis of bamboo-pile was developed PLAXIS software for 2D and 3D. The results presented that the capabilities of the bamboo piles are potential as an alternative for slope stability [8].

Generally, there are two methods for slope stability analysis, including limit equilibrium methods (LE), such as Ordinary, Bishop's, Janbu's, Spencer's, Morgenstern-Price, and numerical analysis methods such as finite element method (FEM). In the LE method for slope stability analysis, the critical slip surface has to be estimated. However, in FEM analysis, no potential slip surface was estimated in advance, and the stress–strain correlation in the slope can also be considered [8]. In this study, two-dimensional (2D) analyses evaluated bamboo piles using ABAQUS Student Edition (SE) software to simulate the slope model. The software is a personal finite element analysis tool for solving limited size problems (1000 nodes for Abaqus/Standard and Abaqus/Explicit. This numerical study aims to analyze the performance of the slope reinforced with inclined bamboo piles as an alternative material used in slope reinforcement. The variation of diameter bamboo piles was modeled to evaluate the influence of inclined bamboo piles on the safety factor (FOS).

2 Shear Strength Reduction (SSR) Finite Element Method (FEM)

Nowadays, shear strength reduction (SSR) has increasingly been used with the finite element method (FEM) for slope stability analyses. Previous researchers have widely used this method to analyze the slope stability of several cases [8–13].

In the SSR finite element method elastic–plastic strength is assumed for slope materials. The factor of safety (FOS) is applied to reduce the strength of soil until failure occurs. For Mohr–Coulomb material model shear strength reduced by a factor of safety can be determined from the equation below.

$$\frac{\tau}{FOS} = \frac{c\prime}{FOS}\frac{\tan \emptyset\prime}{FOS} \tag{1}$$

Equation (1) can be re-written as,

$$\frac{\tau}{FS} = c^* + \tan \emptyset^* \tag{2}$$

where

$$c^* = \frac{c'}{FOS} \tag{3}$$

$$\emptyset^* = arctan\left(\frac{\tan \emptyset'}{FOS}\right) \tag{4}$$

Equations (3) and (4) are reduced Mohr–Coulomb shear strength parameters, and these values can be input into the ABAQUS SE software and then analyzed. There are several types of criteria for determining the failure slope model: numerical iteration non-convergence, suddenly change displacement, plastic strain, or equivalent plastic strain [8–13].

In the computation process, the field variables change following increment step time. The process of reducing material strength be realized by adjusting the material parameters to change with field variables. Since the incremental time change is automatic and manual modification is no longer required, the strength is also automatically decreased. Eventually, according to specific failure criteria, a suitable increment step time is known. Then the safety of the factor and the critical sliding surface of the slope can be found.

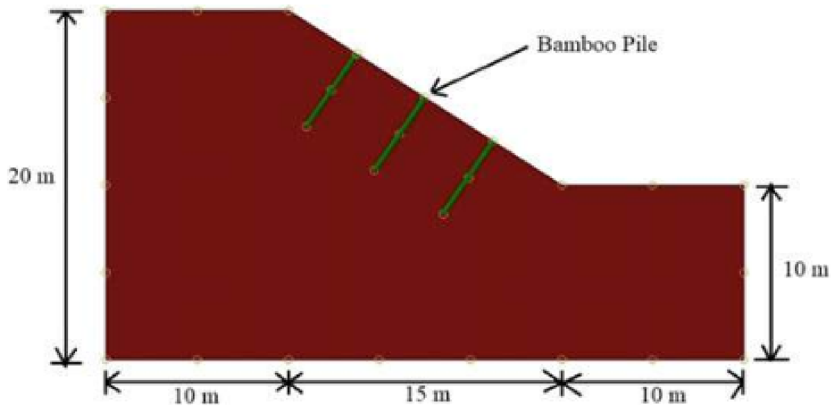

Fig. 1 The geometry of the slope model

3 Numerical Simulation

In the section describing step by step finite element analysis for slope model embankment reinforced with inclined bamboo piles using ABAQUS SE software, including model geometry, material properties, meshing, boundary condition, and loading as follows:

3.1 *Model Geometry*

According to the previous study [14], the geometry of the homogeneous embankment slope model was typically 20 m in height and 35 m long at the base with an inclination of 33.69°. The bamboo pile with 5 m length and 6, 10, 15 cm for diameter were placed two in the edge, one in the middle, and inserted perpendicular to the slope model plane. The geometry slope reinforced with bamboo piles is shown in Fig. 1.

3.2 *Material Properties*

The soil material properties of slope based previous study [14], the elastic–plastic Mohr–Coulomb failure criterion is used in the constitutive model of the soil in the analyses. Because clay assumed to be undrained, so the modulus of elasticity (E), Poisson's ratio (v), cohesion (c), friction angle (φ), and unit weight (γ) are 200 MPa, 0.25, 10°, 20 kPa, and 20 kN/m^3 respectively. In contrast the dilation angle (ψ) assumed zero because of the saturated clay. Meanwhile, the properties of the bamboo piles species *Dendrocalamus asper* are 5 m for length and 6, 10, 15 cm for diameter with the modulus of elasticity (E) 12,000 MPa and Poisson's ratio (v) 0.2.

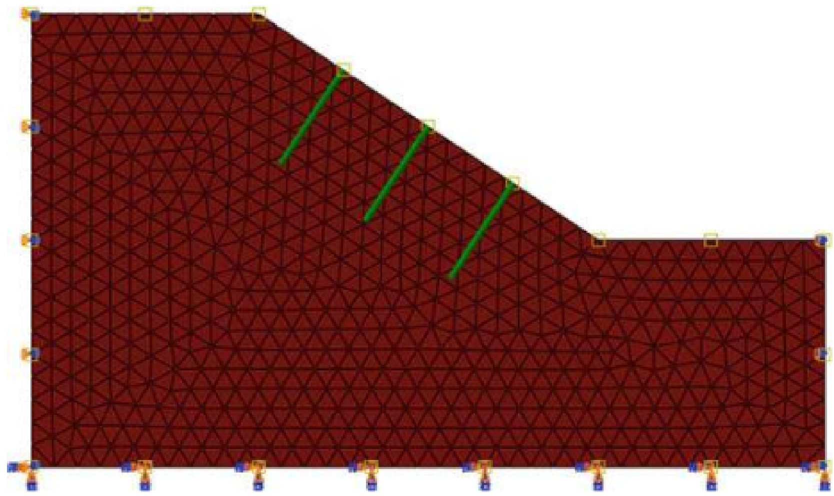

Fig. 2 Meshing and boundary condition of the slope model

3.3 Meshing, Boundary Condition, and Loading

Because the ABAQUS SE has having limitations, the 2D FEM technique has been adopted to solve the slope model in this study. There are 1185 element type CPE3 (3-node linear plane strain triangle) used for soil and type B21 (2-node linear beam in a plane) for the bamboo pile. The bamboo piles are assumed as an embedded elements beam in a set of solid elements. The boundary conditions (BC) on both sides are assigned to be roller which deformation on x-direction, and the fixed is used for the bottom. The meshing and BC of the model are shown in Fig. 2. Only the gravity load was applied in the slope model.

4 Result and Discussion

4.1 The Safety of Factor (FOS)

The slope stability analyses based on SSR using ABAQUS SE software, the factor of safety (FOS) has evaluated base criteria non-convergence of the numerical iteration, suddenly change the dis-placement node control on the top slope model. The displacement of the versus FOS has shown in Fig. 3. It illustrated that the displacement changes suddenly at FOS = 1.293 for clay embankment slope unreinforced. Meanwhile, the clay embankment slope reinforced inclined bamboo piles with diameters of 6, 10, 15 cm increase 1.503, 1.512, 1.515, respectively. The main principle of reinforcement in slopes is to provide stabilizing forces. When bamboo piles are inserted in the slope, additional pullout resistances are provided, so this structure changes safety of factor. The simulation results also indicate that the safety factor depends on the diameter of bamboo piles. With the larger diameter of bamboo piles, the pullout resistance was increased.

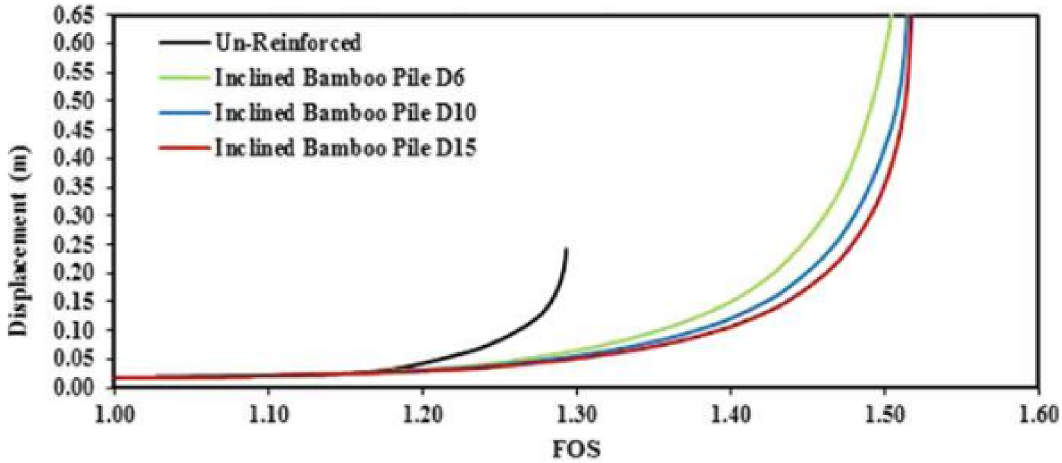

Fig. 3 Displacement versus FOS of the slope model

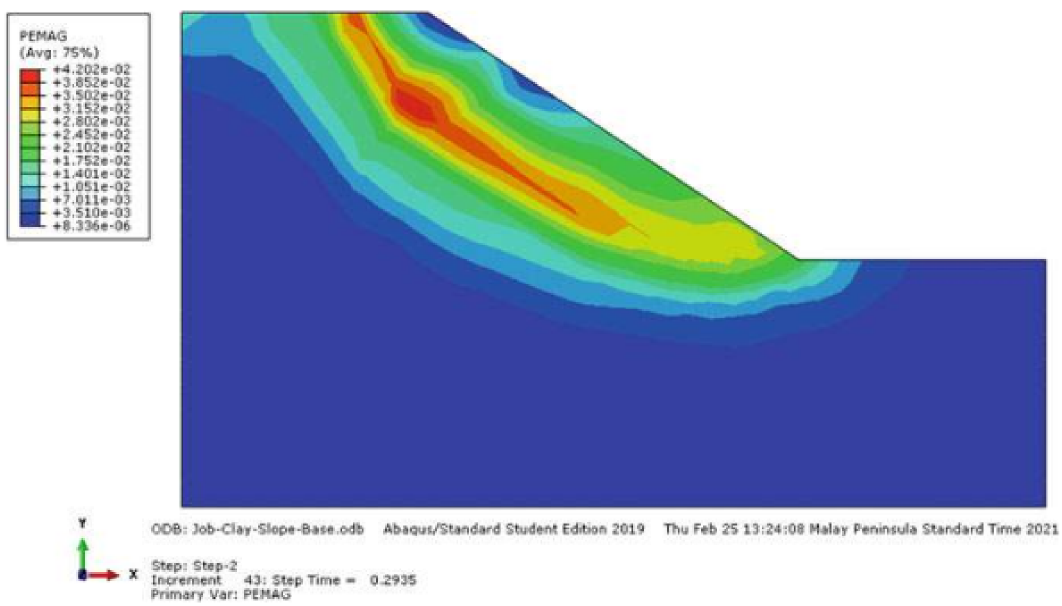

Fig. 4 The equivalent plastic strain (PEMAG) slope model unreinforced

4.2 The Equivalent Plastic Strain (PEMAG)

The bamboo piles are inserted in the slope, and it also changes the stress–strain and failure mechanism. Figure 4 until Fig. 7 shows the equivalent plastic strain (PEMAG) at increment 43rd for unreinforced and 158th for reinforced slope. In the figures, the contour indicates the location of the potential failure of the slope. The different contours shown in the figures indicate the location where the slope failure started (Figs. 5, 6 and 7).

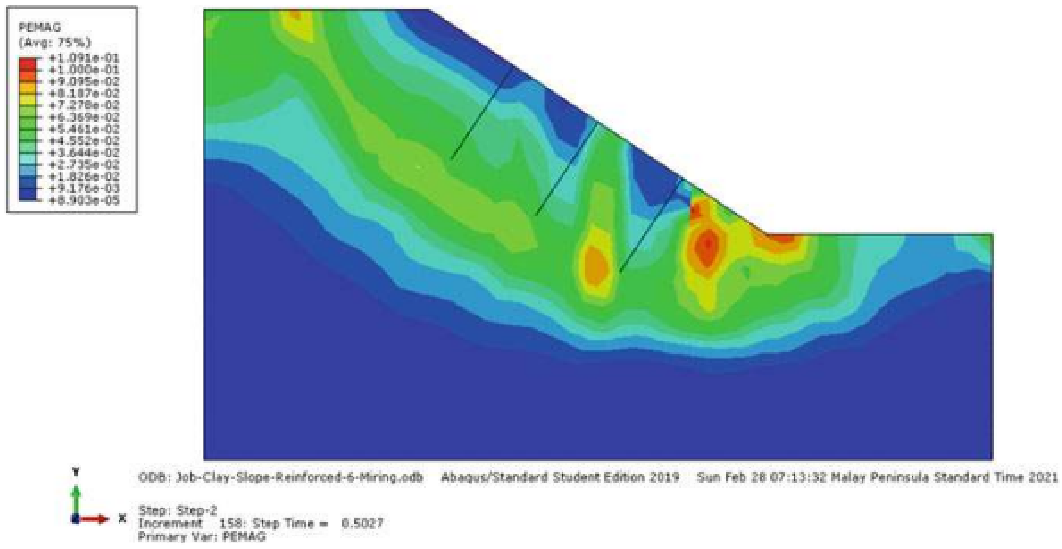

Fig. 5 The equivalent plastic strain (PEMAG) slope model reinforced with inclined bamboo piles diameter 6 cm

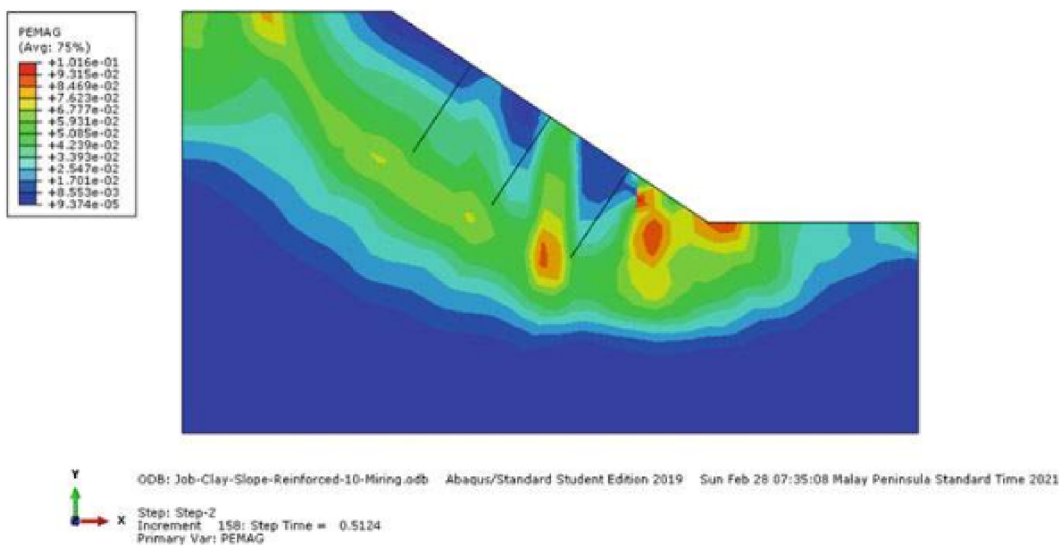

Fig. 6 The equivalent plastic strain (PEMAG) slope model reinforced with inclined bamboo piles diameter 10 cm

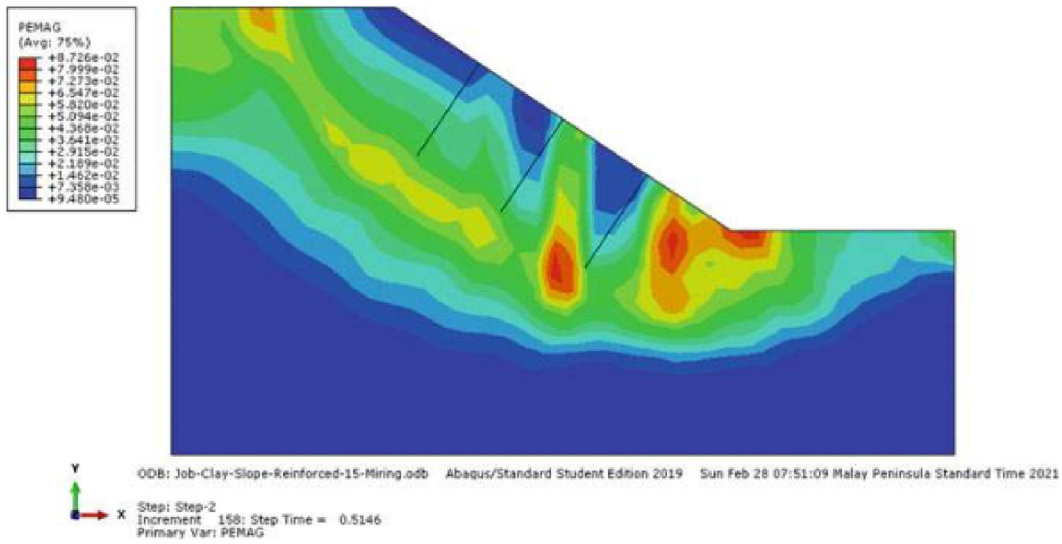

Fig. 7 The equivalent plastic strain (PEMAG) slope model reinforced with inclined bamboo piles diameter 15 cm

5 Conclusion

According to the 2D FEM simulation of soil embankment slope reinforced with inclined bamboo piles with the shear strength reduction (SSR) using ABAQUS SE software, the factor of safety (FOS), and the failure mechanism of the slope were obtained as follow:

1. The factor of safety (FOS) of the slope depends on the diameter of bamboo piles. The clay embankment slope reinforced with inclined bamboo piles with diameter 6, 10, 15 cm increase 1.503, 1.512, 1.515, respectively.
2. When the bamboo piles were inserted in the slope, it also changes the stress–strain and failure mechanism. The equivalent plastic strain (PEMAG) contour indicates the location of the potential failure of the slope.
3. The shear strength reduction (SSR) finite element method (FEM) can be used as an alternative for slope stability analysis of soil embankment slope model reinforced with inclined bamboo piles.

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