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# Laboratory and modelling investigation of root-reinforced system for slope stabilisation

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**Abstract**

Most natural slope failures are induced by seepage and/or rainfall. Soil bioengineering is an environmentally friendly method which employs vegetation to reinforce the soil in sloping terrain. The vegetation can contribute to slope stability in two ways, mechanical and hydrological. This paper demonstrates the effect of a vegetation root matrix on a soil slope and focuses on mechanical reinforcement using an example of vetiver grass. Vetiver grass (*Vetiveria nemoralis A. Camus*) specimens, grown for under a year, were used in this study. The investigation programme includes root observations, direct shear tests and centrifuge model tests. The growing rate of the vetiver roots and the root area ratios were observed during the tests. The cohesion and angle of internal friction of root-reinforced soils were determined from a standard direct shear apparatus and a large direct shear apparatus. A series of centrifuge tests was carried out to demonstrate the effect of vegetation on seepage- and rainfall-induced slope failures. The results indicate that the vetiver roots showed rapid growth within a year and that the shear strength of the root-reinforced soil was significantly increased by the bundle of roots. The results also reveal that the bundle of root fibres in the centrifuge model tests helped to reduce the deformation of the soil slope due to instability by increasing the shear strength of the slope.


*Keywords:* Centrifuge modelling; Laboratory tests; Slopes; Vegetation

## 1. Introduction

Landslides are one of the most widespread earth processes which involve the failure of sloping earth material. Landslides are considered to be one of the most important problems in geotechnical engineering. This is because landslides are usually among the most costly natural disasters in terms of human fatalities and economic loss. In recent years, natural slope instability has increased especially in tropical monsoon zones, such as Southeast Asian countries. There are several factors that can cause natural slope failures, such as geological activity, hydrological influence and human interference, but seepage and rainfall are the main factors. The infiltration of rain water can cause a rise in the groundwater level and an increase in pore water pressure or a decrease in the matric suction of the soil. In addition, the physical process of rainfall infiltration into the ground and its seepage through the soil layers have been studied by hydrogeologists, soil scientists and geotechnical engineers (Ng and Shi, 1998).

To increase slope stability, several methods have been used, such as soil nails, retaining structures, geosynthetic

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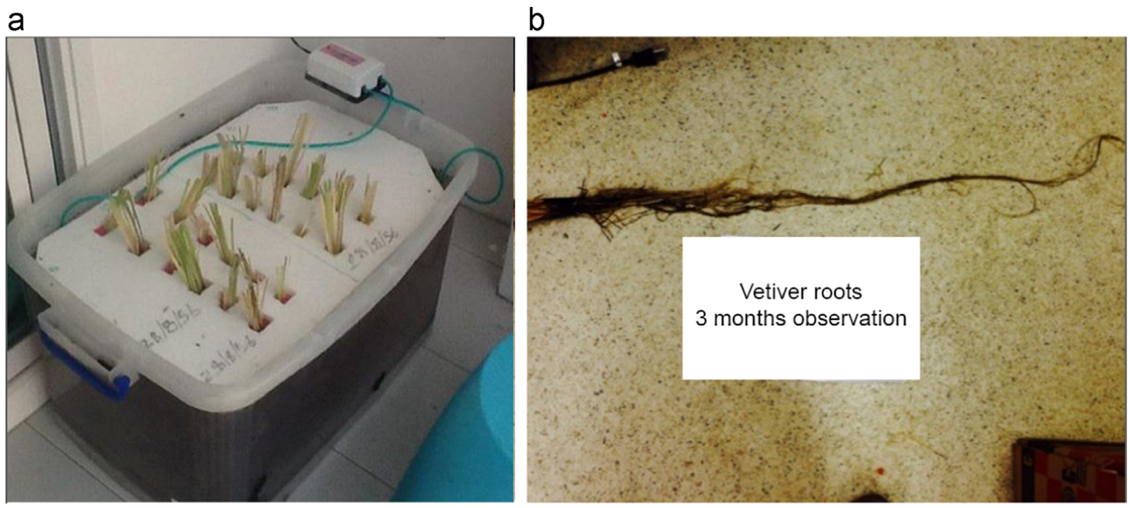


Fig. 1. (a) Vetiver specimens grown in hydroponic conditions and (b) root observation.

Table 1
Chemical test results of planted soil.

| Test | Value | Level |
|---|---|---|
| Alkaline–acidity (pH) | 6.7 | Medium |
| Organic (O) | 12.13% | High |
| Phosphorus (P) | 61 mg/kg | High |
| Calcium (Ca) | 7859 mg/kg | High |
| Magnesium (Mg) | 974 mg/kg | High |
| Potassium (K) | 1996 mg/kg | Very high |

reinforcements and shotcrete. However, these methods are costly and may not be suitable for natural slopes. In ancient times, the use of vegetation in soil slopes and earthen covers for landfill was well recognised, and it is still well-known that the effect of vegetation plays an important role in increasing soil slope stability. Soil bioengineering is an environmentally friendly alternative that uses vegetation for improving slope failure. There are two main contributions whereby vegetation can affect slope stability, i.e., hydrological and mechanical processes. Firstly, changing the soil moisture regime and drawing the water from the soil via evapotranspiration (Ali and Osman, 2008) can increase soil suction. Secondly, the roots of vegetation can enhance slope stability by increasing the shear strength of the soil (Gray and Sotir, 1996; Wu et al., 1979). The role of vegetation in slope stability has been defined by Greenway (1978), Coppin and Richards (1990) and Wu (1995). In addition, this method is applied to prevent shallow failure as well as soil surface erosion in natural slopes.

Vetiver grass (*Vetiveria nemoralis A. Camus*), was promoted to help prevent soil erosion and water runoff or infiltration by the World Bank in the 1980s, and is important in soil bioengineering (Greenfield, 1996). Recently, the Chaipattana Foundation and the Office of the Royal Development Projects Board, Thailand, have promoted the use of vetiver grass for soil and water conservation for many royal projects in Thailand. Vetiver grass is fast growing and requires low maintenance. The length of vetiver roots has been seen to grow up to 2–3.5 m (Chinapan et al., 1997). Vetiver roots can penetrate deep into the ground to form a net-like barrier capable of filtering silt and containing top soil. Normally, shallow failure is a typical failure mode of soil slopes in regions with prolonged and heavy rainfall; it always occurs 1–1.5 m in depth from the surface (Gray and Leiser, 1982). Hence, shallow failure of natural slopes could be prevented by the rooting depth of the vetiver grass which interlocks with the soil particles. Previous research has investigated the tensile root strength properties of vetiver grass for resisting shallow failure and superficial erosion (Hengchaovanich and Nilaweera, 1998).

Recently, the stability of model soil slopes that were reinforced by plant roots has been investigated by Sonnenberg et al. (2010) at 15*g* using a centrifuge. By continuously raising the groundwater table in model slopes, contributions of mechanical root reinforcement were back-analysed based on observed slip surfaces at failure. Takahashi et al. (2014) studied the effect of vegetation structures on seepage-induced slope failure using a 50*g* centrifuge model. Eab et al. (2014) continued the study of Takahashi et al. (2014) focusing on a root-reinforced slope subjected to rainfall infiltration using a rainfall simulator in the centrifuge.

The aim of this paper is to present an investigation programme of the vetiver root-reinforced system for slope stabilisation using a laboratory technique. The shear strength parameters of root-reinforced soils were determined using standard direct shear tests for single vetiver and large direct shear tests for a group of vetiver. The growing rate of the vetiver roots and the root-area ratios were observed by direct measurement and an image processing technique, respectively. Finally, a series of centrifuge model tests using a seepage and rainfall simulator to demonstrate the effectiveness of roots in shallow depths against slope instability was also performed.

## 2. Experimental investigation

In the soil bioengineering approach, the selection of suitable vegetation is the first important step. Vetiver grasses have been