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Performance of an instrumented slope covered with shrubs and deep-rooted grass

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Abstract

Green technology, an integrated design approach that combines vegetation and engineering design methods, can be applied to improve slope stability. Orange Jasmine is a small tropical evergreen shrub which has deep root systems and is considered to be a drought-tolerant plant that adapts well to a wide range of climatic and soil conditions. It can also grow in infertile soils, limestone soils or loam. Vetiver grass has been widely cultivated in many tropical and subtropical regions of the world for soil and water conservation, land rehabilitation, and embankment stabilization. Vetiver grass has deep roots (2–4 m) and adapts well under extreme conditions of temperature, soil, moisture, soil acidity, and alkalinity. The role of Orange Jasmine and Vetiver grass in minimizing rainwater infiltration, for improving the stability of slopes, was investigated on a soil slope in Singapore with its tropical climate. Two slope sections, covered with Orange Jasmine and Vetiver grass, were instrumented with tensiometers, installed at different depths within the slope, and a rainfall gauge. The instruments were connected to a real-time monitoring system to study the pore-water pressure, the rainfall, and the groundwater level in the slope throughout a one-year period. The pore-water pressure characteristics within the slope sections covered with Orange Jasmine and Vetiver grass are analyzed and presented in this paper. The analyses indicate that both Orange Jasmine and Vetiver grass played a significant role in reducing rainwater infiltration into the slope, minimizing the loss of matric suction, and hence, the shear strength of the soil during rainfall and, as a result, maintained the stability of the slope. Vetiver grass and Orange Jasmine appeared to be similar in effectiveness in terms of reducing the rainwater infiltration into the slope.

Keywords: Vetiver grass; Orange Jasmine; Slope stability; Rain; Infiltration; Tropical; Instrumentation; Matric suction

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1. Introduction

Rainfall-induced slope failures occur in response to climatic changes in many parts of the world (Jeng and Lin, 2011; Kawamura and Murab, 2013; Kitamura and Sako, 2010; Zhang et al., 2011). Many of the slope failures constitute socio-economic problems caused by the resulting damage and destruction to infrastructures and agricultural lands. Therefore, it is important to have a preventive measure for slopes that are prone to failure due to rainfall. One possible preventive measure for rainfall-induced slope failures is the use of green technology.

Green technology is an integrated design approach that combines vegetation and engineering design methods to mechanically reinforce slopes, to control erosion, to improve the aesthetics of the environment, to provide visual and noise barriers, and to improve biological diversity (Woods, 1938; VanDersal, 1938; Marchent and Sherlock, 1984; Greenway, 1987; Coppin and Richards, 1990; Menashe, 1993; Meyers, 1993; Greenwood et al., 2007; Norris et al., 2008; Schwarz et al., 2009; Glendinning et al., 2009; Ali et al., 2012). Gray and Leiser (1982) summarized several benefits of woody vegetation, such as root reinforcement, soil moisture modification, buttressing and arching, and increased stability brought about by the surcharge or the weight of the vegetation. Zeimer (1981) showed that the strength of the soil increased linearly as the root biomass increased. Zeimer (1981) also reported that live bush roots were twice as strong as conifer roots of the same size. Zeimer and Swanston (1977) found that roots add strength to the soil by vertically anchoring through the soil mass in the bedrock and by laterally tying the slope together across zones of instability.

Orange Jasmine, *Murraya exotica L.*, is also known as mock orange, satin wood, honey bush, China-box, café de la India, mirto, azahar, naranjo, jazmin, limonaria, and bun (Little et al., 1974). It is a small tropical evergreen shrub which can grow up to 7 m tall and 13 cm in stem diameter, and flowers throughout the year. It has white fragrant flowers and glossy leaves, and is grown as an ornamental tree or hedge. Its stems are supported by taproots with lateral roots and a mesh of fine roots. Seedlings quickly develop deep root systems (Francis, 2003) and grow at a moderate rate. Orange Jasmine has a typical life span of at least 15 years and needs little care. Orange Jasmine can adapt to a wide range of conditions. For example, it can be found in Puerto Rico where it grows in areas with about 750–1900 mm of annual precipitation and from nearly sea level to elevations of 1300 m (Neal, 1965). It is native of China, South and Southeast Asia, and Australasia.

Vetiver grass, also known as *Chrysopogon zizaniodes*, is a perennial grass of the Poaceac family from India. Vetiver has been widely planted in many tropical and subtropical regions of the world for soil and water preservation, land rehabilitation, and embankment stabilization. It has been used in Brazil (Grimshaw, 1994), Fiji (Truoung and Gawander, 1996), Malaysia (World Bank, 1995), the West Indies, and South Africa (National Research Council, 1993). Vetiver grass has deep roots, about 2–4 m in depth, that collect water and provide reinforcement to slopes. It is highly tolerant of extreme conditions such as temperature (from -10° to 48 °C in Australia), soil moisture, soil acidity, and alkalinity (pH from 3.3 to 10.5).

When the roots interact with the soil in which it is grown, a new composite material comprising roots with high tensile strength is formed. The shear strength of the soil is enhanced by the root matrix (Styczen and Morgan, 1995). In this paper, the effect of Orange Jasmine and Vetiver grass in increasing the shear strength of soil and in minimizing rainwater infiltration, for maintaining the stability of slopes during rainfall, was investigated on a soil slope in Singapore with its tropical climate.

2. Site description

Old Alluvium covers an area of 7200 ha, or about 15% of Singapore, and can be found in the eastern and northwestern areas. The soils are the result of rapid deposition by a braided river system of weathered materials from slopes of granite and low grade metamorphic rock from Malaysia (Gobbett and Hutchison, 1973; Stauffer, 1973; PWD, 1976). Old Alluvium comprises sand, gravel, silt, and clay, but mainly silty and clayey sand with a fines content of about 20–30%. The color varies from white, yellow, red, and brown to mixtures of these colors (Ni et al., 2006).

A slope located in Old Alluvium, which had no prior record of slope failure, was chosen for the construction of the green technology slope. One portion of the slope (50 m^2) was covered with Orange Jasmine, another portion of the slope (50 m^2) was covered with Vetiver grass, and another portion of the slope was the original slope with cow grass cover. The slope has a height of 8.2 m, a length of 22.6 m, and a slope angle of 20°. The slope is shown in Fig. 1.

3. Design of slope and field instrumentation

Orange Jasmine and Vetiver grass were planted in June and September 2009, respectively. The slope was excavated to a depth of 200 mm below the top soil surface, as shown in Fig. 1. The study area was demarcated by a trench for the insertion of aluminum impermeable walls and for the

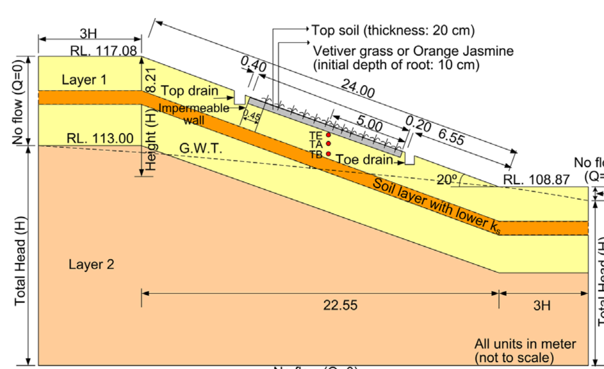

Fig. 1. Schematic diagram of slope with Orange Jasmine and Vetiver grass.