Biochar Capillary Barrier System: Thailand's Strategies and Approaches for Resilient and Sustainable Nature-based Solutions to address Climate Change Impacts on Road Engineering

Dr Auckpath Sawangsuriya, Roads Association of Thailand[1]

Assoc. Prof. Apiniti Jotisankasa[2]

Introduction

Residual soil and weathered rock slopes are typically found in mountainous and hilly terrains in most tropical regions like Thailand and ASEAN countries. These earth slopes are often in the unsaturated condition with negative pore-water pressure or matric suction. The presence of matric suction is a favourable condition because it has a beneficial effect on the shear strength of unsaturated soils and thus increases the stability of slopes. However, when rainfall infiltrates into a slope, the pore-water pressure increases, the matric suction decreases, and the stability of the slope is reduced. This phenomenon causes the slope to become more prone to failure. This is commonly known as rainfall-induced slope failure and is one of the most destructive natural disasters; they are often random and sudden events that are often hard to predict.

According to Iverson (2000) and Polemio & Petrucci (2000), rainfall is the main cause of landslides and slope instability. Rainfall-induced slope failures and surface erosions have been increasingly becoming more severe in Thailand and many other ASEAN countries tropics climates due to more frequent extreme climate conditions and potential climate impacts (severe storms, floods, violent monsoons, strong typhoons, rises in sea levels, frequent tidal surges, prolonged drought, forest fires, prolonged and heavy rainfall, etc.). This climate extremity, in addition to improper urbanization and natural resource exploitation in mountainous and hilly terrains, increases the potential risks of landslides and surface erosion, resulting in catastrophic damage to residential and land transportation infrastructure, a reduction in agricultural productivity, degradation of wildlife and natural forests, time losses and loss of human life.

With the increasing severity of landslides and surface erosion, limited annual government budgets, and global concerns related to environmental issues, the nature-based solution, e.g. an application of vegetative cover placed on top of the capillary barrier system (CBS), is becoming an attractive solution because of its lower cost, higher sustainability, more environmentally friendly measures as well as improved aesthetics compared to traditional concrete-based solutions. CBS is a two-layered cover system that consists of an upper finer-grained layer overlying a coarser-grained layer; it is designed based on unsaturated soil mechanics. This technique has been continuously developed and investigated in several slope stabilizations and erosion control applications (Grimshaw 1994; Khire et al. 2000; Yang et al. 2004; Tami et al. 2004; Zornberg et al. 2010; Rahardjo et al. 2012; Rahardjo et al. 2016; Satyanaga et al. 2021). It can be effectively used to improve slope stability during rainfall by maintaining high values of matric suction in the underlying soil (e.g. Rahardjo et al. 2016), resulting in stable conditions of the slope at all times, and thus mitigate rainfall-induced slope failures during the most critical

[1] Civil Engineer-Expert Level at Bureau of Road Research and Development, Department of Highways, Bangkok, Thailand.
[2] Department of Civil Engineering, Kasetsart University, Bangkok, Thailand.

rainfall events (e.g. Grimshaw 1994; Khire et al. 2000; Yang et al. 2004). By using this technique, it is possible to use ‘biochar’ in the fine-grained upper layer.

Biochar is a carbon-enriched material produced from the thermochemical conversion of various biomass wastes such as wood waste, agro-waste, food waste, manure waste, and municipal/industrial sludge (Zhang et al. 2022). Although this application for slope stabilization has been traditionally used as a landfill cover to reduce water infiltration into protected waste materials, its application to slope stability as an alternative means to effectively control suction is still limited to only relatively warm climates (Scarfone et al. 2022); it has been rarely applied to slopes in the tropics, including Thailand. The main objective of this article is, therefore, to investigate the performance and effectiveness of biochar capillary barrier systems for resilient and sustainable nature-based solutions (Figure 1).

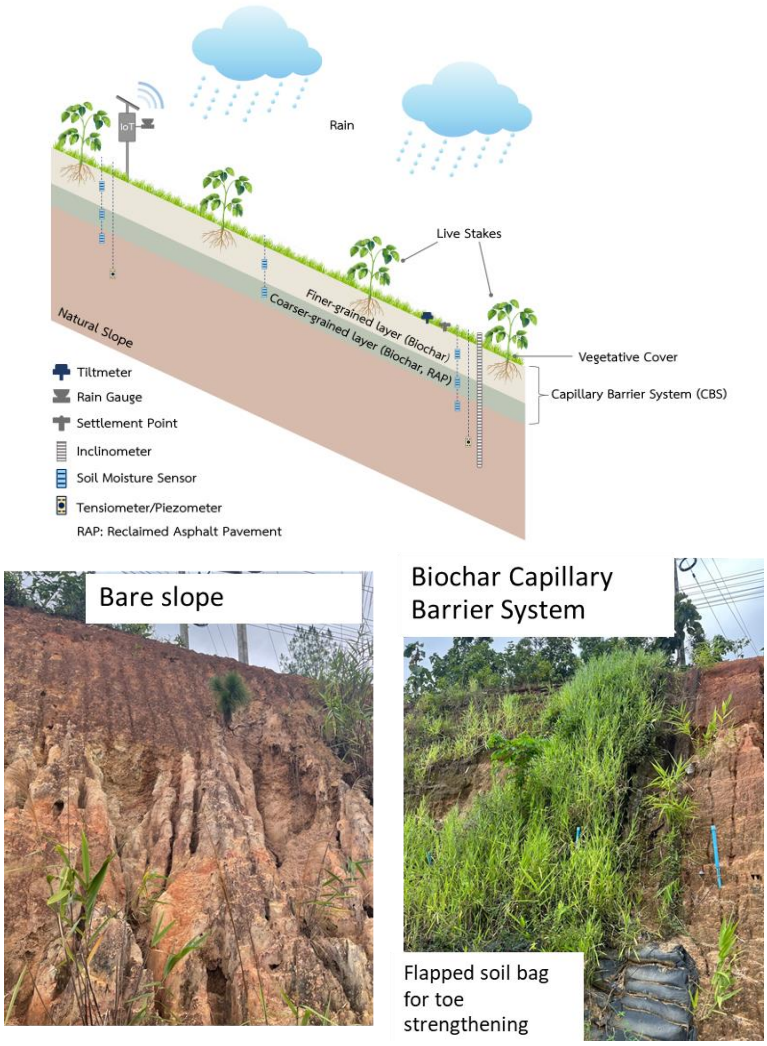

Figure 1: Biochar capillary barrier system

Background

The CBS works based on the contrast between the unsaturated hydraulic properties of the finer and coarser layers. The coarser layer typically has a very low degree of saturation and corresponding unsaturated hydraulic conductivity, which decrease many orders of magnitude with decreasing degrees of saturation. Since the unsaturated hydraulic conductivity of the coarser layer is typically very low and can be many orders of magnitude lower than that of the finer layer, the coarser layer acts as an almost impermeable barrier. This is in contrast to what would occur under fully saturated conditions when the hydraulic conductivity of the coarser layer would be much higher than that of the finer layer.

Infiltrating water starts to enter the finer layer At the top of the slope. The suction at the interface between the finer and coarser layers is relatively high since the water content is low; the coarser layer behaves as an impermeable layer and water is diverted laterally down the slope within the finer layer due to the effect of gravity. At the middle of the slope, the amount of water flowing laterally within the finer layer increases. The degree of saturation at the base of the layer is greater than that further up the slope, and the corresponding suction at the interface is lower. If the suction at the interface decreases to a point where the degree of saturation of the coarser layer increases until continuous water channels are formed within the coarser layer, the coarser layer becomes highly hydraulically conductive, and breakthrough occurs into the coarser layer and eventually into the underlying soil. No more water can be diverted laterally beyond this point on the slope, and infiltration water percolates into the coarser layer. In accordance with lateral drainage, rainwater can also be removed from the CBS by evaporation and evapotranspiration.

Performance and Effectiveness of Biochar Capillary Barrier Systems

The hydraulic characteristics of the nature-based solution for slope resiliency and sustainable mitigation to rainfall-induced slope failure and surface erosion were comprehensively investigated along cut slopes and fill slopes in National Highways in the northern part of Thailand. They included: Highway No. 1192 at km post 11+500, Highway No. 118 at km post 46+700, Highway No. 21 at km post 324+151, and Highway No. 21 at km post 329+700. The topographical conditions at these sites are mountainous and hilly. They are commonly prone to rainfall-induced slope instability under natural and engineered systems due to their slope composition of decomposed granite and colluvium deposits as well as its average annual rainfall of 1,200 – 1,300 mm.

These four experimental sites were installed with a series of field instrumentation consisting of soil moisture sensors, piezometers, tensiometers, an inclinometer, tiltmeters, a rain gauge, and settlement points. They were located near the crest, middle, and toe on each site of the slope.

In addition to the pore-water pressure, soil moisture, and soil movement data collected from the sites over two years, the physical and hydraulic properties of the biochar nature-based solution were determined in the laboratory. The specific gravity (G_s) of the biochar was approximately 1.35. The particle size distribution (PSD) and the soil-water characteristic curve (SWCC) of the biochar is illustrated in Figure 2.

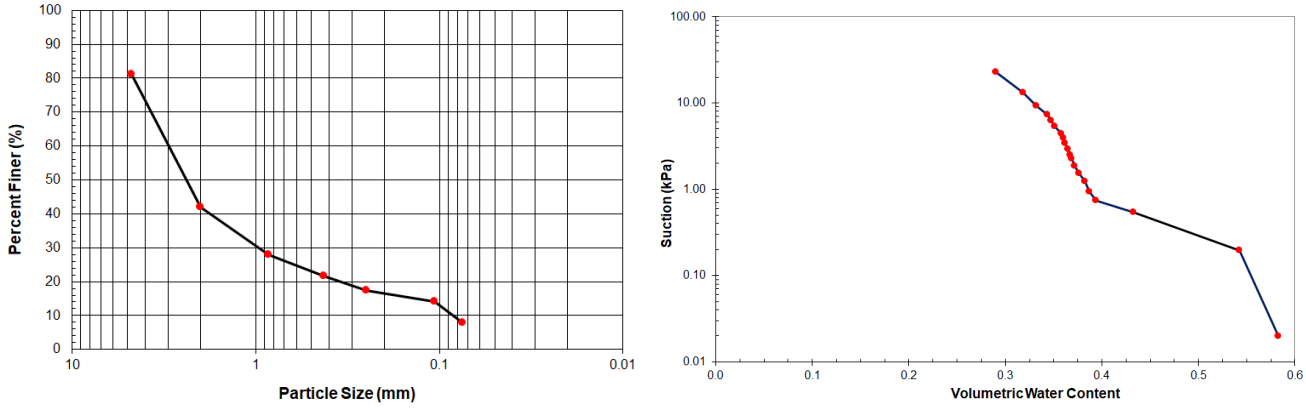

Figure 2: PSD and SWCC of biochar

The performance and effectiveness of the nature-based solution in terms of minimizing rainwater infiltration into the slope and increasing stability against rainfall-induced slope failure and surface erosion were investigated based on the results of the field monitoring as shown by the optimal preservation of negative pore-water pressure in the biochar CBS treatment (see Figure 3).

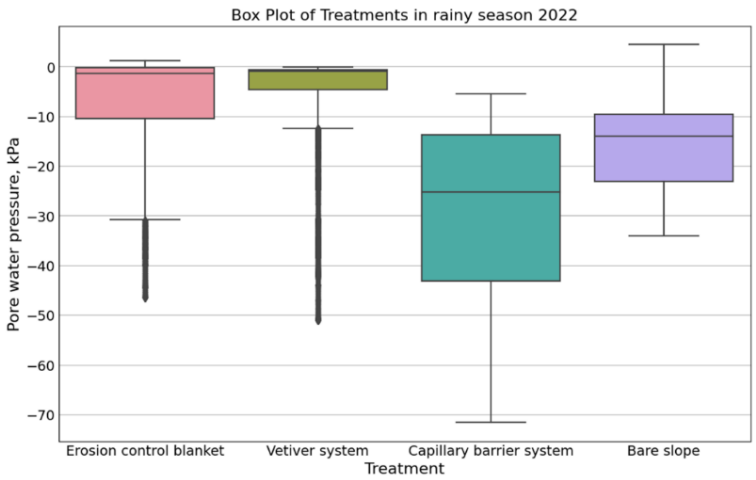

Figure 3. Box-plot of pore-water pressure of different treatments showing the better performance of the biochar capillary barrier system in preserving negative pore-water pressure

Recommendations

A biochar capillary barrier system is timely and efficient for the adoption of strategies and approaches for resilient and sustainable nature-based solutions in Thailand. This technique also supports the advancement of effective, resilient and sustainable mitigation with respect to the increase and the faster recovery of highway slopes' factors of safety under extreme events and climate change impacts. Biochar is generally produced using waste sources such as biosolids, wood, or farm manure. It can be added to topsoil on highway bioslopes to improve topsoils, decrease hydraulic conductivity, and increase the water-holding capacity of topsoil. Therefore, the application of biochar in capillary barrier systems can be potentially considered as a cost-effective state-of-the-art solution for highway slope resiliency, sustainability, environmental-friendliness, and aesthetics in Thailand and other ASEAN countries.

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