Measurement 81 (2016) 13–25

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

The influence of rainfall intensity on soil loss mass from cellular confined slopes

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A R T I C L E   I N F O

Article history:
Received 17 April 2014
Received in revised form 5 March 2015
Accepted 3 November 2015
Available online 1 December 2015

Keywords:
Erosion control
Soil confinement
Soil erosion
Slope stability

A B S T R A C T

Cellular confinement systems serve as effective solutions to any erosion control project. Small model confinements (triangular, circular, and rectangular) measuring 50, 100, and 150 mm, with a depth of 10 mm, were embedded in soil samples at slope angles of 30°, 40°, 50°, and 60°. The observed soil mass losses for the confined soil systems are much smaller. As a result, the size of confinement, rainfall intensity, and slope angle have a direct effect on the soil mass loss results. The triangular and rectangular confinement systems showed the lowest and highest soil loss masses, respectively. The slopes also failed much faster in the unconfined system than in the confined slope.

1. Introduction

Slope failures in the tropical areas are directly related to the rainfall intensity. Refining techniques to avoid rain infiltration play an important role to reduce slope failures, especially for the risky occupied areas close to big cities [1]. Wetting depth in a slope is a key indicator to properly assess the rainfall-induced slope instability. This rainfall infiltration has potential to induce shallow slope failures. It is necessary to control the field infiltration and soil erosion due to a natural rainfall [2]. There are many ways to manage stormwater runoff. A variety of hard armour and soft armour resources are available to repair deteriorating drainage channels. An ideal method to prevent soil erosion is by using the natural vegetation of the channel bed. Aside from protecting the soil surface from the impact of raindrops, it shields the soil from the scouring effect of overland flow and decreases the erosive capacity of the flowing water by reducing its velocity [3]. Merrill [4] investigated the use of gabions in stormwater management and erosion control. The gabions can be used as hard armour to control erosion in soil-retention and hydraulic applications. Geosynthetics as engineered solutions to erosion control are proving their worth in several projects. Tice [5] also explored the use of geosynthetic materials for erosion control. He introduced several successful case histories of using geosynthetics as erosion-control systems in the USA [5].

Cellular confinement systems serve as effective solutions to any erosion control project. They stabilize the slopes, slow the velocity of rainfall and/or stormwater, and prevent soil erosion along the slope, particularly in high-rainfall seasons in tropical areas. They also allow the water to move or stay between the confined surface and the subgrade while the vegetation grows through them. They act like gabions; however, gabions (also known as rock cages) are used as a confinement system for stone. Goldberg [3] also studied channel protection systems. From his research, we conclude that hard armours can be

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http://dx.doi.org/10.1016/j.measurement.2015.11.007

used only when flow velocities exceed the capacity for vegetation. These methods include articulated concrete blocks, poured concrete, riprap, gabions, and confinement systems. Aird [6] investigated channel linings and erosion control systems extensively. He highlighted challenges to slope stabilization such as problems with blankets, soil nails, mesh, and cellular confinement systems. Then, from another research paper published in the same journal, *Erosion Control*, he designed an erosion-control system called "Open-Cell ACB" to slow down the velocity of water and retain the soil simultaneously [7].

Haghighi et al. [8] investigated on the improvement of hole erosion test and results on reference soils. They tried to characterize the internal erosion of soils based on laboratory tests with a hole erosion test apparatus. A new version of the apparatus with improved instruments and an interpretation method is proposed, estimating the erosion rate based on the turbidity of the outflow and independent of hydraulic charge as reference soil textures, several remolded kaolinite–sand mixtures were tested, and the results were analyzed with the proposed and existing interpretation methods.

Galvão et al. [1] studied on the bioengineering techniques associated with soil nailing applied to erosion control and slope stabilization to control erosion and prevent rain-induced failures in a 35-m-high rocky slope (Ponteio Slope) the bioengineering associated with nailing techniques were implemented. After several previous attempts, before 2003, the association of "soil nailing" and bioengineering techniques were cost-effective and succeeded in stabilizing the slope.

In heavy rainfall, confinement systems can help dissipate some of the energy in the water flow through the voids between the individual confined cells [4]. According to Morgan [9] rainfall intensity of 60–75 mm/h results in rill erosion by overland flow. Dunne [10] performed a similar investigation, where rainfall intensity of 70 mm/h was reported for rill erosion in Kenya. Consequently, rainfall intensity (I) ranging from 20 to 75 mm/h was selected in the present study.

Most of the previous work done to evaluate soil erosion is basically in a form of semi-empirical expression. Different researchers employed different parameters, thus inevitably, it will resulted in different conclusion. Different in finding and results are expected, thus the development of empirical relationship for this work was thought to be invaluable in comparing with the works of other researchers. Besides, different approaches have been employed to estimate rates of erosion. In the past, estimates of erosion rates have been based on field measurements. Analyses were simply based on a linear relationship. However, over time, prediction techniques have been developed and improved with advances in computer technology, and estimates using mathematical models have been increasingly used. Mathematical modeling is a tool for the prediction of rates of erosion. A few different solutions have been proposed due to the conflicting ideas and assumptions which have been advanced. As a result, different values of erosion rates have been obtained.

As stated, a full-scale test would probably be the most reliable way to collect useful information for predicting erosion rates on a slope. Often, it is not viable to conduct such a full-scale test and, moreover, only a limited number of tests can be carried out due to economic and time constraints. However, a test on a small-scale model in the laboratory would involve scaling errors, since slope configuration and rainfall are important factors determining the erosion behavior of slopes.

Although a number of field tests and small-scale model tests have been carried out previously, few attempts have been made to compare the results obtained from each type of test. In a study performed by Morgan [9], small-scale models were used to obtain the overland flow and sediment with a known quantity of runoff for different types of soil. However, while performing comparison studies on model runoff and sediment with the field test, the existence of a scale error between the model and the prototype was observed. They attributed this to the variation of the internal friction angle and shear strength of the soil with the detachability level.

Table 1
Test parameters employed by previous researcher.

Researcher	Plot size	Bounded or unbounded	Slope angle	Type of test	Rainfall intensity	Rainfall duration Or Rainfall	Type erosion
Morgan et al. [24]	22 m × 1.8 m	Bounded	Not mentioned	Field test	Not mentioned	Not mentioned	Rill (Sediment)
Hudson [16]	90′ × 24′ 3″ and 100′ × 21′ 9″	Bounded	6.5%, 4.5%, and 3%	Field test	Not mentioned	Not mentioned	Sediment and mechanics
Morgan et al. [24] University of Leuven	4.0 m × 0.4 m	Not mentioned	Specified gradient	Laboratory test	Specified runoff	Specified runoff	Rill (Sediment)
Morgan et al. [24] Silsoe College	1.0 m × 0.8 m	Not mentioned	Specified gradient	Laboratory test	Specified runoff	Specified runoff	Rill (Sediment)
Hudson [18]	Large area	Unbounded	Not mentioned	Field test	Not mentioned	Not mentioned	Splash (Gerlach trough)
Sreenivas et al. [19]	Large area	Not mentioned	Not mentioned	Field test	Not mentioned	Not mentioned	Splash (Small Funnel)
Sheridan et al. [20]	3 m × 0.8 m	Not mentioned	Specified gradient	Laboratory test	100 mm h^{-1}	30 min	Rill and interill (Sediment)
Sheridan et al. [20]	20 m × 70 m, and 20 m × 130m	Not mentioned	Specified gradient	Full Scale test	Not mentioned	Not mentioned	Rill and interill (Sediment)