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A wave flume experiment for studying erosion mechanism of revetments using geotextiles

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A B S T R A C T

Unfavorable erosion to a revetment can affect the stability of the bank and may jeopardize the safety of adjacent structures, thus improvement work is needed to increase the stability of the revetment as well as reducing the possibility of failure. The use of geotextiles as a protection material for banks is not only environmentally friendly, but also stable in the long run. However, improper design of geotextiles may cause considerable loss of soil, which might result in failure. The actual flow behavior in revetments using geotextiles is rather complicated and can be categorized into three zones, namely, the uni-directional flow zone, the cyclic flow zone, and the tangential flow zone. In this study, a wave flume experiment was performed on model revetments using two kinds of geotextiles as the filter material to prevent erosion induced by cyclic flows. Soil migration behaviors were monitored. Furthermore, two kinds of cover blocks, riprap and concrete blocks, were carefully placed on the revetments in order to avoid puncture and abrasion of geotextiles during construction of revetments. The main purpose of this study is to elucidate the erosion control and filtration performance of soil-geotextile filtration systems under wave action. Two nonwoven needle punched geotextiles were tested. The geotextiles both have the same characteristic opening size, but have a different number of constrictions and different structures. One is a thin double-layer nonwoven material consisting of continuous filaments and the other is a thick one-layer nonwoven material consisting of short fibers.

The test result reveals that two different erosion mechanisms occur during wave action. The cyclic wave loadings triggered higher excess pore-water pressure in the upper part of the model and resulted in soil collapse. The geotextile with a higher number of constrictions produced more serious collapse than that with a lower one. At the middle part of the revetments, soil was eroded by the up-and-down drag force of the flow along the bank. In this zone, the thick geotextile displayed better performance in retarding the drag force on the soil surface. In addition, the opening size and thickness of the geotextile as well as the coverage condition provided by the geotextile were the key factors controlling soil erosion.

1. Introduction

Using geotextiles as a protection material for banks is not only environmentally friendly, but also more stable in the long run. As a result, the use of geotextile filters and armor stones to protect river banks and seashores has become popular. Banks are subject to waves induced by winds or boats. These waves generate short-period hydrodynamic pressures on the revetment surface. Consequently, continuous wave actions can be detrimental to soil and revetment stability (Recio and Oumeraci, 2008). In addition, short-period waves hinder the formation of a stable soil-geotextile filter system. In western Taiwan, rubble-mound groin with geotextiles is used at several tidal lands and harbor structures to protect seashores. Under wave action, the cyclic flow may erode soil and jeopardize the structures on land because of an unsuitable soil-geotextile filtration system (Chen et al., 2008).

A typical cross-section of revetment using geotextile is shown Fig. 1. According to the water flow direction, there exist three zones. In zone 1, above high water level, the groundwater always flows into the water side; hence the flow is uni-directional. Fig. 2a shows the details of a soil-geotextile interface in zone 1. According to the hydraulic direction, the flow can be divided into two components, i.e., the flow perpendicular and tangential to the interface, respectively. A great amount of research has been conducted for

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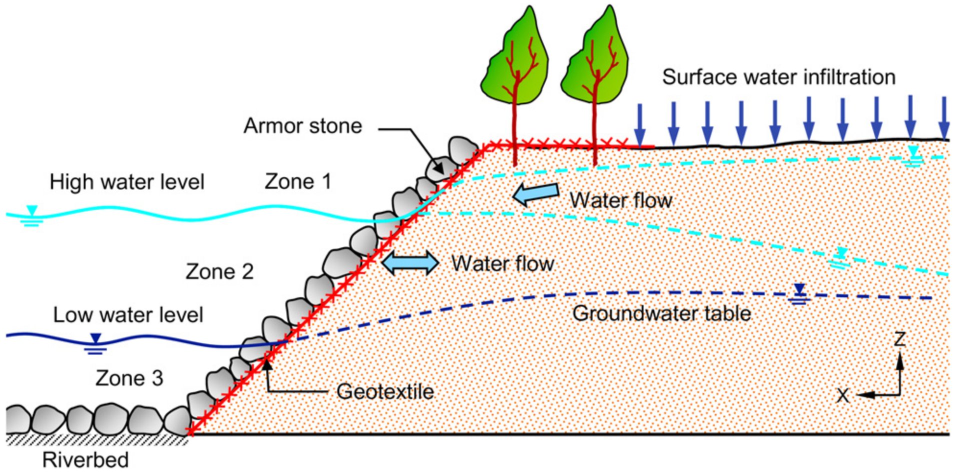

Fig. 1. Typical cross-section of revetments using geotextiles.

geotextile filters under uni-directional flow condition. Selection criteria regarding permeability and retention have been proposed (Chen and Chen, 1986; Luettich et al., 1992; Mlynarek, 2000; Aydilek, 2006). Most of their research focused on the relationship between the soil particle size and the opening size of geotextiles. Moreover, some laboratory tests are frequently adopted, i.e., the gradient ratio test (GR test), the long-term flow test (LTF test), and the hydraulic conductivity ratio test (HCR test), and so forth (Koerner, 2005).

The lowest zone, zone 3, is below low water level. In this zone the percolation rate of water through a soil-geotextile system is insignificant due to a low hydraulic gradient between the water side and the land side. Consequently, the soil erosion behavior along the X–Z plane is not obvious. However, the main erosion problem in this zone is caused by the tangential flow along the bank; this erosion mechanism is different from that of uni-directional flow along the X–Z plane.

Zone 2 occurs between high and low water levels, where the soil-geotextile interface is subject to cyclic flows. The percolation rate of water through a soil-geotextile system is a function of hydraulic gradient. The hydraulic gradient caused by water table fluctuation may be due to sea waves, winds or boats. As shown in Fig. 2b, the flow also has two components like zone 1; nevertheless, the two components are dynamic and cyclic. The erosion behavior induced by the interaction of cyclic perpendicular flow and tangential flow is complicated. Furthermore, design guidances for geotextile filters which take into account dynamic hydraulic loadings are available (Luettich et al., 1992; AFNOR, 1993; Mlynarek, 2000). Certain experiments also have been developed to examine the conditions under dynamic, cyclic and pulsating flows (Cazzuffi et al., 1999; Fannin and Pishé, 2001; Chew et al., 2003; Chen et al., 2008). PIANC (1987) described that the flows in the vicinity of a filter system could be very complex if the waves tended to break, a process further complicated by the presence of an armor stone layer. Additionally, wave flume tests were adopted to investigate the deformation and the hydraulic stability of model revetments (Yasuhara and Recio-Molina, 2007; Recio and Oumeraci, 2007). On the other hand, Huang et al. (2006) used a numerical method to assess the effect of a 5 m high reinforced soil dike with a 2V:1H slope under wave action. The assessment result expresses that the reinforcements provide a significant function of reducing deformations and increasing internal stability of the river dike; however, the finite element model used may not fully represent the complex reinforced soil behavior. Apparently, it is very difficult to accurately reproduce soil hydraulic conditions when conducting a laboratory test. Resultantly, a large-scale test using a wave flume is necessary when different mechanisms take place simultaneously. This study shows the work of reproducing hydrodynamic loadings on revetments, as well as investigating the erosion behavior of soil-geotextile filtration under short-period cyclic flows.

2. Criteria of soil-geotextile filtration

Geotextiles used as a filter must not only remain permeable, but also prevent loss of soil particles. A number of design criteria, such as permeability and retention criteria, have been developed to determine a suitable soil-geotextile filtration system under cyclic flows (CFGG, 1986; PIANC, 1987; Holtz et al., 1998; Mlynarek, 2000).

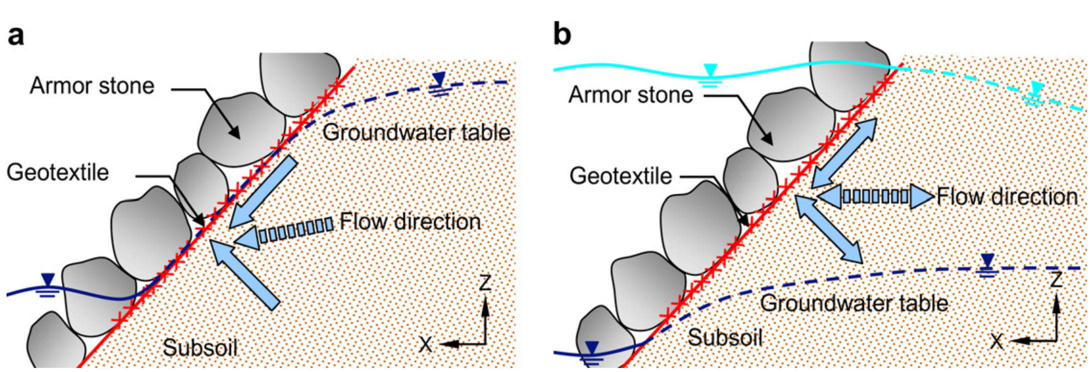

Fig. 2. Detailed views at the soil-geotextile interface subject to flows: (a) zone 1: uni-directional flow, (b) zone 2: hydrodynamic cyclic flow.