+ MODEL

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Journal of Hydro-environment Research xx (2015) 1—14

Journal of Hydro-environment Research

www.elsevier.com/locate/jher

Hydrodynamics in mangrove prop roots and their physical properties

Q6 Xiaofeng Zhang, Vivien P. Chua*, Hin-Fatt Cheong

National University of Singapore, Department of Civil and Environmental Engineering, 1 Engineering Drive 2, Singapore

Abstract

The circulation of water in riverine mangrove swamps is expected to be influenced by mangrove roots, which in turn affect the transport of nutrients, pollutants and sediments in these systems. Geometric properties of mangrove (*Rhizophora* sp.) prop roots in the field were studied through the use of photogrammetric methods and samples of such roots were harvested to determine their material properties in the laboratory. The field studies were carried out in the mangrove areas along some of the coastlines of Singapore where the *Rhizophora* genus are located. We found that the prop roots under tidal hydrodynamic loadings in a mangrove environment can be regarded as fairly rigid on account of a large Young's modulus of about 15 GPa. Physical prop root models were fabricated from downscaling based on field observations with porosity values ranging from 0.96 to 0.98. Flume experiments were performed and measurements of mean flow velocities, Reynolds stress and turbulent kinetic energy (TKE) were made. Our results indicate that the prop roots provide blockage effect on the flow and cause complex secondary flow. The turbulence energy can be generated by both wake and shear, with shear-generated turbulence being dominant in the upper open area between prop roots. A force balance analysis was performed in the nearly uniform flow region to investigate the flow resistance caused by the prop root models. The Chézy roughness coefficient C was found to be 10 and the drag coefficient C_D was found to be 1.2 in the fully developed flow, which agrees with reported field studies in mangrove swamps.

© 2015 International Association for Hydro-environment Engineering and Research, Asia Pacific Division. Published by Elsevier B.V. All rights reserved.

Keywords: Prop roots; Geometrical properties; Material properties; Flow; Turbulence; Roughness coefficients

1. Introduction

Mangrove forests found in most tropical and subtropical areas are characterized by their massive and complex root systems, which may play dominant roles in the dissipation of current and wave energy (Mazda et al., 2007). These natural habitats provide protection for coastal areas and estuaries from storm surge, erosion and tsunamis. In tide-dominated estuaries or rivers, mangroves may not be regarded merely as obstructions to the flow movement, but rather as means to stabilize banks and channels (Nagelkerken et al., 2010). In addition to the mean flow velocities, the characterization of turbulent structures in these environments have also received attention (López and García, 2001).

The mangrove tree is a complex combination of roots, trunk, branches and leaves. Its configuration changes from the bed bottom to the canopy. Mangrove prop roots, found in the genus of *Rhizophora*, are the most representative feature of mangroves and can be characterized on the basis of their geometrical properties. Wolanski et al. (1980) took photographs of *Rhizophora* sp. prop roots, and made two-dimensional sketches of these roots. The fraction of cross-sectional area between two trees that was blocked by prop roots was estimated from these sketches. They found that the blocked area decreased rapidly with root elevation. Mazda et al. (1997) obtained dimensional measurements of tree trunks, prop roots and their geometrical characteristics, such as root heights and root system widths of a number of mangrove trees (*Rhizophora stylosa*) in the field. For a given water depth, the porosity of the mangrove roots system was computed based on the submerged root volume to the total defined volume in order to calculate the drag force induced by the

* Corresponding author.
E-mail address: vivienchua@nus.edu.sg (V.P. Chua).

http://dx.doi.org/10.1016/j.jher.2014.07.010
1570-6443/© 2015 International Association for Hydro-environment Engineering and Research, Asia Pacific Division. Published by Elsevier B.V. All rights reserved.

presence of mangrove roots. Rumbold and Snedaker (1994) measured the mass density of *Rhizophora mangle*, another species under the genus of *Rhizophora*. Their results indicated that the green wood of the mangrove trunk has a higher density than water, but dry mangrove wood with a lower density floats in seawater. The densities of mangrove wood were also reported by Saenger (2002), where they showed that mangrove wood is generally dense so they have resistance to marine deterioration. However, the mechanical behavior of mangrove prop roots received little attention, which resulted in difficulties in simulating the effects of prop roots in physical hydraulic model experiments.

In tide-dominated estuaries, the hydrodynamics are modified by the presence of mangrove roots. Current speeds are decelerated and the directions of flow are altered in deep mangrove forests. Field studies in Coral Creek, Hinchinbrook Island, Australia, showed that velocities in the main creek are as high as 200 cm/s; however, velocities of less than 10 cm/s are found in the mangrove areas (Wolanski et al., 1990). Within heavily vegetated swamps which are 50 m away from the main creek, the peak tidal velocities are less than 7 cm/s (Wolanski, 1992). Katherisan (2003) observed water flow in the Vellar Estuary in southeastern coast of India and found that the tidal velocities within the mangrove swamps are roughly 9 cm/s compared to non-mangrove bank areas where the velocities are between 18 and 20 cm/s. The flow in riverine-type mangrove forests consists of creek and swamp water. Creek water enters or exits the creek, and swamp water floods and ebbs over the banks during each tidal cycle. The current flow inside mangrove swamps close to the creek is predominantly parallel to the creek (Kobashi and Mazda, 2005; Wolanski et al., 1980). However, deep within the mangrove swamps, the flow direction is no longer parallel to the main creek flow, and instead is determined by the water surface gradient between the main creek and swamp (Mazda et al., 2005).

To date few studies have been conducted to understand the influence of prop roots on hydrodynamics, as it is difficult to satisfy hydrodynamic similarity by reducing the scale of vertical configurations of these roots in the laboratory (Mazda et al., 2007). Struve (2003) investigated the influence of mangroves on flow hydrodynamics in a flume using dowels, which were fitted with bent extensions to simulate *Rhizophora* sp. roots. They found that the most important factors influencing flow velocity are the tree diameters and spatial density. Harada et al. (2002) carried out experimental studies to investigate the use of *Rhizophora* sp. trees to reduce the strength of tsunamis. Their mangrove model consisted of three parts: root, trunk and leaf system. The root and leaf systems were made of permeable porous sheet and the mangrove trunk was made of plastic, thus the vertical variation of porosity values in mangroves from 0.964 to 0.973 was achieved. They found that the water level, flow velocity and hydraulic force from tsunami could be reduced significantly behind artificial permeable mangroves. Husrin et al. (2012) also investigated the hydraulic performance of a mangrove forest subject to tsunami in a wave flume using parameterized tree models. Their initial experiments involved the fabrication of a “real” tree model made of hardened clay, exactly based on the shapes of a real *Rhizophora* sp. tree. A second set of experiments was conducted using a tree model consisting of groups of cylinders in a laboratory flume. Their study provided evidence that the mangrove forest subjected to tsunami-like solitary waves higher than the mangrove roots may not provide sufficient damping.

Most previous studies on mangrove hydrodynamics indicate the complex circulation generated in water through mangrove roots makes the flow friction dominated. Furukawa et al. (1997) studied current and sediment transport in mangrove forests at Middle Creek, Cairns, Australia. They found the mangrove roots generate complex two-dimensional current fields and regions with jets, eddies, root-scale turbulence and stagnation. A high value of the Manning friction coefficient $n = 0.1$ was derived in the dense mangrove vegetation. Mazda et al. (1997) applied the momentum equation to obtain a balance between the water surface slope and drag force in pristine mangrove swamps, and they found that the drag coefficient of prop roots decreases with increasing values of Reynolds number from $C_D = 10$ for $Re < 1 \times 10^4$ to $C_D = 0.4$ for $Re > 5 \times 10^4$.

In the study described herein, detailed information on the geometrical (prop root system height, porosity, root shape, length and diameter) and material (root bio-structure, mass density, moisture content and Young's modulus) characteristics of mangrove prop roots were obtained from field work and laboratory tests. Artificial prop root models in the laboratory were downscaled and fabricated based on this information. These models were deployed in a flume and measurements of flow velocities, turbulence and resistance were made to quantify their hydraulic performance. Such measurements would be exceedingly difficult to make in the field where the ground is typically very soft and often inaccessible. It is extremely difficult to obtain reliable field measurements of the velocity profiles and turbulence data especially when there are very short tidal window periods for such measurements. The main motivation of this research is to investigate the properties of mangrove prop roots and their influence on current flow under controlled conditions, which can lead to an enhanced understanding of the transport mechanisms in the natural mangrove environment.

2. Mangrove prop roots

2.1. Geometrical properties

The study was conducted in Berlayer Creek (1°15′N, 103°48′E), Pasir Ris Park (01°22′N, 103°57′E) and Kranji Natural Trail (1°26′N, 103°43′E) in Singapore. The average temperature is between 25 °C and 31 °C, with mean annual rainfall of 2340 mm/year (Singapore National Environment Agency). All three sites have uniform temperature, abundant rainfall and high humidity. Field studies were conducted in the intertidal areas during low spring tides. Twenty single and young *R. stylosa* were surveyed separately. Clusters of old or mature *R. stylosa* with complex interlacing prop root systems

Download English Version:

https://daneshyari.com/en/article/6368783

Download Persian Version:

https://daneshyari.com/article/6368783

Daneshyari.com