Hydrodynamics of flows with vegetated boundaries

Ana Margarida da Costa Ricardo
Joint IST-EPFL doctoral initiative
Funding: Portuguese Foundation for Science and Technology (FTC) and EPFL

Introduction

Within the bioengineering framework, designing a non-erodible channel is a complex fluid-dynamics problem, involving the drag exerted on the boundary, the drag exerted on the plant stems, and the overall friction slope. Most of the existing design criteria employ resistance formulas such as Manning's, calibrated ad hoc. Moving towards physically based design criteria, progress has been made in the characterization of 3D flows over irregular boundaries. This progress is mainly due to the application of double averaging methods (DAM). Such methods, which are a particular form of upscalling, are especially pertinent for the characterization of the flow within and in the near vicinity of plant canopies.

Objectives

The general objective of the proposed research program is to devise a closed conceptual model for the flow over vegetated boundaries at scales of the order of magnitude of the larger wavelength. The specific objectives are i) development of Multiple-Averaged Conservation equations, i.e. conservation equations upscaled to conveniently large scales, filtering out the effect of boundary irregularities incorporating, as form-induced stresses, advection at smaller scales and ii) development of closure models for the form-induced stresses. The methodological proposal comprises theoretical and experimental work.

Experimental facilities and instrumentation

Experimental work was performed in the recirculating tilting flume of the Laboratory of Hydraulics and Environment of IST. This is a 12.5 m long, 40.9 cm wide with side walls made of glass, enabling flow visualization and laser measurements.

Two different experimental tests were carried out:

- constant element's density (S1): rods with 1.1 cm of diameter are randomly but uniformly distributed along the vegetated reach, with densities of 400 stems/m2.

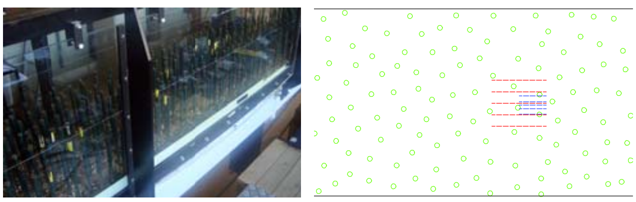

Figure 1 – Photo and art of the plan view of test S1. The dashed lines represent lateral positions where the measurements where performed on.

- varying elements density (S2): two stem's densities were alternated with a fixed period, allowing the interaction of three different wavelengths: two different inter-stem spaces (400 and 1600 stems/m^2) and the characteristic length between the two densities(0.5 m).

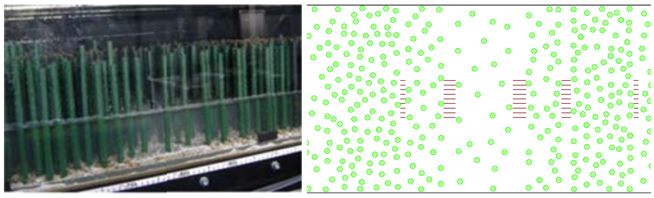

Figure 2 - Photo and art of the plan view of test S2. The dashed lines represent lateral positions where the measurements where performed on.

During the experimental test, instantaneous flow velocities were measured with a Particle Image Velocimetry (PIV) system. The PIV system is composed of laser head, CCD camera, power supply and acquisition system and control. The PIV is an optical technology that allows the obtaining of the fluid's velocity, by measuring seeding particle's velocity. The system is based on a double-cavity laser which allows the user to set the delay between two laser pulses and it is operated with a sampling rate of 15 Hz.

Results

Flows within vegetation covered boundaries show great heterogeneity, however heterogeneity decreases with stem density. These kinds of flows lead a quasisymmetric high vorticity patterns around the stems independently of the stem density. However, stem density impacts the length of the vortex street: for lower densities the inter-stem space is larger allowing the development of the vortex street.

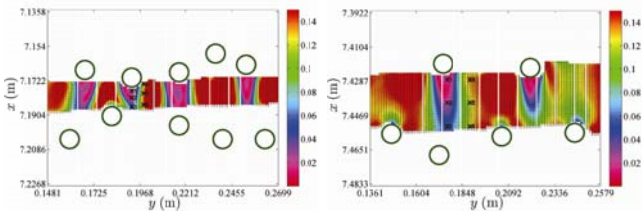

Figure 3 –Time average velocity flow field in a horizontal plan in a reach with 1600 stems/s2 (left) and 400 stems/s2 (right).

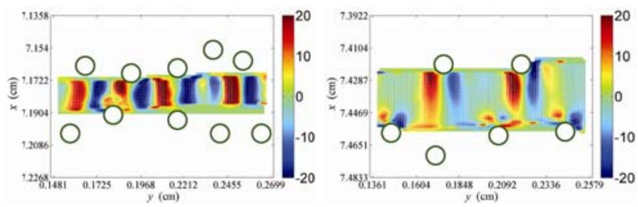

Figure 4 – Mean vorticity field in a horizontal plan in a reach with 1600 stems/s2 (left) and 400 stems/s2 (right).