Effects of submerged vegetation on flow and turbulence characteristics at the apex bend of a meandering flume

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ABSTRACT

Understanding flow characteristics and turbulent structure in the presence of vegetation is important with respect to environmental processes as sediment transport and mixing of transported quantities. In the present paper attention is focused on the kinematic and turbulent processes in presence of flexible submerged vegetation. In particular, the effect of vegetation on the flux of mass distribution and the process of transport is investigated. The analysis is performed with the aid of detailed experimental data collected in a laboratory channel both in the absence and in presence of flexible and submerged vegetation. Results essentially confirms that mass exchanges in the presence of vegetation are strongly influenced by the presence of vegetated stems and by turbulent structures which form between vegetated and no-vegetated zones. The presence of flexible and dense vegetation determines a reduction of the size of turbulent structures and limits the transport process.

1. Introduction

The presence of vegetation in rivers exerts an important ecological function and is very important to maintain suitable habitat. Especially in recent years, some researchers have focused their attention on the role of vegetation in channel's morphodynamics (among others Perrucca et al., 2007). Alteration of hydrological conditions in fluvial systems inevitably leads to changes in river morphology, riparian or riverbed vegetation and ecosystems. Riparian vegetation distribution could also change in time and in space depending on the combination of factors affecting the settling and growth of vegetated elements. Understanding transport processes in the presence of aquatic vegetation, also taking into account its variable spatial distribution, is still a research problem (Katul et al., 2011).

The major part of studies conducted so far in this field consider straight flumes with different types of vegetation on the bed. Poggi et al. (2004) investigated flow turbulence structure in the presence of dense, rigid and submerged vegetation. By taking into account that in the submerged regime the discontinuity in drag at the top of vegetation determines an inflection point, they suggested a phenomenological formulation of the mixing length. Tanino and Nepf (2008) analyzed the lateral dispersion processes in the presence of a random array of a rigid and emergent vegetation for different values of vegetation density. Other researchers focused on submerged flexible vegetation (among others Ghisalberti and Nepft, 2006; Termini, 2015) and verified that the region around the top of the vegetation is the region of highest shear stress and maximum turbulence production. In the present work attention is restricted to the case of flexible and submerged vegetation and the analysis is performed with the aid of detailed experimental data collected in a laboratory channel both in the absence of vegetation and in the presence of vegetation with different configurations.

2. Experimental Data

The detailed experimental program has been conducted in a sine-generated laboratory flume of large amplitude, (deflection angle at the inflection section θ_0=110°) constructed at Department of Engineering - University of Palermo – Italy. For details of the experimental setup and measurement procedures please refer to previous works (see as an example in Termini and Piraino, 2011). For the analyses conducted in the present work data obtained in the absence of vegetation (see in Termini and Piraino, 2011) and over the bed covered by real herbaceous (flexible) vegetation (see in Termini, 2015) have been considered. The experimental runs were conducted with flow discharge $Q = 0.012$ m^3/s and during each run the instantaneous flow velocities ($v_s(t)$=longitudinal, $v_r(t)$=vertical and $v_s(t)$=transversal) were simultaneously measured in sections of mutual distance 50 cm. In the present work attention is devoted to the apex of the bend.

3. Results

The time series of the instantaneous flow velocities components have been used to estimate the corresponding time-averaged components. The results obtained can be summarized as follows:

- a different behavior for the cross-sectional flow occurs in absence and in presence of vegetation: in absence of vegetation three different regions can be identified in the cross-section: the central region where the central circulation cell develops; the outer-bank region where a second counter-rotating circulation cell forms near the free surface; the inner-bank region where the convective radial motion prevails over the cross-sectionl one; in presence of vegetation, the central-region circulation cell seems to be divided into thin circulation cells developing at the top of the vegetated layer, in the outer-bank region the counter-rotating cell also develops but it includes a fluid area more extended than that observed in absence of vegetation.

- the presence of vegetation determines values of the downstream flow velocity lower (around of one order of magnitude) than those obtained in absence of vegetation. As consequence, the horizontal profile of the specific downstream flux of mass, $m_s = \rho h_r \overline{v_s}$ ($\overline{v_s}$ = depth-averaged of v_s; h_r=local flow depth) is strongly modified by the presence of vegetation. In fact, as it can be observed from Fig. 1a, in the absence of vegetation the mass of fluid is essentially concentrated over the deepest part of the cross-section: passing from the inner to the outer bank, the specific downstream flux of mass, m_s, has an increasing trend toward a peak value at the separation between the two circulation cells and, then, it decreases rapidly because of the presence of the outer-bank circulation cell. In the presence of vegetation (Fig. 1b) the flux of mass assumes values lower than those observed in the absence of vegetation showing an alternamce of low-high values because of the presence of the vegetated stems.

- in the presence of vegetation, the mass and momentum transport is strongly controlled by the turbulent motion which develops between and within the vegetated elements.

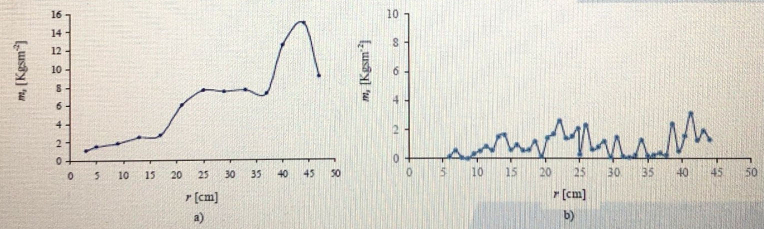

Fig. 1: Horizontal distribution of the specific downstream flux of mass, m_s: a) absence of vegetation; b)presence of vegetation

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