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Four Decades of Progress in Monitoring and Modeling of Processes in the Soil-Plant-Atmosphere System: Applications and Challenges

Effect of vegetation on fluvial erosion processes: experimental analysis in a laboratory flume

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Abstract

The plane evolution of a meander wave is determined by the erosion processes at the banks. Particularly, the outer-bank is considerably vulnerable to the erosion processes. Indirect techniques, which act upon the reduction of the effect of the cross-circulation motion, have been recently proposed to limit the outer-bank erosion. This paper shows preliminary results on the role played by vegetation on cross-circulation motion. The analysis is conducted on the basis of experimental data collected in a large amplitude meandering channel constructed at the hydraulic laboratory of DICAM. Maps describing the cross-stream flow, both over the no-vegetated bed and over the vegetated bed, are shown in peculiar sections along the meandering flume. The comparison between such maps highlights how the intensity of flow velocity and the bank erosion rates reduce as effect of vegetation.

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Keywords: Rivers, meanders, erosion, secondary circulation, vegetation

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Nomenclature

D_{50}	median sediment diameter
h	flow depth
Q	flow discharge
S	bed slope
$v_s(t)$	instantaneous longitudinal velocity component
$v_z(t)$	instantaneous vertical velocity component
$v_r(t)$	instantaneous transverse velocity component
v_r	time-averaged transverse velocity component
v_z	time-averaged vertical velocity component
v_t	time-averaged cross-sectional flow velocity
V_{R1}	instantaneous velocity measured by probes 1
V_{R2}	instantaneous velocity measured by probes 2
V_{R3}	instantaneous velocity measured by probes 3
σ_g	geometric standard deviation

1. Introduction

Morphological river changes (bed topography and/or plane-shape changes) occur as result of natural and/or of human interventions so that alluvial meandering streams strive to achieve an equilibrium configuration [1]. As documented by many experimental and theoretical works [among others 2, 3, 4, 5, 6] the plane shape of a meander wave is the result of the complex interplay flow pattern-bed deformation-bank erosion. The geometric shape of the meander wave gives rise to a complicated flow field which, in turn, modifies the bed topography and reshapes the meander wave through the bank erosion. In fact, in nature, different meandering streams exhibit different geometric characteristics so that the stream conditions may vary from one meander loop to another [5]. Thus, many laboratory and field studies [among others 2, 6, 7, 8, 9], apart numerical researches [see as an example 10], show that the evolution of a meander wave is mainly governed by the bed deformation that drives the erosion process at the channel banks. Particularly, outer-banks are considerably vulnerable to erosion processes.

On the other side, the evaluation of the bank erosion and the consequent migration of meandering rivers is fundamental both because of hazards associated with them and because of their effects in riparian ecosystem dynamics.

Recent researches [see as an example 11, 12] highlight that the advective transport of downstream momentum by the cross-stream flow (that is the flow perpendicular to channel axis), determined as effect of the channel curvature, exerts an important role on the distributions of the downstream flow velocity and the bed shear stress along the channel. Often, in steep outside bends, beside the central circulation cell, a counter-rotating circulation cell forms in the outer-bank region. The presence of such counter-rotating circulation cell could be important in finding an explanation of the meander wave evolution [13].

In fact, experiments show [see as an example 11, 12] that the counter-rotating cell allows the bank shear stress to maintain low values in the outer-side of the bend, determining a sort of a buffer layer protecting the outer bank from the action of the central circulation cell.

Based on the aforementioned, different indirect techniques (such as the introduction either of bubble screen, or of horizontal foundation, or of macro-roughness elements,...), which act upon the reduction of the effect of the cross-circulation motion and/or of the bed topography, have been also recently proposed to limit the outer-bank erosion [see as an example in 14].

In this work the herbaceous vegetation has been used as stream-bank bioengineering protective technique. With the aid of experimental data collected in a large amplitude meandering flume constructed at the Hydraulic laboratory of Dipartimento di Ingegneria Civile, Ambientale, Aereospaziale, dei Materiali (DICAM) - University of Palermo – Italy, the role of the vegetation on the cross-circulation motion (and thus on the bank erosion) has been examined. Detailed measurements of flow velocity have been carried out both over the no-vegetated bed and over the vegetated deformed bed. In this paper, preliminary results obtained by comparying the cross-sectional flows determined for the two aforementioned bed configurations have been reported.

2. Experimental apparatus

The experimental data were collected in a large amplitude meandering flume that follows a sine-generated curve [see also in 5, 6] with a deflection angle of 110°. The meandering flume is two wavelengths long. The experimental apparatus and the flow measurement conditions are also presented in details in previous works [6, 12] and, thus, only some peculiar features are summarized herein. The banks of the flume are rigid and constructed using clear 0.2 cm thick Plexiglas strips; the bed is composed of quartz sand with D_{50}=0.65 mm and geometric standard deviation σ_g=1.3. The plane view of the laboratory flume is reported in Fig. 1.

Two runs were conducted over the deformed rigid bed. The deformed bed was obtained at the end of a mobile-bed run carried out with flow discharge Q=0.012 m^3/s, initial longitudinal centreline bed slope S=0.371% and initial channel-averaged flow depth h=5.2 cm. The first run (run 1) was conducted in absence of vegetation and the second run (run 2) was conducted with bed covered (only along the central reach of the channel one wavelength long – see Figs. 1a, b) by real flexible vegetation.

The instantaneous flow velocity components were measured during each run in peculiar sections along the channel. In this work attention is restricted to sections A, B, C reported in Fig. 1a. The measures were carried out by using the Acoustic Doppler Velocity Profiler (DOP 2000), based on Doppler effect. This instrument consists of a probe that is simultaneously emitter and receiver of acoustic pulses and it allows us to measure the instantaneous velocity profile along the probe's direction. To collect the data used in the present work, three probes with emission frequency of 4 Mhz were used: probe 1 was in vertical direction, probe 2 was inclined of 60° with respect to the horizontal direction, probe 3 was in transversal direction. The measurement point P has been obtained by the intersection of the axes along the probes direction (see as example in Fig. 2 the position of probes 1 and 2). Thus, the instantaneous longitudinal, vertical and transverse velocity components (v_s(t), v_z(t), v_r(t)) have been determined by the following relations:

$$v_s(t) = -\frac{V_{R1} \cdot sen(a) - V_{R2}}{cos(a)} \tag{1}$$

$$v_z(t) = -V_{R1} \tag{2}$$

$$v_r(t) = -V_{R3} \tag{3}$$

where V_{R1}, V_{R2}, V_{R3} are the instantaneous velocities measured by probes 1, 2 and 3, respectively.
Details of measurement conditions (methods, measures accuracy, data sampling rate and acquisition time) can be found in [12]. The measures were conducted by the help of the 3D automatic position system, opportunely fixed at the concrete basement of the channel (see Figs. 1a, b), which uses the language of LabView for control applications (Fig. 1c).

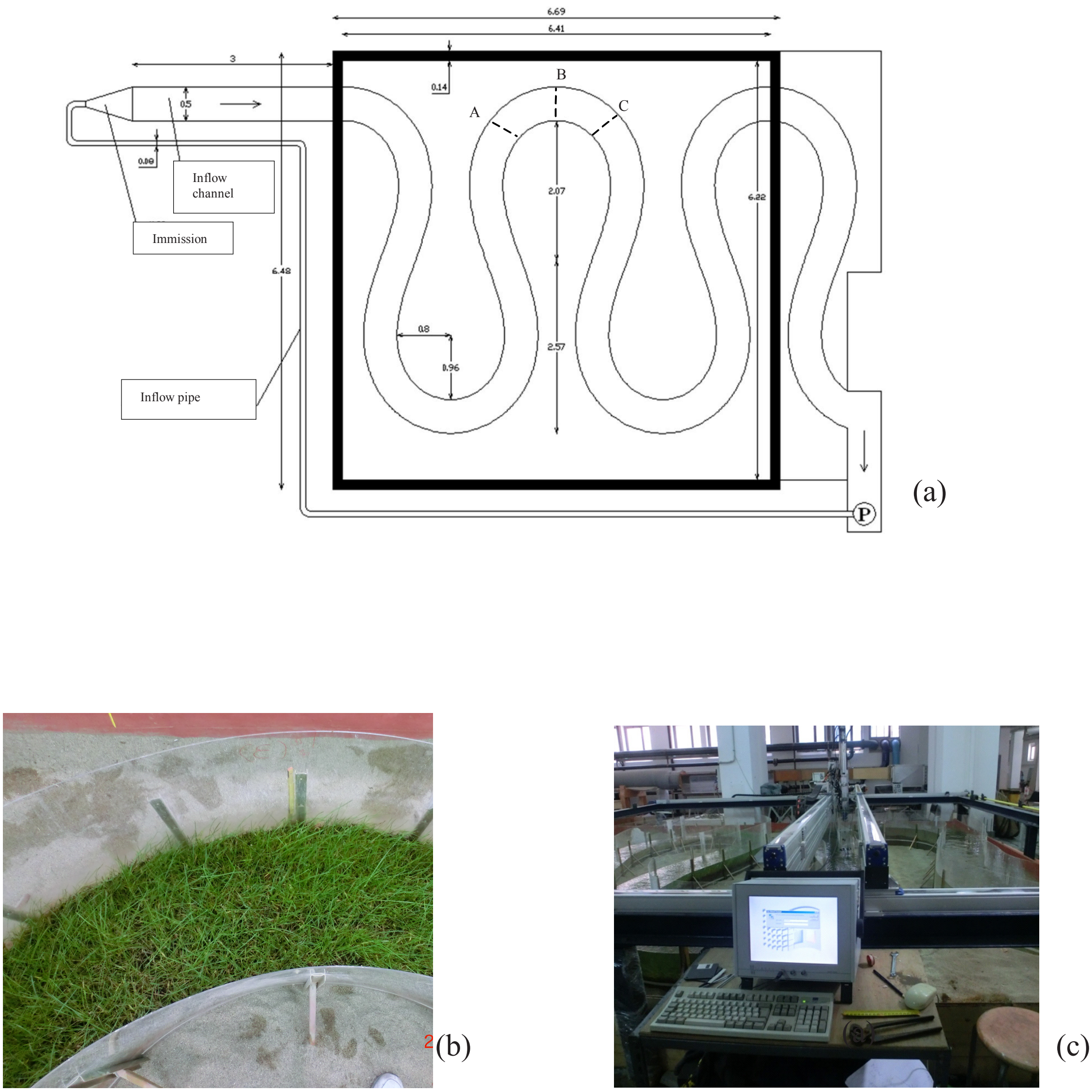

Fig. 1: (a) plane-view of experimental apparatus; (b) sketch view of the vegetated bed; (c) DOP2000 and position system

3. Time-averaged cross-sectional flow velocity

In order to analyze the evolution of the secondary flow motion induced by the channel's curvature, the distributions of the time-averaged radial (v_r) and vertical (v_z) velocity components have been determined in each considered section. These time-averaged flow velocity components have been estimated by using the measured instantaneous velocity components.
The intensity of the resultant time-averaged cross-sectional flow velocity, v_t, has been determined as:

$$v_t = \sqrt{v_r^{\,2} + v_z^{\,2}} \tag{4}$$

Figs. 3 and 4 show, for both runs, the contour maps of v_t in each investigated section (r represents the transversal abscissa). In particular, Fig. 3 shows the v_t patterns in absence of vegetation on the bed. As discussed in previous works [12], three different regions can be identified at the bend apex (section B): the central region where the central circulation cell develops; the outer-bank region (i.e. close to the left bank) where a second counter-rotating circulation cell forms near the free surface; the inner-bank region (i.e. close to the right bank) where the convective radial component prevails over the cross-circulation. Thus, the sediments motion from the outer (where erosion occurs) to the inner (where deposition develops) regions of the cross-section due to the cross-stream flow (and, specifically, to the central-region circulation cell) could be attenuated by the presence of the counter-rotating circulation cell developing near the free surface of the outer-bank region [11]. The counter-rotating circulation cell initiates at the bend entrance (section A). At the bend exit (section C) the counter-rotating circulation cell disappears and a weak counter-rotating circulation cell has been observed near the bed [11].

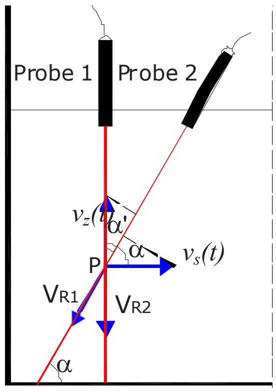

Fig. 2: measurement point

As Fig. 4 shows, the presence of vegetation determines a decrease in the intensity of the transversal flow velocity. Furthermore (Fig. 4), in presence of vegetation the circulation motion is still evident but the circulation cells are more spread and thin than those observed in no-vegetated bed condition. At the apex section (section B) also the counter-rotating cell seems to appear near the free surface of the outer-bank but it is thinner and weaker than that in the case of no-vegetated bed condition.

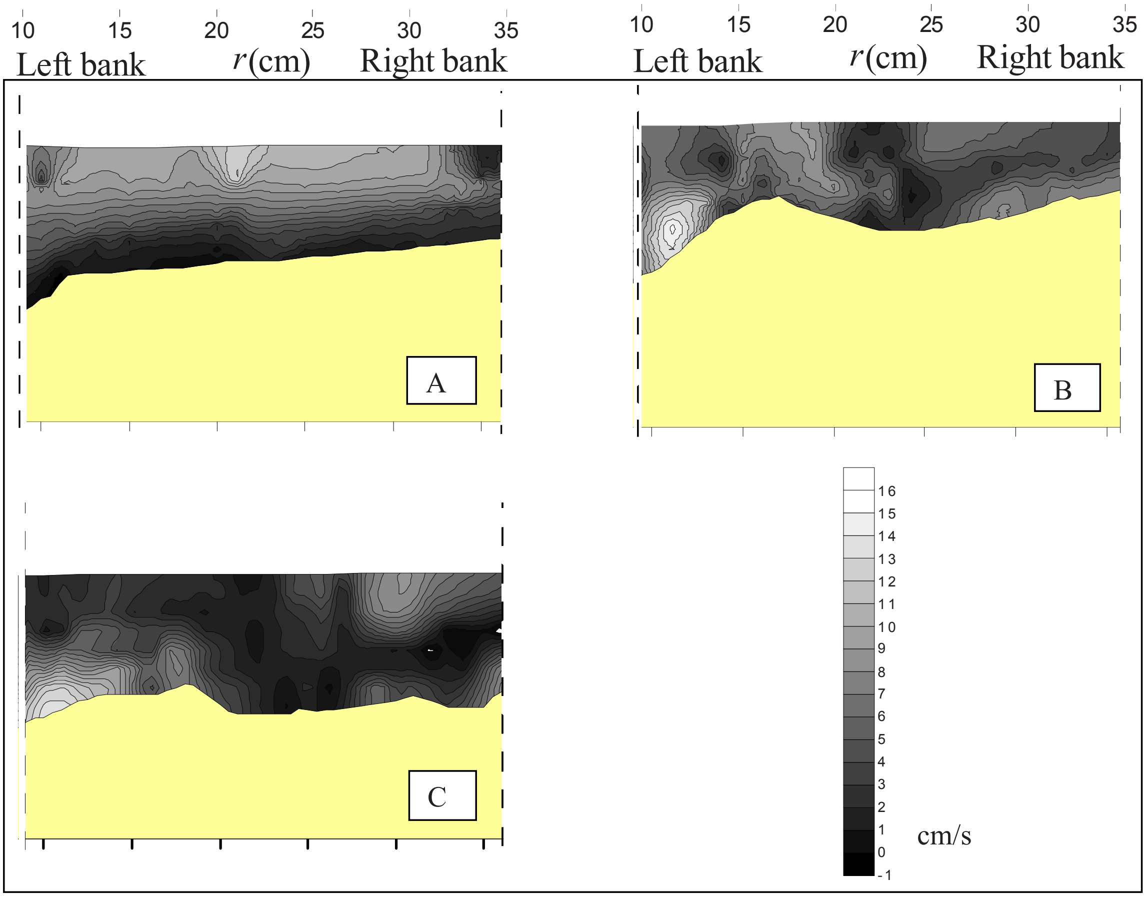

Fig. 3: contour maps of the cross-sectional flow velocity (cm/s) in case of no-vegetated bed

4. Discussion and Conclusion

In this paper the effect of vegetation on cross-circulation motion has been experimentally investigated. To this aim instantaneous velocity data in a meandering laboratory channel have been collected both over the no-vegetated bed and over the vegetated bed. In particular, this paper reports the preliminary results on the distributions of the cross-sectional flow obtained in peculiar sections (bend entrance, apex section, bend exit) of a meander wave.

The comparison between the cross-sectional flow distributions obtained for the two examined bed configurations has highlighted that the presence of vegetation on the bed allows us to obtain a decrease in the intensity of the cross-sectional flow.

In fact, according with [12], in no-vegetated bed condition the formation of two circulation cells at the apex section of the meander wave has been observed. The first is the main central circulation cell and the second is the counter-rotating circulation cell developing near the free surface in the outer bank region. Thus, the central circulation cell should be responsible of the sediment motion from the outer to the inner bank, but the erodible action of flow at the outer bank is reduced by the presence of the counter-rotating circulation cell developing near the outer bank.

In vegetated bed condition, the circulation motion is still evident but it is characterized by circulation cells thinner and more spread than those observed in no-vegetated bed condition. Furthermore, as effect of the presence of vegetation, a decrease of the intensity of the cross-sectional flow has been observed in all the investigated sections.
On the basis of the aforementioned, it can be supposed that the presence of vegetation limits the erosive action of flow at the outer bank.
It should be emphasized that, for the specific purposes of the work, the presented experimental results come only from measurements collected in the investigated sections. Deeper analyses to verify the aforementioned are still in progress.

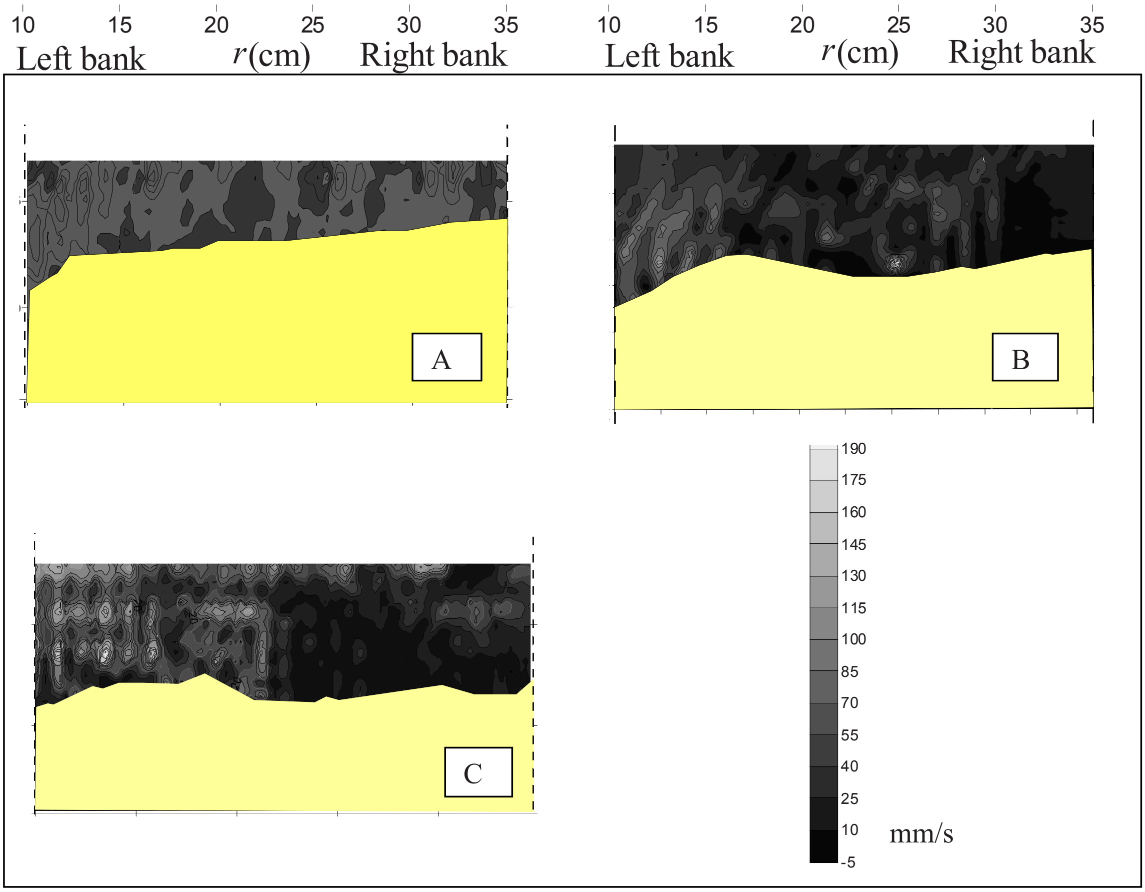

Fig. 4: contour maps of the cross-sectional flow velocity (mm/s) in case of vegetated bed

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