Advances in Water Resources 33 (2010) 601–614

Contents lists available at ScienceDirect

Advances in Water Resources

journal homepage: www.elsevier.com/locate/advwatres

The role of different forms of natural riparian vegetation on turbulence and kinetic energy characteristics

O. Yagci [a,*], U. Tschiesche [b], M.S. Kabdasli [a]

[a] *Istanbul Technical University, Civil Engineering Faculty, Division of Hydraulics, 34469 Maslak, Istanbul, Turkey*
[b] *University of Natural Resources and Applied Life Sciences, Department of Water, Atmosphere and Environment, Vienna, Austria*

ARTICLE INFO

Article history:
Received 16 July 2009
Received in revised form 5 March 2010
Accepted 18 March 2010
Available online 24 March 2010

Keywords:
Floodplain
Natural vegetation
Open channel flow
Turbulence
Vegetated channel
Velocity profile

ABSTRACT

Flow measurements were conducted by ADV Vectrino to investigate the role of different forms of single natural emergent vegetation elements on kinetic energy characteristics and the flow structure in open channel flow. Experiments were carried out for both forms of “erect” and “compressed” vegetation. The findings revealed that the form of “erect” has greater retaining influence on time-averaged mean velocity characteristics than “compressed” form. Furthermore, the turbulence and kinetic energy patterns behind the single vegetation were also examined. An empirical equation giving the relationship between the kinetic energy components of flow was derived based on the data. The ratio between turbulence kinetic energy and mean kinetic energy at a certain distance downstream of vegetation element was predicted by the empirical equation depending on the vegetation characteristics. These predictions were compared with a different experimental data set and produced satisfactory results. Also, the mean flow and turbulence characteristics behind an isolated natural plant and a volumetrically equivalent rigid cylinder were also compared.

1. Introduction

The importance of the conservation of both aquatic and riparian vegetation is today commonly recognized by river engineers. However, it is still a complicated issue to describe quantitatively the phenomenon of “flow passing through aquatic vegetation” since in nature each species is unique in terms of biomechanical and architectural properties.

The estimation of resistance due to vegetation with an acceptable precision is highly important in design of open channels as it directly affects the conveyance capacity. A number of studies in this area aimed to establish the contribution of resistance due to presence of vegetation by one dimensional approach [4,5,13,25,26,30,34,37]. Rigid stem analogy was a necessary simplification in understanding the nature of “flow through vegetation” phenomenon. This simplification was practiced in many 2D [6,12,17,18,20,21,24] and 3D studies [8,10,27,29] in the past. In all these studies, the main idea was to simulate the drag force applied by flow to the vegetation. Kouwen and Fathi-Moghadam [16], Armanini et al. [2], and Wilson et al. [38] measured instantaneous drag force directly on natural vegetation. The rigid stem analogy presents a good starting point in attempting to understand the elaborate flow structure where flowing through riparian vegetation. However, this analogy has some major drawbacks. According to the drag force equation for a rigid cylinder, the drag is expected to increase with the square of the velocity. However, based on the drag force measurements Fathi-Maghadam et al. [7] showed that differing from the standard drag force equation, for flexible tree models, drag force appears to have a linear relationship with velocity due to deflection of the plant foliage area and reduced drag coefficient “C_D” with increasing flow velocity. In fact, as a self-protection reaction of vegetation, the plant compresses, bends and oscillates under the effect of drag force in order to decrease itself in the “frontal” (or “momentum absorbing”) area. This complex dynamic mechanism is neglected by the rigid stem analogy. Another drawback of the rigid stem analogy is that the vegetation is reduced to a stem without considering the presence of branches and foliage. According to Jarvela [13] branches contributed approximately 2/3 to the total leafless projected area for typical floodplain vegetation willows. Wilson et al. [35] showed that the bending of riparian vegetation can have a significantly greater impact on the velocity distribution compared to drag force coefficient. Although it is a known fact that while the viscous drag (i.e. skin friction) is negligibly small compared to form drag for the case of rigid cylinder [33], the role of viscous drag on flow structure where flow passes through real vegetation has not been fully understood yet. Also, Schnauder et al. [28] investigated the effect of permeability of natural vegetation on the flow. Their findings revealed that the degree of anisotropy of turbulence was significantly lower compared to the impermeable plant.

Biomechanical and architectural characteristics of individual plants in a riparian forest exhibit temporal and spatial variation. This variability is higher when the plant community is composed of different species since each species has intrinsic properties. In many

---

[*] Corresponding author. Tel.: +90 212 2856011; fax: +90 212 2856587.
E-mail address: yagciora@itu.edu.tr (O. Yagci).

0309-1708/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.advwatres.2010.03.008

natural riparian forests light-demanding and shade-tolerant species (i.e. grasses, shrubs, and exotic species) live together Johnson and Miyanishi [14]. In order to overcome this inextricability, spatial averaging technique [39] could be applied over a vegetated region large enough to eliminate any variation due to individual vegetation elements, in addition to temporal averaging. At the beginning of this study this option was also discussed and it was decided to take one step back and the necessity of firstly understanding the physical event of "flow through isolated vegetation elements" was acknowledged. It was assumed that knowledge of the mean flow and turbulence structure where flow passes through isolated vegetation helps to give a better understanding of "flow through vegetation community."

The definition of basic natural vegetation forms (i.e., erect, compression, and bending) under the effect of drag force by flow are described in the next section. This study focuses on the case of "erect" and "compressed" forms of emergent vegetation in a flow field. All the experiments were undertaken for these two vegetation forms. The primary aim of this study is to describe quantitatively the role of single natural emergent vegetation on kinetic energy characteristics (i.e. mean kinetic energy to turbulent kinetic energy) and the turbulence structure in an open channel flow.

2. Methods

2.1. Classification of the vegetation forms under the effect of drag force

In natural vegetated open channels, the emergent vegetation with large trunk exhibits three different primary motions under the impact of drag force:

- Erect: The vegetation withstands flow without significant motion. The foliage of the vegetal elements gently moves dependent on its structure.
- Compression: Due to the increasing speed of flow (i.e. augmented drag force), the second degree branches and foliages follow the streamlines, the permeability of the vegetation decreases; the projected area on horizontal plane diminishes. Additionally, indistinct swaying motion of the secondary degree branches and foliages are observed. But swaying motion is not observed in the plant trunk.
- Bending: With the further increase of drag force on the vegetation element, the trunk of the plant cannot withstand flow and starts to bend. In this way, as a self-protection reaction the vegetal element decreases its own frontal area to decrease the drag force.

In addition to these three major plant motions, a permanent oscillation occurs due to the cycle of transition between compression and bending forms.

Since it is a complicated issue to describe quantitative criteria to classify the forms of vegetation under the effect of drag force, herein only some qualitative criteria were defined. Nevertheless, further studies and comprehensive data sets are necessary to improve accurate quantitative criteria for various vegetation species.

In this study, experiments were undertaken in the laboratory flume in order to determine the effect of the different forms of vegetation (i.e. "erect" and "compression") on the energy dissipation and the flow structure. The characterization of the vegetation is presented in the next section.

2.2. Characterization of the vegetation elements

Throughout the experiments three different real tree saplings were utilized. These were *Pinus Pinea*, *Thuja Orientalis*, and *Cupressus Macrocarpa* (Fig. 1). Yagci and Kabdasli [40] classified vegetation into three groups (i.e. Type1, 2, and 3) depending on their "cumulative volume, *V*" versus "height, *h*" relationship. The main differences between these three types are the variation of gradient curves with respect to height (Eqs. (1)–(3)).

$$\left[\left\{(\partial V/\partial h)/\partial h\right\}<0\right] \text{ for Type 1} \tag{1}$$

$$\left[\left\{(\partial V/\partial h)/\partial h\right\}\cong 0\right] \text{ for Type 2} \tag{2}$$

$$\left[\left\{(\partial V/\partial h)/\partial h\right\}>0\right] \text{ for Type 3} \tag{3}$$

The procedure by Wilson et al. [36] was followed to obtain variation of the cumulative volume of the plants with respect to height (Fig. 2). In this procedure, the plants were cut into parts. Then, the volume of each part was determined using a displacement technique (based on Archimedes theory) where each 50 mm

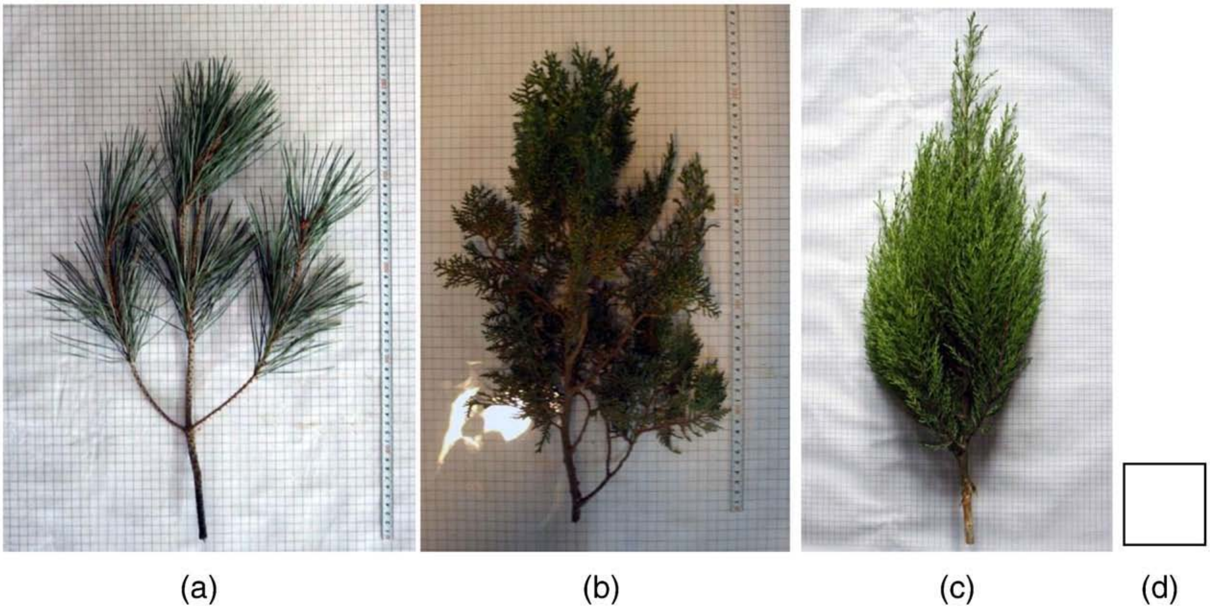

Fig. 1. Vegetation types used in the flume experiments in front of a 1 cm squared grid: (a) *Pinus Pinea* (scale ≈ 0.113), (b) *Thuja Orientalis* (scale ≈ 0.127), (c) *Cupressus Macrocarpa* (scale ≈ 0.067), and (d) reference square: 1 cm × 1 cm.