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Resistance to Flow in a Cobble-Gravel-bed River with Irregular Vegetation Patches and Pool-Riffle Bedforms (Case study: Padena Marbor River)

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1. Introduction

The interaction of river flow and vegetation is very complicated and influenced by various environmental and hydraulic factors such as vegetation characteristics, water temperature, average flow velocity, turbulence, river morphology, bed particle distribution, and river bedforms.

The extensive investigation of the interaction of river flow and vegetation distribution is of considerable importance for river engineering projects.

Recent years have seen an enormous growth of interest in the role of vegetation in sediment transport, water pollution, aquatic habitat and environmental factors. Moreover, a review of flow resistance studies in recent decades of vegetated channels shows that there are many theoretical and conceptual approaches in this regard.

There is a general view that resistance coefficients such as Manning coefficient, Chezi coefficient, and Darcy–Weisbach coefficient depend upon the number of factors such as hydraulic parameters (Reynolds Number, Froud Number and relative depth), bed materials (particle diameter), bedforms, channel geometry, and the dimension of vegetation patches. The quantification of these parameters has been less studied in river engineering subjects. On the other hand, the effect of vegetation patches on flow structure in the presence of 3D pool riffle bedforms in gravel-bed rivers is not still transparently obvious and the depth of validity of logarithmic law, Von Karman constant changes, and estimation of flow resistance have been less considered.

This study was intended to examine the characteristics of velocity profile in the presence of 3D pool riffle bedforms with irregular vegetation patches in a gravel-bed river and to present a semi-analytical relationship of flow resistance.

2. Study area and measurements

The data were collected in four different sections of Padena Marbor River in the south of Isfahan province in summer 2020. The first, second and third sections include the bedforms of large-scale pool and riffle. The first section does not have any vegetation patches in the bed and the second and third sections include vegetation patches in the bed on the right and left of the river, respectively. Figure 1 shows the selected sections for collecting data (A-section, B-section, C-section and D-section) in the Marber Padena River. Moreover, a total station for topographic surveying was used.

Figure 1. Data gathering in Padena Marbor River. A: first section, B: second section, C: third section, and D: fourth section

Bed grading was performed by Wolman method. Flow velocity was measured by Micro Current Meter (MCM) with an accuracy of 0.1 m/s to plot the velocity profile. The measurement time was 30 seconds. In order to increase the accuracy of the experiments, three repetitions were performed at each point. A total of 39 velocity profiles were drawn in the various points of every section.

The predominant flexible submerged vegetation patches are Algae that grow on the riverbed. The Algae can be found abundantly in the Marber Padena river bed that is show in Figure 2. Algae are defined as a group of predominantly aquatic, photosynthetic, and nucleus-bearing organisms that lack the true roots, stems, leaves, and specialized multicellular reproductive structures of plants.

Figure 1. Algae in the Padena Marbor River bed

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There are two boundary layers of turbulence in the theory of the boundary layer of flow in open channels. In the turbulent inner boundary layer, the velocity profile follows the law of the wall and is expressed by Equation 1 as following:

$$\frac{u}{u_*} = \frac{1}{\kappa} \ln\left(\frac{z}{k_s}\right) + B_r \tag{1}$$

Shear velocity is used to analyze the velocity profile theory. In this study, the Boundary characteristics method, which was first proposed by Afzali Mehr and Anctil (2000) for gravel-bed rivers, was used.

The purpose of estimating flow resistance in this study is to investigate the relationship between flow resistance with emphasis on Manning, Chezi, Darcy–Weisbach coefficient and Drag coefficient and geometric dimensions of flexible submerged vegetation patches in the presence of 3D bedforms in a gravel-bed river. Most studies on flow resistance under artificial vegetation conditions have been performed in the laboratory and the effect of natural vegetation has been less studied.

The primary physical parameter affecting the flow resistance is the Blockage Factor (BF) which is defined as the ratio of the front area of the vegetation patches perpendicular to the flow direction to the flow cross-sectional area.

In this study, the relationship between Drag, Manning, Chezi and Darcy–Weisbach coefficients as Resistance Coefficients (RC) with BF has a correlation coefficient greater than 0.8 with the power equation in the form of Equation 2 as following:

$$\mathrm{RC} = \mathrm{m}\, exp(n\mathrm{BF}) \quad \mathrm{R}^2 \geq 0.8 \tag{2}$$

3. Conclusion

In this study, the velocity profile in different sections of a gravel-bed river in the presence of 3D bedforms and irregular distribution of natural submerged vegetation patches was studied. Moreover, power equations were also proposed as a function of Blockage Factor to estimate the flow resistance.

The results of this research suggest that the presence of submerged vegetation patches on the 3D bedforms can significantly change the velocity global distribution terms including flow velocity, shear velocity, Von Karman constant which results in different estimations of flow resistance.

Von Karman constant is changed by vegetation and 3D bedforms, though it cannot be considered equal to 0.4. The value of Von Karman constant in this study ranged from 0.18 to 0.39. Accordingly, the presence of 3D bedforms and irregular distribution of natural submerged vegetation patches reduces this amount in the gravel-bed river.

The relationship between flow resistance coefficient and the Blockage Factor was calculated with a correlation coefficient of 0.8 by the power equation. This nonlinear relationship can be due to the presence of 3D bedform, irregular distribution of natural submerged vegetation patches, and non-uniformity of bed particles (uniformity coefficient greater than four around the vegetation patches) in the bed river.

Chezi coefficient with a relatively high correlation coefficient compared with other resistance coefficients can be a good representative of the flow resistance in this gravel-bed river.