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Full Length Research Paper

Determination of friction factor for rivers with non-submerged vegetation in banks and floodplains

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Due to vegetation flexibility, friction factor varies in flood plains and river banks and is a function of vegetation characteristics and flow conditions. Study of river behavior and effect of vegetation on river systems are very important for water intake in pumping stations, water treatment plans and wastewater and construction of structures such as bridges and diversion channels. Purpose of this research is to develop a relationship for estimation of non-submerged vegetation roughness in the flood plains and river banks. Number of 182 experiments was conducted on a laboratory flume and effect of parameters on the roughness coefficient was evaluated. Results show a nonlinear decrease of roughness coefficient with increasing of flow rate. Increase of velocity from 0.2 to 2 m/s make Manning's coefficient reduces to about 30% of the first case. Decrease of roughness coefficient with decrease of submergence ratio and density was low compared to the velocity effect.

Key words: Friction factors, vegetation, flexibility, non-submerged.

INTRODUCTION

Because of vegetation flexibility in river banks and floodplain, friction factors vary in these areas and are a function of vegetation characteristics and flow conditions. Flow conditions include velocity and depth of flow, and vegetation characteristics are density, flexibility. Vegetation at river banks reduces water flow capacity and causes rising of water level in such areas which may submerge existing structures such as pump stations. Removing vegetation in spite of increasing flow capacity causes instability of the river banks and sometimes endangers the structures, as well as adverse environmental impacts.

Vegetation at river banks is either in submerged or non-submerged forms. Grass vegetation and shrubs are submerged forms, and tall trees are non-submerged. Chen (1976) was conducted some experiments on grass vegetation in laboratory flume in laminar flow regime and showed that friction factor decreases with increasing of Reynolds number. Kouwen (1992) applied boundary layer theory to develop a relationship between Manning's coefficient and product of flow velocity and hydraulic radius. Fisher (1996) showed that vegetation roughness in open channels depend on vegetation type, flexibility, height, density, and their vegetation distribution. Fu-Chun and Hsieh (1999) conducted experiments with mane instead of vegetation and concluded that vegetation friction decrease with increasing depth for non-submerged case, while it decreases for submerged cases. (Kouwen and Fathi-Moghadam, 2000) developed a relationship for non-submerged vegetation roughness concerning flow velocity and depth and as well as a vegetation index to characterize type of vegetation. Vegetation index is defined as a function of first module of natural frequency, height, weight and length of plants. Jarvela (2002, 2004) in two studies for determination of flow resistance caused by different combinations of grass, sedges and willows in submerged and non-submerged condition, concluded that changes in depth, velocity, Reynolds number and vegetation density are key factors; and that the maximum friction factor was obtains for low Reynolds number and velocity. The roughness coefficient for leafy trees was about seven

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times more than leafless trees. Fathi-Moghadam (2006) studied effects of land slope and flow depth on friction factors for non-canalized flow. It was found that friction factors decrease significantly with increase of land slope as result of increase of flow velocity. The friction factor increased with increase of flow depth due to increasing of more submerged elements. Baptist et al. (2007) compared some methods and solved one-dimensional k-3 equation using an artificial network for calculation of vegetation friction factor. Rameshwaran and Shiono (2007) suggested a two- dimensional model for calculation depth- average velocity and shear stress for flow in straight compound channel with flood plain vegetation. The secondary current and friction terms were considered for solution of Navier-Stokes Equations. Fathi-Moghadam (2007) proposed a vegetation index based on first mode of vibration for study of wind flow through four types of coniferous trees. This model can estimate mechanical characteristics of vegetation by considering parameters such as leaf density, shape and flexibility of vegetation. Lai et al. (2008) conducted some flood field measurement on natural rivers and determined flow resistance changes with respect to hydraulic radius variation and flow depth. In this research it has been explained that main channel interaction with flood plains cause the complexity of flow resistance calculation. They have taken two terms of apparent shear stress and mean shear stress in boundary layer and suggested a numerical model for determining the complex friction factor in rivers.

Although many studies on effects of vegetation on friction factors, the suggested coefficients are very variable and a constant Manning's value is normally used in practice for all flow and vegetation conditions. This will lead mathematical river models to an incorrect estimation of water level for rivers. This study has been performed on three vegetation types which are normally grown along rivers and in flood plains in arid and semi-arid zones including south parts of Iran. Effect of flow depth and velocity on vegetation roughness is considered.

MATERIALS AND METHODS

As mentioned above, vegetation friction factors because of flexibility is a function of flow condition and vegetation characteristics. Thus for a relationship between Manning’s and Darcy-Wiesbach friction factors, the effective parameters on Non-Submerged vegetation can be assumed as follow:

$$f_n\left(C_d,V,\rho,Y,H,A,a,g,\psi,D,\mu,\omega,E\right)=0 \tag{1}$$

Where C_d is drag coefficient which is equal to ratio of shear velocity to mean flow velocity; V, representing flow velocity; ρ, water density; Y, flow depth; H, vegetation height; A, area of one side of leaf and branches; a , flume bed area covered by vegetation; g, gravity acceleration; ψ, a parameter showing vegetation type and leaf surface; D, vegetation density; μ, water viscosity; ω, first mode of natural frequency for vegetation; E, elasticity of vegetation. Then the dimensionless parameters could be:

$$f_n\left(\frac{V^*}{V},\psi,\frac{\rho V^2}{E},\frac{Y}{H},D,\frac{A}{Y^2},\frac{a}{Y^2},R_e,Fr,St\right) \tag{2}$$

Three last non-dimensional numbers are Reynolds number, Froude number and Strouhal number, respectively. Froude number was less than 1 in all experiments of this study thus it doesn't have any effect on the modeling. The flow is turbulent and steady state is assumed, so Reynolds and Strouhal numbers are not considered here, and Equation 2 can be reduced as:

$$\frac{V^*}{V}=\alpha\left(\frac{\rho V^2}{\psi E}\right)^{\beta}\left(\frac{Y}{H}\right)^{\gamma}\left(D\frac{A}{a}\right)^{\lambda} \tag{3}$$

Where, $\frac{Y}{H}$ = submerged ratio; $\frac{A}{a}$ = momentum absorption area (Kouwen and Fathi-Moghadam, 2000), and ψE is a parameter for vegetation index which is a function of resonance frequency, density and height of tree. Then according to the relation $\frac{V^*}{V}=\frac{\sqrt{g}}{C}=\frac{n\sqrt{g}}{R_h^{1/6}}$ we have (R_h, hydraulic radius):

$$n=\alpha_1\left(\frac{\rho V^2}{\psi E}\right)^{\beta_1}\left(\frac{Y}{H}\right)^{\gamma_1}\left(D\frac{A}{a}\right)^{\lambda_1}R_h^{1/6} \tag{4}$$

$$f=\alpha_2\left(\frac{\rho V^2}{\psi E}\right)^{\beta_2}\left(\frac{Y}{H}\right)^{\gamma_2}\left(D\frac{A}{a}\right)^{\lambda_2} \tag{5}$$

The experiments were conducted in a 12.6m long, 0.5m wide and 0.6m deep glass-walled flume. Discharge water was provided by a centrifuge pump with maximum 55l/s and 10m head. Three vegetation types, including tall and native populous and tamarisk and mixture of populous and tamarisk with four densities, were tested. Natural bush of this vegetation with 35 cm height were installed in regular spaces (in 100% density at 3 cm distances) in different densities in a 2.8 m part of the flume. Flow depths were 11, 13, 16, 20, 28 cm. Slope of flume bed was variable and was changed from 0.005 to 0.02.

Flow velocity is measured by a miniature propeller current meter with a propeller diameter of approximately 10 mm (Nixon 430 made in UK) with ±1.5% resolution. Velocity was measured 30 cm upper and lower part vegetation and in 6 points in each cross-section.

Using Manning and Darcy-Weisbach equations following relationship were obtained for (f) and (n) coefficients.

$$f=8g\left(\frac{n}{R_h^{1/6}}\right)^2 \tag{6}$$

Vegetation density of 100% was defined in such a way that if we look at flume bed from above, bed flume is nearly invisible. Then by reducing of bush numbers, three other densities were defined. The momentum absorbing area was obtained by scanning the pictures taken from flume top. Auto cad and Elvis software were used to

Table 1. Vegetation index and momentum absorption surface obtained from each tree.

Tree type	Vegetation index	Adsorbed momentum area
Tamarix	2.32	0.175
Populous	2.02	0.150

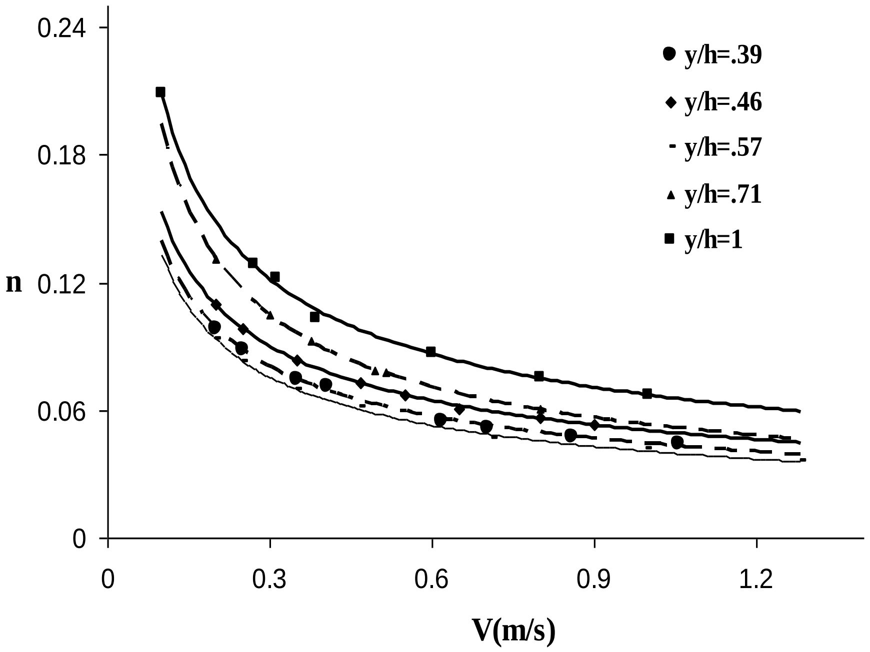

Figure 1. Manning's coefficients verses velocity and ratio of submergence for 100% density (Populous).

count area of black pixels number (A). The method of Fathi-Moghadam (2007) was used to determine the vegetation index (ψE).

RESULTS

The estimated vegetation index and momentum absorbing area for the tested vegetation species are shown in Table 1.

A considerable effect of velocity on Manning n-value for different ratio of submergence is shown on Figures 1 and 2.

Effect of ratio of submergence on Manning's n-value for different channel velocity is shown in Figure 3 for populous (density of 50%). Friction coefficient increases with ratio of submergence due to increase of more roughness elements.

Figure 4 shows considerable increase of Manning's n-value with increase of vegetation density. Figure 5 also illustrates a linear increase of n-value with increase of density as it was with flow depth in Figure 3.

Figure 6 shows variation of n-value with velocity for populous and tamarix. A higher value of n for Tamarix reveals more rigidity of tamarix than populous.

Using SPSS and vegetation index for tamaix and populous (Table 1), results of all flume experiments in this study were incorporated into Eqs. 4 and 5 and following equations for calculation of friction coefficients (n and f) are correlated.

$$n = 0.36\left(\frac{V}{\sqrt{\psi E/\rho}}\right)^{-0.4}\left(D\frac{A}{a}\right)^{0.2}\left(\frac{Y}{H}\right)^{0.48}R_h^{\frac{1}{6}} \qquad R^2 = 0.97 \tag{7}$$

$$f = 10.2\left(\frac{V}{\sqrt{\psi E/\rho}}\right)^{-0.78}\left(D\frac{A}{a}\right)^{0.4}\left(\frac{Y}{H}\right)^{0.95} \qquad R^2 = 0.96 \tag{8}$$

Equations 7 and 8 can be used in river hydraulic models for estimation of friction coefficients (n and f) at any flow

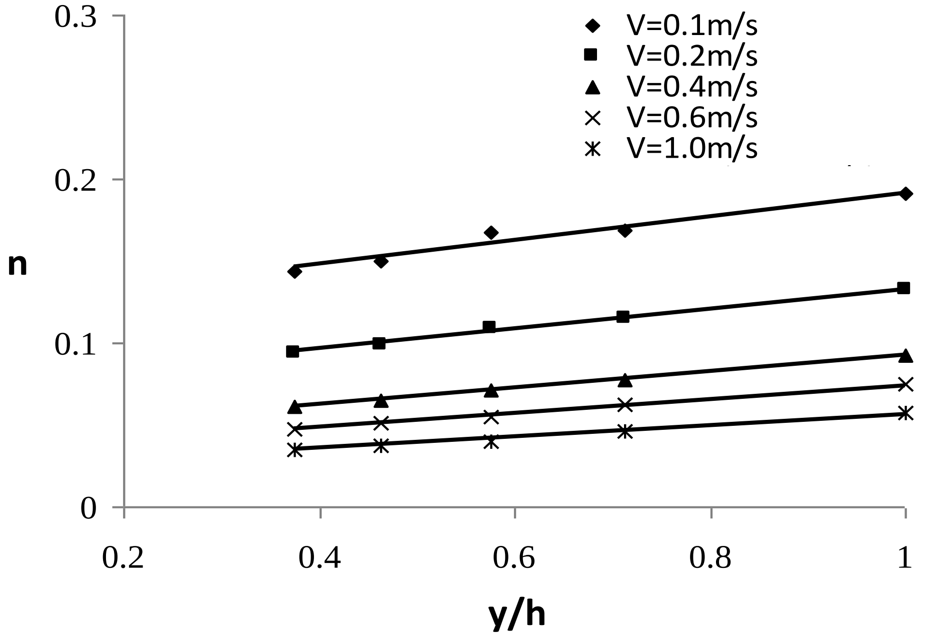

Figure 3. Manning's coefficients changes with submerge ratio in similar velocity in populous in density 50%.

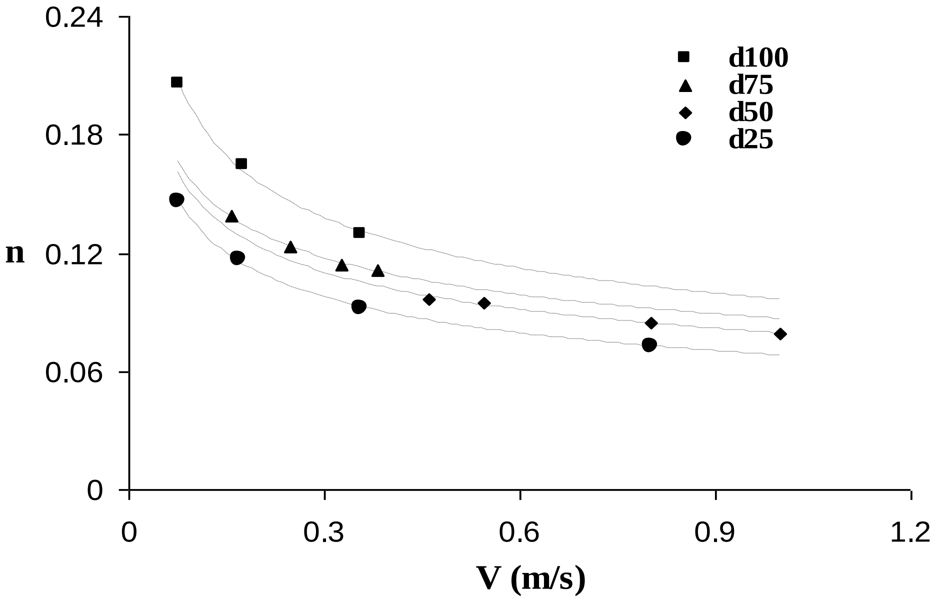

Figure 4. Manning's n verses velocity for different density (Tamarix).

and vegetation conditions in metric system of units.

DISCUSSION

The experiments were conducted to develop a model for estimation of friction factor for non-submergence vegetation along river banks and in flood plains. The results were summarized in Equations 7 and 8 with minimum required parameters. Equations in agreement with previous works (Kouwen and Fathi-Moghadam, 2000); Jarvela (2004) confirm consider effect of flow and vegetation condition on roughness coefficient. The roughness coefficient decreases with increase of flow

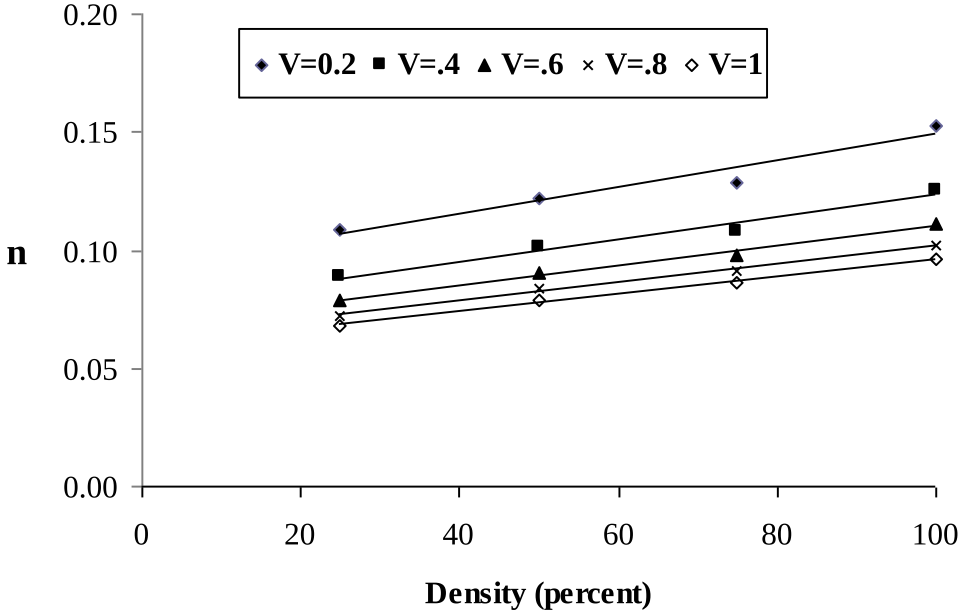

Figure 5. Effect of vegetation density on Manning's coefficients for tamarisk.

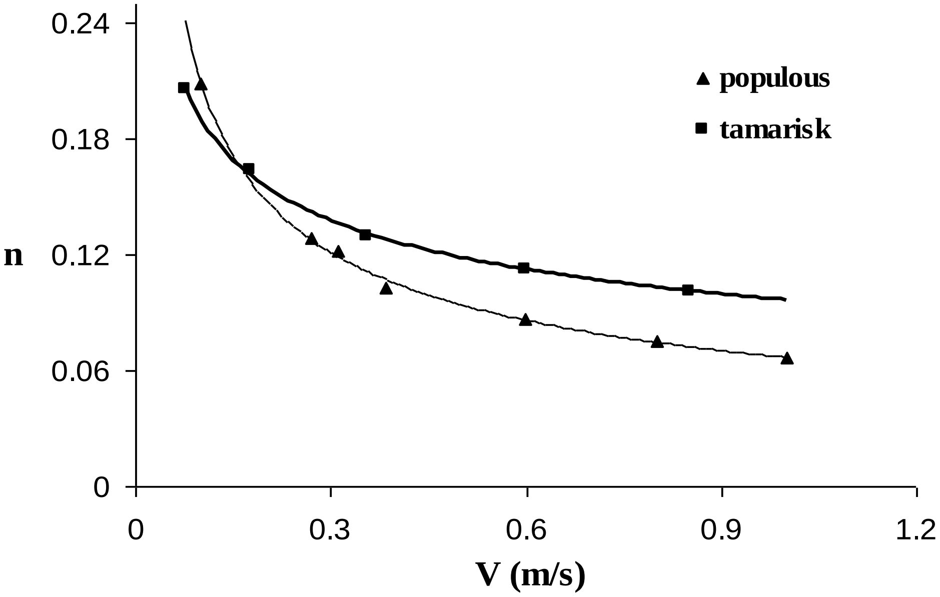

Figure 6. Comparing effect of vegetation type on Manning's coefficients (tamarisk and populous, 100% density).

velocity, while it increases linearly with increase of flow depth and density due to submergence of more roughness elements. This proofs existence of an additive property for increase of roughness elements. The vegetation index showed to be a suitable parameter to characterize mechanical properties and behavior of vegetation against the flow.

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