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Flow Resistance Due to Rigid and Flexible Vegetation: A Review

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Outline of Presentation

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Introduction

- Vegetation such as grasses and shrub frequently grown in the main channel, floodplains and wetlands water areas.
- The flow conditions are extremely complex where flow passes through aquatic riparian vegetation.
- The presence of vegetation is one of the factors that change the mean and turbulent flow field in a channel (Nepf, 2012a).
- Traditionally vegetation regarded as a nuisance and hence it was removed from channels to increase the passage of flow.
- Advances in understanding the behavior of flow over vegetation allow us to improve both the knowledge of flow-velocity profiles and flow resistance and the design of vegetated channels (Tsujimoto, 1999).

Introduction

- In addition, vegetation is known to increase bank stability, reduce erosion, provide habitat for aquatic life, attenuate floods, increase aesthetic values and filter pollutants.
- Recently, efforts are being taken up for river restoration, re-naturalization and rehabilitation of watersheds and watercourses in which growing of vegetation is the first and foremost step (Kothyari et al, 2009a).
- Hence, understanding of interaction between flow, vegetation and sediment is required for recognizing the problem.
- Vegetation affects fluvial processes and is key in current river management and river hydraulics.

Theoretical Background

❑Distinction between submerged and emergent vegetation

- Submerged vegetation refers to the type of vegetation in which the flow depth is more than the height of the vegetation while emergent vegetation is the opposite of submerged vegetation where the Vegetation height is more than the flow depth.

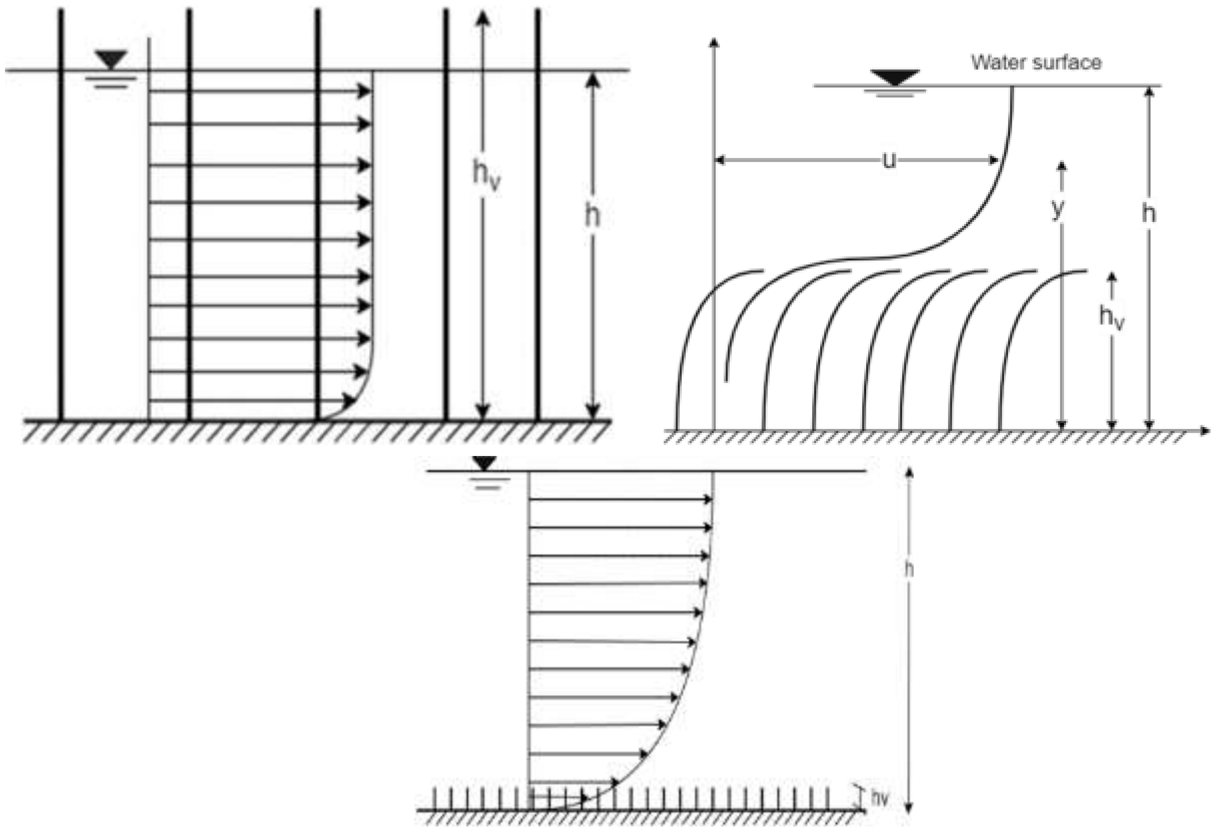

Fig 1: Velocity distribution for Emergent, Submerged and well submerged vegetation

Theoretical Background

❑Distinction between rigid and flexible vegetation

- Flexible vegetation decreases the drag coefficient as bending of vegetation occurs, therefore the study of phenomenon for this case is complicated to non submerged or rigid vegetation.
- The mean velocity profiles in case flexible species depends upon the bending of vegetation and submergence ratio.
- Grasslike vegetation can be considered flexible, shrubby vegetation is, instead, rigid and could assume both the emergent and the submerged configuration.

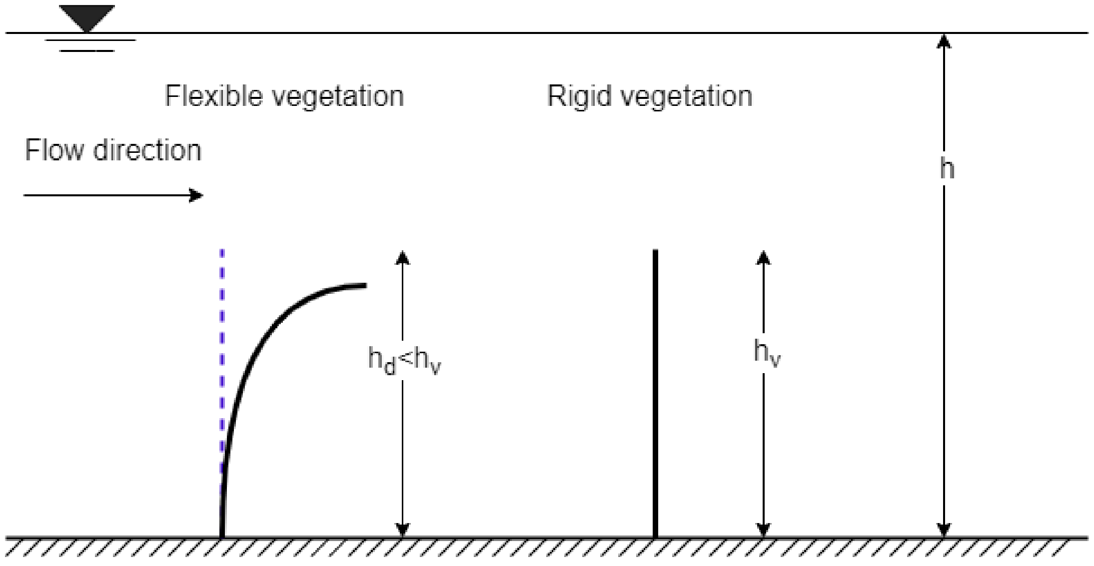

Fig 2: Comparison of Flexible and Rigid vegetation

Velocity Distribution for Rigid Vegetation

Authors	Equations
Petryk and Bosmaijan (1975)	$U_v = \sqrt{\frac{2g}{C_D m D}} * \sqrt{S}$
Stone and Shen (2002)	$U_v = \sqrt{\frac{2g}{C_D m D}} * \sqrt{S} * \sqrt{(1 - D\sqrt{m})} * (1 - \frac{\pi m D^2}{4})$
Hoffmann (2004)	$U_v = \sqrt{\frac{2g}{C_D D}} \sqrt{S} * \sqrt{S_v\, h - \frac{\pi D^2}{2}}$ $\quad s_v = \frac{1}{\sqrt{m}}$
James et al. (2004)	$V = \frac{1}{\sqrt{F_f}} \sqrt{S}$ $\quad \frac{1}{F_f} = \sqrt{\left(\frac{1 - \frac{m\pi D^2}{4}}{\frac{f}{8} + C_D \frac{1}{2} m h D}\right) gh}$

Authors	Equations
Klopstra et al, (1997)	$U = \frac{h_v}{h} U_v + \frac{h - h_v}{h} U_s$
Huthoff (2007)	$U = U_v \left(\sqrt{\frac{h_v}{h}} + \left(\frac{h - h_v}{h}\right) * \left(\frac{h - h_v}{s_v}\right)^{\frac{2}{3} * \left(1 - \frac{h}{h_v}\right)^{-5}} \right)$
Baptist et al, (2006)	$U = \left(\sqrt{\frac{2g}{C_D m D}} * \sqrt{h_v} + \frac{\sqrt{g}}{k} + \ln\left(\frac{h}{h_v}\right) \right) * \sqrt{hS}$
Yang and Choi (2010)	$U = \frac{C_u u_*}{k} \ln\left(\frac{h}{h_v}\right) - \left(\frac{h - h_v}{h}\right) + U_v$

Table 1 & 2: Velocity distribution equations for emergent and submerged Rigid vegetation

Flow Resistance for Rigid Vegetation

- Rigid vegetations are simulated by cylinders in laboratory method for determining the resistance in emergent and submerged condition. The roughness coefficient is based on diameter of cylinder, height, their density and arrangements.

Authors	Equations
Ishikawa et al, (2000)	$C_D = 1.71\lambda^{0.11}$, $C_D = 2.45\lambda^{0.20}$ & $C_D = 3.89\lambda^{0.31}$ For S=1/50, 1/20 and 1/10 respectively
Kothyari et al, (2009)	$C_D = 1.53[1 + 0.45\ln(1+100\lambda) Re_{D*}{}^{-3/50}$
Cheng and Nguyen (2011)	$C_D = \frac{50}{Re_v{}^{0.43}} + 0.7\left[1 - \exp\left(-\frac{Re_v}{15000}\right)\right]$ for Re_v=52-5.6*10^5 $r_v = \frac{\pi}{4} * \frac{(1-\lambda)}{\lambda} D$

Table 3: Flow resistance equations for Rigid vegetation

Flow Resistance for Flexible Vegetation

- Palmer (1945) designed vegetative channels bases on n-VR curves, which is later revised by US soil conservation service.
- Kouwen and Unny (1973), resistance to vegetation is a function of relative roughness (h_d/h).
- Jarvela (2002) revealed that the deflection of flexible plants, flow velocity and depth of flow all will influence the friction factor.
- Yen (2002) suggested to use superposition principle for mixture of vegetation, since for plant species growing in combination, it is difficult predict resistance to flow.

Flow Resistance for Flexible Vegetation

- Noarayanan et al, (2011) determined flow resistance for flexible vegetation arranged in tandem pattern for various flow conditions and vegetative parameters by modifying the general Manning formula for vegetative and non-vegetative channel separately and subtracted later form the former.

$$n = \left\{ \left(\frac{1}{U_{(veg+non)}} \right) * \left(R^{\frac{2}{3}} * S_{(veg+non)}^{1/2} \right) \right\} - \left\{ \left(\frac{1}{U_{(non)}} \right) * \left(R^{\frac{2}{3}} * S_{(non)}^{1/2} \right) \right\}$$

$$h_{f(veg+non)} = \left\{ \left(\frac{U_{u(veg+non)}^2 - U_{d(veg+non)}^2}{2g} \right) + \left(H_{u(veg+non)} - H_{d(veg+non)} \right) \right\}$$

$$h_{f(non)} = \left\{ \left(\frac{U_{u(non)}^2 - U_{d(non)}^2}{2g} \right) + \left(H_{u(non)} - H_{d(non)} \right) \right\}$$

- Where S=energy slope=h_f/length of test section
- Recently, improved flow resistance parameterizations have been done based on LAI (Lead area index) and implemented in hydraulic models (Jarvela, 2004; Aberle and Jarvela, 2015; Vastila and Jarvela, 2014; Box et al., 2021).

Summary

- All descriptions uses vegetation in a simplified form with fixed and identical plant height and diameter. Also, the vegetation is assumed to be a homogeneous equally distributed field. The flow is assumed to be steady and uniform.
- The channel is considered to be sufficiently wide, so that sidewall effects can be neglected. Most descriptions take the bottom roughness into account. However, from literature it is known that the influence of bottom roughness is small in vegetated channels.
- Most descriptions for submerged vegetation are based on the two-layer theory, which makes a distinction between the velocity in the vegetation layer and in the surface layer.

Flow Hydrodynamics in Vegetative Compound Channel

- Yang et al, (2007) studied flow patterns over different types of vegetation on compound channels such as tree, shrub and grass.
- Ahmad et al, (2020) studied flow hydrodynamics in vegetative compound channel of varying heights, such as tall and short rigid vegetation.
- Barman and Kumar, (2022) examined the turbulence in asymmetric compound channel for the combination of both submerged and emergent rigid vegetation.

Critical Appraisal

- Several investigators carried out study on turbulent flow structure in compound channel in presence of vegetation on floodplains.
- However, the study on hydrodynamics of flow with heterogenous vegetation on floodplains yet to be explored.

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Thank You