Experimental Investigation of Energy dissipation through mixed densities of vegetation

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Abstract

The vegetation on the floodplain promotes bank stability, lowers turbidity and erosion, provides habitat for aquatic and terrestrial creatures, has aesthetic qualities, and filters pollutants. This study presents the laboratory experiment on the effect of variable densities of vegetation by changing the water depth and density of vegetation in an open channel laboratory flume. The energy dissipation is calculated using vegetation with varying densities (G/d, where G is the spacing between each two vegetation elements across the stream and d is the cylinder's diameter) and thickness (dn, where d is the vegetation diameter and n is the number of vegetation elements in in a stream-wise direction per unit of cross-stream width). To investigate the effect of vegetation density, two patches of vegetation with different densities are tested by placing them in open channel flume. These vegetation patches are tested by changing the position i.e.; front and back side along the stream flow. It is resulted that the energy dissipation increases by placing lower density vegetation in the front and higher density vegetation at rare side as compared to the higher density vegetation in front and lower density vegetation at the back. The maximum energy dissipation is 46.79% in the case where lower density vegetation is in front and higher density vegetation in the back. The minimum energy dissipation is 9.93% in the case where higher density vegetation is in front and lower density vegetation at the back. Energy Dissipation increases with increasing discharge.

Keywords: *Experimental modeling; vegetation configuration; flow rates; Flume; channel*.

1. Introduction

For deriving the best method to keep the energy dissipation at its low point researchers have worked for years (Nateghi et al., 2016; Rahman et al., 2017; Tanaka, 2012; Thuy et al., 2012). To determine the energy dissipation of flow during a flood, two methods can be used: hard solutions (artificial) and soft solutions (natural). Hard solutions have installing backwater structures, putting gates, and embankments. These solutions require very big investment, and very costly for countries under developing (Tanaka, 2009). Soft solutions such as installation of vegetation, flow through vegetation of various densities can be considered for finding flow characteristics and energy dissipation (Kathiresan and Rajendran, 2005; Osti et al., 2009; Tanaka, 2009; Yanagisawa et al., 2009, 2010). Vegetation as protection or as dissipating energy depend upon vegetation density (Harada and Kawata,2005; Irtem et al., 2009; Tanaka et al., 2011). Installing the vegetation of various densities have different effects, vegetation of higher density have more reflection and hydraulic resistance of water can change the hydraulic characteristics of water and can cause energy dissipation. Backwater rise at upstream of vegetation and density of vegetation has direct relation (Afzal Ahmed et al., 2019). The force of water can be reduced by flowing through vegetation, which decreases the damage downstream or behind the vegetation. By increasing the vegetation density, both the water level and the flow velocity behind the vegetation decreased (Iimura and Tanaka, 2012). Greater vegetation density results in increased water hydraulic resistance and water reflection upstream of the vegetation. Higher-density vegetation increased the water surface profile (slope) in the vegetation-covered area. The water surface profile within the vegetation increases by increasing the vegetation density (Afzal Ahmed et al., 2019). An increase in vegetation width can change the hydraulic characteristics of flow, increasing the water surface slope within the vegetation region, decreased the inundation depth and hydraulic force of water behind the vegetation (Harada and Imamura, 2005). Moreover, Energy reduces behind the vegetation by changing the vegetation density of vegetation (Thuy et al., 2009; Iimura and Tanaka, 2012). Vegetation with varying density also effect the rate of energy dissipation, The average energy dissipation is 25.32% for sparse vegetation at 900, and the average energy dissipation is 31.5% for intermediate vegetation at 900 (Afzal Ahmed et al., 2020). Hydraulic jumps were formed behind the vegetation, during the tsunami (Chanson and Montes, 1995; Ohtsu et al., 2001, 2003). The vegetation arrangement in a forest can change the flow into a supercritical flow that caused the formation of hydraulic jump. A jump formed by water surface waves, water surface slope within the

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vegetation, turbulence in flow, air entrainment and energy dissipation. Hydraulic jumps observed in the downstream of vegetation in a transitional way changing channel slope from steep to mild (Ohtsu et al., 2003). Energy dissipated not only upstream of vegetation but also in vegetation region and downstream of vegetation.

This paper includes the experimental study of energy dissipation in flow through different densities of vegetation. The effect of configuration of vegetation densities is also investigated by altering the position (front and back side) of high and low vegetation. Hydraulic Flume experiments are conducted to calculate the energy dissipation in flow through vegetation of three different densities, three different thicknesses of vegetation and five various inflow conditions.

2. Research Methodology

2.1. Flume Setup

Flume experiments were carried out in the hydraulic laboratory of the University of Engineering and Technology, Taxila's Civil Engineering Department. A 10 meter-long, 0.3 meter-wide, and 0.5 meter-high glass-sided water flume with a bed slope of 1/500 was used.

2.2. Vegetation Conditions

Vegetation of circular cylinder having diameter of 1cm were used in hydraulic flume. Two vegetation configurations, i.e; vegetation of lower density in front and higher density on the back (LFHB) and vegetation of higher density in front and lower density on the back (HFLB) were mounted in the hydraulic water glass-sided flume as shown in the Fig. 1 and 2. Fig.3 a-b shows Experimental model of vegetation with different densities. Five different discharges were used for each density of vegetation. Density of vegetation with dn=180 No-cm was installed in the water flume bed about 4.5 m from the upstream intake. In the water flume bed, around 4.20m from the upstream entrance, a density of vegetation with dn=380 No-cm was mounted. In the water flume bed, around 4.10m from the upstream entrance, a density of vegetation with dn = 580 No-cm was mounted. The following equation was used to compute the widths of vegetation of varying densities:

$$dn = d \times Wv \times \frac{2}{\sqrt{3D^2}} \times 45 \quad (1)$$

Where dn is the vegetation density (180, 380, 580 No-cm), d is the diameter of the vegetation, Wv is the width of the vegetation, and D is the centre to centre distance between the vegetation in the above equation.

At 5cm intervals, the level of water in the hydraulic water flume channel was calculated using an indicated point gauge. After the installation of vegetation of variable densities in the hydraulic flume channel, the inflow was changed according to the five selected flow conditions as mentioned in Table 1.

Table 1: Parametric conditions

Sr. No	h0 (cm)	Q (litre/s)	Forest Type	D (cm)	Wv (cm)	dn (No-cm)
1	1.3,2.8,3.5,4.2,5.5	1.52, 4.32,6.04,10,13.4	LFHB180	3	17.33	180
2	1.3,2.8,3.5,4.2,5.5	1.52, 4.32,6.04,10,13.4	LFHB380	3	36.6	380
3	1.3,2.8,3.5,4.2,5.5	1.52, 4.32,6.04,10,13.4	LFHB580	3	55.85	580
4	1.3,2.8,3.5,4.2,5.5	1.52, 4.32,6.04,10,13.4	HFLB180	2	17.33	180
5	1.3,2.8,3.5,4.2,5.5	1.52, 4.32,6.04,10,13.4	HFLB380	2	36.6	380
6	1.3,2.8,3.5,4.2,5.5	1.52, 4.32,6.04,10,13.4	HFLB580	2	55.85	580

The velocity was measured using calculated values of discharge and depth of water; V=Q/A, where, V is the depth average velocity (m/s), Q is discharge (lit/s) and A is the area of the cross-section (m^2). Using measured values of water depth and velocity, the specific energy was calculated using the equation:

$$\mathrm{E} = y + \frac{v^2}{2g} \quad (2)$$

Where g denotes gravity's acceleration. In this research, Specific Energy 'E' against each value of velocity and water depth was calculated. The energy dissipation on the upstream of vegetation "Eu" was calculated by measuring the average energy dissipation of all the measured points from the start of the vegetation patch to 30 cm towards the inlet. Similarly, the energy dissipation downstream of vegetation 'Ed' is calculated by measuring the average of all the values on the downstream of vegetation starting from the last row of the vegetation patch to 60 cm towards the tailgate. Average energy dissipation (%) was calculated as:

$$\frac{Eu-Ed}{Eu} \times 100 \quad (3)$$

Further h1, h2 were the average flow depth on both sides of the vegetation patch (upstream and downstream). The back water rise (Δh) was calculated against each flow and for each vegetation of different densities as:

$$\Delta h = \frac{h1-ho}{h1} \quad (3)$$

where ho is depth of water without vegetation and "Δh/ho" was calculated.

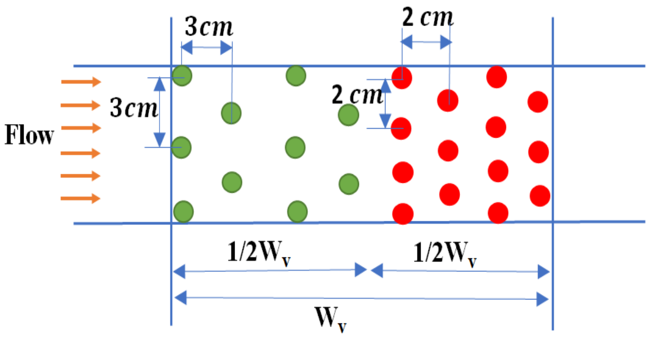

Fig. 1: The Schematic diagram of LFHB

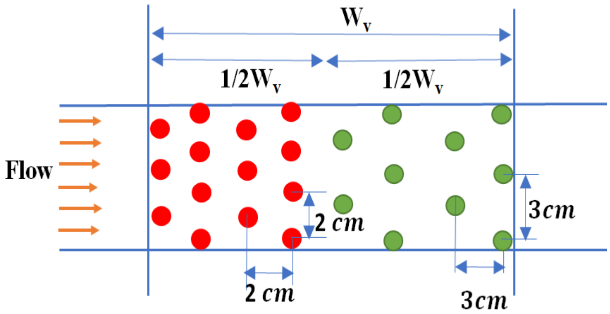

Fig.2: The Schematic diagram of HFLB

(a) (b)

Fig. 3: (a, b) Experimental model of vegetation with different densities

3. Results

3.1. Upstream of vegetation, the backwater rises

As illustrated in Fig. 4 a-c, increasing the discharge, density of vegetation, and thickness of vegetation maximises the water level on the upstream side of vegetation. Vegetation of higher density causes increased in resistance for flow as compared to vegetation of lower density result in increased the level of water on the upstream of vegetation. The maximum average back water rise was measured 0.62cm in the case where higher density vegetation is in front and lower density vegetation in the rare. The minimum average back water rise was measured 0.54cm in the similar case where higher density vegetation is in front and lower density vegetation in the rare. However, the maximum and minimum back water rise was measured in the same case with different discharges. By increasing the discharge, the relative backwater rise (h/ho) was also increased. However, this increment was smaller than the backwater rise (h), indicating that the beginning flow depth (ho) had a smaller impact on backwater rise. Fig. 5 a-c depicts the backwater rise pattern.

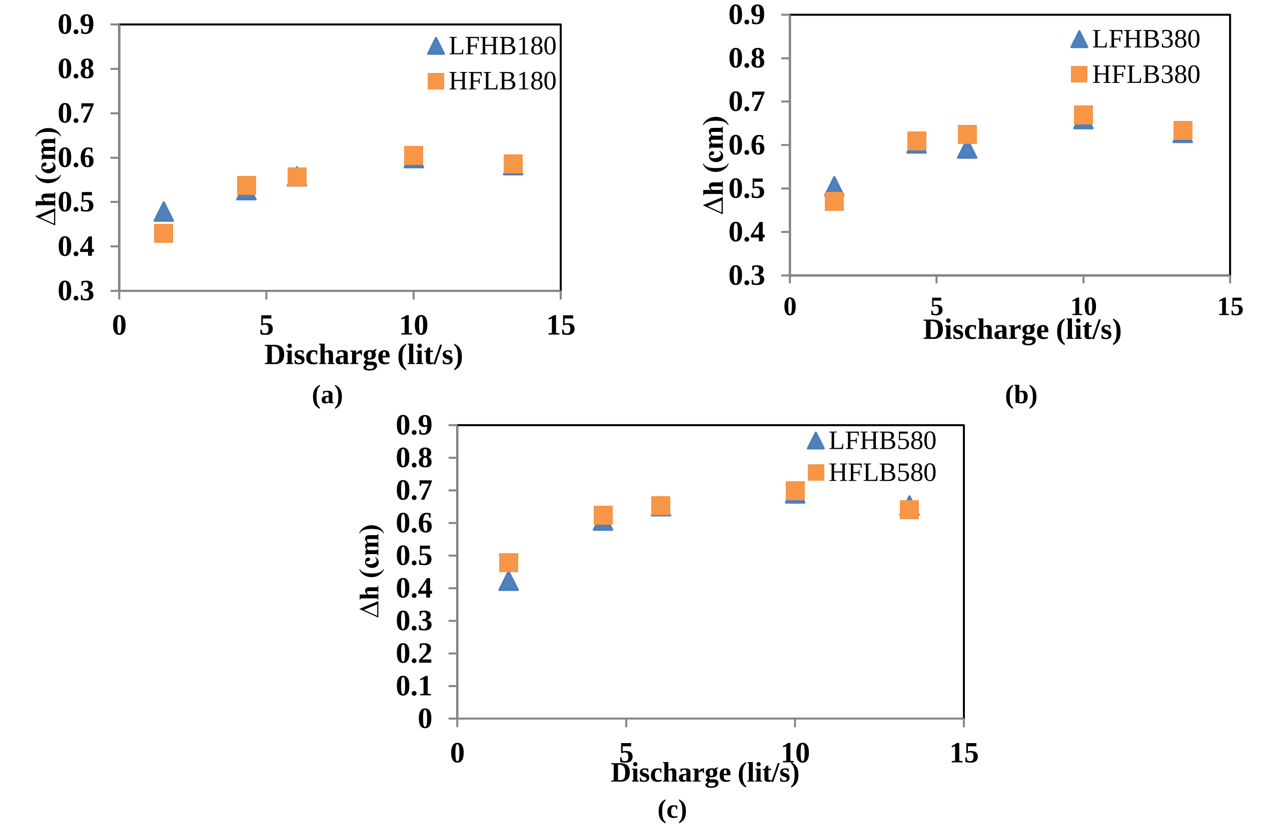

Fig. 4: Backwater rise Δh for various discharges (a)Sparse vegetation dn=180No-cm, (b)Intermediate vegetation dn=380No-cm, (c)Dense vegetation dn=580No-cm

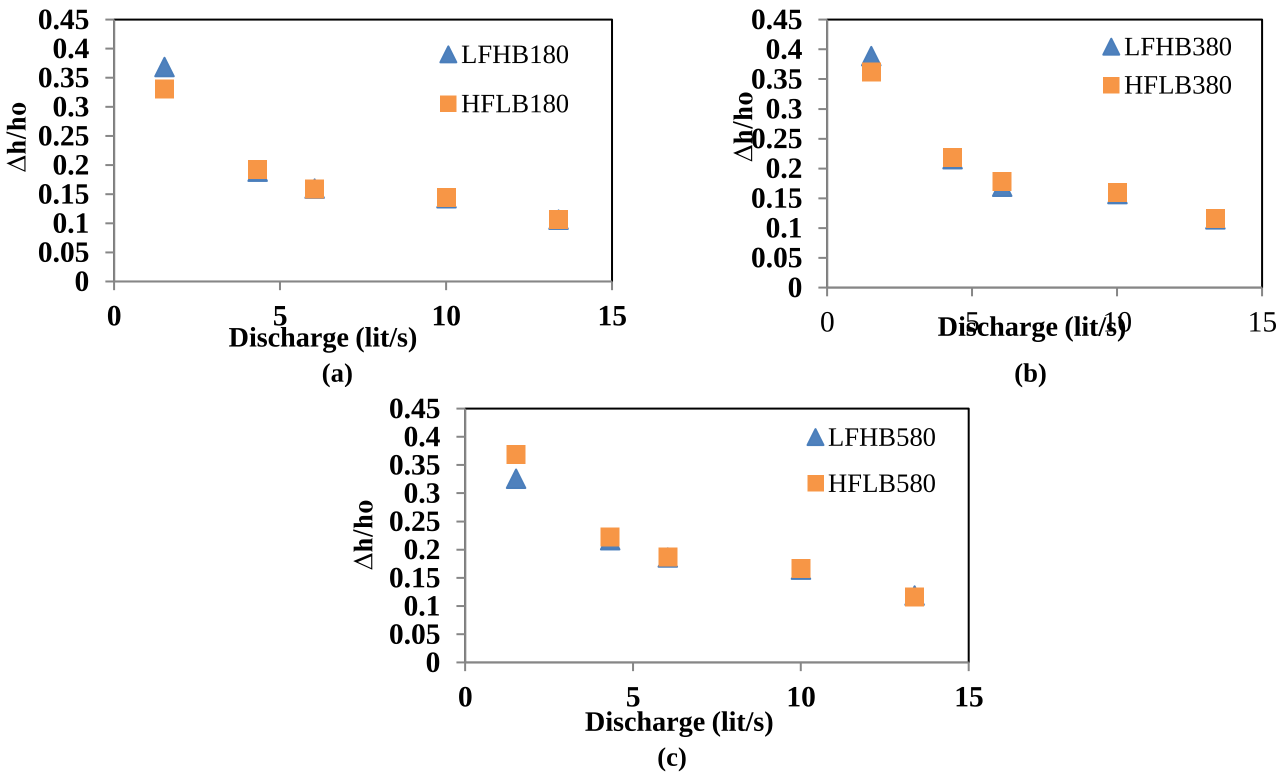

Fig. 5: Relative backwater rise Δh/ho where ho is initial depth of water measured without vegetation. (a)Sparse vegetation dn=180No-cm, (b)Intermediate vegetation dn=380No-cm, (c)Dense vegetation dn=580No-cm

3.2. Loss of Energy due to vegetation density

Energy dissipated in case of reduced water level and velocity of flow downstream of vegetation. The reduction in water level and flow velocity caused by vegetation of varying densities behind the vegetation. The velocity of flow behind the vegetation was reduced when the density of vegetation was increased. Total relative energy loss is lower for a vegetation thickness of dn-180 No. cm. The overall relative energy loss for dn-380 No. cm is more than the vegetation thickness of dn-180N-m. Similarly, total relative energy loss is greatest for dn-580 No. cm. It is resulted that the energy dissipation increases by placing lower density vegetation in the front and higher density vegetation at rare side. The maximum energy dissipates is 46.79% in the case where lower density vegetation is in front and higher density vegetation in the rare. The minimum energy dissipates is 9.93% in the case where higher density vegetation is in front and lower density vegetation in the rare. Energy Dissipation increases with increasing discharge as shown in Fig. 6 (a-c).

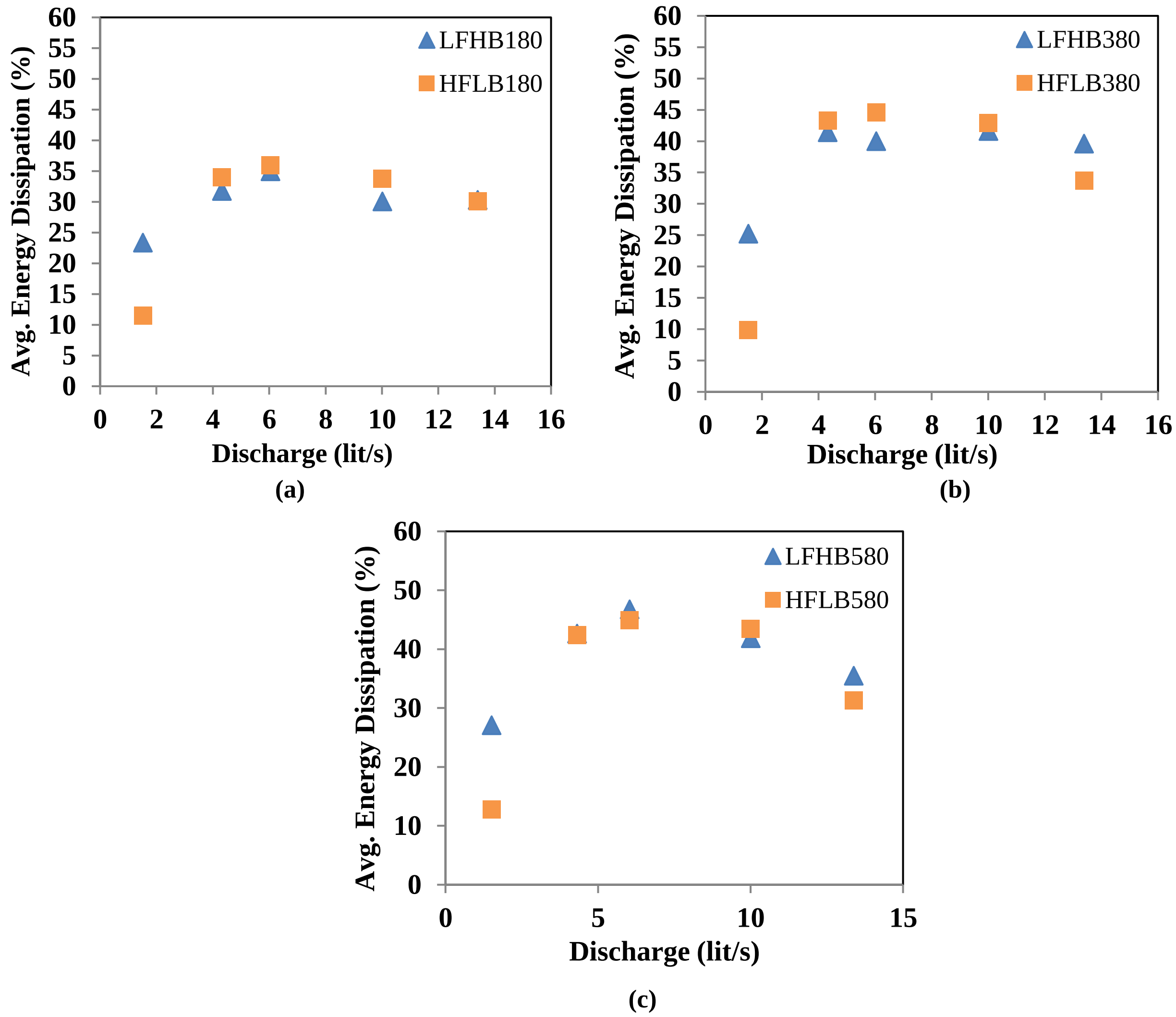

Fig. 6: Relationship between Average Energy dissipation (%) and discharges in vegetation of variable densities. (a)dense vegetation dn=180No-cm, (b)intermediate vegetation dn=380No-cm, (c)sparse vegetation dn=580No-cm

4. Conclusions

In a hydraulic flume with varying inflow, the flow structure with changing water depths, velocity, and energy loss around vegetation of varied densities were investigated.

Upstream of vegetation, either the vegetation density remains constant, but the thickness (width) of the vegetation increases from dn-180 to 580No-cm, causing an increase in backwater rise.

The maximum energy dissipation was observed by placing lower density vegetation in the front and higher density vegetation at rare side i.e; 46.79%. The minimum energy dissipation was by placing higher density vegetation in the front and lower density vegetation at rare side i.e; 9.93%.

Energy dissipation increased with increasing the density of vegetation. However, increasing the thickness of vegetation from dn-180 to 580 No-cm causes an increase in energy dissipation when the density of vegetation remains constant. Energy dissipation increased with increasing the discharge on vegetation of varying density increasing from dn-180 to 580 No-cm.

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