Study of Turbulent Kinetic Energy and Reattachment Length Downstream the Obstruction in an Open Channel

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Abstract: The present paper presents results from an experimental work in an open channel flow. The open channel contains a weir-like obstruction with different leeward slopes. Two discharge values have been used under sub-critical flow conditions. The objective of the present study is to investigate the flow behavior behind a vegetated obstacle. The characteristics explored included the turbulent kinetic energy and recirculation zone behind the vegetated obstacles. It was observed from this work that the TKE has higher values in recirculation regions. On the other hand it was also found to be of high intensity in the vegetated zones of the flow. However TKE was maximum and positive close to the bed at a section at the end of the weir crest and it was negative below the top of the vegetation dowels. As far as recirculation region was concerned, it was observed that the vegetation had no effect on the recirculation zone behind the vegetated weir. In case of weir with mild downstream slope (1:7), the flow separation zone vanished and the energy head loss in this case decreased due to the decrease in form drag of the weir.

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1. Introduction

To estimate the discharge capacity of a river, the knowledge of hydraulic resistance is of the prime importance. During high water stages e.g. floods, water also flows over the floodplains. Floodplains contain lot of features such as summer dikes, access roads, groins etc. These features are generally covered with vegetation. These floodplain obstacles can be considered as obstructions which resemble to vegetated weir-like structures and contribute to the flow resistance during high water stages. The resistance offered by these structures considerably disturbs the conveyance capacity of the river cross-section.

Mostly the hydraulic engineers used the calibrated roughness coefficient for flood and water level predictions but these are not based on physics. The hydraulic resistance due to above mentioned obstacles has been lumped to a single coefficient such as Manning's roughness coefficient. These approaches are used extensively in the field; however these are not reliable to predict water levels during floods. Therefore, this is most important to understand physical behavior of these types of vertical resistance elements in the floodplain.

The effects of submerged and un-submerged rigid and flexible vegetation on the flow have been studied by many researchers such as; Järvelä (2002 and 2004). Some studies were on velocity profiles and turbulent characteristics of vegetated patches in a channel e.g. López and García (2001), Tsujimoto and Kitamura (1990), Klopstra et al. (1997), Baptist (2005) etc. Many researchers investigated the weir properties; such as Rehbock (1929), Villemonte (1947), Chow (1959), Abou-Seida and Quraishi (1976), Govida Rao and Muralidhar (1963), Swamee (1988), Lakshmana Rao (1975), Jain (2001). Rajaratnam (1965) considered velocity measurements of an actual jump, but his instrumentation (a pitot tube) was limited to the measurements of mean velocity characteristics away from the roller region. The same is true for Leutheusser and Kartha (1972), who used a pitot-static tube to measure mean velocity and a Preston tube to measure boundary shear stress. Rouse et al. (1958) are often credited with performing the first detailed measurements of the velocity structure in hydraulic jumps. The measurements of Liu et al. (2004) were used to investigate the spatial distribution of turbulent kinetic energy, Reynolds stress and turbulence micro scale.

Armaly et al. (1983) performed Laser-Doppler measurements of velocity distribution and reattachment length at downstream of a single backward-facing step mounted in a two-dimensional channel. An experimental and numerical study has been done to determine the flow characteristic behind a backward facing step for turbulent by Wee et al. (2004) and Lee and Mateescu (1998). There is no study for the turbulent flow characteristics of vegetated weir-like obstacles.

The objective of the present study is to investigate the flow behavior behind a vegetated obstacle. The characteristics explored included the turbulent kinetic energy and length of recirculation zone behind the vegetated obstacles. For this purpose experimentation was performed in the laboratory and data was gathered to explore these properties of flow.

2. Experimental work

The experimental work was conducted in the Hydraulics Laboratory of Technical University Delft. The detailed description of experimentation can be found from Shahid et. al. (2013). Brief details are as below.

A 14 m long glass-walled flume was used for experimentation. The cross section of the channel was rectangular with dimensions 0.4m×0.4m. Downstream water level was controlled by providing a weir at the end of the channel. Laser doppeler anemometer (LDA) was used for collection of velocity data. The laser lights were able to pass through the glass walled flume. The channel bed was horizontal. Roughness on the channel bed was achieved by using 5-8 mm diameter gravels. A trapezoidal embankment has been was used in this work. Experiments have been performed for cases with and without vegetation. Two discharge values (25 l/sec and 40 l/sec) have been used. One upstream slope (1:4) and two leeward slopes (1:4 and 1:7) were considered in this work (Figure 1). LDA has been used for collection of velocity data over the depth of the flow at different locations along the length of the channel.

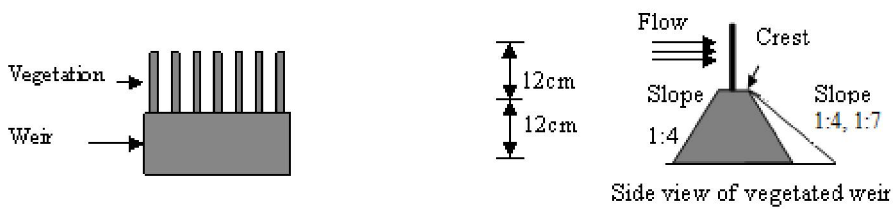

Figure 1. A view of vegetated experimental embankment with side slopes 1:4 and 1:7.

3. Results and discussion

In the following results, the turbulent kinetic energy has been normalized by u_o^2 and the vertical depth was normalized by weir depth Δ.

3.1. Turbulent kinetic energy

The turbulent kinetic energies (TKE) were approximated by using the relation given here:

$$TKE = \frac{3}{4}(\overline{(u')^2} + \overline{(w')^2})$$

Where u' and w' are the instantaneous velocity fluctuations (m/s). As the velocity in third direction has not been measured, it is assumed that this velocity has equal contribution to the turbulent kinetic energy as the transverse velocity fluctuations (isotropy). Adam and Rodi (1990) & Chandrsuda and Bradshaw (1981) used similar equation to calculate the TKE. The Figures 2-3 are showing the TKE profiles for both discharge (25 l/sec & 40 l/sec). At a location upstream of the weir crest (location1) the TKE is very small as compared to the other locations. At the weir crest behind the vegetation (location 2), there is a near bed spike in the both profiles of TKE for vegetated and non-vegetated weir cases and also for both discharge cases. For the vegetated weir the TKE enhanced due to the turbulence generation by the wake and the shear layer production. In submerged vegetation cases the shear layer turbulence production dominates the wake turbulent production and the main contribution is by the shear layer turbulence and it penetrate down to the canopy and the peak is below the top of the vegetation stem. As we go further downstream the crest, the contribution by the weir recirculation zone enhances the turbulence a lot and vegetation contribution diminishes quickly. After the reattachment point the turbulence starts to damp and the TKE profiles diffused over the whole water depth. The profiles for both discharges are showing that the TKE is also enhanced by the high velocities. At location 3 which is 16 cm away from the location 2, the effect of the vegetation on the profiles can be noticed. However at location 4 which is 36 cm downstream of the location 2, the effect of the vegetation is no more. The Figure 4 is showing the TKE for the mild slope case of 1:7 for a discharge value of 40 l/sec. Similar patterns like that of the steep slope 1:4 have been observed in this case also.

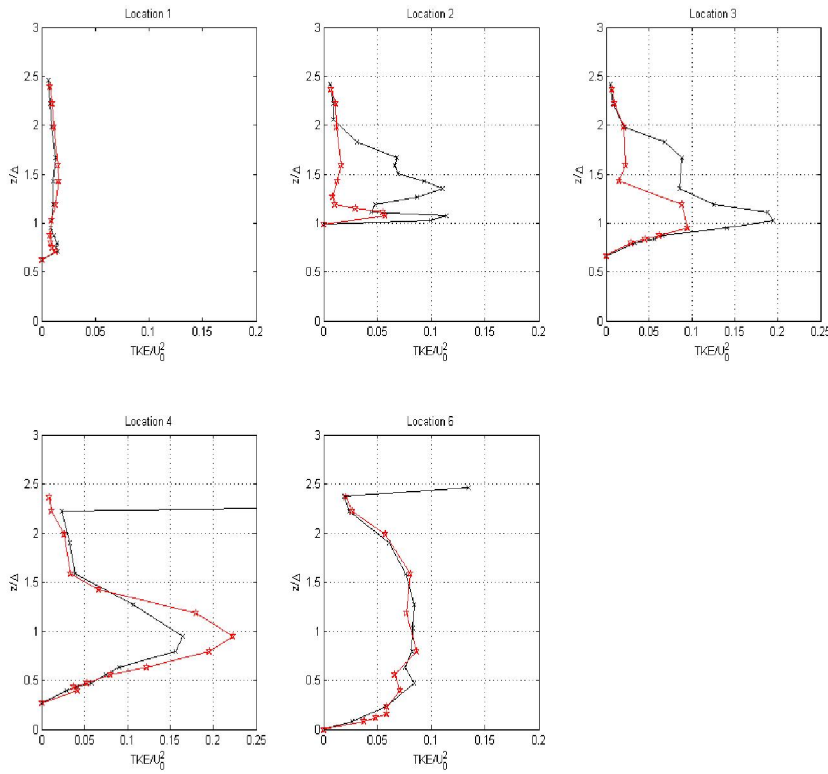

Figure 2: Comparison of turbulent kinetic energy at different locations for the vegetated and non-vegetated weir (*(red) non-vegetated weir and x (black) vegetated weir Q=25 l/sec).

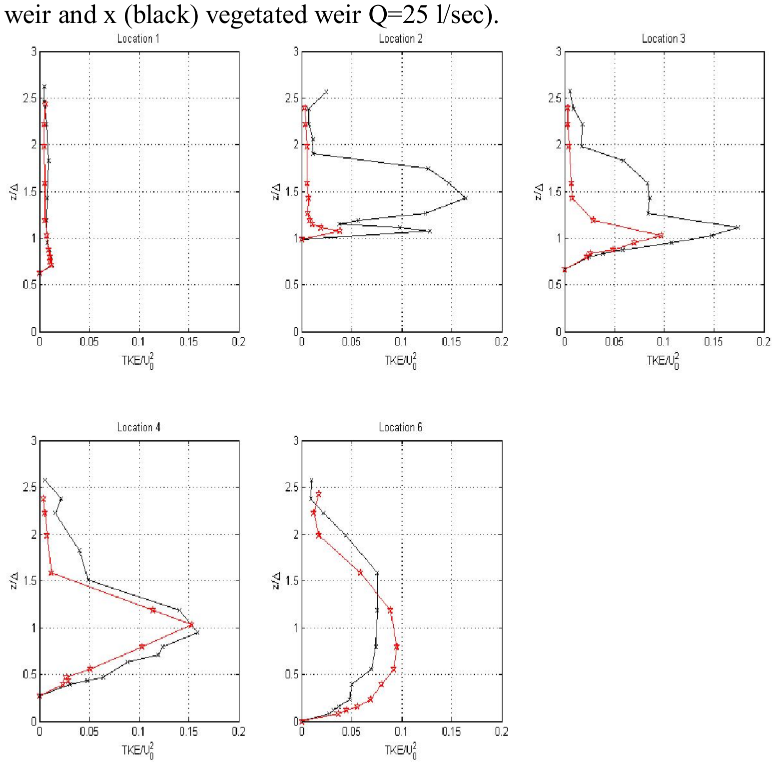

Figure 3. Comparison of turbulent kinetic energy at different locations for the vegetated and non-vegetated weir (*(red) non-vegetated weir and x (black) vegetated weir Q=40 l/sec).

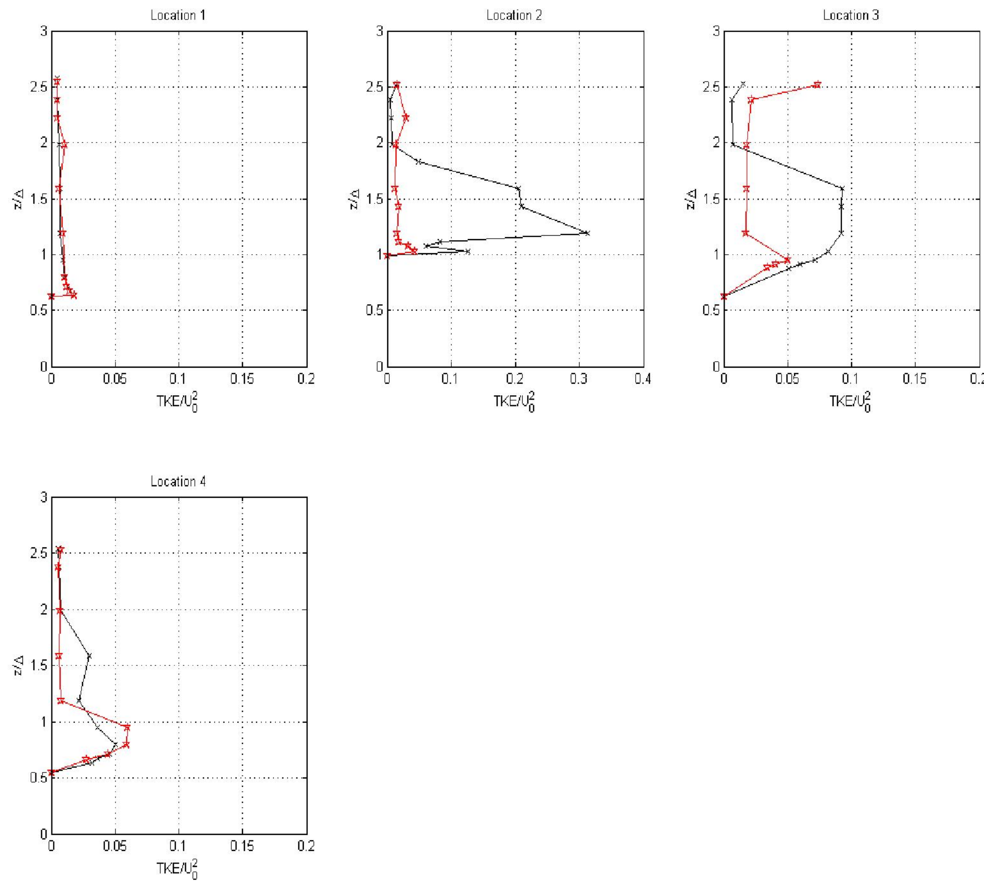

Figure 4: Comparison of turbulent kinetic energy at different locations for the vegetated and non-vegetated weir (*(red) non-vegetated weir and x (black) vegetated weir for a leeward slope of 1:7 with Q=40l/sec).

3.2. Reattachment length:

The flow separations zones behind the non-vegetated/vegetated weir-like structures cause a significant amount of energy dissipation and have a significant influence on flow resistance in the floodplain. It is important to have knowledge about the recirculation zone behind these weir-like structures. Many researchers investigated the flow characteristics behind the backward-facing step such as Chandrasuda and Bradshaw (1981), Hung le (1997), Adam and Johnston (1985) and Lenon and Hill (2006) etc. In spite of large amount of experimental work on the backward-facing step, yet there is a gap of knowledge about the vegetated weir-like structures.

In the separation zone a recirculation eddy with back flow is present near the bed. The net discharge through a vertical cross-section between the bed and the separation streamline is zero. It means the upstream directed discharge between the bed and the point of zero velocity is equal to downstream directed discharge between the point of zero velocity and the separation streamline. Using this assumption, the vertical position of separation streamline is found from:

$$\int_{z_b}^{z_{sep}} u(z)dz = 0$$

Where z is vertical coordinate, with the bed at z = z_b

The reattachment length varies roughly between 4 to 8 times the weir height.

In the following Figure 5, the horizontal velocity profiles for Q=25 l/sec and Fr=0.25 (on the crest of weir, upstream of the vegetation) has been shown. Here the flow condition for the weir is submerged. In these Figures it can be seen that length of the recirculation zone is 0.75 m, which is the 6.2 times the weir height. The maximum height of the recirculation zone is about 0.14 m. In both cases of vegetated and un-vegetated, the recirculation zone height and length is almost the same. So the vegetation on the crest of the weir is not affecting the recirculation zone. The form drag due to the weir and the vegetation can be modeled separately.

As far as the mild leeward slope (such as 1:7) is concerned, it was observed that the flow separation zone behind the weir crest vanishes (not shown in the figure) and the form drag due to the weir decreases.

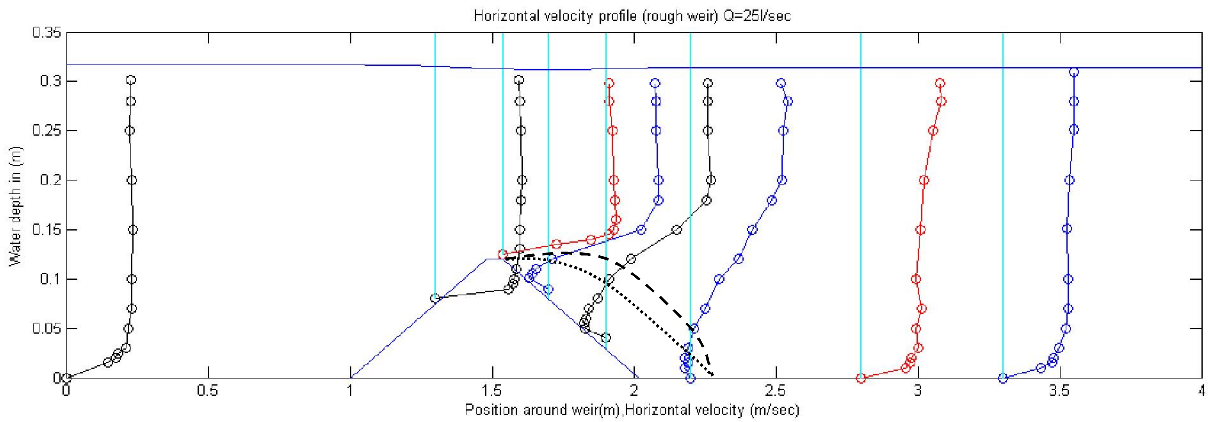

Figure 5(a): Measured horizontal velocity profiles for rough (non-vegetated) weir with downstream slope 1:4 (Submerged flow conditions, Froude No. = 0.25) Q=25 l/sec

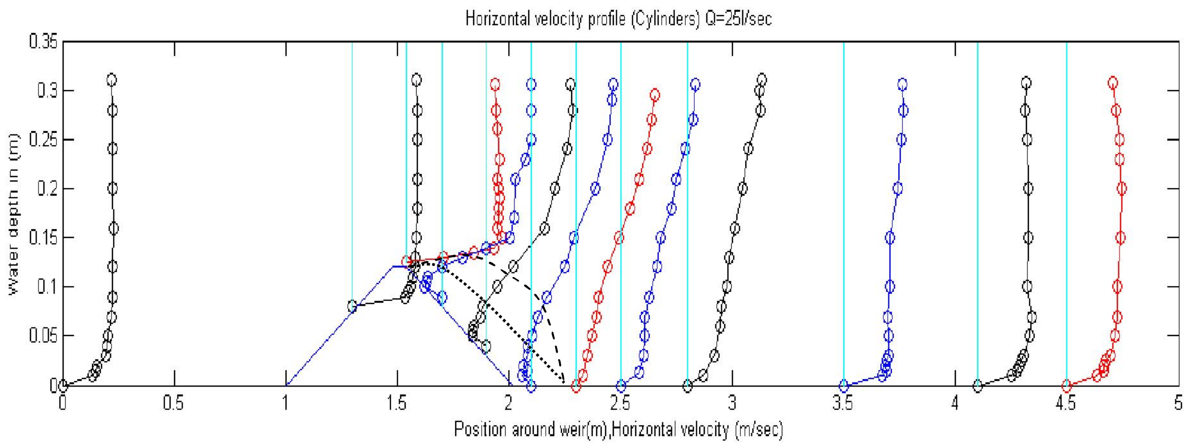

Figure 5(b): Measured horizontal velocity profiles for vegetated weir with downstream slope 1:4 (Submerged flow conditions, Froude No. = 0.25) Q=25 l/sec

4. Conclusions

From this research work, it can be concluded that: the TKE is more in the recirculation zone and the vegetated region of the flow. However at location on the end of weir crest, the TKE is negative below the top of the vegetation dowels whereas near the bed it is positive and maximum. As far as recirculation region is concerned, it was observed that the vegetation is not affecting the recirculation zone behind the vegetated weir. In case of weir with mild downstream slope (1:7), the flow separation zone vanishes and the energy head loss in this case decreased due to the decrease in form drag of the weir.

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References

1. Järvelä J. Flow resistance of flexible and stiff vegetation: a flume study with natural plants. Journal of Hydrology 2002; 269: 44-54.
2. Järvelä, J. Determination of flow resistance caused by non-submerged woody vegetation. Journal of River Basin Management 2004; 2 (1): 61-70.
3. López, F, García MH. Mean flow and turbulence structure of open channel flow through non-emergent vegetation. Journal of Hydraulic engineering 2001; 127 (5): 392-402.
4. Tsujimoto T, Kitamura T. Velocity profile of flow in vegetated bed channels. KHL progressive report 1 1990; Kanazawa University.
5. Klopstra D, Barneveld H J, Van NJM, Van Velzen EH. Analytical model for hydraulic roughness of submerged vegetation. In Managing Water: Coping with scarcity and abundance, San Fransisco 1997; Proceedings of the 27th IAHR Congress: 775-80.
6. Baptist MJ. Modeling floodplain biogeomorph-ology. Delft University Press 2005; Delft.
7. Rehbock T. Discussion of precise weir measurements. Transactions of ASCE 1929; 93: 1143-62.
8. Chow VT. Open channel hydraulics. McGraw-Hill Tokyo; 1959.
9. Villemonte JR. Submerged Weir Discharge Studies. Eng. News Record 1947; 193: 866-69.
10. Abou-Seida MM, Quraishi AA. A flow equation for submerged rectangular weirs. Proc. inst. Civil Eng. 1976; 61(2): 685-96.
11. Govida RNS, Muralidhar D. Discharge characteristics of Weirs of finite crest length. La Houille Blanche 1963; 5: 537-45.
12. Swamee PK. Generalized rectangular weir equations. ASCE Journal of Hydraulic Engineering 1988; 14(8): 945-49.
13. Lakshamana RNS. Theory of weirs, Advances in hydroscience. Academic press, Inc., New York 1975; 10: 310 - 406.
14. Jain SC. Open channel flow. John Wiley and Sons 2001; New York.
15. Rajaratnam N. The hydraulic jump as a wall jet. Journal of Hydraulic Division1965; 91(3): 107-32.
16. Leutheusser H, Kartha V. Effects of inflow condition on hydraulic jumps. Journal of Hydraulic Division 1972; 98(8): 1367-85.
17. Rouse H, Siao TT, Nagaratnam S. Turbulence characteristics of the hydraulic jump. Journal of Hydraulic Division 1958; 84(1): 1-30.
18. Liu M, Rajaratnam N, Zhu D. Turbulence structure of hydraulic jumps of low Froude numbers. Journal of Hydraulic Engineering 2004; 130(6): 511-20.
19. Armaly BF, Dursts F, Pereira JCF, Schonung B. Experimental and theoretical investigation of backward-facing step flow. Journal of fluid mechanics, 1983; 127, 473-96
20. Wee D, Yi T, Annasqamy A, Ghoniem AF. Self-sustained oscillation and vortex shedding in backwar-facing step flows: Simulation and linear instability analysis. Physics of Fluids 2004; 16(9): 876-95.
21. Lee T. Mateescu D. Experimental and numerical investigation of 2-d backward-facing step flow. Journal of Fluids and Structures 1998; 12: 703-716.
22. Ali S, Ghani U, Latif A, Ejaz N, Pasha GA. An experimental study of turbulent flow over a weir-like structure with and without vegetation. Life Science Journal 2013; 10(9s): 315-23.
23. Adams EW, Rodi W. Modeling flow and mixing in sedimentation tanks. Journal of hydraulic Engineering 1990; 116(7): 895-913.
24. Chandrsuda C, Bradshaw P. Turbulence structure of a reattaching mixing layer. Journal of Fluid Mechanics 1981; 110: 171-94.

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