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Control of Velocity Profiles by using Baffle Blocks in Open Canals

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Abstract

Roughness elements is one of the solutions use to protect open channels from erosion and sedimentation. It can be large stone or concrete blocks placed at bed of the channel to impose more resistance in the bed. The geometry of these roughness elements, and their configuration are parameters that play an important role in changing the hydraulic characteristics of the flow. This change can create desirable effects helps to develop better flow management. Velocity distributions along the flume was investigated by conducting a series of tests to find the best height and configuration of roughness elements. Computational Fluid Dynamics, CFD, was applied to simulate the flow in open canal with roughness elements. Standard baffle block was used with heights equal to 3, 4.5, and 6*cm* placed in three different configurations, two lines, four lines and fully rough configurations. The results showed that the velocity values are affected by increasing baffle blocks height and increasing number of lines of roughness elements. The four lines configuration was more effective by decreasing the velocity near the bed compared with two lines and fully rough configurations by about 50% and 10%, respectively. The velocity values increased near the free surface in cases with baffle blocks height 6*cm* or fully rough configuration much more than other cases by about ١0 to 50%. Furthermore, in all cases the roughness height 6*cm* is more effective in decreasing the velocity near the bed than other roughness heights by about 10% to 30%.

Keywords: Velocity Profiles, Computational Fluid Dynamics, Baffle Blocks, Roughness Heights, Configurations.

السيطرة على مقاطع السرعة بأستخدام الكتل الحاجزة في القنوات المفتوحة

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المستخلص

أحدى الحلول المستخدمة لحماية القنوات المفتوحة من التعرية والترسيب في مقاطع محددة على امتداد المجاري المائية هي استخدام عناصر الخشونة والتي قد تكون احجاراً كبيرة أو كتلاً خرسانية توضع في قعر القناة والتي تعمل على زيادة خشونة القعر وينتج عنها اضافة مقاومة للجريان. يعد كل من الشكل الهندسي لعناصر الخشونة وترتيبها عوامل رئيسية مؤثرة في احداث التغيير في الخصائص الهيدروليكية للجريان. يساعد هذا التأثير المرغوب به في تطوير الادارة الصحيحة للجريان.
تم تحري توزيع سرع الجريان على طول القناة بأستخدام سلسلة من الاختبارات وذلك لايجاد أفضل ارتفاع وترتيب لعناصر الخشونة. استخدم برنامج CFD , Computational Fluid Dynamics لمحاكاة جريان الماء خلال القناة المفتوحة بوجود عناصر الخشونة. أستخدم الشكل Baffle Block بثلاثة ارتفاعات مختلفة وهي ٣سم و٤,٥سم و٦سم. تم ترتيب عناصر الخشونة بثلاثة توزيعات مختلفة وهي التوزيع بسطرين على جزء من عرض القناة وباربعة أسطر أيضا على جزء من عرض القناة والتوزيع الكامل على عرض القناة.
أظهرت النتائج تأثر قيم السرعة بزيادة ارتفاع عناصر الخشونة وزيادة عدد أسطر عناصر الخشونة وبينت النتائج ان تأثير التوزيع بالاربعة أسطر يكون أكثر بنسبة ٥٠% من ذلك باستخدام سطرين من عناصر الخشونة وبنسبة ١٠% من التوزيع الكامل على عرض القناة.
تزداد قيم السرعة قرب سطح الماء في حالة أستخدام ارتفاع عنصر الخشونة ٦ سم أو في حالة توزيع عناصر الخشونة على عرض القناة أكثر من باقي الحالات الاخرى وذلك بنسبة ١٠% -٥٠%. تأثير ارتفاع عنصر الخشونة ٦سم يكون أكبر في معدل نقصان السرعة بالقرب من القعر عن باقي أرتفاعات عناصر الخشونة وذلك بنسبة ١٠%-٣٠%.

الكلمات الرئيسية: مقاطع السرعة، حسابات ديناميكية الموائع، مقاطع السرعة، الكتل الحاجزة، أرتفاع الخشونة، التوزيع.

Introduction

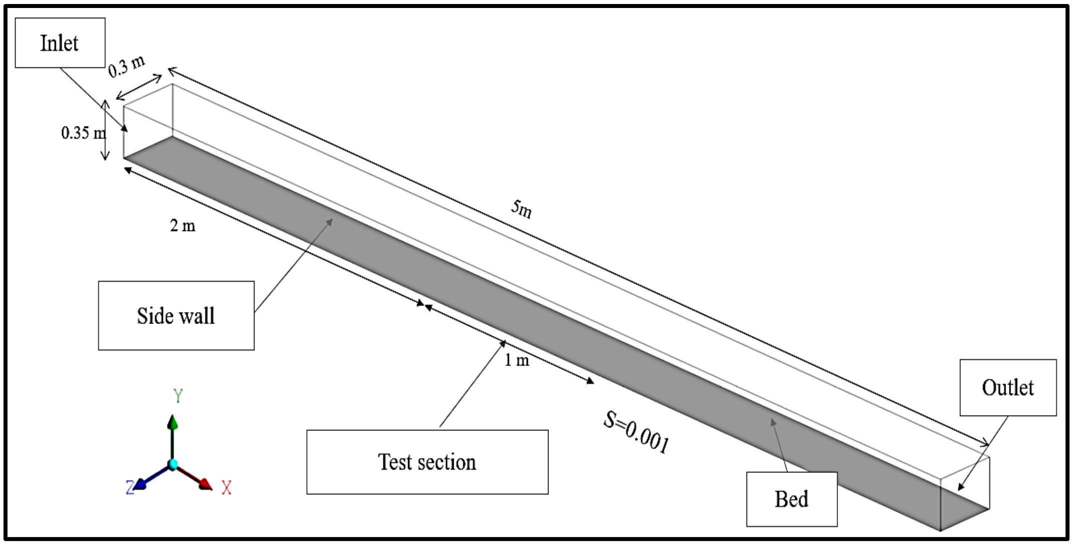
Erosion and sedimentation are two main problems that occur in open channels. Researchers have been studied these problems to discover an alternative solution. Controlling these problems can be applied in a variety of techniques. The use of roughness elements is one of these solutions. Roughness elements can be concrete blocks or large stone placed in the channel bed to create more resistance in the bed with varied configurations, such as (Kim, 2011), investigated the vegetation impact in open channels using cylindrical roughness elements of various configurations. The investigation was carried out by using a numerical simulation. The flow resistance increased as the cylinder Reynolds number and the roughness element density increased. The most important factor in determining turbulence statistics, mean flow, instantaneous flow, and flow resistance was vegetation density. The influence of strip semi cylindrical roughness generated in basically two configurations on a turbulent layer with a reasonably high Reynolds number was investigated by (Abbaspour & Kia, 2014). This study was conducted by using a commercial fluid dynamics (CFD) Software. The percentage of the distance between center-to-center roughness elements to the roughness height identified the experimental parameter values. The roughness configurations influenced the velocity distribution, which had an inverse connection. (Baki, Zhu, & Rajaratnam, 2016) investigated a rock ramp for fish passage in a numerical simulation. The flow parameters were investigated using a three-dimensional computational fluid dynamics solver for variations in discharge, spacing, channel slope, boulder size, and pattern. The numerical model depends on an experimental test. Two different boulder configurations were investigated. In the experimental test, the first configuration was the same as the staggered arrangement. The second design was a clustered boulder configuration with every two rows being closer to each other. The effective

boulder spacing for two alternative boulder designs utilized in a rock-ramp fish pass in longitudinal and transverse orientations. The flow resistance varied depending on the distance between emerging rocks and remained constant in the case of submerged boulders. Utilizing CFD software, (Thappeta, Bhallamudi, Fiener, & Narasimhan, 2017), evaluated the effect of using a single hemisphere element, boulders, and cylindrical roughness elements in a steep open channel with staggered arrangement and randomly distributed. The energy loss was dependent on density, Reynolds number, and submergence ratio, according to the research. The energy loss was reduced while adding boulders since the density of the boulders was increased. The influence of employing cube elements organized in two different densities between two sides was studied by (Akutina, Eiff, Moulin, & Rouzes, 2019). Higher velocities were seen with rough bed at high relative submergence, and the interaction between the two sides was dependent on relative submergence. (Mulahasan, 2016), who investigated the influence of a vegetated floodplain in open channels using cylindrical roughness elements of various diameters. (Bora & Misra, 2018) used PVC wires and bent them according to needs to study the influence of flexible and stiff vegetation. Different heights of wires were offered to the research to simulate vegetation in open channels. (Wang, Ye, Wang, & Yan, 2015), employed five different diameters of sediment roughness and discovered that the velocity distribution was affected by the roughness scale.

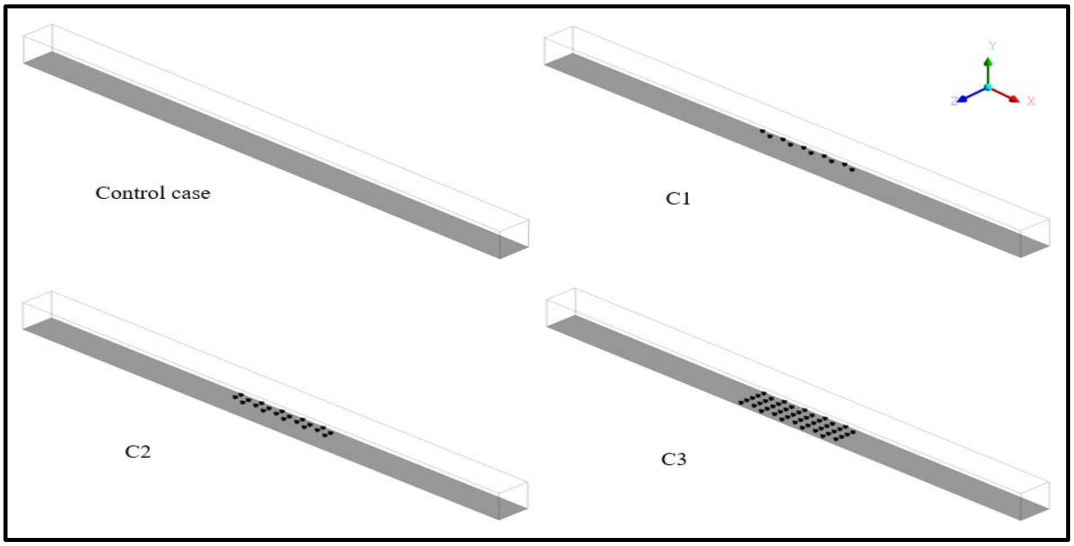
In this study, the flow through the roughened bed flume was modelled to investigate the effect of roughness elements in the flow patterns. Using APDL (ANSYS Parametric Design Language) and CFD software's to simulate the fluid domain. The average Navier-Stokes and continuity equations are numerically solved using ANSYS CFD. The standard k – w model yields an accurate result. The SST k –w (shear stress transport) model is a proving version of the k- model. With the purpose of simplifying the roughness height, the canal bed is laid out with regular roughness elements (baffle blocks) in the pattern placed in various staggered configurations.

Description of the Study Cases

Using CFD software, investigate flowing water in open canal without baffle blocks as a control case. Design the flume with dimensions of 0.3m flume width, 0.35m flume depth, 5m length, and horizontal bed slope, (Ghazal, 2015) using the mechanical APDL product launcher (ANSYS Parametric Design Language). The geometric of baffle blocks is with base (3*3) cm^2 and different heights 3*cm*, 4.5*cm*, 6*cm*. The test section of flume (1*0.3) m^2 is filled with baffle blocks. Three different configurations of baffle blocks have been investigated at test section, two lines, four lines, and fully roughness configurations arranged in a staggered pattern. From center to center of the roughness elements, the distance between rows was 6*cm* and the distance between columns was 10.78*cm* as shown in Figure (1). The inlet water depth is 0.1*m*, and the discharge rate is 5.8*l/s*, respectively. Configuration is the technique of placing roughness elements on the flume's bed. The priority of this research is to study the impact of using baffle blocks with different heights and configurations on the velocity profiles in the fluid domain. That was obtained by comparing the velocity profiles within the test section of the ten case studies.



a- Flume description and test section location.



b- Baffle blocks configurations.

Figure 1: Schematic definition for the case of study.

Design of Models Runs

Various settings applied in this simulation, volume of fluid, transient flow, multiphase flow (air and water), K-omega –SST (shear stress transport), and the PISO technique (Pressure Implicit with Splitting of Operators), were used to perform runs with a computational fluid dynamics CFD application (FLUENT) (pressure-implicit splitting of operators). To calculate the flow, double-precision calculations were required for pressure changes. The mass flow inlet and pressure outlet were used to define the boundary conditions, as shown in figure (a-1). The air and water flow into the domain were specified as inlets. Nonslip walls are described as the bottom and side walls of a flume. The general boundary applied at walls is the no slip boundary, which indicates that the velocity at the walls is zero. To simulate the flow, the heights and configurations of the roughness elements in the test section were studied. All tests have been performed with the same water depth and discharge. Water depth and discharge at the flume's entrance were used to be 0.1*m* and 5.8*l/s*, respectively. The design of the runs was described in Table (1). A coding system is used simplify referring to each run. The first letter C refers to the word Case. The second letter B refer to abbreviation for baffle blocks. Then, the first number refers to the used configuration, 1 represent two lines of roughness elements, 2 represent four lines and 3 represent fully rough. Last number refers to the height of roughness elements. For example, the code CB23 refers to the runs conducted by using four lines configuration and a 3*cm* roughness height. Ten case study were studied including different height and different configuration and without baffle blocks as a control case. Each one takes 30 to 36 hours to simulate the fluid domain.

Table 1: Coding of investigation runs

Configuration								
Two lines			Four lines			Wholly rough		
Height, *cm*								
3	4.5	6	3	4.5	6	3	4.5	6
Code of roughness element								
CB13	CB14.5	CB16	CB23	CB24.5	CB26	CB33	CB34.5	CB36

Results and Discussion

Figures (2) to (8) presents the results of the investigations on the effects of applying baffle blocks in a flume after initialization and computation to provide data for comparison with a control case. Furthermore, it provides the details of a suggestion for which roughness element configuration and height to use as an energy dissipater. The normalize residual should equal $10e^{-3}$ as a convergence criterion. CFD FLUENT's default convergence criteria are adequate.

Figures (2) represent the directions, and the values of the flow velocity profiles as contours within the flow in the flume under the flow conditions of the control case, without baffle blocks.

Generally, the profiles of velocity are not affected along the flow domain because there is no change in the cross section of the flume. The velocity magnitude is 0.19*m/s* in a plane 3*cm* from the bed and 0.205*m/s* in a plane at 6*cm* from the bed and have a maximum velocity of about 0.21*m/s* in a plane 15*cm* from left side of the channel.

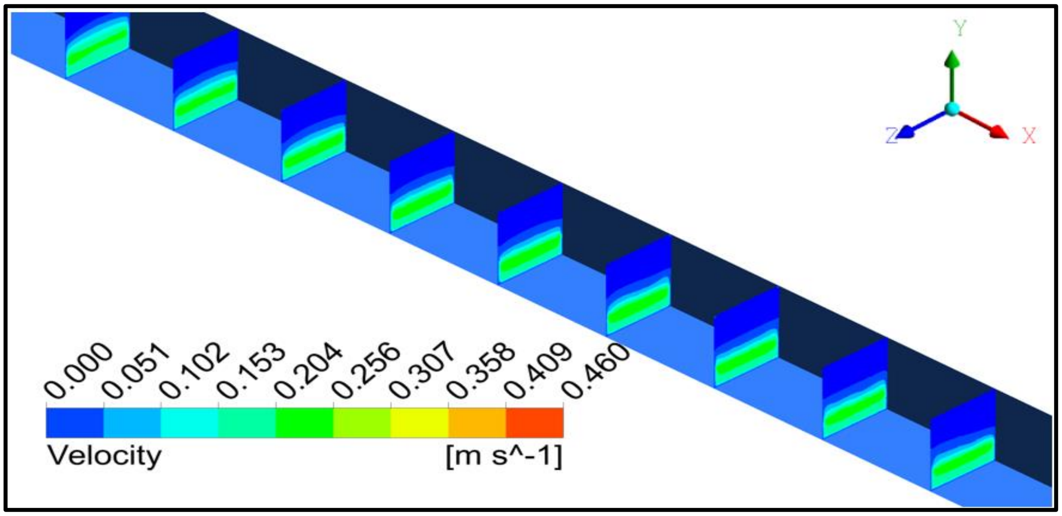


Figure2: Velocity profiles in a flume without baffle blocks

Table (2) and (3) shows the magnitude of velocity and the percentage of decreasing and increasing the velocity evaluation at three different locations, left side, right side, and at the center of the test section.

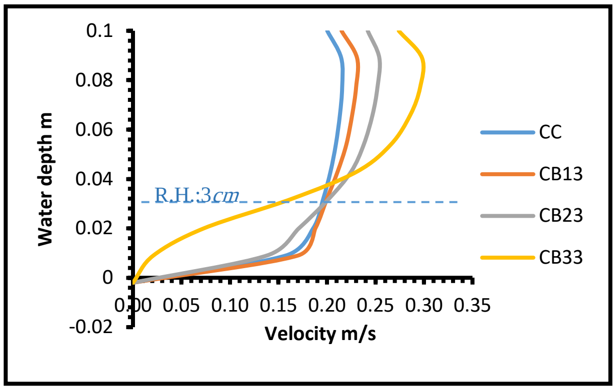
Table 2: Velocity magnitude in different plan in all cases.

Cases	Velocity(*m/s*)				
	At mid. Height of roughness elements		At top surface of roughness elements		Max at the center of the cross section
	Side		Side		
	L	R	L	R	
CB13	0.11	0.19	0.16	0.21	0.23
CB23	0.04	0.21	0.14	0.22	0.26
CB33	0.07		0.16		0.3
CB14.5	0.11	0.21	0.18	0.23	0.24
CB24.5	0.05	0.22	0.15	0.25	0.26
CB34.5	0.06		0.2		0.36
CB16	0.12	0.23	0.205	0.25	0.25
CB26	0.04	0.26	0.16	0.28	0.29
CB36	0.07		0.22		0.41

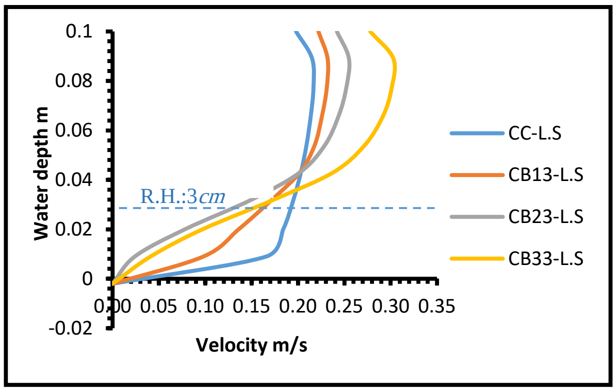
Table 3: Velocity percentage in different plan in all cases.

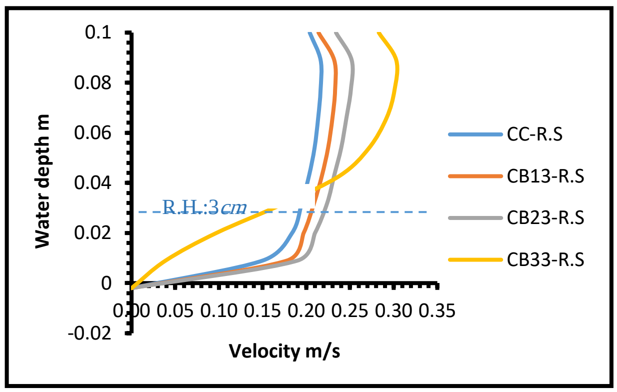
Cases	Velocity%				
	At mid. Height of roughness elements		At top surface of roughness elements		Max at the center of the cross section
	Side		Side		
	L	R	L	R	
CB13	-33	15	-16	11	10
CB23	-76	27	-26	16	24
CB33	-58		-16		43
CB14.5	-41	14	-10	15	14
CB24.5	-73	19	-25	25	24
CB34.5	-68		0		71
CB16	-37	21	0	22	19
CB26	-79	37	-22	37	38
CB36	-63		7		95

Figure (3) to (5) show the comparison between different configurations for baffle blocks roughness elements. With 3*cm* roughness height, at mid height of the roughness elements, the velocity values decreased in four lines and fully rough configurations by about 43% and 35% compared with two lines configuration. At the top surface of roughness elements, the velocity values decreased in four lines configuration by about 10% compared with two lines and fully rough configurations. By increasing the height of roughness elements, with 4.5*cm* roughness height, at mid height of the roughness elements, the velocity values decreased in four lines and fully rough configurations by about 32% and 27% compared with two lines configuration. At top surface of roughness elements, the velocity values decreased in four lines and two lines configurations by about 25% and 10% compared with fully rough configuration. With 6*cm* roughness height, at mid height of roughness elements, the velocity values decreased in four lines and fully rough configurations by about 42% and 26% compared with two lines configuration and decreased by about 22% in four lines configuration and have the same velocity of the control case in two lines configuration. In case of fully rough configuration the velocity values increased approximately 7% at top surface of roughness elements compared with the velocity of the control case.



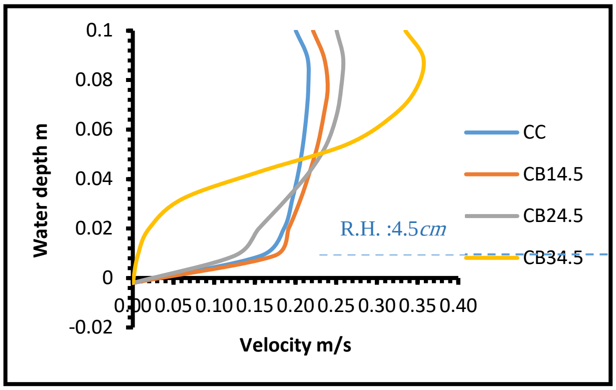
a-At the center of the cross section.



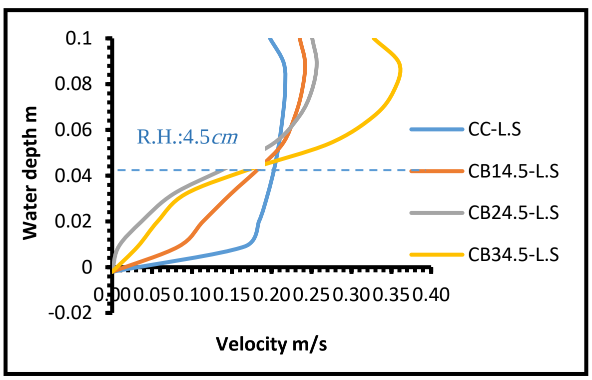


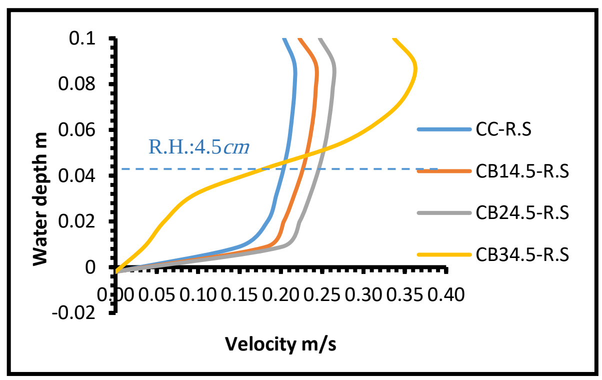
b-At the left side of the flume. c-At the right side of the flume.

Figure 3: Velocity-water depth relationship, comparison between CB13, CB23 and CB33.



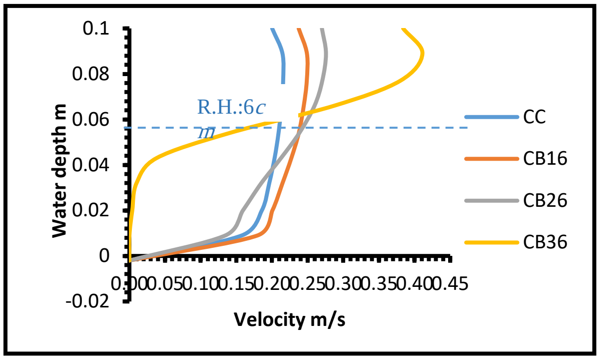
a-At the center of the cross section.



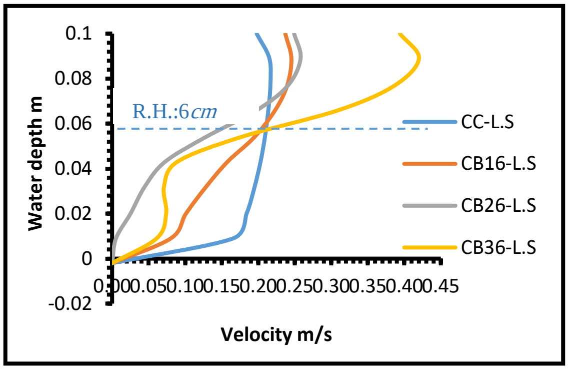


b-At the left side of the flume. c-At the right side of the flume.

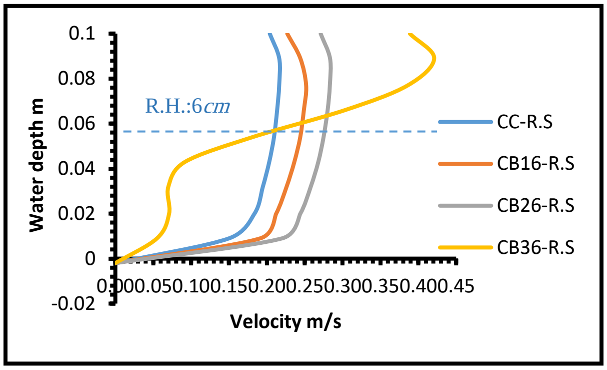
Figure 4: Velocity-water depth relationship, comparison between CB14.5, CB24.5 and CB34.5.



a-At the center of the cross section.



b-At the left side of the flume.

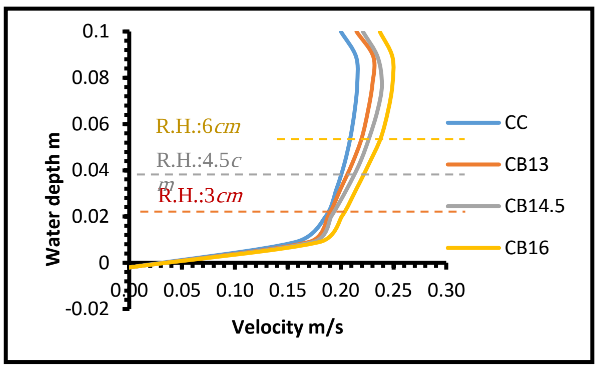


c-At the right side of the flume.

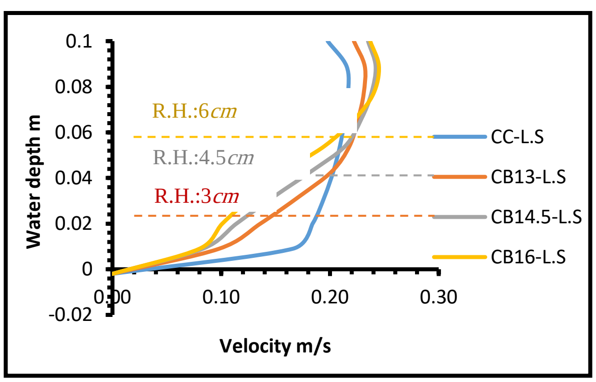
Figure 5: Velocity-water depth relationship, comparison between CB16, CB26 and CB36.

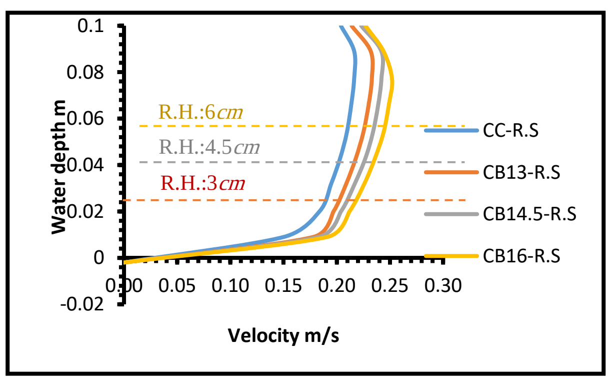
Figure (6) to (8) show the comparison between different heights for baffle blocks roughness elements. In case of two lines configuration, at mid height of the roughness elements, the velocity values decreased by about 8% and 4% for 4.5*cm* and 6*cm* roughness heights compared with the velocity of 3*cm* roughness height. At top surface of roughness elements, the velocity values decreased in 3*cm* and 4.5*cm* roughness heights by about 16% and 10% compared with 6*cm* roughness height. By increasing number of lines of roughness elements with the same conditions, in case of four lines configuration, the velocity values decreased with 3*cm* and 6*cm* approximately

3% and 6% compared with 4.5*cm* roughness height at mid height of the roughness elements. Above the roughness elements, the velocity values decreased approximately 4% and 3% in case of 3*cm* and 4.5*cm* roughness heights compared with 6*cm* roughs' height. In case of fully rough configuration, the velocity values decreased with 4.5*cm* and 6*cm* roughness heights approximately by 10% and 5% compared with 3*cm* roughness height at mid height of the roughness elements. In the zone above the roughness elements, the velocity values decreased with 3*cm* roughness height approximately by 16% and increased by about 7% with 6*cm* roughness height compared with the velocity of the control case. In case of 4.5*cm* roughness height, the velocity values have the same velocity of the control case.



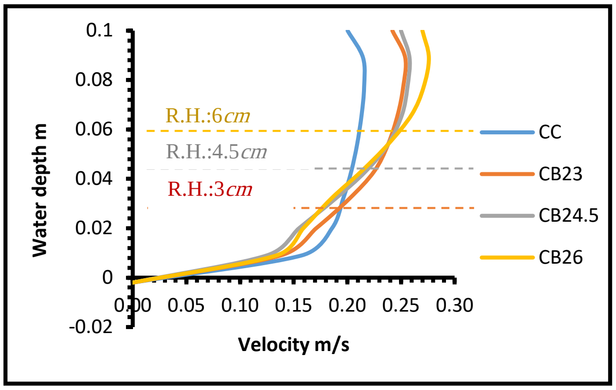
a-At the center of the cross section.



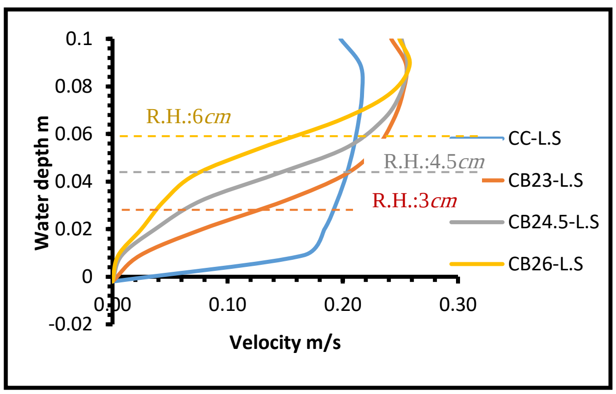


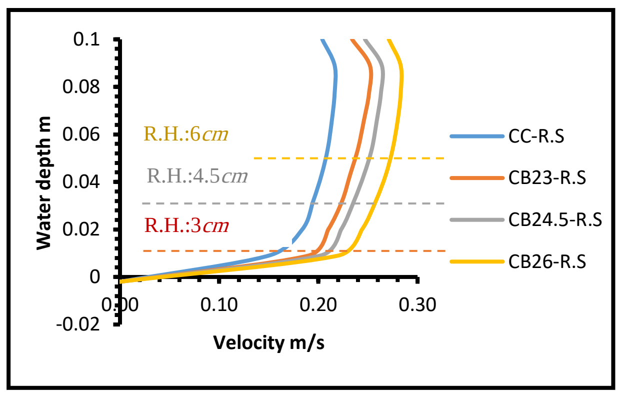
b-At the left side of the flume. c-At the right side of the flume.

Figure 6: Velocity-water depth relationship, comparison between CB13, CB14.5 and CB16.



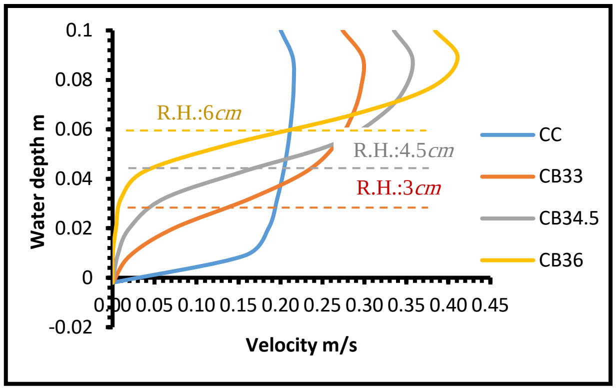
a-At the center of the cross section.



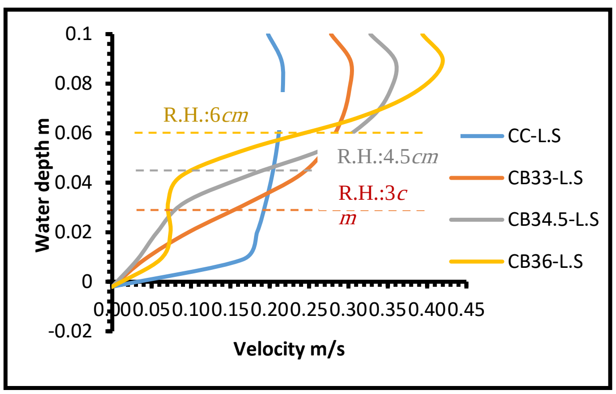


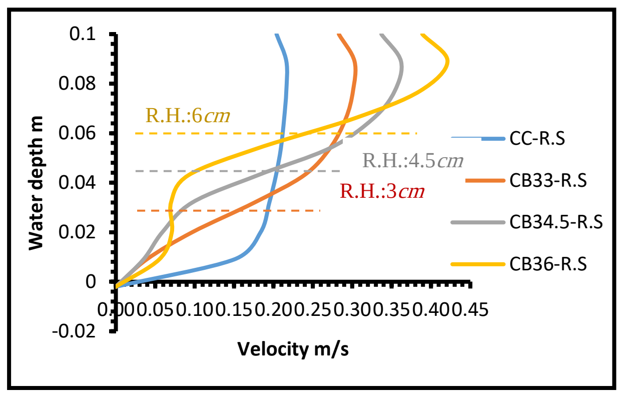
b-At the left side of the flume. c-At the right side of the flume.

Figure 7: Velocity-water depth relationship, comparison between CB23, CB24.5 and CB26.



a-At the center of the cross section.





b-At the left side of the flume. c-At the right side of the flume.

Figure 8: Velocity-water depth relationship, comparison between CB33, CB34.5 and CB36.

Conclusions

The heights and configurations of the baffle blocks changed the velocity profiles in the fluid domain. Increasing the height of the baffle blocks and the number of lines of roughness elements influences the velocity values. When compared to two-line and fully rough configurations, the four-line configuration was more effective, decreasing velocity near the bed by about 50% and 10%, respectively.

The velocity values near the free surface increased by around 10% to 50% in cases with baffle block heights of 6 cm or fully rough configuration compared to other cases. Furthermore, a roughness height of 6 cm is more effective than other roughness heights in reducing velocity near the bed by around 10% to 30% in all cases.

References

Abbaspour, A., & Kia, S. H. (2014, 10 18). Numerical investigation of turbulent open channel flow with semi-cylindrical rough beds. *KSCE Journal of Civil Engineering, 18*(7), 2252-2260.

Akutina, Y., Eiff, O., Moulin, F. Y., & Rouzes, M. (2019, 10 1). Lateral bed-roughness variation in shallow open-channel flow with very low submergence. *Environmental Fluid Mechanics, 19*(5), 1339-1361.

Baki, A. M., Zhu, D. Z., & Rajaratnam. N. (2016, 10). Flow Simulation in a Rock-Ramp Fish Pass. *Journal of Hydraulic Engineering, 142*(10).

Bora, P., & Misra, U. K. (2018). An Experimental Study on Effect of Flexibility of Vegetation on Resistance to Flow. *International Research Journal of Engineering and Technology, 5*(2), 2127-2131.

Ghazal, A. M. (2015). *Manning's Coefficient for Geometric Roughness Elements.*

Kim, S. J. (2011). *3D Numerical Simulation of Turbulent Open-Channel Flow Through Vegetation.*

Mulahasan, S. (2016). *Hydrodynamics of Large-Scale Roughness in Open Channels.*

Thappeta, S. K., Bhallamudi, S. M., Fiener, P., & Narasimhan, B. (2017). Resistance in Steep Open Channels due to Randomly Distributed Macroroughness Elements at Large Froude Numbers. *Journal of Hydrologic Engineering, 22*(12).

Wang, X. K., Ye, C., Wang, B. J., & Yan, X. F. (2015, 12 1). Experimental Study on Velocity Profiles with Different Roughness Elements in a Flume. *Acta Geophysica*, *63*(6), 1685-1705.