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Laboratory Investigation of Environmental Friendly Fishway for Rubber Dams

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ABSTRACT

Since they serve important roles in fish migration and survival, the fishway are the main components of river cross structures like dams. Recent years have witnessed an amalgamation of researches and development of rubber dams within hailing distances of the sea and rivers in the north of Iran that necessitates the establishment of fishways consistent with the environmental demands and standards. The installation of rubber dams near the sea blocked the fishermen crossing over the river and thus created social tensions. Canoe-fishways are such innovative ideas that are completely consistent with the environmental conditions in which brushes like artificial weeds and grasses are used to create energy dissipation. Since the brushes have a good bending radius, they allow small fishing boats to pass through the canals. In this study, three different experimental models of this type of fishways was conducted for different slopes and discharges. The results of the physical model analysis showed that the establishment of plant coverage in the canal, the average flow velocity was reduced by 70%. By increasing the flow discharge up to the submergence, the Manning coefficient increases and it showed a decrease when it submerged completely. The maximum Manning coefficient occurs at the base of submerging which are 0.16, 0.136 and 0.071 at first, second and third arrangements, respectively. Moreover, the dimensionless relationship for determining the Manning coefficients was provided for the first and second arrangements of the submerged brush conditions.

KEYWORD

Rubber dam, Canoe-fishway, submerged vegetation, brush Manning coefficient

INTRODUCTION

Human has always been influential on water resource management, protection against flood, facilitating the travel across the river and also establishing changes in river flow direction and natural features . The late twentieth Century enjoyed the development of river engineering projects which brought about the growing environmental concerns. Considering the sensitive habitat and ecological values of rivers and also the continuation of the aquatic life, the Environment Council approved some regulations in 1995 which necessitates the identification of interrelated environmental regulations and standards and the assessment of environmental impacts arising from the implementation of projects for the construction and operation stages. Therefore, one of the main environmental issues that must be considered in the design of structures such as rubber dams is the construction of fishways.

The absence of fishways in some rubber dam projects being implemented in recent years, such as Khaje-Nafas[1] rubber dam and Miandasht[2] rubber dam, has established some major problems. On the other hand, fishermen and those living near the rivers require crossing the river with their boat hindered by such dam construction on the river which adds to the inadequacies of the rubber dams in the north of Iran [4]. Currently, vertical slot fishways are considered in the design of rubber dams in the north of Iran for the migrant fish passing. The foremost motive for applying this type of fishway is to provide the optimal flow conditions for different discharges, but their effectiveness has not been studied in rivers in Mazandaran and fishway monitoring programs is required to focus on structures in operation because the aforementioned structures are imitated, modeled and built after their analogous counterparts in Europe despite the fact that the native fishes of the Caspian Sea have different conditions than their European ones which led to the reduction of these structures efficiency[3,4].

One of the fishways of these types is canoe-fishway channel in the design and implementation of which the maximum adaptations to the environment have been exerted in that brushes similar to artificial grass are used to create energy losses through which the fish passes[2,1].

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1 On Gorganrood river
2 On Babolrood river

However, all-embracing researches are not conducted on canoe-fishway channel which is almost a novel approach to create turbulence and thus reducing the flow energy which is required to help the fish pass the fishway. Meanwhile, it can be used as a canoe channel for fisherman. The barriers which must serve as flow resistant in the fishway are brushes which are placed with a special arrangement in the channels. Each of these brushes is a set of thin and tough plastic elements making up the apt loss when placed together. In fact, the brush performance is the same as the artificial plants in the canal. Therefore, to determine the flow resistance characteristics in such fishways, the equation of the flow hydraulic resistance in vegetated channels can be considered.

PREVIOUS RESEARCH

The application of plastic elements (artificial grass) was first proposed by Reinhard Hassinger in 2002 and was thoroughly and experimentally investigated in hydraulic laboratory of Kassle University[3] and 40 cases of this fishway type has been implemented in Europe up to 2009.

The idea of this innovative advancement was triggered by the thought that a lot of rough, thin and elastic brushes downgrade energy from one side and also help the boatman pass through it without any problems. Grass stems material should be firm enough to provide the necessary energy loss to help fish pass through the fishway and it should be flexible enough to let the boat pass through these structures without being damaged and after crossing the stems, the stems must have this ability to return back to their original state. Half of these implemented practices on these structures are considered as the fishway and the rest will be considered as the composite structures for fish passing and boats passage. Hasinger (2004) introduced and determined the general principles in the design and implementation of the Canoe- fishway channels.

In 2007, the University of Kassel collaborating with the Germany Research Institute and the Ministry of Environment and Water conducted a research on protecting a kind of river oyster by placing artificial grass.

Halkro group (2008) designed and built the composite canoe fishway channel for the first time in UK [1].

EXPERIMENT METHODOLOGY

The aim of the laboratory studies was to examine the effects of brush arrangements on the hydraulic parameters such as the required discharge to achieve the desired flow depth, water level profiles, water level difference between two adjacent basins and controlling the mean velocity at different slopes and discharges.

To simulate Canoe fishway channel, a rectangular flume with a width of 30 cm, a height of 60 cm and a length of 10 m was used in the hydraulic laboratory of Noshirvani University in Babol.

The flume walls and the base were made of Plexiglas and aluminum, respectively. For making brushes, industrial Teflon plates with the thickness of 5 mm and polyethylene pipes known as the pasta tubes with the diameter of 6 mm were used. The Teflon plates were cut to the desired dimensions and after reticulating them into squares with 1 cm size, the stems cut in 10 cm size was placed in each of the holes. Each stems distance from the adjacent counterparts was 4 mm (Figure 1).

In this study, three brush arrangements (Figure 2, 3 and 4) were examined. The geometrical dimensions of the three arrangements was considered for the carp fish in the Caspian Sea as the model design for fishway channel on rubber dams in the north of the country at the scale of 1:5. A total of 74 experiments were performed to examine the three arrangements. The measurement procedure for the first and second arrangements included five discharges of 3.5, 5, 7, 10, 12.5 l/s and for each discharge five slopes of 5,10, 15, 20 and 25 in thousand were evaluated, and the third arrangement consisted of five discharges of 3.5, 5, 7, 10, 12.5 l/s and for each discharge three slopes of 5, 15 and 25 in thousand were considered, moreover, two discharges of 15 and 18 l/s with a slope of 25 in thousand were also considered in the third arrangement.

A series of experiments for a non-brushed channel with a discharge of 3.5, 5, 7, 10, 12.5 l/s with a slope of 25 in thousand was also considered. The rationale for selecting these discharges, slopes and brushes with different arrangement for conducting the experiment was the similar laboratory records, close to reality fishway channel conditions and laboratory facilities. Of course, it should be noted that the possibility to verify and examine the greater discharges and slopes larger than 0/025 was not available at the laboratory.

In the first and third arrangement, 8 rows of brushes and for the second arrangement 10 rows of brushes were situated and pinned on the channel bed. In each experiment, after installing and sorting the brushes at the bottom of the flume, the desired flow was gradually directed into the flume and by applying the upstream valves, the depth and flow discharge were adjusted.

Each time after the flow stabilization, the water surface profile was measured. Water level measuring was performed and a total of 6 points for each row including three points in the basin middle, downstream sections, brushes upstream and downstream, and the middle of opening was considered. The data in the fourth basin, due to flow stabilization, were used.

Based on such scale, the number of elements (stems) required for each row, regarding the preliminary calculations, was 270 based on the balance between the gravity in the control volume and dragging force caused by the presence of polyethylene elements in each row which was observed in all three arrangements. Figure 2 to 4 show the pictures of three arrangements in the laboratory channel.

In the first arrangement, the brushes were alternatively placed on the left and the right of which the width were18 cm and the length were15 cm. the opening width was 12 cm and the distance between rows (basin length) was 25 cm.

The second arrangement included two rows of two and three brushes being alternatively placed into the channel.

3 In Germany

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In the first set, two brushes with a width of 9 cm and a length of 15 cm were considered the distance of which were 6 cm and 3 cm from the wall of the channel.

In the second set, three brushes were placed in the channel width. On both sides of the channel, two smaller brushes with a width of 4 cm and a length of 15 cm were considered and a brush with a width of 10 cm and a length of 15 cm was situated in the middle having a distance of 6 cm from the left and right brushes. The total width of the opening in each row was 12 cm and the length between the rows (basin length) was 25 cm.

Unlike the two given arrangements, in the third arrangement, the brushes were not alternatively positioned but rather they were placed in rows facing each other in the middle of the channel and having the width of 18 cm and length of 15 cm. The overall opening width in each row was 12 cm (6 cm on each side) and the length between the rows (basin length) was 25 cm.

In fact, the difference among the three arrangements is in their opening distribution in the channel width. For the first arrangement, all the opening will take place in one point and the second and third arrangement witnessed the same opening width which is divided in the channel width. Consequently, regarding the scale of the experiment for all the arrangements, the minimum width of the opening for fish passing (6 cm) were postulated and observed.

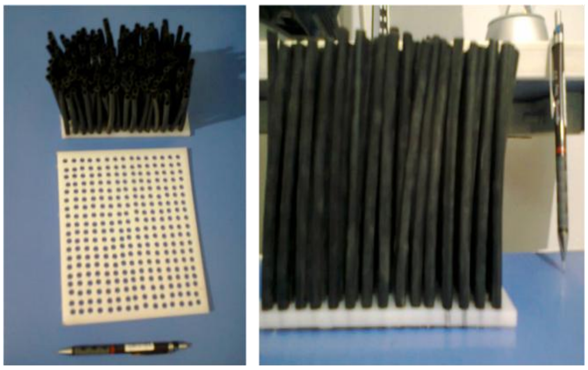

Fig 1: brushes image consisting of polyethylene pipes

Fig 2: first arrangement

Fig 3: second arrangement

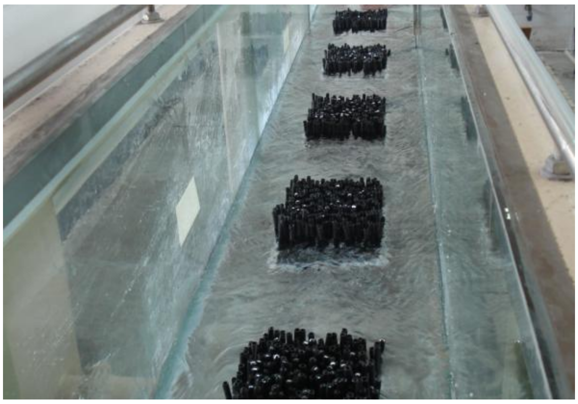

Fig 4: third arrangement

RESULTS AND DISCUSSIONS

Flow depth in fishway channels, different slopes and discharges

One important parameter in the design of fishways is establishing appropriate flow depth in the fishway. Considering the restrictions on the fishway inlet discharges, the fishway design should optimize the passing discharge rate through the adequate depth.

The required discharge values to attain a certain depth of water in the fishways are given in Figure 5. Regarding the specified charts, as it was previously predicted, at a depth level lower than the stem height (non-submergence state), the discharge-depth slope is higher. At the depths level of more than 10 cm (submergence state), the intensity and value of the depth-discharge level is lower than that of non-submergence state.

As the slope increases, the average water depth in the first, second and third arrangements witnessed a respective reduction of 6%, 9% and 18%.

By increasing the discharge from 3.5 liters per second to 12.5 liters per second the water depths level for the three arrangements would be as follows: for the first arrangement, it would be from 67 mm to 156 mm, for the second arrangement, it increased from 56 mm to 147 mm and the third arrangement witnessed an increase from 28 mm to 114 mm and in the channel with no brushes at the bottom, the water depth level increased from 18 mm to 37 mm. The required discharge to reach a depth of 10 cm (equal to stem length) in the first, second and third arrangements would be 5, 5.5 and 10.5 liters per second, respectively. Accordingly, it seems that brushes effect on flow depth in the first arrangement is higher than the other two arrangements. The required discharge to reach a specified depth in the third arrangement is much higher than the other two arrangements and the reason for such discharge difference is the direct flow path of the third arrangement and the spiral flow path for the other two arrangements. As a result, establishing a spiral path in the flow direction will be instrumental in increasing the water level in the channel.

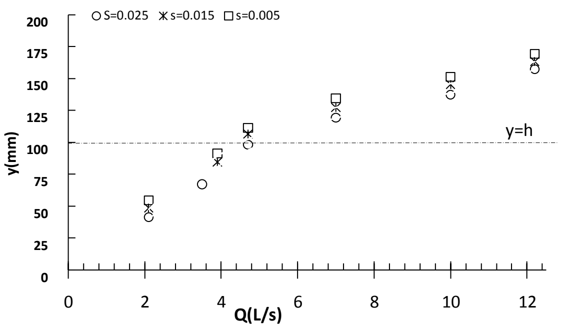

Fig 5-a: brushes effect on increasing channel depth on different slopes and charges -first arrangement

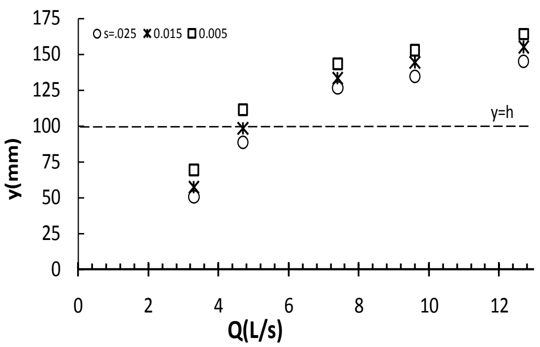

Fig 5-b: brushes effect on increasing channel depth on different slopes and charges - second arrangement

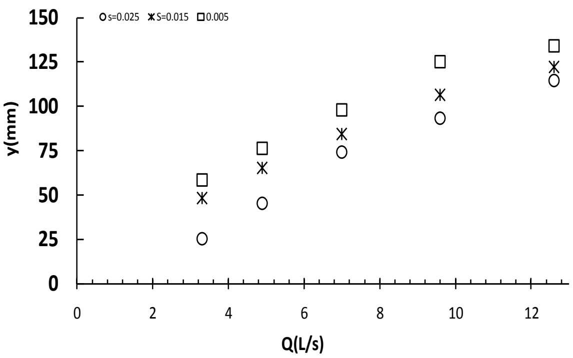

Fig 5-c: brushes effect on increasing channel depth on different slopes and charges - third arrangement

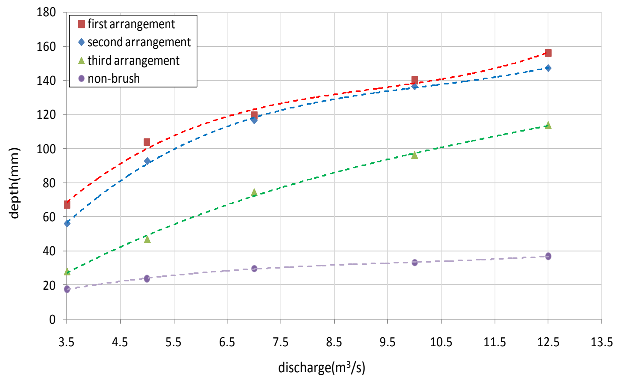

Fig 5-d: the comparison of water depth in three arrangements and also in the non-brush channel on 0.025 slopes

Flow mean velocity in different slopes and discharges

Figure 6 shows the changes in the flow mean velocity in the channel for different slopes and discharges.

As it is shown in Figures 6a to 6f, it is crystal clear that as the slope increases, the flows mean velocity in the channel increases. The increase percentage average in the flow mean velocity caused by a change in the bed slope increase from 0/005 to 0/025 for the first, second and third arrangements were14%, 20% and 40%, respectively. Also, as long as the brushes are in the non-submergence state, flow mean velocity decreases as the discharge increases. But after being fully submerged, the increase in the discharge will bring about flow mean velocity increase. The average flows mean velocities for all the slopes and discharges in the first, second and third arrangements were 0.19, 0.22 and 0.33 m/s, respectively. Figure 6d shows the brushes effect on reducing the flow mean velocity in the channel with bottom slope of 0.025 at different discharges. It can be seen that on this slope, by increasing the discharge rate from 3.5 l/s to 12.5 l/s, the flow mean velocity changes are as follows:

- for non-brush conditions: from 0.7 m/s to 1.1 m/s
- from 0.17 m/s to 0.26 m/s for the first arrangement
- from 0.21 m/s to 0.28 m/s for the second arrangement
- from 0.42 m/s to 0.37 m/s for the third arrangement

It should be noted that in the third arrangement, prior to reaching the submergence state, the flow velocity reduced from 0.42 to 0.31, but after the brushes were submerged, the mean velocity increased from 0.31 to 0.37.

At similar conditions, the mean velocity values for the first, second and third arrangements would be, respectively, 24%, 26% and 44% lower than the mean velocity in the channel with no brushes. Therefore, by installing the brushes in the channels, the flow mean velocity would be reduced by 70%.

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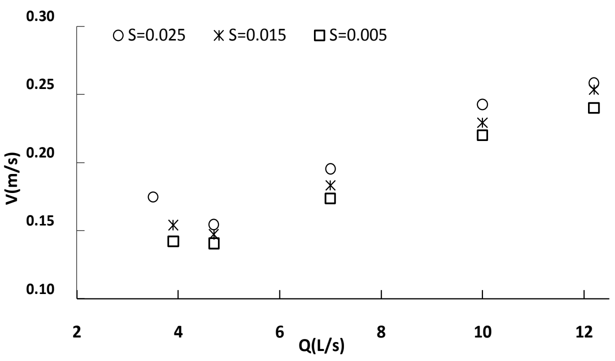

Fig 6-a: the brush Impact in reducing the channel mean velocity on different slopes and charges - first arrangement

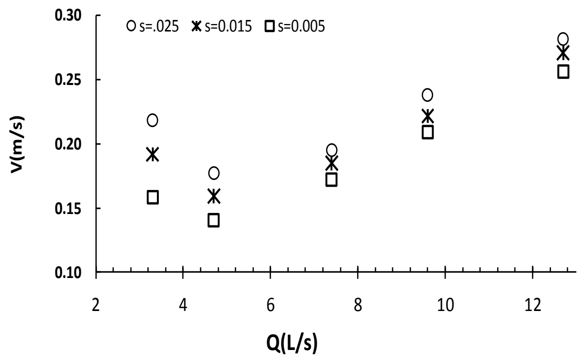

Fig 6-b: the brush Impact in reducing the channel mean velocity on different slopes and charges - second arrangement

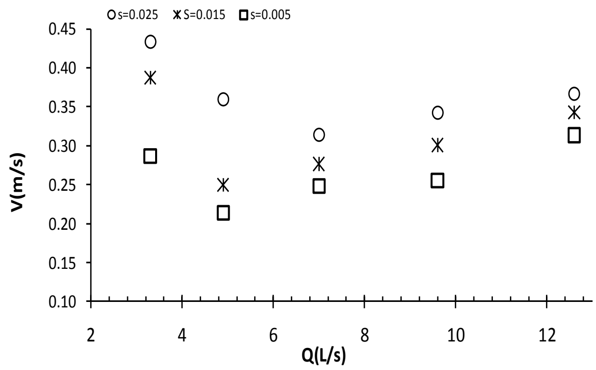

Fig 6-c: the brush Impact in reducing the channel mean velocity on different slopes and charges - third arrangement

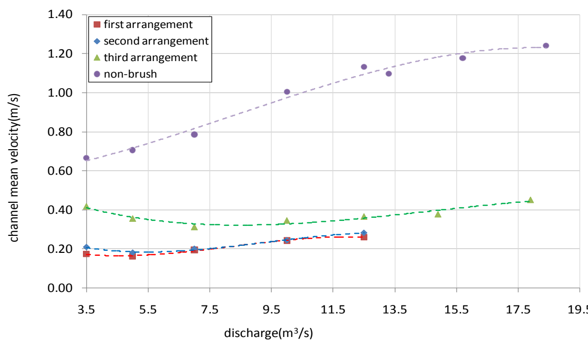

Fig 6-d: the comparison of mean velocity in three arrangements and also in the non-brush channel on 0.025 slope

Evaluating the relationship between hydraulic parameters in the submergence state

The water velocity profile in submergence or non-submergence state of brushes is different. Water velocity profiles within the vegetation, with the exception of a thin layer adjacent to the substrate, is almost uniformly distributed. If the water velocity profile outside the vegetation follows the logarithmic velocity distribution, therefore, it is necessary to examine the relationship between hydraulic parameters in two brushes submergence and non-submergence state. Since providing the optimal conditions for canoe fishway channel it is required that the brushes be submerged, accordingly, the analysis would be merely devoted to the submerged conditions to evaluate the flow parameters. Considering the fact that in most experiments, involving the third arrangement, non-submerged condition was conducted, due to impossibility of higher rates for the limitations of laboratory analysis and experimentation, the parameters variations in submerged condition was not considered for this arrangement.

The relationship between flow mean velocity and flow depth

Figures 7 and 8 present the flow mean velocity and depth for all arrangements with different slopes and discharges.

As mentioned above, by increasing the discharge rate, flow mean velocity and depth are increased but the bottom slope increase would bring about an increase in the flow mean velocity but exerts a reduction in flow depth. By honing on these figures, the required discharge to establish a desired flow depth and flow mean velocity would be achieved.

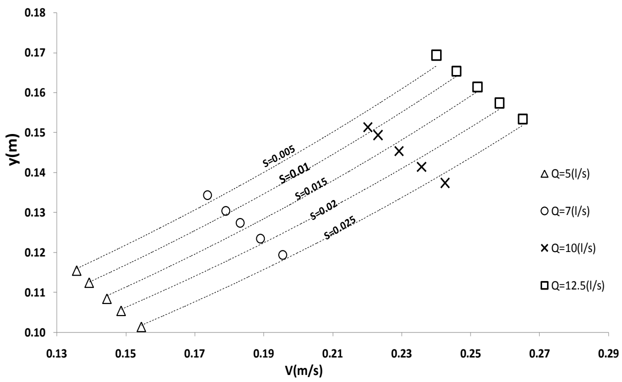

Fig 7: variations in mean velocity and the depth in submergence condition for the first arrangement

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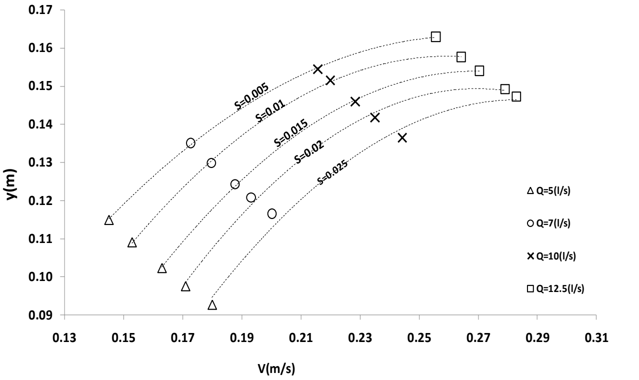

Fig 8: variations in mean velocity and the depth in submergence condition for the second arrangement

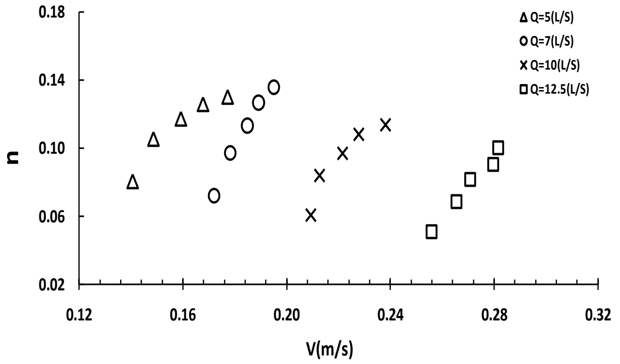

Fig 10: the Manning coefficient variations with velocity for the second arrangement

Velocity and Manning coefficient

To investigate the roughness variation in flow mean velocity for canoe fishway channels, the flow mean velocity changes was considered and measured against roughness coefficient. Variation in flow velocity could be due to changes in the channel bed slope or discharge rate.

Based on Figures 9 and 10, pointing to the constant discharges on average, with an increase in the slope by 0.005, the velocity and Manning coefficient experienced an increase of 3 % and 18 % in the first arrangement, respectively, which also exerted a 5 % change in velocity and 15 % increase for Manning coefficient in the second arrangement. Therefore, in constant discharges, with a slight increase in the velocity derived from the slope increase, the Manning coefficient showed a significant enhancement and it can be concluded that roughness parameters on constant discharges are sensitive to velocity changes.

But at the same slopes, if the velocity is increased by 12% in the first arrangement, the Manning coefficient is reduced by about 20 % and if the velocity experienced a 14 % increase in the second arrangement, Manning coefficient would be reduced by 21 %. As a result, at the constant slopes, by increasing discharge rate and therefore increasing the velocity, the Manning coefficient will decrease. It can be stated that Manning roughness coefficient does not depend on the mean velocity and is primarily influenced by two factors of slope and discharge but is more sensitive to slope.

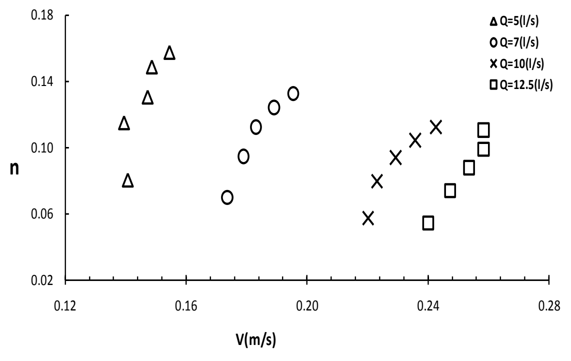

Fig 9: the Manning coefficient variations with velocity for the first arrangement

Manning coefficient variation with slope and discharge

Figures 11 and 12 present the fact that in the submergence condition, Manning coefficient faces a reduction as the discharge increases and it experiences an increases as the slope increases.

Manning coefficient enhancement will be slowed as the slope undergoes higher values. On average, Manning coefficient reduced by 11% for both arrangement as the discharge increases.

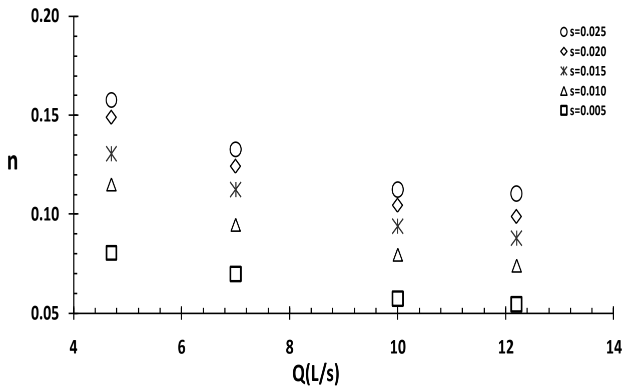

Fig 11: the Manning coefficient variations with discharge and slop for the first arrangement

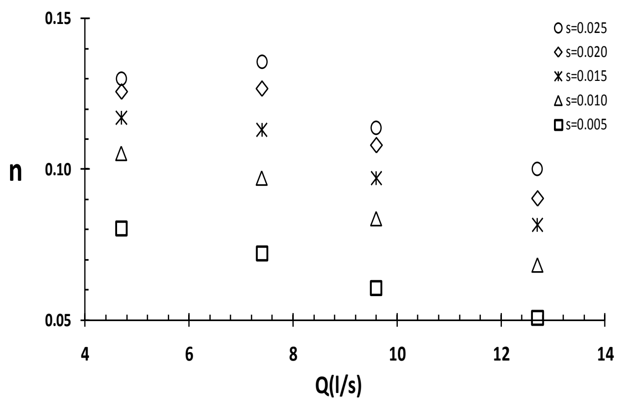

Fig 12: the Manning coefficient variations with discharge and slop for the second arrangement

CONCLUSION AND RECOMMENDATIONS

The results revealed that:

1. By installing the brushes in the channel, the mean velocity is reduced by 70%.
2. The presence effect of brushes on flow depth is higher in the first arrangement compared with the second and third arrangements.
3. The required discharge to achieve the specified depth is higher in the third arrangement, due to direct the flow path, than the two other arrangements that have a spiral flow path. Thus, creating a spiral path to reduce the velocity and, consequently, increase the water level in the channel seems highly efficient.
4. In submergence condition, for the constantly similar slopes, if the velocity is increased by 12% in the first arrangement, the Manning coefficient is reduced by about 20% and if the velocity experienced a 14% increase in the second arrangement, Manning coefficient would be reduced by 21 %.
5. In circumstances submergence, Manning roughness coefficient does not depend on the mean velocity and is primarily influenced by two factors of slope and discharge but is more sensitive to slope. Manning coefficient faces a reduction as the discharge increases and it experiences an increases as the slope increases

Canoe fishway channels provide a new insight for resolving the social and environmental problems caused by rubber dams and it is imperative to obtain more accurate results and more laboratory studies on the effect of higher slope than 2.5%, different stems density and stems diameter, brushes placement order, brushes intervals, different opening width and opening angles against the flow direction on average flow depth changes in canoe fishway channels basins.

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