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The Effect of Adding Geometric Configurations in Pool of Fishway on The Flow Pattern and Maximum Velocity

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ABSTRACT

Fish passes are hydraulic structures widely used to facilitate the migration of fish groups and contribute to maintaining their diversity in rivers with natural flow barriers, both environmentally and biologically. These passes are designed with various engineering modifications, resulting in flow patterns with hydraulic characteristics suitable for specific fish species. This study aims to analyze the hydraulic characteristics of flow, including maximum flow velocity and flow pattern in a standard vertical slot fish pass and its sensitivity to modifications in the pass shape by adding geometric structures in the form of letters L, T, and I inside the basin. A laboratory model was constructed at a 1:4 scale, testing four incline values of 5%, 6.25%, 7.5%, and 8.75%. For each incline, five discharges were tested for the standard shape (without modifications) at 3.83, 5.89, 7.89, 9.69, and 12.41 l/sec. For the modified shapes, three discharges were tested at 3.83, 7.89, and 12.41 l/sec. Results showed that flow in the standard design exhibited three patterns, with the second pattern being the most favorable and the first pattern the least desirable, typically forming with higher discharges. Regarding maximum velocity, it increased with the incline and discharge. When modifying the pass shape, only two patterns were formed, the second and third patterns, eliminating the undesirable pattern. The modifications also contributed to reducing the maximum velocity, especially when the modification changed the flow pattern from the least favorable to the most favorable. The maximum reduction in maximum velocity reached 28.22%, and higher values of velocity reduction ratio were associated with higher discharges. Therefore, these modifications are crucial, especially for high discharges.

Keywords:

Fishpass, Vertical Slot Fishway, Flow Pattern, Maximum Velocity.

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1. INTRODUCTION

Dams are important infrastructure built on rivers, serving to control floodwaters, increase water flow in the river when needed for irrigation and navigation [1]. For decades, dams have also been constructed for water storage and hydroelectric power generation [2]. Despite the benefits provided by dams, they have direct and indirect environmental impacts on the river ecosystem, altering flow patterns, deteriorating water quantity and quality, and disrupting and diminishing riverine aquatic habitats [3]. Dam construction is consedring an obstruction of fish migration along the river course [4], as dams can block the migration path of fish, affecting their growth and reproduction [5]. Fish migration involves two main journeys: the downstream migration, performed by fish in the early stages of their lives, and the upstream migration, undertaken by fully grown fish. Since fish are integral components of aquatic food chains, supporting the biological ecosystem and providing a natural protein source for humanity [6], it becomes essential to address the negative impact of dam construction on fish migration. This can be achieved by building hydraulic structures above or around barriers created in watercourses. The main purpose of designing and constructing such structures is to create safe and suitable means of transportation for fish during their migration upstream[7], and these structures are known as fish passes [8].

Among the various types of fish passes, the vertical slot fish pass is considered a applicable option for reconnecting river sections and establishing a pathway for fish movement [9]. The significance of vertical slot fish passes stands out for several reasons: firstly, fish can move between basins at their preferred depth [10]. Secondly, they can handle significant variations in water levels upstream and downstream, making them suitable for adapting to changes in river discharge [11]. Finally, they are less prone to debris and sediment blockage compared to other types of basin passes [12].The vertical slot fish pass consists of a inclined channel with a rectangular cross-section that divides the channel into several equal basins [13], achieved by placing barriers inside the channel. These barriers have a vertical slot extending to the height of the barrier, designed to allow fish to pass upstream through the channel, as shown in Figure (1).

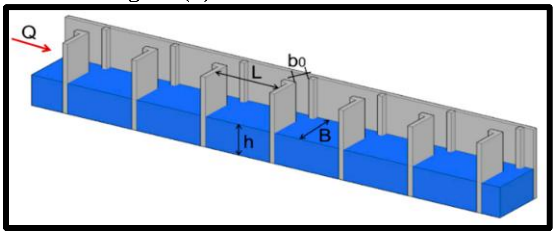

Fig. 1 Schematic of Vertical Slot Fishway [14]

The elements controlling the effectiveness of fish pass design for watercourses are the targeted fish species and the pass itself [15]. For example, understanding the swimming ability of the targeted fish species governs the specifications of water velocities when designing the pass [16]. The design of the pass itself plays a crucial role in its effectiveness [17]. For instance, a researcher [18] studied the hydraulic characteristics of the standard vertical slot fish pass (velocity, flow pattern, recirculation zones, and turbulent energy) and compared these characteristics when changing the shape of barriers between basins to an L-shape. Improved flow patterns for fish, reduced velocity values, and recirculation zones were observed. Another researcher [19] conducted a detailed hydraulic study of various geometric shapes of slots, showing the impact of changing the deflection angle between small and large barriers on maximum velocity in the slot area and also on the flow field in the basin. The results indicated that the water level difference between adjacent basins is a crucial factor in determining the flow field and maximum velocity in the fish pass. By improving the slot design, it is possible to achieve the same discharge and maximum velocity even with larger differences in water level between adjacent basins, significantly reducing the cost of constructing the fish pass. Furthermore, a researcher [20] studied the flow disturbance differences between the standard design and a simplified design of the vertical slot fish pass, revealing higher values for maximum velocity, turbulent kinetic energy, and Reynolds shear stress in the standard design. Another researcher [21] investigated the differences in water depth for vertical slot passages without a central barrier. The adjacent basins should have the same front and rear elevation differences to prevent significant fluctuations in water depth, rather than being homogeneous along the fish pass course. Additionally, a researcher [14] studied some engineering modifications to the pass involving the introduction of cylinders into the basin, changing the shape of the barrier, and the position of the vertical slot. The sensitivity of flow behavior was evaluated for various discharge and incline values. The results showed that introducing cylinders reduced maximum velocity by up to 8.2%. Placing vertical slots on alternating sides increased the values of turbulent kinetic energy and exposed areas to higher values. Another researcher [22] studied the impact of changing geometric parameters of the basin, such as barrier shape, bottom slope, and water level difference between two basins, on the hydraulic characteristics of the flow. Two barrier shapes were used, one resembling the letter H and the other resembling the letter L. The velocity values, turbulent kinetic energy, energy dissipation rate, and vortices were lower with H-shaped barriers compared to L-shaped barriers. Moreover, a researcher [23] investigated the effect of changing the slope on the hydraulic characteristics of the standard vertical slot fish pass. Flow patterns generated with slopes less than 6.67% were more consistent with fish swimming capabilities, providing two-dimensional behavior and hydraulic conditions more suitable for fish. Higher turbulence levels in basins were observed when increasing the slope value. Additionally, a researcher [24] studied the flow patterns formed within the vertical slot fish pass when changing the ratio of the short barrier length to the total width of the basin. Three patterns were identified, with the second pattern (FP2) found to be the most efficient. It produced a gradient in velocity distribution, providing an important stimulus for fish migration behavior, helping fish move within the basin with less energy consumption. FP2 also offered a clear migration path for fish. The characteristics favoring FP2 include the areas of recirculation near the outlet, which have a negative impact on flow behavior in other patterns. FP2 exhibited the lowest energy dissipation rate, not only with lower velocity values but also with two-dimensional flow, where the vertical velocity component was negligible compared to the third pattern, which had three-dimensional flow [25], as shown in Figure (2).

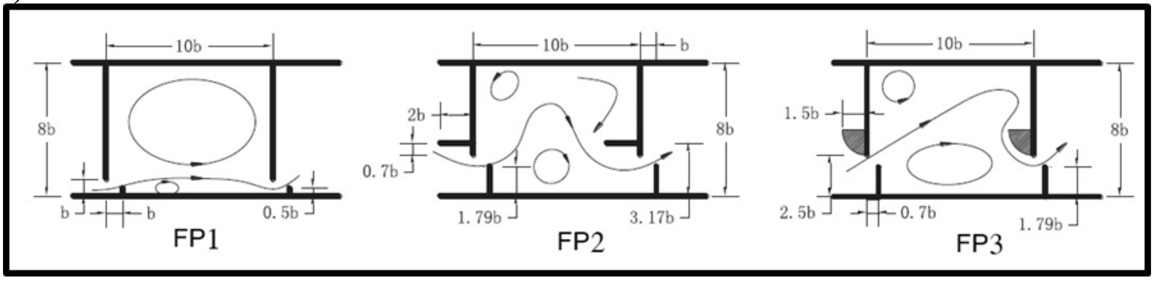

Fig. 2 Illustrate of flow patterns in one chamber [24]

The researcher [26] analyzed the velocity and turbulence field within the vertical slot fishway, where the higher discharges in the basin were strongly associated with the average depths of the upper flow and were slightly less correlated with the higher values of volumetric dissipated energy. Velocity field analysis indicated minimal variations in velocity values with depth and discharge. However, the turbulent kinetic energy field and volumetric dissipated energy fields were influenced by discharge in the region near the barriers. In this area, there was a slight increase in quantities associated with an increase in the flow rate. Nevertheless, the non-significant differences in discharge make vertical slot fish passes versatile, allowing fish to swim through a wide range of discharges, resulting in minor changes in flow characteristics. Additionally, the researcher [27] studied improving the performance of vertical slot fish passes by making some modifications to the standard pass, such as using passes with multiple slots, determining which modifications enhance the pass's hydraulic performance. The results showed that velocities were about 30% lower in multi-slot passes, and turbulence decreased by up to 70% in Reynolds shear stress and 50% in turbulent kinetic energy. Furthermore, another researcher [17] studied the effect of slot width on the hydraulic characteristics of the pass, using five values for slot width. Any increase or decrease in slot width affected flow velocity. The best flow velocity value, 1.23 m/s, was obtained when the slot width was 0.3 m, representing 15% of the basin width. The researcher [28] examined five different angles between barriers, four different widths of the basin, and introduced cylindrical elements placed after the slot behind the barriers. The results showed that as the angle between the barriers increased, the maximum velocity value decreased, and turbulent kinetic energy increased. This was also the case for the addition of cylinders and an increase in basin width. Moreover, a researcher [29] analyzed the flow behavior in the case where the flow pattern was of type FP1 in the vertical slot fishway. The study also assessed the influence on the flow field and turbulence when modifying the pass shape and adding geometrical structures inside the basin. For the FP1 flow pattern, the main flow streamline moved directly from one slot to the next without any bending or spreading within the basin. This caused an increase in the streamflow flow speed as it moved downstream of the river channel [Figure (3)]. Adding geometrical structures inside the basin contributed to improving the flow field and velocity by reducing both the maximum velocity from 2.04 m/s to 1.42 m/s and the average velocity within the basin from 0.67 m/s to 0.58 m/s. It also increased the percentage of the basin area where the velocity is less than or equal to 0.3 m/s (considered favorable for fish and should occupy the largest possible area) from 30.33% to 43.69%. The turbulence field also improved, with a reduction in turbulent kinetic energy from 0.214 m^2/s^2 to 0.132 m^2/s^2 and a decrease in the rate of turbulent energy from 0.05 m^2/s^2 to 0.042 m^2/s^2. Additionally, the percentage of the area where turbulent energy is less than 0.1 m^2/s^2 (considered suitable for fish) increased from 86.13% to 99.81%.

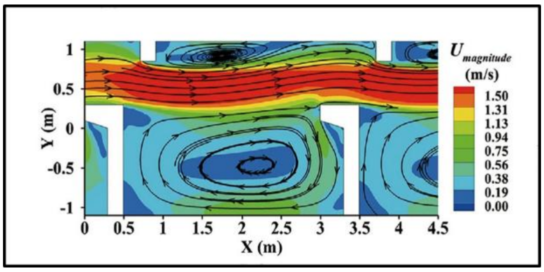

Fig. 3 Velocity distribution [29]

The researcher [30] conducted an analysis of the flow characteristics between the standard vertical slot fishway and a modified model representing changes in the vertical slot location. Geometrical structures in the form of an H were added inside the basin to improve the velocity field. The results showed a 28.5% decrease in maximum velocity, a 21.5% decrease in average velocity, and an increase in the area where velocity is less than or equal to 0.3 m/s from 35% to 43%. Regarding the turbulent kinetic energy field, it improved by reducing its maximum and average values by 30% and 12%, respectively. Additionally, the area where turbulent kinetic energy is less than or equal to 0.1 m^2/s^2 increased by 16%.

The current research aims to study and analyze the velocity and depth distribution in the vertical slot fish pass and compare it when adding geometrical structures in the form of the letters L, T, and I inside the pass basin to enhance its hydraulic performance, a topic not addressed in previous studies.

2. LABORATORY WORK:

Experiments were conducted in the hydraulic laboratory of the Department of Dams and Water Resources / College of Engineering at the University of Mosul. A metallic channel, previously used by researcher [31], with a length of 8.16 m and a width of 1.55 m, was employed. The channel operates with a water recirculation system. The dimensions of the studied part were 5.6 * 1.23 * 0.5 m in length, width, and height, respectively. The channel was equipped with water through a pump with a maximum discharge of approximately 12 *l*/s. The physical model of the fish pass was constructed inside this channel. The model consists of two parts: the first part, with a variable slope of 3.35 m length controlled by a beam in the channel, linked to iron bars connected to the beam on one side and to the bottom of the pass on the other side. This part includes chambers and basins of the pass. The second part of the model, with a length of 2.23 m, consists of a horizontal channel with the same width and height as the pass. Its purpose is to provide tailwater for the pass and determine the discharge within the pass, as it contains a baffle (submerged weir) at the end of the channel [32], with a height of 20 cm, as shown in Figure (4).

The model was built according to the standard design of the vertical slot fish pass [33], as shown in Figure (4). This model was chosen as it is the most common design and the standard reference most widely applied [20]. The key design parameter for the pass is the slot width, represented by "b_0," which serves as a reference for all dimensions and details of the pass, as illustrated in Figure (5).

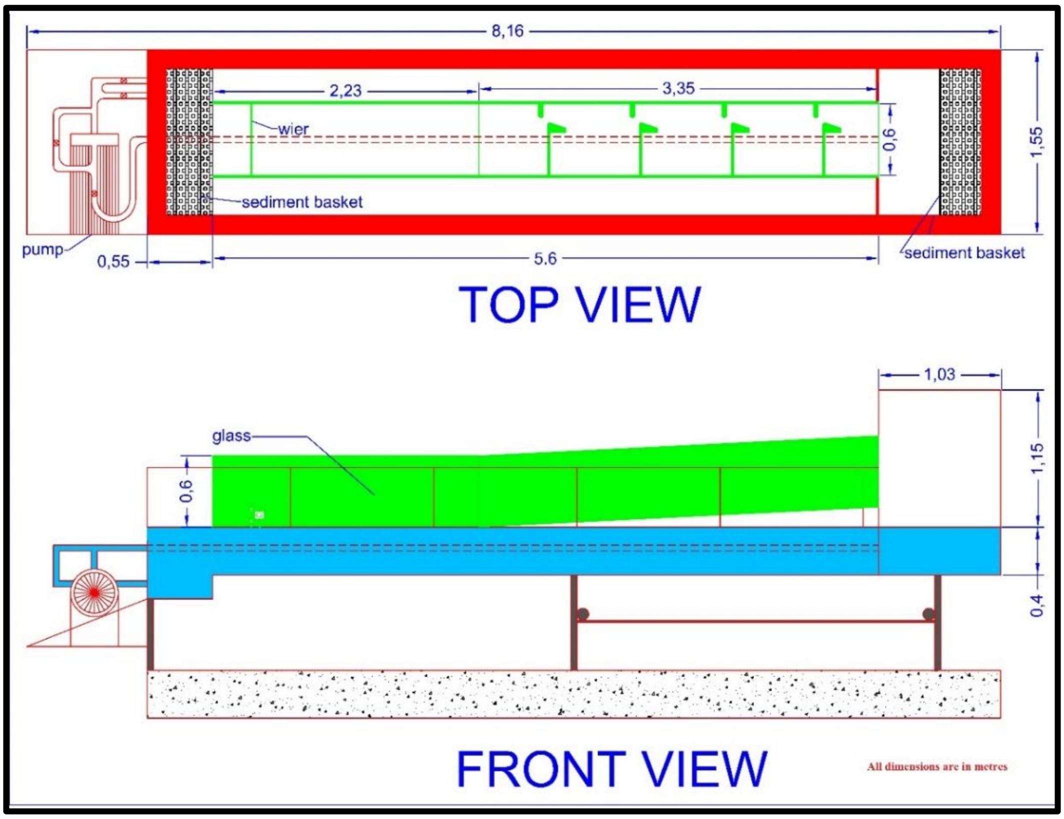

Fig. 4 Schematic of the laboratory channel

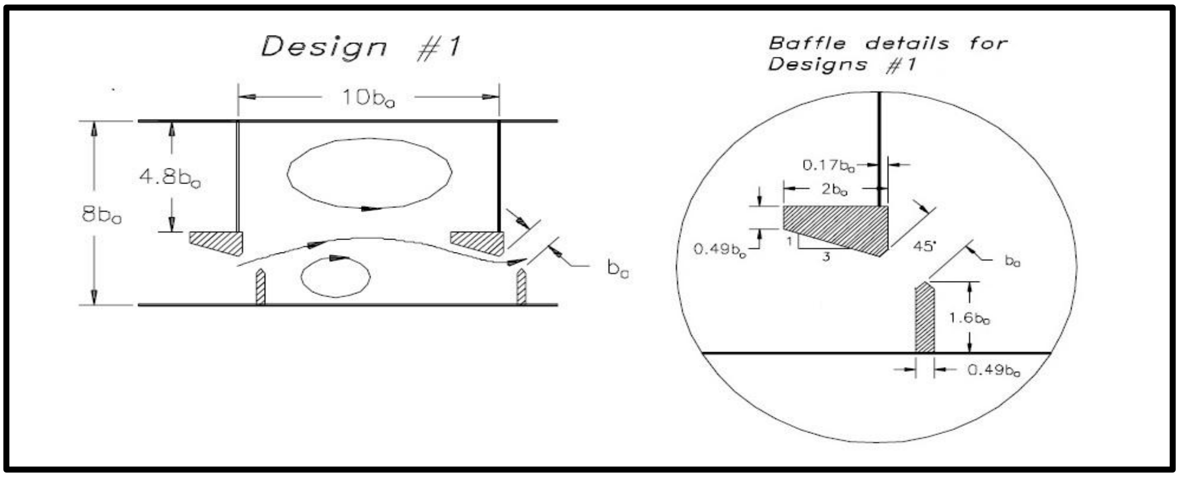

Fig. 5 schematics of the standard vertical slot fish pass according to [33].

The vertical slot width of the fishway was chosen to be 0.3 m. Due to the difficulty of implementing the pass at these measurements within the laboratory channel, as it does not accommodate the pass with actual dimensions, the model was executed at a 1:4 scale of the standard dimensions. This scale corresponds to the laboratory channel dimensions and achieves the modeling criteria of the Froude number [34]. Thus, the slot width became 0.075 m, and the basin's length, width, and height were 0.75 m, 0.6 m, respectively. The basin's length and width were ten times and eight times the slot width, respectively, to be suitable for fish [33].

Modifications were made to the standard model in the form of the letters L, T, and I inside the basin, resulting in four designs: the standard design and three modified designs represented by Figures (7) and (8). Four slope values were tested: 5%, 6.25%, 7.5%, and 8.75%. For each slope, five discharge values were tested: q1=3.83, q2=5.89, q3=7.89, q4=9.69, q5=12.41, with the discharge in *l*/s for the standard design. For the modified designs, three discharges (q1, q3, q5) were used for each slope. For each experiment, readings of flow depth were taken using a Point Gage, with 56 readings per experiment. Flow velocity was measured parallel to the pass bottom using a Pitot Tube. The actual number of velocity readings for each experiment for the standard design was 32 readings, as shown in Figure (6). The middle basin was selected for velocity readings to ensure hydraulic balance, where the extreme conditions at the top and bottom of the water channel have no effect [35]. Surfer 13 contour mapping software was used to draw velocity distribution maps for all experiments. These contour maps, along with the addition of dye inside the pass to trace the flow path [36], were used to determine the flow pattern.

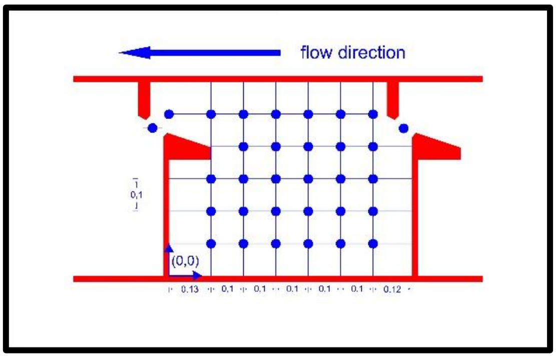

Fig. 6 Illustrates the mesh points for velocity readings, all dimensions in meters

3. RESULTS ANALYSIS:

The velocity distribution inside the basin was determined for the level located 20% to 25% below the water surface, relative to the total flow depth, to identify the maximum velocity value. Regarding the flow pattern, ink was added to the basin during operation to monitor the flow pattern formed and compare it with the calculated contour maps of the velocity distribution.

3.1. Flow Pattern:

In general, there are three flow patterns [24], as illustrated in Figure (2). The first pattern is represented by the streamline of a main flow along the side wall, sloping steeply towards the next opening, without a central streamline curve in the basin. This pattern is abbreviated as FP1. When the main flow transitions from the opening to the basin

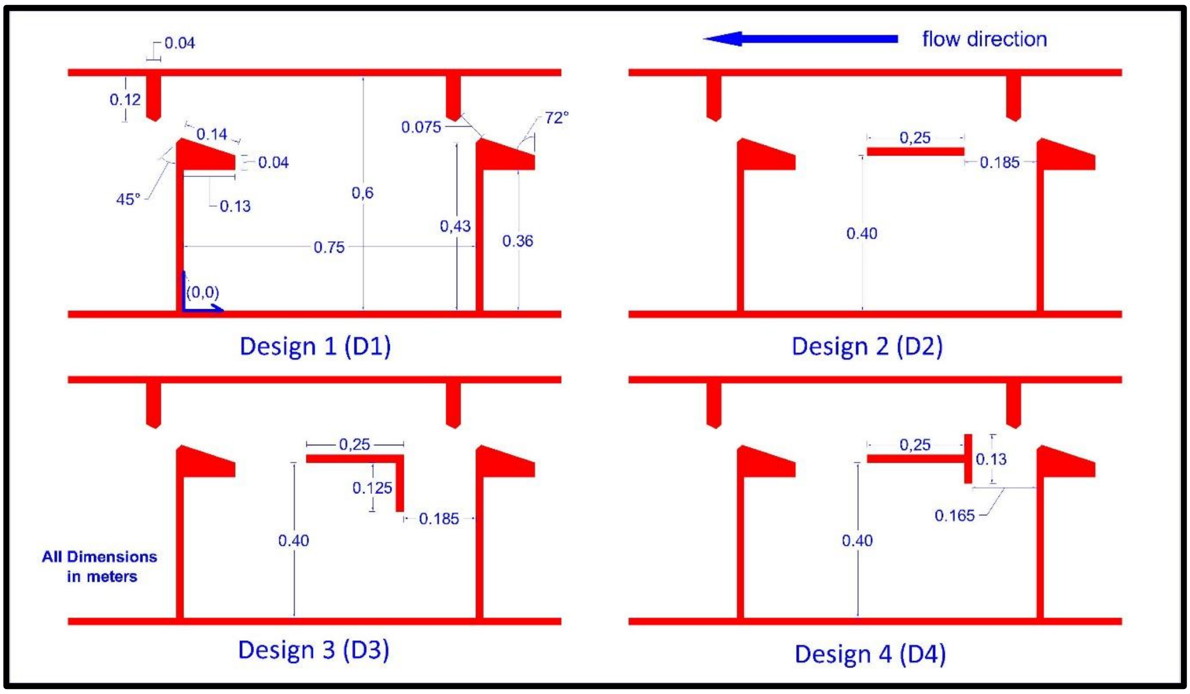

Fig. 7 Diagrams of the standard design and the modified designs

Fig. 8 Images of the laboratory model

in the form of a curved streamline spreading in the basin's center before converging again towards the next opening, this is called the second flow pattern, FP2. It can be considered a transitional pattern between the first and third patterns. The third pattern, FP3, involves the streamline of the flow in a curved form reaching the opposite side wall of the pass.

The second pattern (FP2) is considered the best for fish, as it allows fish to pass with minimal energy consumption and provides a clear migration path due to the gradual velocity associated with this pattern. The patterns formed in the standard design were as follows: for a slope of 5%, the pattern FP1 was formed with discharges q3, q4, q5, while for discharges q1 and q2, the formed pattern was FP2. When the slope increased to 6.25%, the flow behavior for discharges q5 and q4 followed FP1, while q3 and q2 formed the FP2 pattern. The change in flow behavior for discharge q3 from FP1 at a 5% slope to FP2 at a 6.25% slope is attributed to the reduction in flow depth, especially at the basin's entrance. This resulted in a decrease in the momentum of the moving water mass due to gravity, allowing the influence of the flow outside the opening at a 45^o angle to overcome the momentum effect of the water mass towards the outlet. The flow behavior for discharges at a 7.5% slope remained the same as at a 6.25% slope, except for discharge q1, which formed the FP3 pattern instead of FP1. At a slope of 8.75%, the flow pattern for discharges q3, q4, q5 was FP2, while q1 and q2 formed the FP3 pattern, as shown in Table (1). The obtained results are consistent with the findings of researcher [37], indicating that the flow pattern changes due to an increase in slope, either from FP1 to (FP2 or FP3) or from FP2 to FP3.

3.2. Maximum Velocity:

Based on the results, the highest velocity values were observed at the basin's entrance for FP2 and FP3 patterns, indicating energy dissipation within the basin [14]. Meanwhile, the maximum velocity value at the basin's exit was associated with the FP1 flow pattern, consistent with researcher [29]. It was noted that, at low discharges, the maximum velocity was observed at the entrance, regardless of the flow pattern, due to the approaching water depth at the exit to the stable water depth at the channel's end. Additionally, the FP1 pattern provided higher velocity values compared to other patterns. It's worth mentioning that the comparison of maximum velocity values between experiments was made regardless of their location. For example, between two experiments, the highest maximum velocity value was considered, whether its location was symmetrical or not. For instance, in one experiment, the maximum velocity was at the entrance, while in the other experiment, it was at the exit.

3.2.1. Effect of Slope Increase on Maximum Velocity:

The maximum velocity value is related to the slope in a quadratic relationship, as confirmed by researcher [23]. The percentage increase in maximum velocity value is affected by the flow pattern. For discharge q1, the maximum velocity increased by 22.1% with a slope increase to 6.25%, while the increase was 6.2% and 14.3% for slope increases from 5% to 7.5% and 8.75%, respectively. This variation in the percentage increase in maximum velocity value is due to the different flow patterns, with FP1 at a 6.25% slope, FP2 at a lower slope, and FP3 at a higher slope. On the other hand, discharge q2 produced the FP2 pattern for all slopes except at 8.75%, where it formed the FP3 pattern, resulting in nearly identical maximum velocity values. The increase in slope affected discharge q3, changing its flow behavior from FP1 at a 5% slope to FP2 at 6.25%, as an increase in slope reduced the flow depth, especially at the basin's entrance. This resulted in a decrease in the momentum of the moving water mass due to gravity, allowing the influence of the flow outside the opening at a 45-degree angle to overcome the momentum effect of the water mass towards the outlet. The flow behavior for discharges at a 7.5% slope remained the same as at a 6.25% slope, except for discharge q1, which formed the FP3 pattern instead of FP1. At an 8.75% slope, the flow pattern for discharges q3, q4, q5 was FP2, while q1 and q2 formed the FP3 pattern, as shown in Table (1).

3.2.2. Effect of Discharge Increase on Maximum Velocity:

For the same slope, increasing the discharge led to an increase in maximum velocity, as confirmed by researcher [14], considering the flow pattern for each case. At a 5% slope, the percentage change in maximum velocity between discharges q5 and q1 was 32.59%, a relatively large difference due to the difference in the formed flow pattern in the basin. The FP1 pattern formed with discharge q5, resulting in the highest maximum velocity possible, unlike the FP2 pattern accompanying discharge q1, where the maximum velocity value was at its lowest, and its location shifted from the basin exit to the entrance. At a 6.25% slope, the percentage change in maximum velocity was 26.32%, with the highest maximum velocity at discharge q5 and the lowest at discharge q2, not q1. This is because the formed pattern with q1 was FP1, while FP2 formed with q2. At a 7.5% slope, the percentage change in maximum velocity between discharges q5 and q1 was 31.17%, with the same pattern behavior as at a 5% slope, except that FP3 formed with discharge q1 instead of FP2. On the other hand, at an 8.75% slope, the percentage difference in maximum velocity between discharges q5 and q1 was 19.1%, with the pattern behavior being similar for discharges forming FP2 and FP3, resulting in a smaller difference while maintaining the maximum velocity in their respective locations, as shown in Table (1).

3.3 Impact of Adding Confegrations:

Experiments were conducted for modified shapes of the passage and compared with the standard shape for discharges q1, q3, and q5. The additions contributed to the formation of flow patterns of types FP2 and FP3, avoiding the formation of the FP1 pattern, which is considered undesirable due to its mismatch with fish movement and energy.

Table 1: Illustrates the effect of increasing the slope and discharge values on both the flow pattern type, location, and value of maximum velocity

slope %	discharge	Flow patters type	Velocity at inlet cm/sec	Velocity at outlet cm/sec	slope %	discharge	Flow patters type	Velocity at inlet cm/sec	Velocity at outlet cm/sec
5	q1	FP2	72.62	54.99	6.25	q1	FP1	88.68	76.24
	q2	FP2	81.73	64.95		q2	FP2	80.6	73.97
	q3	FP1	89.92	95.61		q3	FP2	85.94	78.45
	q4	FP1	97.43	102.7		q4	FP1	104.61	106.23
	q5	FP1	100.97	107.71		q5	FP1	107.83	109.4
7.5	q1	FP3	77.15	72.74	8.75	q1	FP3	83.06	73.69
	q2	FP2	82.54	74.98		q2	FP3	85.33	77.07
	q3	FP2	87.21	79.27		q3	FP2	89.36	81.11
	q4	FP1	107.58	110.61		q4	FP2	98.56	83.06
	q5	FP1	110.61	112.1		q5	FP2	102.66	88.28

3.3.1. Modified Design with Shape l Confegration:

This modification altered the flow pattern for all discharges and slopes. The predominant pattern was FP2, except for discharge q1 at slopes 6.25, 7.5, and 8.75, where the pattern was FP3. Three scenarios for changing the flow pattern behavior were identified: the first scenario involved a shift from FP1 to FP2, resulting from the addition of geometric structures inside the basin that disrupted the flow pattern, leading to its deviation to the center of the basin and a subsequent change to FP2 or FP3 (Figure 9). This scenario is the most important and effective, providing the highest percentage reduction in maximum velocity, reaching up to 28.22%. The second scenario maintained the FP2 pattern both before and after the modification, showing less impact compared to the first scenario, with a reduction in maximum velocity ranging from 0.0% to 10.56%. The third scenario, the least favorable, involved maintaining the FP3 pattern without modification, leading to an increase in maximum velocity by 1.37% to 8.01% (Table 2).

3.3.2. Modified Design with Shape L Confegration:

This design resulted in the formation of only the FP3 pattern, as the added geometric structure in the basin pushed the flow pattern toward the far side wall (Figure 9). The following scenarios were observed: the first scenario involved a shift from FP1 to FP3, achieving the highest percentage reduction in maximum velocity at 24.41%, which is comparable to the first modification scenario. The second scenario involved a shift in flow pattern behavior from FP2 to FP3, resulting in a reduction in velocity ranging from 0.81% to 11.29%. The third scenario maintained the FP3 pattern both before and after the modification, leading to a slight increase in maximum velocity, with a lower percentage change compared to the first modification (Table 2).

3.3.3. Modified Design with Shape T Confegration:

This modification resulted in the formation of both FP2 and FP3 patterns. The primary cause was the shape and location of the added geometric structure inside the basin (Figure 9). Four scenarios were identified: the first scenario involved a shift from FP1 to FP2, achieving the highest percentage reduction in maximum velocity, slightly exceeding 24%. The second scenario maintained the FP2 pattern both before and after the modification, with a slight decrease in velocity compared to the previous scenario, achieving a maximum reduction percentage of 3.77%. The third scenario, similar to previous modifications, led to an increase in maximum velocity by a percentage ranging from 6.45% to 1.83%, maintaining the FP3 pattern before and after the modification. Additionally, a fourth scenario involved a transition from FP2 to FP3 in one case, resulting in a 14.36% reduction in maximum velocity, as shown in Table 2.

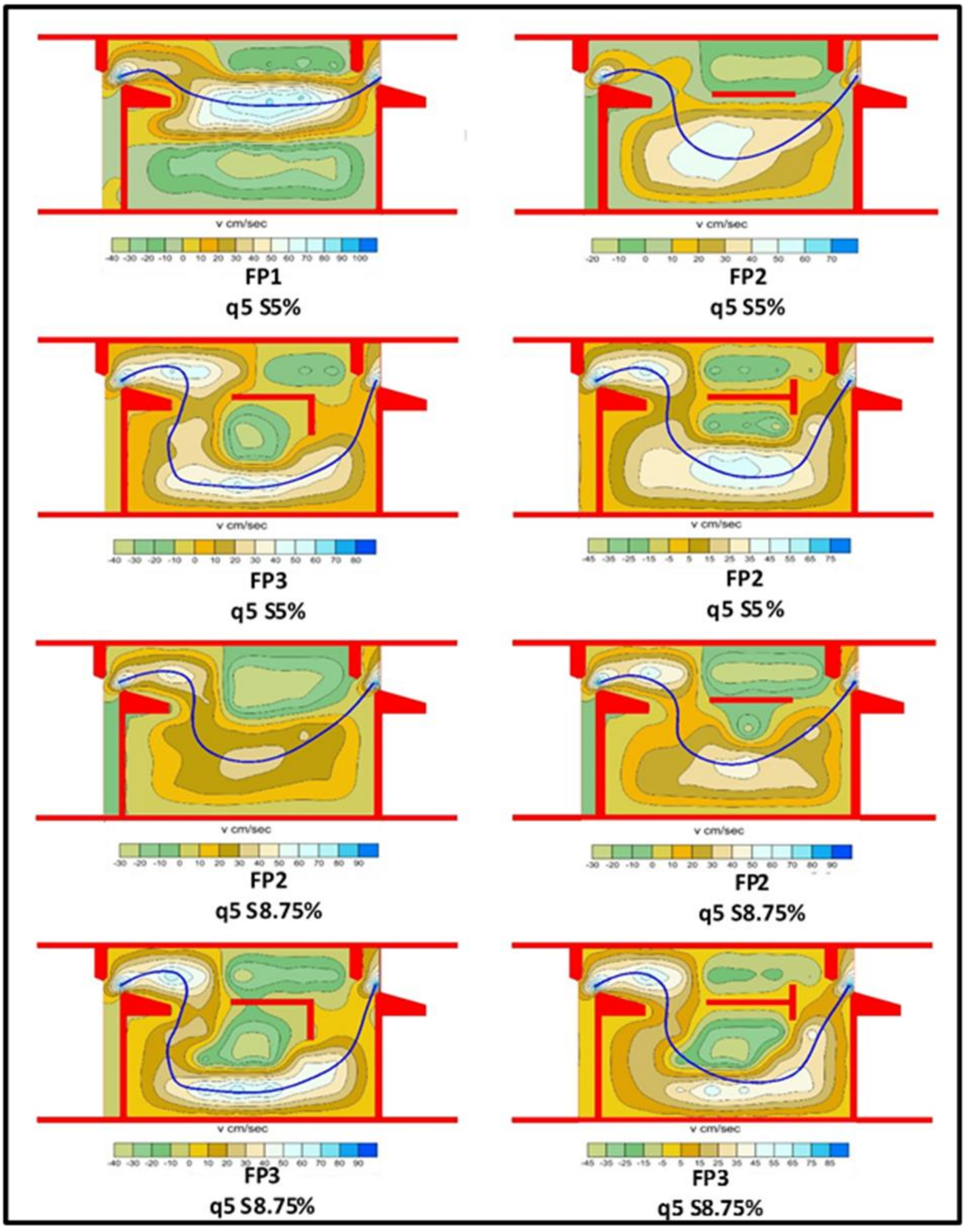

Fig. 9 Illustrates the effect of the modifications inside the basin on the flow pattern for the case of discharge q5 and slopes 5% and 8.75%.

Table 2: Illustrates the impact of added shapes on velocity values and flow patterns

slope %	discharge	Design no.1			Design no.2			
		Flow pattern type	Velocity at inlet cm/sec	Velocity at outlet cm/sec	Flow pattern type	Velocity at inlet cm/sec	Velocity at outlet cm/sec	Reducing velocity %
5	q1	FP2	72.62	54.99	FP2	64.95	45.93	10.56
	q3	FP1	89.92	95.61	FP2	72.62	56.25	24.05
	q5	FP1	100.97	107.71	FP2	64.95	77.31	28.22
6.25	q1	FP1	88.68	76.24	FP3	73.97	66.67	16.59
	q3	FP2	85.94	78.45	FP2	78.45	73.97	8.72
	q5	FP1	107.83	109.4	FP2	80.6	84.74	22.54
7.5	q1	FP3	77.15	72.74	FP3	83.33	74.98	-8.01
	q3	FP2	87.21	79.27	FP2	87.21	79.27	0.00
	q5	FP1	110.61	112.1	FP2	94.49	92.73	15.71
8.75	q1	FP3	83.06	73.69	FP3	84.2	79.12	-1.37
	q3	FP2	89.36	81.11	FP2	88.28	87.55	1.21
	q5	FP2	102.66	88.28	FP2	97.88	96.24	4.66

slope %	discharge	Design no.3				Design no.4			
		Flow pattern type	Velocity at inlet cm/sec	Velocity at outlet cm/sec	Reducing velocity %	Flow pattern type	Velocity at inlet cm/sec	Velocity at outlet cm/sec	Reducing velocity %
5	q1	FP3	67.6	45.93	6.91	FP3	62.19	59.29	14.36
	q3	FP3	77.31	64.95	19.14	FP2	72.62	66.56	24.05
	q5	FP3	70.16	83.85	22.15	FP2	77.31	81.73	24.12
6.25	q1	FP3	73.97	69.19	16.59	FP3	78.89	73.97	11.04
	q3	FP3	76.24	72.56	11.29	FP2	82.7	80.17	3.77
	q5	FP3	78.45	82.7	24.41	FP2	82.7	79.75	24.41
7.5	q1	FP3	80.92	69.48	-4.89	FP3	82.13	77.15	-6.45
	q3	FP3	86.45	83.33	0.87	FP2	85.29	79.27	2.20
	q5	FP3	94.49	90.19	15.71	FP2	90.92	83.73	18.89
8.75	q1	FP3	82.29	80.72	0.93	FP3	84.58	81.11	-1.83
	q3	FP3	88.64	83.06	0.81	FP2	92.86	87.55	-3.92
	q5	FP3	98.86	91.13	3.70	FP2	99.5	93.89	3.08

4. CONCLUSIONS:

This research focused on studying two crucial hydraulic characteristics of fishways with vertical slots: the flow pattern inside the fishway and the maximum velocity value. The investigation explored how these features change with variations in slope and discharge. Four slope values were tested, and for each slope, five discharges were examined for the standard design. The study was conducted under clear water conditions, and modifications were made to the standard fishway by adding structures in the shape of the letters "l," "L," and "T" inside the fishway basin. Three discharges were tested for each slope with the modified shapes. The following results were obtained:

1. Design 1 (Standard): Regarding flow patterns, the second and third patterns dominate for lower discharges, while for higher discharges, the flow behavior tends toward the first pattern. Similarly, for the same discharge, higher slopes tend to shift the behavior of high discharges toward the second pattern. The maximum velocity increases with higher discharge for the same slope, and it also increases with higher slope for the same discharge, provided that the sequence of flow pattern change from the lowest to the highest discharge or slope is from the second or third pattern to the first pattern.

2. Design 2 (Modified with "l" Shape): The second pattern was produced for all discharges except the first discharge for slopes 6.25%, 7.5%, and 8.75%, where the third pattern was produced. The transition from the first pattern to the second pattern reduced the maximum velocity by a percentage ranging from 8.72% to 28.22%. If the third pattern remains unchanged, the maximum velocity increases by a percentage ranging from 1.37% to 8.01%.

3. Design 3 (Modified with "L" Shape): This modification produced the third pattern for all discharges and slopes. The transition from the first pattern, present in the standard fishway before modification, to the third pattern after modification reduced the maximum velocity by a maximum percentage of 24.41%. Note that this reduction percentage is lower than that achieved with Design 2. There is a slight increase or decrease in maximum velocity when the third pattern remains unchanged, with or without modification.

4.Design 4 (Modified with "T" Shape): The dominant pattern was the second, except for the first discharge for all slopes, where the third pattern was produced. The transition from the first pattern to the second pattern showed a similar behavior to Design 2, with a maximum reduction percentage of 24.41%. Similarly, if the third pattern remains unchanged, the study showed a behavior similar to Design 2.

The study concluded that adding modifications to the standard shape of the main fishway always produces better patterns for fish, excluding undesirable patterns. Therefore, modifying and improving the patterns contributes to reducing the maximum velocity inside the basin by a percentage that can reach up to 28.22%.

REFERENCES

[1] S. Chen, B. Chen, and B. D. Fath, “Assessing the cumulative environmental impact of hydropower construction on river systems based on energy network model,” Renew. Sustain. Energy Rev., vol. 42, pp. 78–92, 2015, doi: https://doi.org/10.1016/j.rser.2014.10.017.

[2] C. Nilsson, C. A. Reidy, M. Dynesius, and C. Revenga, “Fragmentation and Flow Regulation of the World’s Large River Systems,” Science (80-.)., vol. 308, no. 5720, pp. 405–408, Apr. 2005, doi: 10.1126/science.1107887.

[3] L. Benejam, S. Saura-Mas, M. Bardina, C. Solà, A. Munné, and E. García-Berthou, “Ecological impacts of small hydropower plants on headwater stream fish: from individual to community effects,” Ecol. Freshw. Fish, vol. 25, no. 2, pp. 295–306, 2016, https://doi.org/10.1111/eff.12210

[4] D. Tickner et al., “Bending the curve of global freshwater biodiversity loss: an emergency recovery plan,” Bioscience, vol. 70, no. 4, pp. 330–342, 2020, https://doi.org/10.1093/biosci/biaa002

[5] X. Mao, J. Li, W. Yi, and X. Luo, “Study on optimizing the structure of the fishway [J],” J. Sichuan Univ. Engineering Sci. Ed., vol. 43, no. S1, pp. 54–59, 2011.

[6] A. J. Lynch et al., “The social, economic, and environmental importance of inland fish and fisheries,” Environ. Rev., vol. 24, no. 2, pp. 115–121, 2016, https://doi.org/10.1139/er-2015-0064

[7] X. Luo and J. Li, “Study on structure and hydraulic characteristics of vertical-slot fishway,” J. Yangtze River Sci. Res. Inst., vol. 27, no. 10, p. 50, 2010, https://api.semanticscholar.org/CorpusID:112525058

[8] C. H. Clay, Design of fishways and other fish facilities. CRC Press, 2017.

[9] M. Larinier and G. Marmulla, “Fish passes: types, principles and geographical distribution-an overview” in Proceedings of the second international symposium on the management of large rivers for fisheries, RAP publication Bangkok, Thailand, 2004, pp. 183–206, https://api.semanticscholar.org/CorpusID:132530481

[10] F. Romão et al., “Passage performance of two cyprinids with different ecological traits in a fishway with distinct vertical slot configurations,” Ecol. Eng., vol. 105, pp. 180–188, 2017, doi: https://doi.org/10.1016/j.ecoleng.2017.04.031.

[11] J. F. Fuentes-Pérez, F. J. Sanz-Ronda, A. Martínez de Azagra Paredes, and A. García-Vega, “Modeling water-depth distribution in vertical-slot fishways under uniform and nonuniform scenarios,” J. Hydraul. Eng., vol. 140, no. 10, p. 6014016, 2014, https://doi.org/10.1061/(ASCE)HY.1943-7900.0000923

[12] M. Liu, N. Rajaratnam, and D. Z. Zhu, “Mean flow and turbulence structure in vertical slot fishways,” J. Hydraul. Eng., vol. 132, no. 8, pp. 765–777, 2006, https://doi.org/10.1061/(ASCE)0733-9429(2006)132:8(765)

[13] L. J. Alvarez-Vázquez, J. J. Júdice, A. Martínez, C. Rodríguez, M. E. Vázquez-Méndez, and M.

A. Vilar, "On the optimal design of river fishways," Optim. Eng., vol. 14, pp. 193–211, 2013, https://doi.org/10.1007/s11081-011-9175-x

[14] D. G. Sanagiotto, J. B. Rossi, and J. M. Bravo, "Applications of computational fluid dynamics in the design and rehabilitation of nonstandard vertical slot fishways," Water, vol. 11, no. 2, p. 199, 2019, https://doi.org/10.3390/w11020199[15] T. T. Rodríguez, J. P. Agudo, L. P. Mosquera, and E. P. González, "Evaluating vertical-slot fishway designs in terms of fish swimming capabilities," Ecol. Eng., vol. 27, no. 1, pp. 37–48, 2006, https://doi.org/10.1016/j.ecoleng.2005.09.015

[16] M. Mallen-Cooper, "Swimming ability of adult golden perch, Macquaria ambigua (Percichthyidae), and adult silver perch, Bidyanus bidyanus (Teraponidae), in an experimental vertical-slot fishway," Mar. Freshw. Res., vol. 45, no. 2, pp. 191–198, 1994, https://doi.org/10.1071/MF9940191

[17] I. H. Hameed and A. N. Hilo, "Numerical Analysis on the Effect of Slot Width on the Design of Vertical Slot Fishways," in IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2021, p. 12094, DOI:10.1088/1757-899X/1090/1/012094

[18] R. An, J. Li, R. Liang, and Y. Tuo, "Three-dimensional simulation and experimental study for optimising a vertical slot fishway," J. hydro-environment Res., vol. 12, pp. 119–129, 2016, https://doi.org/10.1016/j.jher.2016.05.005

[19] M. Bombač, M. Četina, and G. Novak, "Study on flow characteristics in vertical slot fishways regarding slot layout optimization," Ecol. Eng., vol. 107, pp. 126–136, 2017, https://doi.org/10.1016/j.ecoleng.2017.07.008

[20] E. Quaranta, C. Katopodis, R. Revelli, and C. Comoglio, "Turbulent flow field comparison and related suitability for fish passage of a standard and a simplified low-gradient vertical slot fishway," River Res. Appl., vol. 33, no. 8, pp. 1295–1305, 2017, https://doi.org/10.1002/rra.3193

[21] G. Li, S. Sun, H. Liu, T. Zheng, and C. Zhang, "Water profiles in vertical slot fishways without central baffle," Int. J. Heat Technol., vol. 35, no. 1, pp. 191–195, 2017, https://doi.org/ 10.18280/ijht.350125

[22] Y. Li, X. Wang, G. Xuan, and D. Liang, "Effect of parameters of pool geometry on flow characteristics in low slope vertical slot fishways," J. Hydraul. Res., 2019, https://doi.org/10.1080/00221686.2019.1581666

[23] E. Quaranta, C. Katopodis, and C. Comoglio, "Effects of bed slope on the flow field of vertical slot fishways," River Res. Appl., vol. 35, no. 6, pp. 656–668, 2019, https://doi.org/10.1002/rra.3428

[24] G. Li, S. Sun, C. Zhang, H. Liu, and T. Zheng, "Evaluation of flow patterns in vertical slot fishways with different slot positions based on a comparison passage experiment for juvenile grass carp," Ecol. Eng., vol. 133, no. March, pp. 148–159, 2019, doi: 10.1016/j.ecoleng.2019.04.008.

[25] S. Wu, N. Rajaratnam, and C. Katopodis, "Structure of flow in vertical slot fishway," J. Hydraul. Eng., vol. 125, no. 4, pp. 351–360, 1999, https://doi.org/10.1061/(ASCE)0733-9429(1999)125:4(351)

[26] D. G. Sanagiotto, J. B. Rossi, L. L. Lauffer, and J. M. Bravo, "Three-dimensional numerical simulation of flow in vertical slot fishways: validation of the model and characterization of the flow," RBRH, vol. 24, 2019, https://doi.org/10.1590/2318-0331.241920180174

[27] F. Romão, A. L. Quaresma, J. M. Santos, S. D. Amaral, P. Branco, and A. N. Pinheiro, "Multislot fishway improves entrance performance and fish transit time over vertical slots," Water (Switzerland), vol. 13, no. 3, 2021, doi: 10.3390/w13030275.

[28] M. Ahmadi, A. Ghaderi, H. M. Nezhad, A. Kuriqi, and S. Di Francesco, "Numerical investigation of hydraulics in a vertical slot fishway with upgraded configurations," Water (Switzerland), vol. 13, no. 19, 2021, doi: 10.3390/w13192711.

[29] D. Zhang, X. Bian, X. Shi, J. Deng, and Y. Liu, "Design of a bilateral-symmetric multi-slot fishway and its comparison with vertical slot fishway in terms of hydraulic properties," River Res. Appl., vol. 39, no. 5, pp. 954–969, 2023, doi: 10.1002/rra.4125.

[30] D. Zhang, C. Liu, X. Shi, Y. Liu, and Y. Qu, "A novel H-shape fishway with excellent hydraulic characteristics," J. Hydrol. Hydromechanics, vol. 71, no. 1, pp. 64–79, 2023, doi: 10.2478/johh-2022-0026.

[31] M. S. Alhmdany, M. A. Alsawaf, and Z. A. Sulaiman, "Numerical and Physical Modelling to Dissipate the Flow Energy of Spillway Using Multiple Rows of Chute Blocks," *Al-Rafidain Engineering Journal (AREJ)*, vol. 27, no. 1, pp. 166–174, 2022, doi: https://doi.org/10.33899/rengj.2021.130576.1112.

[32] M. I. Alsaidi, G. A. A.-M. Hayawi, and M. A. Alsawaf, "Study of Scour Around Cylindrical Bridge Piers with Circular Openings," *Al-Rafidain Engineering Journal (AREJ)*, vol. 25, no. 2, pp. 66–74, 2020. Doi: https://doi.org/10.33899/rengj.2020.126863.1029.

[33] C. Katopodis, "Introduction to fishway design," Oceans, no. January, p. 67, 1992, [Online]. Available: http://www.wra.gov.tw/public/attachment/41110254871.pdf

[34] A. Ballu, G. Pineau, D. Calluaud, and L. David, "Characterization of the flow in a Vertical Slot Fishway with macro-roughnesses using

unsteady (URANS and LES) simulations," 37th IAHR World Congr., no. August, 2017.

[35] G. Gilja, E. Ocvirk, and R. Fliszar, "Experimental investigation of the reynolds shear stress exceedance rate for the injury and disorientation biocriteria boundary in the pool-orifice and vertical slot type fishways," Appl. Sci., vol. 11, no. 16, 2021, doi: 10.3390/app11167708.

[36] A. Y. Abdalhafedh and N. K. Alomari, "The effect of entrance edges shape of the diversion channel on the dividing streamlines behavior at the junction region," *Al-Rafidain Engineering Journal (AREJ)*, vol. 26, no. 2, pp. 218–226, 2021, doi: https://doi.org/10.33899/rengj.2021.130181.1096.

[37] L. Tarrade, A. Texier, L. David, and M. Larinier, "Topologies and measurements of turbulent flow in vertical slot fishways," Hydrobiologia, vol. 609, no. 1, pp. 177–188, 2008, doi: 10.1007/s10750-008-9416-y

تأثير اضافة التراكيب الهندسية داخل حوض معبر الاسماك على نمط وسرعة الجريان القصوى

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الملخص:

ان معابر الاسماك هي منشات هيدروليكية تستخدم بصورة كبيرة لامرار مجموعات الأسماك المهاجرة وتساهم في الحفاظ على تنوعها في الأنهار التي يقطع جريانها الطبيعي عوارض تفصلها بيئيا وبايولوجيا. تم تصميم هذه المعابر مع العديد من التعديلات الهندسية، وبالتالي ستتشكل أنماط تدفق من خلال هذه التعديلات بخصائص هيدروليكية ملائمة لأنواع اسماك معينة. تهدف هذه الدراسة الى تحليل الخصائص الهيدروليكية للجريان ومنها السرعة القصوى للجريان، ونمط الجريان في معبر الفتحة الراسية القياسي ومدى تأثرها عند تعديل شكل المعبر باضافة تراكيب هندسية على شكل الاحرف I، L، T داخل الحوض. حيث تم بناء نموذج مختبري بمقياس 1:4، وتم اختبار اربع قيم للميول وهي 5، 6.25، 7.5، 8.75 % ولكل ميل تم اختبار خمسة تصاريف بالنسبة للشكل القياسي (بدون تعديلات) 3.83، 5.89، 7.89، 9.69، 12.41 لتر/ثا، اما بالنسبة للاشكال المعدلة فتم اختبار ثلاث تصاريف 3.83، 7.89، 12.41 لتر/ثا. اظهرت النتائج ان الجريان في التصميم القياسي يكون على شكل ثلاثة انماط للجريان الافضل هو النمط الثاني والاسوء هو النمط الاول الذي يتشكل بالعادة مع التصاريف العالية وبالنسبة للسرعة القصوى تزداد بزيادة الميل والتصريف. اما عند تعديل شكل المعبر سيتكون نمطين فقط وهما النمط الثاني والثالث وبالتالي التخلص من النمط غير المرغوب فيه. كذلك ساهمت التعديلات في خفض قيمة السرعة القصوى خصوصا عندما يغير التعديل نمط الجريان من النمط الاسوء الى النمط الافضل فقد وصلت اقصى نسبة لتقليل قيمة السرعة القصوى الى 28.22% ودائما ما تصاحب اعلى قيمة لنسبة تقليل السرعة القصوى التصاريف الاعلى وبالتالي تزداد اهمية هذه الاضافات مع التصاريف العالية.

الكلمات الدالة:

معابر الاسماك، معابر الفتحة الراسية، نمط الجريان، السرعة القصوى.