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Optimal flow pattern around hybrid groins with various orientations to improve fish habitat via Experimental Investigation using Acoustic Doppler Velocimeter

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Abstract Given the growing interest in river restoration and natural river improvement, groins are recommended as an essential hydraulic component for creating riparian habitats and controlling local flow. The optimum design of groins for environmental purposes is still not defined despite its long history of improving river flow dynamics. The primary goal of this paper is to determine the influence of hybrid groins' orientation angle and geometry on both the flow velocity and structure to enhance fish habitat. This study investigates six models of unsubmerged hybrid L-shape groins installed in a straight channel with a deformed bed. The hybrid L-shape groins consist of two parts, an impermeable part that objected to the flow, and a permeable one (piles rows) arranged in the flow direction. The influences of groin's both contraction/length ratio and orientation angle on the flow velocity and structure are studied. The contraction ratio represents the impermeable groin length relative to channel width (W/B), while the orientation angle (θ) is the groin inclination angle in the up/downstream direction. Groin models with 25% contraction ratio and up/downstream orientation angle (θ) of 45°, 60°, and 90° were used. Groin with an orientation angle of 45° toward downstream has introduced the highest reduction on the flow velocities. Also, groin with θ=90° downstream introduced low velocities, but these velocities still more than the reduction of 45° case. The area of the dead zone -the zone of low velocities- in the case of θ=45° is about 70 % more than that of θ=90°.

Keywords: Fish habitat, Flow structure, Hybrid groins, Orientation angle, Velocity distribution.

1 Introduction

The phrase "river training structure" refers to any structure built inside a river to direct, maintain or control the river's flow. The groins are popular and widely used as river training structures. They are considered one of the most suitable techniques for habitat restoration [1-4]. In the design process of groins, there are a lot of parameters to be considered. To make it obvious what these characteristics genuinely serve, engineers have conducted significant researches using different techniques such as experimental studies, theoretical examinations, computer simulations, and field studies [3, 5].

Groins have a variety of functions, including deepening the main channel to improve navigation, diverting the flow away from weak riverbanks, promoting sedimentation on necessary regions, and providing an ecosystem by regulating the velocity and flow direction [6-11]. They decrease the velocities along the riverbank and produce recirculation zones behind a structure, which creates the ideal conditions for biological life. Aquatic life uses the recirculation zone as a refuge during floods [12]. The velocity is reduced in the region of the blocked flow field downstream of a single groin. Typically, this area is known as a dead zone[13]. The flow velocity in this region is about 25-30% of the mainstream velocity [7]. Such structures are beneficial for improving the habitat of aquatic organisms in urban rivers[14].They create shelter for aquatic species, increasing their diversity. Weak and little fish shouldn't be swimming in the river's main channel because of the high velocity. Thus, the dead zone provides fish with a suitable refuge [15, 16].

Recently, experimental studies, computer models, and on-site observations have all been used to investigate the ecological effects of groins. According to the results, the diversity of river habitats can be increased by creating medium and low-flowing in rivers. When the quality of the ecosystem is improved, aquatic creatures may have more space to live [17].[18, 19] discovered that species and habitat diversity had a significant association with water depth and current velocity.

Fish can find shelter in the scour pools during periods of high flow and can remain and feed during times of low flow, making them excellent habitats for fish. One of the earliest studies was conducted to identify the ideal design criteria for groins [20]. According to the results of their experimental investigation, a groin with an orientation angle of 135° downstream produces the most scour and

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provides a favorable environment for aquatic habitats. The maximum velocity and bed shear stress for 135° at flow direction groin are found lower than the other two cases 90° and 45° [15].

Studies by [21, 22] and others have investigated that groin fields having slow flow velocities and shallow water encourage vegetation growth, silt deposition, and the best conditions for fish to survive and feed. [23] studied the effects of flow velocity and water depth on fish habitats both with and without groins. They discovered that the groins can contribute to increase the fish habitat. The weighted useable area and fish habitat functional area proportion are related.

[24] demonstrated that the restoration which consisted of two transverse groins improved the habitat suitability for more fish species compared with the pre-restoration conditions. Salmon habitats downstream of the restored reach were improved due to the bed grain size fining. [21] used a scaled physical model of 1:40 to study the flow near the Dutch River Waal, the results showed variations in turbulence between the submerged groins and the emergent ones. The flow in the groin fields region in the submerged stage exhibits an alternating accelerating and decelerating pattern between flow over and around the groins but does not exhibit the circulation pattern as seen in the emerged state.

According to [25] the water velocity reached its maximum when the width of groin was equivalent to one-fifth width of the flume. [26] used 2D flume model for measuring the velocity distribution associated with spur dikes and scour holes to define the influence of groin length and orientation angle. He indicated that the groin length is directly proportional to velocity at the groin field. [27] The impact of groin system submergence and length on the flow force coefficient was examined by conducting experimental studies of velocity distribution and water depth around groins. [28] studied the flow patterns around the groin on the Yangtze River's Yizheng section. They found that the groin system offered a reliable migration path and an abundance of food for fish. [29] studied the velocity fields and turbulence patterns close to groins covered in ice with various roughness coefficients. The groins were positioned at three orientation angles 90°, 60°, and 45°. The results showed that the most substantial velocity fluctuation happened relatively to the groin tip and above the scour hole. As comparison to down flows produced by orientations angles of 45 and 60, the 90° groin generates the strongest down flow everywhere around it. It is abundantly obvious from the results that by lowering the dike orientation angle from 90° to 45°, the velocity profiles are moved upward and the depth of the scour hole is reduced by 5–10% for every 10 angle decrease. [30] examined the water surface profile, flow rate, scour, and deposition pattern near environmentally friendly notched groins. The results show an essential change in the flow pattern at the notches generated in the middle of localized overflow groins. Because different flow conditions prevented depositional structures from growing along their borders, both the main channel and the groin's field are linked. When the notch depth was 2/3 of the groin height, the notched groins had beneficial environmental effects.

The system of the groin is a hydraulic system that can considerably improve the environment for fish. The characteristics of the surrounding water flow greatly influence the ability of fish to adapt to different fields. However, the impact of groin design on flow fields, scour, velocity, and sediment deposition close to the groin is still unclear [31].

A review of the literature reveals that, despite the significant amount of experimental research and numerical works on groins, there is still much interest in and discussion regarding how to improve the groin's shape, orientation angle, and contraction ratio to increase their efficiency in improving the flow environment for fish. All previous studies showed that the flow structure around groin and velocities distribution pattern in their region is still need further investigation. Therefore, the present study aims to determine the effect of a contraction ratio 25% and different orientation angles (45°, 60°, 90°) U.S and D.S on flow velocity distribution in the groin region to maintain the river ecosystem and improve fish habitat. For this reason, the study focuses on detailed velocity measurements on scoured deformed bed after reaching equilibrium state. The velocities are measured by using an Acoustic Doppler Velocimeter (ADV) to select the velocity reduction zone that is considered the suitable environment for fish.

2 Experimental Method and Procedures

Experiments were conducted at the Irrigation and Hydraulics Laboratory, Civil Engineering Dept., Assiut University, Egypt. Tilting flume is used of 13.5 meters length, 0.3 meters in both width and depth, and 10 m long transparent test section. The channel bottom slope was adjusted for the experiments to be 0.0025. The permitted discharge (Q) was 7.41 lit/sec. It was measured using a manometer board and a regular nozzle meter. The flowing water depth was measured with a point gauge moved on a movable sliding carriage with a 0.10 mm accuracy. The flowing water with a Froude number of 0.18 was adjusted to 12.5 cm using tailgate installed at the flume end.

A movable sand bed with a thickness 10 cm and median size d50=0.67mm was used for the experiments. The movable sand bed was located at a distance 2 m downstream the entrance section of the flume. therefore, a false bed with 10cm depth was furnished for the first 3.0 m of the flume length at upstream and for the 3.0 of the flume length downstream with 10 cm depth. The false bed constructed from an acrylic block with 10 cm thickness for the U.S and D.S part of the false bed. Experimental conditions are shown in **Table 1**, and the used flume and a detailed sketch of the experimental setup are illustrated in **Fig. 1**.

Table 1. Experimental conditions.

Submergence	*Non-submerged*
Discharge Q(lit/sec)	*7.41*
Flume slope S	*0.0025*
Water depth h_w(cm)	*12.5*
Mean velocity u_o (cm/sec)	*20*
Froude number Fr	*0.18*
Sand size d_{50}(mm)	*0.67*
Permeability p%	*57.33*

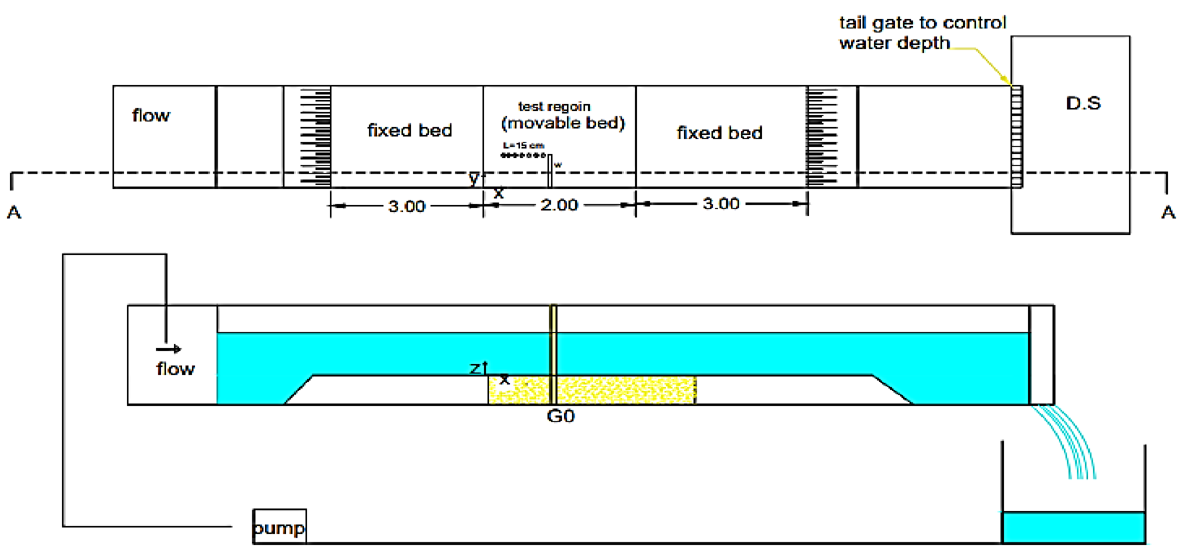

Fig. 1 Flume and experimental setup.

The groin model's location serves as a starting point for the x-coordinate, the flume's right wall for the y-axis, and the initial flatbed level for the z-axis. In present research, the scour hole attained equilibrium after roughly 4 hours with no change in the scour depth. Both the longitudinal and transverse flow velocities components U and V; respectively, in the groin's field and within the scour hole were measured at the horizontal plane (HP) that roughly located at 0.40 of the water depth. The velocity measurements extended from 30 cm upstream the groin to 100 cm downstream. The velocity measured using an Acoustic Doppler Velocimeter (16-MHz Micro ADV, Sontek) with a sampling frequency of 50 Hz and duration time of 1 minute as shown in **Fig. 2** and **Fig. 3**.

Fig. 2 Acoustic Doppler Velocimeter (ADV).

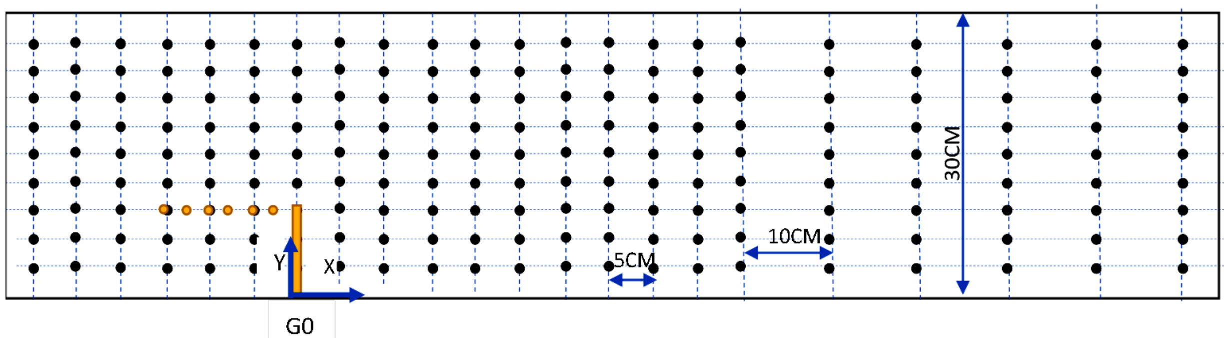

Fig. 3 The experimental flume's plan view with the measurement locations marked with dots.

The experiments were conducted using hybrid groin models consisting of permeable and impermeable sections. The impermeable section is perpendicular to the flow direction and consists of an 8.0 mm thick acrylic plate. The permeable section is parallel to the flow direction and made from acrylic circular piles with diameter of 8.0 mm, permeability of 57.33%, a length ratio (L/W =2, where L & W are lengths of the permeable and impermeable groins; respectively) as shown in **Fig. 4**. A fixed contraction ratio (W/B=25%, where B is the flume width) was used for all cases of groin models with angles 45°, 60°, and 90° upstream and downstream. In the test area, models were placed 4 m downstream from the intake on the right side of the flume. Details of experimental runs are shown in Error! Not a valid bookmark self-reference. and **Fig. 4**. The runs names are formulated as direction of groin orientation, orientation angle, and contraction ratio. For example, (U.S ,90) means that the groin oriented upstream with angle 90°.

Table 2. Details of the experimental runs.

RUN No.	RUN Name	Impermeable groin length (W) cm	Permeable groin length (L) cm	Groin Length Ratio (L/W)	Groin contraction ratio (W/B)	Angle θ
1	U.S ,90	7.5	15	2	1/4	90° U.S
2	D.S ,90					90°D.S
3	U.S ,60					60°U.S
4	D.S ,60					60°D.S
5	U.S ,45					45°U.S
6	D.S ,45					45°D.S

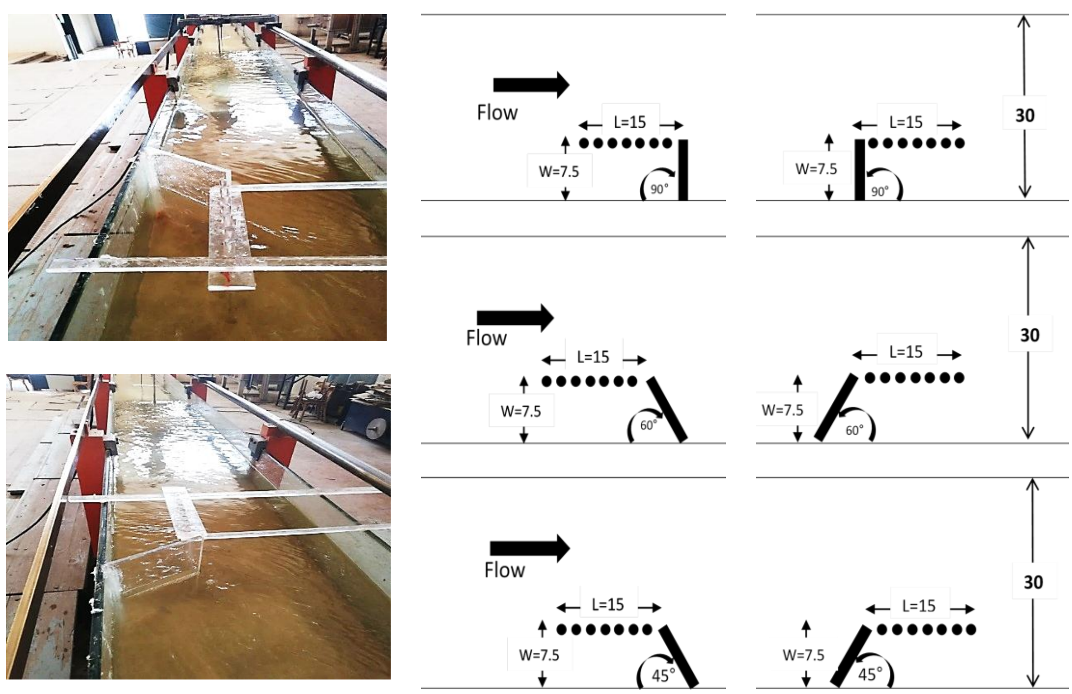

Fig. 4 Setup of Groins model with different orientation angles.

3 Results and Discussion

3.1 Longitudinal and Transverse Velocity

Data post-processing and velocity profiles were plotted for the recirculation area and the main flow zone. velocities and induced a recirculation zone behind them. **Fig. 5** and **Fig. 6** show vectors of resultant flow velocity and the contour maps of the velocity components U and V at various channel cross-sections over the scouring bed.

According to the analysis, the greatest velocity changes occur near the tip of the groin and above the scour hole. When the groin orientation angles upstream increased, the result is a larger scour hole and a smaller dead zone downstream due to the increase of the velocity component values. It is noticed that all orientation angles upstream give a higher flow velocity than the orientation angles downstream. All velocities on the other side of the flume are highest compared to the groin vicinity. When the bed reaches equilibrium, sediment is formed on the other side, reducing the water flow area. The 90º D.S groin provides a relatively low velocity near the groin, but its effect increases the velocity on the other side, as shown in **Fig. 5**. The maximum velocity increased by about 50% of the mean approach velocity for all orientation angles, and 45° gives the least value. The blockage ratio of the flow cross-section reduces with a reduction in groin orientation angle towards downstream from 90° to 45°. Thus, the horseshoe vortex and down flow both decrease.

Fig. 6 shows that all maximum values of the transverse velocity occur upstream groin, while minimum values downstream them. It is noticed that the maximum velocity reaches maximum value at the groin tip and in the scour hole, moving towards the left bank. In the flow recirculation region, the transverse velocity on the reverse direction.

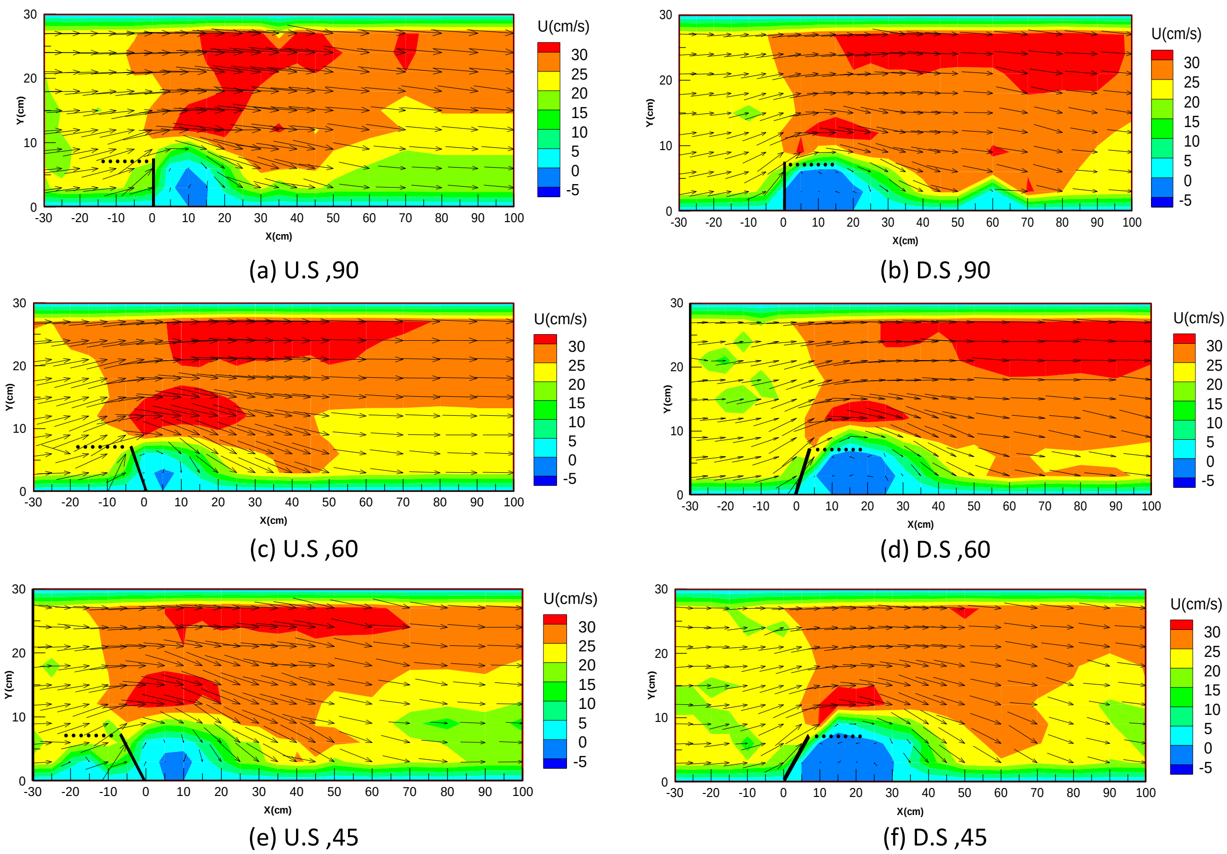

Fig. 5 Contour maps of the longitudinal velocity (U) at Z= 5.0 cm from bottom.

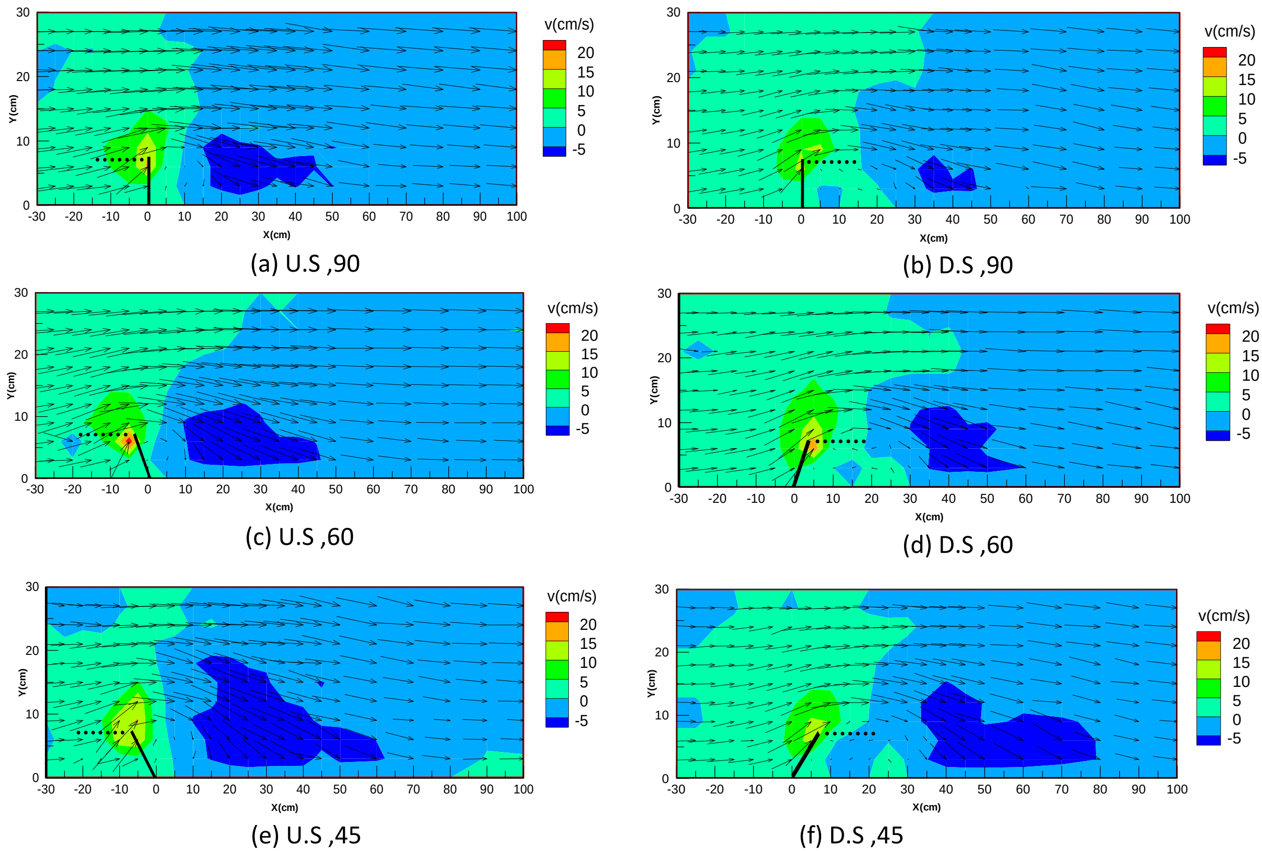

Fig. 6 Contour maps of transverse velocity (V) at Z=5.0 cm from bottom.

3.2 Velocity Reduction Zone

The velocity is reduced in the region of the blocked flow field downstream of a single groin. Typically, this area is known as a dead zone (velocity reduction zone). It is considered for longitudinal velocity less than ±25% of mean velocity (≤ ± 5 cm/sec). The low velocity zone increases by changing the orientation angle in downstream direction, as shown in **Fig. 7**. The case of D.S 45 has the largest area of the low-velocity zone, whereas case of U.S 90 has the smallest one. Comparing dead zone area for all orientation angles, the dead zone of the orientation angle of 45° D.S model is more than those of both angles 90° and 60° D.S groin by 70% and 45%, respectively. The orientation angles toward downstream cause decreasing in the flow velocity values more than groins towards upstream, so they are considered the best condition that gives suitable area for fish habitat.

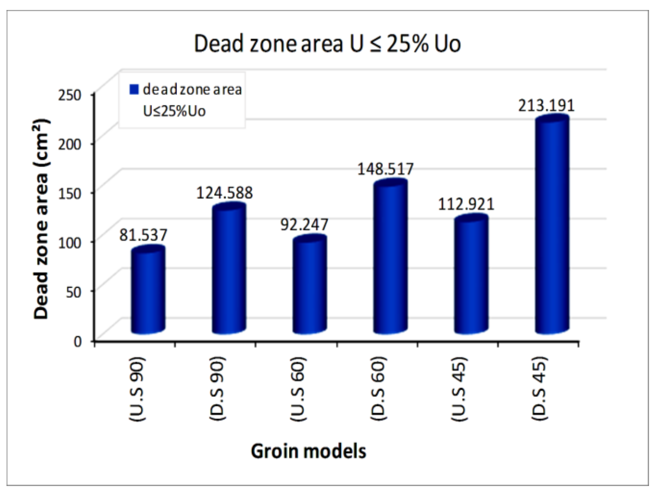

Fig. 7 Comparison between dead zone area for all cases (where, U/Uo ≤ ±25%).

3.3 Effects of Orientation Angles on Tip Velocity

The time average relative longitudinal velocity (U/U_o) at axis passes near groin tip were plotted from longitudinal relative distance X/W = -4 to X/W = 13.33 with different orientation angles is shown in **Fig. 8** and **Fig. 9**. The contraction ratio is kept constant as 0.25 to investigate clearly the effect of groin orientation angle on the longitudinal velocity.

For orientation angles toward upstream, it is found that groin oriented by 90° gives low velocity values upstream the groin. When compare the velocities downstream the groin for three angles, the oriented angle 60° give maximum velocity values and 90°,45° gives low values respectively. The lowest velocity value occurs for angle 90° at a relative distance X/W = 1.33 downstream groin equal to 0.57, the heights velocity values are found form X/W = 2 to 4 as shown in **Fig. 8**.

For all orientation angles toward downstream, the maximum longitudinal velocity occurs just downstream near the groin tip. Groin orientated by 90° produces the most significant values and gives large value at relative distance =0.67 from groin and equal to 1.7. The groin oriented by 45° gives the minimum values (0.12) at relative distance X/W =2.0 downstream the groin as shown in **Fig. 9.**

When compare all angles we can conclude that oriented angle 60° U.S and 90°D.S give largest values so it is not suitable for fish improvement. Groin oriented by 45° D.S gives lowest values.

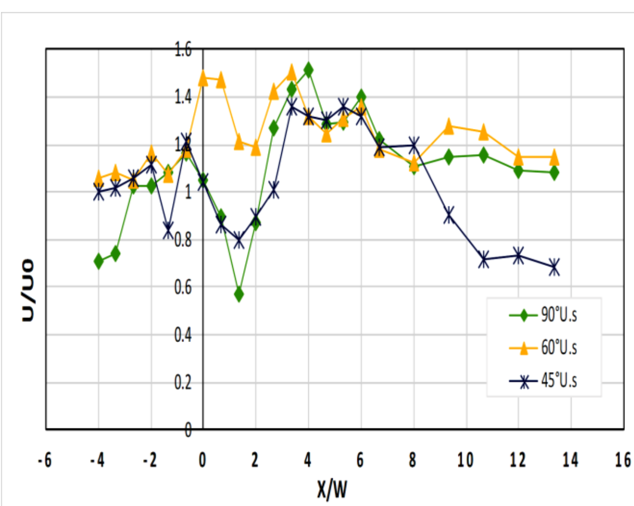

Fig. 8 Relative longitudinal Velocities at groin tip for 25% Contraction Ratio and Different Orientation Angles toward U.S.

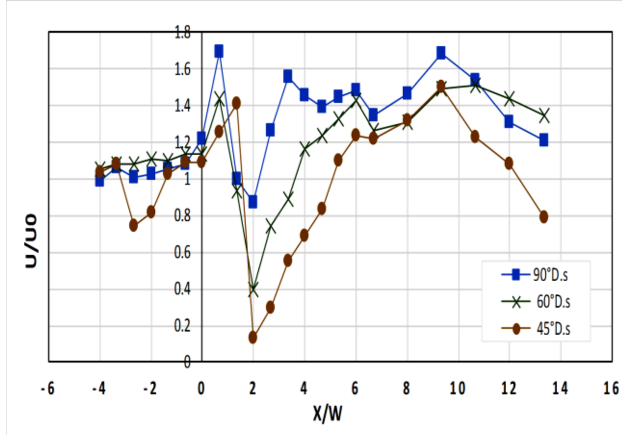

Fig. 9 Relative longitudinal Velocities at groin tip for 25% Contraction Ratio and Different Orientation Angles toward D.S.

The time average relative transverse velocity (V/V_o) at axis passes near groin tip were plotted from longitudinal relative distance X/W = -4 to X/W = 13.33 with different orientation angles is shown in **Fig. 10** and **Fig. 11**.

For orientation angles toward U.S, the highest velocity occurred upstream groins. Groin oriented by 90° gives maximum transverse velocities equal to 36 at groin tip. All values of the minimum transverse velocity are recorded downstream groins as shown in **Fig. 10**.

For orientation angles toward D.S, the maximum transverse velocities for all angles are found just downstream groin at relative distance X/W= 0.67 and groin Oriented by 60° D.S results in the highest value (33.3) as shown in **Fig. 11**. The transverse velocities downstream groin for attracting and repelling groin with the same orientation angle upstream and downstream do not differ noticeably. Groin Oriented by 45° D.S gives lowest values.

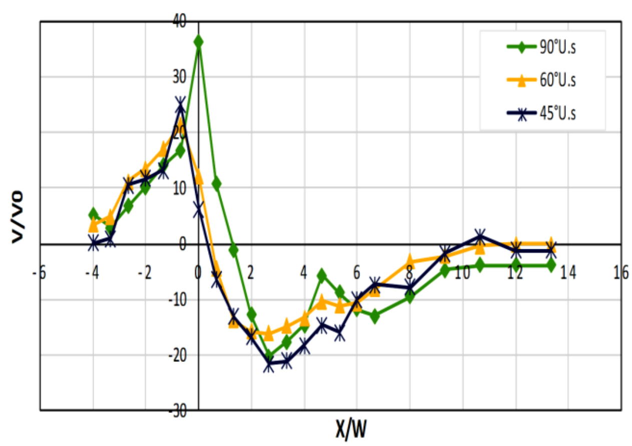

Fig. 10 Relative transverse velocities at groin tip for 25% Contraction Ratio and different Orientation Angles toward U.S .

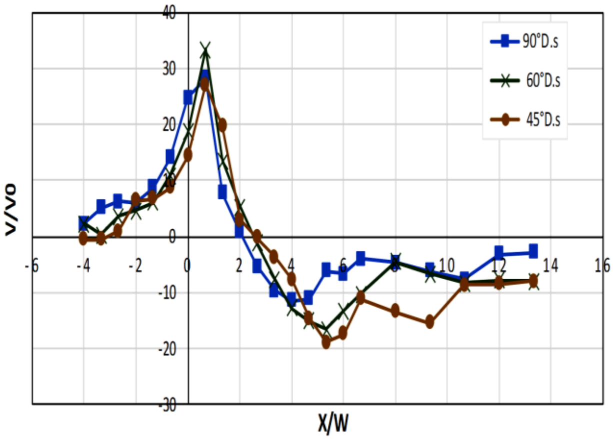

Fig. 11 Relative transverse velocities at groin tip for 25% Contraction Ratio and different Orientation Angles toward D.S .

4 Conclusions

The findings of this study which examined and investigated the flow in open channel with groins may have practical values, especially regarding fish habitat. The study used hybrid groins with different orientation angles with only a contraction ratio of 25% (groin length/channel width), as recommended by [32].

The following main conclusions can be drawn:

- The presence of the groin effects on both the recirculation zones, the flow structures, and velocity distributions. Groin increased velocity in the main flow. The lowest velocity zone created in case of groin with orientation angle of 45° downstream, which is also ideal for aquatic ecosystems.
- In case of groin with 90° down/upstream, zone of velocity reduction is created in the groin vicinity while there is an obvious impact on the other side where the velocity increased and silt accumulated more.
- As the angle of the groin's orientation toward the upstream increases, a smaller dead zone downstream groin is formed.
- The groin's permeable part doesn't affect the upstream region but downstream one, it causes moving of the recirculation zone away downstream, which can provide the required protection. Furthermore, small fish be protected from predators and provide a suitable living environment and refuge.
- Values of the transverse velocities are reduced downstream groin and increased upstream it.
- According to hybrid groin installation, the mainstream flow average velocity upstream groin increased by 1.25 to 1.5 times its approach value.
- Area of the negative (reduced) velocity zone in case of groin with 45° downstream increased by 70% and 45% more than groin of 90° and 60° downstream; respectively.
- The flow velocity reaches its maximum value at groin tip and in the scour hole, and shifted towards the left bank.
- The groin with orientation of 45° D.S produced minimum velocity (maximum velocity reduction). Good agreement with numerical simulation on turbulent flows around a single groin[15].
- Orientation angles 60° U.S and 90°D.S give largest values of velocities.

The suitable values of velocity to improve fish habitat in groin vicinity is near to 5cm/s as studied [33]. Finally, using single hybrid groin with 45° orientation angle downstream created a large area of lower velocity that is favourable for aquatic habitats.

Notations

In this paper, the following symbols are employed:

U	: Longitudinal velocity
V	: Transverse velocity
U_o	: Mean longitudinal velocity
V_o	: Mean transverse velocity
L	: length of permeable part of groin
U.S	: Upstream
D.S	: Downstream
B	: Flume width
W	: length of impermeable part of groin

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