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STUDY OF WATER SURFACE PROFILE FOR DIFFERENT SHAPES OF SIDE WEIR

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Abstract: In this research the water surface profile and water surface elevation were studied for different shapes of side weirs. 26 sample of wooden side weir were manufactured with a different shapes and height set upstream side channel with and opposite flow direction. The oblique side weir with θ = 30°, 45°, 75° and 90° show uniformity of descending of stream lines with steep drop along the downstream face of the weir, and that the stream lines consider upstream to the right and downstream to the left for θ = 90°, but for θ = 45°, 60° and 75° the water surface profile almost parallel when the side weir inclined to the left of side channel wall but when oblique weir inclined to the right of channel wall the stream lines consider upstream and downstream weir position with steep drop. When side weir placed with flow direction stream lines were uniform better than placed opposite flow direction, and variation of height does not affect the water surface profile, while the location of separation and recession of water stream lines were different according to the apex angle of triangular side weir θ = 45°, 60°, 75° and 90° and the direction of weir with and opposite flow direction.

Keywords: surface profile, side weir, water elevation, stagnation zone

1. INTRODUCTION

A side weir is an over flow weir widely used in irrigation, drainage, sewer networks, flood protection and environmental engineering applications. A review of literature indicates that rectangular sharp crested side weir have been studied extensively by Ackers (1957), Colings (1957), Subramany and Awasthy (1972) and others. The water surface profile for side weir were studied by a number of researcher As Aydin (2012) modeled the free surface flow over the triangular labyrinth side weir by using Volume of Fluids (VOF) method, to describe the flow characteristics in subcritical flow conditions. A valid method, Grid Convergence Index (GCI) was used to determine the numerical uncertainty of the simulation results. The simulation results were compared with experimental observations for weir height (12-16) cm and width (25-50) cm, the water level along the side weir drops slightly at the upstream end of side weir, then rise quickly toward the downstream end of the weir, a vortex or circular motion occurrence to causes a drop of water level at the upstream of triangular labyrinth weir. Especially when F1 > 0.3, a significant surface jump occurs downstream of minimum water level, While the Froude number is increasing, this surface elevation rises and moves to the downstream of side weir. The water level is almost horizontal approximately in the last third of the weir length for relatively low F1 < 0.3 and the water level in the centerline of the main channel rises gradually from the upstream end toward the downstream end of the weir. Eghbalzadeh & et.al (2012) present a theoretically study depending on incompressible fluid Reynolds-averaged continuity and momentum equations, to observe a separation zone at the front of the side weir and the stagnation zone at the downstream end of the side weir. The location and size of the separation zone depend on the Froude number on the upstream side of the weir. When the upstream Froude number is increased, the separation zone area moves toward the downstream end of the side weir. Vatankhah (2012) presents an analytical solution for establishing the water surface profile along a side weir for width of 60 cm in a triangular channel. He noted there that the flow depth increases with distance for the subcritical flow regime and decreases with distance for the supercritical flow regime. Analytical solution for calculating flow profile shows that the water surface profile at the main channel axis decreases from upstream to downstream in case of supercritical flow, while in subcritical flow regime the water surface profile increases from upstream to downstream. Al-Taee (2011) use Runge-Kutta method to analyses the flow profile along inclined side weirs for different angles, an equation of calculated Cd was developed and shows the possibility of increasing discharge passing over side weir at same depth of water at 40% when crest lip inclined compared with horizontal side weir. Emiroglu & et. al. (2011) presents a comprehensive laboratory study, including 843tests for the discharge coefficient and surface profile of a sharp crested rectangular side weir of width (0.15-1.5) m and heights (12-20) cm in a straight channel. He note that the water depth at the upstream end of the side weir is lower than that at the downstream end of the side weir. The water level quickly rises toward the downstream end of the weir. The change in water level is not noticeable in almost the last third of the weir length, This shows that the side weir entrance effect does not spread as for as the centerline of the main channel, but occurs only near the weir crest. Emiroglu & et. al. (2010) develops an experimental study for a rectangular and triangular side weirs located on a straight channel of lengths 25-75 cm and heights of the weir 12-20 cm and weir included angles with 45°-150°. They examined the water depth in the upstream end of the side weir is lower than water depth in the downstream end of the side weir. Water surface profiles along side weirs drop slightly at the upstream end of the weir crest. This is due to the side-weir entrance effect at the upstream end. Then the water level rise quickly toward the downstream end of the weir toward the mid span of the crest, the rate of rise decreases substantially. The change of water level is not noticeable in nearly the last third of the weir length, where the water surface is almost horizontal The separation zone and the reverse flow at the downstream end of the side weir were also observed. The existence of separation zone is due to the diversion that occurs from the path of maximum velocity thread. The location of the separation zone and the reverse flow area depend especially on the Froude number, weir included angle and length of weir to channel width ratio. When *Froude number* is increased, the separation zone and reverse flow area move toward the downstream end of the side weir the water surface level along the main channel centerline is almost horizontal. Cosar & Agaccioglu (2004) have contributed experimentally study of triangular side weir of angle (60°-120°) in both of straight and bend channels. Lateral flow affects the bend characteristics and vice versa. During the flow visualization, the stagnation zone and reverse flow area occurred due to the secondary and there are depend on the upstream Froude number in the main channel, as well as on the overflow length of the side-weir. The intensity of secondary circulation created by the bend increases both with an increase in Froude number and the over flow length. These conditions together cause much more deviation angle and kinetic energy toward the side weir in the bend.

In this research a review and discussion of water surface profiles were present for a different shape of side weir normal, oblique to the right and left of channel wall with 30°, 45°, 60° and 75° and a triangular side weir with apex angels 45°, 60°, 75° and 90° put with and opposite the direction of flow and a semi-circular and semi-hexagon put with and opposite flow direction all the models have different height (P=9,12,15) cm, the models of height P=12 cm were drawn using Surfer program (Version 8.0).

2. EXPERIMENTAL SETUP

The experiments were carried out in hydraulic laboratory/ Dams and Water Resources department. 26 sample of wooden side weir were manufactured with different shapes and height set upstream side channel with and opposite flow direction as following:

1. Side weir with triangular end lip with apex angle (θ = 45°, 60°, 75° and 90°).
2. Oblique side weir with (θ = 30°, 45°, 75° and 90°).

3. Simi-hexagonal side weir.
4. Simi-circle side weir.

Three heights of side weir 9, 12, 15 cm were used to compare between them. The main channel was 10 m length, 30 cm width and 45 cm height, linked with side channel perpendicular to main channel at 4.6 m upstream main channel with 2 m length, 15 cm width and 30 cm height. Main channel manufactured with glass wall and three point gage to measure water height. Side channel was made with plastic walls and iron bed as shown in figure (1). Table (1) shows details of side weir samples. Rectangular sharp crested weir (standard weir) used to measure discharge in main channel with 10 cm height set at 35 cm downstream main channel, manufactured according to (BSI 1965). Water height above side weir was measured by point gage. Discharge of side channel was (0.45-5.7) l/s, so number of experiments was 110 test. water depths upstream standard weir were measured by point gage at 40 cm from main channel end and discharge of main channel calculated according to equation (1), (Al- Omari 2011) as following:

$$Q_m = 0.579\ h_m^{1.5} \qquad (1)$$

where: Q_m : discharge of main channel (L^3/T), h_m : water depth upstream standard weir (L)

Total discharge was measured after close side channel by the same way. Discharge of side channel calculated by subtract main discharge from total discharge as shown in equation (2).

$$Q_s = Q_t - Q_m \qquad (2)$$

where: Q_s : discharge of side channel (L^3/T),

Q_t : total discharge (L^3/T)

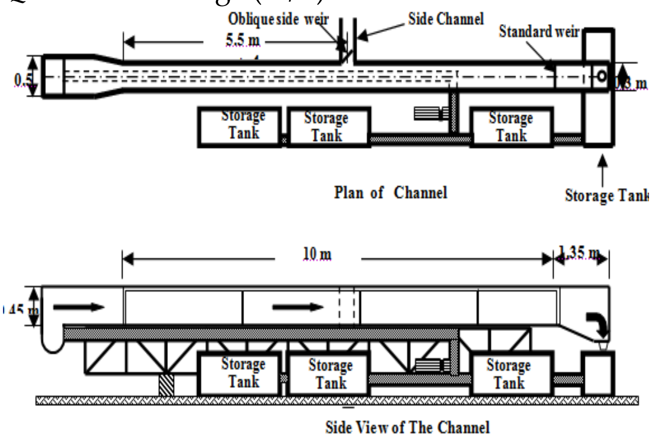
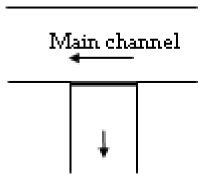
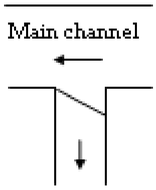
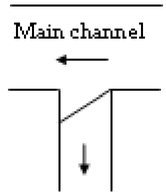
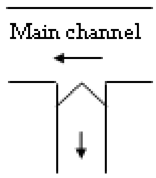
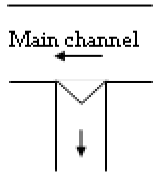
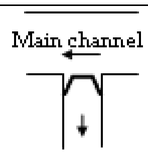
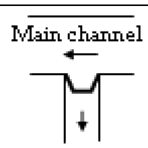
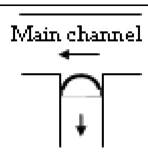
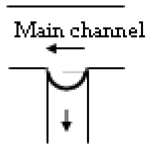


Figure (1), Channel cross section

Table (1). Details of side weir models

Type of side weir	Side weir direction: With flow direction	Side weir direction: opposite flow direction
Normal side weir		
Obique side wier		
Side weir with triangular end lip		
Semi-hexagonal side weir		
Semi-circle side weir		

3. DISCUSSION OF RESULTS:

A. Water surface profile:

The experimental results of the measurements of water surface profile for different shapes of side weirs, were plotted as follows.

1. Water surface profile for normal side weir (perpendicular to side channel wall) with P=12 cm height is plotted in figure (2). From figure we can observe the uniformity descending of stream lines with steep drop along the downstream face of the weir.
2. Figures (3,4) shows water surface profile of oblique side weir with 30°, and P=12 cm placed to the right and left of side channel wall respectively. From figure (3) it is clear that stream lines were coincide at the right upstream and left downstream side weir and figure (4) shows almost parallel stream lines when the side weir inclined to the left of side channel wall.

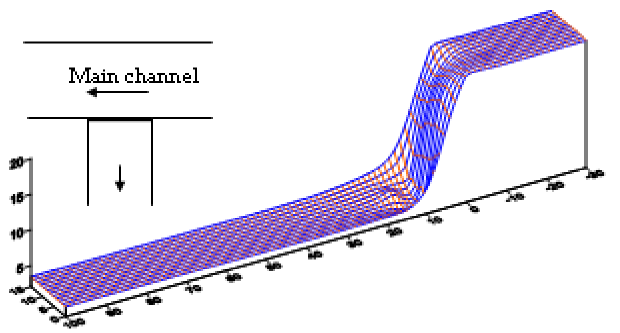


Fig. (2) water surface profile for normal side weir P =12 cm

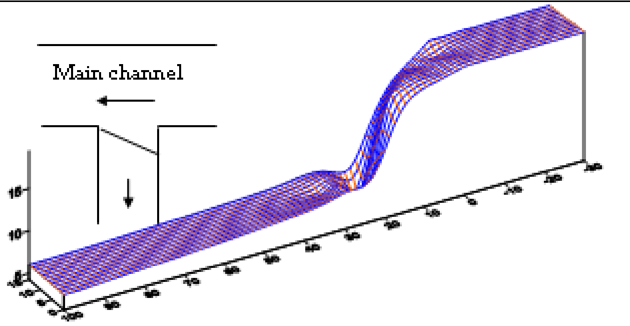


Fig. (3) water surface profile for oblique side weir of P =12 cm & θ= 30o to the right of side channel wall

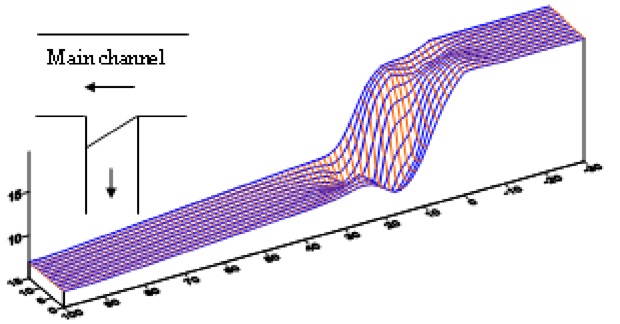


Fig. (4) water surface profile for oblique side weir of P =12 cm & θ= 30° to the left of side channel wall

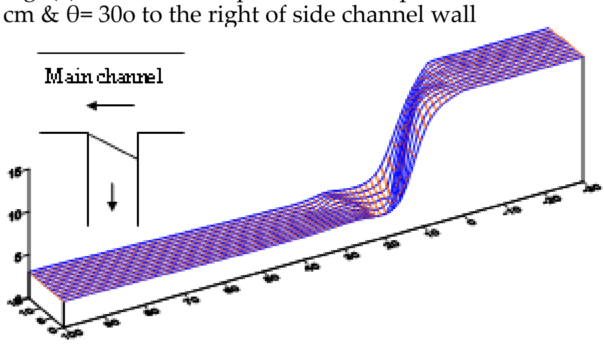


Fig. (5) water surface profile for oblique side weir of P =12 cm & θ= 45° to the right of side channel wall

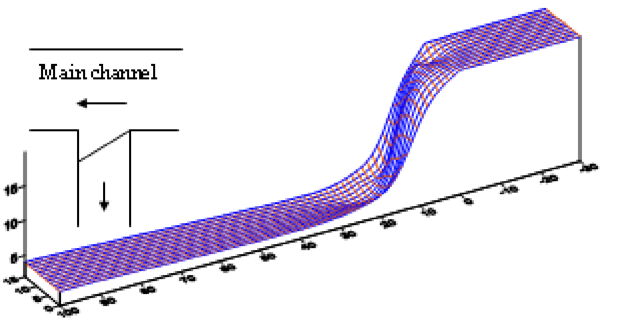


Fig. (6) water surface profile for oblique side weir of P =12 cm & θ= 45° to the left of side channel wall

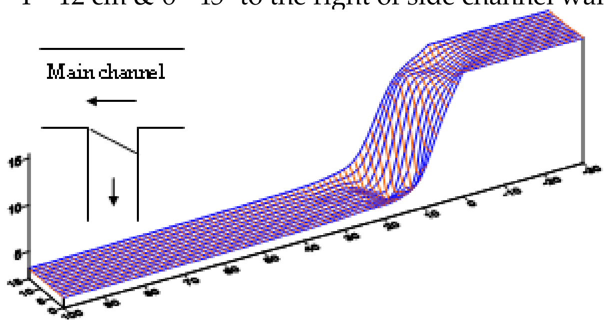


Fig. (7) water surface profile for oblique side weir of P =12 cm & θ= 60° to the right of side channel wall

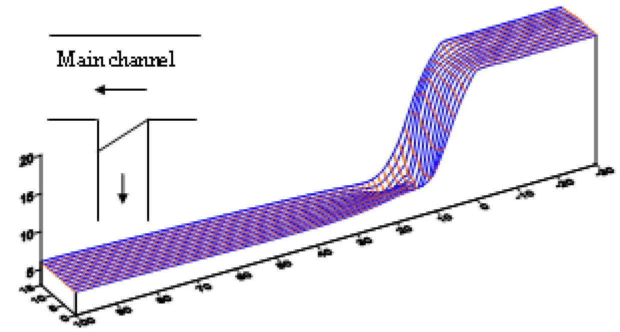


Fig. (8) water surface profile for oblique side weir of P =12 cm & θ= 60° to the left of side channel wall

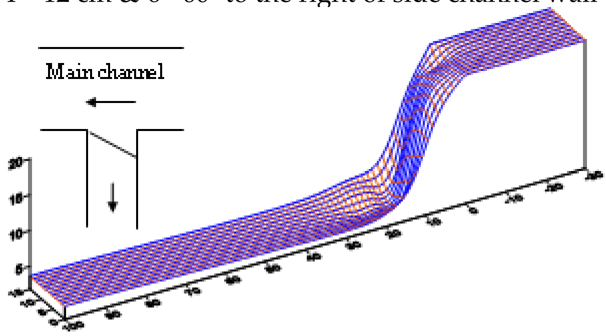


Fig. (9) water surface profile for oblique side weir of P =12 cm & θ= 75° to the right of side channel wall

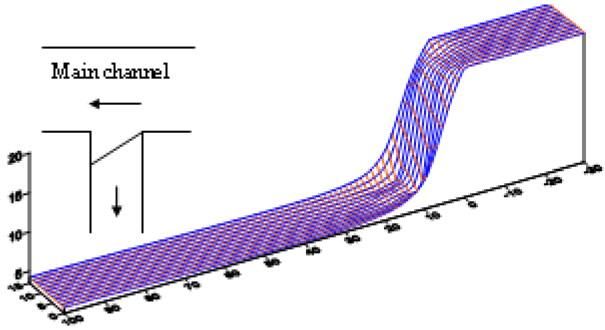


Fig. (10) water surface profile for oblique side weir of P =12 cm & θ= 75° to the right of side channel wall

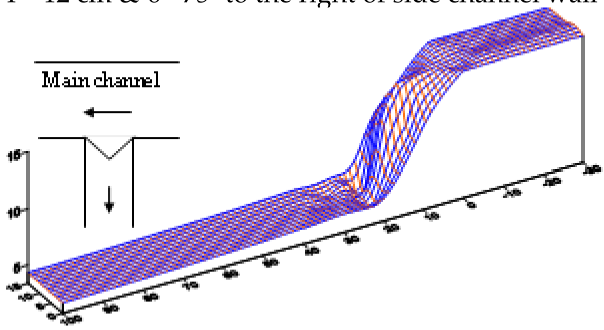


Fig. (11) water surface profile for triangular side weir of P =12 cm & apex angle 45° with flow direction

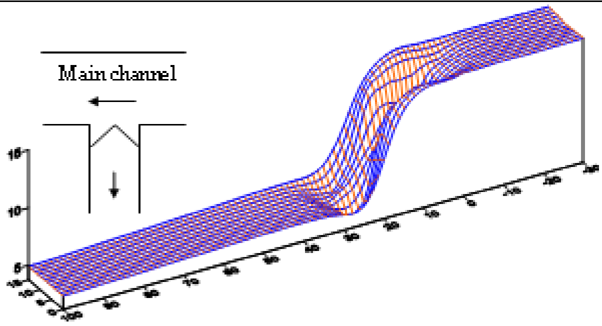


Fig. (12) water surface profile for triangular side weir of P =12 cm & apex angle 45° opposite flow direction

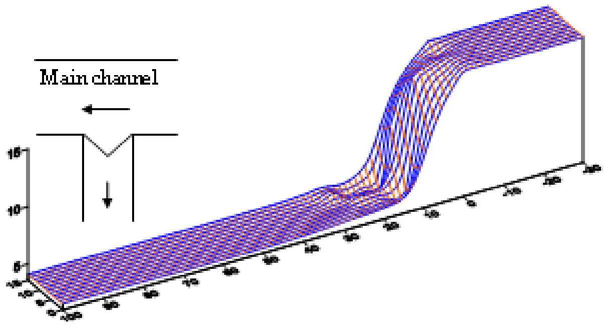


Fig. (13) water surface profile for triangular side weir of P =12 cm & apex angle 60° with flow direction

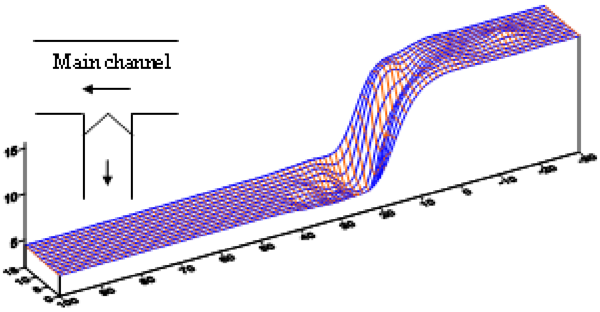


Fig. (14) water surface profile for triangular side weir of P =12 cm & apex angle 60° opposite flow direction

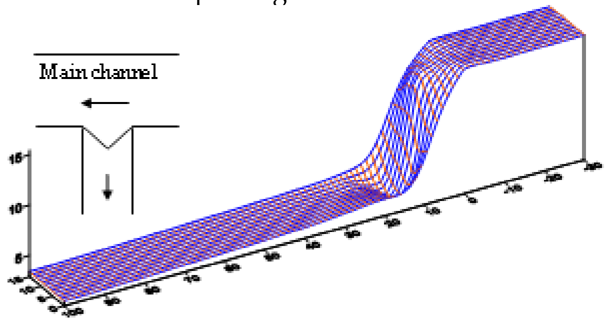


Fig. (15) water surface profile for triangular side weir of P =12 cm & apex angle 75° with flow direction

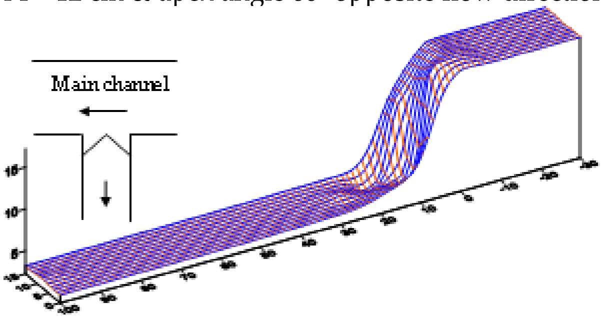


Fig. (16) water surface profile for triangular side weir of P =12 cm & apex angle 75° opposite flow direction

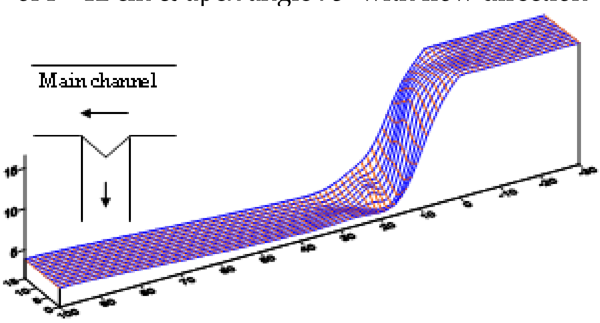


Fig. (17) water surface profile for triangular side weir of P =12 cm & apex angle 90° with flow direction

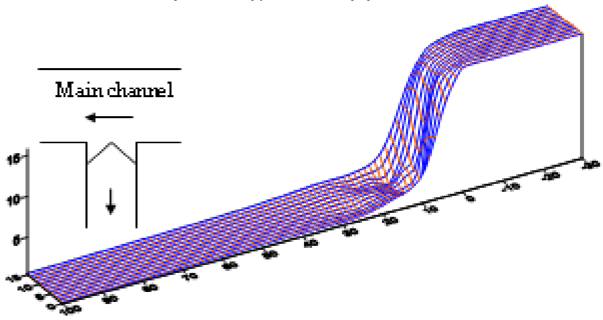


Fig. (18) water surface profile for triangular side weir of P =12 cm & apex angle 90° opposite flow direction

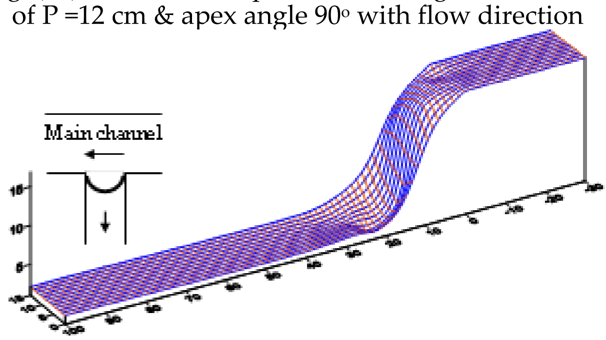


Fig. (19) water surface profile for semi circular side weir of P =12 cm with flow direction

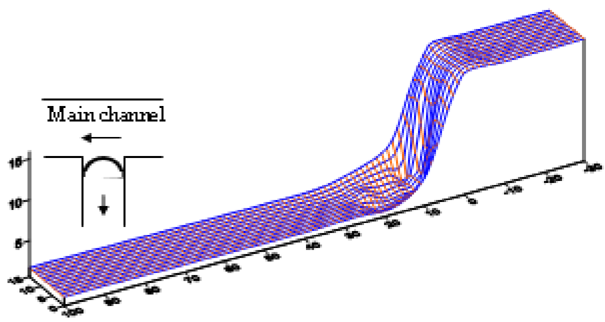


Fig. (20) water surface profile for semi circular side weir of P =12 cm opposite flow direction

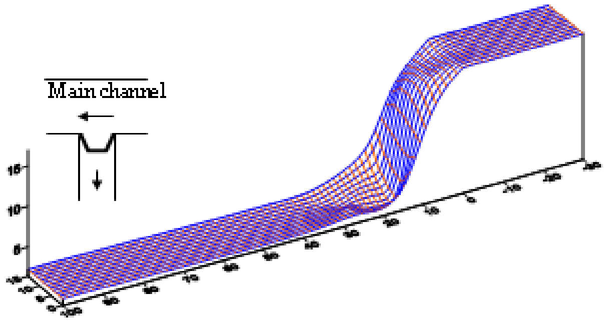


Fig. (21) water surface profile for semi hexagon side weir of P =12 cm with flow direction

3. Figures (5,6) shows water surface profile for oblique side weir with P=12 cm and angle of 45^{o} placed to the right and left of side channel wall respectively. From figure (5) it is clear that when the side weir inclined to the right of side channel wall, stream lines coincide upstream and downstream weir position with steep drop. Figure (6) shows almost uniformity of water stream lines when the side weir inclined to the left of side channel.
4. Figures (7-10) shows water surface profile of oblique side weir with 60^{o}, 75^{o} to the right and left of side channel wall with P=12cm. From figures it is clear that stream lines were uniform when the side weir inclined to the right of side channel and the uniformity of stream lines increase when the angle of oblique side weir increase until stream lines became full uniform when the oblique side weir placed with 75^{o} with side channel wall.
5. Figures (11-18) shows water surface profile for triangular side weir with 45^{o} with and opposite flow direction with P=12 cm. Figures shows that when triangular side weir placed with 45^{o} opposite flow direction the water surface profile be uniform more than when side weir placed with flow direction.
6. Figures (13, 14) shows water surface profile for triangular side weir with 60^{o} with and opposite flow direction. It is clear that stream lines were steeping. Uniform when the side weir placed opposite flow direction better than that when weir placed with flow direction.
7. Figures (15,16) shows water surface profile for triangular side weir with and opposite flow direction with 75^{o} with side channel wall. From figures it is clear that the stream lines of water surface profile become uniform in direction of flow better then opposite to flow direction.
8. Figures (17,18) shows water surface profile for triangular side weir with 90^{o}. From figures it is clear that the uniformity of stream lines for weir placed with flow direction is better than that when weir placed opposite to flow direction.
9. Figures (19,20) shows water surface profile for semi-circle side weir placed with and opposite flow direction when P=12 cm. Figures shows that stream lines were uniform when the side weir placed with flow direction better than that when placed opposite to flow direction.
10. Figures (21,22) shows water surface profile for semi hexagonal side weir placed with and opposite flow direction with 12 cm height, also the uniformity of stream lines for weir placed with flow direction is better when weir placed opposite to flow direction.

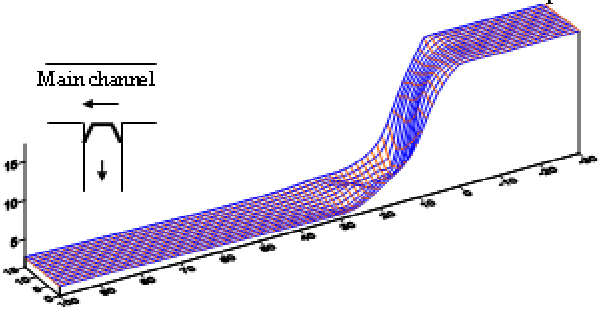


Fig. (22) water surface profile for semi hexagon side weir of P =12 cm opposite flow direction

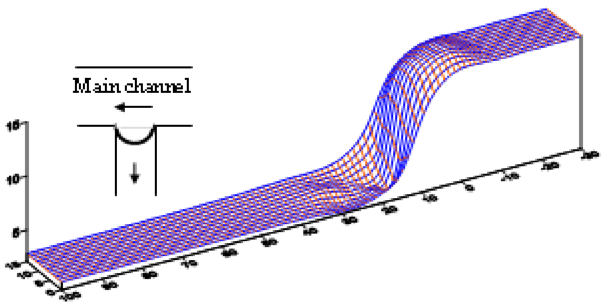


Fig. (23) water surface profile for semi circular side weir of P =9 cm with flow direction

11. Variation of weir height doesn't affect the water surface profile, that's clear from figures (23,19,24) which shows water surface profile for semi-circle side weir placed with flow direction for P=9,12,15 cm. From figures the water surface profiles drop steeping uniform downstream the weir for the three cases.

B. Contour lines of water surface elevation:

1. The contour lines of water surface elevation of normal side weir (perpendicular to side

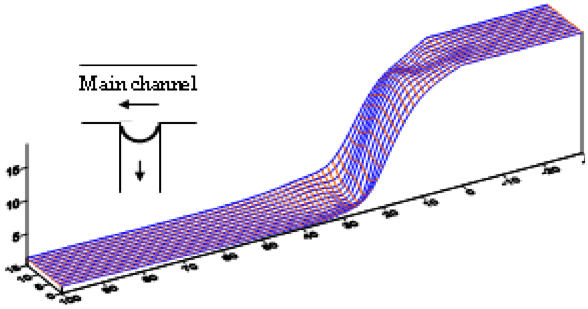


Fig. (24) water surface profile for semi circular side weir of P =15 cm with flow direction channel wall) with P=12 cm is plotted in figure (25) we can see that the stream lines parallel upstream the side weir and there is along separation zone downstream, and oblique side weir with 30°, 45°, 60° and 75° with side channel wall is plotted in figures (26-33) respectively. From figures we can see that there is a variation of separation zone and variation recession of water stream lines.

2. Figures (34-41) show water surface elevation for triangular side weir with 45°, 60°, 75° and 90° placed with and opposite flow direction with P=12 cm. From these figures it is clear that location of separation zones and recession of water stream lines were different according to the angle of triangular side weir and direction of flow.
3. Figures (42,43) show water surface elevation for semi-circle side weir placed with and opposite flow direction and figures (44,45) show water surface elevation for semi hexagonal side weir placed with and opposite flow direction with P=12 cm. From these figures we can observe the location of separation and recession of water stream lines.
4. Froude number for all shapes of side weir with P=12 cm with and opposite flow direction were calculated in table (2). We can observed that Froude number when oblique side weir inclined 45° to the right and left of side channel wall is greater than when θ = 30°, 60°, 75° and 90° angle while putting oblique weir included to the right or left of side channel did not affect Froude number and that changing the angel of triangular side weir did not affect much Froude number. While Froude number for semi-hexagon and semi-circle side weir almost equal with the direction of flow and opposite direction of flow.

Table (2). Details of side weirs samples

Type of side weir	angle	Direction of flow	
		right	left
Oblique	90°	0.0507	0.0507
	75°	0.0557	0.0534
	60°	0.04	0.0414
	45°	0.1013	0.115
	30°	0.072	0.073
Triangular	90°	0.0769	0.087
	75°	0.0929	0.0868
	60°	0.1173	0.0999
	45°	0.106	0.1344
Semi - hexagonal	---	0.0769	0.0845
Semi- circle	----	0.0723	0.0932

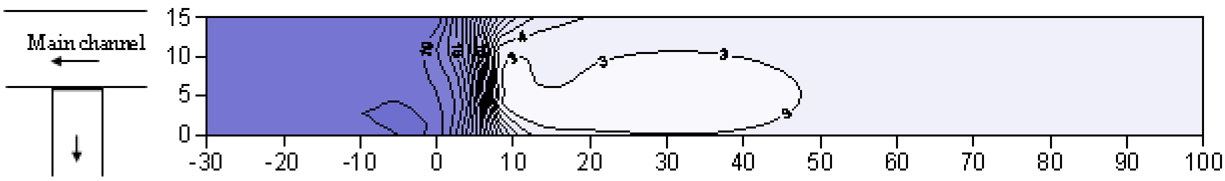


Fig. (25) water surface elevation for normal side weir of P=12cm

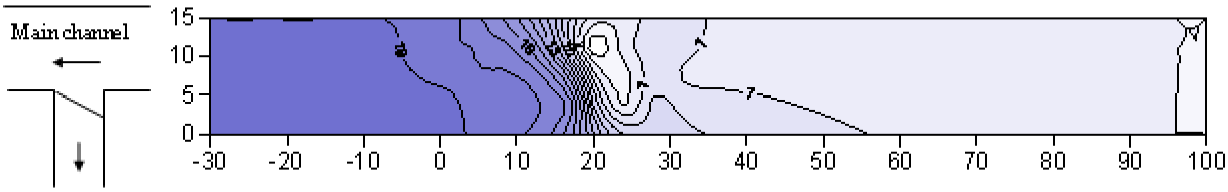


Fig. (26) water surface elevation for oblique side weir of P=12cm & θ=30° to the right of side channel wall

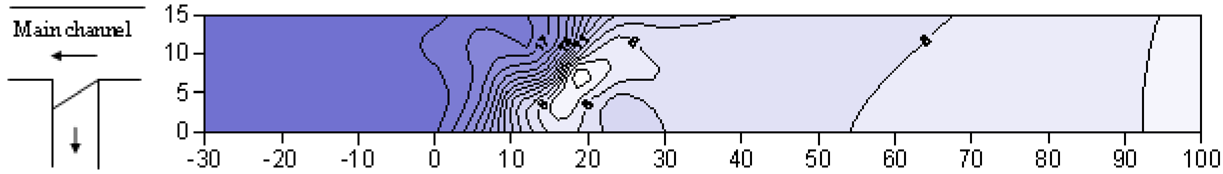


Fig. (27) water surface elevation for oblique side weir of P=12cm & θ=30° to the left of side channel wall

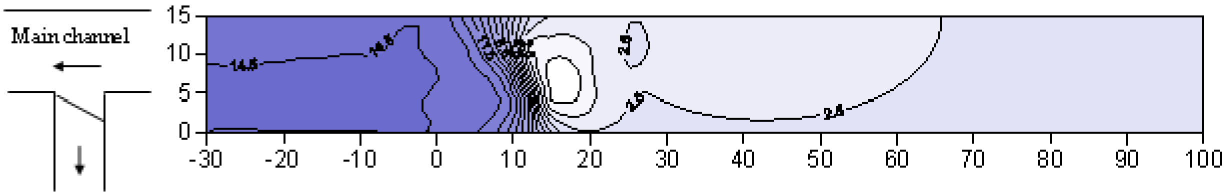


Fig. (28) water surface elevation for oblique side weir of P=12cm & θ=45 to the right of side channel wall

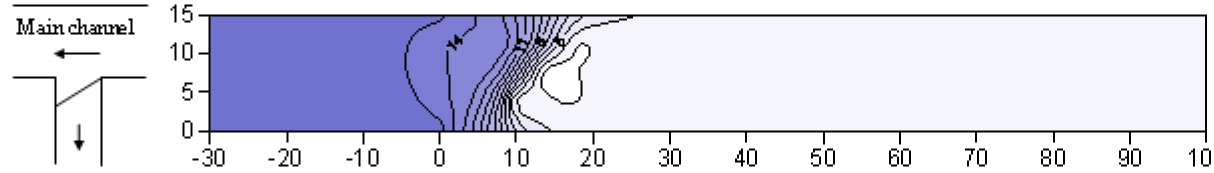


Fig. (29) water surface elevation for oblique side weir of P=12cm & θ=30 to the left of side channel wall

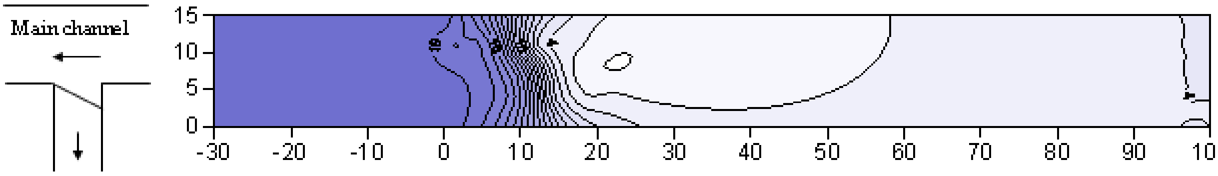


Fig. (30) water surface elevation for oblique side weir of P=12cm & θ=60° to the right of side channel wall

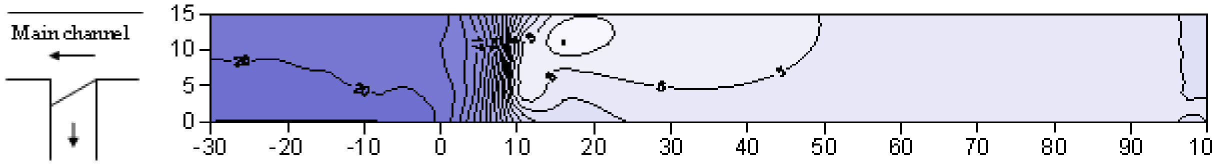


Fig. (31) water surface elevation for oblique side weir of P=12cm & θ=60° to the left of side channel wall

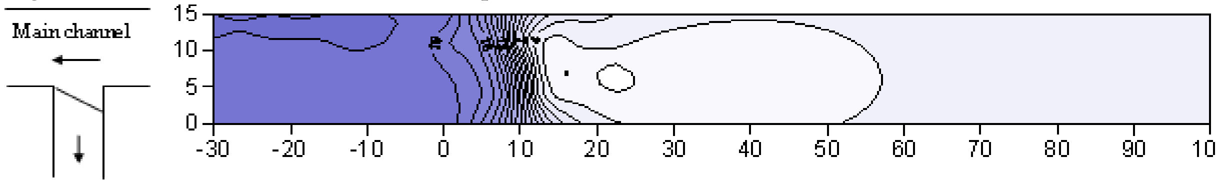


Fig. (32) water surface elevation for oblique side weir of P=12cm & θ=75° to the right of side channel wall

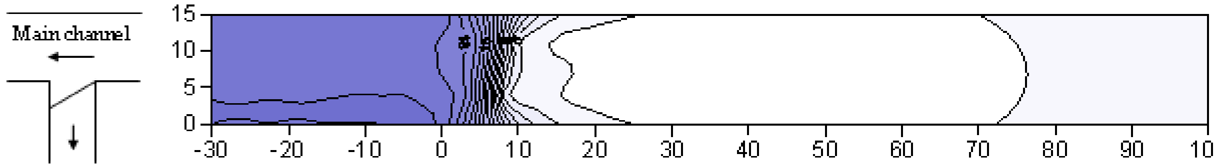


Fig. (33) water surface elevation for oblique side weir of P=12cm & θ=75° to the left of side channel wall

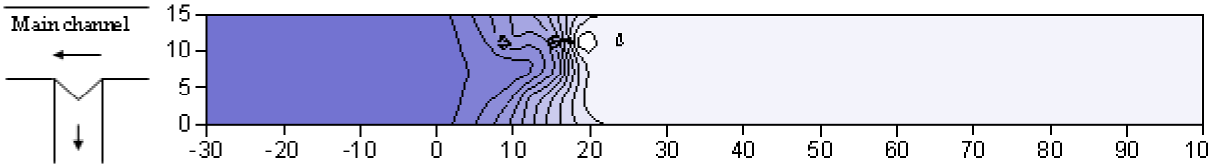


Fig. (34) water surface elevation for triangular side weir of P=12cm & θ=45° in the direction of flow

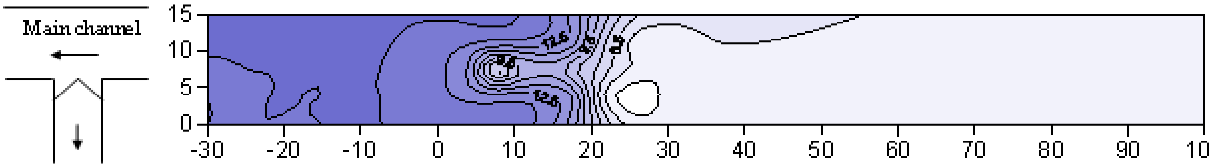


Fig. (35) water surface elevation for triangular side weir of P=12cm & θ=45° opposite direction of flow

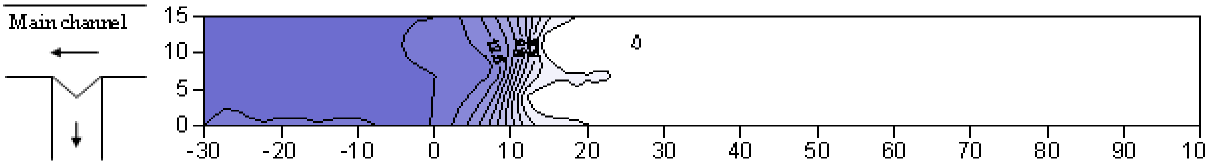


Fig. (36) water surface elevation for triangular side weir of P=12cm & θ=60° in the direction of flow

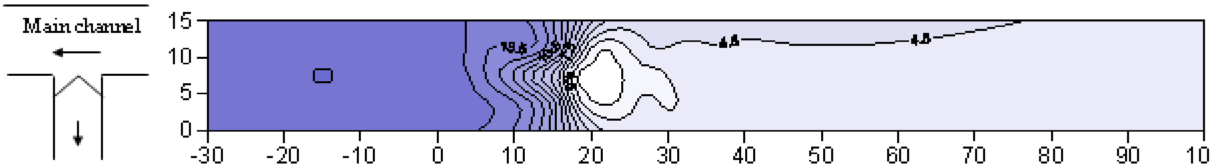


Fig. (37) water surface elevation for triangular side weir of P=12cm & θ=60° opposite direction of flow

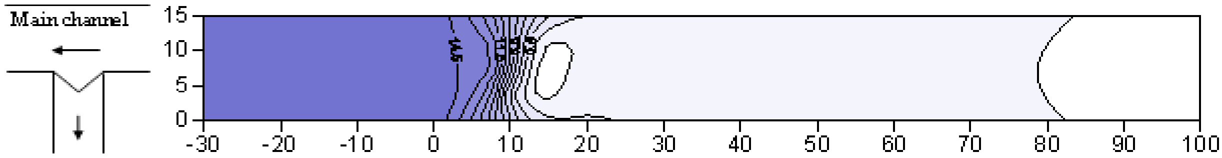


Fig. (38) water surface elevation for triangular side weir of P=12cm & θ=75° in the direction of flow

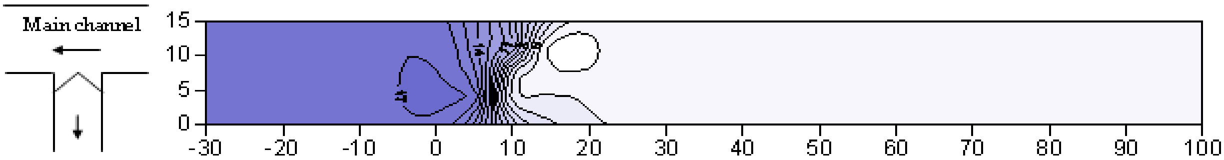


Fig. (39) water surface elevation for triangular side weir of P=12cm & θ=75° opposite direction of flow

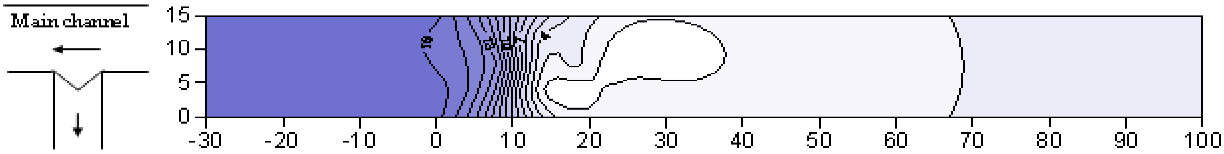


Fig. (40) water surface elevation for triangular side weir of P=12cm & θ=90° in the direction of flow

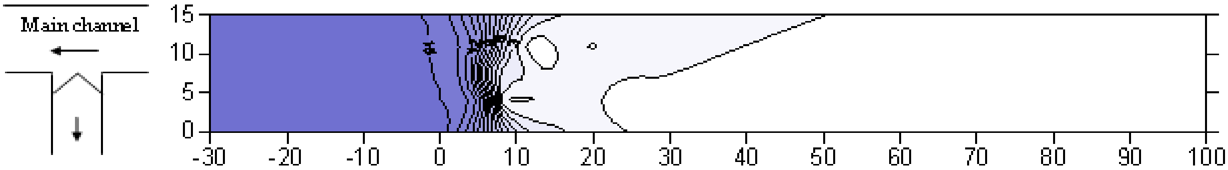


Fig. (41) water surface elevation for triangular side weir of P=12cm & θ=90° opposite direction of flow

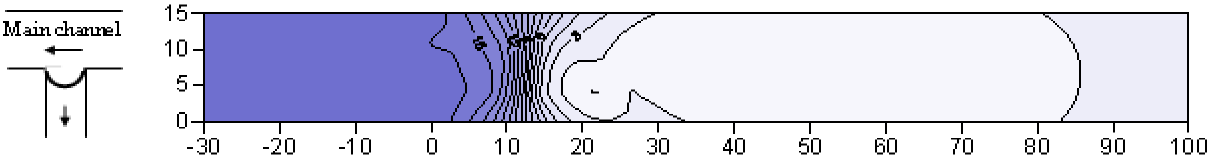


Fig. (42) water surface elevation for semi circular side weir of P=12cm in the direction of flow

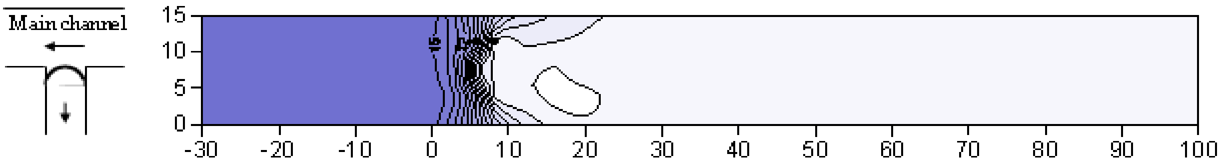


Fig. (43) water surface elevation for semi circular side weir of P=12cm opposite direction of flow

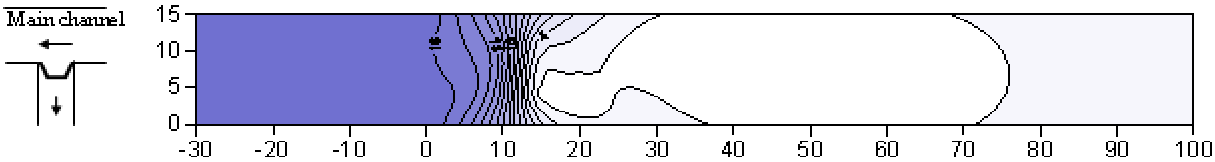


Fig. (44) water surface elevation for semi hexagon side weir of P=12cm in the direction of flow

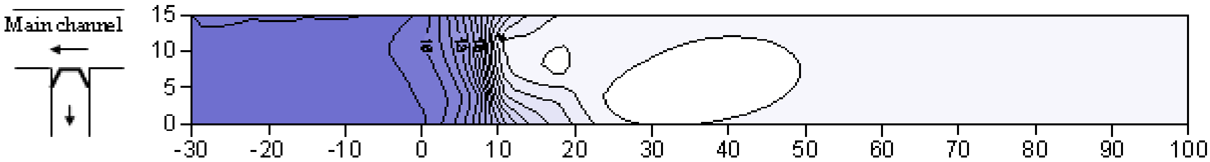


Fig. (45) water surface elevation for semi hexagon side weir of P=12cm opposite direction of flow

4. CONCLUSION:

From the experimental results of this study the following conclusions can be drawn:

1. We can observe the uniformity of descending of stream lines with steep drop along the downstream face of the weir for straight side weir.
2. The stream lines were coincide up stream to the right and downstream to the left of side weir for the normal side weir, and for oblique side weir the water surface profile almost parallel stream lines when the side weir inclined to the left of side channel wall.

3. When the side weir inclined to the right of side channel wall, stream lines coincide up stream and downstream weir position with steep drop.
4. Stream lines were uniform when the side weir inclined to the right of side channel and the uniformity of stream lines increase when the angle of oblique side weir increase until stream lines became full uniform when the oblique side weir placed with 75^o with side channel wall.
5. Stream lines were uniform when the side weir placed with flow direction better than that when placed opposite to flow direction.
6. Variation of weir height doesn't affect the water surface profile.
7. The location of separation zones and recession of water stream lines were different according to the angle of triangular side weir and direction of weir.
8. Froude number when oblique side weir inclined 45^o to the right and left of side channel wall is greater than when side oblique weir inclined 30^o, 60^o, 75^o and 90^o with channel side while oblique side weir inclined to the right of side channel did not affect Froude number and that changing the angel of triangular side weir did not affect much Froude number. While Froude number for semi-hexagon and semi-circle side weir almost equal with the direction of flow and opposite direction of flow.

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