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The Effect of a Sluice Gate Edge on Water Surface Profile

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ORIGINAL ARTICLE

ABSTRACT: In this paper the effect of the lower gate edge on the water surface profile (W.S.P) have been studied in a rectangular flume with four gate openings (2, 3, 4 and 4.5) cm, five upstream of water heads (18.9,21,24,26 and 28.9) cm and five gate cases (vertical and inclined vertically by angle $(45)^{o}$ with and opposite to flow direction)with horizontal and sharp lower edge (inclined by angle $(45)^{o}$) Were adopted in the experiments. The results show that the convergence length for inclined gate with flow direction and horizontal edge increases by (28.7)"%" with respect to vertical, while decreases by (21.4)"%" when gate inclined opposite to flow direction and horizontal edge. The convergence angle decreases by (38.7)"%" when gate inclined with flow direction and horizontal edge, while increase by (22.4)"%" when gate inclined opposite flow direction and horizontal edge. The horizontal lip for the inclined gate with flow direction reduced the (W.S.P) convergence angle and then reduced the scour downstream sluice gate.
Keywords: sluice gate, water surface profile, tail water, finite elements

LIST OF SYMBOLS:

H_1	L	Upstream water depth
a	L	Gate opening
k_1		Vertical gate constant
k_2		Inclined gate constant
y_o	L	Contraction water depth
y_t	L	Tail water depth
x	L	Horizontal distance of (W.S.P) from gate
y	L	Vertical distance (depth) of (W.S.P) from channel bed
L	L	Length of convergence
β		Sluice gate sloping angle
γ		(W.S.P) convergence angle
θ		Gate lip angle
Q_m	L^3/T	Measured discharge
g	L/T^2	Acceleration due to gravity

INTRODUCTION

A sluice gate is a hydraulic structure for controlling the discharge, and the flow under sluice gate can be divided into two types, free flow and submerged flow.

The free flow occurs when the tail water level is equal or less than the gate opening and the water surface is smooth, while the submerged flow occurs when the tail water level is above the gate opening and the water surface become rough.

Many studies have been made to study free and submerged flow discharged through the sluice gate (Rajaratnam and Subramanya, 1967, Isaacs, 1977, Cheng et. al., 1981, Masliyah et al., 1985 and Finni and Jeppson, 1991) studied the characteristics of flow under vertical sluice gate theoretically using numerical and finite elements methods. (Smith, 1977), Rajaratnam, (1977), Noutsopoulos and Fanariotis (1978), Swamee, (1992), Ohtsu and Yasuda (1994) and Lin et al. (2002) studied the characteristics of flow under vertical sluice gate experimentally using laboratory channels.

While Rajaratnam and Humphries (1982) and Hager (1999) studied the characteristics of flow upstream vertical sluice gate experimentally and Nago, (1978) and Montes (1997) deal with characteristics of under flow of inclined sluice gate, and (Swamee et al., 2000) studied the characteristics of flow under skew sluice gate experimentally using laboratory channel and obtained equations for the elementary discharge coefficient using these equations.

This paper present the results of an experimental investigation on a vertical and inclined sluice gate, and the effect of the gate lip and its inclination on water surface profile (W.S.P) downstream gate.

EXPERIMENTS

The experiments were carried in the hydraulic laboratory/college of engineering / Mosul University. The used flume has a rectangular section, 10 m long, 30 cm wide and 45 cm depth with glass walls and aluminium bed, Figure 1. The discharge measurements have been carried by a weir 30 cm wide and 15 cm depth fixed at the channel end.

The sluice gates were manufactured from wood 30 cm wide 40 cm height and 6 mm thickness, they installed in five different positions: a- Vertical with horizontal edge, b- Inclined with flow direction with horizontal edge, c- Inclined opposite flow direction with horizontal edge, d- Inclined with flow direction with sharp edge, e- Inclined opposite flow direction with sharp edge. Figure 2

The gates were installed at a distance 2.9m from the channel entrance, to ensure uniform flow and suitable distance downstream gate for measurements.

Four gate openings (a=2, 3, 4 and 4.5 cm), were considered to ensure same openings in all gate cases (A1=2cm, B1=3cm, C1=4cm, D1=4.5cm) and five upstream water levels (H=18.9,21,24,26 and 28.9 cm) (different discharges) were used, for each gate opening, which will make the total number of experiments equal to (100) runs, i.e. twenty experiments for each gate case

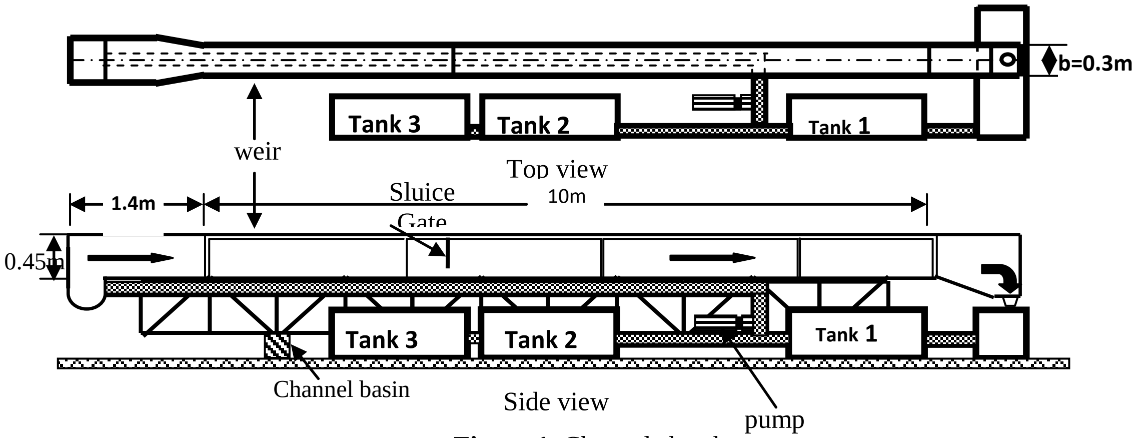
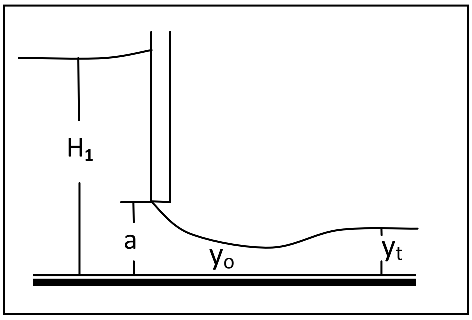
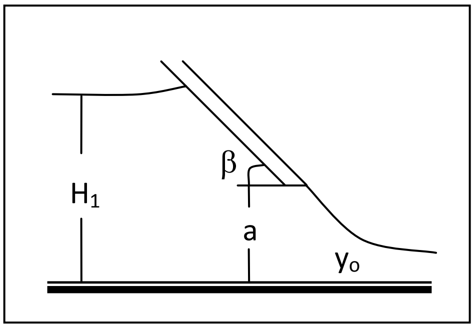


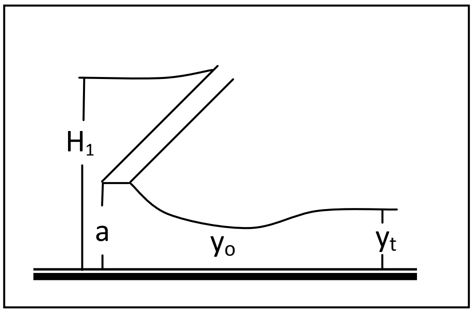
Figure 1. Channel sketch



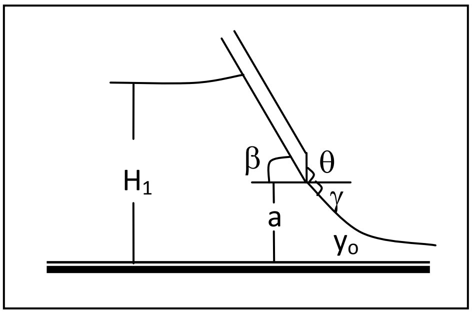
a) Vertical with horizontal edge



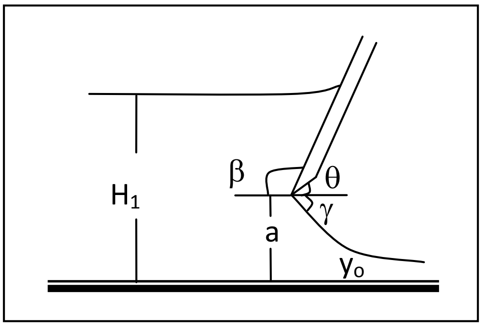
b) Inclined with flow direction with horizontal edge



c) Inclined opposite flow direction with horizontal edge



d) Inclined with flow direction with sharp edge



e) Inclined opposite flow direction with sharp edge

Figure 2. Definition sketch of sluice gate

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WATER SURFACE PROFILE:

The water surface profiles (W.S.P) of flow discharged from the sluice gate have been drawn for all gate openings and gate cases:

Figure 3 shows the water surface profile for the vertical gate (β=0) with horizontal edge (θ=0). The length of contraction (L) continue to a distance from 3 to 7 cm from the total distance of water surface profile (x) downstream gate then it could be seen that the convergence disappears (be straight line).

From table 1 the angle of converging stream issuing about $(\gamma=49)^o$ and the distance required for convergence to disappear (length of contraction (L)) is found to be a function of gate openings.

L α a……………………………………. (1)
$L = k_1{*}a$ ………………………………...(2)

Where:
L= length of convergence (cm)
k_1= constant for vertical gate.
a= gate opening. (cm).

Table 1. Characteristics of (W.S.P) convergence for vertical gate

Case of gate	L (cm)	k_1	γ
Vertical	3 – 7	1.5	49

Where:
γ = W.S.P converging stream angle

Figure 4 shows the water surface profile for the gate inclined $(\beta=45)^o$ with flow direction with horizontal edge (θ=0), in table (2) the length of contraction continue to distance ranged from L=3.95 to 8.8 cm downstream the gate (increases by (28.7)"%" compared with vertical gate) and the angle of the converging stream issuing from the gate decreases by (38.7)"%" compared with vertical gate.

Figure 5 refers to the water surface profile for gate inclined $(\beta=45)^o$ with flow direction with sharp edge (θ=45). The length of contraction extend to distance ranged from L=3.9 to 8.7cm downstream the gate (increases by (27.0)"%" with respect to vertical gate) and the angle of the converging decreases by (30.6)"%" with respect to vertical gate, table (2).

Figure 6 shows the water surface profile for the gate inclined $(\beta=45)^o$ opposite flow direction with horizontal edge (θ=0). The convergence length continue to distance ranged from L=2.4 to 5.4 cm down stream the gate (decreases by (21.4)"%" compared with vertical gate) while the angle of the convergence increases by (22.4)"%" compared with vertical gate, table 3.

Figure 7 refers to the water surface profile for the gate inclined $(\beta=45)^o$ opposite the flow direction with sharp edge $(\theta=45^o)$, the length of contraction extend to a distance ranged from L=2.5 to 5.6 cm downstream gate, table (3) (decreases by (18.33"%") with respect to vertical gate) and the angle of convergence increases by (18.3)"%" with respect to vertical gate.

From Figures 3-7 the distance required for water surface profile convergence to disappear (the distance L) for gate inclined with and opposite flow direction, with horizontal and sharp edge is found to proportion with gate (openings, slops and lower edge), so:

L α a, β, θ………………………………...(3)
$L = k_2 {*}a {*}\beta {*} \theta$ …………………...……(4)

Where:
β = gate inclined angle with vertical
k_2 = constant for inclined gates.
θ= gate lower edge angle.
(in all figures above only the results of four experiments were shown, since it was not possible to show all the twenty runs on diagram)

Table 2. Characteristics of (W.S.P) convergence for gate inclined with flow direction

Inclined gate cases	**L (cm)**	**"%" Increasing from vertical**	**k_2**	**"%" Increasing from vertical**	**γ**	**"%" decreases from vertical**
$(\beta=45)^o$ $(\theta=45)^o$	3.9 – 8.7	27.0	1.95	30	34	30.6
$(\beta=45)^o$ $(\theta=0)^o$	3.95 – 8.8	28.7	1.97	31.3	30	38.7

Table 3. Characteristics of (W.S.P) convergence for gate inclined opposite flow direction

Inclined gate cases	**L (cm)**	**"%" decreases from vertical**	**k_2**	**"%" decreases from vertical**	**γ**	**"%" Increasing from vertical**
$(\beta=45)^o$ $(\theta=45)^o$	2.5 – 5.6	18.33	1.25	16.67	58	18.3
$(\beta=45)^o$ $(\theta=0)^o$	2.4-5.4	21.4	1.2	20	60	22.4

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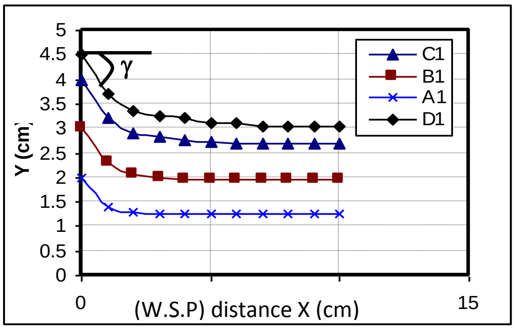

Figure 3. (W.S.P) for the vertical gate (β=0)° with horizontal edge (θ=0)° (Where (x) is the horizontal distance of (W.S.P) from the sluice gate, and (y) is the vertical distance (depth) of (W.S.P) from channel bed to sluice gate opening)

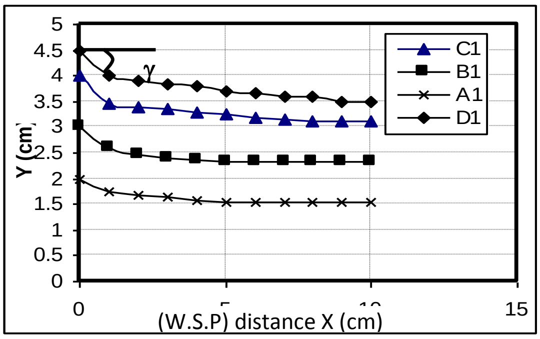

Figure 4. (W.S.P) for gate inclined (β=45)° in the direction of flow with horizontal edge (θ=0)°.

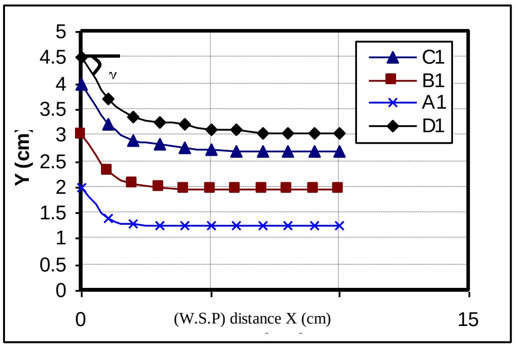

Figure 5. (W.S.P) for gate inclined (β=45)° in the direction of flow with sharp edge (θ=45)°.

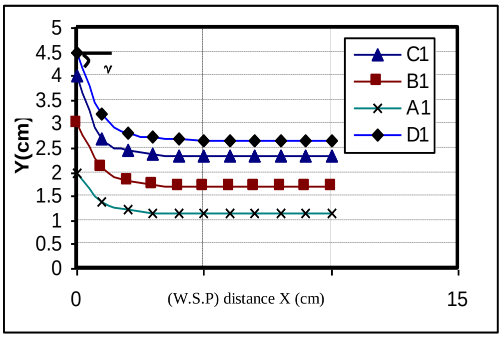

Figure 6. (W.S.P) for gate inclined (β=45)° opposite flow direction with horizontal edge (θ=0)°

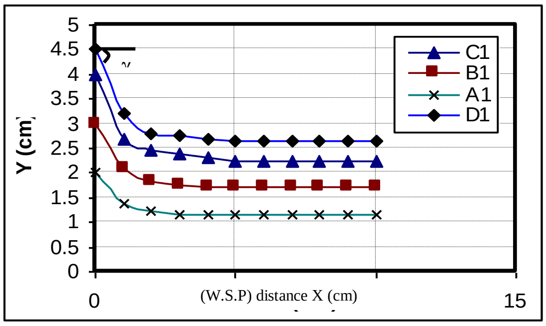

Figure 7. (W.S.P) for gate inclined (β=45)° opposite the flow direction with sharp edge (θ=45)°

CONCLUSION

From the experiments and the analysis of results it can be see that the inclined gate at (45)° opposite the direction of the flow at maximum decrease in the water surface convergence distance with (21.4"%") less than the vertical gate, while the inclined gate at (45)° in the direction of the flow an increase in the water surface convergence distance with (28.7"%") more than the vertical gate.

The horizontal lip of the gate gives an increase of the water surface convergence distance in the case of inclined gates in the direction of flow, while it decreases the convergence distance for the inclined gates opposite the direction of flow.

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