Analysis of Side Sluice in Trapezoidal Channel

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ABSTRACT

Side sluice gates are used in open channel to divert the flow from parent channel to side channel for different purposes like irrigation, land drainage, sewage system, sanitary system and storm relief. In the recent past, many researchers have investigated the behavior of side sluice considering the parent channel shape as rectangular. In most of the practical cases trapezoidal shaped parent channel is used. Hence it is necessary to establish safe and economic angle of entrance at the side channel. In the present investigation, trapezoidal parent channel and rectangular side channel arrangement was chosen for study. In this study, effects of upstream side bank alignment of parent channel on the coefficient of discharge and water surface profiles were discussed. The four alignments of side bank (90^0,75^0,60^0,45^0,30^0) were studied with respect to the direction of flow in parent channel. This study showed that as Froude number increases, coefficient of discharge decreases. In practical application, instead of using upstream side bank alignment of parent channel as normal (90^0), it is good to use 75^0, 60^0, 45^0, 30^0.

Keywords: Side sluice gate, CFD, Trapezoidal channel, Coefficient of discharge.

1. INTRODUCTION

Side sluice gates are functionally used as the control valve for the side channels as well as for the small dams. Side sluice gates are mainly used in the open channels to divert the flow from main channel into a side channel. Side weir and side sluice are somewhat similar structures only the difference is, weir is overflow structure and sluice gate is underflow structure. Flow through the side sluice gate is the typical case of spatially varied flow with decreasing discharge. The differential equation for this case is presented in equation (1)

$$\frac{dy}{dx} = \frac{S_o - S_f - \alpha \frac{Q\,dQ}{gA^2\,dx}}{1 - \alpha \frac{Q^2 T}{gA^3}} \qquad (1)$$

Where, S_o= bed slope the parent channel, S_f = represents friction in terms of slope, α = kinetic energy correction factor, Q = discharge in the parent channel upstream of the sluice, dQ/dx = discharge per unit length over the side sluice gate, A= area of cross section of flow in the parent channel, T = Top width of parent channel section, g= acceleration due to gravity.

The discharge per unit length of the side sluice gate as given by Chow V. T. (1959) is as follows

$$\frac{dQ}{dx} = aC_d\sqrt{2gy} \qquad (2)$$

Where, C_m = discharge coefficient of the side sluice gate, a = depth of sluice gate opening.

Swamee [9] (1992) introduced an equation for discharge coefficient for free and submerged flow. Swamee [10] (1993) found that the coefficient of discharge is the function of depth of flow and sluice gate opening and derived equation for same. Ojha [8] (1997) observed that the elementary discharge coefficient depends on the slot geometry. Ghodsian [5] (2003) studied the side sluice gate in both free and submerged condition and concluded that the coefficient of discharge is not only the function of depth of flow, gate opening but also the approach Froude number and also derived equation for the same. Esmailzadeh [4] (2014) analyzed the 3-Dimensional velocity profile in the vicinity of the side sluice gate and commented that the maximum value of flow diversion angle □ is observed at the end of the side gate.

2. GOVERNING EQUATION

The Navier-Stokes equations are the basic governing equations for a viscous fluid along with the continuity equation-

$$\frac{\partial u}{\partial t}+\frac{1}{V_F}\left\{uA_x\frac{\partial u}{\partial x}+vA_y\frac{\partial u}{\partial y}+wA_z\frac{\partial u}{\partial z}\right\}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+G_x+f_x \qquad (3)$$

$$\frac{\partial v}{\partial t}+\frac{1}{V_F}\left\{uA_x\frac{\partial v}{\partial x}+vA_y\frac{\partial v}{\partial y}+wA_z\frac{\partial v}{\partial z}\right\}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+G_y+f_y \qquad (4)$$

$$\frac{\partial w}{\partial t}+\frac{1}{V_F}\left\{uA_x\frac{\partial w}{\partial x}+vA_y\frac{\partial w}{\partial y}+wA_z\frac{\partial w}{\partial z}\right\}=-\frac{1}{\rho}\frac{\partial p}{\partial z}+G_z+f_z \qquad (5)$$

$$\frac{\partial uA_x}{\partial x}+\frac{\partial vA_y}{\partial y}+\frac{\partial wA_z}{\partial z}=0 \qquad (6)$$

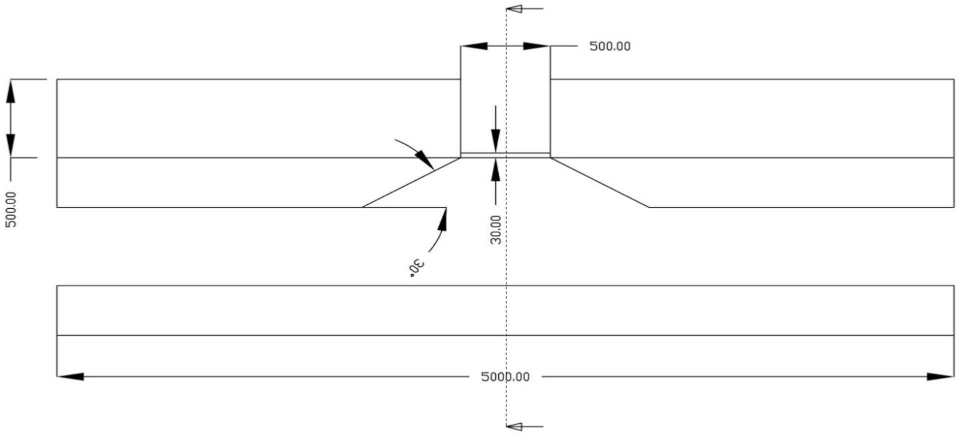
Where, V_F is the fractional volume open to flow, is fluid density, (u, v, w) are velocities in (x, y, z) direction respectively, t is time, (A_x, A_y, A_z) are fractional areas open to flow in (x, y, z) direction (G_x, G_y, G_z) are body accelerations, (f_x, f_y, f_z) are viscous accelerations.
These are the simplified equations for incompressible free surface flow with constant viscosity. Fluid configuration is defined in terms of volume of fluid (VOF) function, F(x, y, z, t). This function represents the volume of fluid per unit volume and satisfies the equation-(7)

$$\frac{\partial F}{\partial t}+\frac{1}{V_F}\left[\frac{\partial}{\partial x}(FA_xu)+\frac{\partial}{\partial y}(FA_yv)+\frac{\partial}{\partial z}(FA_zw)\right]=0 \qquad (7)$$

Navier-Stokes Equations are solved by using readily available software. The continuous domain is replaced by a discrete domain using grid. For every cell of grid the discrete equations are derived, boundary conditions are defined and solved. Though the solution can never be exact, it can be fairly accurate. Various numerical methods exist to solve the differential equations. Finite volume method for solving the equation is used.

3. NUMERICAL MODEL

The geometry consists of three main components, these are parent channel, side channel and side sluice gate and these are constructed in the Autodesk Inventor. Side sluice is placed half way down the channel. Parent channel is trapezoidal channel and designed as a most efficient channel. Side sluice gate is paced in rectangular side channel. Five different entrance angles (90^0, 75^0, 60^0, 45^0, 30^0) are considered for the study. Side sluice gate opening kept constant throughout the study. Dimensions of model are 0.5m bottom width, 0.55m depth of channel, side sluice opening is 0.1m, and length of side sluice is 0.5m.



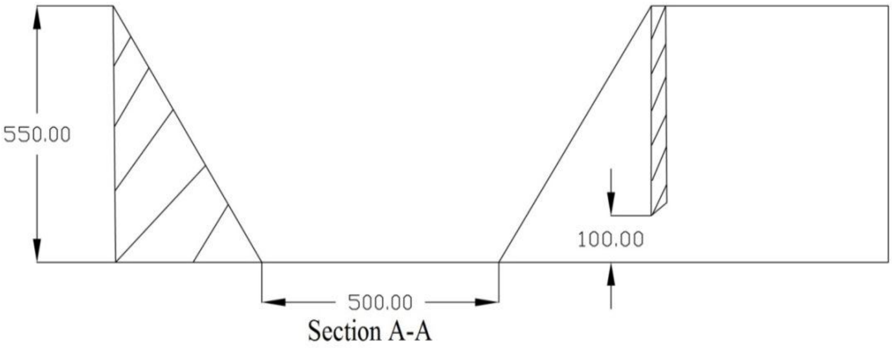


Figure 1: Plan, elevation and section of side sluice gate of 30^0 entrance angle.
(All Dimensions in mm)

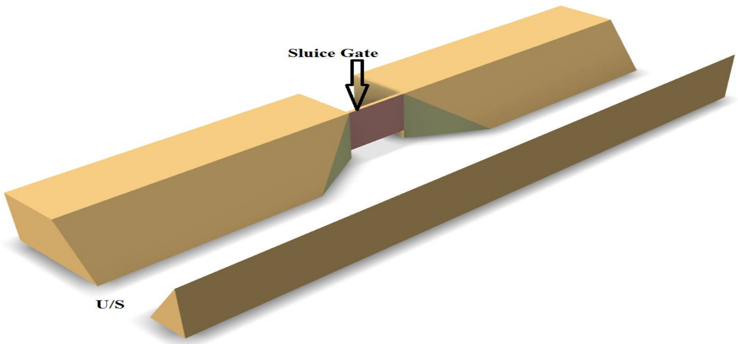


Figure 2 3D Representation of the model showing Side Sluice

4. RESULTS and DISCUSSIONS

4.1 Discharge coefficient for different entrance angles of side sluice gate

All the required parameters are computed from the total 40 simulation by CFD software and coefficient of discharge is calculated by using eq-(2). The coefficients of discharge and Froude number for different angles were compared along with this water surface profile are studied.

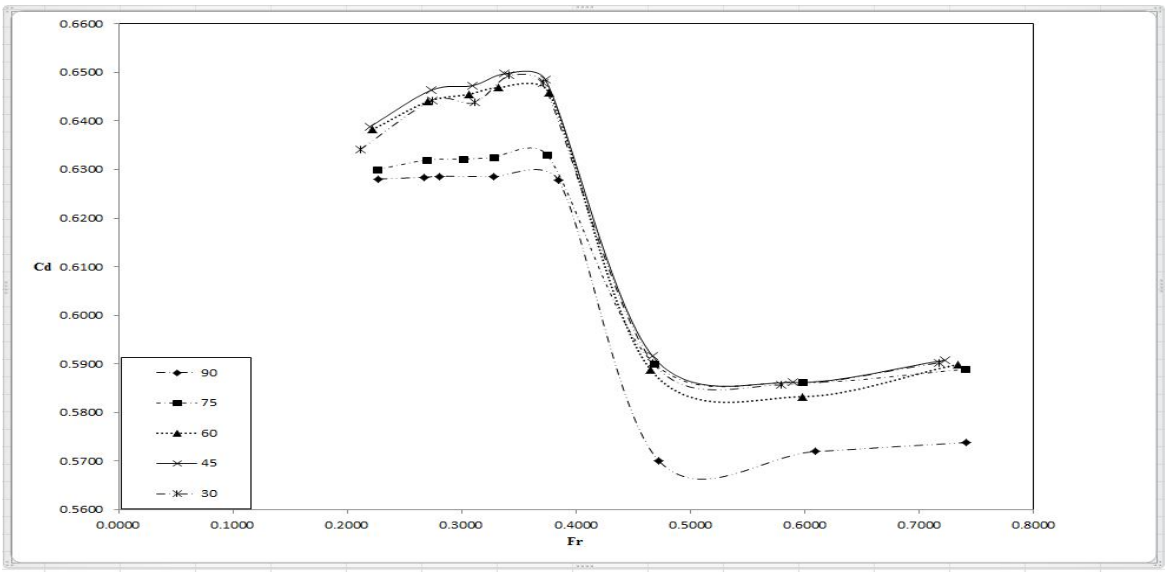
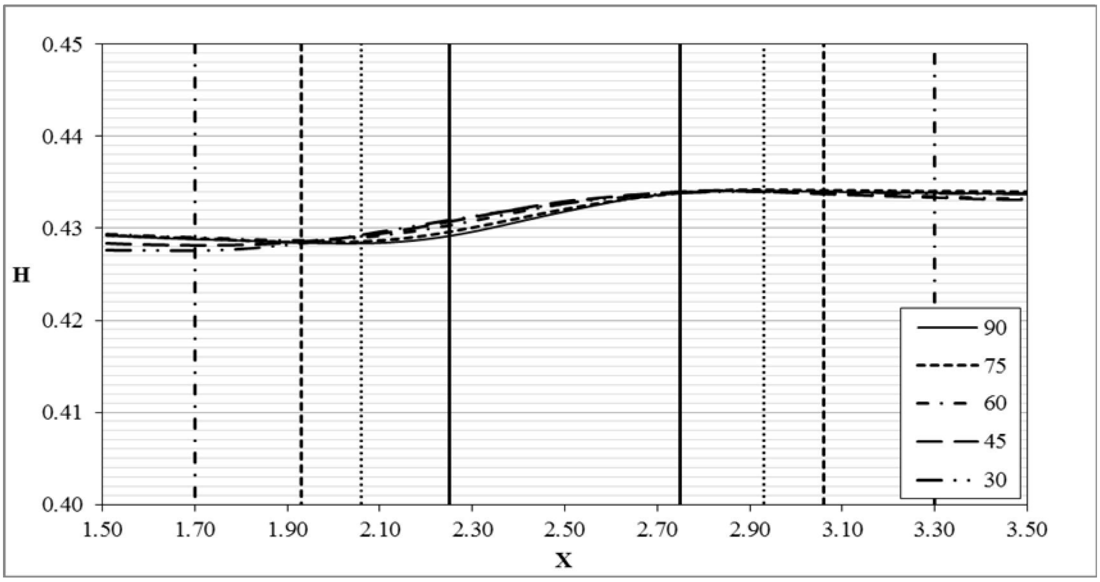


Figure 3 3D Representation of the model showing Side Sluice

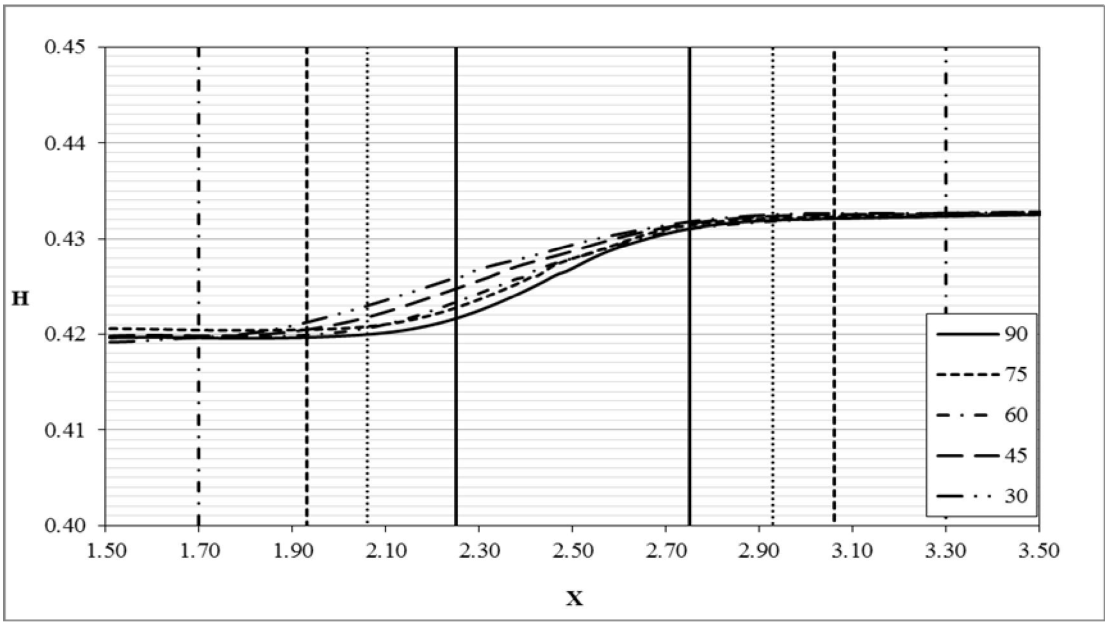
The plot of discharge coefficient versus Froude number is presented in the Figure-3. Coefficient of discharge for 90^0 is less than that of the other angle i.e. this modification in the parent channel is effective to increase the discharge through the side sluice gate. Plot shows that, the Cd for angles 30^0, 45^0, 60^0,$75^0$and 90^0 increases up to Fr. No. =0.36 then it decreases suddenly up to Fr. No.= 0.46 and again increases gradually. Cd for angles of 30^0, 45^0, 60^0, 75^0 shows almost same profile while for 90^0 it fall below the others. Amongst all the entrance angles Cd for 45^0 is maximum for all the discharges.

4.2 Water surface Profile

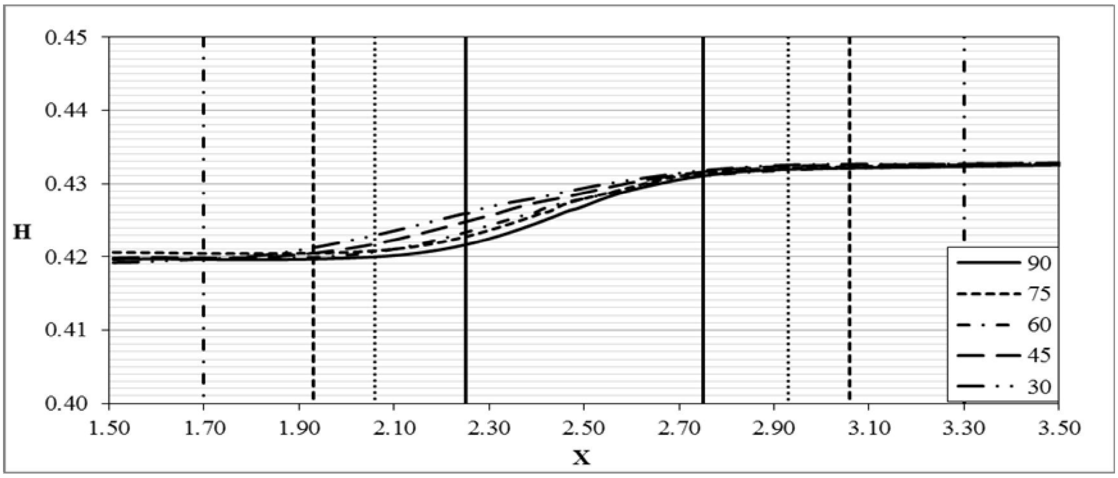
Water surface levels were measured along the main channel to describe the water level in main channel as shown in Fig-4. The water level at upstream of the side sluice gate is lower than the downstream it means it satisfy the equation of specially varied flow given by V. T. Chow. This drop of water level at the upstream and increase in the water level in downstream is due to the splay given to the side bank and reduction in flow rate in the parent channel along the side sluice gate. Surface profiles for five angles were compared for different discharges which are 0.150 m^3/s to 0.35 m^3/s. Profile for 0.15 m^3/s, 0.20 m^3/s and 0.30 m^3/s are shown in fig-4.



Q=0.150



Q=0.200



Q=0.300

Figure 4: Variation of surface profile with different entrance angle for various discharges

In all simulated cases, water level in parent channel rises along the side sluice gate. Rise of water level is not uniform. For the discharge of $0.150m^3/s$ all the water profiles for different angles are overlapping in nature. As discharge increases from 0.15 to 0.35 water surface profiles are not smooth because of momentum of water increases. From above fig-4 it is clear that the water surface profile for the smaller discharges are overlapping in nature and for higher discharges separation of each profile is clearly seen. Water level rises from where the expansion of the main channel (which is shown by vertical line) is started.

5. CONCLUSION

This paper reports simulated results on the side sluice gate under free flow condition. To minimize turbulence and to reduce the strength of eddies on the upstream of the side sluice, some modification were made in the parent channel. In this study the effect of these modifications on the discharge coefficient and on the water surface profiles were discussed in detail. By changing the upstream bank alignment angle (90^0, 75^0, 60^0, 45^0 and 30^0) and parent channel discharge, total of 40 cases were simulated and analyzed for obtaining surface profile and coefficient of discharge. From these results, following conclusions were made.

Water level at the upstream end of side sluice is lower than that at the downstream end of side sluice. Depth of water increases along opening of side channel. Increase in depth of the water along the side sluice is not uniform and non-linear in nature.

Initially, marginal increase in Cd is observed as the Froude number increases, but after at about Fr. No. = 0.36 the sudden drop in the Cd is observed in all the cases considered. Further increase in Froude number beyond 0.46 again marginal increasing Cd is obtained. If upstream bank angle is reduced from 90^0 to 45^0 the Cd increases. Almost same Cd is obtained for 60^0, 45^0, 30^0 of upstream side bank angle. This study helped in design of the side sluice gate to select the proper upstream bank angle of side sluice gate.

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