EXPERIMENTAL STUDY AND NUMERICAL SIMULATION OF COEFFICIENT OF DISCHARGE THROUGH VERTICAL SLUICE GATE USING STEPPED SILL

A DISSERTATION
SUBMITTED IN PARTIAL FULFILLMENT OF REQUIREMENTS
FOR THE AWARD OF DEGREE OF

MASTER OF TECHNOLOGY

IN

HYDRAULICS AND WATER RESOURCES ENGINEERING

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CANDIDATE DECLRATION

I, Aniket Kumar Sharma, Roll. No. 2K17/HFE/04 student of M.Tech. in Hydraulics and Water Resources Engineering, hereby declare that the project dissertation titled **"Experimental Study and Numerical Simulation of Discharge Coefficient through Vertical Sluice Gate with Stepped Sill"** which is submitted by me to the Department of Civil Engineering, Delhi Technological University, in partial fulfillment of requirement for the award of degree of "Master of Technology", is real and authentic research work of my own under supervision of Prof. Rakesh Kumar, Department of Civil Engineering. To the best of my knowledge this research work embodied in the thesis has not been submitted by anyone other for the award of any Degree, Diploma and Fellowship.

Place: Delhi **ANIKET KUMAR SHARMA**

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CERTIFICATE

I hereby certify that the Project Dissertation titled "**Experimental Study and Numerical Simulation of Discharge Coefficient of Flow through Vertical Sluice Gate with Stepped Sill**" which is submitted by **Aniket Kumar Sharma**, 2K17/HFE/04, Department of Civil Engineering, Delhi Technological University in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or anywhere else.

Place: Delhi **Prof. RAKESH KUMAR**

Date: **SUPERVISOR**

ABSTRACT

Sluice gates are mainly used for controlling discharge through irrigation canals. The flow is termed as free flow or submerged flow when it depends upon upstream head, gate opening and downstream head. When the sluice gate height exceeds some design criteria then double or triple leaf gates are provided. In some cases when double and triple leaf gates are not easy to provide due to some economic reason then a sill is constructed below single leaf sluice gate to reduce its height to meet the desirable design criteria of single leaf sluice gate. The use of stepped sill below sluice gate improves the discharge coefficient effectively.

The objective of present study to analyze the experimental data collected on the effect of constructing stepped sill below a sluice gate and validates its parameters through ANSYS-FLUENT. The past studies proved that the trapezoidal sill of downstream slope of 1V:5H improves the discharge coefficient below the gate and produces the minimum increase in the jump length formed downstream compared to other downstream slopes of sills. In this way with constructing stepped sill and the data collected from experiments on the below-gate sill of this particular downstream slope will be analyzed by calculating dimensionless parameter.

The experimental analysis carried out on three groups of model made of aluminum sheet and each model of stepped sill have different heights (P = 2, 4, 6 cm respectively) and each physical model is tested with four gate openings as (D = 1.5, 2.0, 2.5, 3.0 cm) respectively. Numerical simulation done in ANSYS and value of discharge coefficient is validated by probe value by calculating pressure, depth of flow and discharge at different section and plot the different contours variation.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my project supervisor Prof. Rakesh Kumar for his supervision, invaluable guidance, motivation and support throughout the extent of the project. I have benefited immensely from his wealth of knowledge. I extend my gratitude to my college, Delhi Technological University (formerly Delhi College of Engineering) for giving me the opportunity to carry out this project. This opportunity will be a significant milestone in my career development. I will strive to use the gained skills and knowledge in the best possible way, and I will continue to work on their improvement, in order to attain desired career objectives.

Place**:** **Aniket Kumar Sharma**

Date: 2K17/HFE/04

M.TECH.

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ABBREVIATIONS

Q_{th} = the theoretical discharge passing gate opening

W = width of channel

D = the gate opening

ΔH = difference in head

g = gravitational acceleration

C_d = coefficient of discharge

Q_{act} = the actual discharge passing gate opening

Y_1= depth of water over the sill upstream (L)

Y_2= depth of water over the sill downstream (L)

Y_t = depth of tail water over the bed

L = total length of sill (L)

L_1 = upstream sill length (L)

L_2 = downstream sill length (L)

P = sill height (L)

h= step height (L)

Fr= Froude Number under gate

Re= Reynolds number

We = Weber Number

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Sluice gates are widely used in irrigation canals, land drainage system, urban sewage system and sanitary engineering and as head regulators of distributaries for controlling the discharge. The flow is termed as free flow or submerged flow when it depends upon upstream head, gate opening and downstream head. When the sluice gate height exceeds some design criteria then double or triple leaf gates are provided as needed. Sluice gates as a hydraulic structure are used in open channels to control the flow and measure its outflow rate. These gates may be free or submerged according to the extent of the water depth at the downstream of the gate to the gate opening. They may be used in prismatic or in non-prismatic channels. Almost every water resources project has a reservoir or diversion work for the control of floods or to store water for irrigation or power generation, domestic or industrial water supply. A spillway with proper control mechanism is almost invariably provided for release of waters during excess flood inflows. Releases of water may also be carried out by control devices provided in conduits in the body of the dam and tunnels. In order to achieve flow control, a gate or a shutter is provided in which a leaf or a closure member is placed across the waterway from an external position to control the flow of water. Control of flow in closed pipes such as penstocks conveying water for hydropower is also done by valves, which are different from gates in the sense that they come together with the driving equipment, whereas gates require a separate drive or hoisting equipment.

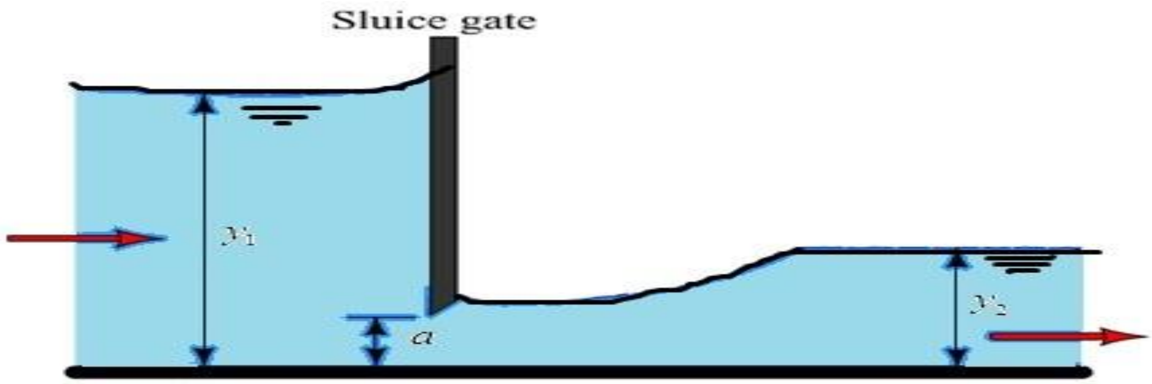

Figure 1.1: Flow below a vertical sluice gate

Generally flow takes place in open channels due to energy difference so it is important regarding functioning of gate. Upstream depth corresponding flow is Y_1 and downstream depth is $Y_{2\ \text{and}}$ vertical sluice gate is provided for the controlling the flow. There are different types of gates are provided for specific purposes for which they may be used at possible locations in which to install, and suitable hoists with which to operate. A brief outline is also provided on the common types valves used to regulate flow in penstocks. The Bureau of the Indian Standards code IS 13623: 1993 "Criteria for choice of gates and hoists" provides the basic classification of gates, which may be done according to the following criteria-

- Location of the sluice gate with respect to reservoir water surface basis
- Head of water over sill of gate basis
- Operational requirement basis
- Material used in fabrication basis
- Mode of operation basis
- Shape of gate basis
- Discharge through gate basis
- Type of flow passage with which connected and its location basis
- Location of seal basis
- Location of skin plate basis
- Closing characteristics basis
- Drive to operate basis

1.2 Classification of Gates

1.2.1 Based on location of opening with respect to water head available

The different types of gates used in water resources projects may be broadly classified as either the Crest or Surface type, which are intended to close over the flowing water and the Deep-seated or Submerged type, which are subjected to submergence of water on both sides during its operation. The different types of gates falling under these categories are as follows:

Crest type gates

1.Vertical type gate

2.Radial type gates

3.Ring gate

4.Sector gate

5.Stony gate

6.Falling gate

7.Two tier gate

8.Falling Shutters

Deep seated gates

1.Vertical gate

2.Deep seated radial gate

3.Disc gate

4.Cylindrical gates

5.Ring follower gate

6.Jet flow gate

7.Ring seal gate

1.2.2 Based on the type of flow passage with which connected and its location

Gates are a part of most of the openings provided in any water resources project. They may be used to regulate flow through spillways, sluices, intakes, regulators, ducts, tunnels, etc., to name a few. The following list provides classification of gates based on its association with a particular water passage. The gates associated with hydropower have only been briefly described here. They are described in more detail in the next module-

1. Crest gates
2. Sluice gate
3. Depletion Sluice gate
4. Construction Sluice gate

5. Head regulator gate
6. Diversion tunnel gate
7. Penstock gate
8. Surge shaft gate
9. Navigation lock gate
10. Balancing gate

1.2.3 Based on head over Sill

1. Low head gate: head less than 15 m

2. Medium head gate: head between 15 m and 30 m

3. High head gate: head more than 30 m

1.2.4 Based on operational requirements

1. Service gates (main gate): To be used for regulation and routine operation such as main gate for regulation of flow through spillway sluices, outlets, etc.

2. Emergency closure gates: To close the opening in flowing water condition in case of emergency such as emergency penstock gate.

3. Maintenance gate: Bulkhead gate, emergency gate, stop-logs, which are used for maintenance of service gates.

4. Construction gates: Required to shut off the opening during construction or to finally close the opening after construction such as construction sluice gates, diversion tunnel gates, etc.

1.2.5 Based on material used in fabrication

1. Steel gates

2. Wooden gates

3. Reinforced concrete gates

4. Aluminum gates

5. Fabric (plastic) gates/Rubber gate

6. Cast iron gates.

1.2.6 Based on mode of operation

1. Regulating gates: Operated under partial openings. Generally the main regulating gates are the service gates.

2. Non-regulating gate: Gates not suitable as well as not intended for operation under partial gate openings.

1.2.7 Based on shape

1. Hinged type gates: Such as radial gates, Sector gates, hinged leaf gates and falling shutters.

2. Translatory type gates: Rolling gates such as fixed wheel gate, Stoney gate and slide type gate.

1.2.8 Based on drive to operate

1. Manually operated gates

2. Electrically operated gates

3. Semi automatic gates

4. Automatic gates, such as:

   i) Float operated gates

   ii) Water powered automatic gates

   iii) Solar powered gates

   iv) Computer controlled gates

1.3 Mathematical Model

The actual discharge to its theoretical value is well known as the coefficient of discharge C_d which simulates the physical properties of the flow phenomena including flow losses , defined as

$$Q_{th} = D \cdot W\sqrt{2g\Delta H} \tag{1}$$

Where,

Q_{th} = theoretical discharge passing through gate opening

D = gate opening provided

W = width of channel

ΔH = head difference available

The value of coefficient of discharge is defined as the ratio of actual discharge to the theoretical discharge-

$$C_d = \frac{Q_{act}}{Q_{th}} \tag{2}$$

Based on the energy principles presented in Eq.(1) and the definition Eq. (2) with the employment of the dimensional analysis, functional relationship of dimensionless parameters can be forwarded as in Eq.(3)-

$$C_d = f\,(Fr,\ Y_1/Y_2,\ P/H,\ H/D\ ,\ P/L_1\ ,\ P/L_2\ ,\ P/D\ ,\ P/Y_1\ ,\ P/Y_2\ ,Y_1/D\ ,\ D/L\ ,H/D\ ,H/Y_1\ ,\ Re,\ We) \tag{3}$$

1.4 Significance of Froude Number

It defined as the ratio of inertia force to the gravity force which plays a important role in case of flow in open channels. Generally the Froude number depends on depth of water to describe flow as subcritical and supercritical. A hydraulic jump occurs once the flow goes from supercritical flow (Fr > 1) to subcritical flow (Fr < 1) or, from risky flow to a strongest flow. The values of Reynolds number and Weber number are not affected to turbulent flow generated and neglecting surface tension value. Froude number can be presented by the following relation –

$$Fr = \frac{V}{(gy)^{0.5}} \quad (4)$$

1.5 Numerical Modelling

SOFTWARE AND NUMERICAL MODELLING BY ANSYS

Software - ANSYS Inc.

Version – 19.1 student version

Component Utilised – Fluent (CFD)

ANSYS Fluent is a state-of-the-art computer program for modelling fluid flow, heat transfer, and chemical reactions in complex geometries.

ANSYS Fluent is written in the C computer language and makes full use of the flexibility and power offered by the language. Consequently, true dynamic memory allocation, efficient data structures, and flexible solver control are all possible. In addition, ANSYS Fluent uses a client/server architecture, which enables it to run as separate simultaneous processes on client desktop workstations and powerful computer servers. This architecture allows for efficient execution, interactive control, and complete flexibility between different types of machines or operating systems.

1.5.1 ANSYS Software

ANSYS software program is used to layout merchandise, as well as to create, simulations. ANSYS is a general purpose software, used to simulate interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic for engineers.

1.5.2 Computational Fluid Dynamics

Computational Fluid Dynamics (CFD) is a set of numerical methods applied to obtain approximate solution of problems of fluid dynamics and heat transfer. CFD is not a science by itself, it is a way to apply the method of numerical analysis to another fluid flow or mass transfer. CFD are used because there are many engineering problems that can't be solved by analytical or experimental approach. CFD solutions can only be as accurate as the physics models on which they are based. "Computational fluid dynamics" (CFD) is a branch of Mechanics of fluid that uses statistical assessment and statistics systems to answer and have a look at issues that involved fluid flows. Laptop systems are used to implement the calculations required to, simulate the intercommunication of beverages and gases, with surfaces described through limiting conditions.

1.5.3 Role of ANSYS FLUENT in Field Problem

A Fluent simulation begins with initialization and proceeds, over a number of iteration to convergence. It contains broad physical modeling in software ANSYS. Fluent basically tells the basic behavior of field problem, its consequences, and factor affecting the parameters involved. Design modular tells about the geometrical behavior similar to the field application.

It also gives the result as per limit of accuracy in ANSYS probe. Simulation of any field problem is analyzed by satisfying it with different boundary condition.

1.5.4 Methodology

Several methods exist for predicting turbulent flows with CFD. Three most popular approaches in engineering are:

DNS: direct numerical simulation

Is the approach in which the Navier-Stokes equations are solved for all of the motions in the turbulent flow. Since all scales of the turbulence are solved, this method is “exact” but it puts very high demands on computational resources. Currently, DNS is possible only at low Reynolds numbers and for relatively simple geometries. It is used for studying and understanding turbulence and for the verification of RANS and LES turbulence models.

LES: large eddy simulation

In this method, the Navier-Stokes equations are filtered. This means that only the small turbulent eddies (that are smaller than the size of a filter that is usually taken as the mesh size) are removed. The largest-scale motions of the flow are solved, while the small-scale motions are modeled: the filtering process generates additional unknowns that must be modelled in order to obtain closure. Also here, turbulence models are used. Because they are only used to model the scales of turbulence smaller than the size of the filter (grid), they are called “sub grid-scale models”. Because this method solves more of the turbulence and models less (compared to RANS), the accuracy of the simulation is improved, however at the expense of increasing computer requirements. Important research work in this field is ongoing and in an increasing number of cases, simulations of wind flow around buildings with LES are conducted.

RANS: Reynolds averaged Navier-Stokes

These equations are derived by averaging the Navier-Stokes equations (time-averaging if the flow is statistically steady or ensemble-averaging for time-dependent flows). With the RANS equations, only the mean flow is solved while all scales of turbulence have to be modelled (i.e. approximated). The averaging process generates additional unknowns (Reynolds stresses) and as a result the RANS equations do not form a closed set. Therefore approximations have to be made. These approximations are called turbulence models (e.g. k-ε models). The RANS method is the one that has been most widely applied and validated in the field of numerical computation of wind flow around buildings and air flow inside buildings.

1.6 Need For the Proposed Study

Irrigation projects consist of canal system and structure works to regulate the flow in the system. Sluice Gates are used to control the discharge and water level. Sills below sluice gates reduce their height and weight, especially in cross regulators constructed in deep channels. We are determining the value of Coefficient of discharge (C_d) with adequate data of actual discharge (Q_{act}) and (Q_{th}) executed with experimental setup which is validate with Numerical Simulation through ANSYS Software using standard RANS k-ε model.

The discharge coefficient of the sluice gate is taken as the main criterion for the flow below the sluice gate.

1.7 Research Objective

Stepping sill is a structure used instead of the sloping sills to reduce materials and cost of construction. The performance of such stepped sill is important due to widely used of sills with gates in irrigation structures. Study in laboratory flume is carried out on submerged flow under vertical sluice gate using stepped sill. The objective of the present study is to investigate the comparison performance of stepping sill under different vertical gate opening with stepped sill and to suggest an equation for discharge coefficient in case of submerged flow condition.

Present study is about to investigate the effect of the presence of a stepped sill under vertical sluice gate on the discharge coefficient. Both the cases of subcritical and supercritical submerged flow conditions are analyzed. The analysis will to provide more information on the effect of the sill parameters P/h and P/L and the most important flow parameters Y_1/D, and $\Delta Y/D$ on flow below submerged gate with sill. Using nonlinear regression analysis non-dimensional equations are developed for predicting the coefficient of discharge for submerged stepped sill sluice gate for supercritical and subcritical flow regimes.

1.8 Future Scope

Stepping sill is a structure used instead of sloping sills which reduce material and cost of construction.

In this study stepping sill is used with different step size and different sluice gate opening which concluded the improvement in the value of coefficient of discharge. Further any different shape of sill can be used for improvement of discharge coefficient.

In canal irrigation it meets the actual demand of discharge at the head of water course. Coefficient of Contraction can be evaluated as per the requirement of project.

A stage-discharge relationship can also be developed for field data collected for any river in future research work.

CHAPTER 2

LITERATURE REVIEW

Arbhabhirama and Abella (1972), Arbhabhirama and Wan, Khalifa and Mcorquodale, France, Hager they all investigated first about the characteristics of non-prismatic channel. It was concluded that the radial basins are proved to be more efficient in dissipating the energy than the rectangular basin. So it is likely to use the gradual expanding stilling basins (radial basins) for more safety of the hydraulic structures against its failure and to be more economical. This study gives results about the discharge characteristics of gates with sill upstream of radial diverging channel reach (radial stilling basin).

Young (1982) studied about the concept of Stepped sill evolved from stepping spillway. The utility of a stepped spillway for the upper still water dam and managed 75% reduction in energy. He successfully dissipates the energy by adding such a few step to the downstream face of spillway and eliminated the deflecting water jet. Along him Sorensen also performed experiment on physical model for stepped spillways, where he found that adding a few steps to the downstream face of the spillway eliminated the deflecting water jet.

Salama (1987) done experiment on three models of sills with different downstream slopes and vertical upstream face. From his experiment he found that the value of discharge coefficient under the sluice gate is increased by constructing a sill below it. He showed his result by graphical method and establishes the relationship between dimensionless parameter and gives the correlation coefficient for best suited results.

Saiad et al. (1991) studied the effect of a sill under gate for submerged flow conditions using trapezoidal flat top sills with different downstream slopes and different heights. His study showed that discharge coefficient increases by increasing downstream slope of sill.

With him Ibrahim also analyzed the experimental data of supercritical submerged flows at fixed Froude number Fr (1.806, 1.462, 1.255 and 1.018). He found that the discharge coefficient attain their maximum values when the lateral sill is constructed at a distance of ¾ of the basin length from the gate.

Negm et al. (1998) investigated the effect of the sill parameters Z/b and Z/B (Z= sill height, b= top width of the sill, B= bottom width of the sill) on flow below submerged gate with sill. With his study he found that the sill below the gate increases discharge coefficient of the gate and the rate of increase depends on the configuration of both the sill and the gate as well as on both the sill and flow parameters.

Negm, A.M. et al. (2001) studied about the behaviour of submerged flow below vertical gate with sill upstream of horizontal diverging channel. He conducted a experiment in a laboratory flume with 10 cm wide, 31 cm deep and 3.0 m long. It is concluded that the presence of sill below the gate has considerable effect on the discharge coefficient of the gate, and observed that the discharge coefficients is depended on the different dimensionless parameter as under-gate Froude number and the differential head ratio.

Dae-Geun Kim (2007) a water resource engineer studied the Numerical Simulation by Ansys-Fluent. His study shows that numerical tool Ansys using the Reynolds averaging Navier-Stokes (RANS) model are sufficiently to calculate the discharge coefficients, pressure and velocity distribution for free flow past a sluice gate. Kim also concluded about the variation of coefficient of discharge with different dimensionless parameter.

Neveen Y. Saad, (2011), concluded the effect of the circular-crested sills with different radii and constant heights, upstream and downstream slopes below vertical sluice gates on the discharge coefficient in case of submerged supercritical flow condition. He done experimental study in a flume with 250 cm long, 15 cm wide and 30 cm depth. He found that the main factor affects the discharge coefficient is B/Z, and the circular-crested sill produces a bigger discharge coefficient than the flat-crested sill only if B/Z of the circular-crested sill is equal or smaller than that of the flat-crested one.

H. Khalili Shayan, J. Farhoudi (2013), studied the energy loss of free flow under sluice gate. They both present an equation for estimating energy loss factor and then the effect of this parameter on increasing discharge coefficient's accuracy.

Jean G Chatila & Bassam R Jurdi (2013) studied the experimental investigation into the hydraulics of ogee-profile stepped spillways, examines their viability as an alternative to smooth-back spillways which is seful in case of stepped sill study.

L. Cassan & G. Belaud (2015) done Numerical study of sluice gates is rather recent although it provided an efficient method to explore the flow characteristics and improve the knowledge about the gate behaviour. Among expected results, this study aims at improving the determination of the contraction coefficient. To this end, 2D RANS simulations were performed with four different turbulence models through Ansys-Fluent. The numerical simulations were compared with experimental results and other theoretical approaches based on potential flow assumptions treated to find out discharge coefficient along with velocity distribution graphs.

CHAPTER 3

METHODOLOGY

3.1 Material and Equipment Used

Submerged flow through vertical gate opening is on the same side of upper limb of specific energy, it is subcritical flow in which the energy equation can be applied between the upstream and downstream the gate. The difference between the water surface levels on the two side of the gate ΔH, is the potential energy to overcome all the flow resistance between the two sides. Theoretically it has no energy lost as assumed. Different dimensionless parameters are studied experimentally and wall shear, velocity, pressure, discharge calculated using ANSYS-FLUENT software. On the basis of calculated data results are finalized. This project work is compared with previous study as well as through ANSYS Numerical Simulation.

For experimental purpose aluminum sheets are used. These sheets are presented to investigate the effect of stepped sill to reduce the downstream energy of a hydraulic structure (sluice gate).

Stepped sill of following specification is used:

- Material used to make sill is aluminum.
- 'h' in cm, where 'h' is spacing between two consecutive step of aluminum sheet.
- Height or depth of strip is varies as 2, 4 and 6 cm.
- Width of sheet is 30 cm.
- Bed slope is increasing in the order ranging from 1V:5H, 2V:5H and 3V:5H

3.2 Experiment Setup in Laboratory

For performing the experiment following specification are given below:

Experimental work has done in Hydraulics Laboratory, Branch of civil engineering, "Delhi Technological University". A Rectangular flume 30 cm wide, 40 cm deep and 8.0 m long. The fences of the flume have been created obvious. Water is drawn from a tank to fill a tub of the flume by a pump. Aluminum films with stepped sill had been fixed up on the flume bed just below the sluice gate in upstream section. Point gauge was used to measure the water level at the center line of the flume with accuracy of 0.001 m. The sluice gate is regulated by screw mechanism for opening it. It is made up of steel sharp edge of thickness 0.0004 m. Three models of stepped sill were made of aluminum sheet of total length 0.45 m with additional runs without sill of four gate opening.

The experiments carried out on three groups of models each model of stepped sill have different heights (P = 2, 4, 6 cm respectively) and each physical model is tested with four gate openings as (D = 1.5, 2.0, 2.5, 3.0 cm). Each sill step size is takes (h = 5 cm).

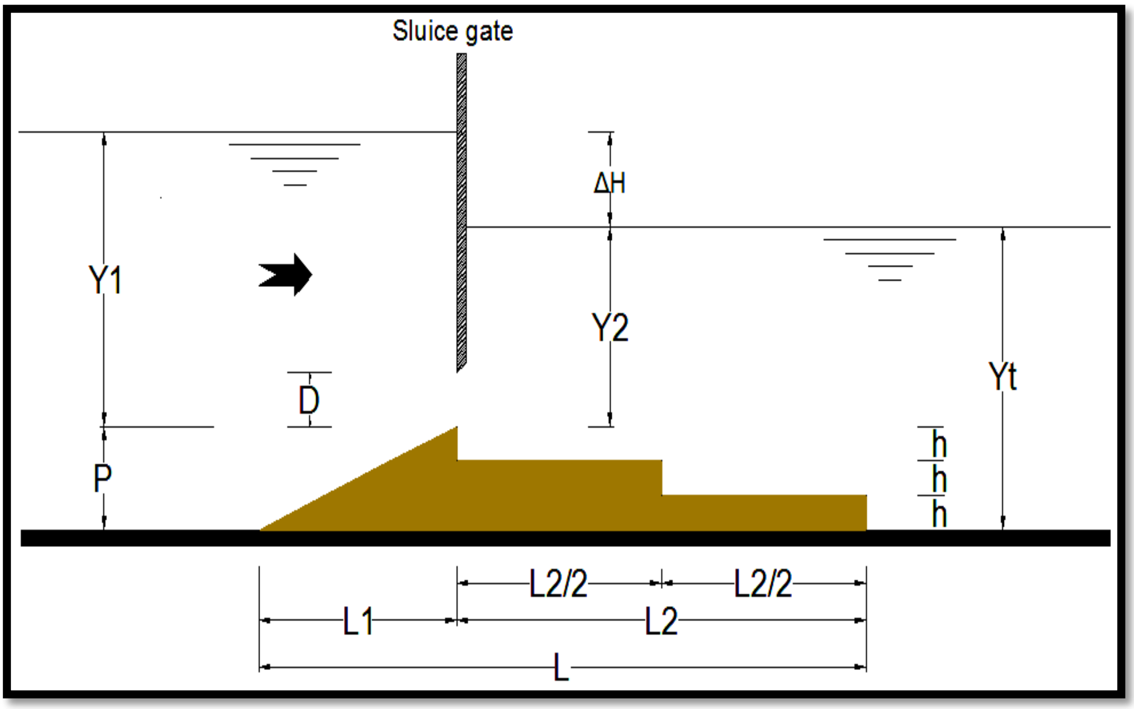

Figure 3.1: Definition sket

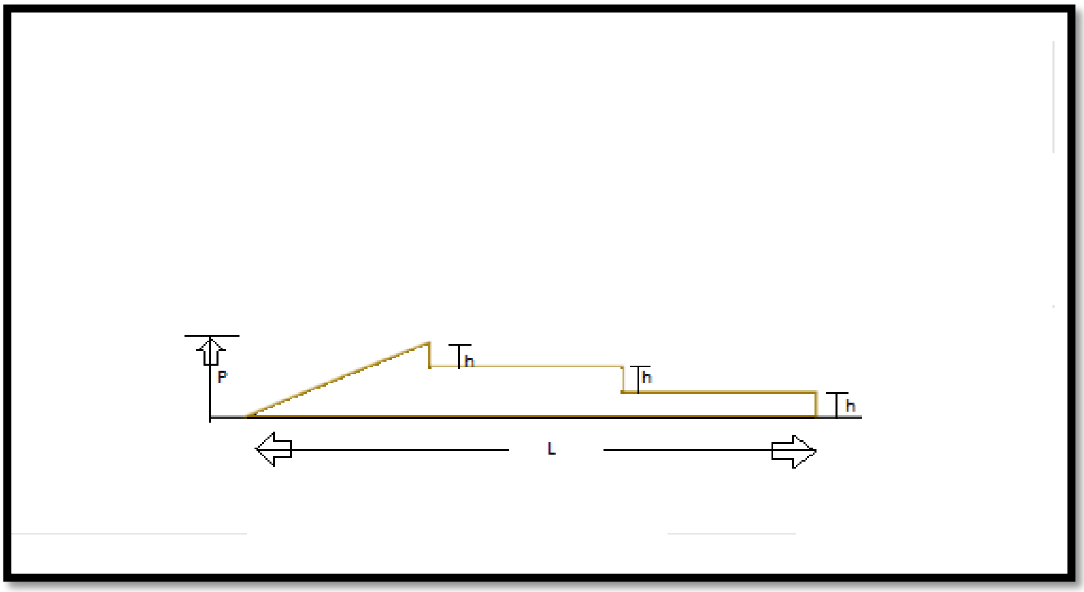

Figure 3.2: Line Diagram of stepped sill

3.3 Photographs of aluminum sheets used for experiment

Figure 3.3: Aluminium Stepped sheet

Figure 3.4: Vertical Sluice gate in flume

Figure 3.5: Placing of Stepped Sill Model below Sluice Gate

Figure 3.6: Flow under Vertical Sluice gate in flume

Figure 3.7: Digital Pressure Meter

CHAPTER 4

OBSERVED DATA & VALIDATION OF RESEARCH

4.1 Observed Data and Dimensionless Parameters

(a) Upstream water depth $Y_1$and Tail water depth Y_2 needed to cause a flow.

(b) Upstream pressure P_1 and Downstream pressure P_2.

(c) Head difference ΔH.

(d) Actual Discharge $Q_{act.}$

(e) Discharge at the downstream of flume using tank.

(f) Coefficient of discharge C_d.

(g) Froude Number Fr.

4.2 Dimensionless Parameters with Measured Discharge and discharge coefficient are following:

- Q_m and ΔH
- Y_1/Y_2 and C_d.
- C_d and Fr no.
- h/Y_t and Fr no.

4.3 Table for Observed Data

Table 1: Test model details

Sill Height (cm)	Model No	Gate Opening (D) (cm)	P/L_1	h/L_2	h/L	h/L_1	D/L_2	P/L_2
P =0	1	1.5	-	-	-	-	0.08	0.00
	2	2.0	-	-	-	-	0.109	0.00
	3	2.5	-	-	-	-	0.136	0.00
	4	3.0	-	-	-	-	0.163	0.00
P= 2	1	1.5	0.24	0.035	0.024	0.075	0.08	0.109
	2	2.0	0.24	0.035	0.024	0.075	0.109	0.109
	3	2.5	0.24	0.035	0.024	0.075	0.136	0.109
	4	3.0	0.24	0.035	0.024	0.075	0.163	0.109
P=4	1	1.5	0.45	0.07	0.048	0.148	0.08	0.218
	2	2.0	0.45	0.07	0.048	0.148	0.109	0.218
	3	2.5	0.45	0.07	0.048	0.148	0.136	0.218
	4	3.0	0.45	0.07	0.48	0.148	0.163	0.218
P=6	1	1.5	0.65	0.098	0.075	0.225	0.08	0.352
	2	2.0	0.65	0.098	0.075	0.225	0.109	0.352
	3	2.5	0.65	0.098	0.075	0.225	0.136	0.352
	4	3.0	0.65	0.098	0.075	0.225	0.163	0.352

Table:2 Table for calculating discharge Coefficient

Crest Level Available (H_1) = 40.44 cm

P_1(kg/cm^2)	P_2(kg/cm^2)	P_2-P_1/pg (m)	Q_m (litre/sec)	H_2 (cm)	H=H_2-H_1	Cd = Qact/Qth	Average
1.3	1.65	3.5	32.8	49.5	9.06	0.61	
1.0	6	6	50.795	50.85	10.41	0.64	0.643
0.65	1.5	8.5	60.458	51.35	10.95	0.68	
1.35	1.50	3.7	33.85	52.58	9.42	0.681	
1.1	5.8	6.5	52.85	54.85	10.81	0.724	0.719
0.70	1.6	8.9	64.32	55.12	10.96	0.752	
1.45	1.72	3.95	36.52	49.85	9.55	0.698	
1.2	6.8	7.32	55.60	51.36	10.95	0.785	0.783
0.82	1.85	9.4	68.52	52.52	10.99	0.81	

4.4 Validation of Research Work

It is divided into two section one is graphical method another is Numerical simulation i.e. ANSYS. In this study graphical simulation as follows under-

4.4.1 Graphical Method

(a) Head (ΔH) and Measured Discharge (Q_m) for gate opening (D) = 2 cm for step size (P) = 0, 2, 4 and 6 cm

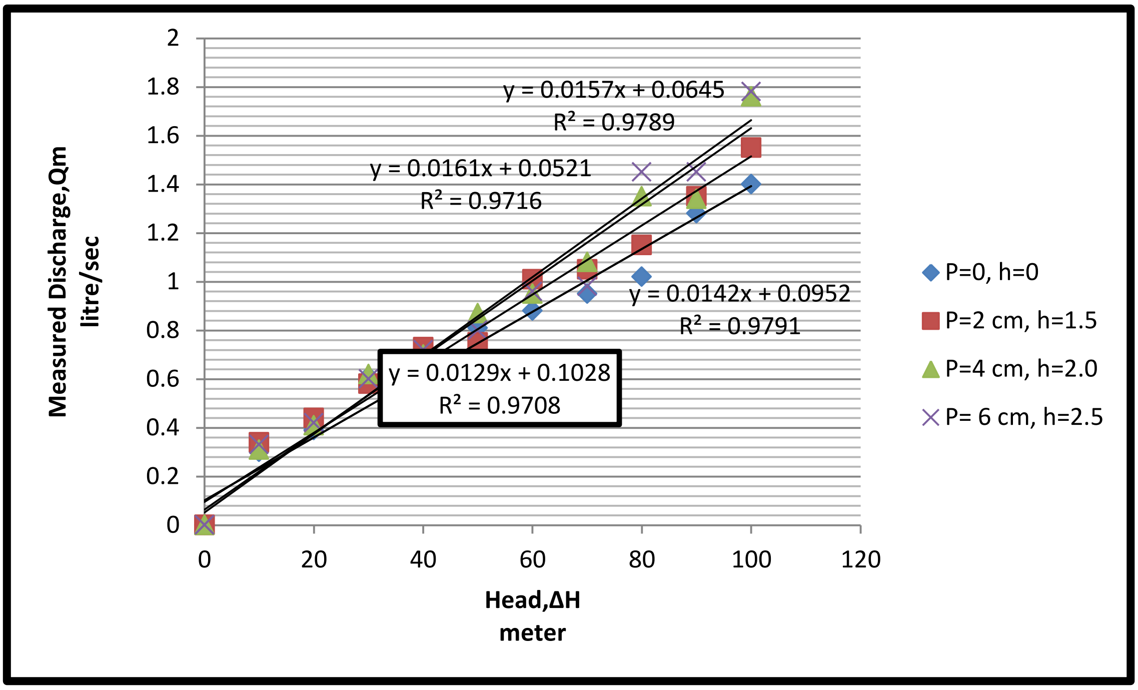

Figure 4.1: Experimental results of present study are plotted between ΔH and Q_m with Coefficient of determination (R^2).

Comment:- Graph is plotted between Head and measured discharge and study the value of measured discharge increases with head difference similar to past study done by Salem (1990).

(b) Head (ΔH) and Measured Discharge (Q_m) for Stepped sill

It can be also noted that the discharge is affected by the step height (h), the discharge increase for a fixed gate opening with the increase height of sill to a certain value, and then the effect of the higher step height became a negative due to the sudden expansion caused by a higher step height.

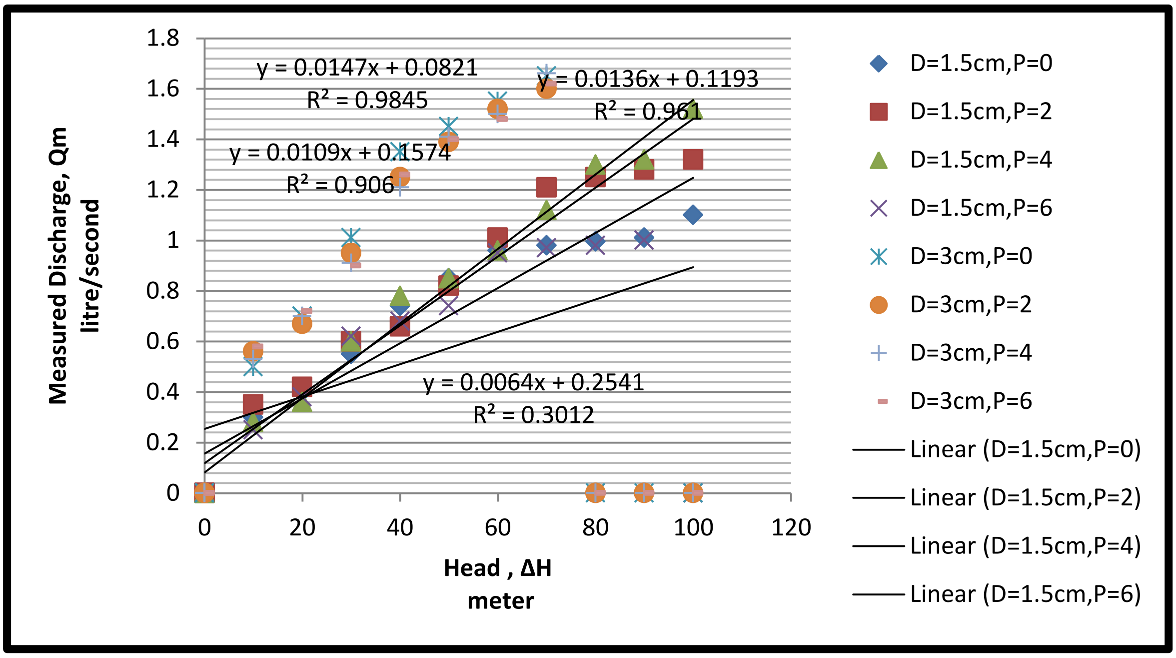

Figure 4.2: Experimental results of present study are plotted between ΔH and Q_m for stepped sill.

Comment:- In this study the value of Q_m increases with ΔH as graph plotted above as per previous study done.

(c) Discharge Coefficient (Cd) and Froude number (Fr) for different values of P and D.

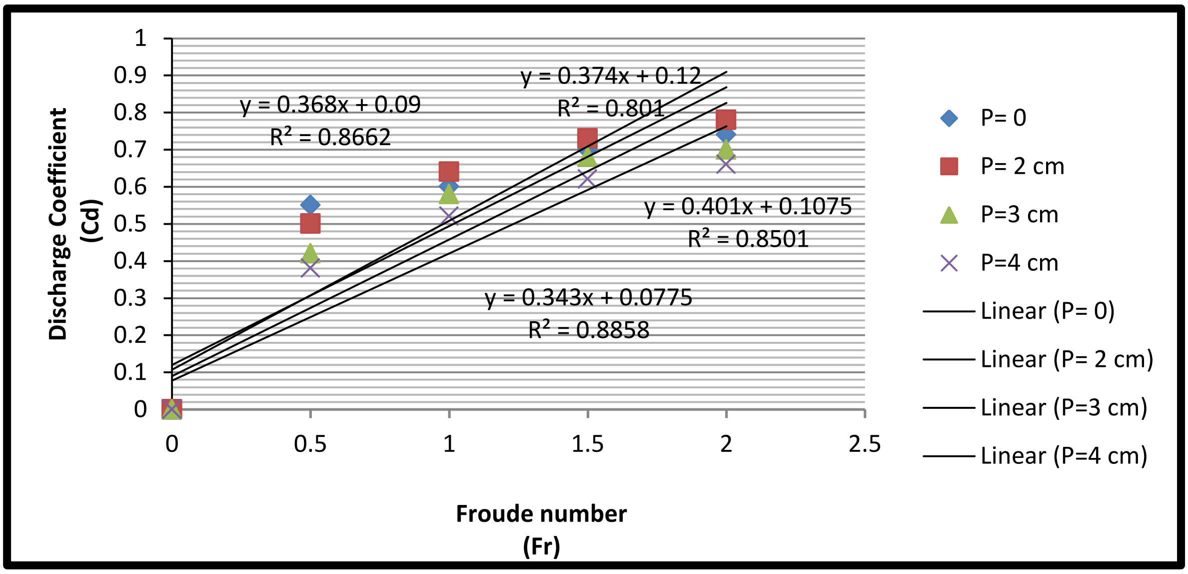

Figure 4.3a: Experiment result of Discharge Coefficient (C_d) and Froude number (Fr) for different values of P

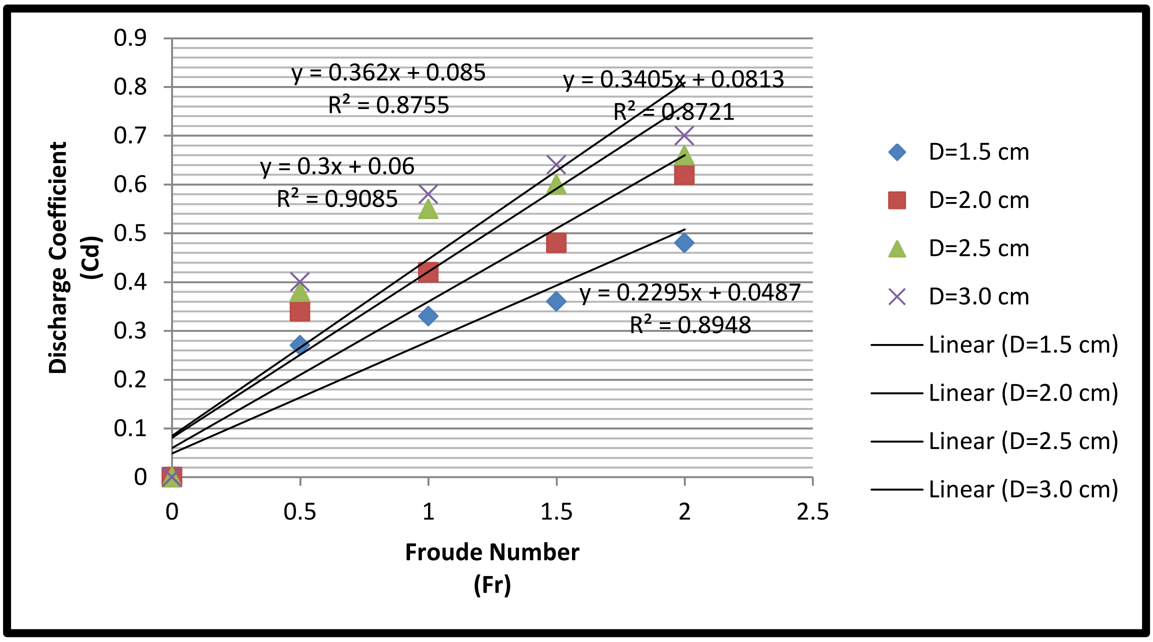

Figure 4.3b: Experiment result of Discharge Coefficient (C_d) and Froude number (Fr) for different values of gate opening (D)

Comment:- The effect of calculated dimensionless parameters on discharge coefficient C_d are studied. There is an increase in the value of discharge coefficient (C_d)with the increase of Froude number as shown above, and also increases with increase of gate opening. It can be noticed the negative effect of step height on the value of C_d due to the increase of step height.

(d) Discharge Coefficient (Cd) and Y_1/Y_2 for different values of P and D.

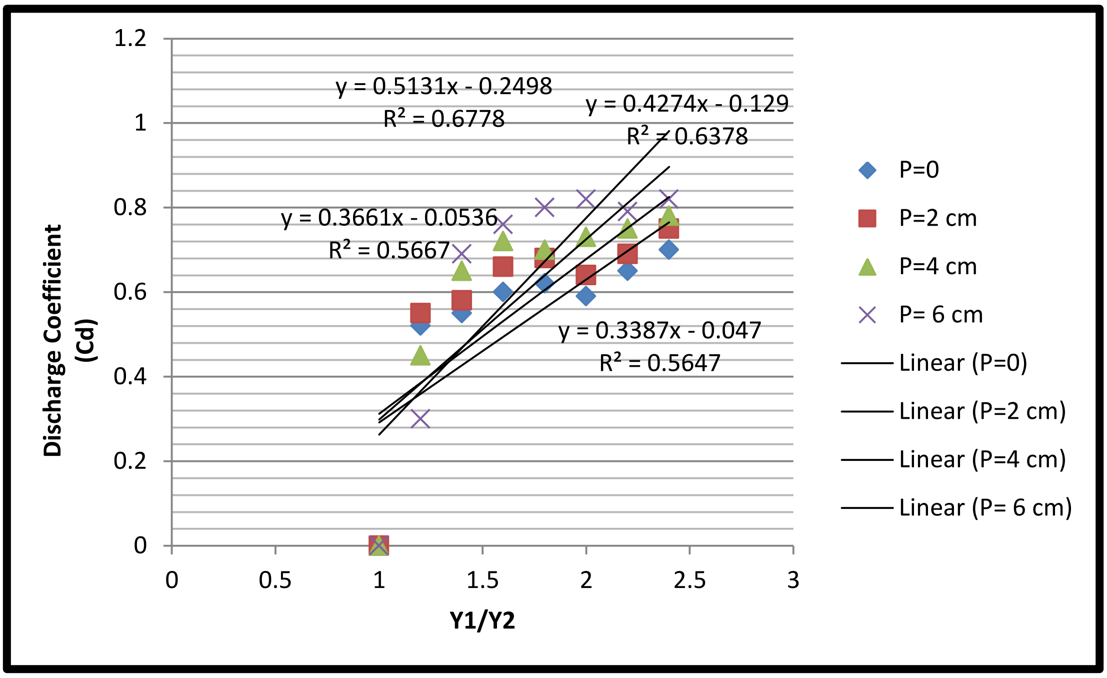

Figure 4.4a: Discharge Coefficient (Cd) and Y_1/Y_2 for different values of P

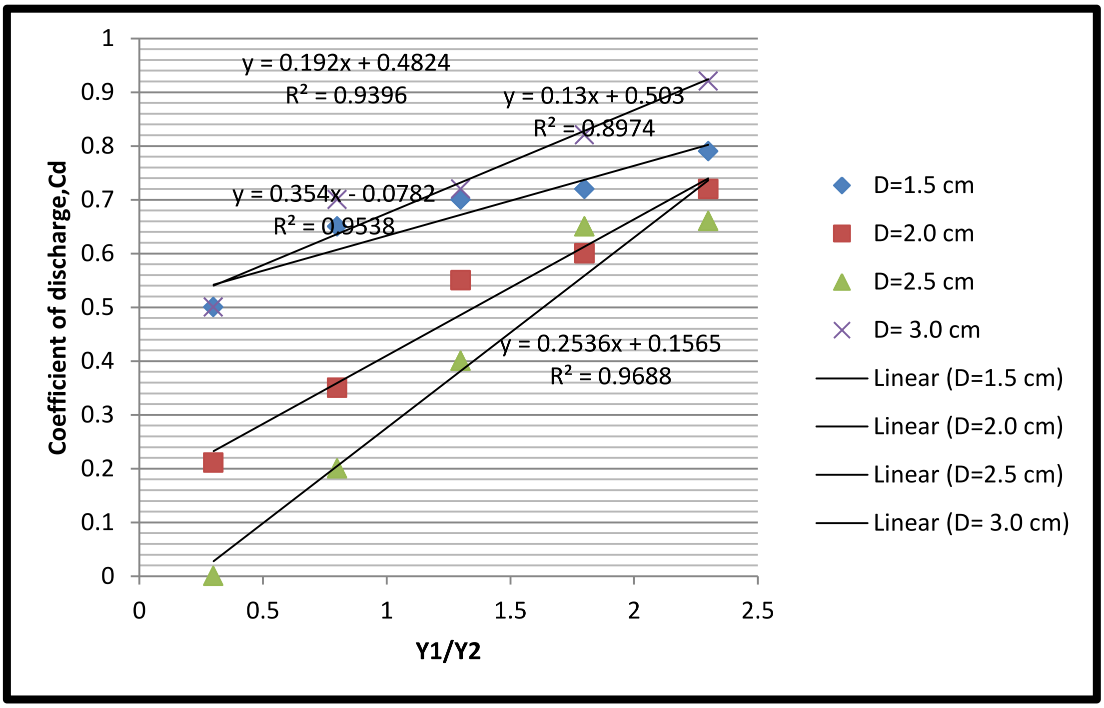

Figure 4.4b: Discharge Coefficient (Cd) and Y_1/Y_2 for different values of D

Comment: - The coefficient of discharge Cd decreases with increase of step height that's caused by the sudden expansion at the outlet after the gate. The coefficient of discharge Cd increase with the increase of $Y_1/Y_{2.}$

(e) Discharge Coefficient (Cd) and h/Y_t for different values of P and D.

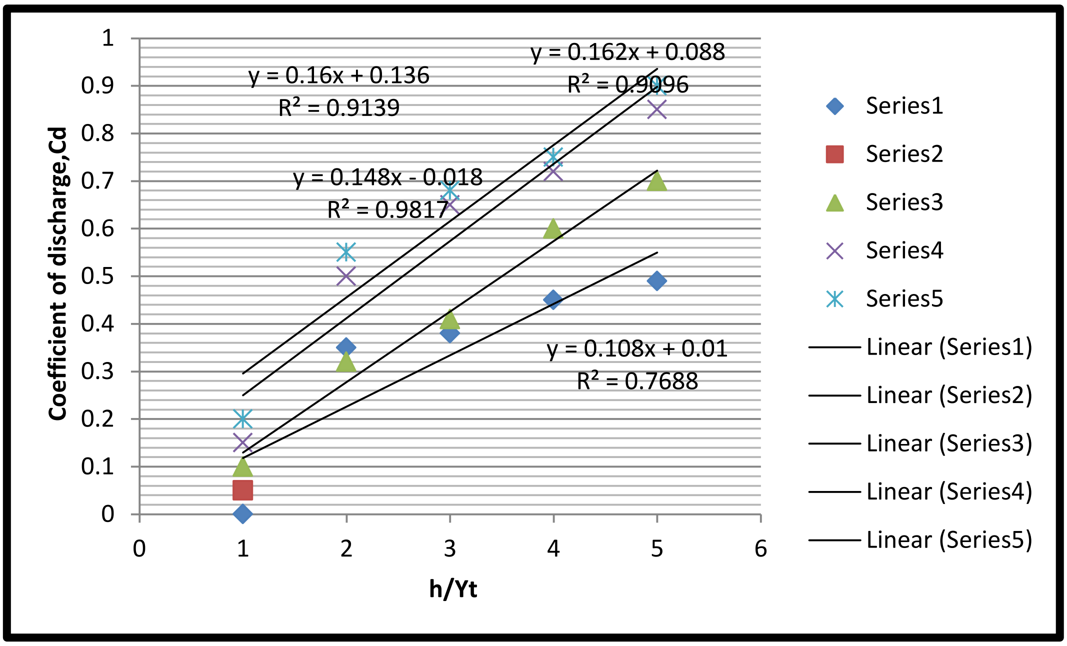

Figure 4.5: Experiment result of Discharge Coefficient (C_d) and h/Y_t for different values of P and D.

Comment:- The value of h/Yt increase when the step height (h) increase for a certain value of downstream depth, that's mean a more sudden expansion physically exists, which cause more head loss and less performance of gate reducing the value of C_d.

The measured physical quantities within the experimental limitations of three groups and four heights of gate openings are listed in Excel sheets contents' data of various parameter runs used to calculate the dimensionless parameters as in chats and linear curve drawn.

4.4.2 Numerical Simulation by ANSYS Software

The procedure and quantities are illustrated below for the verification of research work through ANSYS software -

(a) Inlet pressure and outlet pressure are calculated

(b) Dimensionless parameter are calculated with loss percentage

(c) Coefficient of discharge is calculated

(d) Velocity distribution contour, Mass flow rate contour, Pressure Contour, Velocity vector contour, Volume fraction contour are plotted

4.5 Steps followed during Numerical Simulation through ANSYS

(a) Geometry and Name Selection

Design of the model is done in Workbench on Design Modular. Dimension are provided approximately same as experimental setup. Naming of flow domain is done to mention inlet, outlet, sluice wall, top wall, stepped sill and lower wall.

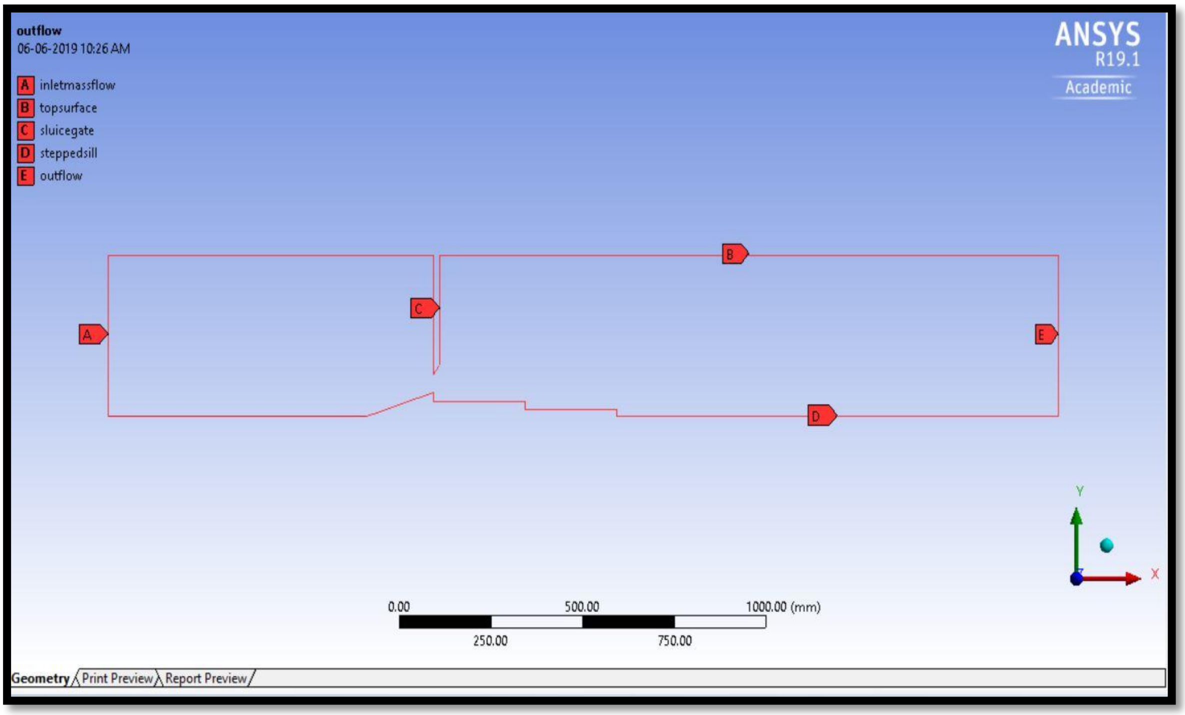

Figure 4.6: Geometry in ANSYS

(b) Meshing

Meshing is done using mesh generate command. Fineness of mashing is done using sizing command in ANSYS-FLUENT. In sizing command, desired size of minimum mesh length is given and project is updated. This gives us a fine meshed model.

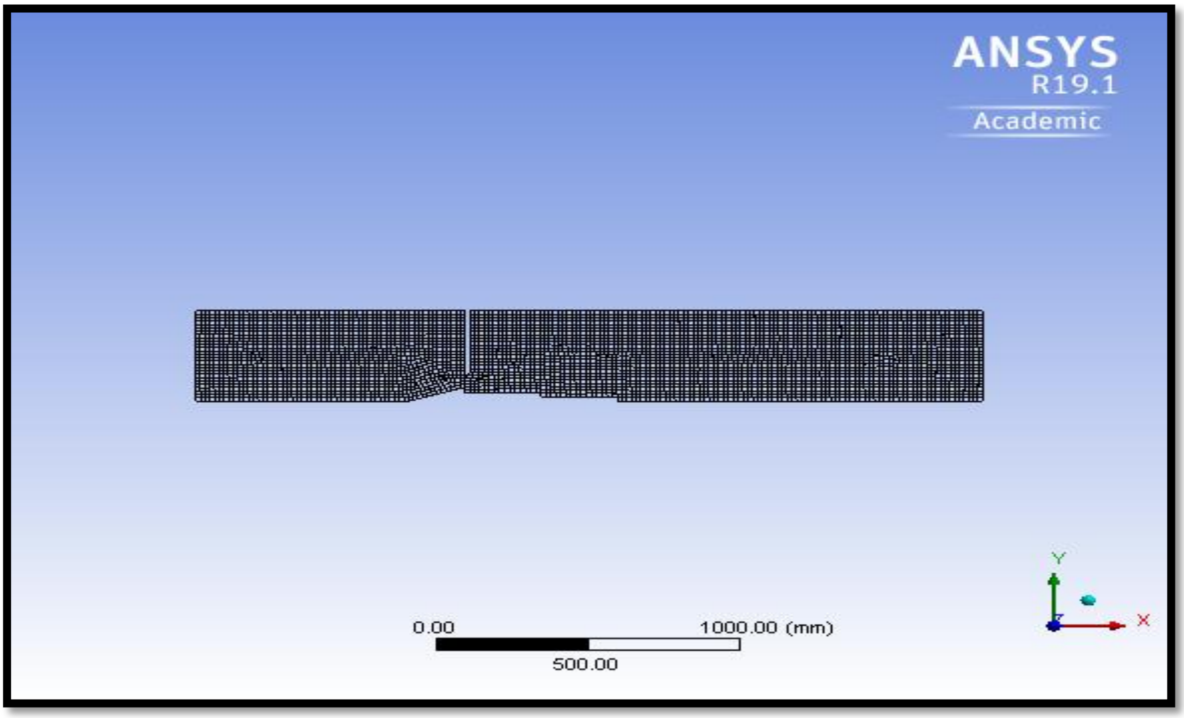

Figure 4.7: Meshing in ANSYS

(c) Setup

Work report file generated in ANSYS regarding units used in geometry, initial boundary condition, Various name selection, solid surface are listed below-

Table: 3 Table for Calculating Units in ANSYS

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

TABLE:4

Model (A3) > Geometry

Object Name	Geometry
State	Fully Defined
Definition	
Source	C:\Users\kaushal\Desktop\aniket ansys\aniket_files\dp0 \FFF\DM\FFF.agdb
Type	DesignModeler
Length Unit	Meters
Bounding Box	
Length X	2584.2 mm
Length Y	400. mm
Length Z	0. mm
Properties	
Volume	0. mm^3
Surface Area(approx.)	1.0096e+006 mm^2
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	1193
Elements	1087
Mesh Metric	None
Update Options	
Assign Default Material	No
Basic Geometry Options	
Parameters	Independent
Parameter Key	
Attributes	Yes
Attribute Key	
Named Selections	Yes
Named Selection Key	
Material Properties	Yes

Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	Yes
Coordinate System Key	
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	Yes
Compare Parts On Update	No
Analysis Type	3-D
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	No

TABLE:5

Model (A3) > Geometry > Parts

Object Name	Surface Body
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Coordinate System	Default Coordinate System
Thickness	0. mm
Thickness Mode	Refresh on Update
Offset Type	Middle
Behaviour	None
Reference Frame	Lagrangian
Material	
Assignment	
Fluid/Solid	Defined By Geometry

Bounding Box	
Length X	2584.2 mm
Length Y	400. mm
Length Z	0. mm
Properties	
Volume	0. mm³
Centroid X	-21219 mm
Centroid Y	1056.1 mm
Centroid Z	0. mm
Surface Area(approx.)	1.0096e+006 mm²
Statistics	
Nodes	1193
Elements	1087
Mesh Metric	None

TABLE:6
Model (A3) > Coordinate Systems

Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. mm
Origin Y	0. mm
Origin Z	0. mm
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

TABLE:7

Model (A3) > Mesh

Object Name	Mesh
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	CFD
Solver Preference	Fluent
Element Order	Linear
Element Size	Default(130.75 mm)
Export Format	Standard
Export Preview Surface Mesh	No
Sizing	
Use Adaptive Sizing	No
Growth Rate	Default (1.2)
Mesh Defeaturing	Yes
Defeature Size	Default(0.65375 mm)
Capture Curvature	Yes
Curvature Min Size	Default (1.3075 mm)
Curvature Normal Angle	Default (18.0°)
Capture Proximity	No
Bounding Box Diagonal	2615.0 mm
Average Surface Area	1.0096e+006 mm^2
Minimum Edge Length	17.76 mm
Quality	
Check Mesh Quality	Yes, Errors
Target Skewness	Default (0.900000)
Smoothing	Medium
Mesh Metric	None
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition

Transition Ratio	0.272
Maximum Layers	2
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Assembly Meshing	
Method	None
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	
Rigid Body Behavior	Dimensionally Reduced
Triangle Surface Mesher	Program Controlled
Topology Checking	Yes
Use Sheet Thickness for Pinch	No
Pinch Tolerance	Default (1.1768 mm)
Generate Pinch on Refresh	No
Sheet Loop Removal	No
Statistics	
Nodes	1193
Elements	1087

TABLE:8

Model (A3) > Mesh > Mesh Control

Object Name	Face Sizing
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	1 Face
Definition	
Suppressed	No
Type	Element Size
Element Size	30.0 mm
Advanced	
Defeature Size	Default (0.65375 mm)
Behavior	Soft
Growth Rate	Default (1.2)
Capture Curvature	No
Capture Proximity	No

TABLE:9

Model (A3) > Named Selections > Named Selections

Object Name	inletmassflow	topsurface	sluicegate	steppedsill	outflow
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Geometry	1 Edge	2 Edges	3 Edges	7 Edges	1 Edge
Definition					
Send to Solver	Yes				
Protected	Program Controlled				
Visible	Yes				
ProgramControlled Inflation	Exclude				
Statistics					
Type	Imported				
Total Selection	1 Edge	2 Edges	3 Edges	7 Edges	1 Edge
Length	400. mm	2567.6 mm	596.84 mm	1953.8 mm	400. mm
Suppressed	0				
Used by Mesh Work sheet	No				

(d) **Results**

1. Velocity-Contour

The Velocity contour shows the variation of velocity at the various section of the flume. Velocity is highest below the sluice gate at converging part and reducing downstream.

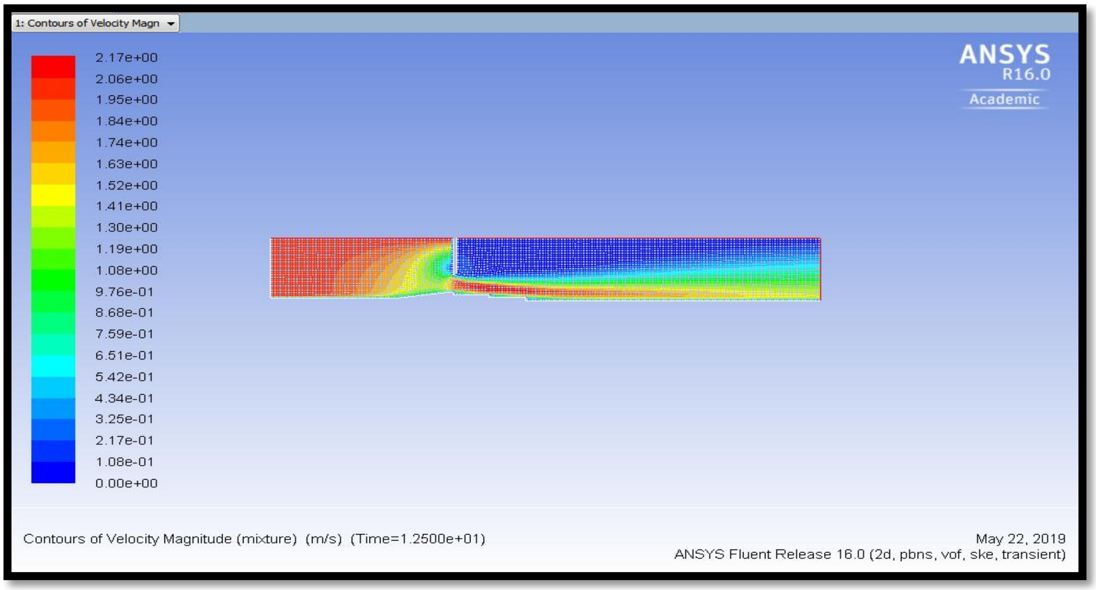

Figure 4.8: Velocity Contour

2. Contour of stream line

Variation of stream line is represented below gives the actual direction of flow in the flume. It is mentioned the velocity flows takes place from upstream section to downstream section by representing it with arrow.

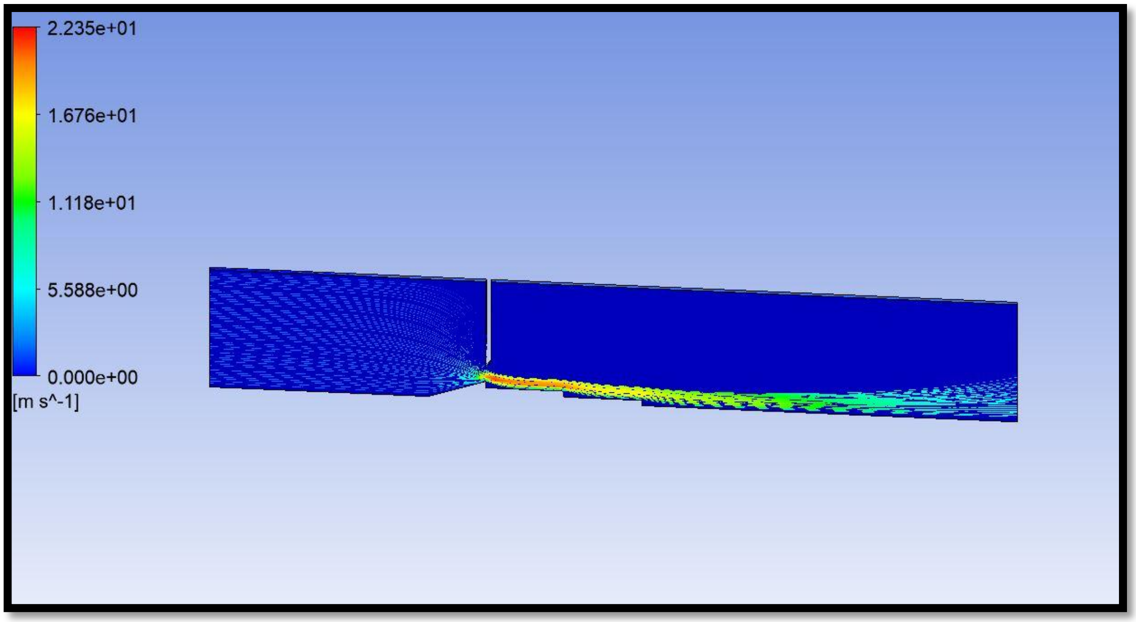

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Figure 4.9: Contour of Stream line

3. Contour of Static Pressure

In this figure the pressure will be maximum in upstream side near the sluice gate.

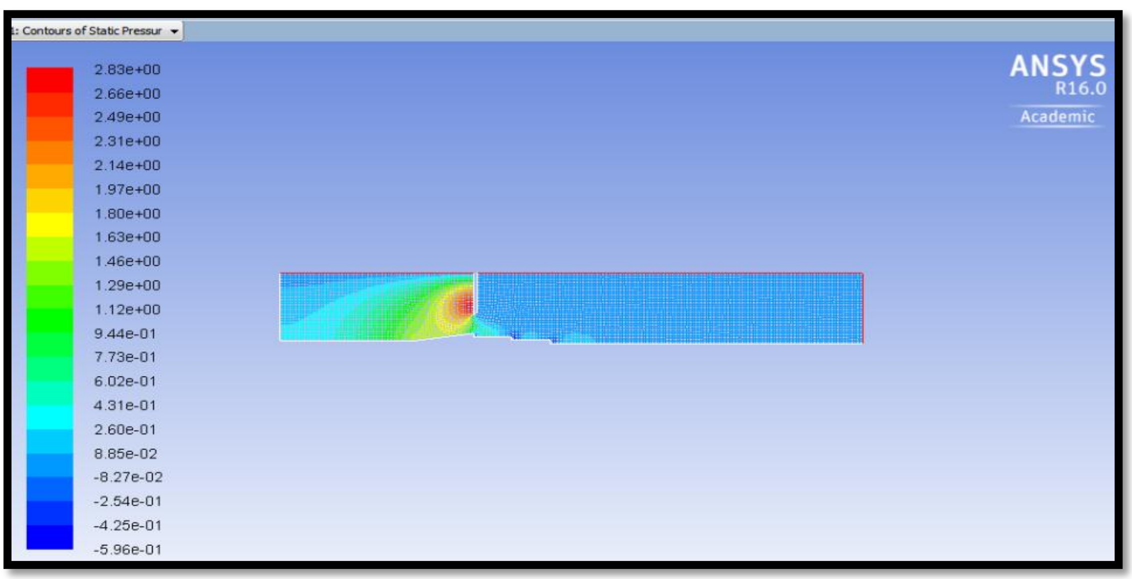

Figure 4.10: Pressure Contour

4. Contour of Volume flow

Volume of flow is represented in the below figure as flow takes place in flume.

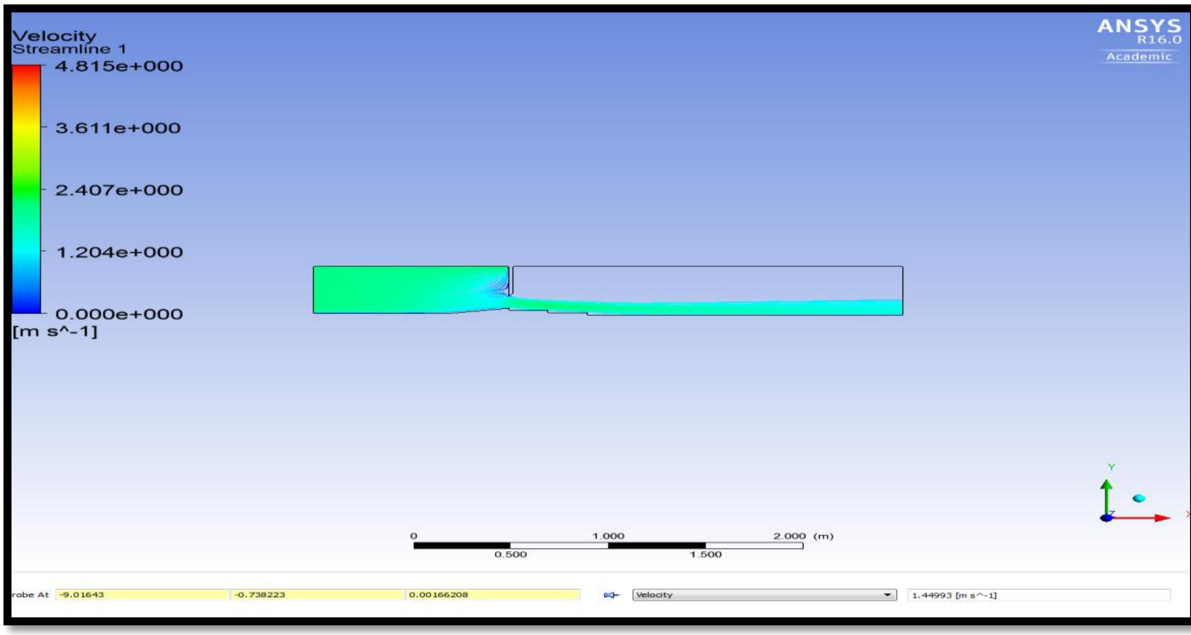

Figure 4.11: Contour of volume flow

5. Iterations done for calculation

The iteration are done for the calculation made to achieve the desired result. Its shows the accuracy up to the step size taken closer to the maximum number of iteration taken as in figure shows that it is 5000 iteration approximation.

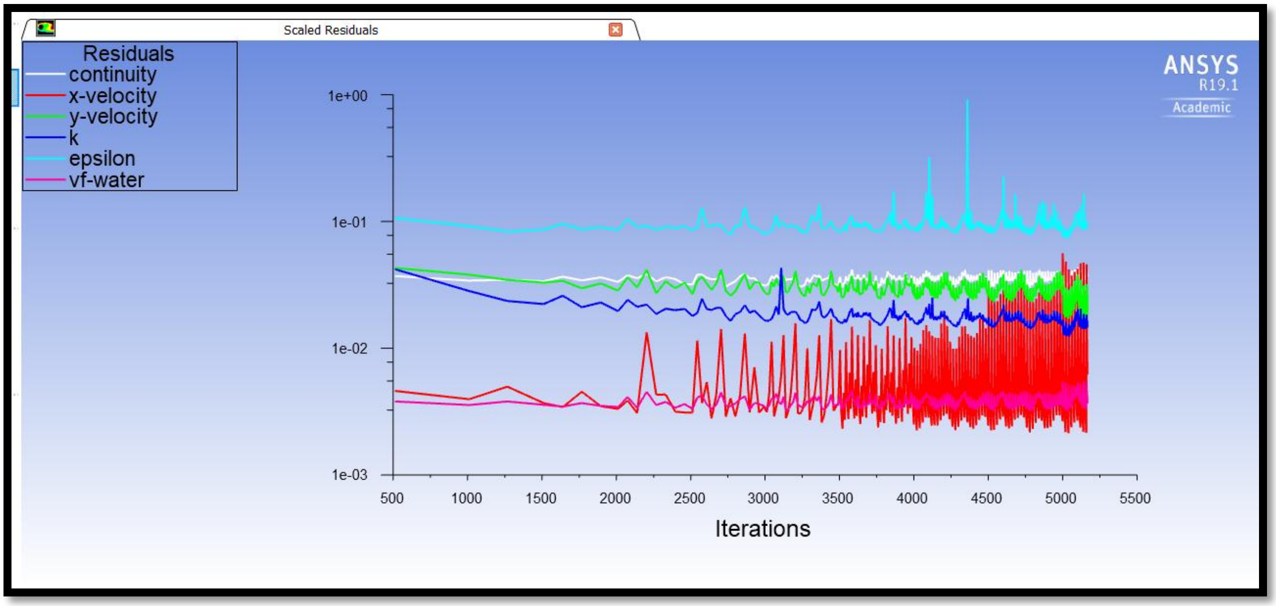

Figure 4.12: Iteration done for calculation

4.6 Data for comparison of coefficient of discharge by ANSYS Probe

Table: 10

Sill Height (cm)	Gate Opening D,(cm)	Y_1 (cm)	Y_2 (cm)	Q_{act} (m^3/sec) ANSYS	C_d (Experimental)	C_d (ANSYS)	Error in %
P = 2	1.5	30	11.6	0.0397	0.643	0.573	12.22
	2.0	30	12.5	0.0591			
	2.5	30	14.7	0.0628			
	3.0	30	15.6	0.0672			
P = 4	1.5	30	11.8	0.0495	0.719	0.652	10.27
	2.0	30	12.9	0.0645			
	2.5	30	13.85	0.0678			
	3.0	30	15.8	0.0782			
P = 6	1.5	30	12.4	0.0581	0.783	0.697	13.31
	2.0	30	14.2	0.0662			
	2.5	30	15.23	0.0725			
	3.0	30	17.56	0.0792			

4.7 Result comparison with the previous researches

Table: 11

Summary of Previous Experimental Investigations on the Discharge Coefficient

Investigator	Gate opening (cm)	Range	Remarks
Rajaratnam and Subramanya (1967)	2.6-10.1	0.595	increasing slightly as G/E_1 increases
Nago (1978) (reported by Roth and Hager (1999)	6.0	0.520	decreasing as G/E_1 increases
Roth and Hager (1999)	5.0	0.492	decreasing as G/E_1 increases
Negm, Alhamid, El-Saiad (2001) Using trapezoidal sill	5.0	0.495	decreasing as G/E_1 increases
Sarhan Abdulsatar Sarhan (2013) using prismatic sill	5.0	0.77	decreasing as G/E_1 increases

Where,

E_1 = Energy at Upstream of sluice gate section

CHAPTER 5

RESULT & DISCUSSION

Following results are obtained from experimental study and simulation discussion-

- The stepped sill has a positive effect on the performance of vertical sluice gate to a certain step size as done in the laboratory which is similar to the previous researcher as using trapezoidal sill and triangular sill. Stepped sill is also economical as reducing the material cost.

- The discharge coefficient slightly increases as the height of sill (P) increases.

- In Experimental Analysis trend between dimensionless parameters are plotted and compared with previous study done by researcher.

- Graphical trend of present study is similar in nature of previous study done by Negm(2000) and Kim(2007).

- The coefficient of discharge increases with increase of Fr, D/L, h/Y_t as in the previous study.

- The coefficient of discharge decreases with increase of $P/\Delta H$, $\Delta H/D$, Y_1/Y_2, Yt/D as per previous study.

- The actual discharge Q_{act} ranging from 32.8 litre/second to 68.520 litre/second in experiment analysis while discharge in ANSYS at downstream ranges between 39.7 litre/second to 79.2 litre/second.

- Value of discharge coefficient ranges from 0.643 to 0.783 in experimental study while it ranges 0.578 to 0.697 in ANSYS FLUENT with average error of 11.93%.

- Higher sill under gate gives the smallest backup water depth and submerged jump length, but the highest energy loss. The forward flow and the reverse flow increase as the sill height increases.

- Higher sill under gate generates the largest values of the near bed velocity.

- The forward flow and the reverse flow increase as the sill height increases.

- Results revealed in this study via the developed statistical Equations predicting actual discharge, discharge coefficient with those obtained by some of the previous researchers.

- The proposed formulas are applicable within the entire range of the experimental parameters.

CHAPTER 6

CONCLUSION

- The discharge coefficient slightly increases as the height of sill (P) increases up to certain limit as studied in experimental study.
- The coefficient of discharge increases with increase of Fr, D/L, h/Yt.
- The coefficient of discharge decreases with increase of P/ΔH, ΔH/D, Y1/Y2, Yt/D.
- Higher sill under gate gives the smallest backup water depth and submerged jump length, but the highest energy loss.
- Regression analysis is used to analyze the experimental data. Non-dimensional discharge equations were developed to predict the discharge coefficient for both supercritical and subcritical flow regimes. The predictions agreed well with the experimental data.
- Graphical trend of present study is quiet similar to the previous study which tells that work is reliable.
- A good agreement between the measured and calculated discharge by the suggested equations with R^2= 0.9716, 0.972, 0.9704 and 0.9641 respectively.
- Error in the experimental work to numerical Simulation through ANSYS is approximate 11.93%.
- Further research can be performed for optimization of the energy dissipation.
- Further research can be initiated to establish Stage-Discharge relationship for a field problem.

References

[1]. Rajarathnam,,N. and K Subramanya (1967), 'Flow Equation For the Sluice Gate' , Journal of Irrigation and Drainage Div., Proc , ASCE, Vol. 93, No.3, pp 167-186.

[2]. Isaacs, L.T. (1977) studied on "Numerical solution for flow under sluice gates." Journal of Hydraulics Div., ASCE.

[3]. Tanwar, M. P. S. (1984). "Flow through side sluice," ME thesis, University of Roorkee, Roorkee, India.

[4]. Salama M (1987). "Flow below sluice gate with sill. Journal of Egyptian Society of Engineers".

[5]. El-Saiad AA, Abdel-Hafiz E, Hammad MN (1991). Effect of sill under gate on the discharge coefficient. Journal of Egyptian Society of Engineers, Cairo Egypt, Cairo Egypt.

[6]. Negm A. M. and El-Saiad A. A. 1993. Subcritical Submerged Flow Characteristics Beneath Silled Sluice Gates. Proc. of AEIC-93, December 18-21, Faculty of Engineering, Al-Azhar University, Naser City, Cairo.

[7]. Sehgal, C.K. (1996). "Design guidelines for sluice gates." J. Hydraul. Eng., March 1997.

[8]. Negm AM, AA Alhamid, AA El-Saiad (1998). "Submerged flow below sluice gate with sill".

[9]. Tel, J. (2000). "Discharge relations for radial sluice gates." M.Sc. thesis, Delft Technical University, Delft.

[10]. Ibrahim AA (2000). "Analysis and Formulation of supercritical submerged flow below gate in Radial Basin with lateral sill", Engineering Research Journal, Al-Mataria Faculty of Eng, Helwan.

[11]. Negm, A.M. (2000). “Discharge Characteristics of Submerged Flow Below Vertical Gate US Horizontal Radial Stilling Basin With Transverse Sill”, Engineering Research Journal, Al-Mataria Faculty of Eng., Helwan University.

[12]. Negm AM, GM Abdel-Aal, MN Salem (2001). “Characteristics of submerged flow below gate with sill in non-prismatic channels”, Proceedings of the International Conference on Water Technology, March 23-25, 2001, Egypt.

[13]. Jung-Fu Yen, Chih-Han Lin and Chang-Tai Tsai. 2001. “Hydraulic Characteristics and Discharge Control of Sluice Gates”, Journal of the Chinese Institute of Engineers.

[14]. Saad N.Y. 2007. “Effect of circular-crested sill shapes under sluice gate on supercritical free flow characteristics’,Ain Shams University, Engineering Bullet.

[15]. Dae-Geun Kim (2007), water resources engineering KSCE Journal of Civil Engineering “Numerical Analysis of Free Flow Past a Sluice Gate” studied that Sluice gates are widely used for flow control in open channels.

[16]. Neveen Y Saad (2011). Flow Under a Submerged Gate With a Circular- Crested Sill, Nile Basin Water Science & Engineering Journal.

[17]. M. Bijankhan, V. Feito and S. Kouchakzadeh. (2012), “ New stage-discharge relationships for free and submerged sluice gates.”,Flow Measurement and Instrumentation Journal. 28: 50-56.

[18]. Sarhan AS (2013). Analysis of Submerged Flow under a Gate with Prismatic Sill, ARPN Journal of Engineering and Applied Sciences.

[19]. Shayan, H.K, Farhoudi, J., and Oshan, R. (2014). “Estimation of flow discharge under the sluice and radial gates based on contraction coefficient.” IJST, Trans. Civil engineering.

[20]. Cassan & G. Belaud Supagro Montpellier, UMR G-EAU, 2, place Pierre Viala, 34060 Montpellier cedex, France (2015),“RANS simulation of the flow generated by sluice gates”. Numerical study of sluice gates.