STUDY OF AERATION EFFICIENCY OVER THE PIANO KEY WEIRS

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I, Kanchan Singh, Roll No. 2K19/HFE/11 of M.Tech (Hydraulics and Water Resource Engineering), hereby declare that the work embodied in this dissertation entitled **" STUDY OF THE AERATION EFFICIENCY OVER THE PIANO KEY WEIRS"** which is submitted by me to the department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. An authentic record of my work carried out under the supervision of Prof. Anbu Kumar. This work is not previously formed the basis for the award of any other Degree or Diploma Associateship. Responsibility for any plagiarism related issue stands solely with me.

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This is to certify that the thesis entitled **"Study of the aeration efficiency over the Piano Key Weirs"** submitted by **Ms. Kanchan Singh** in partial fulfillment of the requirements for the award of **Master of Technology in Civil Engineering** with specialization in **Hydraulics and Water resource Engineering** at the Delhi Technological university, Delhi is an authentic work carried out by her under my supervision and guidance.

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ABSTRACT

Aeration is the process of increasing the dissolved oxygen content of water, which is an important water quality parameter for the survival of flora and fauna on this planet. The dissolved oxygen level can be increased using hydraulic structures or by installing mechanical aerators. Hydraulic structures proved to be an economical and efficient way of enhancing the aeration process, thereby increasing the dissolved oxygen in the water stream. It develops large amounts of air bubbles; as a result, contact surface area increases, and hence the water-air -mass transfer accelerates. Weirs are having the highest aeration efficiency among all hydraulic structures. Various researchers study the aeration process involved in weirs and various experiments have been done to study the parameters involved. As literature said that the aeration efficiency of the different hydraulic structures depends on their geometry. According to past studies, the researchers have stated that the hydraulic structures help enhance the dissolved oxygen of the water body. Rivers clean themselves naturally after movement over a certain distance by the process of aeration. It is also known as the self-cleaning nature of rivers. Weirs also follow the same process for cleaning as well as maintaining the various water quality parameters. They function in the same manner as rivers naturally perform the self-cleansing process for its purification. In the self-cleansing process, the river clears itself and maintains various water quality parameters. In order to enhance the DO content of the water body (river, dams, and reservoirs), an experimental study was conducted in Fluid Mechanics and Hydraulic Laboratory at the Delhi Technological University. The primary goal of this research was to increase the DO content of the water body through aeration. The author conducted an experimental study over three different types (Type-A, Type-B, and Type-C) of Piano Key Wier models and compared them to achieve this goal. The present study's findings conclude that the aeration of the free-flowing water can be enhanced by constructing hydraulic structures across the stream or river.

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Date: **Kanchan Singh**

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LIST OF SYMBOLS

L-weir length

W- weir width

Wi- inlet cycle width

L- weir length

W- width of the weir

W_i- inlet cycle width

W_o- outlet cycle width

B- control structure footprint

B_i- inlet cycle cantilever length

B_o- outlet cycle cantilever length

g - acceleration due to gravity= 9.81m/sec^2

N- no. of keys

ABBREVIATION

DO- dissolved oxygen

PK Weir- Piano Key Weir

ADV- Acoustic Doppler Velocimeter

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Today, the world is suffering from a severe fresh water shortage, which has an adverse effect on both human health and aquatic life. The dissolved oxygen content of water is an important water quality parameter for the survival of flora and fauna on this planet.

Various biological and chemical processes taking place in the river systems control the concentration of DO in water. DO in water is used by micro-organisms for respiration and the decomposition of organic material present in river streams. Aquatic plant's photosynthesis aids in the recovery of dissolved oxygen, which is used by microorganisms in the decomposition of organic matter in the river system. The aeration process also replenishes the river system's depleted dissolved oxygen levels. It is a process in which close contact between air and water occurs, which results in the absorption of oxygen by water. DO should not be less than 4mg/l in order for aquatic life to exist.

There exist a couple of ways in which DO concentration can be enhanced, but in today's era, with the growing technology and understanding, hydraulic structures are being used to maintain the DO in the water stream. Hydraulic structure enhances the aeration process. Hydraulic structures like weirs, cascades, spillways, water jets are used for this purpose. Out of all these, Weirs have the maximum Oxygen transfer efficiency (Gameson, 1957). Hydraulic structure introduces a large number of air bubbles into the stream to increase the contact surface area, which accelerates oxygen concentration. They prove to be economical and more efficient compared to the various other artificial aeration processes

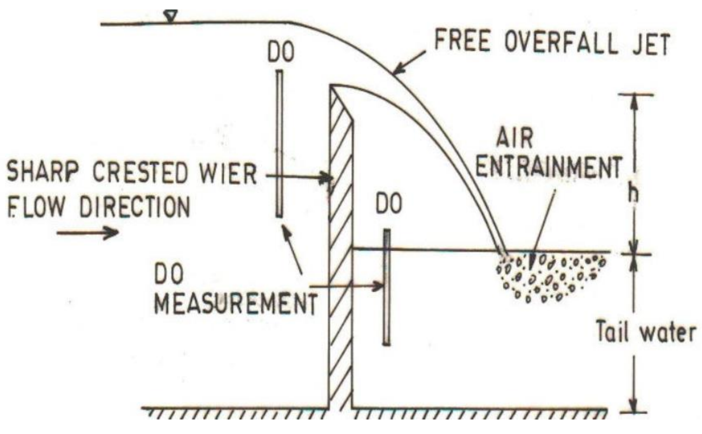


Fig-1.1 Diagram showing the aeration process by Weirs.

1.2 BACKGROUND OF AERATION IN WEIRS

Rindel and Gulliver (1991) equation compares the instantaneous rate of change of dissolved oxygen concentration (dc/dt) and the rate of air mass transfer

$$\frac{dC}{dt} = k_1 \frac{A}{V}(C_s - C) \quad \text{.......(1.1)}$$

where K_1 = liquid mass transfer coefficient

A/V= Specific area per unit volume

C_s = Saturation concentration of Dissolved Oxygen

C = Dissolved Oxygen concentration

Keeping C_s as constant and integrating the above equation, we get the relation between the upstream and downstream dissolved oxygen concentration equation

$$E = \frac{C_d - C_u}{(C_s - C_u)} = 1 - \frac{1}{r} \quad \text{......(1.2)}$$

Where, C_d= downstream dissolved oxygen concentration

C_u = Upstream dissolved oxygen concentration

C_s = Saturation Dissolved oxygen

E = Oxygen transfer efficiency

r = deficit ratio

1.3 COMPONENTS INFLUENCING AERATION EFFICIENCY

Various factors influencing the amount of oxygen transfer at the structure are as follows:

1.Water temperature- Because water temperature affects oxygen transfer efficiency, researchers have traditionally used a temperature correction factor. Gameson et al. (1958) specified the most commonly used temperature correction factor for hydraulic structures.

$$1 - E_{20} = (1 - E)^{\frac{1}{f}} \quad \text{....(1.3)}$$

where,

$$f = 1.0 + 0.02103(T - 20) + 8.261 * 10^{-5}(T - 20)^2 \quad \text{...(1.4)}$$

E_{20} = Air mass transfer efficiency at standard temp (20° C)

E = Air mass transfer efficiency at measured temp (t)

2.Water quality- the quality of water is also a very important factor for the oxygen transfer taking place at the hydraulic structure. If the water contains the active type of suspended solids, it will affect the aeration process. The active type of suspended solids slows down the diffusion process as well as surface tension at the interface thereby affecting the aeration in water.

3.Tailwater depth- tailwater depth is the depth of water available at the downstream side of the weir. It impacts the oxygen transfer efficiency at the weir. Greater time and greater path traveled by the bubble in the downstream pool will increase the chances of increased aeration efficiency. It was found by Avery and Novak (1978) that tailwater depth should be approximately 0.6 times the drop height to achieve maximum aeration efficiency. Drop height is the difference in water level between upstream and downstream of the weir.

4.Drop height- Drop height is the difference between the water level on the upstream and downstream sides of the weir. The aeration process increases as the drop height increases, this is due to the surface profile changes from smooth to rough profile, thereby entraining more air and increased efficiency.

5.Weir Discharge- variation in aeration efficiency can be seen with discharge. Oxygen transfer efficiency starts decreasing as the discharge starts rising. A decrease in aeration efficiency is seen due to growing discharge, bubble contact, and penetration time gets reduced. Thereby decrease in aeration efficiency.

1.4 BACKGROUND OF WEIRS

Weirs are the hydraulic structure that is built across the open channel (rivers) to obstruct the flow of water. They help in the measurement of discharge, adjust water levels for preventing flooding, and improve navigation of water and generation of power. They also act as a spillway of a dam.

Spillways are of two types:

1. Free flow spillway
2. Gated Spillway

Weirs come in the category of free-flow spillways. Free flow spillways are safe and straightforward than gated spillways (Lemperiere and Ouamane (2003)). The primary purpose of constructing a weir is to control water.

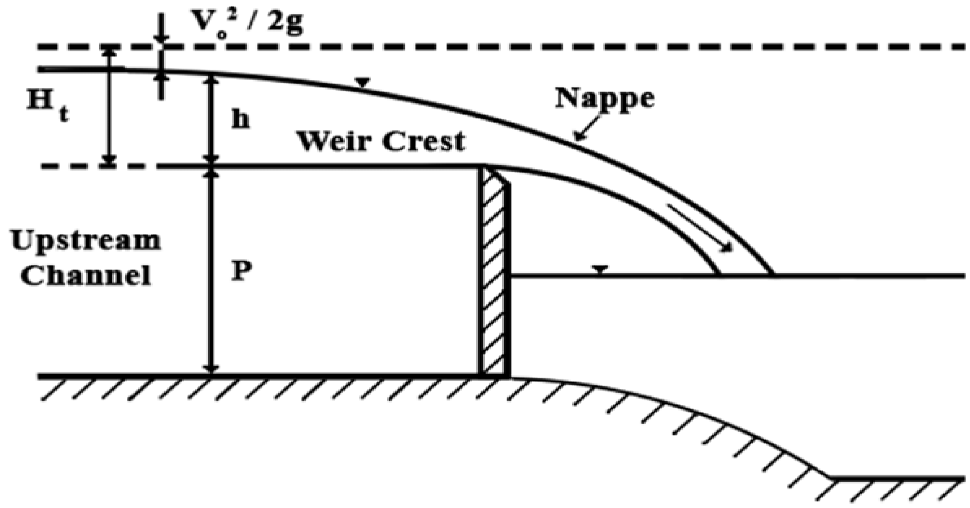


Fig-1.2 Diagram showing different components of Weir

1.5 TYPES OF WEIRS

Weirs are of many types based on:

1. **Geometry of weir**

a) Rectangular b) Triangular

c) Semi-circular d) Trapezoidal

e) Labyrinth f) Piano Key Weir

2. **Shape of the crest**

a) Sharp-crested weir

b) Broad- crested weir

c) Ogee-shaped weir

3. **Types of weirs based on the effect of the weir sides on the nappe**

a) contracted weir b) suppressed weir

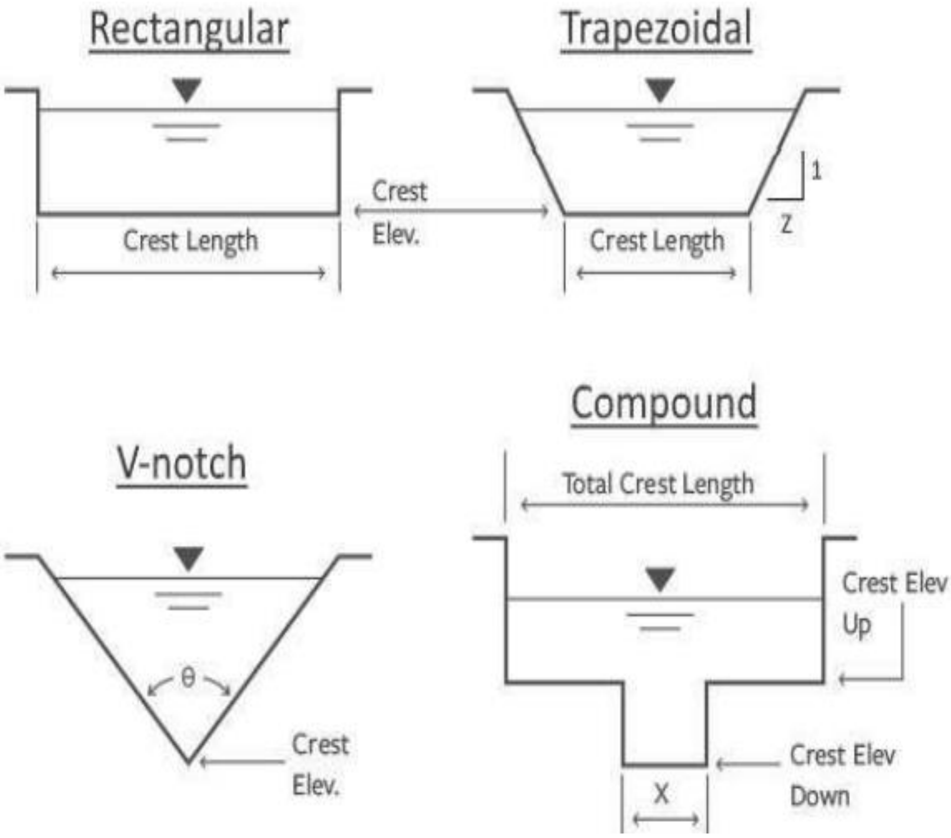


Fig-1.3 Diagram showing completely different geometries of the weir

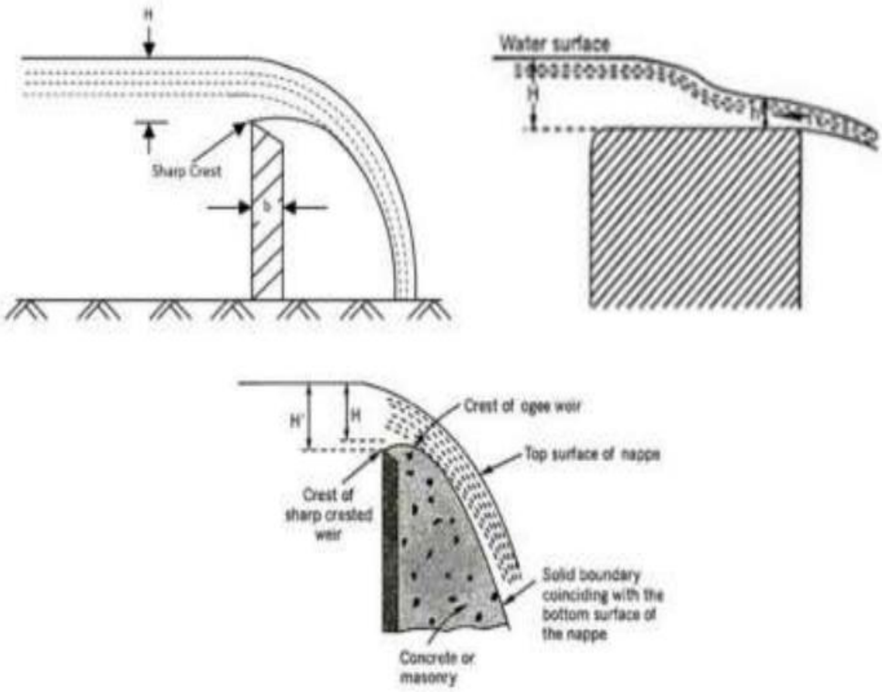


Fig-1.4 Diagram showing sharp-crested weir (left), broad crested weir (right), Ogee weir (bottom)

Fig-1.5 Diagram showing Labyrinth weir

Fig-1.6 Diagram showing Piano key Weir.

The weir's labyrinth design is intended to pass giant flow at the low head by enlarging the effective length in relation to the channel dimension. By modifying the Labyrinth weir's pure mathematics, its discharge potency is increased three to four times that of the linear weir. (Tullis, Amanian, and Waldron, 1995).

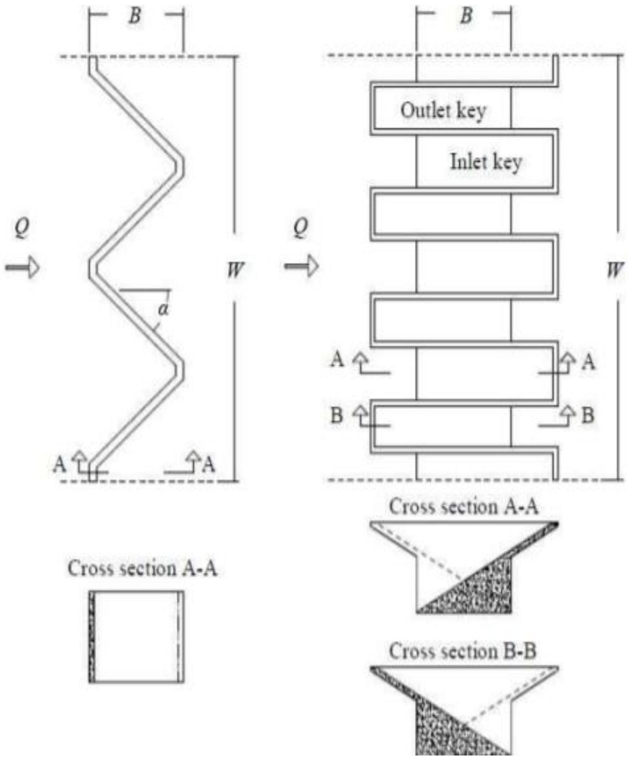


Fig-1.7 Drawing of trapezoidal Labyrinth weir (left) and Piano Key weir(right)

The discharge Efficiency of free flow weirs is heavily influenced by the shape of the weir. Discharge potency of free flow weirs is incredibly a lot of keen about the pure mathematics of the weir. Three ways to extend the discharge potency of weirs

By enlarging the weir's dimensions.

By lowering the height of the weir.

By increasing weir length with within the existing dimension of channel, dynamic linear to the nonlinear weir (Anderson,2011)

1.6 PIANO KEY WEIR

It is the modified geometry of the weir associated with the Labyrinth weir, as well as the use of overhangs, that reduces the basis length. It has an alternate rectangular plan and the added benefit of sloped bases.

Compared with Labyrinth weirs, Piano Key Weir has high discharge capacity, economic and small area requirements for its installation. For the same headwater level and crest footprint, the discharge efficiency of the Piano Key Weir was found to be 10% higher than that of the labyrinth weir. (Anderson & Tullis, 2011).

Piano Key Weirs are used as spillways in dam structures. Spillways are the structures that ensure the safe release of floodwater in dam structures. They act as a safety valve for a dam structure as it allows surplus water to move from upstream to downstream safely. Its capacity should be adequately designed to dispose of the surplus water that arrived due to flooding. It was found that around one-third of dam failure is due to improper spillway capacity (Schleiss, 2011). As a result, the piano key weir became very important in improving the spillway of the existing dam. Its distinct geometric features make it an excellent dam rehabilitation solution.

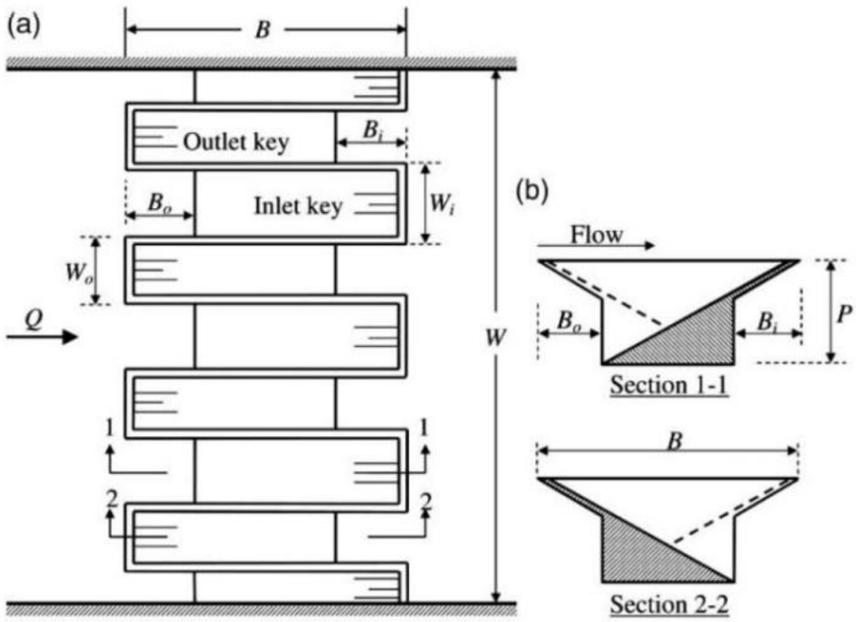


Fig-1.8 Diagram showing view of piano key weir.

1.6.1 TYPES OF PIANO KEY WEIR

Types of Piano Key Weir and its information

1. Type A Piano Key Weir
2. Type B Piano Key Weir
3. Type C Piano Key Weir
4. Type D Piano Key Weir

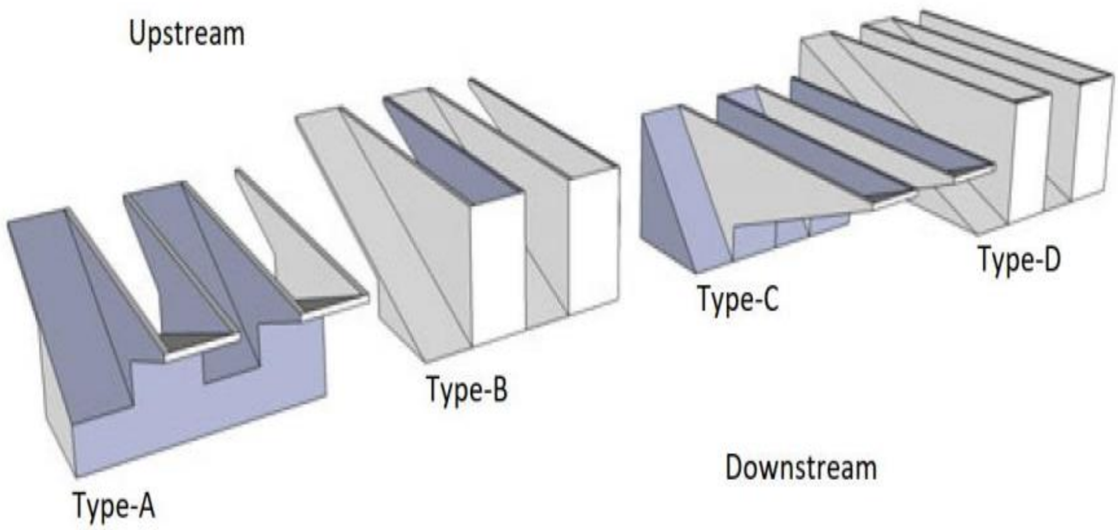


Fig- 1.9 Diagram showing different types of Piano Key Weir.

Overhangs are present on both the upstream and downstream sides of a Type-A Piano Key Weir. The Type-A Piano Key Weir is self-balancing due to the presence of an overhang on both sides. It is not necessary to have symmetrical overhangs. $20m^3$/sec/m is the specific discharge up to which Type-A Piano Key Weir economically accommodates (Schleiss,2011). This is used in existing Gravity dams to increase spillway capacity.

Type-B Piano Key Weir contains only upstream overhang. Due to less structural load, they can accommodate discharge up to $100m^3$/sec/m. They are less balanced as compared to Type-A Piano Key Weirs. So, they are used in new dam structures where they can be appropriately supported.

Only the downstream side of a Type-C Piano Key Weir has an overhang. The Type-D Piano Key Weir is an improved version of the Labyrinth weir. They are used when a larger footprint is required due to the greater availability of the area. It is employed in alluvial rivers. (Lemperiere, et al., 2011).

1.7 FLOW PATTERN OVER THE LABYRINTH WEIR

As we know, discharge flowing over the labyrinth weir increases with an increase in crest length. This condition is only valid when the Labyrinth weir is operated under a low head. As the upstream head increases, the flow pattern transitions through the following stages:

1. Fully Aerated – This flow falls over the entire length of the labyrinth weir's crest. The discharge capacity is unaffected by tailwater depth or nappe thickness during this phase.
2. Partially aerated- As the head increases, due to the convergence of opposing nappe and tailwater depth, flow changes from fully aerated to partially aerated. Because of nappe interference, aeration becomes difficult. The discharge coefficient is also reduced.
3. Suppressed- when no air is present under the nappe, then suppressed phase is reached. Its efficiency decreases and reaches like a linear weir. This phase should be avoided as the head increases more with an increase in discharge.

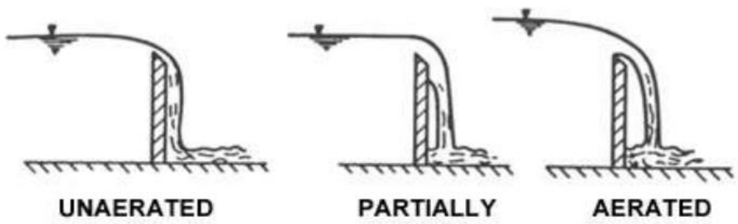


Fig-1.10 Diagram showing flow phases

1.8 FLOW PATTERN OVER THE PIANO KEY WEIR

At low head, the flow pattern shifts from partially clinging nappe to leaping nappe and then to springing nappe. The inlet key downstream crest is more supplied at the high head than the Piano Key lateral crest. For both high and low upstream heads, there is no change in supply to the upstream crest of the outlet key. As the head increases, a critical section develops along the downstream inlet key.

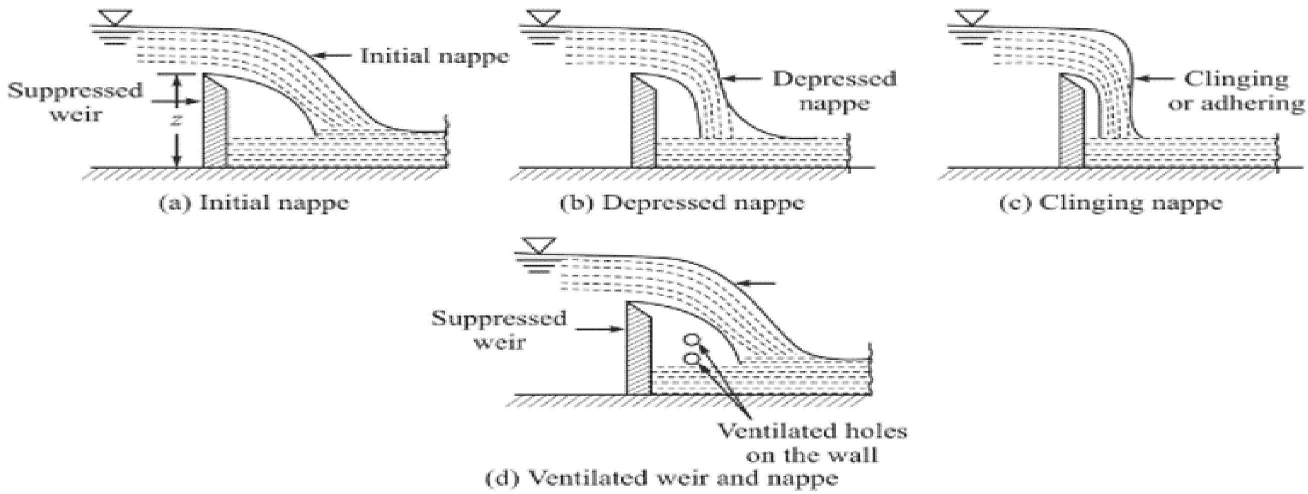


Fig-1.11 Different types of nappe

1.9 OBJECTIVES OF THE STUDY

The primary goal of this research is to determine the aeration performance of various types of Piano Key Weir models through experimental investigation. The objectives are as follows

1. To study the aeration performance of different types of Piano Key Weir models.
2. To study the variation in aeration efficiency for a particular discharge over the various Piano Key Weir models with various drop heights.
3. To make a comparison among all the models.

1.10 THESIS ORGANIZATION

This thesis is divided into five chapters, the first of which is this introduction. Chapter 2 presents the pertinent literature on the aeration efficiency of the Piano Key Weir. The third chapter discusses the methodology and instruments used to conduct the experimental investigation into the aeration efficiency of all types of Piano Key Weirs. The experimental study's findings are discussed in Chapter-4. The fifth chapter contains a summary of the thesis as well as its conclusions. It also includes the thesis's potential scope.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

This chapter describes the author's various works in the field of aeration of Piano Key Weir. Piano Key Weir is superior to Labyrinth Weir. When compared to the Labyrinth Weir, the Piano Key Weir has superior hydraulic performance and is more cost-effective. As PK Weirs are self-aerating and require a small footprint for its installation that is why it is gaining more importance in research.

2.2 LITERATURES

Following works have been done in the field for enhancing the aeration process to increase the dissolved oxygen content in the river or stream.

- **Hauser et al.(1995)** dealt with improving the oxygen deficit releases from the hydropower projects. Water from hydropower plants needs to be improved for various water quality parameters like dissolved oxygen. They also illustrated an improvement for the weir type to be used in hydropower projects. Laboratory, as well as field testing of a prototype, was done by the author. Laboratory testing was done to modify the labyrinth weir to make it cost-effective and check the aeration process. They used three types of prototypes in the experiment as TVA South labyrinth, TVA Chatuge infuser, and GBRA canyon labyrinth weir; their aeration results were plotted concerning drop height.

  They concluded that all modified weirs have high aeration efficiency as compared to the simple Linear weir. They also suggested that a safe and effective Labyrinth weir can be constructed by lowering length to half. They also founded that all prototypes tested can remove half of the oxygen deficit from the water.

- **Baylar and Bagatur (2000) studied the** effect of weir geometry on the aeration process. Weir geometry used were rectangular, triangular, trapezoidal, and semicircular weir. They found that oxygen transfer depends on jet shapes and jet shape depends on the geometry of the weir. They also discovered that triangular weirs have the highest aeration efficiency, while rectangular weirs have the lowest. The efficiency of semicircular and trapezoidal shapes was nearly equal. They proposed that the tailwater depth be set so that air bubbles can penetrate to the maximum depth for oxygen transfer.

- **Machiels et al.(2010)** The measurement of water depths, velocity, and discharge on the component of the Piano Key Weir was used to investigate various Piano Key Weir behaviors.
- **Schleiss (2011)** did a comparative study between Labyrinth and Piano Key Weir. For the design of the dam and any hydraulic structure, the basic criteria involved was that the structure must be hydraulically efficient and safe in operation just as free crest spillway. The discharge capacity was found to be directly proportional to crest length, hence various experiments and numerical calculations were done to increase the length of the crest. The Labyrinth weir is one such development that increases the crest length, thereby increasing the discharge up to a certain limit. He founded that the Piano Key Weir was hydraulically efficient and economical and requires less space for its installation as compared to the Labyrinth weir. He also concluded that the construction cost of the Piano Key Weir was also found to be less as compared to the Labyrinth weir.

  In contrast to the Labyrinth weir, the apex of the Piano Key Weir is inclined by turns both upstream and downstream, with chosen slopes of inlet and outlet keys. They have more overhang parts on both the upstream and downstream sides, which reduces the amount of land required for the construction of a Piano Key type weir. Schleiss also compares the Piano Key Weir to the corresponding Rectangular Labyrinth Weir and discovers that the Piano Key Weir has a higher discharge efficiency.

- **Anderson and Tullis (2012)** compared the laboratory physical model of the Piano Key Weir and Rectangular Labyrinth Weir. After experiments, they found that the Piano Key Weir had higher discharge efficiency.
- **Aras and Berkun (2012)** The significance of tailwater depth was investigated and discovered to be a very important parameter for the design of dam spillways and stilling basins. They discovered that tailwater depth played an important role in dissolved oxygen transfer. They analyzed smooth and stepped spillway models for dissolved oxygen transfer. They found that accurate estimation of tailwater depth was very important for the reduction of the cost of the hydraulic structure.
- **Pfister & Schleiss (2013)** gave the general design equation associating head and discharge. Crest length and weir height effects were also founded by them.

- **Kumar et al. (2014)** utilized the stepped cascade to increase the turbulence in the flowing water and increase the surface area so that air gets entrained in the water. They took the different quality of water samples and their aeration process was studied at stepped cascade. An experiment was done on different stepped sizes keeping the slope the same.

- **Machiel et al.(2014)** investigated to prove the design of a Piano Key Weir They demonstrated the effect of inlet key width, outlet key width, weir height, and overhang lengths on the discharge capacity of the Piano Key Weir.

- **Tiwari and Sharma (2015)** studied the turbulence phenomenon**.** Turbulence being a very complex phenomenon in open channel require to study for the design of Piano Key Weir. An acoustic doppler velocimeter was used to capture turbulence characteristics in an open channel.

- **Bilhan et al. (2016)** It was determined that the Labyrinth weir has a higher discharge capacity than the traditional conventional weir. To begin, in the dam where the spillway width was limited, Labyrinth weirs were used as the spillway. They investigated the hydraulic performance of a Labyrinth weir and discovered that it was dependent on its geometric features.

  They experimentally determine the discharge coefficients of a Circular Labyrinth weir and a sharp-crested Trapezoidal Labyrinth Weir. They discovered that the crest shape of the Labyrinth weir has a significant impact on discharge capacity. The Trapezoidal Labyrinth Weir was found to be more hydraulically efficient than the circular Labyrinth weir. They also came to the conclusion that the Trapezoidal Labyrinth weirs were also easy to construct. To reduce the impact of vibration on the labyrinth weir, nappe breakers were installed in the experiment by the author.

- **Denys (2017)** explained the various beneficial features of the Piano Key Weir. He gave an economic and safe solution as spillway capacity can be enhanced without increasing the dam wall.
- **Komal et al.(2017**) computed the experimental results of Piano Key Weirs in linear regression and Adaptive Neuro-Fuzzy Inference programming tools (ANFIS). ANFIS is one of the

artificial intelligence techniques which combines fuzzy logic and artificial neural network techniques. They compared, Linear regression model and ANFIS models for their best suitability for predicting aeration efficiency of piano key weir having rectangular and trapezoidal geometry. They concluded that ANFIS (trimf) and Linear regression were the most effective modeling techniques in the approximation of the oxygen transfer coefficient.

- **Belzner et al.(2017)** tested the models of Labyrinth and Piano Key Weir in both free flow and submerged conditions. They concluded that submergence sensitivity of Piano Key Weir and triangular Labyrinth weir was slightly less as compared to trapezoidal and rectangular Labyrinth weir.
- **Xinlei Guo et al.(2018)** discovered the discharge capacity of the Piano Key Weir. The proposed formula's and numerical model's results were compared. Both approaches were found to be effective in estimating discharge capacity and designing Type-A Piano Key Weirs.
- **Jaiswal and Goel (2019)** helped in the selection of weir geometry to be used in rivers to get the maximum oxygen transfer efficiency. The geometry which would enhance the aeration process and help in maintaining the dissolved oxygen in the water was concluded by them. They concluded that a triangular weir gives the best aeration potential when compared to the rectangular, semicircular, and trapezoidal shape of weirs.

  They also compared the triangular weir having different apex angles (30°, 45°, 90°, and 135°). They found that a triangular weir having a 30° apex angle was having higher oxygen transfer efficiency. The authors also compared the aeration potential of weirs, Labyrinth weir, and hydraulic jump. They found that weirs have better aeration efficiency.

- **Abhash and Pandey (2020)** concluded that Piano Key Weir was the best option for new as well as existing dams for dam rehabilitation. They helped in finding a new alternative that was efficient as well as economical for resolving the problem of reservoir storage capacity.

2.3 CONCLUSIONS

This chapter presents the various literature reviews cited over the aeration performance of different types of weir structures. It was discovered that Piano Key Weirs are more efficient and cost-effective than Linear and Labyrinth weirs. It was also determined that Piano Key Weirs are a new option for increasing dam spillway capacity for both existing and new dams.

CHAPTER 3

METHODOLOGY AND INSTRUMENTS USED

3.1 INTRODUCTION

The thesis includes laboratory experiments to determine the aeration efficiency of the Piano Key Weir's Type-A, Type-B, and Type-C models. All physical hydraulic models are tested in Hydraulics and Fluid mechanics laboratory in DTU to study the aeration efficiency of the various Piano Key Weir models.

3.2 EXPERIMENTAL SETUP

The experiment is being carried out at Delhi Technological University's hydraulics lab. The tests were carried out in a straight rectangular channel 10 m long, 0.516 m wide, and 0.6 m high. The channel is fed by a pump of 20 H.P connected with a series of pipes of 4-inch supply, delivering the discharges up to 50 L/s. The flume supply line calibrates by orifice meter (0.25% uncertainty), and discharge can adjust with a supply valve's help. The channel has massive tilting arrangements of a longitudinal slope of 2.5 % upstream and 0.5 % downstream of the main channel. Water enters the flume via the head tank, which contains a metal screen gate or baffle wall as well as a synthetic membrane or a manufactured film to ensure uniform flow conditions (to improve approach stream consistency). The water depth at the downstream site is controlled by a tailgate fixed at the trunk channel. The Plexiglas plate sheet is facilitated up to 6.5 m flume sidewalls for phenomenal assessment of the flow patterns on the whole channel height. Flume is equipped with a 4-20 mA ultrasonic level sensor (accuracy ± 0.2 % ±1 mm) instrumentation carriage and a pointer gauge of ± 0.1 mm, which is utilized to quantify the height of the water surface and crest elevations in various sections. Discharge is determined by 4-20 mA electromagnetic flowmeters (accuracy ± 0.2 % ±1 L/s). The ADV was used to calculate the mean flow velocities (Acoustic Doppler Velocimeter). ADV is extremely reliable for capturing turbulence characteristics in an open channel stream in the laboratory's research facility.

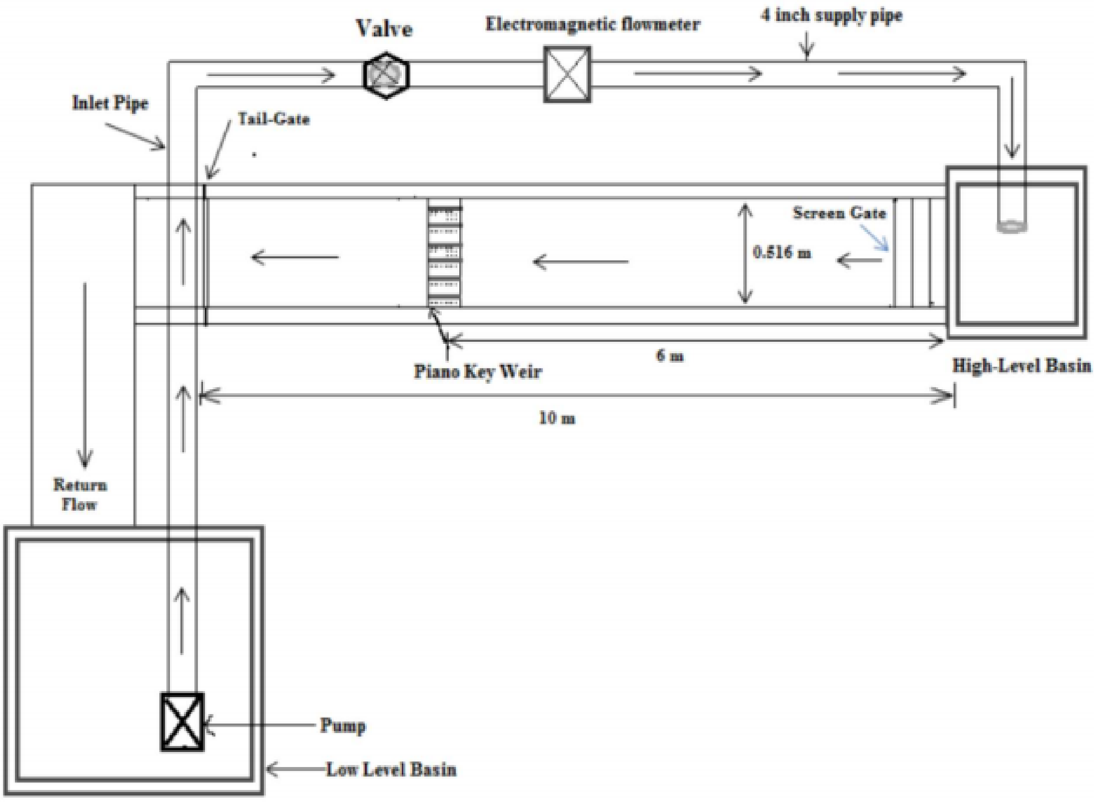


Fig-3.1 Systematic plan view of the experimental setup

3.2.1 VARIOUS APPARATUS USED IN THE EXPERIMENT

1. ADV (Acoustic Doppler Velocimeter)- It is based on the Doppler shift principle. Using this principle, velocity is measured in three dimensions. Acoustic signals are sent in the water of a particular frequency by transmitting probe. The receiver probe receives the returned signal after striking the particulate in the water. The change in the frequency of the received signal help in calculating the instantaneous velocity at a point.

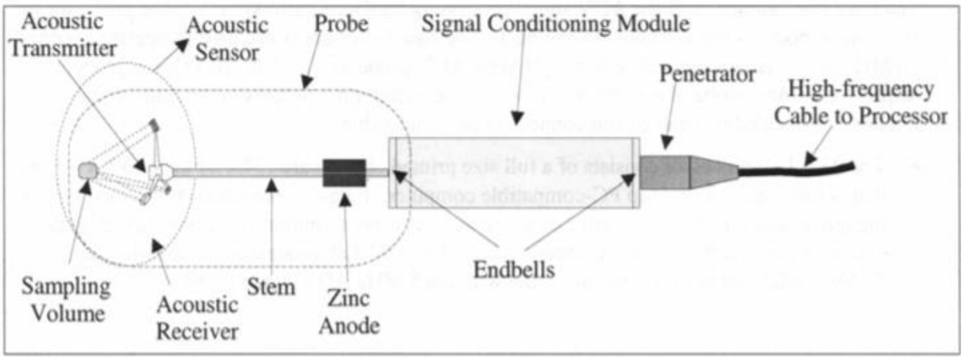


Fig-3.2 Diagram showing ADV probe

2. **Portable electronic meter-** This device is used to determine the amount of dissolved oxygen in water. The current flowing through the probe electrode is calibrated to a specific concentration of dissolved oxygen. These probes are easy to operate, reliable, easy to use and calibrate.

Fig-3.3 Portable electronic meter

3. **Winkler's method for dissolved oxygen measurement**

Procedure:

1. Take 300 ml of water sample in BOD bottle for DO determination.
2. Add 1ml (Sodium hydroxide + potassium iodide + Sodium azide) solution and 1ml $MnSO_4$
3. Shake the above solution by inverting it.
4. Brown precipitate will be formed.

Fig-3.4 Brown precipitate formation

5. Let the precipitate settle down.

Fig-3.5 Precipitate settlement

6. Add 1ml concentrated H_2SO_4 and dissolve the precipitate.

Fig-3.6 Dissolving the precipitate

7. Take the brown solution and add the freshly prepared starch solution.
8. This brown color will turn blue.

Fig-3.7 Brown color turning blue

9. Titrate with Standard Sodium Thiosulfate Solution (0.025N) until colorless.

Fig-3.8 Titration burette

10. Record the volume of sodium thiosulphate used, which gives the amount of dissolved oxygen in mg / litre.

4. **Pointer gauge-** It is a device used to take water surface elevation measurements.

3.3 PHYSICAL MODELING CONCEPT

Models (small scale) are the replica of the prototype. Models are built prior to the prototype to study in advance various parameters associated with the prototype. The hydraulic model helps in selecting the suitable design of prototypes. If the prototype and model have similar flow conditions based on geometric, kinematic, and dynamic similarities, they are said to have similar flow conditions. (Chanson,1999)

Geometric similarity- This type of similarity exists when the length, width, and depth ratio of prototype and model are the same.

$$L_r = \frac{L_p}{L_m} = \frac{W_p}{W_m} = \frac{D_p}{D_m} \qquad \text{……………………(2.1)}$$

Where p is a prototype (small scale) and m is model (large scale)

Kinematic similarity- this type of similarity exists when the ratio of the velocity of prototype and model are the same.

$$V_r = \frac{V_{p1}}{V_{m1}} = \frac{V_{p2}}{V_{m2}} = \frac{V_{p3}}{V_{m3}}$$ …………………..(2.2)

Dynamic similarity – This type of similarity exists when the ratio of forces in prototypes and models are the same.

$$F_r = \frac{f_{p1}}{f_{m1}} = \frac{f_{p2}}{f_{m2}} = \frac{f_{p3}}{f_{m3}}$$ ……………………(2.3)

$$V_r = \sqrt{L_r}$$ …………………….(2.4)

$$Q_r = V_r L_r{}^2 = L_r{}^{\frac{5}{2}}$$ ……………………(2.5)

$$F_r = M_r = \frac{L_r}{T_r{}^2} = \rho_r L_r{}^3$$ ……………………..(2.6)

As the flow in the stream is open channel flow. It is also governed by gravity force.

So, the Froude number plays a necessary role. It helps in maintaining the dynamic similarity of prototypes and modeling.

Froude Number-it is that the quantitative relation of inertia force to gravity force.

$$Froude\ No = \frac{V}{\sqrt{g}\,\sqrt{L}}$$ ……………………(2.7)

Where V is velocity

g is the acceleration due to gravity

L is length

3.4 MODEL DIMENSIONS

All models of the piano key weir are made from an acrylic sheet of a thickness of 6mm.

Dimensions of Piano key models (Testing models)

L/W= 5

Table-3.1 Model dimensions

S.No	Configurations	Type-A PKW	Type-B PKW	Type-C PKW
1.	L	167.5cm	168.5cm	168.6cm
2.	W_i	8.8cm	8.8cm	8.8cm
3.	W_o	6.9cm	6.9cm	6.9cm
4.	B	28cm	34.3cm	21.5cm
5.	B_i	9.33cm	0	14.3cm
6.	B_o	9.33cm	22.86cm	0
7.	No. of keys(N)	3	3	3

3.5 EXPERIMENTAL PROCEDURE

1. Place the Piano key weir model to be tested in the flume.
2. Fix the model with clay properly so that water passes over the weir, reducing leakages so that accuracy of measurements can be maintained.
3. Place ADV and pointer gauge in the flume for recording measurements.
4. ADV is attached to horizon ADV software in the laptop from where velocity measurements are recorded.
5. Start the pump and allow water to flow over the weir such that nappe formation takes place.
6. The discharge is varied as 3, 5,6,7,10,12 and 15 l/sec on four different drop heights (0 cm,5cm,10 cm and 15cm) of the models.
7. ADV is used to record velocity upstream and downstream of the weir for each discharge.
8. 8.For the same above discharge, pointer gauge is used to measure the water level of upstream & downstream of the weir.
9. A BOD bottle is used to collect samples for DO calculations upstream and downstream of the weir.

10. Winkler's method is performed on the collected samples for DO measurement.
11. Recheck of DO values is done by electronic DO meter and all data are recorded on excel sheets.
12. Repeat the preceding steps on all three types of Piano Key Weir models (Type-A, Type-B, and Type-C).

(a)

(b)

Fig-3.9 (a) and (b) showing flow and nappe formation over Type-A P K Weir

Type-A PK Weir model has cantilever portion in upstream as well as the downstream side. The nappe is a water jet that passes over a weir structure as shown in Fig-3.9 . To ensure optimal hydraulic performance, the behavior of the nappe should be considered during the design of weirs and spillways. The geometry of the weir, as well as the aeration condition of the nappe, have an impact on hydraulic performance (Crookston & Tullis, 2013)

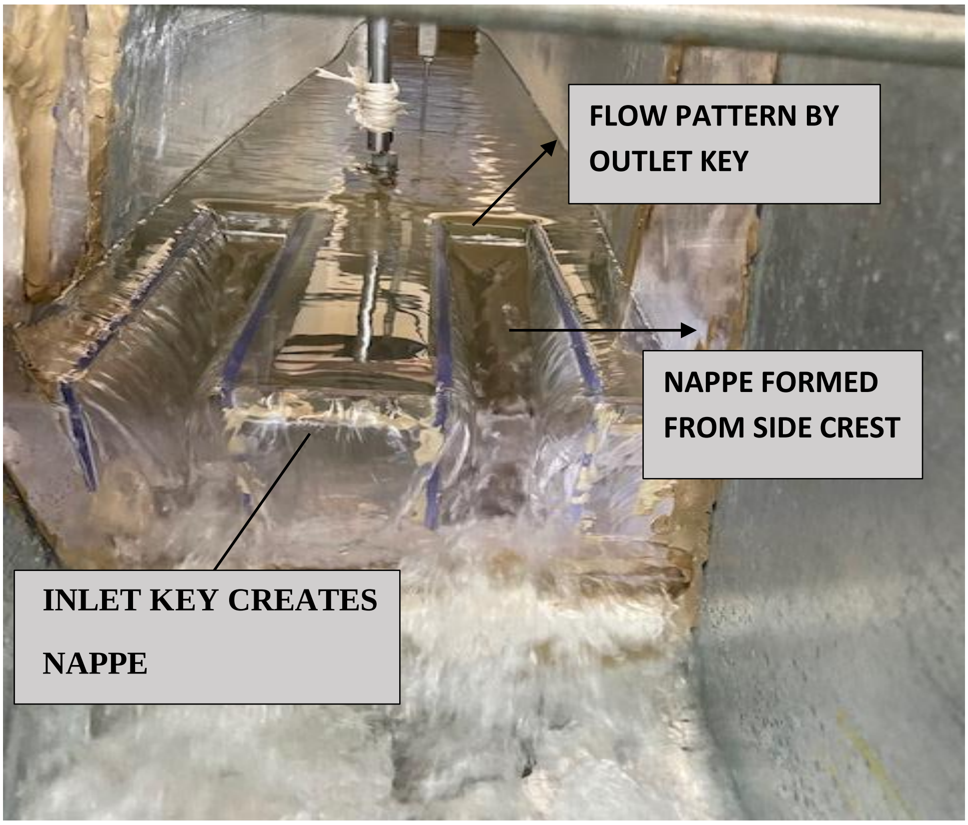
In the case of a PK Weir, flow over the lateral and downstream inlet key crests forms a continuous curtain with an enclosed air pocket, i.e. a nappe (Denys et al., 2017). The overflow location along the crest, and thus the fall height, determine the nappe thickness. Flows from opposite lateral crests may collide at higher flows or in narrow outlet keys, but this has no effect on discharge efficiency if free flow conditions are followed (Machiels, 2012).

For PKWs, three typical nappe behaviours are observed, and they can all occur concurrently at different locations along the lateral crests for a specific flow (Machiels, et al., 2011) .

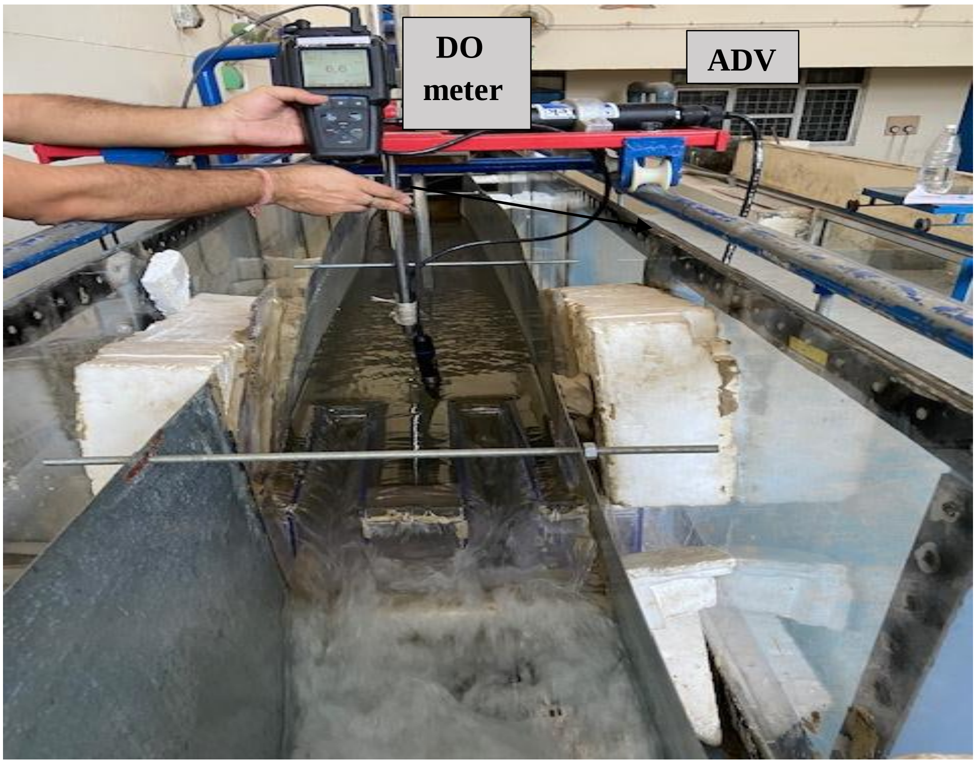
A clinging nappe occurs at low heads or velocities when there is no air beneath the nappe and it clings to the crest and the downstream wall of the structure; a depressed or leaping nappe occurs at higher heads when the nappe begins to pull away from the wall but remains in contact with the downstream end of the crest.

Under the nappe, the pressure is generally negative, and the space is only partially ventilated or aerated. At even higher heads, the nappe separates from the crest's upstream edge, resulting in a free or springing nappe. The atmospheric pressure beneath the nappe, which is typically obtained by ventilating a weir, distinguishes the nappe. The width of the crest and the depth of the headwaters determine the transitions from clinging to leaping and further to springing.

(a)



(b)



(c)

Fig-3.10 (a), (b)&(c) showing flow and nappe formation over Type-B P K Weir

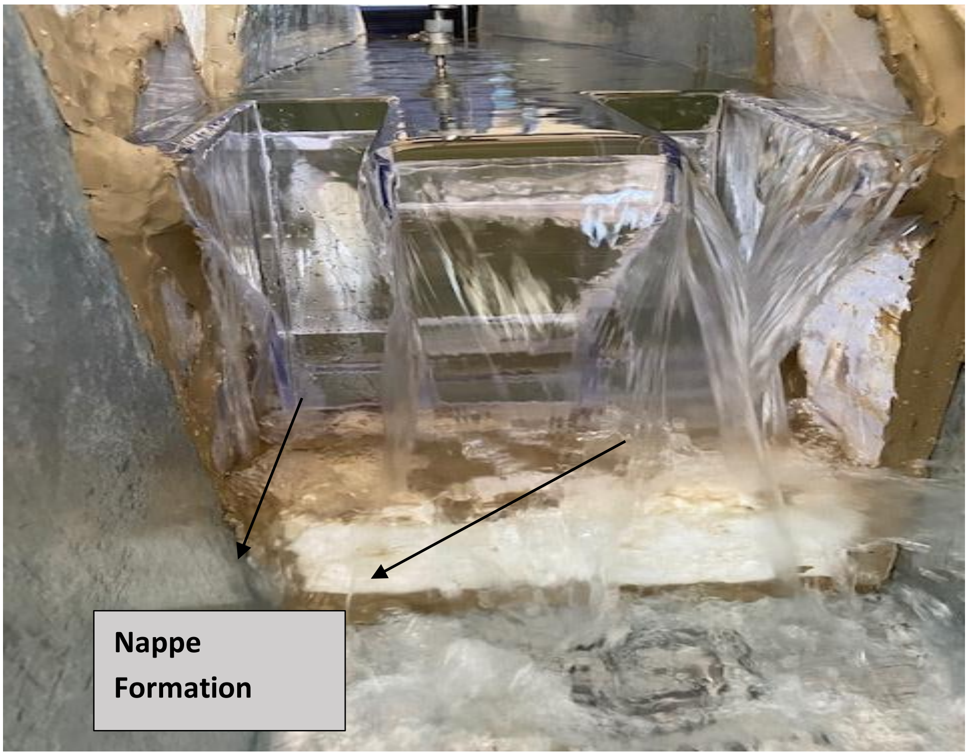
The flow over Type-B PK Weir is divided into three sections.

1. Flow over the upstream crest into the outlet key
2. Flow over the downstream crest into the inlet key.
3. Lateral flow over the crest into the inlet key.

The interaction of the three discharges above results in a complicated three-dimensional flow, as illustrated in Fig-3.10 (b). With higher heads, the amount of spilled water from the side crest entering the outlet key increases, lowering hydraulic efficiency until the two discharging nappes mutually interact, forming a single nappe and causing the PK Weir to behave like a linear weir.

When the water flowed over the sidewall crest, two nappes were discovered. The first, further upstream, is attached to the side crest and has no aeration beneath it. The second, on the other hand, is aerated and detached (or separated) from the side crest. The configuration of the weir and the discharge determine its location. The separation increases as the discharge increases.

(a)



(b)

Fig-3.11 (a)&(b) showing flow and nappe formation over Type-C P K Weir

Type-C Piano Key Weir model has cantilever portion on the downstream side. Nappes formed are shown in Fig-3.11. Along with floating debris, debris from below the surface may approach the PK Weir in riverine settings. Such debris may accumulate beneath the upstream overhangs of a typical Type-A PK Weir and must be manually removed. Type-C PK Weirs with only downstream overhangs have been shown to collect less driftwood. (Belzner et al. 2017).

CHAPTER 4

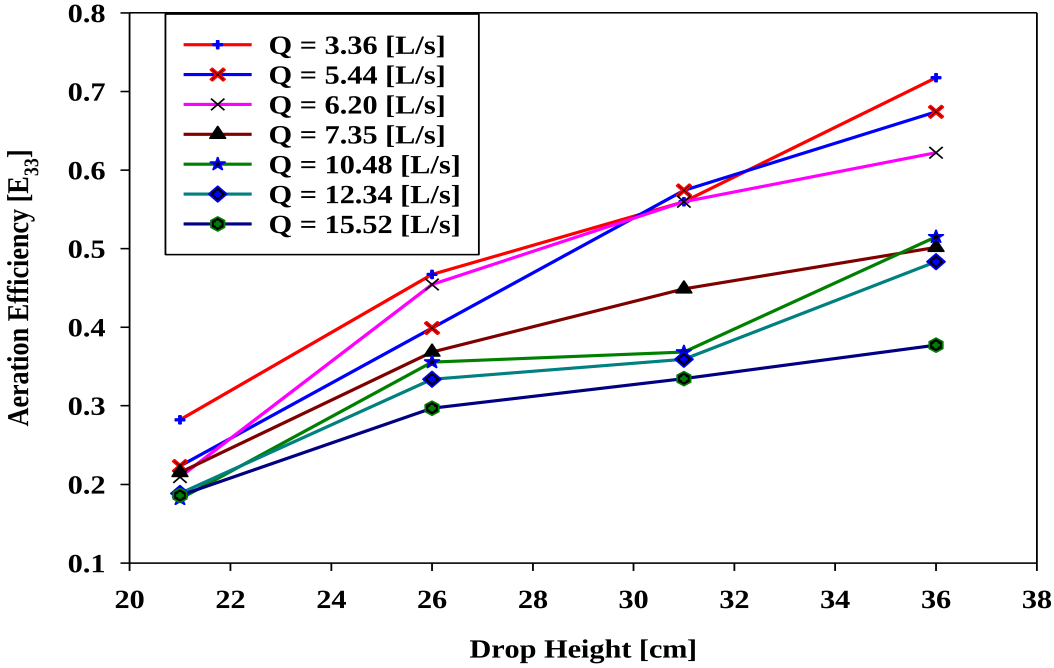
RESULTS AND DISCUSSION

4.1 GENERAL

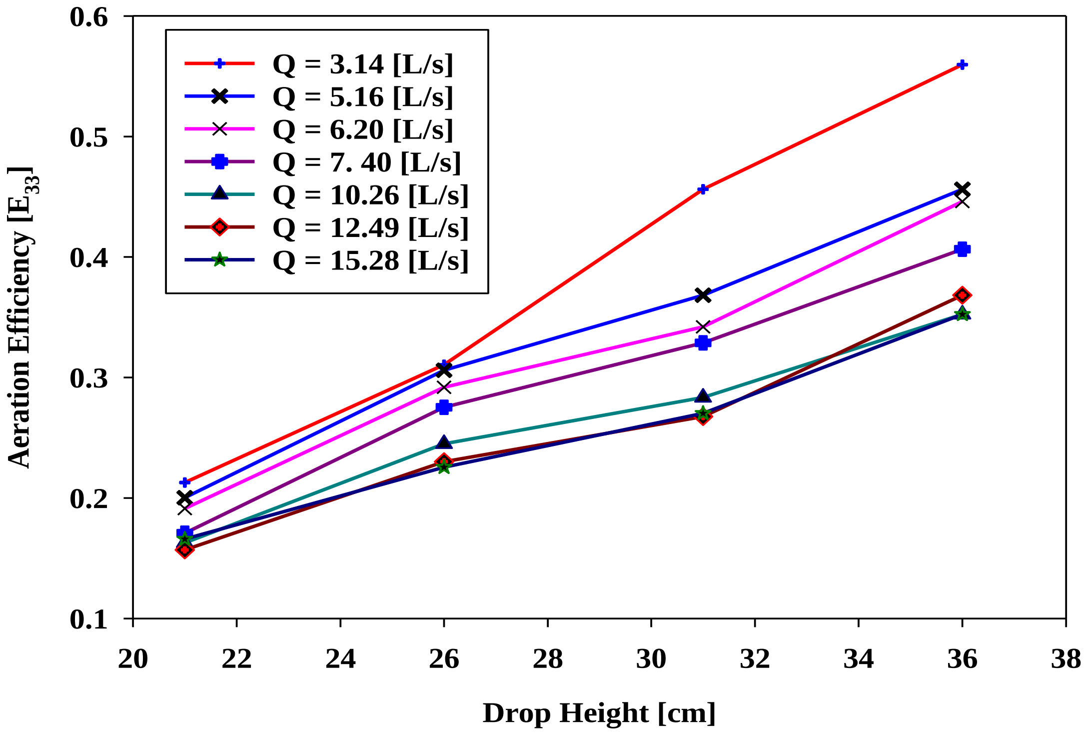
Following are the results of a series of experiments on all three types of physical hydraulic models. To gain a better understanding of the results obtained from the analysis, the results are discussed in the form of plots.

4.2 THE EFFECT OF DIFFERENT DROP HEIGHTS ON AERATION EFFICIENCY

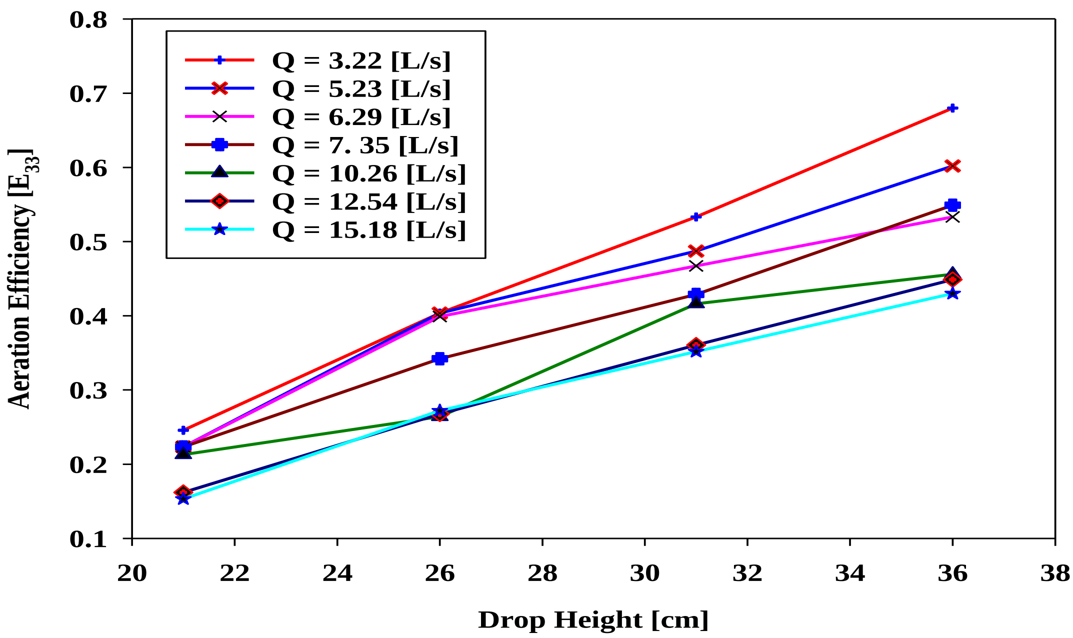
The results of the experiments are shown in the figures below as E_{33}V/s drop height. For constant discharge values, the results are shown as plots of aeration efficiency (E_{33}) versus drop height. The following points illustrate the explanation of the obtained result.



(a) Type-A



(b) Type-B



(c) Type-C

Fig-4.1 Variation in Aeration Efficiency as a Function of Discharge and Drop Height for (a) Type-A, (b) Type-B, and (c) Type-C Piano Key Weirs

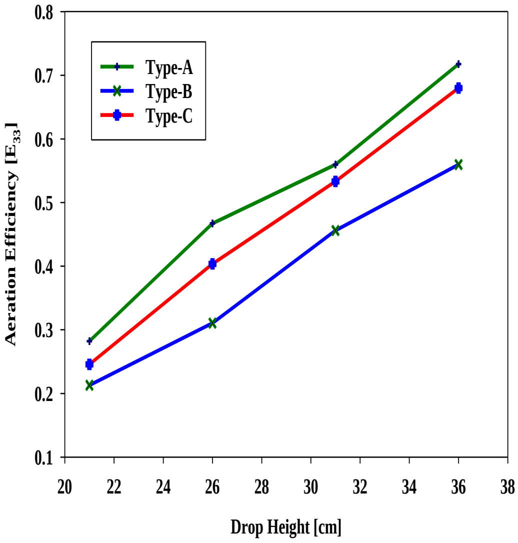
Fig-4.1 shows that the aeration efficiency of all three types of Piano Key Weirs. An increase in oxygen transfer efficiency is observed conspicuously with drop height for all model types (Type-A, Type-B, and Type-C). The drop height is the difference in the water level of the upstream and downstream sides of the weir. Aeration increases as drop height increases. Deeper penetration of the bubbles formed and their longer contact time with increased drop height will lead to higher aeration values. It is also worth noting that aeration efficiency decreases as discharge value increases. As discharge increases, bubble penetration and contact time in the downstream water pool decrease, resulting in decreased aeration efficiency.

In the Type-A model, the discharge (Q)= 3.36 L/s has the highest aeration values. The aeration efficiency is 0.2820 at a drop height of 21 cm. Aeration efficiency is calculated to be 0.7175 at a drop height of 36 cm. It is also worth noting that discharge (Q)=15.52 L/s has the lowest aeration values for the Type-A model. The aeration efficiency is 0.1858 at a drop height of 21 cm. Aeration efficiency is found to be 0.3771 at a drop height of 36 cm.

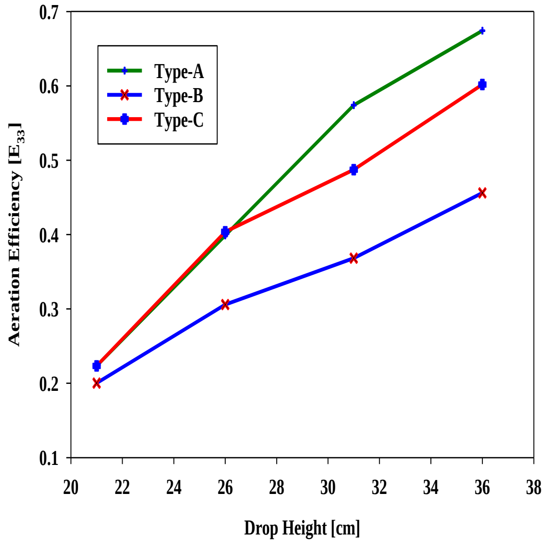
It can be seen that the discharge (Q)= 3.14 L/s has the highest aeration values for the Type-B model. Aeration efficiency is calculated to be 0.2128 at a drop height of 21 cm. Aeration efficiency is calculated to be 0.5597 at a drop height of 36 cm. The discharge (Q)=15.28 L/s has the lowest aeration values, according to the Type-B model figure. At a drop height of 21 cm, the aeration efficiency is 0.1659. Aeration efficiency is calculated to be 0.3525 at a drop height of 36 cm.

And as per the Type-C model, the discharge (Q)= 3.14 L/s has the highest aeration values. Aeration efficiency is calculated to be 0.2456 at a drop height of 21 cm. The aeration efficiency is 0.6798 at a drop height of 36 cm. At the discharge (Q)=15.28 L/s, the Type-C model has the lowest aeration. At a drop height of 21 cm, the aeration efficiency is 0.1531. Aeration efficiency is found to be 0.4301 at a drop height of 36 cm.

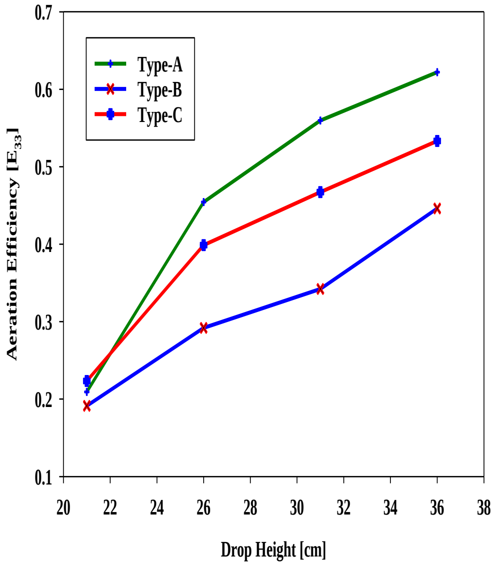
4.3 AERATION PERFORMANCE VARIATION WITH DROP HEIGHT



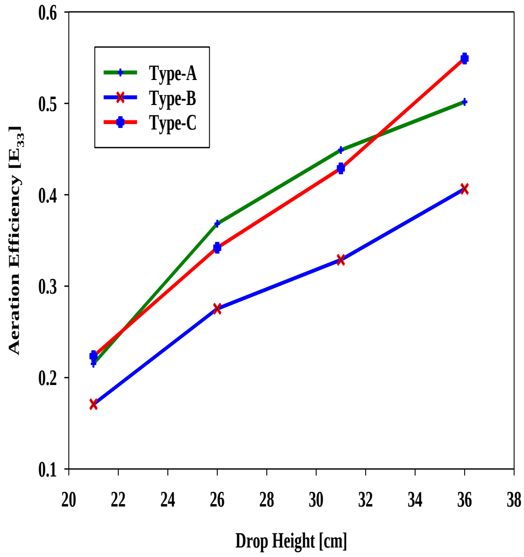
(a) Q = 3.2 [L/s]



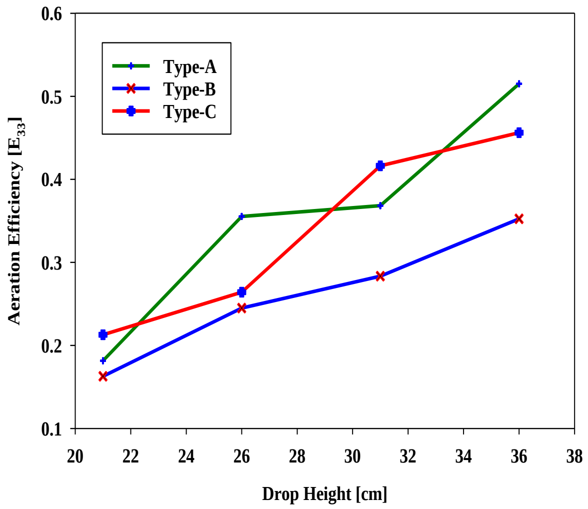
(b) Q = 5.3 [L/s]



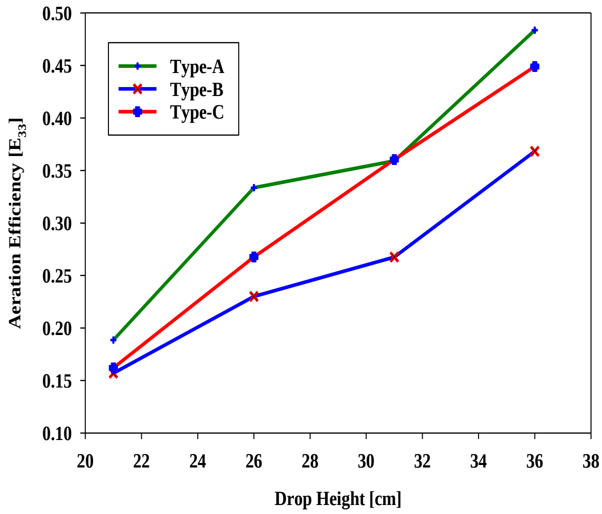
(c) Q = 6.2 [L/s]



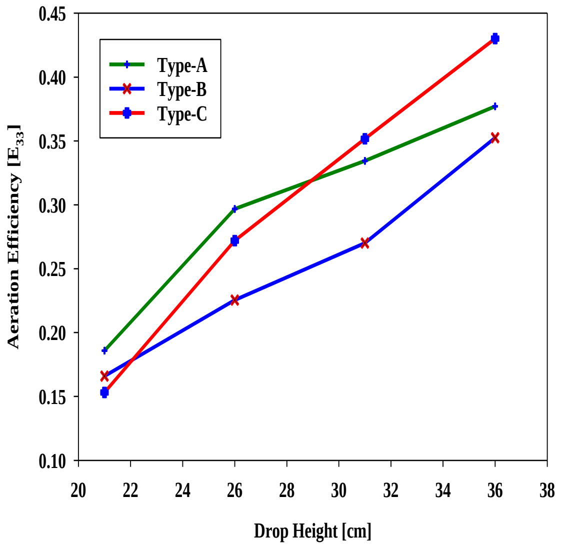
(d) Q = 7.4 [L/s]



(e) Q = 10. 32 [L/s]



(f) Q = 12.50 [L/s]



(g) Q = 15.30 [L/s]

Fig- 4.2 Aeration performance variation for all three models with Drop height for **(a)**Q=3.2L/s **(b)**Q=5.3L/s**(c)**Q=6.2L/s**(d)**7.4L/s**(e)**Q=10.32L/s**(f)**Q=12.50L/s**(g)**Q=15.30L/s

Fig- 4.2 (a) to (g) shows variation in aeration performance of all three models. The aeration efficiency of all three models increases with drop height but decreases with discharge. For a given discharge value, the Type-A Piano Key Weir model has the highest aeration efficiency and the Type-B Piano Key Weir model has the lowest. The aeration value of the Type-C Piano Key Weir model comes in between the type-A and type-B Piano Key Weir model.

The Piano Key Type-A model and the Type-C Piano Key Weir models have downstream overhang portions where free jet formation occurs. This downstream overhang gives the advantage to these models. When the free jet hits the downstream water pool, it causes turbulent mixing and air entrainment, resulting in oxygen transfer.

At the constant discharge value, Q=3L/s, the aeration efficiency of all three types of Piano Key Weir models is compared in **Fig-4.2(a).** The Type-A model clearly has the best aeration efficiency. The Type-A model's aeration efficiency is 0.2820 at a drop height of 21cm and 0.7175 at a drop height of 36cm.

It should also be noted that the Type-B Piano Key Weir has a low aeration efficiency. At a drop height of 21cm, the aeration efficiency is found to be 0.2128. At a drop height of 36 cm, the aeration efficiency is 0.5597. The Type-C model's aeration values are in the middle of those of the Type-A and Type-B Piano key weir models.

At the constant discharge value, Q=5L/s, the aeration efficiency of all three types of Piano Key Weir models is compared in **Fig-4.2(b).** The Type-A model has the most efficient aeration. At a drop height of 21cm, the aeration efficiency is found to be 0.2233. At a drop height of 36 cm, the aeration efficiency is 0.6741.

It's also worth noting that the Type-B Piano Key Weir model has a low aeration efficiency. At a drop height of 21cm, the aeration efficiency is 0.2002. At a drop height of 36 cm, the aeration efficiency is calculated to be 0.4561. The Type-C model's aeration values are in the middle of those of the Type-A and Type-B Piano key weir models.

At the constant discharge value, Q=6L/s, the aeration efficiency of all three types of Piano Key Weir models is compared in **Fig-4.2(c).** The Type-A model clearly has the best aeration efficiency. At a drop height of 21cm, the aeration efficiency is found to be 0.2092. At a drop height of 36 cm, the aeration efficiency is calculated to be 0.6221.

It is also interesting to note that the Type-B Piano Key Weir model has a low aeration efficiency. Aeration efficiency is found to be 0.1912 at a drop height of 21cm. Aeration efficiency is calculated to be 0.4461 at a drop height of 36 cm. The aeration values of the Type-C model are in the middle of those of the Type-A and Type-B Piano key weir models.

Fig-4.2(d) compares the oxygen transfer efficiency of all three types of Piano Key Weir models at constant discharge, i.e., Q=7L/s. It can be seen that the Type-A model has the highest value for oxygen transfer efficiency. Aeration efficiency is calculated to be 0.2150 at a drop height of 21cm. Aeration efficiency is determined to be 0.5017 at a drop height of 36 cm. It is also worth noting that the Type-B Piano Key Weir model has a low aeration efficiency. Aeration efficiency is calculated to be 0.1708 at a drop height of 21cm. Aeration efficiency is calculated to be 0.4065 at a drop height of 36 cm. The aeration values of the Type-C model are in the middle of those of the Type-A and Type-B piano key weir models.

The aeration efficiency of all three types of Piano Key Weir models is compared in **Fig-4.2(e)** at the constant discharge value, Q=10L/s. It is clear that the Type-A model has the best aeration efficiency. It is found to be 0.1814 at a drop height of 21cm and 0.5150 at a drop height of 36 cm. The aeration values of the Type-C model are in the middle of those of the Type-A and Type-B piano key weir models. It is also worth noting that the Type-B Piano Key Weir model has a low aeration efficiency. Aeration efficiency is found to be 0.1628 at a drop height of 21cm. The aeration efficiency is 0.3525 at a drop height of 36 cm.

Fig-4.2(f) compares the aeration efficiency of all three types of Piano Key Weir models at constant discharge, i.e., Q=12L/s It is clear that the Type-A model has the best aeration efficiency. Aeration efficiency is found to be 0.1885 at a drop height of 21cm. The aeration efficiency is 0.4835 at a drop height of 36 cm. It is also worth noting that the Type-B Piano Key Weir model has a low aeration efficiency. Aeration efficiency is calculated to be 0.1569 at a drop height of 21cm. Aeration efficiency is calculated to be 0.3683 at a drop height of 36 cm. The aeration values of the Type-C model are in the middle of those of the Type-A and Type-B Piano Key Weir models.

Fig- 4.2(g) compares the aeration efficiency of all three types of Piano Key Weir models at constant discharge, i.e., Q=15L/s It is clear that the Type-A model has the best oxygen transfer efficiency. At 21cm drop height, the oxygen transfer efficiency is observed to be 0.1858. The aeration efficiency is 0.3771 with a drop height of 36 cm. It is also worth noting that the Type-B Piano Key Weir model has a low oxygen transfer efficiency. At a drop height of 21cm, the oxygen transfer efficiency is found to be 0.1659. Aeration efficiency is calculated to be 0.3525 at a drop height of 36 cm. The aeration values of the Type-C model are in the middle of those of the Type-A and Type-B Piano Key Weir models.

4.4 CONCLUSIONS

The Type-A Piano Key Weir model has the highest aeration efficiency of all the Piano Key Weir models tested. It is the best-suited geometry for dam rehabilitation for existing as well as new dams. The Type-A Piano Key Weir geometry has a cantilever overhang on both the upstream and downstream sides which are advantageous for trapping oxygen in the water. Aeration is a very important process for maintaining dissolved oxygen, which is a very important water quality parameter for the survival of aquatic as well as population dependent on freshwater. It is the optimal weir geometry for maximum aeration efficiency. After Type-A Piano Key Weir, Type-C Weir geometry proved to be good for aeration. Type-B Piano Key Weir model shows the least aeration efficiency among all the models.

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 SUMMARY

Laboratory experiments were conducted to determine the aeration efficiency of three different types of Piano key Weir models. On four different drop heights of the models, the discharge was varied from 3 to 15 L/sec.

5.2 CONCLUSIONS

The following significant findings can be drawn from this research.

1. It is discovered that drop height is an important parameter governing oxygen transfer at the weirs. It can be seen logically that oxygen transfer efficiency at the weir will increase as drop height increases.
2. The oxygen transfer is affected more significantly with drop height as compared to increasing the discharge over all the drop height.
3. The geometry of the PK Weir significantly affects the oxygen transfer efficiency over the weir structure as a result Type-A PK Weir has maximum aeration efficiency whereas Type-B has the lowest aeration efficiency at a particular discharge value.
4. Important factors for aeration are found to be discharged, drop height, and tailwater depth. Air bubbles formed should penetrate to the maximum possible depth to enhance the aeration process.

5.3 FUTURE SCOPE

Improved observation of the overflow nappe is required to assess the accuracy of the air demand estimation.

Given that water, mass dampens the natural frequency of the structure, the effect of increased downstream water levels on vibration can be assessed.

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