STUDY OF HYDRAULIC JUMP FOR DIFFERENT SEQUENT DEPTH RATIOS

A PROJECT REPORT

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Submitted by:

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled "**STUDY OF HYDRAULIC JUMP FOR DIFFERENT SEQUENT DEPTH RATIOS**" in partial fulfilment of the requirements for the award of the MASTER OF TECHNOLOGY and submitted in the Civil Engineering Department of the Delhi Technological University, Delhi is an authentic record of my own work carried out during a period from August 2021 to May 2022 under the supervision of Prof. S. Anbukumar, Professor, Civil Engineering Department, Delhi Technological University, Delhi, India.

The matter presented in this thesis has not been submitted by me for the award of any other degree in this or any other information

(DAISY SINGH)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

(Prof. S. Anbukumar

Supervisor

Date: 30-05-2022

ABSTRACT

When the flow takes place from supercritical flow to subcritical flow, the hydraulic jump occurs. A hydraulic jump occurs when a supercritical stream meets a subcritical stream of sufficient depth, and it is usually accompanied by large-scale turbulence at downstream, which dissipates the majority of the kinetic energy in the supercritical flow. The hydraulic jump majorly acts as the dissipator of the energy that dissipates the excess energy of water flowing downstream in different types of hydraulic structures.

This study investigates the hydraulic jump characteristics in a rectangular open channel flume provided with sluice gates at both the ends of the flume. The experimental study was conducted on a 10 m long rectangular flume having a width of 0.30 m and height of 0.40 m and the two-sluice gate is 3 m apart.

This Project was mainly carried out to understand the different characteristics of the hydraulic jump, studied both analytically and experimentally, including various result in the form such as conjugate depth relation ($\frac{y_2}{y_1}$), length of the jump, relative loss of energy ($\frac{E_L}{E_1}$) of the jump, and water profile of the jump. In total, 15 number of sample experiments was performed with inflow Froude's number (F_1) varying from 1.55 to 1.73. It is concluded that sequent depth ratio and length of the jump decreases with increase in the slope while the relative energy loss ($\frac{E_L}{E_1}$) increases with increase of the pre-jump Froude's number (F_1) for different slopes. The height of the jump increases with the increase in the length of the jump forming the M_3 water profile of the jump. The discharge at each point is nearly equal, indicating that there is a continuous flow. This experimental study is in agreement with previous studies of water profile done by various researchers.

ACKNOWLEDGMENT

This project necessitated a lot of guidance and help from a lot of individuals, and I feel myself fortunate to have gotten it all at once.

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DAISY SINGH

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LIST OF SYMBOLS

B: Width of the rectangular flume

Q: Discharge

E_1: Specific Energy that occurs before the jump

E_2: Specific Energy that occurs after the Jump

E_L: Loss of the Energy of the jump

$\frac{E_L}{E_1}$: Relative Energy Loss

F_1: Initial Froude number

F_2: Final Froude number

g: Acceleration due to gravity

H_j: Jump Height

L_j: Jump Length

V_1: before the jump, mean flow velocity

V_2: after the jump, mean flow velocity

Y_1: Depth of the flow that occurs before the jump

Y_2: Depth of flow that occurs after the jump

$\frac{E_2}{E_1}$: Efficiency of jump.

CHAPTER - 1

INTRODUCTION

1.1 HYDRAULIC JUMP

When a supercritical fluid goes to a subcritical state, that is the time when a hydraulic jump takes place. When a velocity of high intensity, low-depth stream bumps into velocity of low intensity, high-depth stream (supercritical flow), the former's surface rises abruptly (subcritical flow). This is referred to as a hydraulic jump, and it is usually accompanied by large-scale turbulence, which dissipates the majority of the kinetic energy in the supercritical flow. This can happen in a canal beneath a regulating sluice, at the bottom of a spillway, or where a steep channel slope flattens out abruptly.

Rectangular channels as well as other channels which are non-rectangular in shape can experience the formation of the jump. The non-rectangular channels can be triangular channels, parabolic channels, trapezoidal channels or instantly expanding channels.

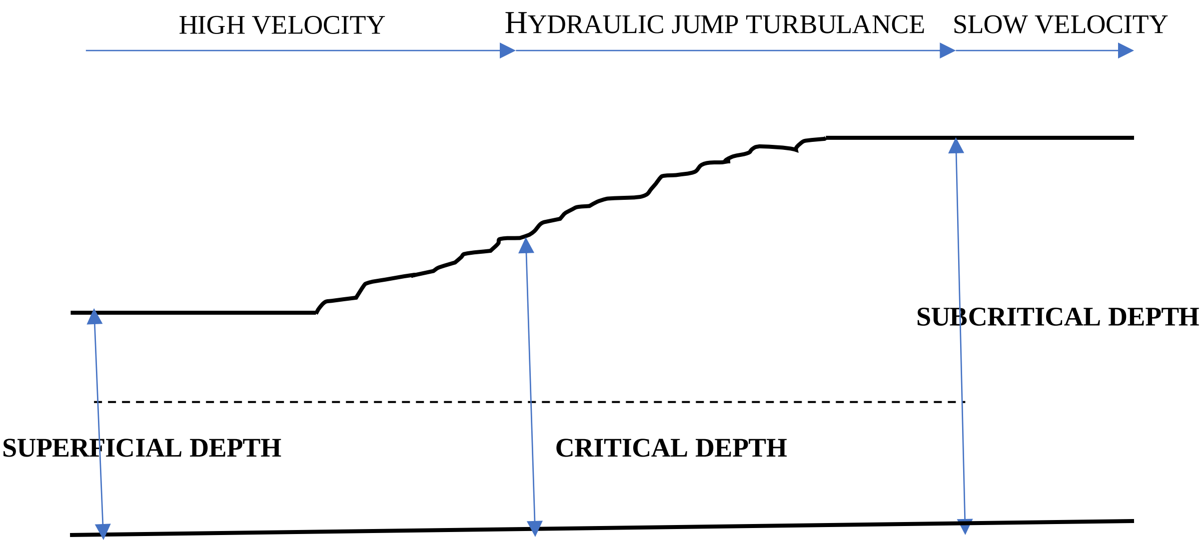

Fig. 1.1: Hydraulic Jump

Water gets a lot of energy and velocity when it falls over a spillway, a vertical, or a glacis fall. If left unregulated or uncontrolled, this fast velocity will cause significant erosion and scouring of the work's downstream soil. In such settings, the hydraulic leap phenomenon can be highly effective at dispersing the kinetic energy of the water.

It's worth noticing that the depth before and after the jump is always lower. The initial depth (y_1) happens before the jump, while the second depth (y_2) happens thereafter (y_2). These depths are recognised from the alternate depths $y_{1'}$ and $y_{2'}$ by their separate energy curves in the image. $y_{2'}$' is the depth that would occur in a sub-critical flow if no energy loss occurred during the leap formation; y_2 is the actual depth that occurs after the jump, including the energy loss E_L.

The hydraulic jumps seen are comparable to standing waves that can be employed as chemical mixers or pollution control aerators because most open routes with moving liquid, such as rivers, dams, and spillways, produce a large volume of air. Hydraulic jumps in a rectangular flume are studied using physical tests to determine their properties and energy dissipation. Whether or whether a hydraulic jump occurs is determined on the initial fluid speed. No jump will be possible if the fluid's initial speed is less than the critical speed.

1.2 DIFFERENT TYPES OF HYDRAULIC JUMP

The jump on a horizontal floor might be categorized as follows, depending on the incoming Froude No. F_1:

- The flow is crucial when $F_1 = 1$, therefore no leap is conceivable.
- When $F_1 = 1$ to 1.7, the water surface undulates, resulting in an undular jump.

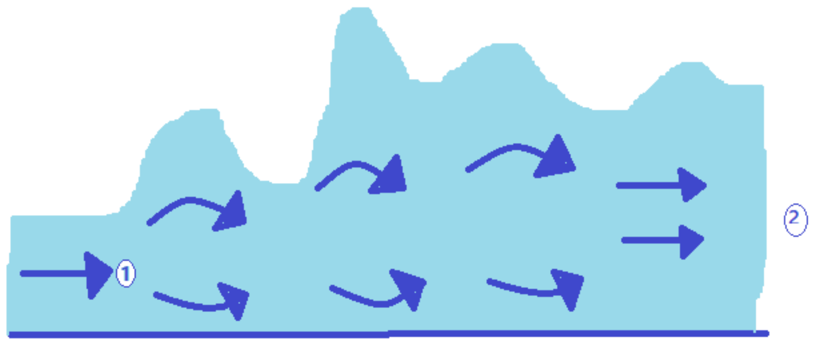

Fig. 1.2: Uundular Jump

Where 1 is the inlet of the water and 2 is the outlet of water.

- When F_1 = 1.7–2.5, a sequence of little rollers form on the jump's surface, while the water downstream stays smooth. This is referred to as a "weak jump." The velocity remains essentially constant throughout with minimal energy loss.

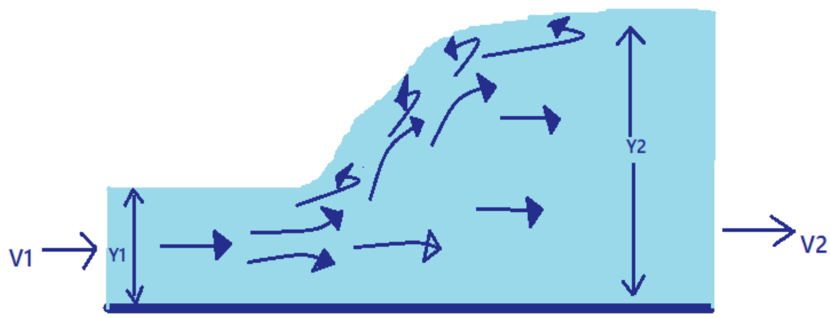

Fig. 1.3: Weak Jump

Where,

V_1 is the velocity at the inlet and V_2 is the velocity at the outlet and

Y_1 is the pre-jump depth and Y_2 is the post jump depth.

- When a jet that is oscillating enters the bottom of the jump and returns back to the surface with no periodicity for F_1 = 2.5 to 4.5, an oscillating jump is a name for this type of jump. For Dams, the approaching Froude number normally occurs in this zone or the preceding zone, i.e., the weak jump zone. Energy dissipators and stilling basins must be properly built for such scenarios.

Fig. 1.4: Oscillating Jump

- The leap is nicely balanced and performs at its optimum for F_1 = 4.5 to 9.0. The amount of energy dissipated varies between 45 and 70%. A steady jump is a name for this type of jump.

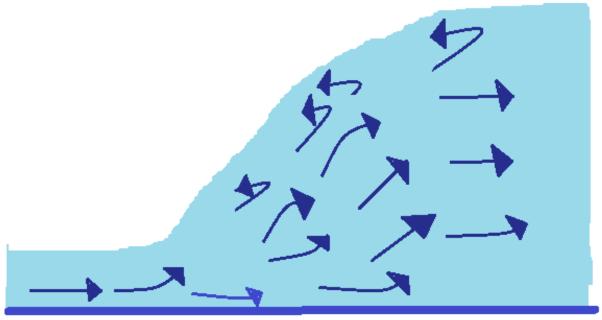

Fig. 1.5: Steady Jump

- At F_1 = 9.0 and above, the jump is powerful, with energy dissipation reaching up to 85%. This type of jump is called a "strong jump".

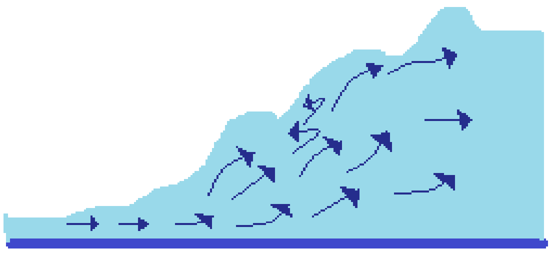

Fig. 1.6: Strong Jump

The aforementioned Froude number ranges are estimates that may overlap to some extent depending on local conditions.

1.3 REQUIRED CONDITIONS FOR THE DEVELOPMENT OF THE HYDRAULIC JUMP

- The Froude number value should range in between one and one hundred.
- When the Froude number is between greater than or less than 1.0.

- If the value of the Froude number is less than 1.0 then the hydraulic jump will not occur.

1.4 THE HYDRAULIC JUMP'S PRACTICAL APPLICATION

A lot of energy is lost since the jump is accompanied by a lot of turbulence. As a result, the hydraulic jump is used to disperse energy. Because the energy level of a dam is so high at downstream, a system is in place to perform a hydraulic leap and dissipate it. If the surplus energy is not absorbed, it will start scouring the bed and damage the banks of the bed. Then the channel will start to deepen, which is undesirable.

- It is also used to mix the chemicals in order to treat water.
- It can also be used to aerate municipal water sources.
- A hydraulic leap causes a rapid rise in depth, resulting in a heavy down word load. The Apron thickness and the uplift force, both lowered as a result. As a result, the apron's price has been decreased.
- At control sections, it produces specialised conditions of the flow to satisfy specific requirements including gagging stations, flow monitoring, and flow regulation.

1.5 Classes of Hydraulic Jump

- **Common Hydraulic Jump:**

  The familiar hydraulic jumps that occur in daily of life such as during the use of a household sink. The jump can also be observed in different forms like circular, inflow of water surrounded by stationary wave. The occurrence hydraulic jump is where, the obviously turbulence generates in still water. the, As the water spreads when it hits, with an increase in flow depth to a critical radius. In this situation the flow is suddenly rises in the form of jump with a increase in, subcritical depth of flow.

- **Man-Made type of Hydraulic jump:**

  The additional category of hydraulic leap is the man-made jumps, which are created by the implementation as weirs and sluice gates. As common the main motive of hydraulic jump is to dissipate the more vivacity of water flowing with a velocity of high flow.

  Various researchers and scientists have been performing the experiments with roughness effects of hydraulic leap and they have been able to produce steadily in lopsided forms. In additional applications of hydraulic jump practically, the jumps are produced in the surrounding environment with particular reason such as to reduce the erosion of bed and prevent it as much as. In any stream the erosion may takes place because of the high velocity of flowing of flow which carry the sediments and transport it with its flow. By reducing the velocity of flow of the flowing water and producing a jump we can prevent the stream bed. Ordinarily in these situations, with the use of a weir or sluice gate we can produce a hydraulic jump where the flow is turbulent. The mixing of any chemical ingredient with a compound is additional real use of hydraulic jumps. By producing a hydraulic leap, it makes quickly the turbulence in the flow, and allow the adequate mixing without any extra mechanism. This process of producing hydraulic jump used by the waste water industries, as a technique for mixing of chemical solutions, and to reduce the extra needs of implementation of expensive techniques.

1.6 Categories of hydraulic jumps:

The classes of hydraulic jumps are stationary and moving form.

- **Moving hydraulic jump:**

  The wave forms by the moving tides against the flow direction and form a jump is a hydraulic jump. This type of wave based on the water level difference and forms a undular wave. The observed difference in elevation of water level was large. A water fall is also a additional form of this type of hydraulic jump. In this undulation and rolls are formed in the waves.

- **Stationary hydraulic jumps:**

  We can see commonly this type of hydraulic jump on rivers, dam out fall and irrigation works. At higher velocity the flow of liquid discharges in to a zone of hydraulic structure, which sustain a lower velocity. It occurs when spill way moving down where it terminates in stationary hydraulic jump, results in reduction of water flow due to sudden rise.

1.7 PROPERTIES OF HYDRAULIC JUMP

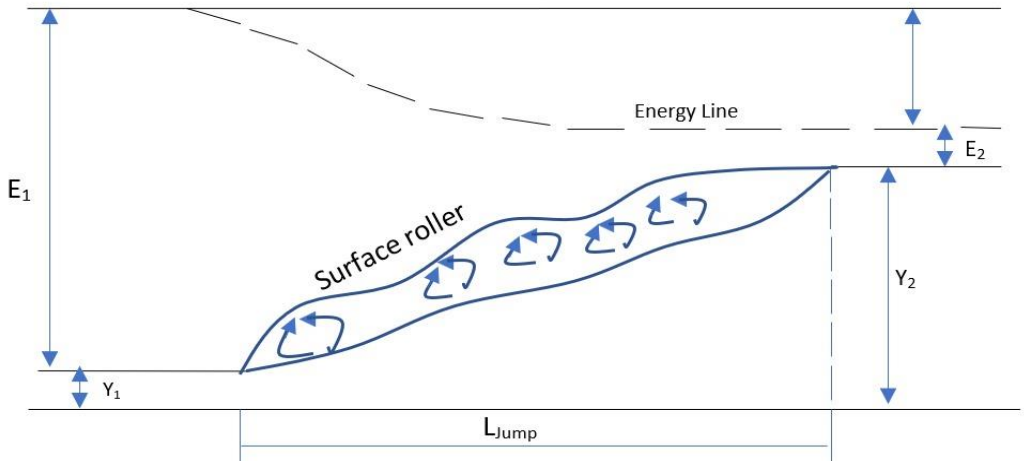

Fig. 1.7: Properties of Hydraulic Jump

(i) Ratio of the sequent depth of the Hydraulic leap:

It is the proportion of depth at the upstream and depth at the downstream of the hydraulic leap whose impulse function is equal to a discharge given.

The equation which relates the sequent depth $\frac{y_2}{y_1}$ to the initial Froude number is known as Belanger momentum equation given by: -

$$y_2 = \frac{1}{2}y_1\left(\sqrt{1+8{F_1}^2}-1\right) \quad (1)$$

Fr_1= Froude number of the approaching flow

$$Fr_1 = \frac{V_1}{\sqrt{gy_1}} \quad (2)$$

Fr_2= Froude number of leaving flow

$$Fr_2 = \frac{V_2}{\sqrt{gy_2}} \quad (3)$$

Where,

Y_2 is the post-jump depth,

Y_1 is the pre-jump depth,

V_1 is the jump's initial velocity,

and V_2 is the jump's final velocity.

For the bigger value of the Froude number, the sequent depth can be calculated by

Using.

$$\frac{y_2}{y_1} = 1.41F1.$$

Supercritical flow occurs when $F_2 \geq 1$; when Fr =1, critical flow occurs; and when $F_2 \leq 1$, the subcritical flow occurs.

The Subcritical flow is caused by $F_1 \leq 1$, critical flow is caused by $F_1=1$, and supercritical flow is caused by $F_1 \geq 1$.

The following assumptions were made in the development of the above formula:

- The jump occurs abruptly.
- The flow is maintained throughout.
- Friction is minimal.
- The bed is positioned horizontally.

(2) The Loss of Energy: - The energy destitution of the energy E_L in leap is acquired by applying energy equation at the section.

$$E_L = E_1 – E_2$$

$$E_L = E_1 – E_2 = \frac{(y_2 - y_1)^3}{4y_1y_2}$$

(3) Height of jump: - denoted by H_j, it is the differentiation in the flow height before the jump and after the leap as shown in the figure

$$H_j = Y_2 – Y_1$$

(4) The Jump Length (Lj): - Ljump is a necessary variable which affects the dimensions of the stilling basin where the jump is used as shown in the figure above. It is the horizontal distance between the toe of the leap to the section when the level of the surface set off stable following acquiring the depth which is highest.

(5) Location of the jump (L_x): -Whenever the equation of momentum is satisfied between the supercritical and subcritical parts of the stream formation of hydraulic jump is takes place. In other words, if the approaching depth y_1, the sequent depth $y_{1'}$ and the approaching Froude number Fr_1 satisfies equation (2) in a smooth rectangular channel, the hydraulic jump will occur. Location of Hydraulic jump is measured from the weir o r inlet sluice gate to the point where the flow fluctuates or roller starts.

1.8 IMPORTANCE OF THE FROUDE NUMBER

- Defines subcritical drift or critical flow.
- A Froude variety larger than one could be a critical flow whereas a Froude variety but one could be a subcritical, flow.
- If you want to very own a hydraulic leap the, Froude range must be larger than or successful.
- A hydraulic soar happens once the flow goes from critical waft ($F > 1$) to subcritical, glide ($F< 1$) or, from risky flow to a strong float.
- A hydraulic rise won't arise as soon as a drift goes, from subcritical, go with the flow ($F < 1$) to a critical flow ($F > 1$).

1.9 THE SCOPE OF THE STUDY

The foremost aim of the current investigation is to analyse and study the different properties of the hydraulic leap for various slopes and compare them with analytical results. Also, the analysis and comparison of the same characteristics for the horizontal channel and the sloping channel takes place in this investigation.

1.10 THE AIM OF THE STUDY

The present study aimed at quantifying and comparing experimental data for various slopes of the horizontal rectangular channel with a theoretically predicted profile of hydraulic jump. The incoming Froude no. and depth of jumps were controlled by controlling the flow rate through the variation of openings of valve. This study enables us to show the variations with slope and how it differs from the horizontal.

CHAPTER - 2
LITERATURE REVIEW

2.1 INTRODUCTION

Dams, reservoirs, barrages, canals, and other hydraulic infrastructure are examples. These structures are important because they must store and supply water for a variety of uses, including irrigation, agriculture, and power generation. The safety of these structures is critical. Significant amounts of money, human lives, and time are lost when these organisations collapse.

These failures are caused not only by inadequate structure construction and design, but also by high-velocity water erosion of the bed. The fast-moving water could erode the bed or the surface. The water flow through the bed is quite significant. Water with a high super-critical flow rate and velocity passes through the Stilling Basin's surface. As a result, a roughness or energy dissipater will be required to diminish the energy of flowing water and safely transfer it downstream without causing structural damage.

In this approach, the structure must be built to discharge a great amount of energy from flowing water while remaining stable. As engineers, we must guarantee that our structures are both safe and secure, as well as strong enough to meet budgetary requirements.

[1] Elnikhely (2014) For flow properties, in rectangular channel, the staggered roughness effect was the subject of research in this journal. An artificially staggered roughness was provided to the flume's base, and the profile of the water's surface was recorded at several spots. A fibreglass sheet was utilised for roughness, and all relevant observations were recorded. After 31 observations, roughness reduces following depth, duration of leap, and relative energy loss when compared to a smooth bed. The experimental data closely matches the relative depth and energy loss estimations.

[2] Neluwater et al. [2013] On a Rocky Bed, the properties of the hydraulic jump were the subject of research in this journal. The studies were conducted out in a horizontal flume with the roughness created by laying wooden blocks of various sizes on the flume's bed at varying distances. Following that, the necessary data was captured, including the subsequent depth, leap length, and discharge. On the smooth as well as the rough bed of various sizes with and without roughness, the curve between the consecutive depth ratio vs Froude number was plotted. Equations were developed as a result of the study and interpretation of these graphs.

[3] Imran and Akib (2013) "An examination of hydraulic jump characteristics under varied channel bed conditions" was the subject of an experiment. The hydraulic jump qualities that are feasible on various rough or corrugated beds are listed in this article. The energy is diffused via a hydraulic leap generated by baffle blocks. Energy is dissipated via a rough or corrugated bed. The jump and subsequent depth were reduced when compared to a smooth bed. The ramifications of rough or corrugated beds, as well as how to install them, are examined in this study. Finally, scientists determined that a corrugated or bumpy bed worked better than a smooth bed.

[4] Chern and Syamsuri (2013) A S.P.H (smoothed particle hydrodynamic) technique was used to explore the "The hydraulic jump properties on the effect on the corrugated bed". The hydraulic leap is common in open-channel flows, producing erosion and bed degradation, according to the article. As a result, it's vital to minimize the hydraulic leap and dissipate the high energy. One of the techniques is a corrugated bed, therefore a S.P.H model is utilised to investigate hydraulic jump characteristics and the influence of the corrugation on jump. Corrugated beds of various shapes and sizes were employed, including triangular, trapezoidal, and sinusoidal. The amount of energy wasted, the depth of the water, and the length of the leap were all measured and recorded. A rough bed loses more energy than a smooth bed, and a sinusoidal bed can lose up to 32% more energy than the other corrugated bed types. A method of interpolating a function in terms of the values of a set of disturbed particles is known as S.P.H.

[5] Habibzadeh etal. (2012) The "Baffle blocks performance in a submerged hydraulic jump" was investigated. The broad test series was done to cover the entire area in terms of submergence factor, block organisation, and Froude numbers. Using dimensional analysis, each parameter influence and its conclusion were described and analysed. The flow regimes of re-attaching wall jet (RWJ) and deflected surface jet (DSJ) were identified (DSJ). Factors like block shape and position, submergence factor, and Froude number influence the prevalence of a particular regime. Due to deflection generation, the DSI regime was discovered to waste more energy. It has a small river flow zone in the RWJ comparison. An empirical equation was established for a specific flow zone.

[6] Habibzadeh etal. (2011) "Exploratory examination of submerged hydraulic leap using blocks" was the title of the experiment. The submerged leap in the downstream side sluice gate with baffle blocks and wall was the focus of the early effort. In the experiments, a baffle block and a wall were employed. The drag coefficient connection was built using the momentum equation, which was validated by data from the baffle wall set of experiments. The justification or role of the submergence function in energy dissipation has been discovered, with the maximum excess efficiency parallel to the Froude leap.

[7] Elsebaie and Shabayek (2010) A variety of corrugated beds were employed to create roughness. The impact of these various forms was explored in this study. Sheets with sinusoidal, triangular, trapezoidal, and rectangular geometries were used to study hydraulic leap. On a smooth bed, the amount of tail water necessary to make a jump is minimal. The jump is shorter on different corrugated beds than on smooth beds. Because of the interaction with the corrugated bed, the shear stress produced by supercritical flow is decreased.

[8] Carallo et al. (2007) A "The hydraulic jump on a bed which is rocky" was used in one experiment. A horizontal flume with a rough bed was used in this experiment. Various sizes of stones and gravels were used to produce the bed's roughness. The Roughness influenced the gravel on the subsequent ratio of depth and the length of the roller was investigated. According to their findings, the ratio of roughness height and the Froude number to the flow at the upstream provide the new equation of momentum solution for the following 33 ratio of depth. Curves were drawn to depict the link between depth and Froude no. Between the theoretical and experimental sequent depth ratios, curves were created. following flow depth and roller length vs. succeeding depth ratio vs. determined value. The hydraulic leap parameter on a bed which is rough was examined in this study. The succeeding depth ratio, as well as Froude no., reduced as bed roughness increased.

[9] Ead and Rajaratnam (2002) "Hydraulic jump on the bed which was corrugated" was the name of the experiment. For Froude numbers 4 to 10, varied relative roughness levels were recorded in this experiment. According to this experiment, the required tail water depth for a leap is substantially less than that required for a smooth bed. Because of the roughness, the jump is about half the length of a bed was smooth. The different profiles of the velocity at various points were found to be equal with a minor deviation from the plane wall jet profile.

[10] Ali Mohamed (1991) The length of the rectangular hydraulic leap effect of stilling Basin on the roughened bed" was the subject of an experiment. A hydraulic jump study was performed on low head structures. In this work, the rough bed channel was investigated under various flow conditions in order to determine its maximum roughness length from a hydraulic and economic standpoint. The data was analysed statistically, and the inspection was carried out with roughness in the form of cubes. A realistic practical equation is required to depict the hydraulic jump characteristics using roughness for the optimum duration of roughness. A general formula for jump length with uneven bed is created by the use equation of in the flow direction.

[11] Hughes and Flack (1984) "Hydraulic leap qualities across uneven bed" was the subject of an experiment. A strip roughness bed and closely packed gravels were employed to create roughness on a smooth bed. Data on the succeeding depth, depth of the tailwater, jump length and the flow rate were collected once the experiment was completed. The graphs illustrate that the length of the roughness boundary decreases of the leap and therefore the jump depth and that this is connected to the Froude number and roughness degree.

[12] Yu Zhou, Jianhua Wu et al. (2020) An experiment was conducted on "The dissipation of energy and the uniform flow of the stepped hydraulic-jump spillways". A hydraulic jump-stepped spillway, a new type of stepped spillway designed to improve unit discharge capacity and energy dissipation, was studied using physical model experiments. According to the statistics, uniform flow via the hydraulic-jump-stepped spillway has a lower specific energy, indicating that it disperses energy more effectively, particularly for big unit discharges.

[13] Youngkyu Kim, Gyewoon Choi et al. (2015) "Hydraulic Jump and Energy Dissipation with Sluice Gate" was the subject of an experiment. This research employed a hydraulic experiment to investigate weir-specific hydraulic phenomena, compare hydraulic jumps and downstream flow characteristics, and investigate hydraulic variables such as water levels, velocities, and energy. As a result, in terms of hydraulic jumps, sluice gates resembled fixed weirs, whereas downstream supercritical flow increased, prolonging overall hydraulic jumps. Installation heights were shown to be responsive to energy dissipation in energy dissipator systems. In this experiment, the most effective energy dissipator height was 10% of the downstream free surface water depth. According to these studies, energy dissipators should be utilised to conserve energy because they have been shown to reduce hydraulic leaps and safeguard the riverbed behind sluice gates. Properties of Channel Beds in a Variety of Situations." The main purpose of this study is to see if corrugated and roughened beds may be used to shorten and deepen hydraulic jumps. The implications of corrugated and roughened beds, as well as the findings of different researchers in various installation methods, are examined in this study. Finally, smooth bed applications outperformed corrugated and roughened bed applications on a constant basis. This analysis also revealed a number of areas in which more research is needed.

[14] Mostafa M El-Seddik (2017) In a laboratory experiment, carried out in a rectangular open channel flume, the development of hydraulic leap and the impact of flow patterns on water resources were investigated. This experiment shows how super-critical flow behaves behind a sluice gate at varied flow rates and downstream depths. To see how sensitive the Froude number is, the model is tested by altering the flow-meter and over-shot weir in the flume. It might be able to figure out why the jump flow's velocity is so high. Under the influence of various gate openings, the position of the hydraulic leap as well as the energy dissipated are examined.

[15] Prasanna S V S N D L, Suresh Kumar N (2019) "Reproduction of Water Surface Profile Using ANSYS – CFD" was the study's title. The goal of this research is to determine how different discharges affect the water surface profile. A User Defined Function was used to evaluate and plot the simulation results (UDF). Running the C programme in the fluent solver yielded all of the parameters required to depict the water surface profile in all of the cells downstream of the gate. For the stated discharges, both experimental and analytical calculations accord with the water surface profile.

[16] Neveen B. Abdel-Mageed (2015) They investigated variable and major features of the hydraulic leap such as subsequent depth, relative hydraulic jump length, and relative distance to the pump while working on various hydraulic jump characteristics with the influence of channel slope. On a rectangular channel downstream (DS) of the vertical gate, these characteristics were investigated. To match with the other independent components, the jump's length, subsequent depth ratio, and distance were determined. In addition, there was an apparent agreement between the jump length findings.

[17] Beirami and Chamani (2003) worked on the sequent depth ratios with sloping channels in the Hydraulic Jump where they investigated by creating a large variety of hydraulic jumps on an ogee standard weir with horizontal and sloping inverts at the ends. The weir was used to create a supercritical flow and different slopes of 0, -0.025, -0.05, -0.075 and -0.10 were built at the downstream of the weir. Using the horizontal momentum equation, a method for computing the consecutive depth ratio is shown. The authors' and other researchers' findings support this notion. It was established that the lowest Froude number required to establish jumps on negative slopes was connected. According to observations, when the gravitational force component in the leap was opposing the flow direction, the water surface of the surface roller became undular and unstable. On such a high slope, controlling the hydraulic leap was practically impossible. A negative basin slope lowers the subsequent depth ratio, while a positive slope raises it, according to experimental evidence.

[18] Ohtsu and Yasuda (1991) investigated the sloping channels in the Hydraulic jump, the transition from supercritical to subcritical flow in sloping channels is thoroughly investigated under a variety of slopes. The hydraulic criteria for the construction of D type of jump, which takes place wholly on the slope, and B type of jump, which takes place partially on the slope and partially in the horizontal channel, have been established. There are additional reasonable formulae for the following depths and jump lengths. The wall jet is used to explore the transition zone's streamwise decline in maximum velocity.

[19] Richard and Gavrilyuk (2013) investigated the classical turbulent hydraulic leap is addressed using a conservative hyperbolic two-parameter model of shear shallow-water flows. Using roller length measurements and deviation from the Bélanger equation, the following depth ratio's wall enstrophy and roller dissipation coefficient are calculated (experimental data by Hager & Bremen, J. Hydraul. Res.). The free-surface geometry of the hydraulic leap is accurately depicted by stationary solutions to the model. Leap toe oscillations can also be predicted using the model. The jump toe oscillates at a given frequency if the upstream Froude number is more than 1.5, while the solution becomes static if the Froude number is less than 1.5.

[20] Alikhanil et al. (2006) The Hydraulic Jump vertical end sill in a stilling basin was explored since stilling basins with continuous sills are commonly used as energy dissipators downstream of hydraulic structures. The impact of a single vertical continuous sill and its placement on changing the depth and length of a forced jump in a stilling basin is investigated without taking into account tailwater level, which is variable and completely controlled by downstream river conditions. A sill with five unique heights is located at three different longitudinal distances in a scaled model of a stilling basin. The hydraulic properties of the jump were measured and compared to the average hydraulic leap under various discharges. According to data, the sill has a significant impact on energy dissipation. A new link between sill height and position has been discovered.

[21] Raouf Emile Baddour (2017) studied in quiescent ambient water, the properties of turbulent entrainment of thermohaline internal hydraulic leaps are investigated. Underflow and overflow leaps are both considered. The effect of thermohaline buoyancy on flow generation is the study's main focus. A nonlinear temperature and linear salinity equation of state that is correct across the temperature and salinity spectrum is used to determine thermohaline buoyancy. Thermohaline buoyancy generates smaller, less diluted underflow jumps and larger, more diluted overflow jumps, according to the study. When temperature and salinity buoyancy operate in opposite directions, these nonlinear buoyant effects become very obvious. Using a matching technique, hydraulic controls with vertical and/or horizontal constrictions downstream indicate many stationary miscible jump solutions.

[22] Chang et al. (2022) investigated the gas-liquid two-phase flow parameters under 1 Mpa in a pipeline-riser system. The HJP in the upstream horizontal region was measured using electrical capacitance volume tomography (ECVT). The flow regime transition limits were changed to minimize gas and liquid velocities due to the impact of the riser at the end of the horizontal pipe. In the upstream horizontal stretch, liquid slug formation and gas-liquid eruption stages normally occur before the HJP, and the HJP has a phase that corresponds to severe slugging flow. The Pearson correlation coefficient between the HJP upstream and the pressure fluctuations in the three main structures (horizontal, downward, and riser sections), the period consistency, and the sequential relationship between them was examined to confirm that the pressure fluctuations in the downstream riser were the main cause of the HJP upstream.

[23] Dhar et al. (2022) The purpose of this study is to see how planar hydraulic jump impacts the end of stratified gas-liquid flow in a small rectangular conduit using an experimental technique. Stratified flow is ended by a "natural" planar jump in both co and counter current flow when the Froude number of the incoming liquid surpasses unity (supercritical flow). Oscillatory leap causes flooding in counter current flow, but undular jump causes slugging at greater phase velocities in co-current flow. The velocities of surface gas and liquid at the start of huge waves downstream of the co-current flow jump support Taitel and Dukler's criterion, but not Gargallo et al's.

[24] S.K. Mazumder (2020) studied the hydraulic jump characteristics in a stilling basin with a steep slope and a positive step at the basin's end (hence referred to as basin). Many hydraulic jump features have been studied both analytically and practically. A total of 144 experiments were conducted, with Froude's number (F_1) inflows ranging from 4 to 10. In comparison to a conventional jump on a level floor, the subsequent depth ratio, jump length, and roller length decrease by 20%, 39.3%, and 32.6 percent, respectively, as the slope and height of the positive step increases. The proportional energy loss increased by 13% more than in a conventional leap as the slope and step height increased.

CHAPTER - 3
METHODOLOGY

Details of the theoretical work and experimental work carried out is mentioned in this Chapter of the thesis.

3.1 EXPERIMENTAL WORK

3.1.1 OBJECTIVE OF THE WORK DONE

Objective of this study is to study the different sequent depth ratios for different slopes by creating the hydraulic jump in the open channel rectangular flume which has 0.030 m depth and 10 m length and analyse the change in the characteristic of the jump due to the variation of the slope by keeping the discharge constant.

3.1.2 INSTRUMENTS USED IN THE EXPERIMENT-

(i) Flume-

Flumes are used in open channels to assess flow rate (discharge). They usually range in width from a few centimetres to over 15 meters. The water depth in the approach portion of flumes can range from a few centimetres to over two meters.

Flumes, as opposed to weirs, have the advantage of causing less head loss through the device, but they are further hard to build and study. The head is measured upstream of the throat, in the so-called "approach channel" of the flume.

For rectangular flumes, head is measured 3 to 4 times the maximum expected head upstream from the throat. Because the head does not vary greatly with position, this location is relatively arbitrary.

As a result, unlike a parshall flume, the exact placement of the head measurement is not as critical. Because the rectangle can have a high throat (a hump), the head must be measured from the top of the hump rather than the bottom of the approach channel.

Rectangular flumes have a constriction at the throat or a raised invert (bottom) at the throat to work. In a properly operated flume, either characteristic can create critical flow near the throat. These flumes are easier to build and may be readily integrated into an existing channel.

Flumes (like weirs) are meant to force a transition from sub-critical to super-critical flow, according to flume analysis. The transition in flumes is induced by the design of flumes with a constriction at the throat, a rise of the channel bottom, or both. Flow passes through critical depth at the flume throat as a result of such a transition. Energy is minimised at the critical depth, thus there is a direct link between water depth and velocity.

However, measuring critical depth in a flume is physically problematic because its exact location is difficult to detect and may vary with flowrate.

As a result, the upstream depth, which is a very trustworthy measurement, can be used to determine flowrate.

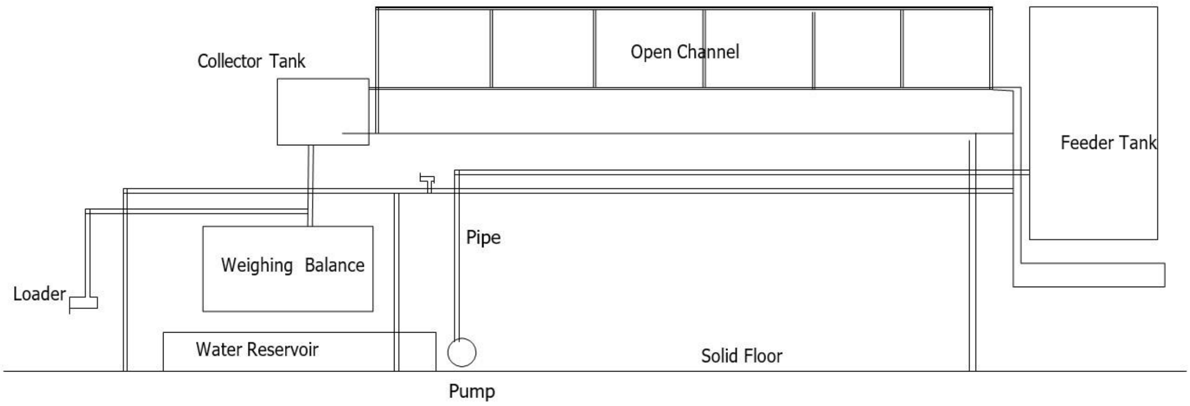

Fig. 3.1: Schematic diagram of the flume

Schematic Diagram of the Rectangular Open channel Flume in the available in the Laboratory.

Photograph 3.1

The rectangular flume used in this project was placed in the Laboratory of the college.

(ii) Brick-

The term "brick" was originally used to describe a dried clay block, but it is now used to describe a wide range of chemically cured masonry blocks. Interlocking, mortaring, and gluing bricks together are all options. Bricks are mass-produced in enormous quantities and comes in a wide range of groups, class, substance, and dimensions that differ by location and intervals. To regulate hydraulic jump and enhance hydraulic jump efficiency, a block with measurements was placed in the flume's centre. The downstream roller of the hydraulic leap rises to the point that it nearly overflows.

Photograph 3.2

Brick used as an obstruction in the jump having a size (190mm×90mm×90mm)

(iii) Sluice Valve-

The pump is used to regulate the pressure flowing in rectangular flume of open channel flow.

Photograph 3.3

(iv) Point Gauge-

The sequent depths y_1 and y_2 is measured in the experiment with the help of Point gauge. This is the instrument which is used to measure the flow depth. It is generally fitted on railsover the flume so that it can slide from one point to another for easy measurement.

Photograph 3.4

(v) Storage Tank-

The Storage Tank which was used for transferring the water and measuring the discharge.

Photograph 3.5

(vi) Inlet valve: It used to control the rate of flow during the experiment, increase or decrease in the flow controlled by the inlet valve.

(vii) Sluice gate at both the ends of the flume: Sluice gates were present at the start and end of the rectangular open channel flume, by maintaining the opening of these gates the hydraulic leap is formed in the channel.

(viii) Water pump: It is necessary for the flow of water through the flume.

3.1.3 MEAUSREMENTS TAKEN IN THE EXPERIMENT

In the experiment inlet pressure is measured, slope of the rectangular channel is measured, height before the jump and height after the jump is measured and velocity of the flow is measured at various interval flume length, and the jump length is calculated.

3.2 EXPERIMENTAL PROCEDURE

The experiment is carried out in the hydraulics lab of the Delhi technological university, the flume used in the experiment is 10 m long rectangular flume having width 0.30 m and height 0.40 m and the two-sluice gate are 3 m apart. The slope of the flume is maintained with the help of the rotatingscrew which is situated at the base of the flume. The flume is made of steel structure and the transparent glass so that the jump can be easily seen.

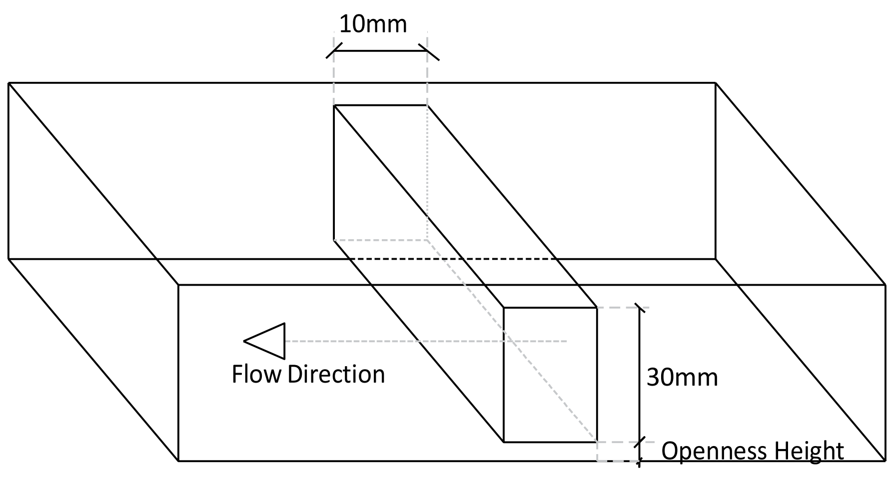

Fig. 3.2: shows a schematic diagram of brick placed in the rectangular flume.

In this experiment a rectangular working flume is used which is connected with the supply tank for the flow of water, there is an inlet and outlet pipe through which the water from the tank goes to in the rectangular flume and from the flume goes into the tank again. Inlet pipes are fitted with the orifice meter which shoes the pressure at which the water is flowing in the pipe by the pump. The flume has a rail fitted to in the upper section on which point gauge is fitted, rails help the movement of point gauge throughout the flume for measurement of depth of the flow. Flume have two sluicegates fitted in at one at the inlet and other at the tail end both of them can be regulated with the help of screw fitted on the side of the sluice gate. Jump formation is controlled with the help of these sluice gate. Other than that, Pitot tube is also used here to compute the flow velocity at specific length along the flume. Flume is checked for any leakage of water for the correct reading there should not be any leakage from it.

Photograph 3.6: Shows Occurrence of hydraulic jump in the rectangular flume.

Photograph 3.7: Shows Brick placed in the flume and used as an obstruction to regulate the flow.

Photograph 3. 8: Shows Side view of the hydraulic jump.

The Experiment is carried out for the different types of slopes:

1. Initially 0° slope is maintained of the rectangular channel, for the first case channel should be horizontal.
2. Pump is turned on and water is allowed to flow through the pipes. The water flowing through the inlet pipe is managed by the screw present at the inlet pipe.We have maintained the same pressure throughout the experiments for all the different slopes.
3. After the flow through the flume has taken place than flow is regulated with the help of the sluice gate present.
4. opening of the sluice gate is controlled at both the ends so that the jump can be formed
5. Jump formed should be stable so that the readings can be taken.
6. After the jump has reached the stable state in the flume readings are taken.
7. Initially bed depth is measured, after that the height of the surface of the water flowing after the jump is measured with the help of the point gauge. The differentiation in the bed height and the flowing water height gives the height of the jump of the condition.
8. Marking on the flume along the length are made at the 1.5 m, 2 m, 2.5 m from the starting sluice gate. so that the reading can be taken at this fixed length in all the cases.
9. We divide the 0.30 m wide flume from right side to left and have taken readings at 5 cm, 10 cm, 15 cm, 20 cm, 25 cm.
10. Pitot tube connected with the manometer is than placed into the flume carefully and fixed at 3cm height above the bed of the flume and along with point gauge so that velocity can be measured at 5 cm, 10 cm, 15 cm, 20 cm, 25 cm.
11. The same procedure is repeated for 1°, 2°, 3° by changing the slope of the flume and reading are taken similarly at different point along the length and width.

b = channel width = 30mm = 0.030m,

v_1= measured pre-hydraulic flow velocity,

v_2 = measured post-hydraulic flow velocity,

y_1 = measured beginning water depth,

y_2 = measured post-hydraulic leap water depths,

Q = discharge = 0.012 m^3sec,

g = 9.806 m/s^2,

y'= sequent depth ratio, i.e., $\frac{y_2}{y_1}$, where y_2 is equal to

$$y_2 = \frac{1}{2} y_1 \left(\sqrt{1 + 8{F_1}^2} - 1 \right)$$

A_1 = Area of the pipeline = 11.95m^2

A_2 = Area of the Rectangular Flume

Formula used for finding the Velocity at the inlet,

$$Q = A_1 V_1$$

$$V_1 = 0.001 \text{m/s}$$

CHAPTER - 4

RESULTS AND DISCUSSIONS

- Many physical laboratory experiments were conducted to determine that how the sluice gate influenced the location of the hydraulic jump and the different types of hydraulic jump (Table 1). The investigate solutions shows that the hydraulic Jump proceeds towards the opening of the sluice gates grows, until the gate is immersed fully.
- According to the research, the sluice gates and the discharge is connected to the different types of hydraulic jump. The approaching Froude number (F_1) rises from 1.55 to 1.73 when discharge (Q) rises from 20 to 30 l/min in supercritical flow with constant y_2 and gate opening.
- However, increasing post-jump depth(y_2) from 0.0755 m to 0.1038 m increases F_1 from 1.55 to 1.73 for continuous discharge and gate opening. The simulated post-jump depth (y_2) is roughly 5 cm bigger than the measured data when pre-jump depth (y_1) is 0.01 m and discharge (Q) is 50 l/sec.
- Flume's small size and low discharge may account for the minimal difference between simulated and actual results. The position of the hydraulic leap and the depth of water beyond the sluice gates are both dictated by the opening of the gates in combination with constant conjugate depths of discharge, according to the findings.
- Furthermore, a 0.45 m shift in energy is caused by a change in the downstream depth and the upstream depth.

Table: 4.1 Represents different characteristics of the hydraulic jump carried out experimentally.

S No.	Pre-Jump (y_1) in (m)	Post-Jump (y_2) in (m)	Sequent Depth y’ in (m)	Froude Number (F_1)	Froude Number (F_2)	Energy Loss (E_L)	Jump Length (L_j) in (m)	Jump Height $H=y_2-y_1$ (m)	L/y_1	L/y_2	E_1	E_L/E_1
1.	0.037	0.0755	2.01	1.7345	0.0415	0.514	4.51	0.0380	4.00	1.98	0.0947	5.92
2.	0.038	0.0760	2	1.7330	0.0416	0.494	4.65	0.0380	3.94	1.97	0.0952	5.84
3.	0.038	0.0770	1.98	1.7324	0.0418	0.507	4.71	0.0383	3.84	1.97	0.0952	5.75
4.	0.039	0.0775	1.977	1.7265	0.0490	0.472	4.85	0.0383	3.72	1.85	0.0962	5.55
5.	0.040	0.079	1.975	1.7233	0.0404	0.469	4.92	0.0390	3.61	1.81	0.0972	5.30
6.	0.041	0.0815	1.97	1.7161	0.0398	0.497	5.010	0.0403	3.39	1.71	0.0982	5.18
7.	0.042	0.0828	1.94	1.7087	0.0392	0.574	5.062	0.0403	3.24	1.65	0.0992	5.02
8.	0.043	0.0841	1.94	1.6954	0.0386	0.478	5.15	0.0409	2.12	1.60	0.1002	4.92
9.	0.046	0.0873	1.88	1.6827	0.0370	0.440	5.26	0.0411	2.81	1.49	0.1032	4.85
10.	0.048	0.0898	1.85	1.6545	0.0376	0.424	5.354	0.0413	2.64	1.42	0.1052	4.72
11.	0.049	0.0922	1.855	1.6339	0.0363	0.447	5.467	0.0425	2.55	1.37	0.1062	4.55
12.	0.051	0.0940	1.842	1.6015	0.0365	0.414	5.556	0.0429	2.39	1.31	0.1082	4.30
13.	0.053	0.0970	1.80	1.5876	0.0368	0.415	5.742	0.0432	2.23	1.24	0.1102	4.18
14.	0.054	0.0987	1.80	1.5624	0.0354	0.419	5.80	0.0439	2.16	1.20	0.1112	4.07
15.	0.058	0.1038	1.76	1.5549	0.0357	0.400	5.852	0.0451	1.93	1.09	0.1152	3.92

The following results were made based on the investigation:

- **The Froude no. vs the sequent depth ratio –**

  The Froude number was calculated using the ratio of the sequent depth ($\frac{y_2}{y_1}$). When the approach Froude number and channel slope change, as seen in the Fig. 4.1, the ratios of the sequent depth vary. As the channel bed slope and approaching Froude number increase, the subsequent depth ratio appears to grow.

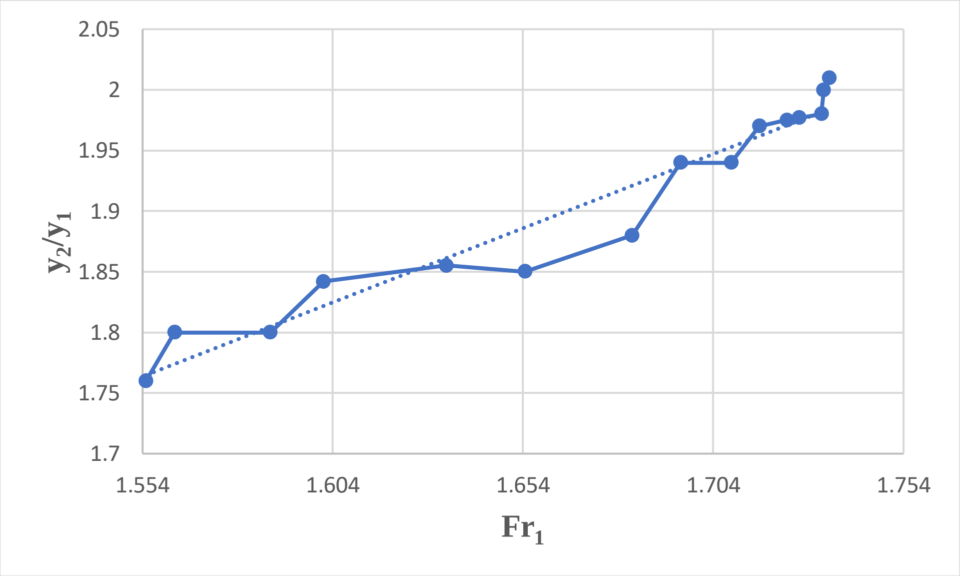

Fig. 4.1 Experimental results of present study are plotted between sequent depth and Froude number (Fr_1).

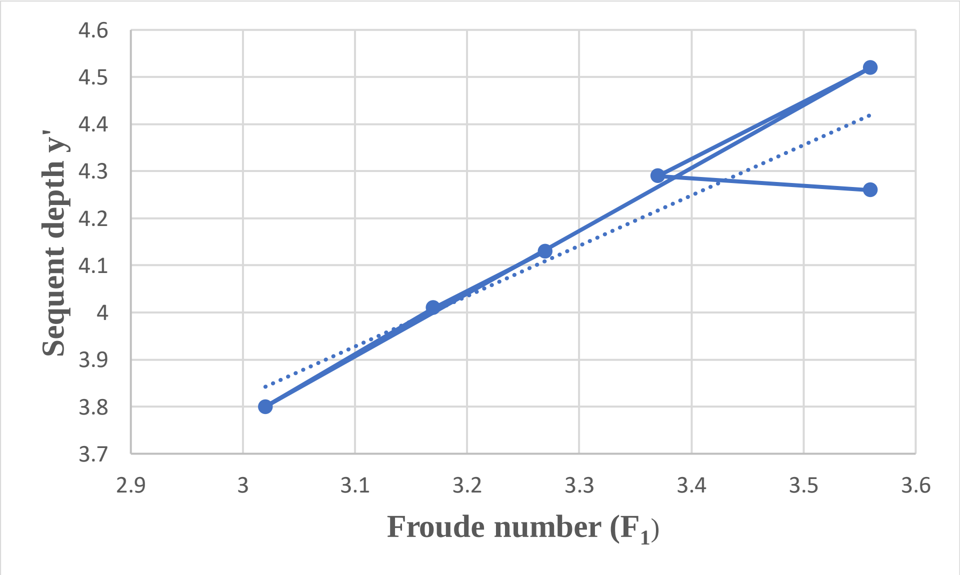

Fig. 4.2: Experimental results of previous study by [14].

- **Variation of water surface profile –**

The Height of jump varies with Length of jump as shown in fig. 4.3. The height of the jump increases with the increase in the jump length. In present study water profile is recorded and this result is similar to past study of [16] shown in fig. 4.4.

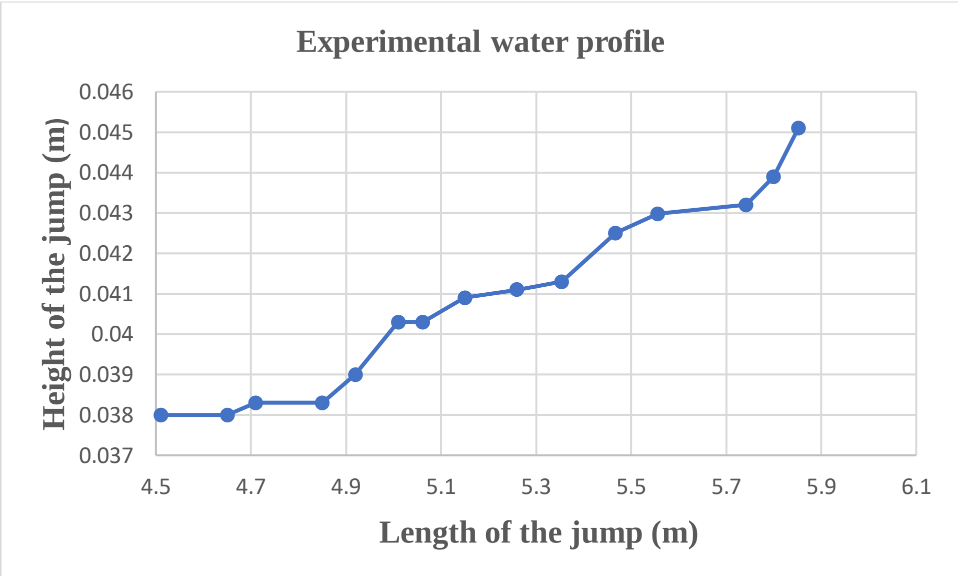

Fig. 4.3: Experimental results of the water profile show the M_3 water profile.

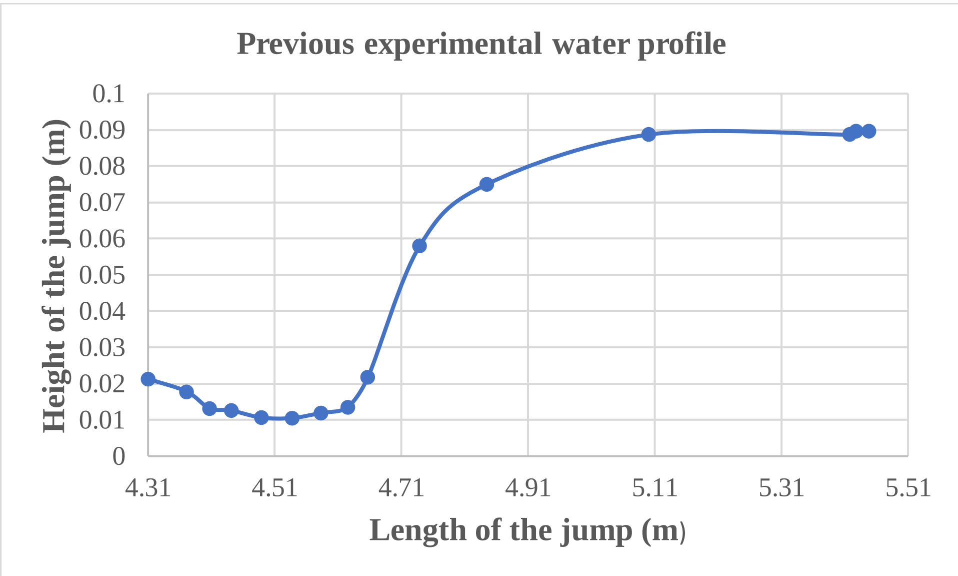

Fig. 4.4: Experimental profile of previous study of [16].

- **Length to jump ratio** –

In fig. 4.5, the jump length which is dimensionless in nature is shown versus F_1. The Jump length which is dimensionless in nature grows practically linearly with the Froude number, according to the data. The findings are in line with what we already know about hydraulic leap behaviour. According to [10], other investigations in this subject indicate a similar tendency.

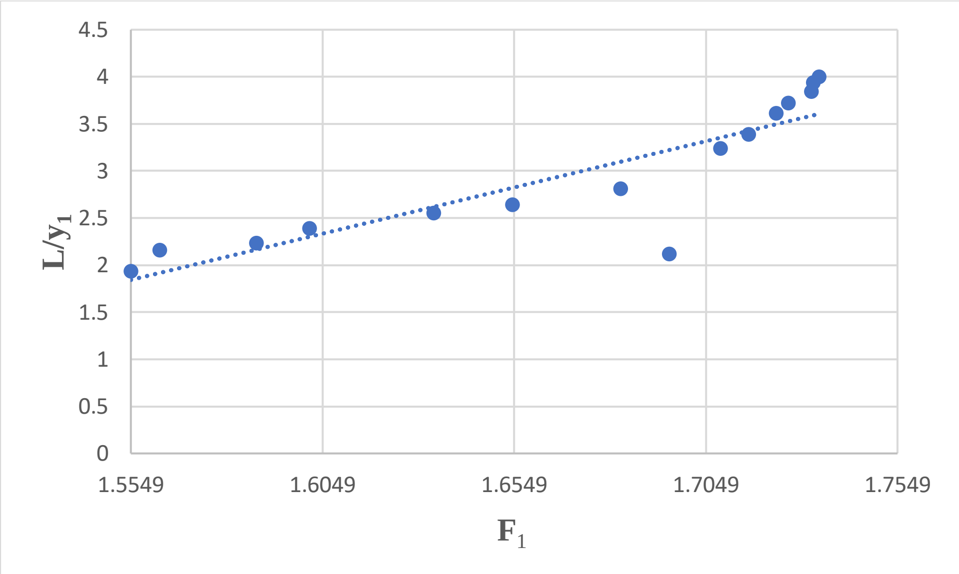

Fig. 4.5: Experimental results of present study plots a relationship between the length of jump ratio and the Froude number.

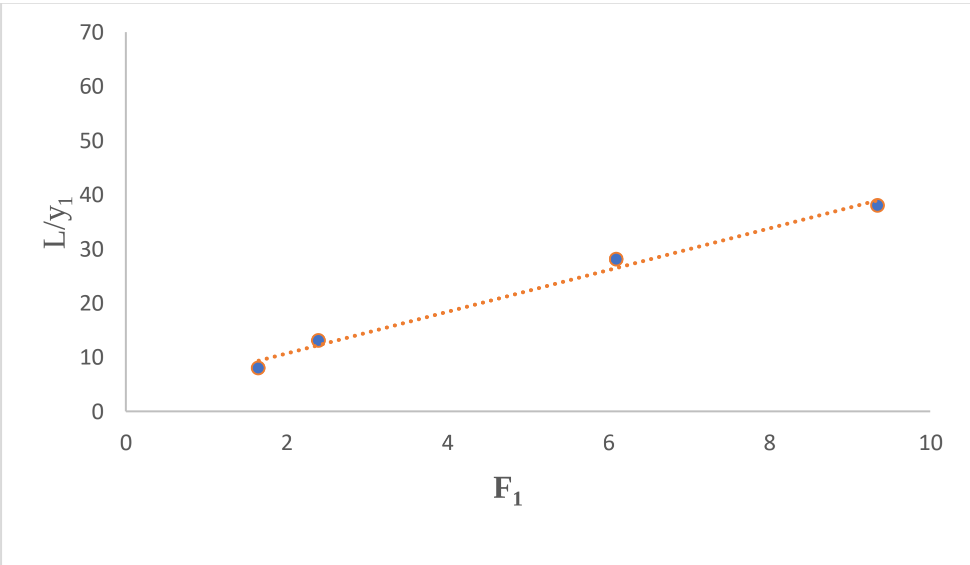

Fig. 4.6: Experimental results of previous study plots a Relationship between the length to jump ratio and the Froude number [10].

- **Variation of $\frac{L}{y_2}$ and the Froude number –**

  In present study dimensionless parameter jump length ratio corresponding to Y_2 is shown and this result is almost similar to past study of Rajaratnam.

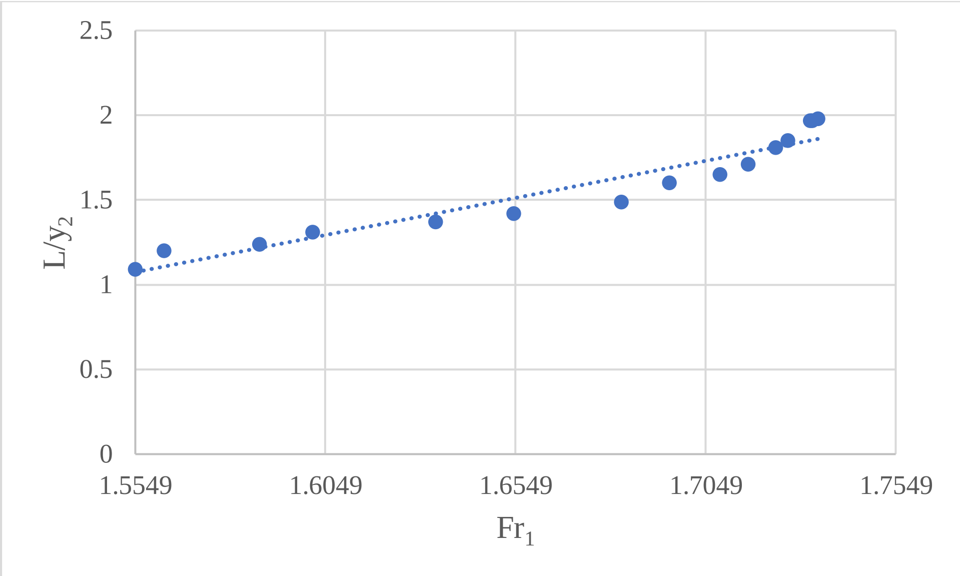

Fig. 4.7: Experimental Results of present study are plotted between $\frac{L}{y_2}$ and The Froude number (Fr_1).

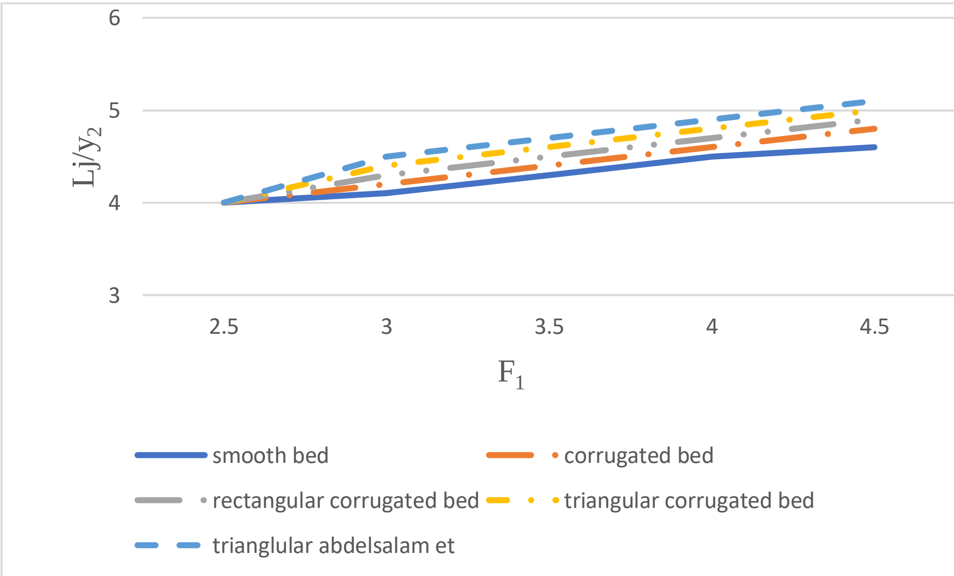

Fig. 4.8: Previous study Variation of $\frac{L_j}{y_2}$ and the Froude number by [10].

- **Hydraulic Jump Length –**

  Fig. 4.9 represents the relation between hydraulic jump length (Lj) and the sequent depth (y_2) for different slopes. It clears that the hydraulic jump length increases by 70% and the sequent depth increases by 100% while fig. 4.10 is the previous study by [21].

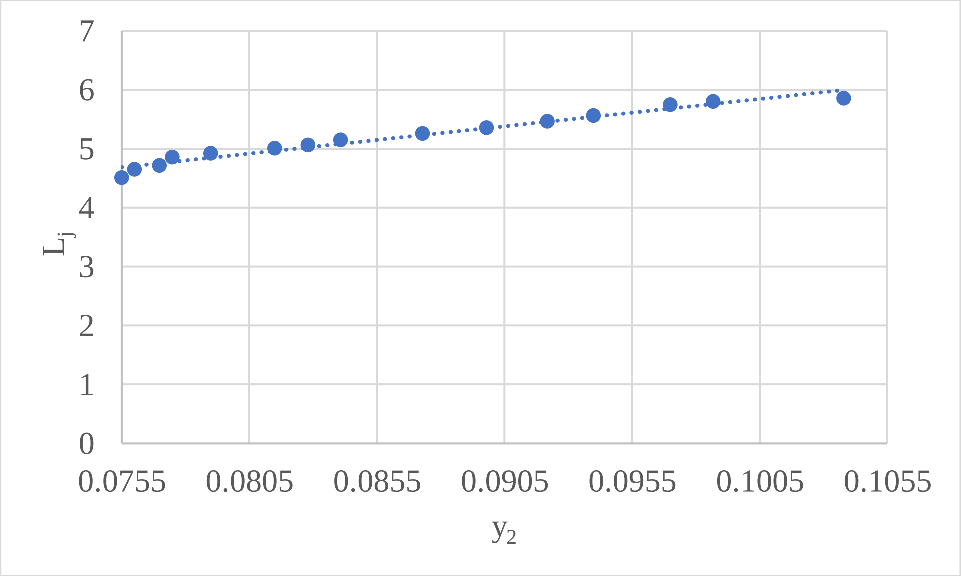

Fig. 4.9: Present study variation of the hydraulic jump length (L_j) and the post Jump depth (y_2).

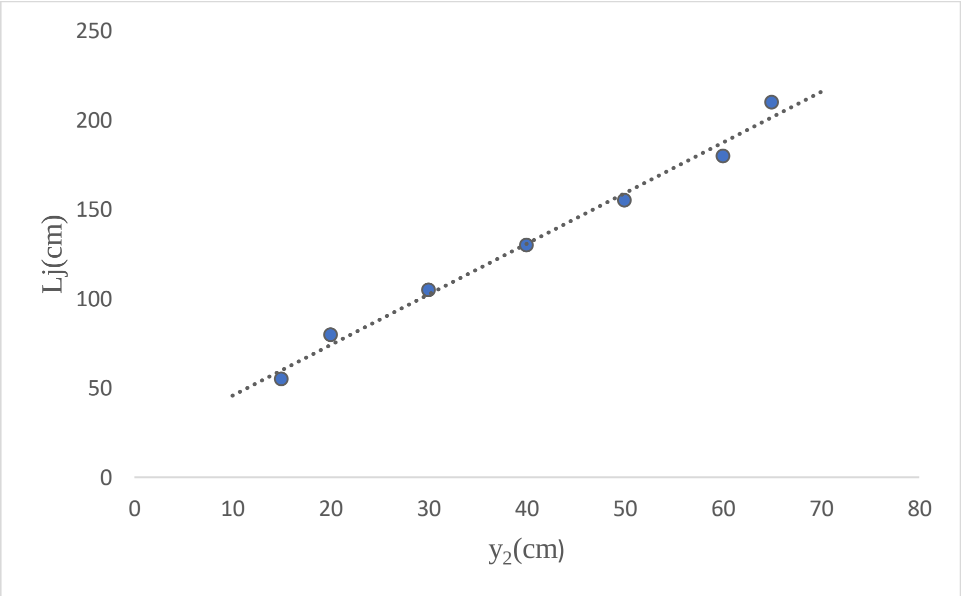

Fig. 4.10: Previous study of the hydraulic jump length (L_j) with Post jump Depth (y_2).

- **Energy Dissipation –**

Fig.4.11 demonstrates the relationship between the Froude number and the relative energy loss ($\frac{E_L}{E_1}$) for various kinds slope. It is noticed that the relative energy loss non-linearly increases with the increase in the approaching Froude number from 1.5 to 1.7 and the slope of the channel bed while fig. 4.12 is the previous study by [10].

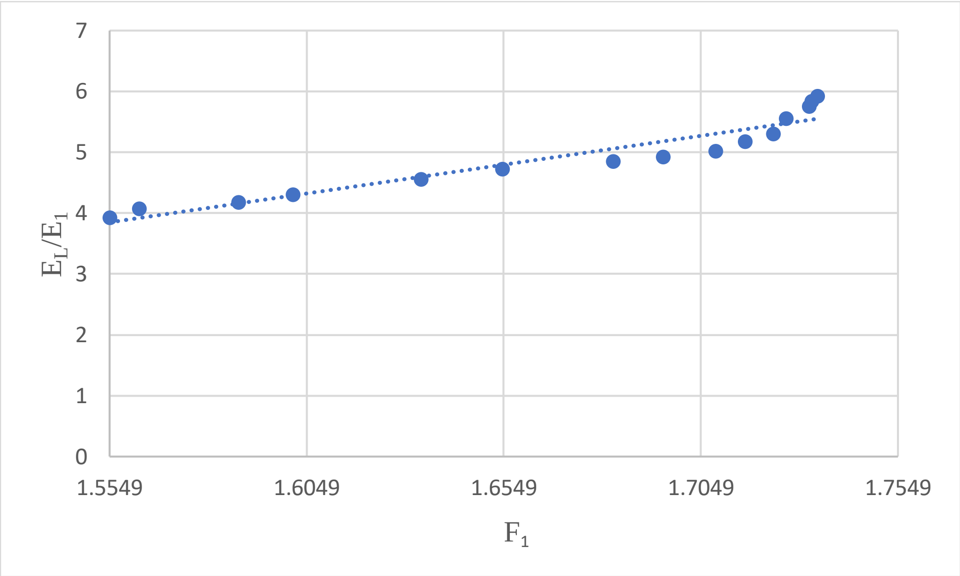

Fig. 4.11: Present study of variation between the percentage of dissipation of energy and the Froude number.

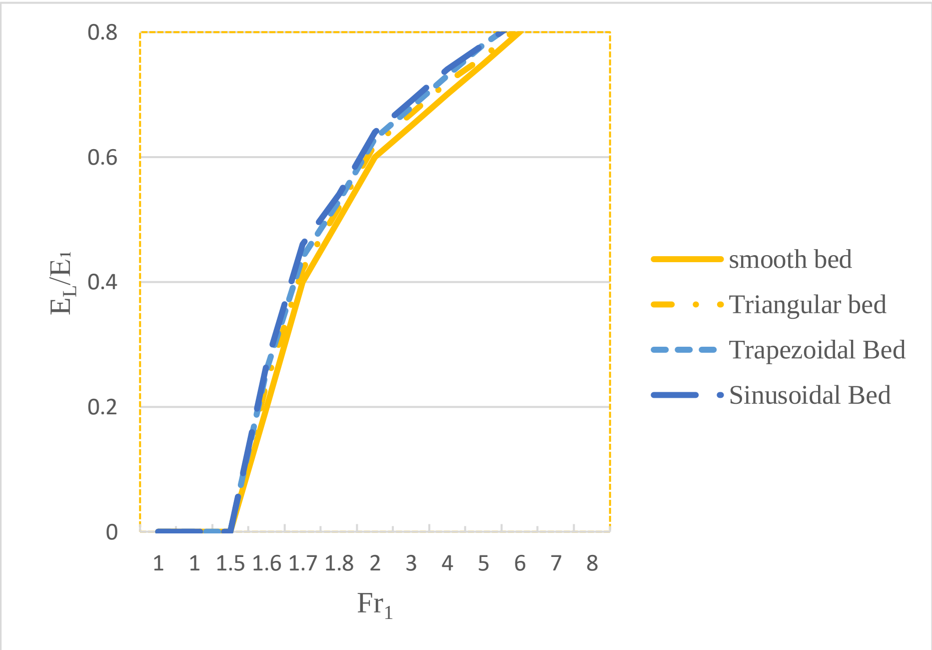

Fig. 4.12 Previous study of variation the percentage of dissipation of energy and the Froude number [10].

- **Variation of y_2 with time –**

  The value of y_2 must be sufficiently consistent to provide a qualitative result. Figure 4.13 shows how y_2 has changed over time. The steady state is obtained after 10 seconds while fig. 4.14 represents the past study by [21].

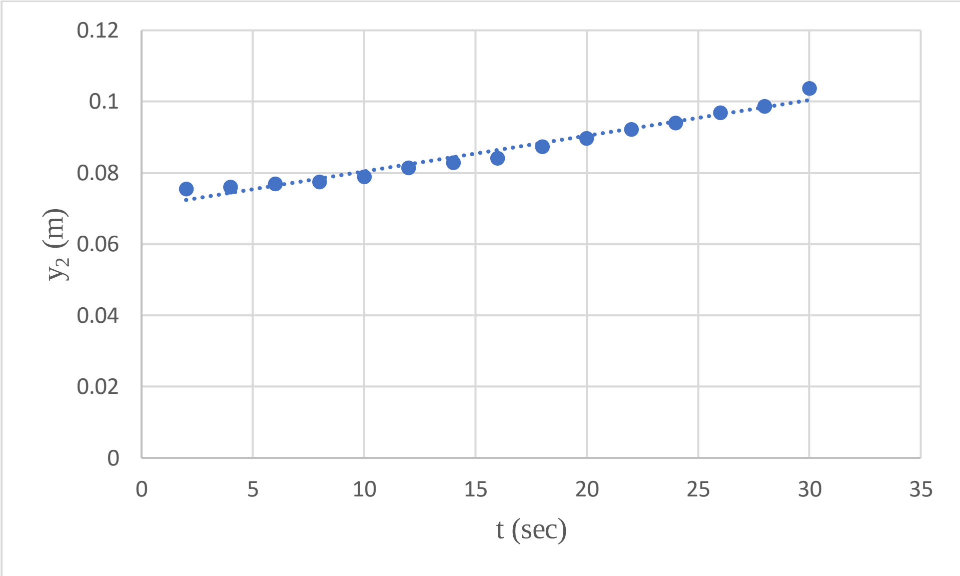

Fig. 4.13: Shows present study variation of y_2 with time.

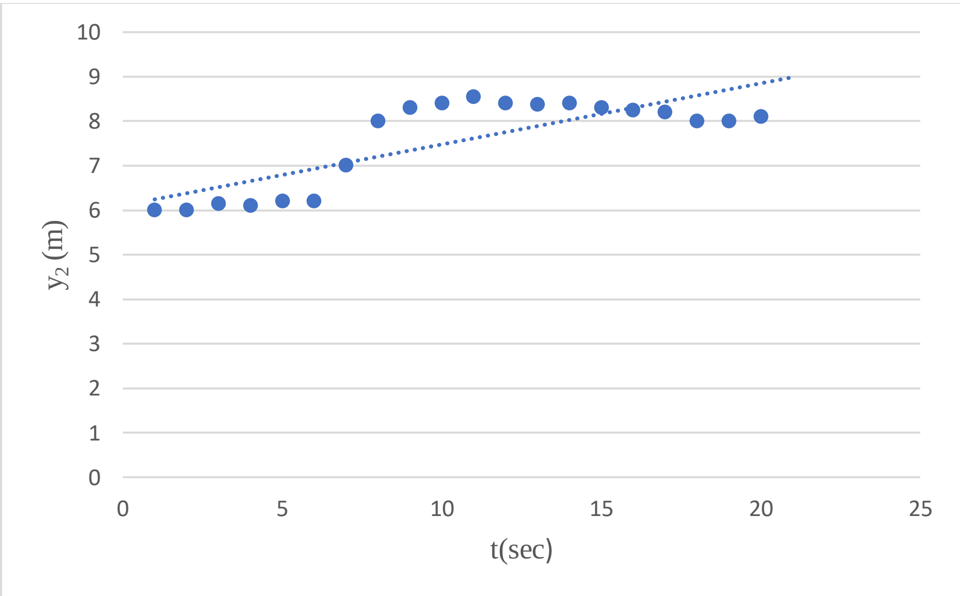

Fig. 4.14: shows previous study variation y_2 with time [21].

- **Type of jump –**

  Subcritical fluxes are indicated by Froude values ranging from 0.035 to 0.041 ($0.035<Fr_2<0.041$). The Froude values range from 1.5549 to 1.7309 ($1.5549<Fr_1<1.7309$) at the pre-hydraulic jump phase, indicating that the fluxes were supercritical and the jumps acquired shown in fig. 4.15 was an undular jump.

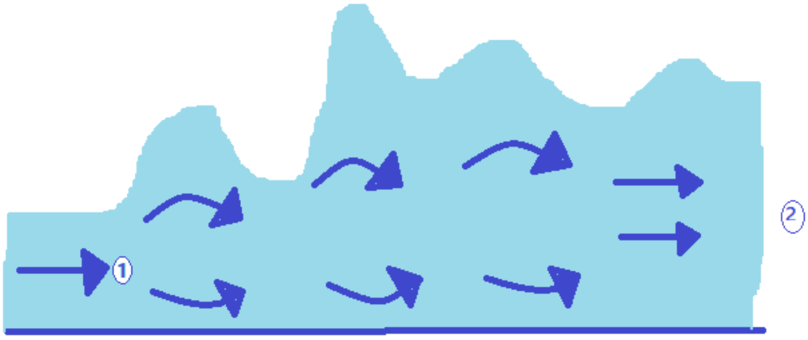

Fig. 4.15: Shows the undular jump formed in the experiment

CHAPTER - 5
CONCLUSIONS

A flow is performed in this study employing a waterway with a movable sluice gate to analyse the hydraulic jump. Several Results are shown in the form of graph to show the change in the pattern of the properties of the hydraulic jump. These results have been concluded from the experiment performed in the laboratory. The following are some of the most important interpretations drawn from the study of hydraulic jump properties:

- The Froude number has a great impact in the reduction of the jump length and subsequent depth. The amount of reduction was minimal for small Froude numbers, but it was higher for large Froude numbers.
- Subcritical flows are denoted by Froude number values varying from 0.035 to 0.041 ($0.035 < Fr_2 < 0.041$). At the pre-hydraulic jump phase, the Froude number values vary from 1.5549 to 1.7309 ($1.5549 < Fr_1 < 1.7309$), indicating that the flow was supercritical and the jump obtained was an undular jump.
- For the level-bedded restricted flume, the energy loss due to hydraulic jump ranged from 0.37 to 0.48, denoting some energy gain with a faster rate of discharge through the flume. Because it indicates a supercritical flow area, the movable sluice gate may cause hydraulic problems.
- The sequent depth ratio and the length of the jump and the decreases with increase in the slope while the Relative energy loss increases with the increase of the pre-jump Froude's number (F_1).
- The height of the jump increases with the increase in the length of the jump forming the M_3 water profile of the jump.
- When the results of this study and the prior study was compared, the values of the attributes studied differed by 15 – 20 %. The variance in results could be due to an instrumental or reading error during the experiment. The study's findings are satisfactory.

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