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An Experimental Analysis of Characteristics of Hydraulic Jump Based on Froude Number

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Abstract: This thesis presents an experimental investigation of hydraulic jumps in open-channel flows, with a primary focus on the role of Froude number in influencing jump characteristics. The study aimed to enhance our understanding of hydraulic jumps, their energy dissipation, and practical implications for hydraulic engineering. Experimental data was collected through a carefully designed flume setup, systematically varying flow conditions to cover a wide range of Froude numbers. The experimental program was conducted on a 6 m long, 0.30 m wide, and 0.75 m deep rectangular flume. The analysis of hydraulic jumps was carried out by examining flow depth, velocity, and energy dissipation across the jump region. Results revealed distinct relationships between Froude number and jump characteristics, shedding light on the critical role of this dimensionless parameter in jump formation and stability. Furthermore, the thesis discusses practical implications for hydraulic structures and energy dissipation in various engineering applications. The findings of this research contribute to the field of open-channel hydraulics and provide valuable insights for hydraulic engineers and practitioners. Understanding the relationship between Froude number and hydraulic jumps is essential for designing efficient and stable hydraulic systems. This work underscores the importance of incorporating Froude number considerations into hydraulic engineering practices, ultimately leading to more effective and sustainable water management solutions.

***Index Terms* -** Froude Number, Characteristics of Jump, Energy dissipation, Relationship between Froude Number and Characteristics of jump.

I. Introduction

In his description of the hydraulic jump, Bidone stated that "once a stream has been established in a rectangular channel, the waters thus restrained rise immediately up to a certain height against the gate and form an intumescence" if the water flow is completely impeded by lowering a gate in any section of the channel itself. When supercritical flow, which is a fast-moving, smooth flow, abruptly transitions to subcritical flow, which is a slow-moving, turbulent flow, it is known as a hydraulic jump. The sudden change causes turbulence, energy dissipation, and water depth to rise quickly.

Characteristics like elevated water surface, surface waves, increased turbulence, and energy dissipation make hydraulic jumps easy to identify. Based on their Froude number, they are divided into two types: undular, week, oscillating, steady, and strong jumps. Each type has different levels of turbulence and wave formations. For many engineering applications, it is essential to comprehend hydraulic jumps. In order to effectively manage and control water flow while minimizing potential damage from high-velocity flows, engineers use this knowledge when designing spillways, energy dissipation structures, and hydraulic systems in dams.

Hydraulic jumps are observed and analyzed by researchers through field studies or experiments in laboratory flumes. Hydraulic jump behavior is explained and predicted by theoretical models grounded in the principles of fluid dynamics, including momentum, energy, and mass conservation. These models are a useful supplement to experimental data. There are applications for hydraulic jumps in many disciplines, such as environmental science, hydrology, and civil engineering. They play a crucial role in the design of hydraulic structures, flood control strategies, and water conveyance system efficiency enhancements.

In fluid mechanics, engineering design, and the comprehension of water-related phenomena in natural and artificial environments, hydraulic jumps offer an intriguing interplay between fluid flow and energy dissipation. The hydraulic jump principle is useful in many real-world situations. It minimizes erosion and prevents structural damage by enabling effective energy dissipation in hydraulic structures such as spillways and energy dissipators. In addition to helping with flood control, water resource management, and environmental preservation, hydraulic jumps also help regulate water flow and sediment transport in rivers and channels.

When it comes to dissipating energy beneath spillways and outlets, design engineers most frequently utilize the hydraulic jump. By allowing for 60–70% energy dissipation in the basin itself, a well-designed hydraulic jump can reduce damage to buildings and the streambed. Even with such effective dissipation of energy, stilling basins still require careful design to prevent major damage from abrasion, vibration, uplift, and cavitation. There is a wealth of literature available for this kind of engineering.

II. Types of Hydraulic Jumps

There are various types of hydraulic jumps based on the Froude number. Important to remember is that in every scenario, a hydraulic jump can only occur when the flow transitions from super-critical to sub-critical. Among the various kinds are:

1) Undular Hydraulic Jump: Waves that propagate downstream and are smooth and oscillatory are a characteristic of undular jumps. In contrast to steady jumps, undulating jumps because a gradual rise in water surface elevation. These jumps usually appear when the inflowing flow has a greater Froude number, which causes the flow to become wavy or undulating. The Froude number for undular jumps usually lies between 1 and 1.7.

2) Weak Hydraulic Jump: A weak hydraulic jump is a gentler variation of a traditional or steady hydraulic jump, defined by less of an increase in the elevation of the water's surface and less turbulence in the downstream flow. Weak jumps usually occur when the incoming flow has a smaller energy gradient or a lower initial velocity. The Froude Number usually falls between 1.7 and 2.5 for weak jumps.

3) Oscillating Hydraulic Jump: Regular variations in the water surface elevation and flow characteristics, which alternate cyclically between supercritical and subcritical flows, are characteristics of an oscillating hydraulic jump. Usually, these jumps appear in particular hydraulic configurations or flow conditions. The Froude number for an oscillating jump is between 2.5 and 4.5.

4) Steady Hydraulic Jump: The most common and well-known kind is the steady hydraulic jump, also known as the classical hydraulic jump. It can be identified by its sudden rise in water surface elevation, turbulent waves, and significant energy dissipation. In contrast to the first high-velocity inflow, the flow downstream of the jump is more uniform and slower in nature. The Froude number normally ranges from 4.5 to 9 for a steady jump.

5) Strong Hydraulic Jump: When compared to a steady jump, a strong hydraulic jump exhibits a larger increase in water surface elevation and a more turbulent downstream flow. It happens when there is a greater energy gradient or a higher initial velocity in the incoming flow. When a jump is strong, the Froude number is more than 9.

III. Calculation of Hydraulic Jump

Hydraulic jump calculations entail figuring out a number of variables pertaining to the flow circumstances both before and after the jump. The upstream flow depth (h_1), upstream flow velocity (V_1), downstream flow depth (h_2), downstream flow velocity (V_2), and energy loss during the jump are the main variables that must be computed or ascertained.

Here are the general steps involved in calculating a hydraulic jump:

- Determine the initial flow conditions: Measure or obtain the values of the upstream flow depth (h_1) and velocity (V_1) before the jump.

- Calculate the initial flow specific energy: Calculate the specific energy of the flow before the jump using the equation: $E_1=h_1+(v_1^2/(2g))$,
  where g is the acceleration due to gravity.

- Determine the downstream flow depth: Use the specific energy equation to calculate the downstream flow depth (h_2) after the jump. Rearrange the equation as $h_2=E_1-(v_2^2/(2g))$,
  where V_2 is the velocity of the flow after the jump.

- Determine the energy loss: Calculate the energy loss during the jump by subtracting the downstream specific energy ($E_2 = h_2 + (v_2^2/(2g))$)

- From the initial specific energy (E_1). The energy loss represents the dissipated energy during the jump.

- Check for energy balance: Confirm that the energy loss during the jump is equal to the energy gained due to the rise in water surface elevation. The energy balance equation is:

$$E_1 - E_2 = (h_2 - h_1) + (V_2^2 - V_1^2)/(2g)$$

- Verify the flow type: Determine whether the jump is a steady, weak, strong, or undular jump based on the calculated flow depths and velocities and their relationship to the critical depth and Froude number.

Froude Number	Ratio of height after to height before jump	Descriptive characteristics of jump	Fraction of energy dissipated by jump
≤ 1.0	1.0	No jump; flow must be supercritical for jump to occur	none
1.0–1.7	1.0–2.0	Standing or undulating wave	< 5%
1.7–2.5	2.0–3.1	Weak jump (series of small rollers)	5% – 15%
2.5–4.5	3.1–5.9	Oscillating jump	15% – 45%
4.5–9.0	5.9–12.0	Stable clearly defined well-balanced jump	45% – 70%
> 9.0	> 12.0	Clearly defined, turbulent, strong jump	70% – 85%

IV. Experimental Setup

The Hydraulic Engineering Laboratory at Shantilal Shah Engineering College in Bhavnagar, Gujarat, was the site of the entire set of experiments. A sharply crested spillway and a recirculating flume make up the experimental setup for flow rate measurements. There were multiple hydraulic jumps in the flume due to different channel bed conditions. There was a 6 m long, 0.27 m wide, and 0.75 m deep flume in use.

The set-up of the experiment includes:

- A 6-meter flume in length.
- Spillway.
- Velocity measurement by float method.
- Water collecting tank.
- Pump for the supply of water.
- Measuring tape.
- Meter gauge with a scale & pointer.

There is a 6 m long, 0.27 m wide, and 0.75 m deep flume in use. After that, the flume is thoroughly cleaned while being kept dry and allowing water to flow freely across its surface. Because the flow of water through it and experimental observations must be impacted by any kind of roughness or dust.

Observations are made on a smooth bed. In order to create a hydraulic jump in the flume, the tail gate is moved and the amount of water allowed through the sluice gate and flume is adjusted so that the water level becomes steady at the upstream side. The hydraulic jump's position can be adjusted by adjusting the tail gate.

The terms "Y_1" and "Y_2" denote the super-critical and sub-critical depths of flow, in that order. The "Y_1" or supercritical flow depth and the "Y_2" or subcritical flow depth suddenly separate from one another. The distance between the beginning and ending points is the jump's length. The jack was rotated to alter the discharge in order to record additional sets of observations after all of the observations for the first set had been recorded. The process is repeated with the discharges adjusted, and the pertinent variables are recorded for the smooth bed state. The same procedures are repeated for a rough bed.

Figure 1. 1 Hydraulic Laboratory SSEC Bhavnagar

Figure 1. 2 Depth measuring Gauge & Downstream Gate

Figure 1. 3 Bed Slop adjustment mechanism

4.1 Flume Description

The experiments are carried out at Shantilal Shah Engineering College's Hydraulic Engineering Laboratory in Bhavnagar, Gujarat. A rectangular flume measuring 6.08 meters in length, 0.27 meters in width, and 0.75 meters in depth was used for the experiments (Fig. 1.1). A 30 horsepower variable speed centrifugal pump at the downstream end of the flume powers the recirculating flow system. A valve in the inlet pipe that emerged from the tank helped control the flow of water into the flume.

4.2 Spillway Description

The spillway is 0.27 meters wide, 0.42 meters long, and 0.34 meters high. A spillway allows for the controlled release of water from a dam or levee downstream, frequently into the dammed river itself. The purpose of the spillway is to prevent water damage to areas of the building that aren't designed to withstand it.

4.3 Depth Measurement

The lab has two different gauge types available with a trolley setup. Point gauges were used in the experiments. Both gauges have a measuring scale on top, and a trolley can be used to move them along a flume (Fig. 1.2).

1. Point gauge: A point gauge is used to measure the depth of water by subtracting the difference between the water's surface level and the bed level. Measurement using a level base,

2. Flat-bottom gauge: A flat gauge is used to measure scour on the most upstream side of a circular bridge pier or at the bridge pier's nose.

4.4 Velocity Measurement

Velocity in the flume is calculated using the Float technique. The float technique of determining velocity is used by timing the amount of time it takes a floating body to travel a predetermined distance and noting its location in the channel.

The surface float travels at the same speed as the water's surface. A submerged float attached to a surface float via an adjustable line constitutes a subsurface float, which tracks the mean velocity directly. The ideal circumstances for float measurements are as follows:

- The canal needs to have a continuous flow throughout its entire reach; it needs to be straight and have a roughly uniform cross-section.
- Additionally, any surface-level impediments that could hinder the flow of water and consequently, its velocity.

4.5 Experimental Procedure

Steps to be follow for conducting an experiment:
Step 1: Fill the hydraulic flume tank with clear water for conducting experiments.
Step 2: The experiments were carried out on the smooth horizontal bed.
Step 3: Investigating hydraulic jump characteristics on smooth horizontal bed, the bed was levelled and the bed readings were taken using the depth gauges.
Step 4: After opening the control valve, the ogee spillway was adjusted to achieve a still water column at upstream of the ogee spillway while trying to obtain a hydraulic jump in downstream side.
Step 5: In each experimental run initial depth, final depth and flow velocity were measured
Step 6: The above procedure was repeated for five different Froude number.
Step 7: In this situation, the initial depth (y_1), final depth (y_2), length of jump and the flow velocity were measured.

- Head loss formula: = Total Head before Jump – Total Head after Jump
  $= (y_1 + v_1^2/2g) – (y_2 + v_1^2/2g)$
- Efficiency of Jump = (Head loss / Total Head before Jump) * 100
- Froude Number = v1/sqr(g*y1)

Step 8: The above procedure was repeated for seven different spacing arrangements.

Figure 1. 4 Image of Hydraulic Jump Formation

V. EXPERIMENTAL DATA COLLECTION AND ANALYSIS

4.1 General

Hydraulic jump experiments have been conducted for different Froude Numbers of jump over horizontal channel smooth bed.

A Total of Seven Runs on smooth bed flow rates were taken. The table below provides information about the data that was gathered.

Table 1 Experimental measurements

Depth of flow (Y) cm	Velocity At U/S (V) m/s	Discharge(Q) m3/s	Y_1 Cm	Y_2 Cm	Y_2/Y_1	Velocity at pre jump (V_1) m/s	Velocity at post jump (V_2) m/s	Froude no. (Fr_1)	Head over spillway cm	Length of jump cm
38.5	0.078	0.0081	0.8	4.5	5.62	2.62	0.481	9.35	5	19
38.5	0.078	0.0081	0.8	5.3	6.62	2.12	0.314	7.56	5	20

38.5	0.078	0.0081	0.9	5.1	5.67	3.28	0.413	11.04	5	25
38.5	0.078	0.0081	0.7	5.0	7.14	3.26	0.523	12.44	5	39
38.5	0.078	0.0081	0.7	5.6	8.0	4.11	0.700	15.6	5	75

Table 2 Experimental measurements

Depth of flow (Y) cm	**Velocity At U/S (V) m/s**	**Discharge(Q) m3/s**	**Y_1 Cm**	**Y_2 Cm**	**Y_2/Y_1**	**Velocity at pre jump (V_1) m/s**	**Velocity at post jump (V_2) m/s**	**Froude no. (Fr_1)**	**Head over spillway cm**	**Length of jump cm**
39	0.080	0.0084	0.9	5.6	6.22	1.95	0.341	6.56	6.4	13
39	0.080	0.0084	0.9	6.3	7.00	2.26	0.281	7.61	6.4	22
39	0.080	0.0084	1.0	6.1	6.10	3.99	0.720	12.74	6.4	53
39	0.080	0.0084	0.9	6.2	6.89	3.87	0.616	13.02	6.4	63
39	0.080	0.0084	0.9	6.8	7.55	4.64	1.115	15.61	6.4	88

Table 3 Experimental measurements

Depth of flow (Y) cm	**Velocity At U/S (V) m/s**	**Discharge(Q) m3/s**	**Y_1 Cm**	**Y_2 Cm**	**Y_2/Y_1**	**Velocity at pre jump (V_1) m/s**	**Velocity at post jump (V_2) m/s**	**Froude no. (Fr_1)**	**Head over spillway cm**	**Length of jump cm**
41	0.130	0.0143	1.2	8.1	6.75	1.90	0.280	5.53	7.2	30
41	0.130	0.0143	1.2	9.6	8.00	2.67	0.324	7.78	7.2	44
41	0.130	0.0143	1.3	9.6	7.38	5.97	1.023	16.71	7.2	87
41	0.130	0.0143	1.3	9.7	7.46	5.36	0.862	15.01	7.2	88
41	0.130	0.0143	1.4	10.5	7.50	7.20	1.987	19.42	7.2	120

Table 4 Experimental measurements

Depth of flow (Y) cm	**Velocity At U/S (V) m/s**	**Discharge(Q) m3/s**	**Y_1 Cm**	**Y_2 Cm**	**Y_2/Y_1**	**Velocity at pre jump (V_1) m/s**	**Velocity at post jump (V_2) m/s**	**Froude no. (Fr_1)**	**Head over spillway cm**	**Length of jump cm**
42.5	0.158	0.0181	1.6	9.7	6.06	2.16	0.328	5.45	8.4	63
42.5	0.158	0.0181	1.7	11.5	6.76	2.87	0.420	7.02	8.4	70
42.5	0.158	0.0181	1.7	11.1	6.52	3.97	1.168	9.72	8.4	79
42.5	0.158	0.0181	1.7	11.4	6.70	4.44	0.651	10.87	8.4	85
42.5	0.158	0.0181	1.8	12.5	6.94	7.07	1.120	16.82	8.4	93

Table 5 Experimental measurements

Depth of flow (Y) cm	Velocity At U/S (V) m/s	Discharge(Q) m3/s	Y_1 Cm	Y_2 Cm	Y_2/Y_1	Velocity at pre jump (V_1) m/s	Velocity at post jump (V_2) m/s	Froude no. (Fr_1)	Head over spillway cm	Length of jump cm
43	0.182	0.0211	1.9	10.9	5.73	2.20	0.350	5.10	9.5	53
43	0.182	0.0211	2.0	12.6	6.30	2.79	0.339	6.29	9.5	67
43	0.182	0.0211	1.8	11.9	6.61	3.86	1.005	9.18	9.5	74
43	0.182	0.0211	1.9	11.3	5.94	4.23	0.668	9.80	9.5	81
43	0.182	0.0211	1.9	12.4	6.52	6.73	1.103	15.58	9.5	90

Table 6 Experimental measurements

Depth of flow (Y) cm	Velocity At U/S (V) m/s	Discharge(Q) m3/s	Y_1 Cm	Y_2 Cm	Y_2/Y_1	Velocity at pre jump (V_1) m/s	Velocity at post jump (V_2) m/s	Froude no. (Fr_1)	Head over spillway cm	Length of jump cm
44.5	0.254	0.0305	3.1	18.0	5.80	5.67	0.967	10.10	9.5	60
44.5	0.254	0.0305	2.3	15.3	6.65	7.50	1.126	15.78	9.5	72
44.5	0.254	0.0305	2.3	15.2	6.61	7.90	1.136	16.63	9.5	77
44.5	0.254	0.0305	2.1	17.3	8.23	7.85	1.312	17.29	9.5	84
44.5	0.254	0.0305	1.9	15.7	8.26	8.05	1.745	18.64	9.5	97

Table 7 Experimental measurements

Depth of flow (Y) cm	Velocity At U/S (V) m/s	Discharge(Q) m3/s	Y_1 Cm	Y_2 Cm	Y_2/Y_1	Velocity at pre jump (V_1) m/s	Velocity at post jump (V_2) m/s	Froude no. (Fr_1)	Head over spillway cm	Length of jump cm
45	0.277	0.0336	3.0	19.1	6.36	7.26	1.292	13.38	9.8	61
45	0.277	0.0336	2.5	17.5	7.00	8.84	1.294	17.85	9.8	80
45	0.277	0.0336	2.4	16.2	6.75	8.42	1.421	17.35	9.8	85
45	0.277	0.0336	2.3	16.8	7.30	8.29	1.844	17.45	9.8	91
45	0.277	0.0336	2.3	16.6	7.21	8.82	1.872	18.56	9.8	112

Table 8 Experimental measurements

Depth of flow (Y) cm	Velocity At U/S (V) m/s	Discharge(Q) m3/s	Y_1 Cm	Y_2 Cm	Velocity at pre jump (V_1) m/s	Velocity at post jump (V_2) m/s	Froude no. (Fr_1)	Total Head before jump (m)	Total Head after jump (m)	Head Loss in Hydraulic Jump (m)	Fraction of Energy Dissipated by Jump
38.5	0.078	0.0081	0.8	4.5	2.62	0.481	9.35	0.358	0.057	0.301	84.08
38.5	0.078	0.0801	0.8	5.3	2.12	0.314	7.56	0.237	0.058	0.179	75.53
38.5	0.078	0.0081	0.9	5.1	3.28	0.413	11.04	0.556	0.060	0.496	89.21
38.5	0.078	0.0081	0.7	5.0	3.26	0.523	12.44	0.549	0.064	0.485	88.34
38.5	0.078	0.0081	0.7	5.6	4.11	0.700	15.6	0.868	0.081	0.787	90.67

Table 9 Experimental measurements

Depth of flow (Y) cm	Velocity At U/S (V) m/s	Discharge(Q) m3/s	Y_1 Cm	Y_2 Cm	Velocity at pre jump (V_1) m/s	Velocity at post jump (V_2) m/s	Froude no. (Fr_1)	Total Head before jump (m)	Total Head after jump (m)	Head Loss in Hydraulic Jump (m)	Fraction of Energy Dissipated by Jump
39	0.080	0.0084	0.9	5.6	1.95	0.341	6.56	0.203	0.061	0.142	69.95
39	0.080	0.0084	0.9	6.3	2.26	0.281	7.61	0.269	0.066	0.203	75.46
39	0.080	0.0084	1.0	6.1	3.99	0.720	12.74	0.821	0.087	0.734	89.40
39	0.080	0.0084	0.9	6.2	3.87	0.616	13.02	0.772	0.081	0.691	89.50
39	0.080	0.0084	0.9	6.8	4.64	1.115	15.61	1.106	0.131	0.975	88.15

Table 10 Experimental measurements

Depth of flow (Y) cm	Velocity At U/S (V) m/s	Discharge(Q) m3/s	Y_1 Cm	Y_2 Cm	Velocity at pre jump (V_1) m/s	Velocity at post jump (V_2) m/s	Froude no. (Fr_1)	Total Head before jump (m)	Total Head after jump (m)	Head Loss in Hydraulic Jump (m)	Fraction of Energy Dissipated by Jump
41	0.130	0.0143	1.2	8.1	1.90	0.280	5.53	0.196	0.085	0.111	56.63
41	0.130	0.0143	1.2	9.6	2.67	0.324	7.78	0.375	0.101	0.274	73.07
41	0.130	0.0143	1.3	9.6	5.97	1.023	16.71	1.829	0.149	1.680	91.85
41	0.130	0.0143	1.3	9.7	5.36	0.862	15.01	1.477	0.135	1.342	90.86
41	0.130	0.0143	1.4	10.5	7.20	1.987	19.42	2.656	0.306	2.350	88.48

Table 11 Experimental measurements

Depth of flow (Y) cm	Velocity At U/S	Discharge(Q) m3/s	Y_1 Cm	Y_2 Cm	Velocity at pre jump (V_1)	Velocity at post jump (V_2) m/s	Froude no. (Fr_1)	Total Head before jump (m)	Total Head after jump (m)	Head Loss in Hydraulic Jump (m)	Fraction of Energy Dissipated by Jump

	(V) m/s				m/s						
42.5	0.158	0.0181	1.6	9.7	2.16	0.328	5.45	0.253	0.102	0.151	59.68
42.5	0.158	0.0181	1.7	11.5	2.87	0.420	7.02	0.437	0.124	0.313	71.62
42.5	0.158	0.0181	1.7	11.1	3.97	1.168	9.72	0.820	0.181	0.639	77.92
42.5	0.158	0.0181	1.7	11.4	4.44	0.651	10.87	1.021	0.135	0.886	86.78
42.5	0.158	0.0181	1.8	12.5	7.07	1.120	16.82	2.56	0.1887	2.371	92.62

Table 12 Experimental measurements

Depth of flow (Y) cm	Veloc ityAt U/S (V) m/s	Discha rge(Q) m3/s	Y_1 Cm	Y_2 Cm	Veloc ityat pre jump (V_1) m/s	Velocit y atpost jump (V_2) m/s	Frou de no. (Fr_1)	Total Head before jump (m)	Total Head after jump (m)	Head Loss in Hydrau lic Jump (m)	Fractio n of Energy Dissipat ed by Jump
43	0.182	0.0211	1.9	10.9	2.20	0.350	5.10	0.265	0.115	0.150	56.60
43	0.182	0.0211	2.0	12.6	2.79	0.339	6.29	0.416	0.131	0.285	68.50
43	0.182	0.0211	1.8	11.9	3.86	1.005	9.18	0.777	0.170	0.607	78.12
43	0.182	0.0211	1.9	11.3	4.23	0.668	9.80	0.931	0.135	0.796	85.49
43	0.182	0.0211	1.9	12.4	6.73	1.103	15.58	2.327	0.186	2.141	92.00

Table 13 Experimental measurements

Depth of flow (Y) cm	Veloc ityAt U/S (V) m/s	Discha rge(Q) m3/s	Y_1 Cm	Y_2 Cm	Veloc ityat pre jump (V_1) m/s	Velocit y atpost jump (V_2) m/s	Frou de no. (Fr_1)	Total Head before jump (m)	Total Head after jump (m)	Head Loss in Hydrau lic Jump (m)	Fractio n of Energy Dissipat ed by Jump
44.5	0.254	0.0305	3.1	18.0	5.67	0.967	10.10	1.669	0.227	1.442	86.39
44.5	0.254	0.0305	2.3	15.3	7.50	1.126	15.78	2.889	0.217	2.672	92.48
44.5	0.254	0.0305	2.3	15.2	7.90	1.136	16.63	3.203	0.217	2.986	93.22
44.5	0.254	0.0305	2.1	17.3	7.85	1.312	17.29	3.161	0.260	2.901	91.77
44.5	0.254	0.0305	1.9	15.7	8.05	1.745	18.64	3.321	0.312	3.009	90.60

Table 14 Experimental measurements

Depth of flow (Y) cm	Veloc ityAt U/S (V) m/s	Discha rge(Q) m3/s	Y_1 Cm	Y_2 Cm	Veloc ityat pre jump (V_1) m/s	Velocit y atpost jump (V_2) m/s	Frou de no. (Fr_1)	Total Head before jump (m)	Total Head after jump (m)	Head Loss in Hydrau lic Jump (m)	Fractio n of Energy Dissipat ed by Jump
45	0.277	0.0336	3.0	19.1	7.26	1.292	13.38	2.716	0.276	2.440	89.85

45	0.277	0.0336	2.5	17.5	8.84	1.294	17.85	4.007	0.260	3.747	93.51
45	0.277	0.0336	2.4	16.2	8.42	1.421	17.35	3.637	0.264	3.362	92.44
45	0.277	0.0336	2.3	16.8	8.29	1.844	17.45	3.525	0.341	3.184	90.34
45	0.277	0.0336	2.3	16.6	8.82	1.872	18.56	3.987	0.344	3.642	91.36

4.2 Graphical Analysis

4.2.1 Graph shown the variation between Froude number (Fr) and Y_2/Y_1

- The experiment was conducted on a smooth bed, and a Graph (Figure 1.5 to 1.11) was made between Froude Number and Y_2/Y_1 using the observed data from Tables 1 to 7.

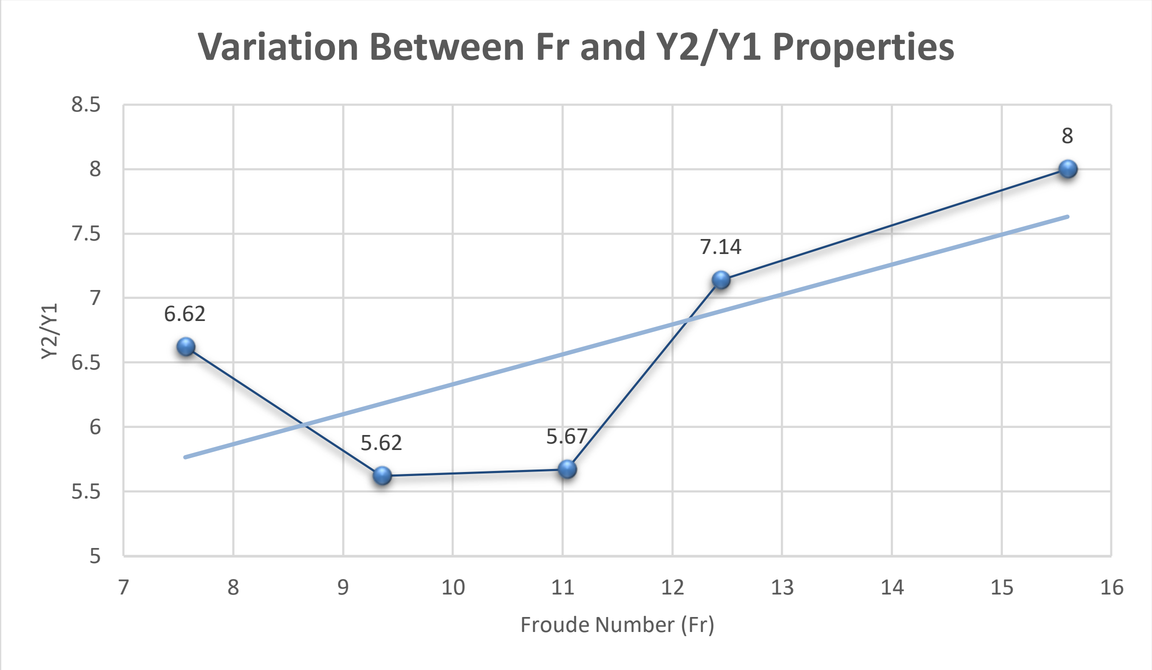

Figure 1. 5 Variation between Froude Number (Fr_1) and Y_2/Y_1 Properties

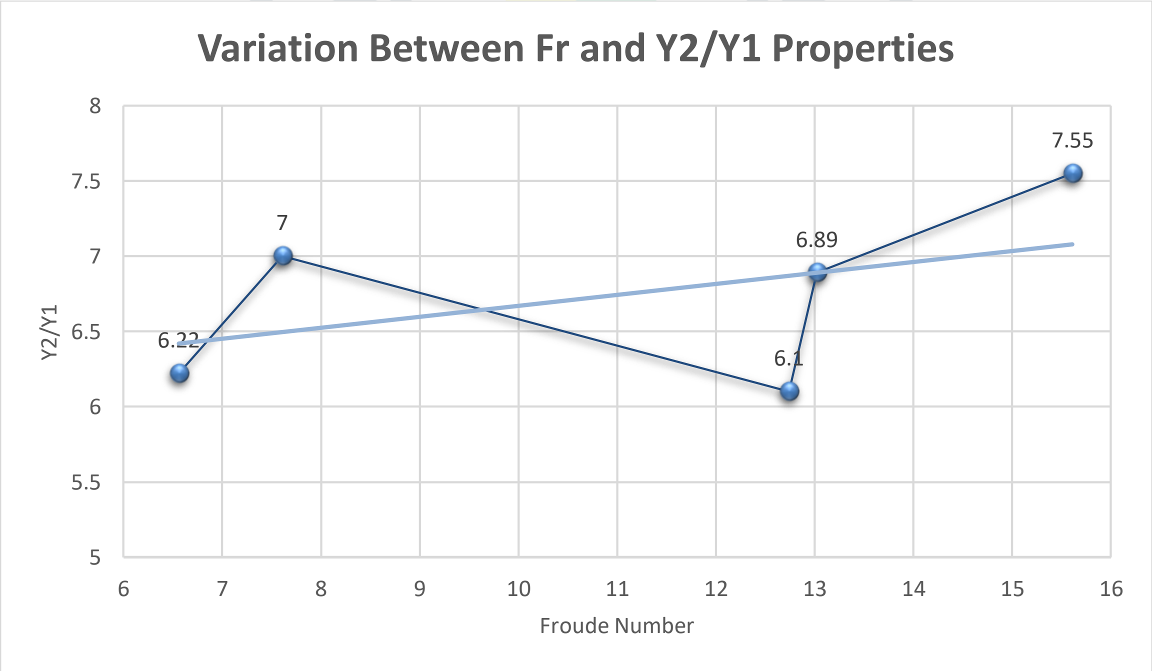

Figure 1. 6 Variation between Froude Number (Fr1) and Y2/Y1 Properties

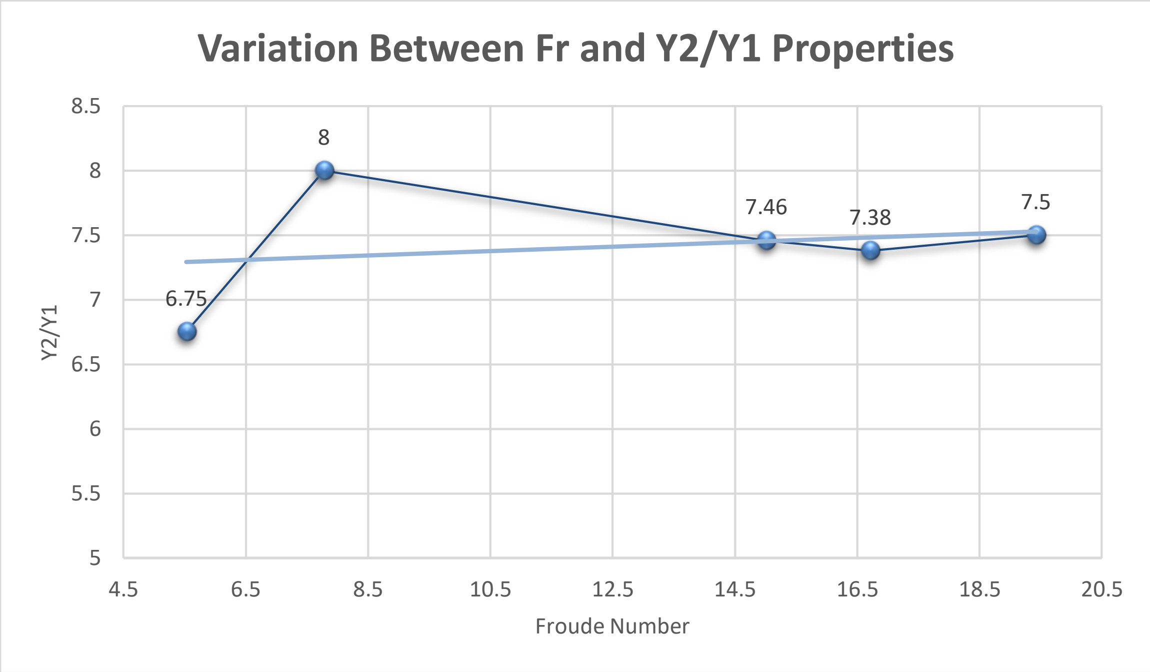

Figure 1. 7 Variation between Froude Number (Fr_1) and Y_2/Y_1 Properties

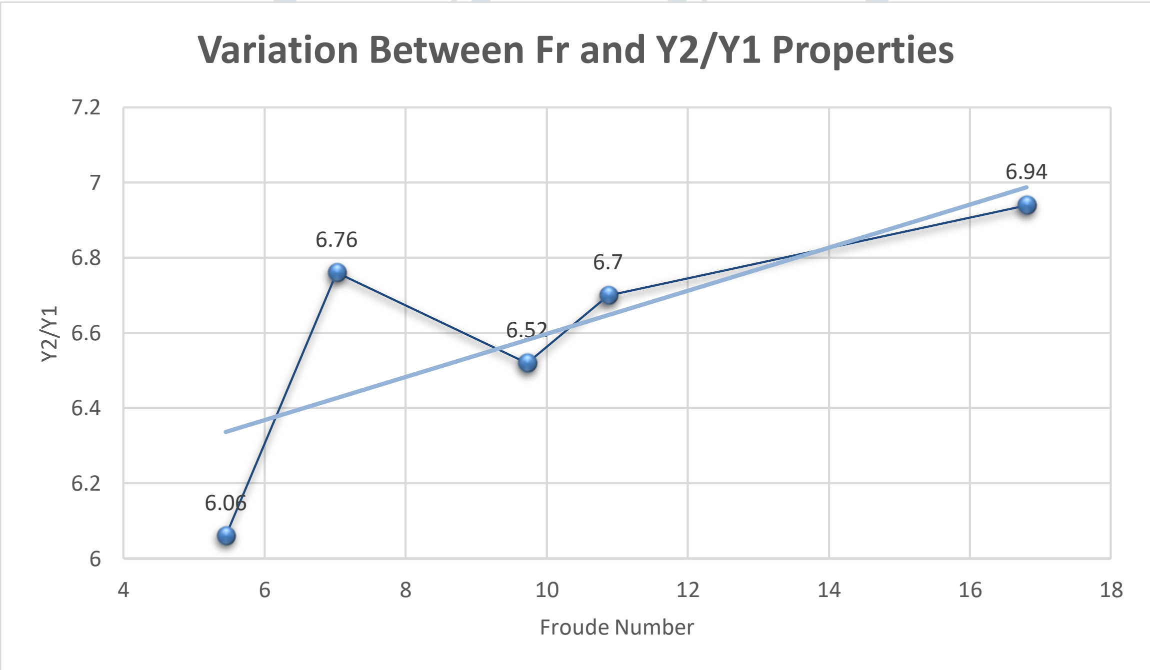

Figure 1. 8 Variation between Froude Number (Fr_1) and Y_2/Y_1 Properties

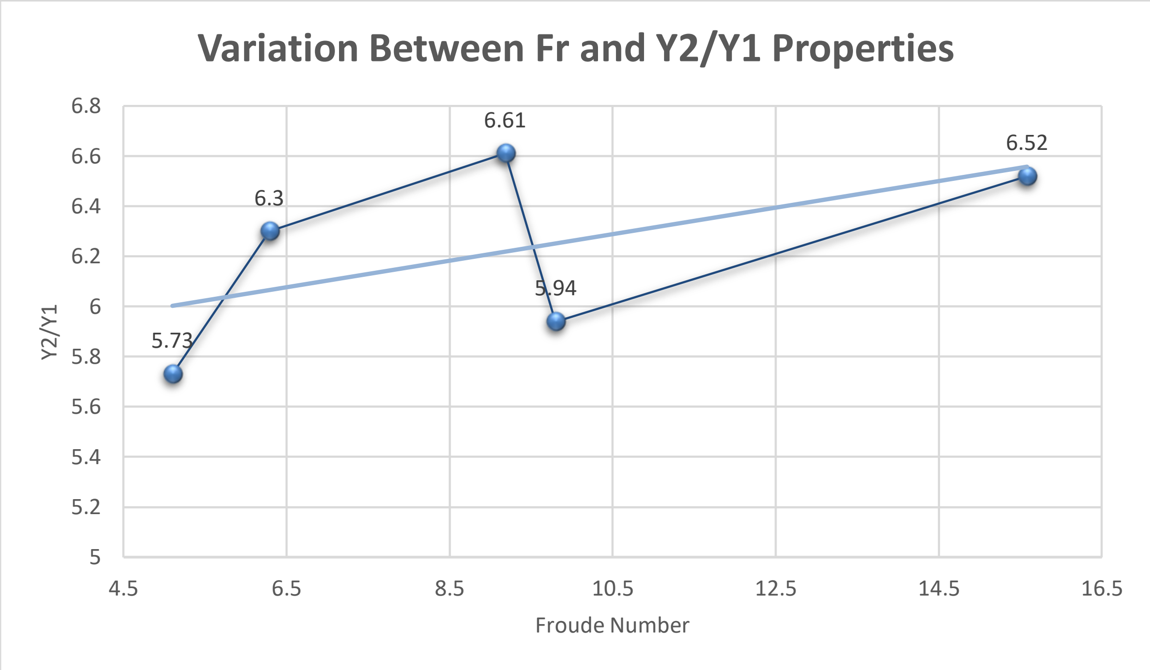

Figure 1. 9 Variation between Froude Number (Fr_1) and Y_2/Y_1 Properties

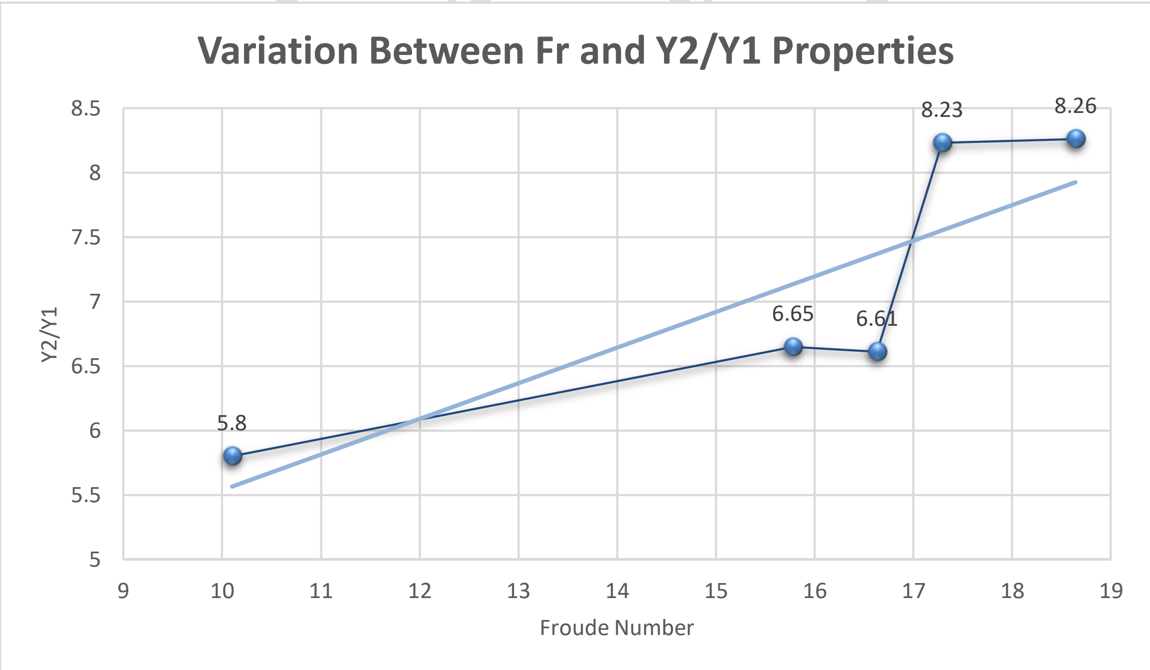

Figure 1. 10 Variation between Froude Number (Fr_1) and Y_2/Y_1 Properties

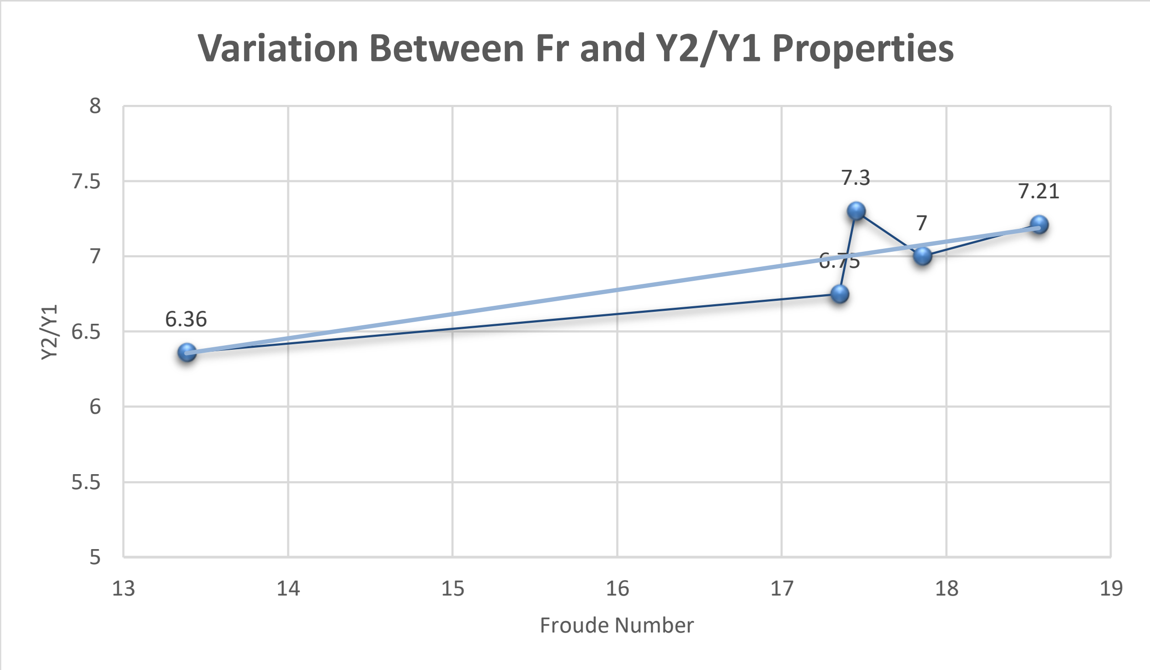

Figure 1. 11 Variation between Froude Number (Fr_1) and Y_2/Y_1 Properties

4.2.2 Graph shown the variation between Froude number (Fr) and Length of Jump

- The experiment was conducted on a smooth bed, and a Graph (Figure 1.12 to 1.18) was made between Froude Number and Length of Jump in cm using the observed data from Tables 1 to 7.

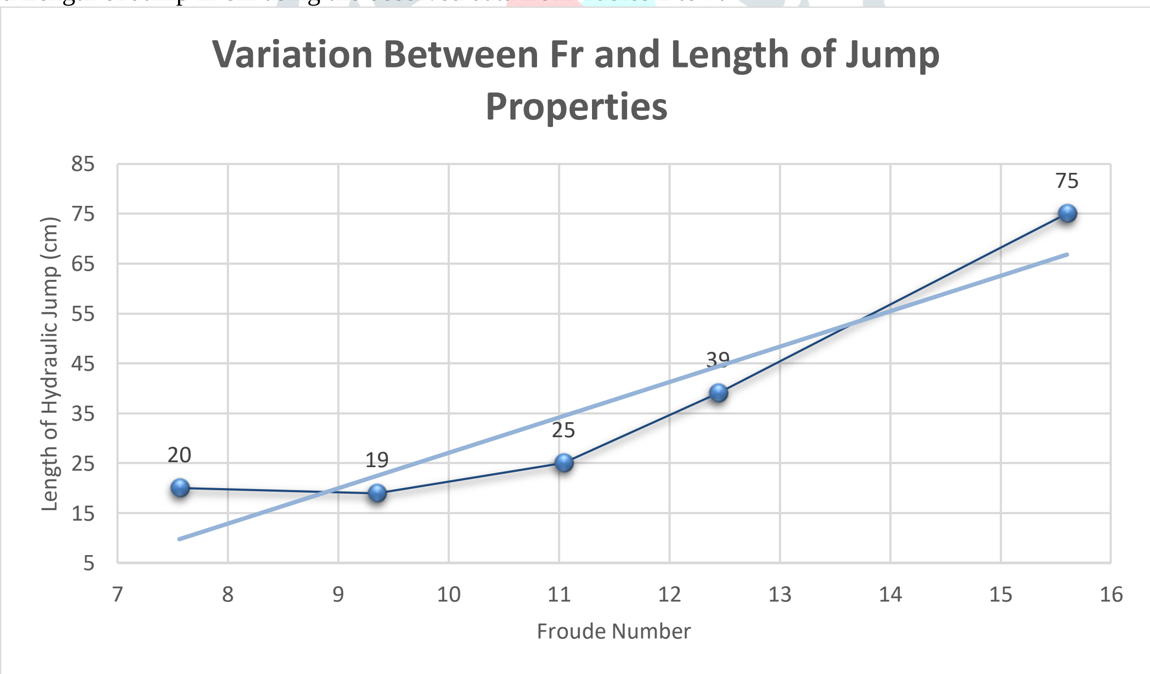

Figure 1. 12 Variation between Froude Number (Fr_1) and length of jump

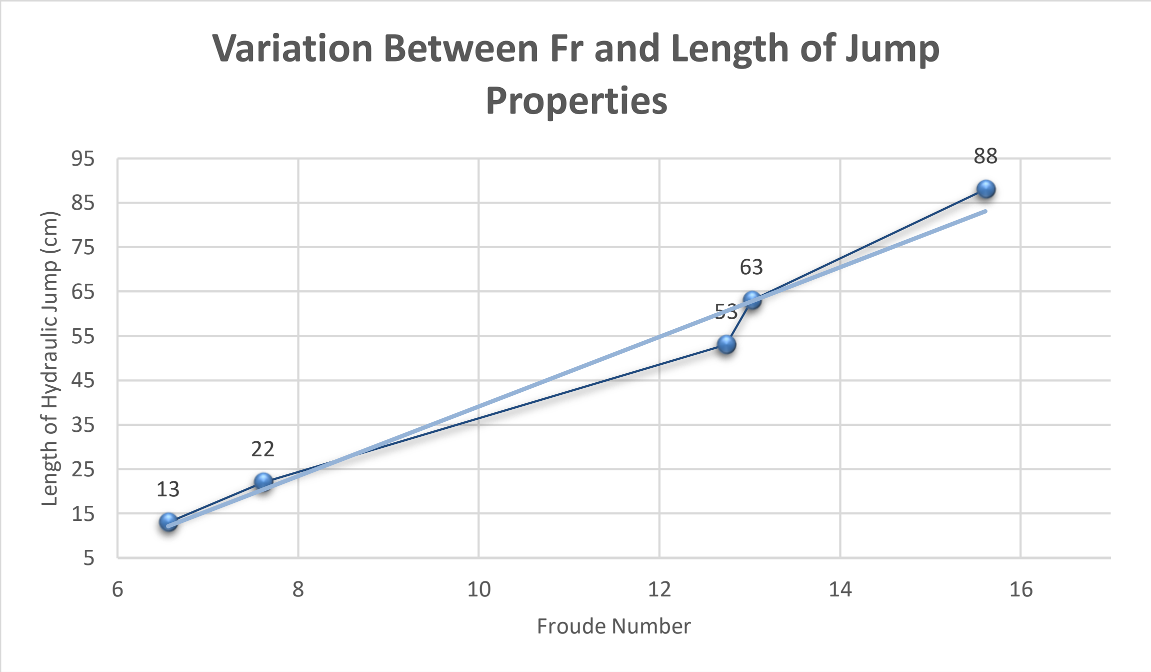

Figure 1. 13 Variation between Froude Number (Fr_1) and length of jump

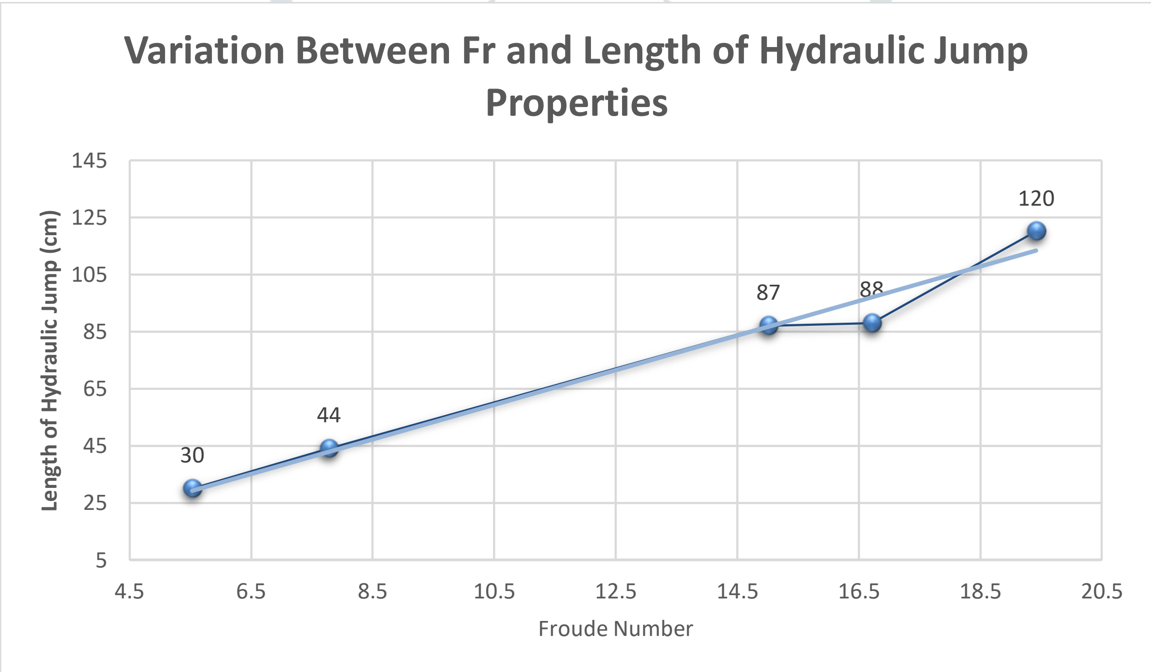

Figure 1. 14 Variation between Froude Number (Fr_1) and length of jump

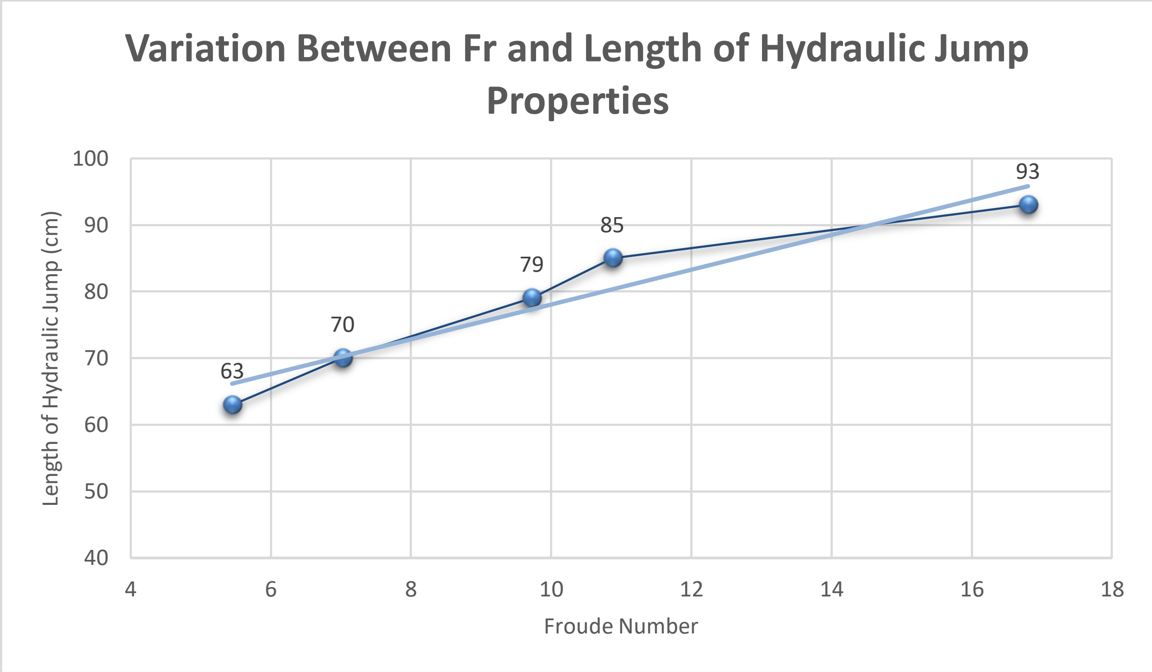

Figure 1. 15 Variation between Froude Number (Fr_1) and length of jump

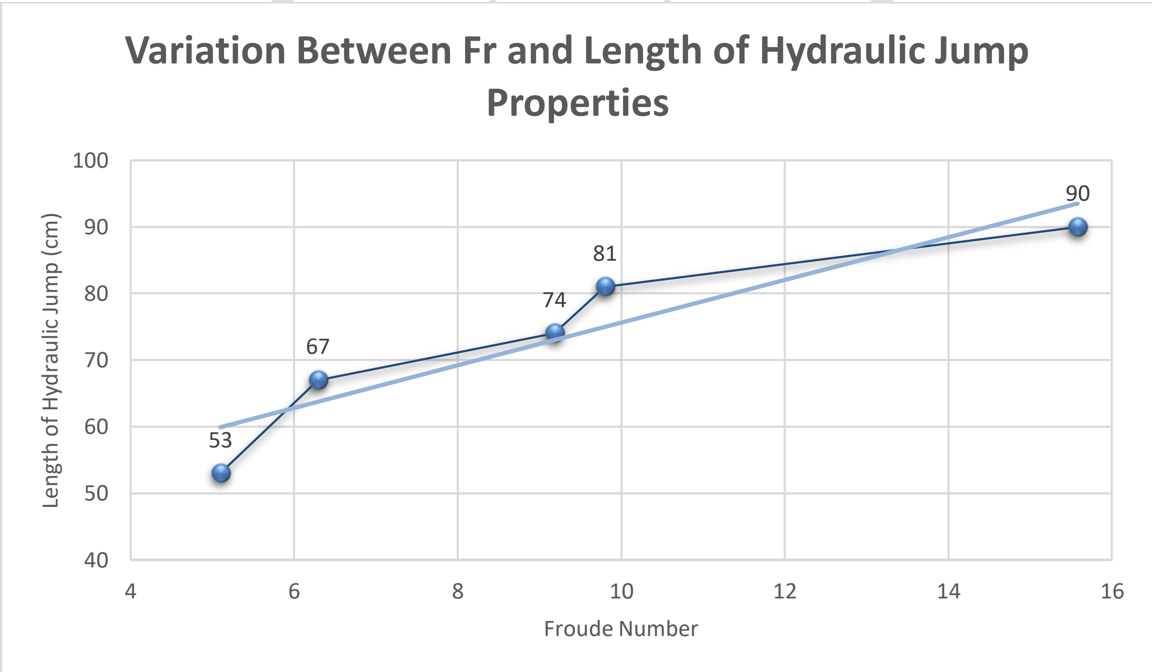

Figure 1. 16 Variation between Froude Number (Fr_1) and length of jump

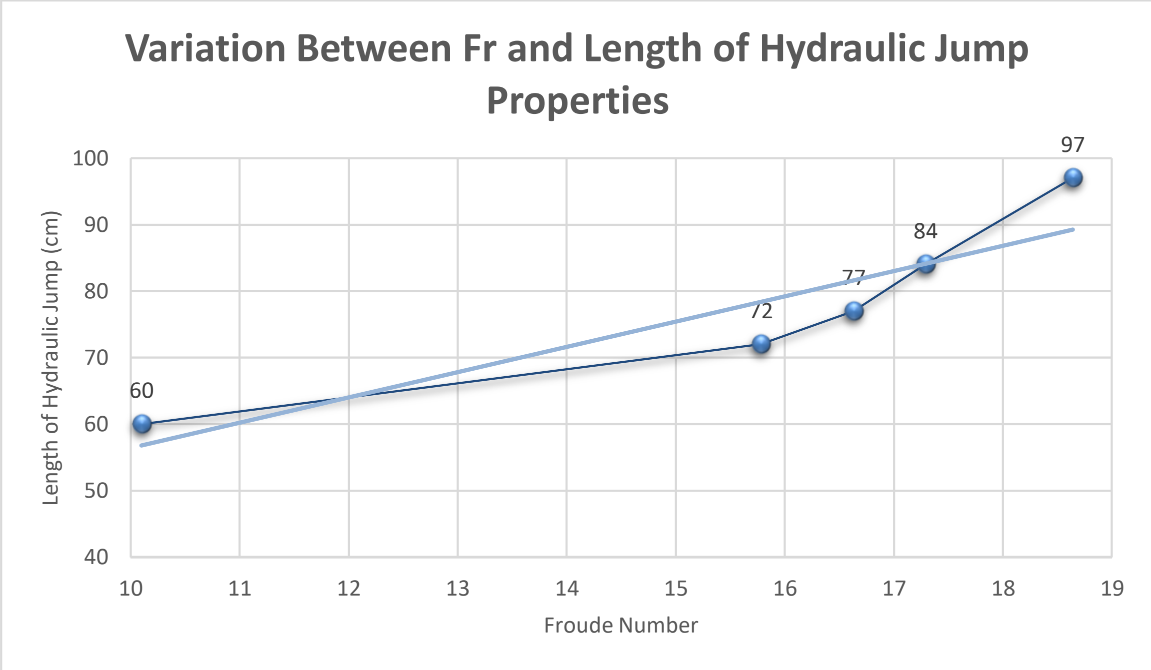

Figure 1. 17 Variation between Froude Number (Fr_1) and length of jump

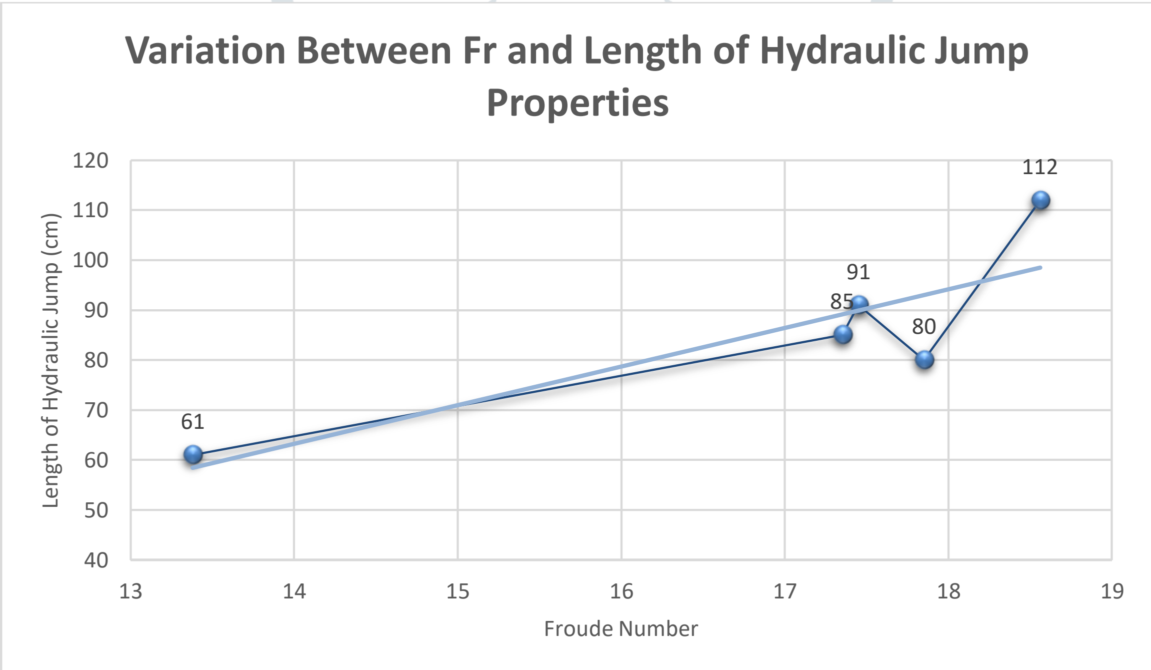

Figure 1. 18 Variation between Froude Number (Fr_1) and length of jump

4.2.3 Graph shown the variation between Froude number (Fr) and Fraction of Energy Dissipated by Jump

- The experiment was conducted on a smooth bed, and a Graph (Figure 1.19 to 1.25) was made between Froude Number and Fraction of Energy Dissipated by Jump using the observed data from Tables 8 to 14.

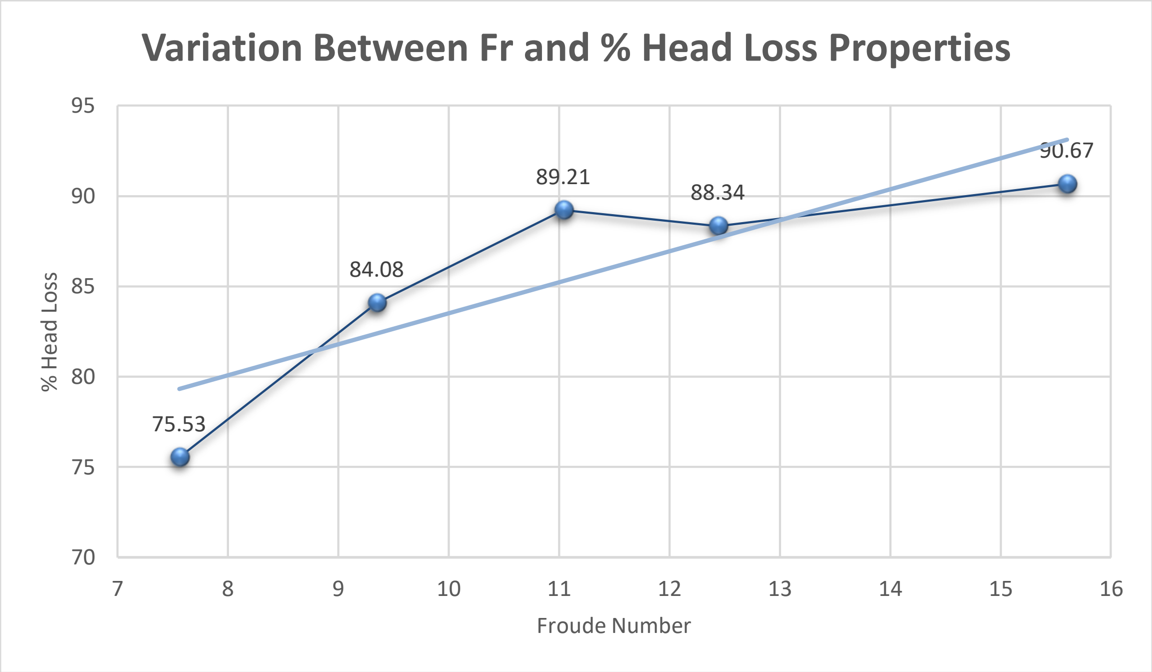

Figure 1. 19 Variation between Froude Number (Fr_1) and % Head loss

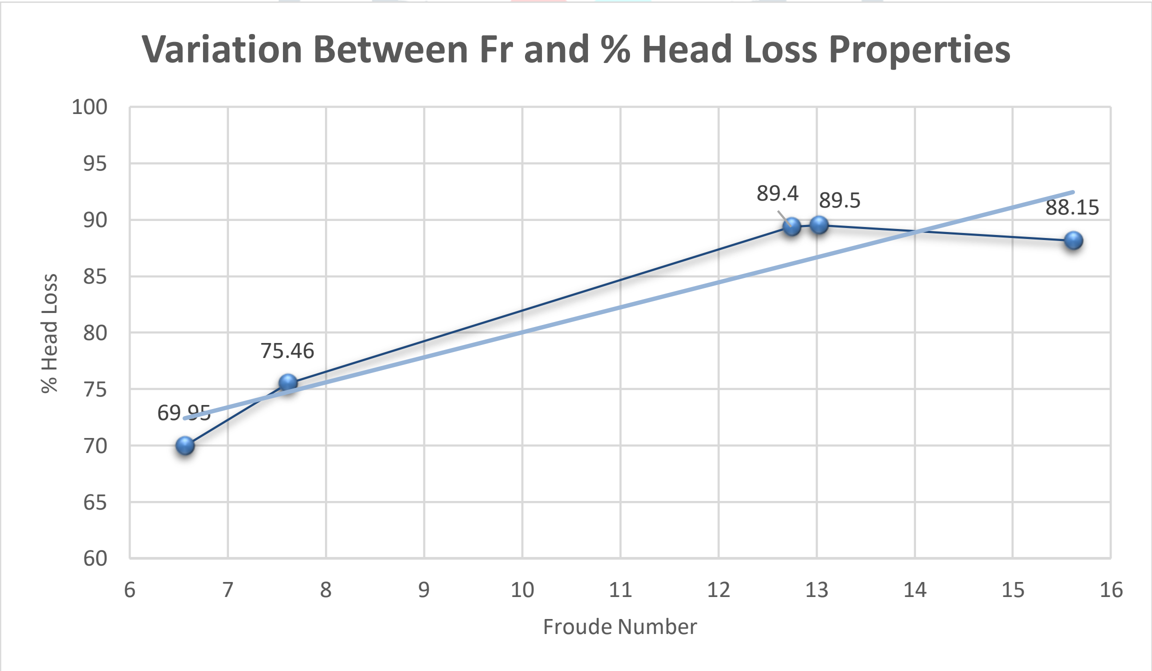

Figure 1. 20 Variation between Froude Number (Fr_1) and % Head loss

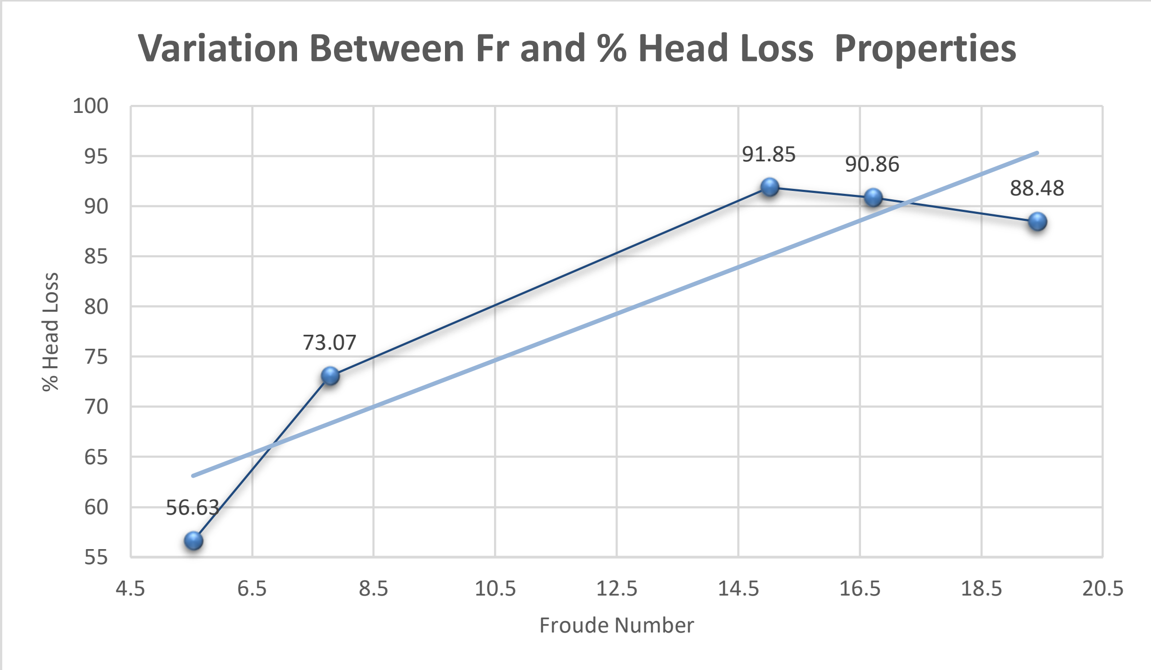

Figure 1. 21 Variation between Froude Number (Fr_1) and % Head loss

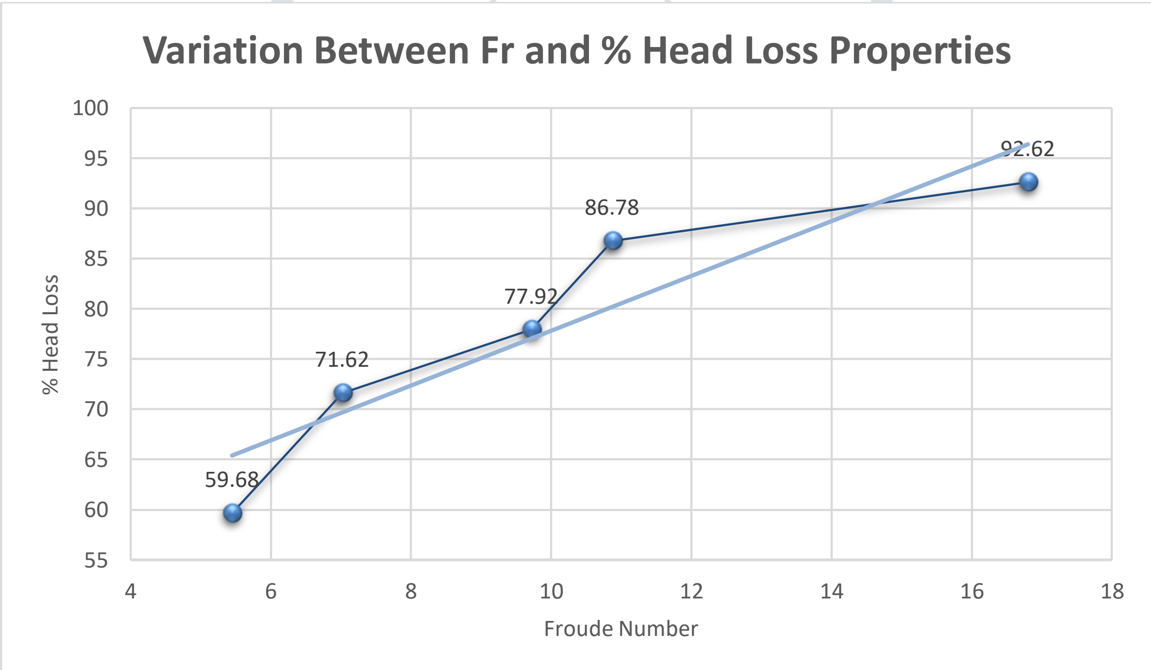

Figure 1. 22 Variation between Froude Number (Fr_1) and % Head loss

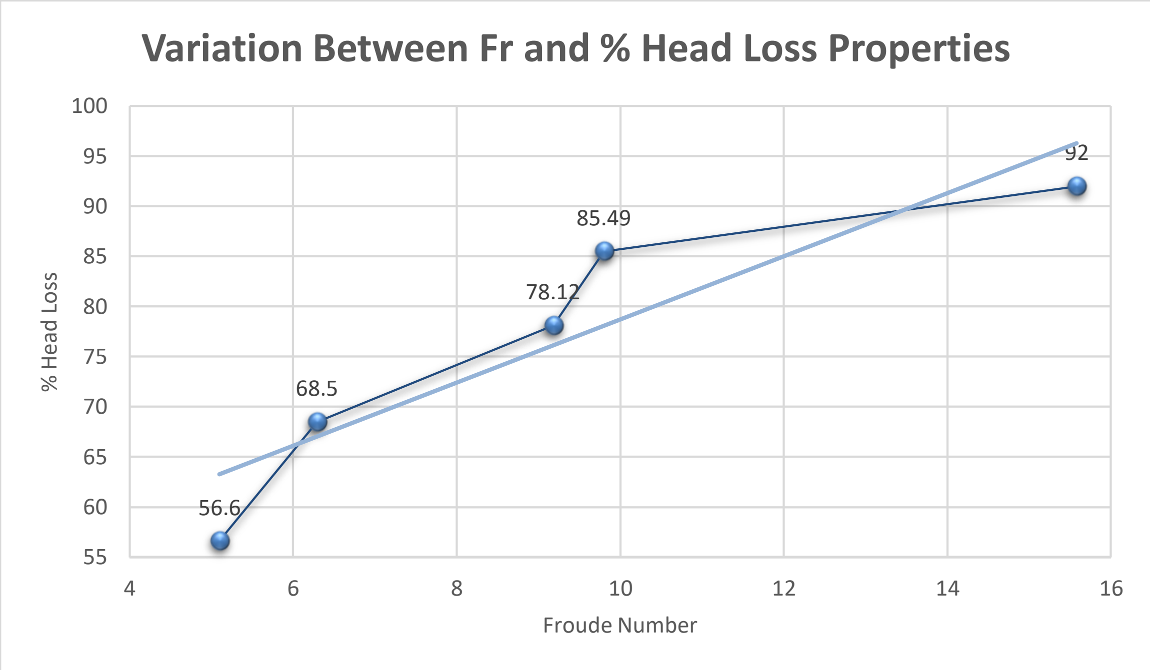

Figure 1. 23 Variation between Froude Number (Fr_1) and % Head loss

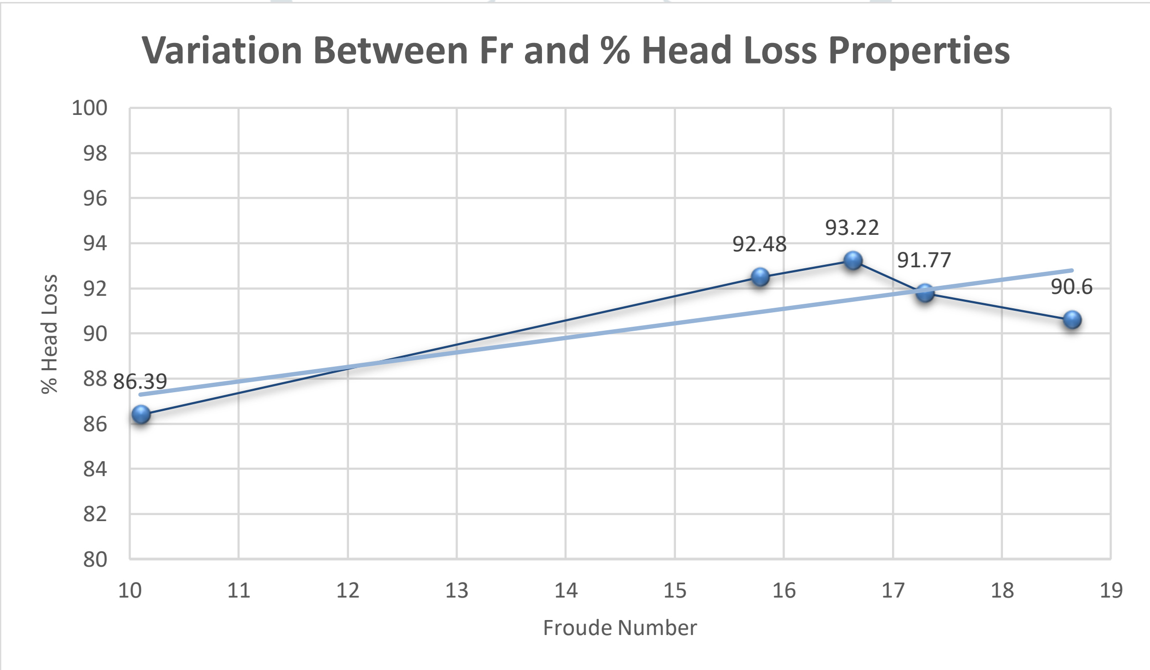

Figure 1. 24 Variation between Froude Number (Fr_1) and % Head loss

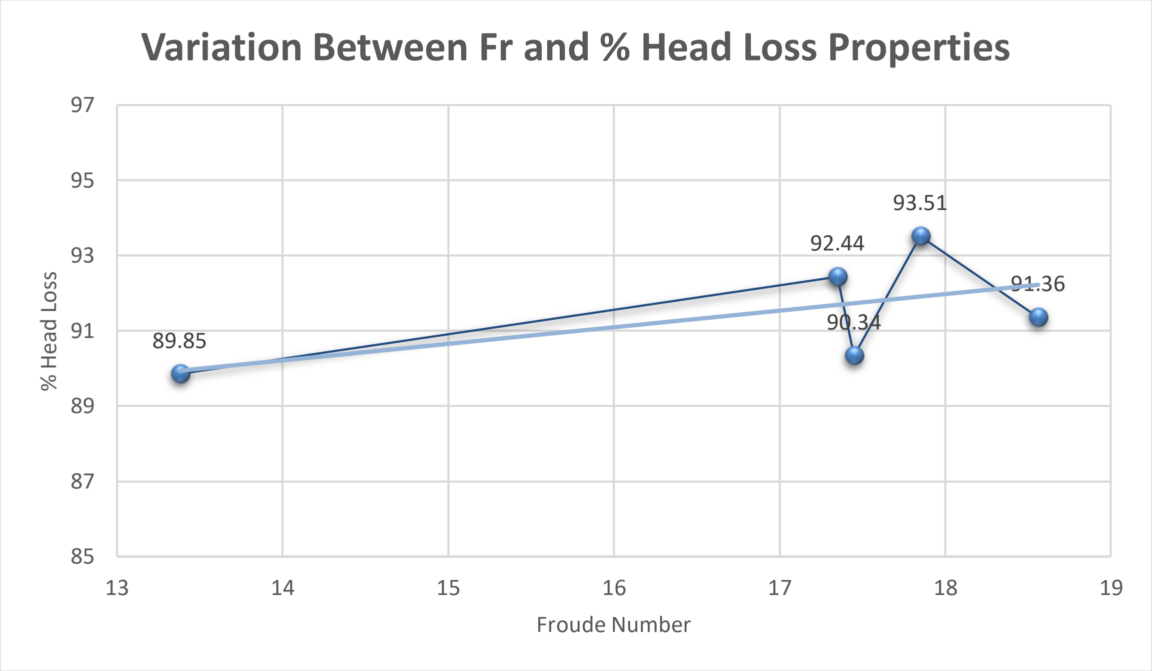

Figure 1. 25 Variation between Froude Number (Fr_1) and % Head loss

VI. RESULT AND DISCUSSIONS

- The main purpose was to study the effect of Froude Number on Hydraulic Jump Characteristics.
- In this practical the Minimum Froude Number was 5.10 and Maximum Froude Number was 19.42.
- In this practical the Minimum Length of Jump was 13cm and Maximum Length of Jump was 120cm.
- Minimum Y_2/Y_1 property is 5.62 and Maximum Y_2/Y_1 ratio is 8.26.
- Minimum % Head Loss (Efficiency of Jump to dissipate Energy or Fraction of Energy Dissipated by Jump) 56.60% and Maximum 93.51%.
- A total of 9 Readings were found which has Froude Number between 4.5 to 9 in this experiment. It means that this jumps are Stable or Steady Jump.
- And Remaining 26 Readings were found which has Froude Number greater than 9 in this experiment. It means that this jumps are Strong Jump.

VII. CONCLUSION

- From this Experiment It can be seen that Sequent depth ratio (Y_2/Y_1), Length of the jump and relative energy loss (Fraction of Energy Dissipated by Jump) increases with increase in Froude number.
- This Experimental study focused on hydraulic jumps with High Froude numbers, i.e. Fr_1 = 5.10 and 19.42
- Length of Jump increases with increase in Froude number and Length of Jump is 7 times the Height of Jump (Y_2 - Y_1) in Ideal theoretical condition but in this experiment it is equal to 8.4. Reason: - Because in experimental set up some roughness is still present over boundaries so length of jump increase with roughness.
- A total of 9 Readings were found which has Froude Number between 4.5 to 9 in this experiment. It means that this jumps are Stable or Steady Jump. Steady Jump with Froude Number 5.10 to 9 which dissipate the Energy of Jump on an average 67.45%. (from this study)
- Remaining 26 Readings were found which has Froude Number greater than 9 in this experiment. It means that this jumps are Strong Jump. Strong Jump with Froude Number 9 to 19.42 which dissipate the Energy of Jump on an average 89.03%.

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