STUDY OF THE BEHAVIOUR OF HYDRAULICS JUMP OVER ROUGH HORIZONTAL BED USING DIFFERENT SIZES OF WOODEN BLOCKS

MAJOR PROJECT REPORT

Submitted in partial fulfilment of the
Requirements for the award of the degree of

MASTER OF TECHNOLOGY
In
HYDRAULICS AND WATER RESOURCE ENGINEERING

Submitted by
ABHINAV SINGH
ROLL No. 2K13/HFE/12

Under the guidance of

Dr. MUNENDRA KUMAR

Department OF CIVIL Engg. DTU

DEPARTMENT OF CIVIL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
DELHI

Department of Civil Engineering

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

JULY 2015

CERTIFICATE

This is to certify that thesis report entitled "**STUDY OF THE BEHAVIOUR OF HYDRAULICS JUMP OVER ROUGH HORIZONTAL BED, USING DIFFERENT SIZES OF WOODEN BLOCKS**" being submitted by me is a bonafide record of my own work carried by me under the guidance of Dr. MUNENDRA KUMAR in the partial fulfilment of the requirement for the award of the degree of Master of Technology in Civil Engineering with specialization in Hydraulics and Water Resource Engineering, Delhi Technological University, DELHI-110042. The matter embodied in this project has not been submitted for the award of any other degree.

ABHINAV SINGH

Roll No: 2K13/HFE/12

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

Dr. MUNENDRA KUMAR
Department of Civil Engineering
Delhi Technological University
(Formerly Delhi College of Engineering)

CANDIDATE DECLARATION

I hereby certify that the work that is being presented in this **MAJOR PROJECT REPORT**, entitled "STUDY OF THE BEHAVIOUR OF HYDRAULICS JUMP OVER ROUGH HORIZONTAL BED, USING DIFFERENT SIZES OF WOODEN BLOCKS" in partial fulfilment of the requirements for the award of the Master of Technology degree in Hydraulics and Flood control , submitted to the Department of Hydraulics and Water resource Engineering, Delhi Technological University India, is an authentic record of my work carried out till the month of July, 2015, under the guidance of **Dr. MUNENDRA Kumar**, Associate Professor of Hydraulics and Flood control , Delhi Technological University, Delhi.

The matter embodied in this has not been submitted for the award of any other degree.

Place: Delhi **ABHINAV SINGH**

Date: JULY, 2015 ROLL NO. : **2K13/HFE/12**

ACKNOWLEDGEMENT

The culmination of this MAJOR PROJECT REPORT on the “STUDY OF THE BEHAVIOUR OF HYDRAULICS JUMP OVER ROUGH HORIZONTAL BED USING DIFFERENT SIZES OF WOODEN BLOCKS “ has brought me one step closer to the completion of the Master of Technology degree in Hydraulics and Water Resource Engineering. The MAJOR PROJECT report has led me to the acquisition of specialized and state of the art knowledge, required for the development of my dissertation thesis, and it was also an opportunity to improve my lecture presentation performance and research skills. Therefore through this I would like to show my appreciation to everyone that made this possible:

To my Supervisor **Dr. MUNENDRA Kumar**, Associate Professor of Hydraulics and Flood control department, D.T.U who provided me invaluable guidance and assistance in the preparation of this major project report.

Finally but not least, I want to express my gratitude to all the Professor and non-teaching staff of the department, who has made possible my training as Hydraulics and Flood control Engineer.

Place: Delhi **ABHINAV SINGH**

Date: JULY, 2015 ROLL NO. 2K13/HFE/12

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NOTATIONS

The following symbols are used;

A = area of flume m^2

B = flume width

F_{r_1} = Froude number at super critical flow

F_{r_2} = Froude number at sub critical flow

g = acceleration due to gravity

h = head difference (cm.)

Lj = length of hydraulic jump

q = discharge per meter width (m^2/s)

Q = Discharge m^3/s

v = velocity of flow (m/s)

y = flow depth

ABSTRACT

A hydraulic jump is a phenomenon of hydraulics which is frequently observed in open channel flow such as rivers and spillways. The hydraulic jump depends on the initial fluid speed. If the initial speed of the fluid is below the critical speed, then no jump is possible.

This project discusses about the behaviour of hydraulic jump on rough horizontal bed and its implementation in field. In the previous studies various types of roughness were used. For the present study to create roughness on bed by using, different sizes of wooden blocks with different spacing between them are used and seen its effect on hydraulic jump properties such as sequent depth ratio, roller length & the loss of energy etc. For this a large no. of experimental series were carried out with different cases. It was found that the rough bed dissipates more energy with a decrease in length of jump as compared to a smooth bed. To see the effect of roughness some relationships were also plotted. It was also found that sequent depth ratio is function of Froude no. Here with an increase in discharge the sequent depth ratio decreases. By plotted another relation between Froude No. and sequent depth, it was found that with increase in Froude No., the sequent depth ratio also increases rapidly. The ratio of spacing and height should be in proportionate manner; otherwise it will not serve as a rough bed. Because the increased height of roughness works as an obstruction not as a roughness. If the ratio of height decreases with their spacing, then it works as a smooth bed not rough bed. For this study some empirical equations & results were used which are helpful in estimation of Froude no. and other properties of hydraulic jump.

CHAPTER - 1

CHAPTER - 1

INTRODUCTION

1.1 Hydraulic Jump

Hydraulic jump in a rectangular channel is a natural happening that occurs when the flow changes from supercritical to subcritical flow. In this passage, the water surface rises suddenly. The jump can occur in the rectangular as well as non rectangular channels such as triangular, parabolic, trapezoidal, gradually expanding and abruptly expanding channels.

In this air and water are mix thoroughly, and generally a large amount of energy is dissipated. In other words, a hydraulic jump takes place when a discharge of water with higher velocity of supercritical flow on the upstream side is met with a subcritical flow on downstream side of reduced velocity and with different depth of flow. There are several model & Numeric methods produced such as Standard Step Method or HEC-RAS, digital terrain model (DTM) , HEC –Geo RAS(Hydrologic Engineering Centre), SPH (smoothed particle hydrodynamics) method etc. are used to accompany the supercritical flow and subcritical flow to find out where in a certain reach a hydraulic jump will form.

Source: https://en.wikipedia.org/wiki/File:StAnthonyFalls_apron

Figure: 1.1 Condition of formation Hydraulic jump (Saint Anthony Falls in Minneapolis)

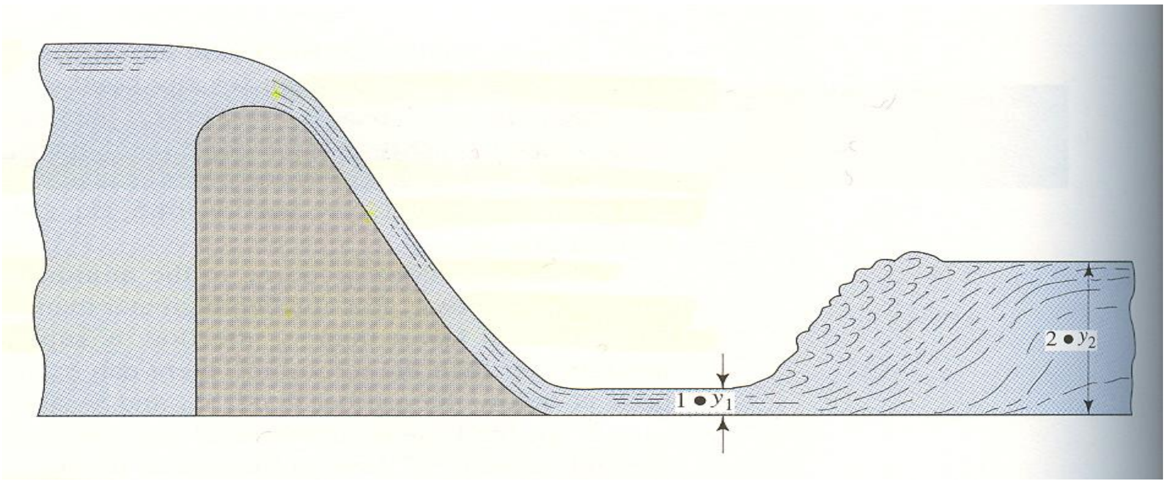
The occurrence of hydraulic jump is dependent upon the initially fluid speed .If the beginning speed of the fluid is below the critical speed, and then their no jump is possible. For beginning speed of flow which are not appreciably above the critical speed, the transition seems as an undulating wave.

1.2 Condition for formation of hydraulic jump

- When the depth of flow changed from supercritical to sub critical depth of flow.
- When the Froude number value range varies in less than 1 or greater than 1
- The hydraulic Jump in the flowing will not occur when the value of Froude number is less than 1.0
- No Jump will form when the flow will occur from subcritical to supercritical flow condition – only vice versa condition.

1.3 Practical applications of the jump:

- As the jump is accompanied by high turbulence, there is high energy loss. Therefore, the hydraulic jump is used as an energy dissipater. Downstream of a dam, the energy level is quite high as such an arrangement is made to form hydraulic jump and dissipate the energy. If the energy is not dissipated, the excessive energy will scour the bed and erode the banks. This will result in deepening of the channel which is not desirable.
- It is also used as a mixing device for mixing chemical for water purification.
- It is also used to aerate water for municipal water supplies.
- When the hydraulic jump forms, the depth abruptly increases which results in heavy down word load. Due to this, the uplift force is reduced and it will reduce the thickness of the apron. Thus the cost of the apron is reduced.
- It is used to Raising water levels in canals to increase irrigation exercise and reduce pumping heads.
- To reduce the uplift pressure beneath the hydraulic structures foundation.
- It creates special flow conditions to meet certain special type of need at control sections – gagging stations, flow measurement, flow regulation.



Source: Hydraulic jump and weir flow (http://udel.edu/~inamdar/EGTE215/Jump_weirs)

Figure 1.2: Flow over a weir

At section 1(y_1) flow – supercritical flow

At section 2 (y_2) flow – subcritical flow

$$Y_2 \,/\, Y_1 \ = \frac{1}{2}\,[\sqrt{1+8F_{r_1}^2}\ \text{-}1] \qquad \text{.........................} \ (1.1)$$

Where,

At section 1(y_1) = sequent depth at section 1

At section 2(y_2) = sequent depth at section 2

F_{n1} = Froude number at section 1.

Note – Depth of flow at section 2 i.e.Y_2, depends on the depth of section 1 i.e. Y_1 and the Froude number.

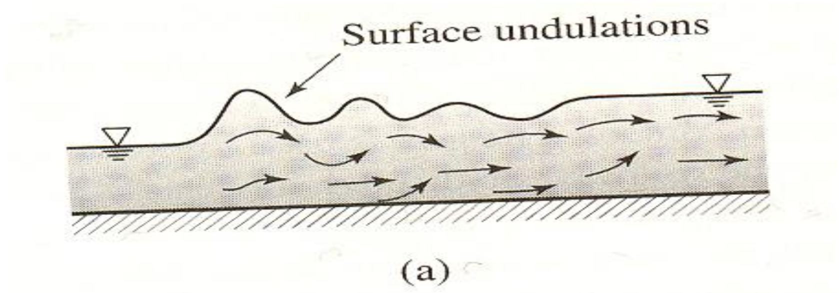
1.4 Types of hydraulic jumps

Hydraulic jump on the basic of Froude number are classified as;

$$F_{r_1} \ = \ v/\sqrt{gy_1}$$

1.4 (a) Undular jump (1 < F_{r_1} <1.7)

- Undulation are Slight
- Two conjugate depths are close to each other.
- Transition is not abrupt – slightly ruffled water surface.



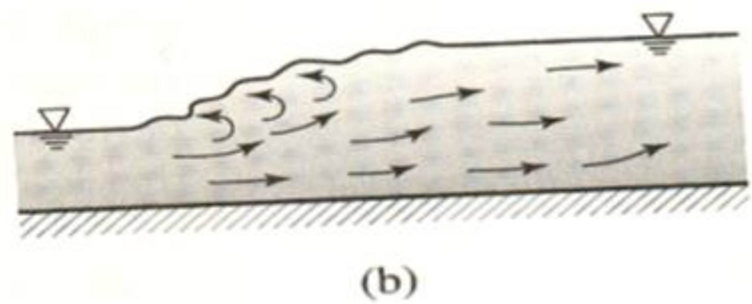
Source: http://udel.edu/~inamdar/EGTE215/Jump_weirs

Figure 1.3: Undular jump

F_{r_1} (Froude number corresponding to supercritical flow) lies between 1and 1.7.the jump formed is called as undular jump. In fact there are undulations on the free surface and this cannot be classified as hydraulic jump. Practically there is no loss energy.

1.4 (b) Weak jump (1.7< F_{r_1} <2.5)

- In this jump generation of rollers and eddies on the surface
- In this condition loss of the energy of water is small.
- The depth ratio in between initial depth to final depth varies in between the range of 2.0 and 3.1.



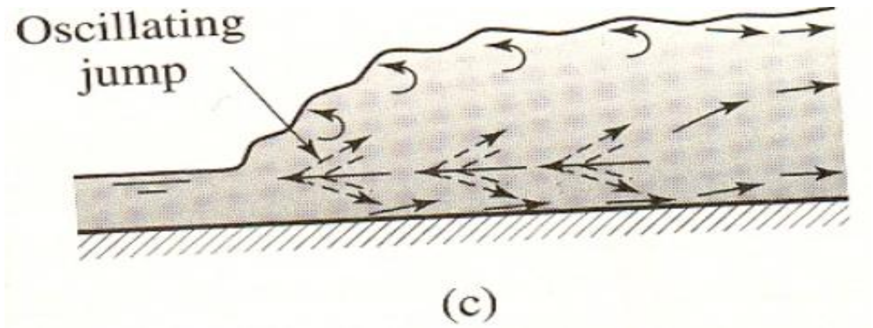
Source: http://udel.edu/~inamdar/EGTE215/Jump_weirs

Figure 1.4: Weak jump

F_{r_1} lies between 1.7 and 2.5; the hydraulic jump formed is called as week jump. In this case a number of small rollers appear on the surface of the jump and the liquid surface on the downstream side is smooth. The energy loss in the jump is low.

1.4 (c) Oscillating jump (2.5 < F_{r_1} <4.5)

- In this type of jump, a jet is oscillating from the bottom of channel to the surface of water.
- The depth ratio in between initial depth to final depth varies in between the range of 3.1 and 5.0
- To prevent the devastating effects, the jump of this type should be avoided.



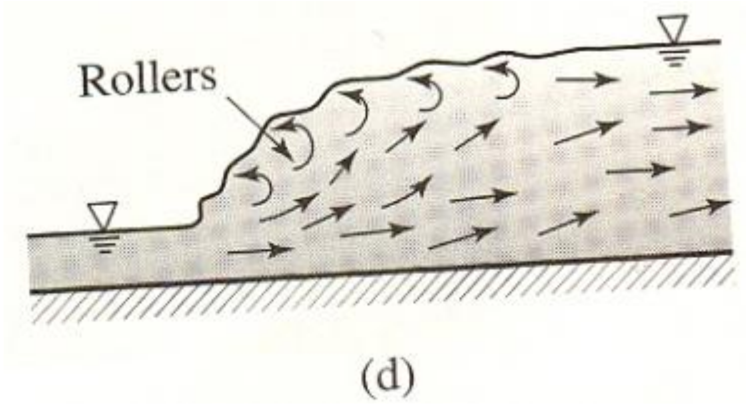
Source: http://udel.edu/~inamdar/EGTE215/Jump_weirs

Figure 1.5: Oscillating jump

F_{r_1} lies in between 2.5 and 4.5 then the jump formed is called as oscillating jump. In this type of jump, a jet is oscillating from the bottom of channel to the surface of water. It results in an irregular repeated force which can damage the bed and banks of the channel on the downstream side. This range of $F_{r,}$ therefore, would be avoided. However, it is the most commonly encountered range of F_1 and therefore we have to take some other measures need to be taken this one.

1.4 (d) Stable jump (4.5<F_{r_1} <9)

- This type of jump is good energy dissipation
- By this jump a considerable rise in downstream condition of water level
- The depth ratio in between initial depth to final depth varies in between the range of 5.9 and 12.0.



Source: http://udel.edu/~inamdar/EGTE215/Jump_weirs

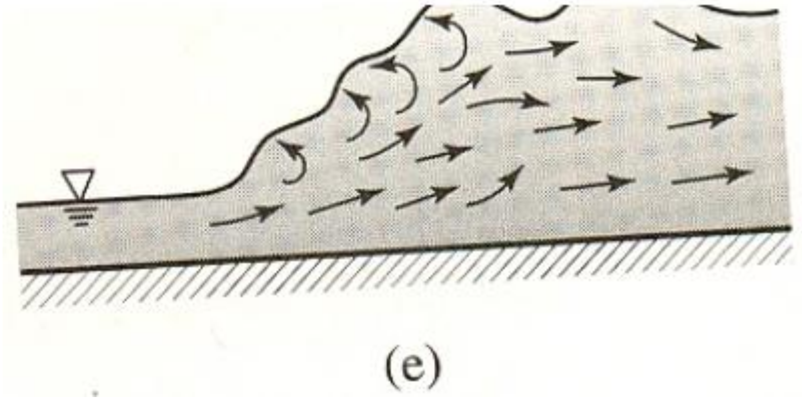
Figure 1.6: Stable jump

F_{r_1} lies between the range 4.5 and 9.0 then the jump formed is known as steady jump. This is the most sensible type of jump as the energy dissipation is large and the surface of downstream side is smooth. There is no damage on downstream side due to travel of the water wave. It is exhaustive to tail water level gives best economical design

1.4 (e) Strong or rough jump (F_{r_1} > 9)

- This type of Jump is become growingly rough.
- The value of Froude no. Fn1 should not be exceeding 12; otherwise required stilling basins will be large and huge.

- The ability of this type of jump for the dissipation of energy is huge.
- The depth ratio in between initial depth to final depth varies in between the range of 12.0 and 20.0.

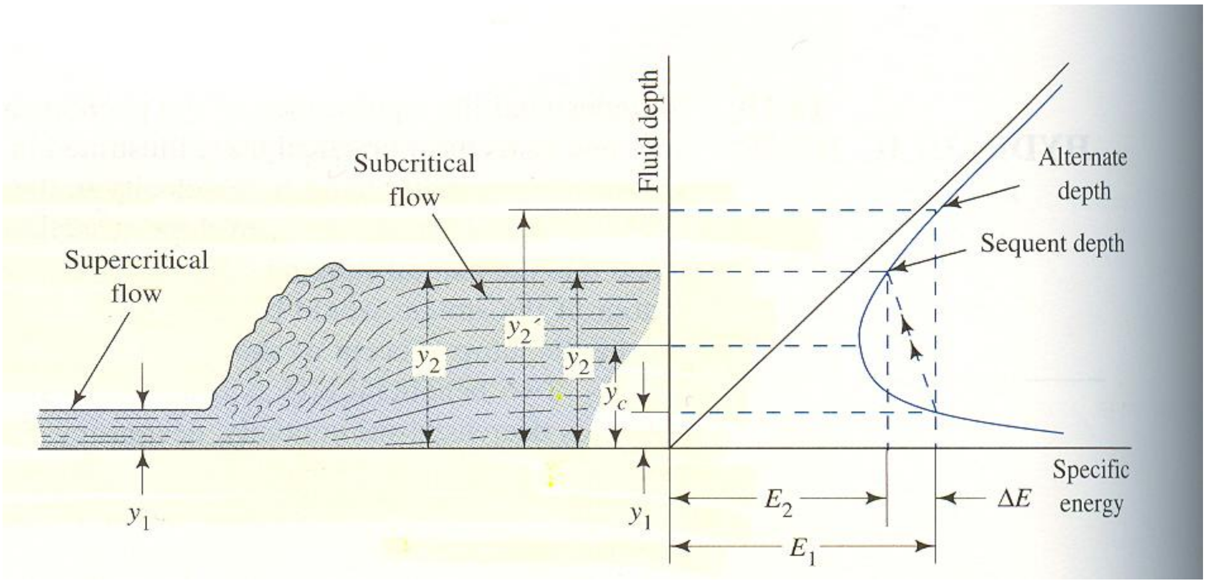


Source: http://udel.edu/~inamdar/EGTE215/Jump_weirs

Figure 1.7: Strong jump

F_{r_1} is greater than 9.0, the jump formed is known as strong jump and surface downstream is absolutely rough. Although the energy dissipation is large i.e., 85% but it is not a desirable type of jump as it can cause huge damage on the downstream side.

1.5 Specific Energy conditions in the Hydraulic jump



Source: http://udel.edu/~inamdar/EGTE215/Jump_weirs

Figure 1.8: Specific energy diagram

Loss of energy in terms of sequent depth

$$E_1 - E_2 = (Y_2 - Y_1)^3/4Y_1Y_2 \qquad \text{.......................} \; (1.2)$$

Total energy of flow refered to datum head is given as

$$E = z + y + \frac{v^2}{2g} \qquad \text{.......................} \; (1.3)$$

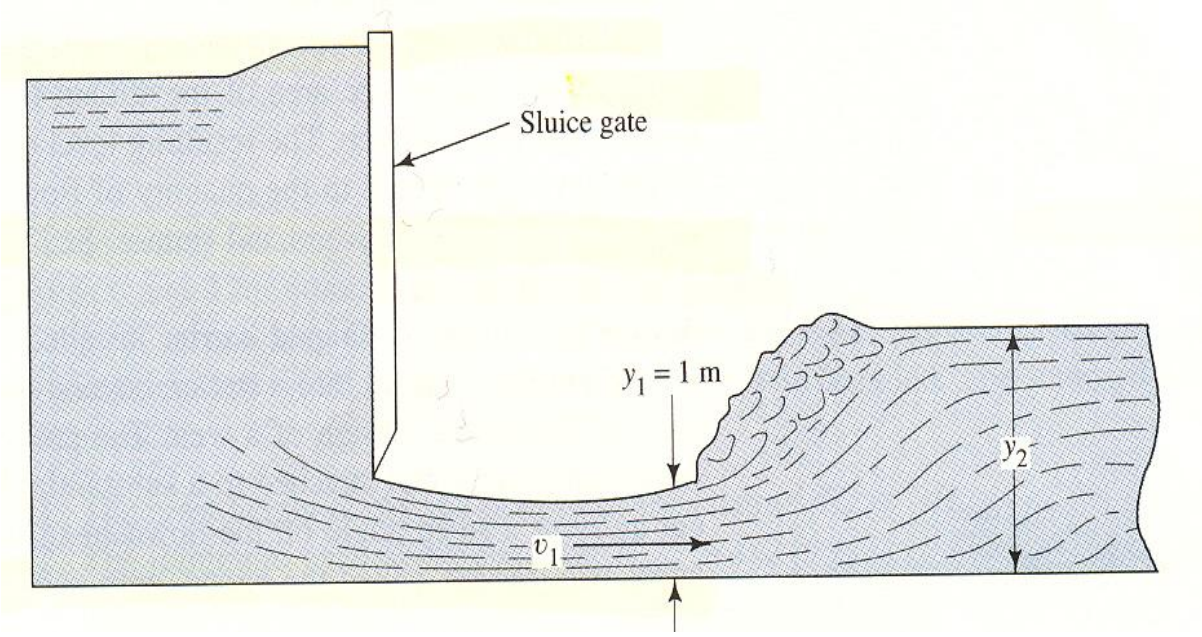
Where, y = depth of flow liquid

v = mean velocity of flow liquid (m/s)

z = datum head

Note:

- Theoretical depth after jump – alternate depth
- Actual depth after jump – sequent depth
- Length of jump – varies – but about 7 times the sub critical depth.



Source: http://udel.edu/~inamdar/EGTE215/Jump_weirs

Figure 1.9: Sluice gate diagram

- **Height of jump**: Height of jump is the difference in between depth of pre jump and post jump. It is denoted by h_j .
- **Length of jump: The** hydraulic jump length is defined as the distance in between section 1 and 2, from where jump starts forms to the end of section 2.
- **Sequent Depth**: In a channel, the depth of flow before the jump is known as the initial depth. It is denoted by Y_1. The depth of flow after the jump is known as post jump it is denoted by Y_2.

1.6 Features of rapidly varied flow

Following are the characteristics of rapidly varied flow:

- The curvature of streamlines is highly pronounced and due to this profile discontinuous or broken which causes high turbulence.
- As the curvature of streamlines is quite pronounced, the pressure distribution is not hydrostatic.
- As this type of flow occurs over a small reach, the frictional force is neglected.
- Velocity is non-uniform hence usual momentum equation cannot be applied.
- Eddies, rollers and separation of flow are common.

1.7 Classes of Hydraulic Jump

1.7 (a) Common Hydraulic Jump:

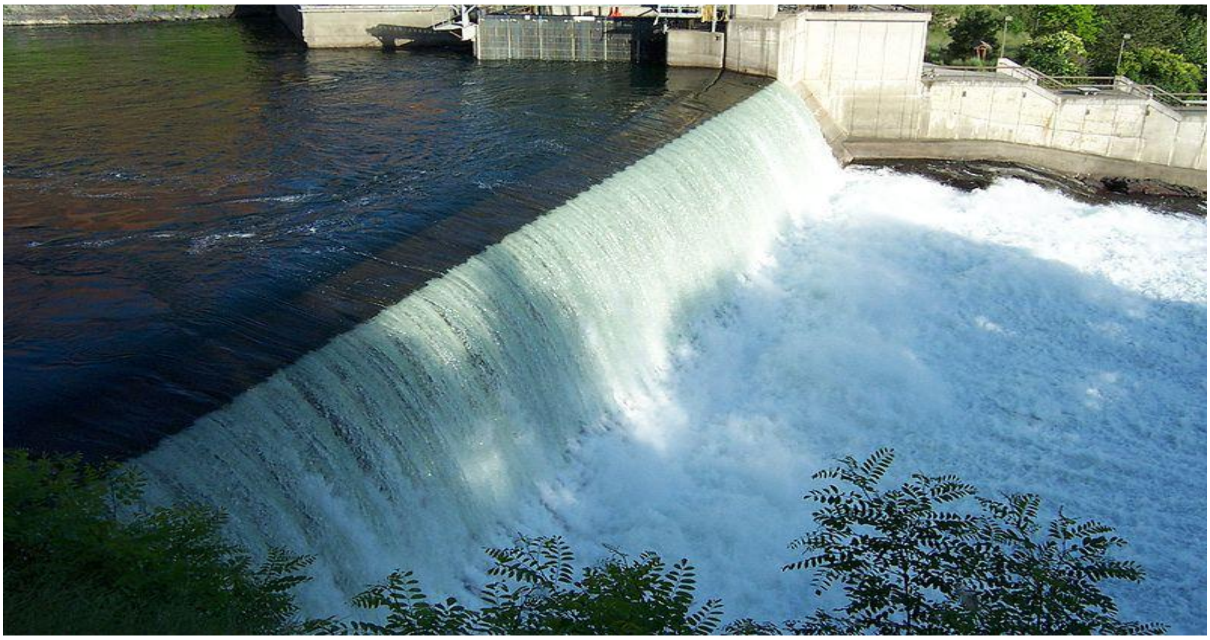
The familiar hydraulic jumps that occur in daily of life such as during the use of a household sink. The jump can also be observed in different forms like circular, inflow of water surrounded by stationary wave. The occurrence hydraulic jump is where, the obviously turbulence generates in still water. 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.

Source: https://en.wikipedia.org/wiki/File:Hydraulic_jump_in_sink.jpg

Figure 1.10: Sink Flow Condition

1.7(b) Man Made Hydraulic Jump:

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



Source: https://en.wikipedia.org/wiki/File:Riverfront_Park_WA_0271.jpg

Figure 1.11: Manmade hydraulic condition

Various researchers and scientists have been performing the experiments with the effects of roughness on of hydraulic jump and they have been able to produce steady 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 due to 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 in a solution is additional practical use of hydraulic jumps. By producing a hydraulic jump, it makes rapidly 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.

Source: https://en.wikipedia.org/wiki/File:Burdekin_Dam.jpg

Figure 1.12: Manmade hydraulic condition

1.8 Categories of hydraulic jumps:

The classes of hydraulic jumps are stationary and moving form.

1.8 (a) 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.

1.8 (b) 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.

1.9 Energy dissipater

Rollers form at the base when the downstream depth is more than required for the formation of hydraulic jump. Roller will scour the bed if material on the bed is loose. However, in case of sound bed rock no problem will be faced.

In case of high head and low tail water level, it works like a skilling spillway as discussed above.

Bucket used are of two types

Buckets

Solid roller

(used when TW depth > Y_2)

Bucket is solid roller formation takes

Place inside and outside the

Bucket, bed beyond bucket is ended

(apron may save the bed from erosion)

Slotted roller

There are some openings in the lip.

energy is partly dissipated in these

opening and partly due to roller formation

Bucket is solid roller formation takes place inside and outside the buckets, bed beyond bucket is eroded (apron may save the bed from erosion).

1.10 Hydraulic jump as energy dissipater

The water flowing over spillway has lot of potential energy which is converted into kinetic energy. The arrangements are to be made to dissipate this energy; otherwise it may cause scouring of bed and erosion of banks. These arrangements are known as energy dissipaters.

The energy of supercritical flow can be dissipated by the following two ways:

- By converting the supercritical flow into subcritical flow by means of a hydraulics jump.

- Bucket type energy dissipater may be used.
- Post jump depth depends on tail water level. The tail water level depends upon the hydraulic dimensions and slope of the river channel below. Hence for different discharges. The tail water depth is found by actual gauge observation and by hydraulic calculation. The depth after the jump for all discharge is computed by the following formula:

$$Y_2/ Y_1 = \frac{1}{2} [\sqrt{1+8F_{r_1}^2} -1] \quad \text{..................................} (1.4)$$

Now prepare **tail water curve** (TWC) by plotting q against tail water depth similarly. On the same graph q may be plotted againstY_2. This curve is called as the **jump height curve** (JHC) or Y_2 curve.

Five cases arise as shown,

- TWC and JHC curves coincide at all discharges.
- TWC lies above JHC for all discharges.
- TWC lies below JHC for all discharges.
- TWC lies above JHC for small discharges and below JHC for large discharges.
- TWC lies below JHC for small discharges and above JHC for large discharges.

Below the spillway, the energy dissipation arrangements depend on the type of curves started above.

1. **Energy dissipaters for case (a):** in this case, as already explained TWC and JHC coincide at all discharges. In such an event, a simple concrete apron of length 5 (Y_2 –Y_1) may be sufficient as shown in fig. The hydraulic jump forms on this apron.
2. **Energy dissipaters for case (b):** in this case, TWC lies above JHC for all discharges. As the jump forming at the toe is totally submerged, energy dissipation is very little.

   The problem can be solved by following two ways:

   - Sloping apron above the river bed may be provided and jump is allowed to focus on the sloping apron. The jump will form at a location where Y_2(less than tail water depth at toe) is available
   - Second option is to provide roller bucket type energy dissipater

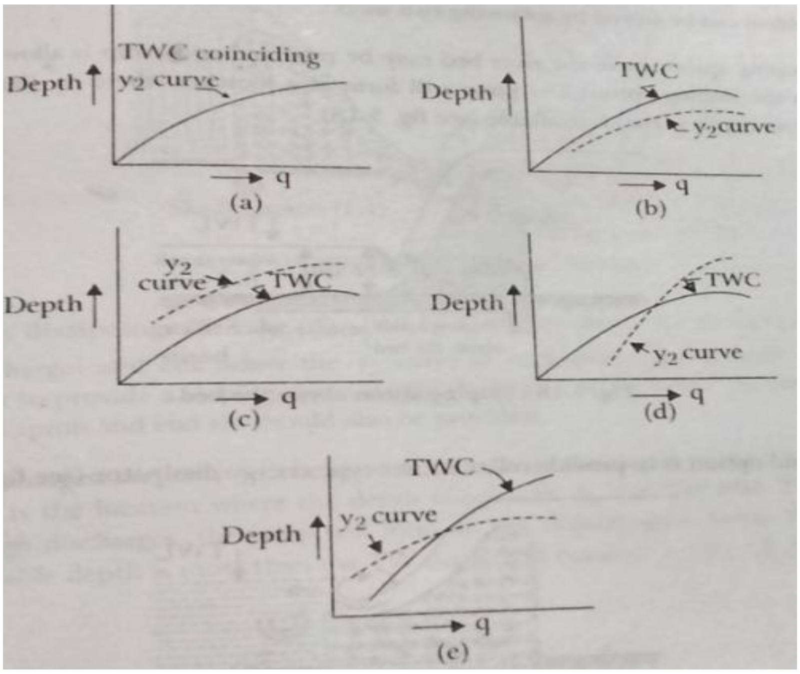
3. **Energy dissipaters for case (c):** for case (c) when TWC lies below JHC at all discharges.

- One of the options to provide Ski jump bucket.
- Another option is to provide sloping apron as in case (b) but below the river bed. This will allow depth Y_2which is greater than tail water depth to be available by allowing the jump to form on the sloping apron. This sloping apron and the horizontal cistern of length 5 (Y_2 - Y_1) will be in cutting and is very expansive.

4. **Energy dissipaters for case (d):** when TWC lies above the Y_2curve or JHC, for small discharges and lies below the Y_2 curve at high discharges. In such a case, the solution is to provide a sloping apron partly above and below the river bed. The horizontal apron and end still should also be provided.

   At low discharges, the jump will be allowed to form on the sloping apron above the river bed. This is the location where the depth is equal to Y_2 and less than TW depth. In case of high discharges, the jump will form on the sloping apron below the river bed. Here available depth is more than the TW depth and equal toY_2.

5. **Energy dissipaters for case (e):** in this case, the same arrangement is to be made as in the previous case. In this solution, the jump will form on the apron below the bed at low discharges whereas at high discharges, the jump forms on the apron above the bed.



Source: Open Channel Flow (V.C. Agarwal)

Figure 1.13: Energy dissipater curve

1.11 Characteristic of hydraulic jump (Source: Open Channel Flow (V.C. Agarwal))

The following are generally known as the characteristic of the jump:

1.11(a) Relative Energy Loss: E_L/E_1

The E_L/E_1 can be shown to be given by

$$E_L/E_1 = (\sqrt{1 + 8F_{r_1}^2} - 3)^3 / 8\ (F_{r_1}^2 + 2)\ (\sqrt{1 + 8F_{r_1}^2} - -1) \qquad (1.5)$$

1.11(b) Efficiency of the jump: E_2/E_1

$$E_2/E_1 = 1 - E_L/E_1 = 1.0 - (\sqrt{1 + 8F_{r_1}^2} - 3)^3 / 8(F_{r_1}^2 + 2)\ (\sqrt{1 + 8F_{r_1}^2} - 1)$$

$$= 1 - 4\ F_{r_1}^2 + (1 + 8F_{r_1}^2)^{3/2} / 8\ F_{r_1}^2\ (2 + F_{r_1}^2\ ) \qquad (1.6)$$

1.11(c) Relative Height of the jump : h_j/E_1

$$hj\ /E1 = (\sqrt{1 + 8F_{r_1}^2} - 3\ /\ F_{r_1}^2 + 2) \qquad (1.7)$$

1.11(d) Relative Pre-jump Depth:Y_1/E_1

$$Y_1/E_1 = 2\ /\ F_{r_1}^2 + 2 \qquad (1.8)$$

1.11(e) Relative Post-jump Depth: Y_2/E_1

$$Y_2/E_1 = (Y_2/Y_1)\ /\ (E_1\ /\ Y_1)$$

$$= 1/2\ [\sqrt{1 + 8F_{r_1}^2} - 1]\ /\ (F_{r_1}^2 \quad + 2)/2$$

$$= [\sqrt{1+8F_{r_1}^2} - 1...]\ /\ (F_{r_1}^2 \quad + 2) \qquad (1.9)$$

1.11(f) Relative length of jump: The following expression is available for the relative length of the jump.

French (1985): $L_j/Y_1 = 9.75\ (F_{r_1} -1)^{1.01}$

Hager (1992): $L_j/Y_1 = 220\ \tan h\ F_{r_1} - 1/\ 22$

Bradley and Peterka $L_j/Y_2 = 6$ for $4 < F_{r_1} < 12$

1.11(g) Relative length of the Roller

Hager (1992) $L_r/Y_1 = -12 + 160\ \tan h\ F_{r_1}/20$ for $y_1/B < 0.1$

Chanson (1999) $L_r/Y_1 = 160\ \tan h\ (F_{r_1}/20) - 1.2$ for $2 < F_{r_1} < 16$

1.12 Objective of the work

As earlier discussed that the hydraulic structures such as dam, reservoirs, barrage etc are the important hydraulic structures because they have stored water for useful purpose such as irrigation or electricity purposes. The safety of these structures is most important with their safe design. Because failure of these structures causes serious damage of economical value as well as human life and also the wastage of labour, time for its re-construction and maintenance. It is also discussed that there are various prevention measures for its safety by providing the energy dissipater at its basin to dissipate the more energy of water and safety passer it to the down-stream side without erosion of the surface.

The main objective of this work is to study out the effect of different types of roughness at its bed to dissipate the more energy of water and passes it to the down-stream side safety without any erosion of bed. With this it is also to be observe the effect of this roughness on the hydraulic jump properties such as sequent depth , length of jump velocity of flow etc all the parameter related to hydraulic jump and also seen the effect in between the smooth bed and rough bed with their relative properties.

1.13 Overview of the work

In the discussion the measures are discussed to prevent erosion of the bed of the hydraulic structure due to the flowing water with a very high velocity and safety passes it to the d/s side without any damage to the structure by providing the rough or corrugated bed with different sizes and their different spacing in between the roughness elements. It is also to be observe the effect on the different hydraulic jump properties such as sequent depth, length of jump, flow velocity, energy loss etc. By changing the spacing of specimen. Further in this work two different sizes of wooden blocks are used of rectangular shape. Also as a combination of different sizes and their different spacing in between them observation are carried out by allowing the different discharge condition on each spacing with different sizes of blocks.

CHAPTER - 2

CHAPTER – 2

Literature review

2.1 Introduction

There are various types of hydraulic structures are such as dam, reservoir, barrage, canal, etc. are the important structures, because they have to store the water in it as well as supply the water for various useful purposes, such as irrigation or agricultural work and electrical generation purpose etc. The safety of these structures most important. Failure of these structures causes a serious damage of economical value as well as of human life, and time also.

These failures are caused not only by the faulty construction and design of structure, but also due to the process of erosion of bed through which water is flowing with a very high velocity of flow. This high velocity of the flowing water has a capacity of the erosion of the bed or surface. The water passing through the bed have a super-critical flow. The water flows through the surface with a high super-critical flow and high velocity is called as Stilling-Basing.

So, for this high energy of flowing water we have to provide a roughness or energy dissipater to reduce the energy of water as well as safely pass it to the downstream side without any damage of structure. In this way, we have to design the structure not for only to make a good jump also for high energy dissipatation, to dissipate the energy of flowing water in a large amount and with stability as well. As an engineer we have to keep in mind that our structure is safe and strong and the strength should good within the economic consideration.

Many Researchers as Elnikhely (2014), Neluwater et al. (2013), Imran and Akib (2013), Chern and Syamsuri (2013), Habibzadeh etal. (2012), Habibzadeh etal. (2011), Elsebaie and Shabayek (2010), Carallo et al. (2007), Ead and Rajaratnam (2002) Ali Mohamed (1991), Hughes and Flack (1984) etc..have Performed Experiments for Analysis of the Hydraulic Jump;

Elnikhely (2014) performed a study on “Effect of staggered roughness element on flow characteristics in rectangular channel”. In this an artificial staggered roughness was provided at the base of flume and at the different sections recorded the profile of surface of water. For roughness, fibre glass sheet were used and all required observations were recorded. After these observations it was found that roughness decreases sequent depth, length of jump and increases the relative loss of energy as compared to a bed of smooth condition. The proposed experimental data are agreed with the formulas derived for relative depth and energy loss satisfactorily. By used the multiple linear regressions (M.L.R) to the model hydraulic jump characteristics prediction equation were developed.

Neluwater et al. [2013] carried out a study on “Characteristics of hydraulic jump over a rough bed". The experiments were carried out in a horizontal flume by providing the roughness by placing the wooden blocks of different sizes with their different spacing in between the blocks and place it on the bed of the flume. After that all the required data such as sequent depth, length of jump, discharge etc was recorded. Then the curve was plotted between the sequent depth ratio vs Froude number without roughness on smooth bed and with roughness of the rough bed with different sizes of roughness. By the study and analysis of theses graphs the equations were also developed. This study showed that jump distance reduces with roughness.

Imran and Akib (2013) performed an experiment on “A review of hydraulic jump properties in different channel bed conditions”. This paper gives a comprise literates, available properties of hydraulic jump on different rough or corrugated beds. Hydraulic jump is used to dissipate the energy and the jump is generates with baffle blocks. Rough or corrugated bed shows dissipation of energy. As compared to smooth bed the jump and sequent depth reduced. This paper comprises discussion on rough or corrugated bed implications and their installation by various researchers. Finally it was observed that the performance of a corrugated or rough bed is better as compared a smooth bed.

Chern and Syamsuri (2013) have studied the “Effect of corrugated bed on hydraulic jump characteristic using a S.P.H method (smoothed particle hydrodynamic)”. It was stated that the hydraulic jump is common in open channel flows and by this erosion and damage of the bed takes place. So, the reduction in the hydraulic jump and dissipation of this high energy is important. For this the corrugated bed is one of the methods, So to know the effect of this bed corrugation on jump a S.P.H model is applied and evaluated for the hydraulic jump characteristics. A different type of corrugated bed such as triangular, trapezoidal, sinusoidal was used in this. All the parameters such as depth of water, length of jump, energy dissipation were recorded. For the analysis purpose it was found that the rough bed dissipate more energy than a smooth bed and in between all the types of corrugated beds, the sinusoidal bed can dissipate more energy as other ones. S.P.H is an interpolating method which allows express a function in terms, group of its value of disturbed particles.

Habibzadeh etal. (2012) carried an experiment on “Performance of baffle blocks in submerged hydraulic jump”. For covering the range of submergence factor, arrangement of blocks and Froude numbers a wide test series were conducted to cover the whole area. To explain and analysis the each parameter effect and its result the dimensional analysis was used. The re-attaching wall jet (RWJ) and deflected surface jet (DSJ) two flow regimes were noticed .On the factors i.e. shape of block and its location, submergence factor and Froude number the happening on a specific regime depend. By the generation of deflected if was found that DSI regime dissipate more energy. In the comparison of RWJ it had a small rivers flow region. For a single one flow region, empirical equation was produce. For critical value prediction of submergence factor.

Habibzadeh etal. (2011) performed an experiment on “Exploratory study of submerged hydraulic jump with blocks”. A primary work was performed on submerged jump in the downstream side sluice gate with baffle blocks and wall. On baffle block and wall, experimental series were carried out. Drag coefficient relation was derived the use of momentum equation that was justified by baffle wall series experiment data. It was found that efficiency of energy dissipation was justification or role of submergence function with efficiency maximum excess efficiency parallel to Froude jump.

Elsebaie and Shabayek (2010) performed an experiment on “Formation of hydraulic jump on a corrugated bed”. For roughness creation the corrugated bed of different shapes were used. In this study the effect of these different shapes on the hydraulic jump properties were studied. Sinusoidal, triangular, trapezoidal and rectangular shaped sheets were and studied their effect on hydraulic jump. It was observed that the tail water required to form a jump is smaller than on smooth bed. On different corrugated bed the length of the jump is smaller than a smooth bed. By this, there is a reduction in shear stress which produced by super-critical flow through interaction with the corrugated bed.

Carallo et al. (2007) performed an experiment on “Hydraulic jump on rough bed”. In this experimental work a horizontal flume with rough bed were used. For the roughness of bed, different sizes of aggregates and gravels were used. The analysis was done for the effect of this roughness created by these gravels on the sequent depth ratio and roller length. By this investigation they said that new solution of the momentum equation which is for sequent depth ratio is a function of Froude number and the ratio in between the height of roughness and the up-stream flow depth. Curves were plotted in between sequent depth and Froude no. to see the relation in between them. Curves were also plotted in between the theoretical and experimental sequent depth ratio, length of roller and sequent depth of flow verses sequent depth ratio verses calculated value of this. In this investigation the analysis was done for hydraulic jump parameter on rough bed. It was found that the sequent depth ratio decreases with the increases in bed roughness as well as Froude no.

Ead and Rajaratnam (2002) carried out an experiment of “Hydraulic jump on corrugated bed”. The experiment was performed for the range of Froude number 4 to 10 and different values of relative roughness were observed. By this experiment it was found that the required tail water depth to form a jump is considerable smaller then for a smooth bed. Due to this roughness there is also a reduction in length of jump of about half of smooth bed. he velocity profiles at different sections were found to be same, with a slight different from plane wall jet profile.

Ali Mohamed (1991) performed on experiment on “Effect of roughened bed stilling Basin on length of rectangular hydraulic jump”. Analysis of the hydraulic jump of low head structures was carried out. In this the rough bed channel with different variety of condition of flow was experimented to gain its maximum roughness length from the point of view of hydraulics as well as economic. For the study roughness in the form of cubes was used the data was analysed by the statistical method. For the optimum length of roughness a render practical equation is required to express the hydraulic jump characteristics by the use of roughness. For jump length with rough bed the momentum equation is used in the flow direction to achieve a general formula.

Hughes and Flack (1984) carried out an experiment on “Hydraulic jump properties over rough bed”. For the creation of roughness on smooth bed, strip roughness bed and gravels win densely packed condition were used. The experiment was performed and collected the observation which contains sequent depth, tail water depth, length of jump rate of flow. The graphs based on experimental result shows that roughness of the boundary reduces the length of jump and sequent depth and it is related to Froude number and degree of roughness.

CHAPTER - 3

<u>CHAPTER – 3</u>

Methodology

3.1 Method of work

In this work, we studied the effect of hydraulic jump on smooth horizontal bed without and with roughness and observed all the required parameters. Then the observations are recorded at each set by changing the spacing of wooden blocks. The same procedure is repeated the for another height of wooden block and recorded the observation to carried out to know that which is more effective.

In this experimental work wooden blocks of two different heights are used with their different spacing in between them. Then these blocks are fixed with their alternative spacing in the flume as a creation of roughness.

In Case 1, size of wooden blocks is **30 × 0.5 × 2.5cm** with a spacing of **2.5, 5, 10, 14, & 17cm** alternatively under each set of observation by changing this spacing.

The another size of wooden block for case 2 is **30 × 0.5 × 3.5cm** with a spacing of **3.5, 7, 10, 14, 17, & 20cm** alternatively under each set of observation. The discharge also changed with the each set of observation at a single one by one changing the spacing.

3.2 Experimental set up

The set up of the experiment includes:

- A 6 meter long flume with a hump.
- Pitot tube for measurement of velocity.
- Inverted U-Tube manometer for measure head difference with its fixing stand.
- Rubber tube.
- Wooden block of sizes (for roughness creation)
    - 30 × 0.5 × 2.5 cm.
    - 30 × 0.5 × 3.5 cm.
- Packing material for the fixing of wooden blocks.
- Clay for the fixing of hump.
- Water collecting tank.

- Sluice gate.
- Pump for the supply of water.
- Measuring tape.
- Meter gauge with a scale & pointer.

The experimental set up consists of the entire thing which is written above already. The flume used is 6 meter in length, 30cm width and 60cm in depth. Then the flume is cleaned in dry condition and water is allowed to freely pass through its surface for its complete cleaning. Because any type of roughness or dust have to be affected our experimental observation as well as flow of water through it. Then a hump is fixed in the flume at their required appropriate place, and the sides are filled by the clay for completely fill the gap in between the sides of flume and hump. Because the water which will pass through the sides it will surely affect the observations. Then the clay is allowed to completely dry. After its drying, the first set of observation on smooth bed is taken. For this flow of water allowed through the flume over the hump. Then after that sluice gate are adjusted to create a hydraulic jump. When a jump is formed at its approximate constant condition, the observations are recorded. In this firstly we have take the flow depth at up-stream side before jump with point gauge by just touch the pointer at the surface of water. After that at the surface of flume observation also taken, and by the subtraction of these readings the depth of water before jump is measured. Again by the above procedure for depth of water after the jump in the nearly still were measured. This depth of water also taken with the help of pointer gauge at surface of water and the bottom. The first depth of water before the jump it known as super-critical section depth of water. At the section the velocity of flow is very high. The last depth of water after the jump is known as sub-critical depth of water. The sub-critical depth depends on the condition of super-critical depth. The notation of super-critical depth of flow is “Y_1” and the sub-critical depth of flow is “Y_2”.

In between super-critical flow depth i.e. “Y_1” and sub-critical flow depth i.e. “Y_2” a jump is formed, y_1 from where the jump is start forming to the Y_2 side where the jump ends and flow is in nearly still condition. This distance in between them starting and end of jump is known as length of jump. This length of jump is roughly measure with the help of measuring tape. After the velocity of flow at Y_1 and Y_2 both the sections were measured with the help of pitote tube which is connected with a inverted U-Tube manometer to measure the head difference. After record all the observations for the first set, the discharge were changed by rotating the nozzle for recording the second set of the observation. In the second set again the depth of flow at section 1 before jump and at section 2 after jump are taken. All the important parameters as Y_1 andY_2, length of jump, velocity of flow for the find out of discharge etc are recorded. Now again changed the discharge for the third set of observation, and noted down all the important parameters which are required. The process is repeated by changing several different discharges and all the relevant important parameters were recorded for the smooth bed condition.

Now for **Case 1** Rough bed condition, wooden blocks are fixed at the bed of flume having different sizes with a different spacing in between them. Firstly for roughness the blocks are cut in the sizes of 30 × 0.5 × 2.5 cm. Then after its cutting paint is applied on it to reduce the effect of water shrinkage, fungus effect, swelling effect etc. all the effects which are harmful for a wood.

After completion of its painting work it is freely allowed to dry. When the paint is completely dried, a procedure is followed to fix these blocks in the flume at its base. For its fixing a packing material is used to fix these blocks and all the blocks are fixed at different spacing's. The blocks are fixed at a spacing of 2.5cm. After its fixing finally checked all the blocks are fixed properly and arranged at the given spacing and no one is loose from all of these blocks. Because at the full discharge condition, blocks are to be surely affected by it, and will get loose. Now after its complete checking procedure water is allow passes through it. When the water flows, sluice gate is regulate for the formation of jump. After the formation of jump effect of roughness on the hydraulics jump is to be observed. The jump is high on rough bed as compared to smooth bed and dissipation of energy is more than smooth bed.

Then all the important parameters i.e. sequent depth Y_1 and Y_2 at section 1 and 2, length of jump, velocity of flow etc. are recorded, and the effect of roughness on these parameters is observed. The observations are compared with smooth bed. The discharge is changed several times and recorded all the parameters at each changed discharge.

Now for the second slot of reading the spacing were changed in between the wooden blocks and increase it by 5cm. Then the above procedure is repeated for taken the observation at different discharge

As by the given procedure, the observations at different spacing in between the wooden blocks as 2.5cm, 5cm, 10cm, 14cm and 17cm at the varying discharge were recorded.

Now for **Case 2** another size of wooden blocks i.e. 30 × 0.5 × 3.5cm. is taken and cutted. Then these blocks are painted for its protection and after drying this are on the bed of flume.

For first slot of reading spacing of 3.5cm is taken which is equal to the height of block in between them and fixed all blocks at this spacing in between each one. Then by repeating the above given procedure all the required data is collected i.e. sequent depth Y_1 andY_2, length of jump, velocity by changing discharge.

After this another changed size of spacing is used in between the blocks i.e. 7cm. Now different spacing of 3.5cm, 7cm,10, 14cm, 17cm, and 20cm is adopted for blocks and observation are taken at varying discharge by the repetition of above given procedure and collect all the required data.

3.3 Calculation:

For finding out the no. of wooden blocks used in experiment to create roughness on bed,

We refer as per the "Neluwater et al. [2013]" reference no. 2, of Characteristics of Hydraulic Jump

Over Rough Bed details are taken from;

Minimum Element height = 0.8 cm

At this height minimumY_1 = 3 cm

Ratio in between ht. & Y_1 = 0.8/3 = 0.25 cm

Maximum Element height = 1.5 cm

At this height minimumY_1 = 3 cm

Ratio in between ht. & Y_1 = 1.5 /3 = 0.5 cm

Now the range of ht. of wooden element lies in between 0.25 to 0.5

Case: 1

Available sizes are;

- 0.5 × 2.0 cm
- 0.5 × 2.5 cm
- 0.5 × 3.0 cm
- 0.5 × 3.5 cm
- 0.5 × 4.5 cm

Y_1 at full discharge on smooth bed without hump = 6.77 cm

- Ratio in between ht. & Y_1 = 2/6.77
  = 0.295

- Ratio in between ht. & Y_1 = 2.5/6.77
  = 0.369
- Ratio in between ht. & Y_1 = 3/6.77 = 0.443
- Ratio in between ht. & Y_1 = 3.5/6.77
  = 0.516
- Ratio in between ht. & Y_1 = 4.5/6.77
  = 0.664

Above all four values in the b/w given range, then we have adopt the size from the above values

- 0.5 × 2.5 cm
- 0.5 × 3.5 cm

No. of piece of wooden block required:

Length of space where strips were fixed = 45cm + 100cm + 45cm

Where, 1m (the approx length of jump on smooth bed) & 45cm. Extra on both sides.

= 45cm + 100m. + 45cm

= 190 cm

For block size 0.5 X 2.5 cm, spacing in between = 2.5cm

Number of strips required $= \frac{190}{2.5+2.5} = 38$

≈ 40 pieces

Same procedure is applied for the calculation of **Case - 2** i.e. 3.5 cm

Total no. of piece for 3.5 cm ht. = 40 pieces

3.4 Observations Tables

When the flow changes from supercritical to sub critical a jump is formed. These tables and observations show the behaviour of hydraulic jump with the different conditions on smooth and rough bed. For these different conditions the collected data or observations are given below;

For Smooth Horizontal Bed

Figure 3.1 – Hydraulic Jump on smooth bed

Table No. 1 – Jump on smooth horizontal bed

S. No.	Y_1 (cm)	Y_2 (cm)	h (cm)	V (m/s)	Y2/Y1 (exp.)	Y2/Y1 (Theo.)	Q (m^3/s)	Froude No. (F_{r_1})
1	5.91	20.83	19	1.930	3.525	3.119	0.0342	2.535
2	5.61	20.70	16.6	1.804	3.696	2.976	0.0303	2.431
3	5.31	20.50	19.5	1.955	3.825	3.343	0.0311	2.696
4	4.91	20.48	19.3	1.945	4.17	3.489	0.0286	2.799
5	4.33	16.95	17.3	1.842	3.915	3.527	0.0239	2.826
6	3.14	14.80	16.2	1.773	4.713	4.045	0.0167	3.200

Sample Calculation for S. No. (1)

Y_1 = 5.91 cm

Y_2 = 20.83 cm

v = $\sqrt{2gh}$

=1.930 m/s

Q = a × v

= 0.30 × .0591 × 1.930

= 0.0342 m^3/s

Froude No. $F_{r_1} = v/\sqrt{gy_1}$

= 2.535

Y_2 / Y_1 (expe.) = 3.525

Y_2 / Y_1 (Theo.) = $\frac{1}{2}$ [$\sqrt{1 + 8F_{r_1}^2}$ -1]

= 3.119

Figure 3.2 – Wooden blocks without colour & with colour

CASE (1)

For Rough Horizontal Bed (with block height 2.5 cm)

Condition [1] - (Block height 2.5 cm & spacing 2.5 cm)

Figure 3.3 – Wooden Blocks at (2.5 cm spacing)

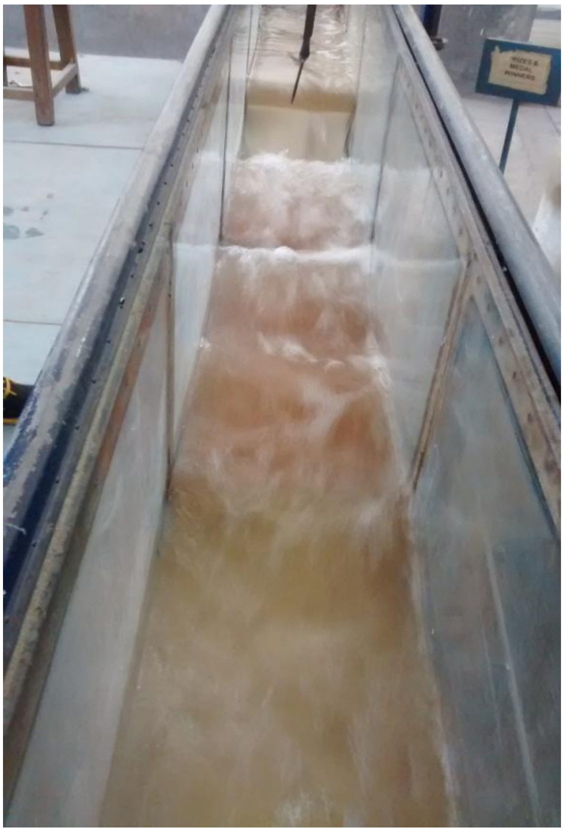


Figure 3.4 – Hydraulic Jump at (2.5 cm spacing)

Figure 3.5 – Hydraulic Jump at (2.5 cm spacing)

Table No. 2 – Jump on Rough bed (Spacing – 2.5 cm)

S. No.	Block Ht. (cm)	Spacing (cm)	Y_1 (cm)	Y_2 (cm)	h (cm)	V (m/s)	Y_2/Y_1 (exp.)	Y_2/Y_1 (Theo.)	Q (m^3/s)	Froude No. (F_{r_1})
1	2.5	2.5	5.91	18.66	21.7	2.064	3.157	3.367	0.0365	2.712
2	2.5	2.5	5.61	16.86	21.8	2.068	3.005	3.409	0.0348	2.787
3	2.5	2.5	5.36	16.46	21.5	2.056	3.07	3.541	0.0330	2.836
4	2.5	2.5	4.93	18.25	20.9	2.025	3.072	3.652	0.0299	2.914
5	2.5	2.5	4.35	16.36	19.6	1.961	3.76	3.78	0.0256	3.006
6	2.5	2.5	3.14	13.45	16.8	1.813	4.297	4.154	0.0170	3.272
7	2.5	2.5	2.18	11.35	13.6	1.633	5.206	4.532	0.0106	3.534

Figure 3.6 – Hydraulic Jump on Rough bed (2.5 cm spacing)

Sample Calculation for S. No. (1)

Y_1 = 5.91 cm

Y_2 = 18.66 cm

v = $\sqrt{2gh}$

= 2.064 m/s

Q = a x v

= 0.30 ×.0591 × 2.064

= 0.0365 m^3/s

Froude No. F_{r_1} = v/$\sqrt{gy}$

= 2.712

Y_2 / Y_1 (expe.) = 3.157

Y_2 / Y_1 (Theo.) = $\frac{1}{2}$ [$\sqrt{1 + 8F_{r_1}^2}$ -1]

= 3.367

Note: Same procedure of calculation will be applied for rest of the conditions.

Condition [2] - (Block height 2.5 cm & spacing 5 cm)

Figure 3.7 – Wooden Blocks at (5 cm spacing)

Figure 3.8 – Hydraulic Jump at (5 cm spacing)

Table No. 3 – Jump on Rough bed (Spacing – 5 cm)

S. No.	Block Ht. (cm)	Spacing (cm)	Y1 (cm)	Y_2 (cm)	h (cm.)	V (m/s)	Y_2/Y_1 (exp.)	Y_2/Y_1 (Theo.)	Q (m^3/s)	Froude No. (F_{r_1})
1	2.5	5	5.91	16.86	20.6	2.012	2.853	3.272	0.0365	2.644
2	2.5	5	5.61	17.32	20.2	1.990	3.087	3.325	0.0334	2.682
3	2.5	5	5.36	15.56	20.1	1.99	2.903	3.419	0.032	2.749
4	2.5	5	4.93	18.02	19.9	1.975	3.677	3.555	0.0292	2.846
5	2.5	5	4.35	16.23	19.7	1.970	3.731	3.809	0.0250	3.027
6	2.5	5	3.13	12.72	18.1	1.88	4.064	4.238	0.0176	3.392
7	2.5	5	2.18	10.63	13.5	1.627	4.876	4.510	0.0106	3.522

Condition [3] - (Block height 2.5 cm & spacing 10 cm)

Figure 3.9 – Wooden Blocks at (10 cm spacing)

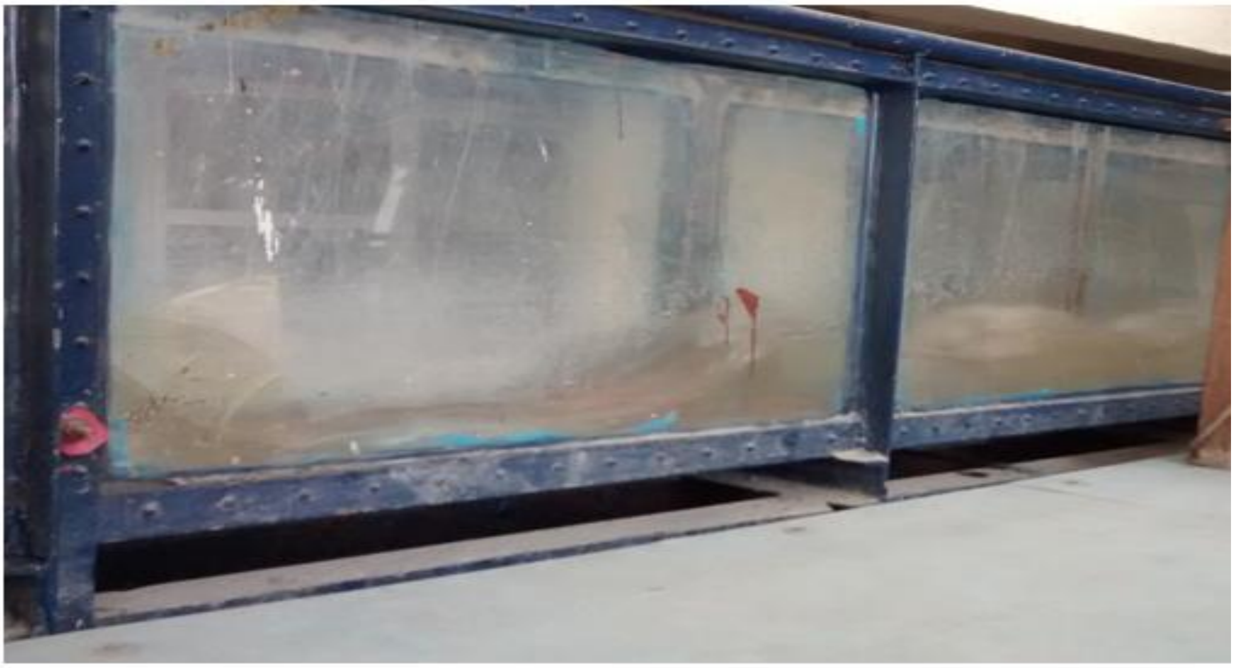


Figure 3.10 – Hydraulic Jump at (10 cm spacing)

Figure 3.11 – Hydraulic Jump at (10 cm spacing)

Table No. 4 – Jump on Rough bed (Spacing – 10 cm)

S. No.	Block Ht. (cm)	Spacing (cm)	Y_1 (cm)	Y_2 (cm)	h (cm)	V (m/s)	Y_2/Y_1 (exp.)	Y_2/Y_1 (Theo.)	Q (m^3/s)	Froude No. (F_{r_1})
1	2.5	10	5.91	13.55	18.3	1.895	2.293	3.058	0.0336	2.491
2	2.5	10	5.61	18.05	18.2	1.89	3.217	3.202	0.0318	2.594
3	2.5	10	5.36	13.34	17.5	1.852	2.488	3.144	0.0297	2.553
4	2.5	10	4.93	11.55	18.7	1.915	2.357	3.930	0.0283	2.757
5	2.5	10	4.35	13.73	18.3	1.894	3.156	3.628	0.0247	2.900
6	2.5	10	3.13	13.68	15.2	1.726	4.370	3.916	0.0162	3.113
7	2.5	10	2.18	12.76	13.8	1.645	5.853	4.546	0.0107	3.560

Condition [4] – Block height 2.5 cm & Spacing 14 cm

Figure 3.12 – Wooden Blocks at (14 cm spacing)

Figure 3.13 – Hydraulic Jump at (14 cm spacing)

Table No. 5 – Jump on Rough bed (Spacing – 14 cm)

S. No.	Block Ht. (cm)	Spacing (cm)	Y_1 (cm)	Y_2 (cm)	h (cm)	V (m/s)	Y_2/Y_1 (exp.)	Y_2/Y_1 (Theo.)	Q (m^3/s)	Froude No. (F_{r_1})
1	2.5	14	5.91	13.87	18.3	1.894	2.347	3.063	0.0336	2.490
2	2.5	14	5.61	15.79	21.1	2.034	2.815	3.409	0.0342	2.742
3	2.5	14	5.36	15.95	18.8	1.921	2.965	3.297	0.0308	2.649
4	2.5	14	4.93	13.32	17.3	1.842	2.718	3.280	0.0272	2.65
5	2.5	14	4.35	12.46	17.36	1.845	2.864	3.526	0.024	2.825
6	2.5	14	3.13	11.44	16.2	1.783	3.665	4.081	0.0167	3.22
7	2.5	14	2.18	10.42	13	1.59	4.779	4.370	0.0103	3.441

Condition [5] – Block height 2.5 cm & Spacing 17 cm

Figure 3.14 – Wooden Blocks at (17 cm spacing)

Figure 3.15 – Hydraulic Jump at (17 cm spacing)

Table No. 6 – Jump on Rough bed (Spacing – 17 cm)

S. No.	Block Ht. (cm)	Spacing (cm)	Y_1 (cm)	Y_2 (cm)	h (cm)	V (m/s)	Y_2/Y_1 (exp.)	Y_2/Y_1 (Theo.)	Q (m^3/s)	Froude No. (F_{r_1})
1	2.5	17	5.91	18.32	21.1	2.034	3.009	3.313	0.036	2.673
2	2.5	17	5.61	16.32	21	2.032	2.909	3.404	0.0341	2.738
3	2.5	17	5.36	16.56	20.7	2.02	3.083	3.628	0.0325	2.786
4	2.5	17	4.93	15.15	20.6	2.010	3.092	3.634	0.0297	2.892
5	2.5	17	4.35	14.86	20.1	1.985	3.416	3.769	0.0259	3.039
6	2.5	17	3.13	10.56	19	1.931	3.373	4.455	0.0181	3.486
7	2.5	17	2.18	8.39	18.5	1.905	3.848	5.352	0.0124	4.123

CASE - 2

For Rough Horizontal Bed (with block height 3.5 cm)

Condition [1] - (Block height 3.5 cm & spacing 3.5 cm)

Figure 3.16– Wooden Blocks at (3.5 cm spacing)

Figure 3.17 – Hydraulic Jump at (3.5 cm spacing)

Table No. 7 – Jump on Rough bed (Spacing – 3.5 cm)

S. No.	Block Ht. (cm)	Spacing (cm)	Y_1 (cm)	Y_2 (cm)	h (cm)	V (m/s)	Y_2/Y_1 (exp.)	Y_2/Y_1 (Theo.)	Q (m^3/s)	Froude No. (F_{r_1})
1	3.5	3.5	5.92	17.55	20.5	2.005	2.964	2.639	0.0355	2.634
2	3.5	3.5	5.61	17.18	20.3	1.996	3.062	2.690	0.0335	2.690
3	3.5	3.5	5.38	16.95	19.7	1.965	3.151	2.710	0.0315	2.710
4	3.5	3.5	4.91	16.32	19.8	1.971	3.323	2.835	0.0291	2.836
5	3.5	3.5	4.34	16.15	19.5	1.955	3.721	3.009	0.0255	2.993
6	3.5	3.5	3.13	14.73	17.7	1.863	4.721	3.380	0.0175	3.363

Sample Calculation for S. No. (1)

Y_1 = 5.91 cm

Y_2 = 17.55 cm

v = $\sqrt{2gh}$

=2.005 m/s

Q = a × v

= 0.30 × .0591 × 2.005

= 0.0355m^3/s

Froude No. F_{r_1} = v/$\sqrt{gy}$

= 2.634

Y_2 / Y_1 (exp.) = 2.964

Y_2 / Y_1 (Theo.) = $\frac{1}{2}$ [$\sqrt{1 + 8F_{r_1}^2}$ -1]

= 2.639

Note: Same procedure of calculation will be applied for rest of the conditions.

Condition [2] - (Block height 3.5 cm & spacing 7 cm)

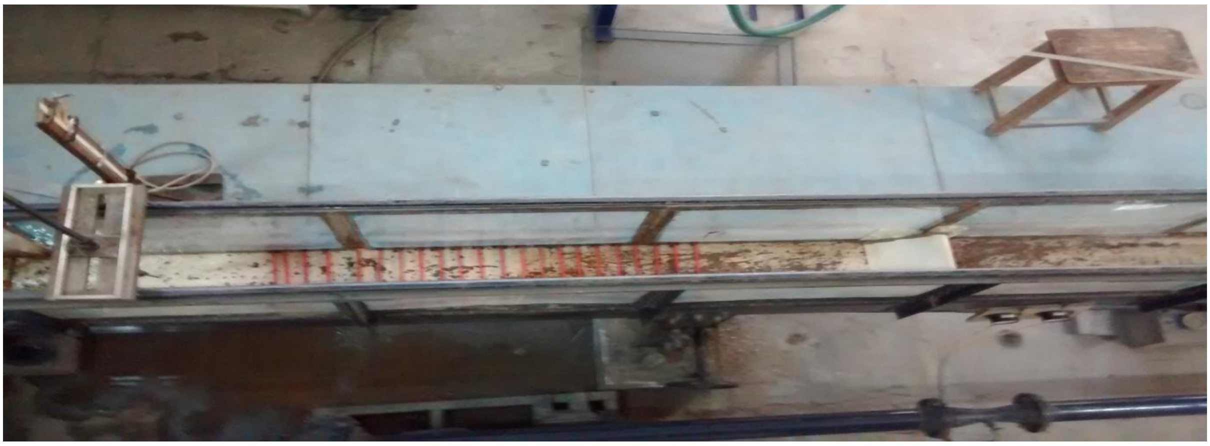


Figure 3.18 – Wooden Blocks at (7 cm spacing)

Figure 3.19 – Hydraulic Jump at (7 cm spacing)

Table No. 8 – Jump on Rough bed (Spacing – 7 cm)

S. No.	Block Ht. (cm)	Spacing (cm)	Y1 (cm)	Y2 (cm)	h (cm)	V (m/s)	Y_2/Y_1 (exp.)	Y_2/Y_1 (Theo.)	Q (m^3/s)	Froude No. (F_{r_1})
1	3.5	7.0	5.92	17.24	20.16	1.988	2.912	2.612	0.0352	2.612
2	3.5	7.0	5.61	16.79	20.4	2.001	2.992	2.696	0.0336	2.697
3	3.5	7.0	5.38	16.56	20.3	1.996	3.078	2.755	0.0321	2.756
4	3.5	7.0	4.91	16.67	20.2	1.990	3.395	2.863	0.0294	2.863
5	3.5	7.0	4.33	16.10	20	1.980	3.709	3.032	0.0258	3.032
6	3.5	7.0	3.13	13.63	18.36	1.898	4.368	3.425	0.0178	3.425

<u>Condition [3] -</u> <u>(Block height 3.5 cm & spacing 10 cm)</u>

Figure 3.20 – Wooden Blocks at (10 cm spacing)

Figure 3.21 – Hydraulic Jump on Rough bed (10 cm spacing)

Table No. 9 – Jump on Rough bed (Spacing – 10 cm)

S. No.	Block Ht. (cm)	Spacing (cm)	Y_1 (cm)	Y_2 (cm)	h (cm)	V (m/s)	Y_2/Y_1 (exp.)	Y_2/Y_1 (Theo.)	Q (m^3/s)	Froude No. (F_{r_1})
1	3.5	10	5.92	16.56	19.9	1.976	2.797	2.599	0.035	2.599
2	3.5	10	5.61	16.38	19.6	1.960	2.919	2.641	0.033	2.641
3	3.5	10	5.38	15.75	19.8	1.970	2.928	2.728	0.0318	2.717
4	3.5	10	4.91	15.95	19.7	1.966	3.248	2.829	0.029	2.829
5	3.5	10	4.33	16.06	19.9	1.975	3.700	3.025	0.0257	3.025
6	3.5	10	3.13	13.68	17.8	1.868	4.384	3.371	0.0175	3.371

<u>Condition [4] -</u> <u>(Block height 3.5 cm & spacing 14 cm)</u>

Figure 3.22 – Wooden Blocks at (14cm spacing)

Figure 3.23 – Hydraulic Jump at (14 cm spacing)

Table No. 10 – Jump on Rough bed (Spacing – 14 cm)

S. No.	Block Ht. (cm)	Spacing (cm)	Y_1 (cm)	Y_2 (cm)	h (cm)	V (m/s)	Y_2/Y_1 (exp.)	Y_2/Y_1 (Theo.)	Q (m^3/s)	Froude No. (F_{r_1})
1	3.5	14	5.92	17.16	20.1	1.985	2.898	2.608	0.0351	2.608
2	3.5	14	5.61	16.69	19.8	1.970	2.975	2.654	0.0331	2.654
3	3.5	14	5.38	16.58	19.5	1.955	3.082	2.696	0.0315	2.696
4	3.5	14	4.91	16.75	19.8	1.971	3.411	2.835	0.0291	2.836
5	3.5	14	4.33	16.37	19.4	1.950	3.771	2.986	0.0253	2.987
6	3.5	14	3.13	13.88	18.6	1.911	4.448	3.449	0.0179	3.449

Condition [5] - (Block height 3.5 cm & spacing 17 cm)

Figure 3.24 – Wooden Blocks at (17 cm spacing)

Figure 3.25 – Hydraulic Jump at (17 cm spacing)

Table No. 11 – Jump on Rough bed (Spacing – 17 cm)

S. No.	Block Ht. (cm)	Spacing (cm)	Y_1 (cm)	Y_2 (cm)	h (cm)	V (m/s)	Y_2/Y_1 (exp.)	Y_2/Y_1 (Theo.)	Q (m^3/s)	Froude No. (F_{r_1})
1	3.5	17	5.92	16.56	17.9	1.875	2.797	2.440	0.0332	2.454
2	3.5	17	5.61	16.18	19.55	1.958	2.884	2.638	0.0329	2.639
3	3.5	17	5.38	15.56	17.9	1.874	2.892	2.584	0.0302	2.585
4	3.5	17	4.91	15.16	18.9	1.925	3.087	2.769	0.0284	2.769
5	3.5	17	4.33	14.96	18.55	1.907	3.447	2.920	0.0248	2.921
6	3.5	17	3.13	14.18	17.9	1.874	4.544	3.380	0.0175	3.382

Condition [6] - (Block height 3.5 cm & spacing 20 cm)

Figure 3.26 – Wooden Blocks at (20 cm spacing)

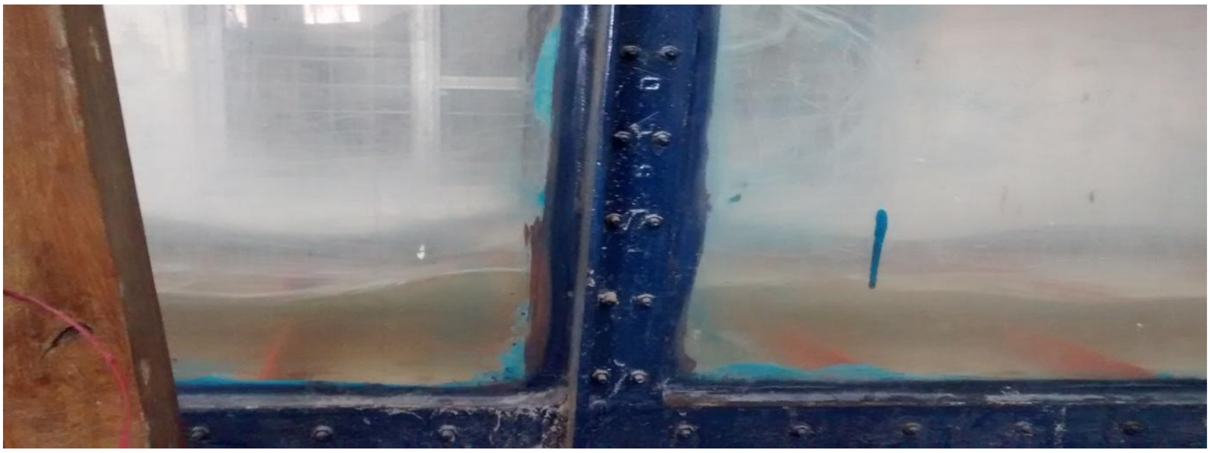


Figure 3.27 – Hydraulic Jump at (20 cm spacing)

Table No. 12 – Jump on Rough bed (Spacing – 20 cm)

S. No.	Block Ht. (cm)	Spacing (cm)	Y_1 (cm)	Y_2 (cm)	h (cm)	V (m/s)	Y_2/Y_1 (exp.)	Y_2/Y_1 (Theo.)	Q (m^3/s)	Froude No. (F_{r_1})
1	3.5	20	5.92	17.26	19.26	1.943	2.916	2.553	0.0344	2.554
2	3.5	20	5.61	15.70	19	1.931	2.798	2.603	0.0325	2.602
3	3.5	20	5.38	16.16	18.9	1.926	3.003	2.659	0.031	2.656
4	3.5	20	4.91	16.28	19	1.930	3.316	2.775	0.0284	2.776
5	3.5	20	4.35	15.96	19.4	1.951	3.677	2.990	0.0254	2.988
6	3.5	20	3.12	13.58	18.2	1.890	4.352	3.411	0.0177	3.412

CHAPTER – 4

CHAPTER - 4

Results & Discussions

For Smooth Horizontal Bed

The experiment was firstly performed on smooth bed.

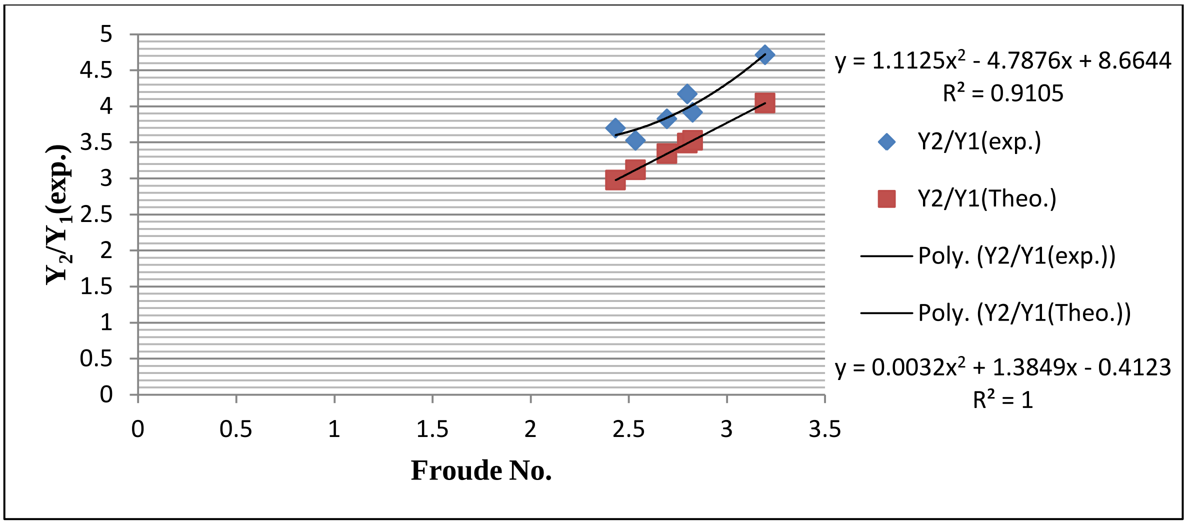


Figure 4.1 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp. & Theo.)

For Y_2/Y_1 (expe.) $R^2 = 0.9105$

For Y_2/Y_1 (Theo.) $R^2 = 1$

The experiment was performed on smooth bed and the observed data from Table No.-1 was plotted between Froude no. and sequent depth ratio (Theo. and exp.), which is shown in figure 4.1. By the plot a slight variation were found between theoretical and experimental values. The previous study was also conducted in similar manner and the revealed similar results as obtained in present study. Now the roughness applied in case 1 in the form of wooden blocks on the surface and observation were taken.

CASE (1)

For Rough Horizontal Bed (with block height 2.5 cm)

Condition [1] - (Block height 2.5 cm & spacing 2.5 cm)

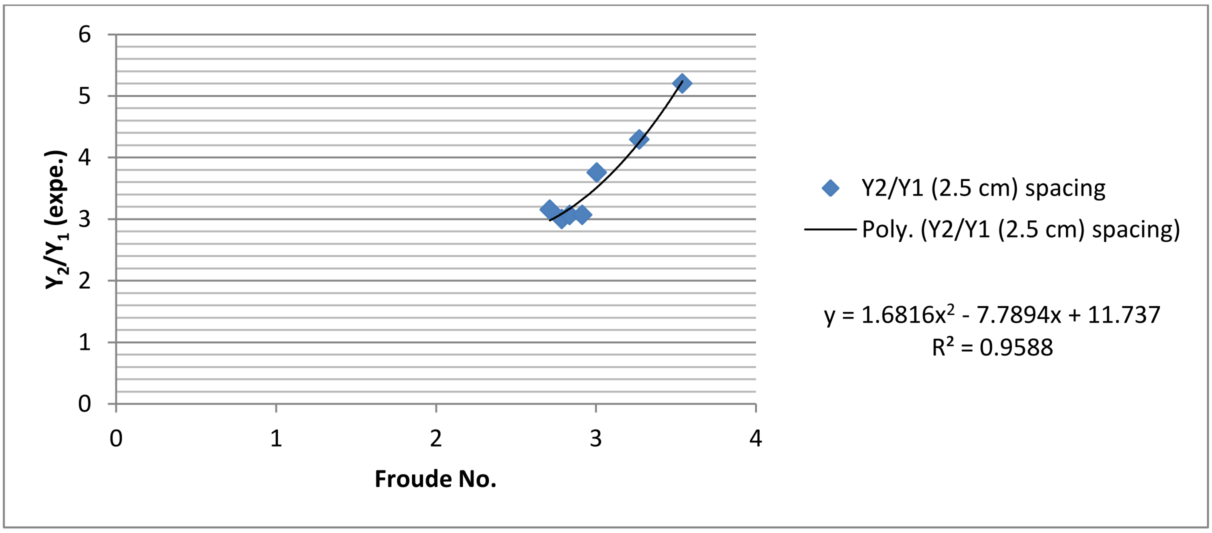


Figure 4.2 – Variation between Froude No (F_{r_1}). and Y_2/Y_1 (exp.)

Figure no. 4.2 is based on the observations shown in Table no. 2, by which graph is plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio also increases rapidly.

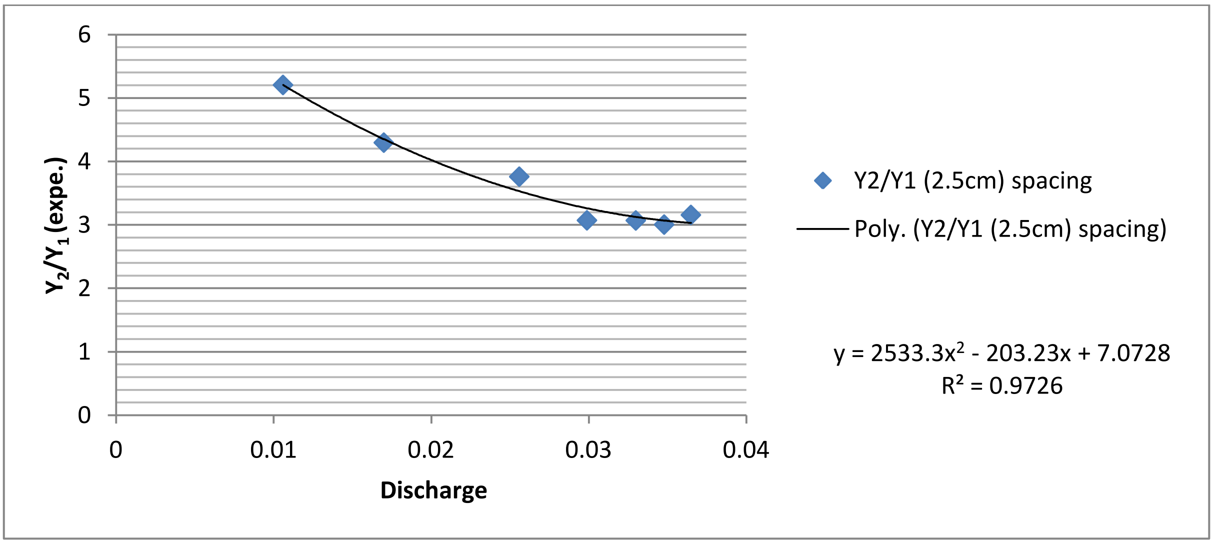


Figure 4.3 – Variation between Discharge (m^3/s) and Y_2/Y_1 (exp.)

Figure no. 4.3 is based on the observations shown in Table no. 2, by which graph is plotted between Discharge (m^3/s) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in discharge, sequent depth ratio decreases.

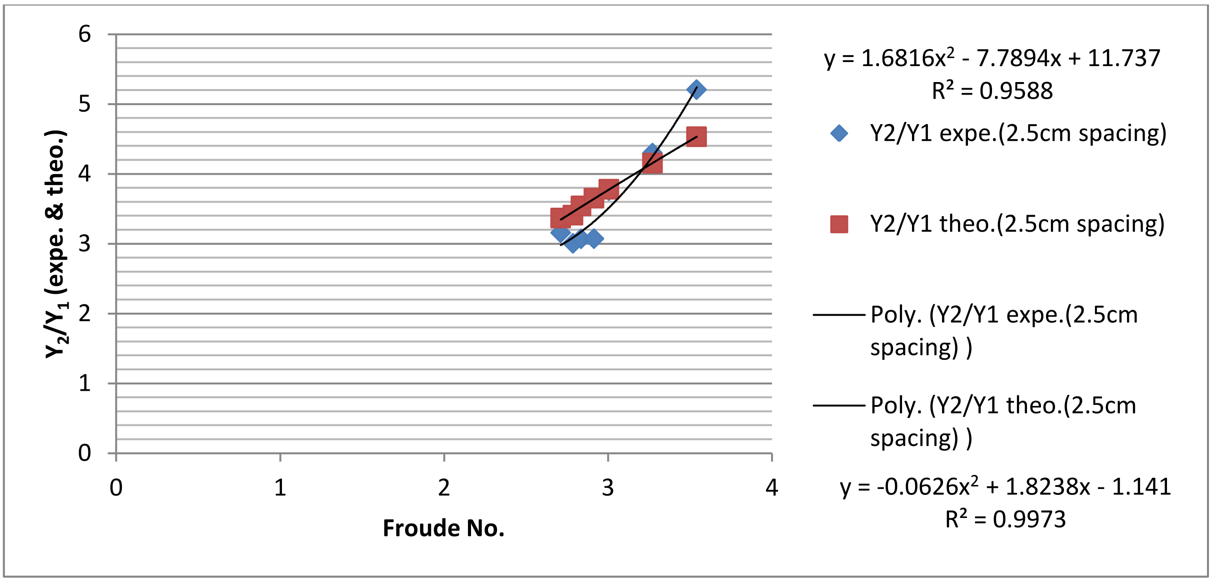


Figure 4.4 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp. & Theo.)

For Y_2/Y_1 (exp.) $R^2 = 0.96$

For Y_2/Y_1 (Theo.) $R^2 = 0.9973$

Figure no. 4.4 is based on the observations shown in Table no. 2, by which graph is plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio (exp. & Theo.) both also increases.

Condition [2] - (Block height 2.5 cm & spacing 5 cm)

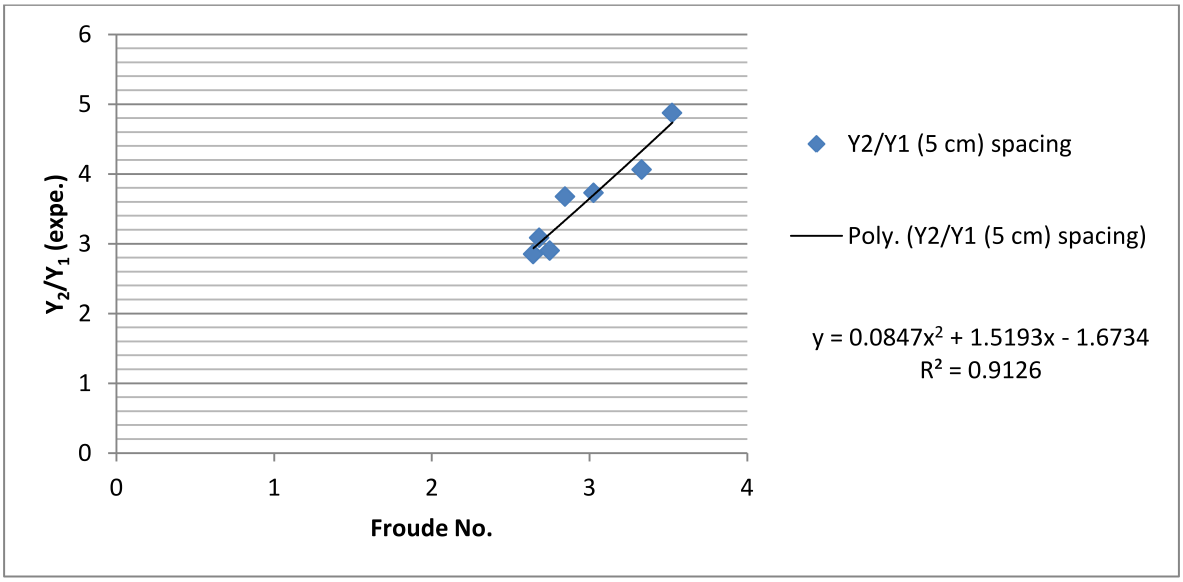


Figure 4.5 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.)

Figure no. 4.5 is based on the observations shown in Table no. 3, by which graph is plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio also increases rapidly.

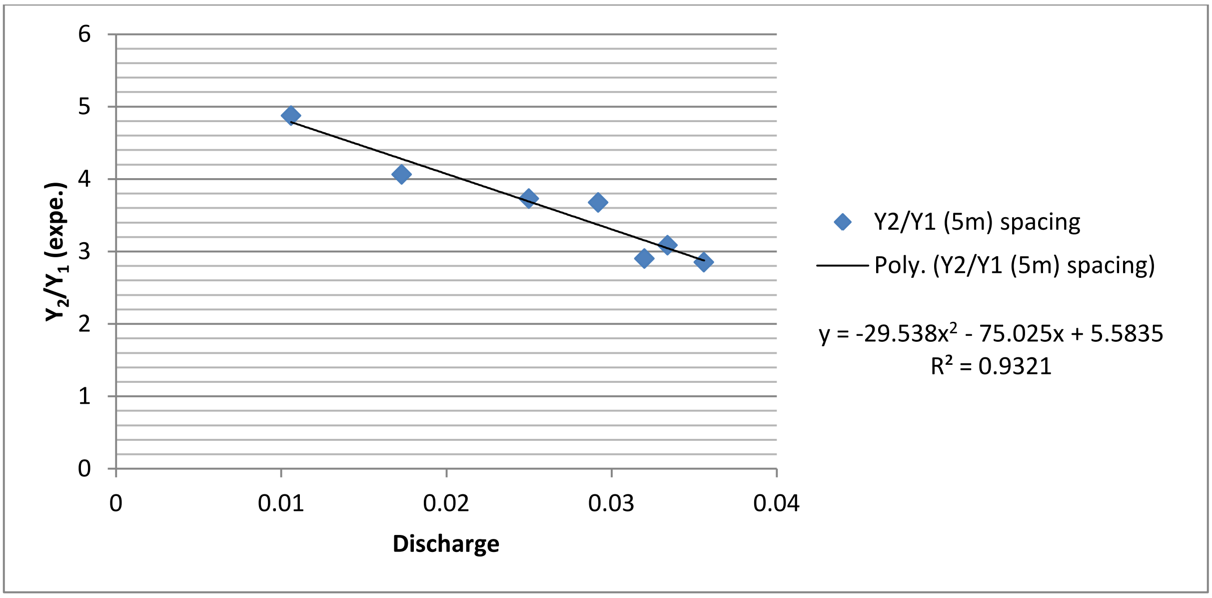


Figure 4.6 – Variation between Discharge (m^3/s) and Y_2/Y_1 (exp.)

Figure no. 4.6 is based on the observations shown in Table no. 3, by which graph is plotted between Discharge (m^3/s) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in discharge, sequent depth ratio decreases.

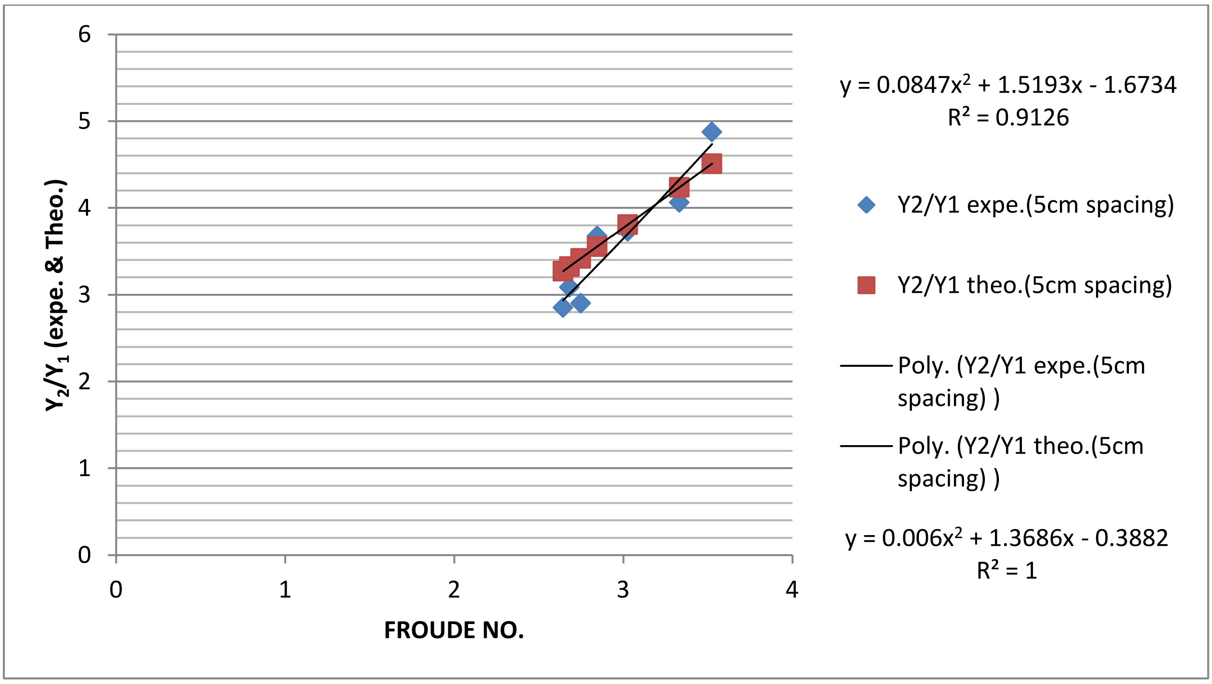


Figure 4.7 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp. & Theo.)

For Y_2/Y_1 (exp.) $R^2 = 0.9126$

For Y_2/Y_1 (Theo.) $R^2 = 1$

Figure no. 4.7 is based on the observations shown in Table no. 3, by which graph is plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio (exp. & Theo.) both also increases.

Condition [3] - (Block height 2.5 cm & spacing 10 cm)

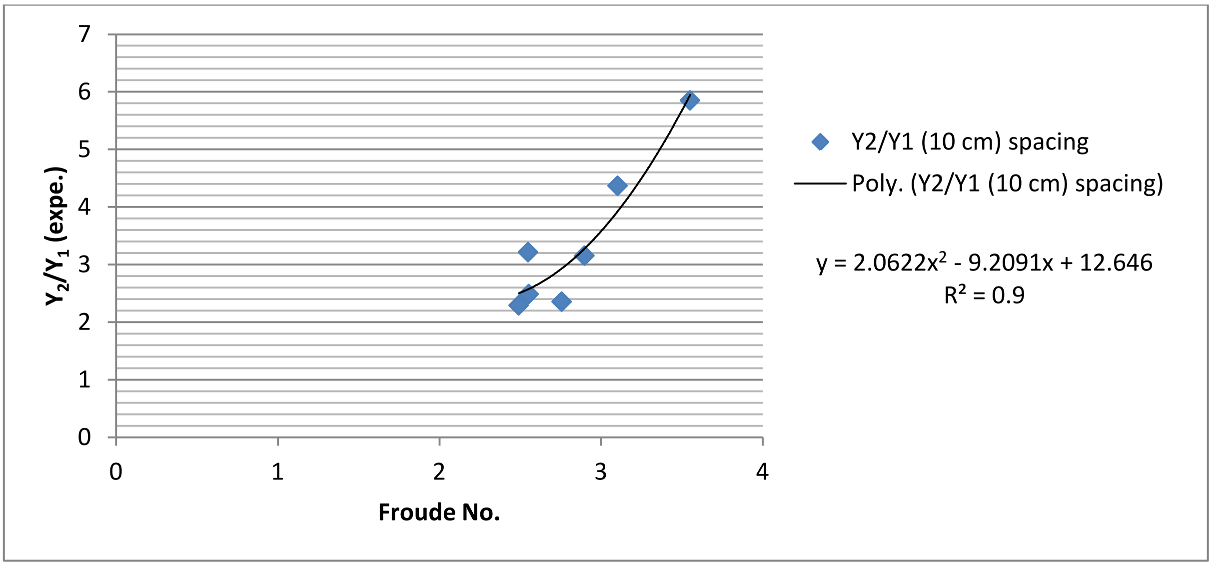


Figure 4.8 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.)

Figure no. 4.8 is based on the observations shown in Table no. 4, by which graph is plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio also increases rapidly.

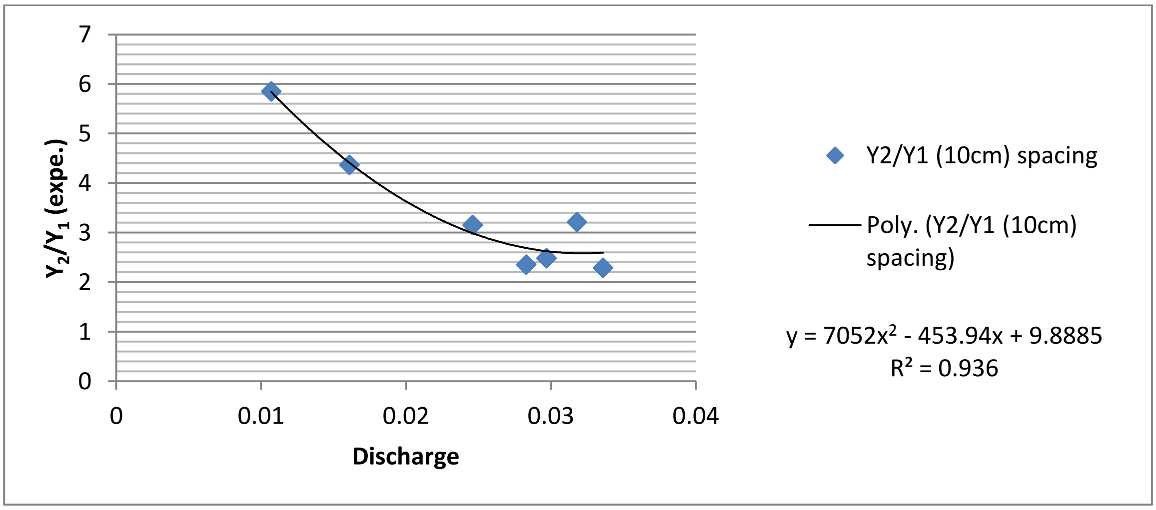


Figure 4.9 – Variation between Discharge (m^3/s) and. Y_2/Y_1 (exp.)

Figure no. 4.9 is based on the observations shown in Table no. 4, by which graph is plotted between Discharge (m^3/s) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in discharge, sequent depth ratio decreases.

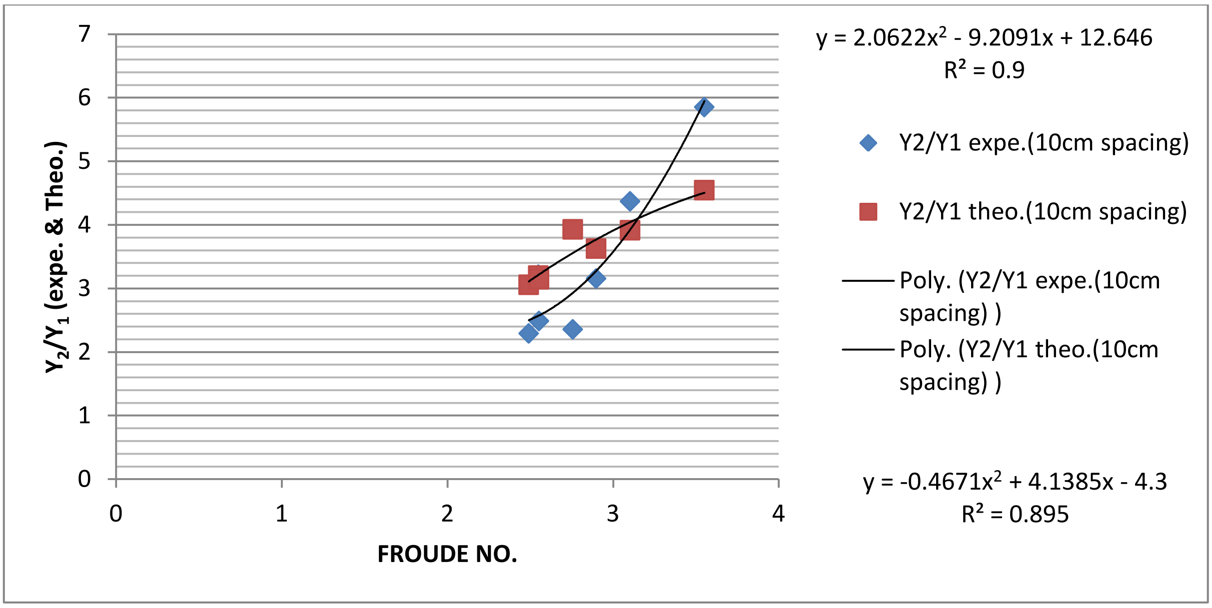


Figure 4.10 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp. & Theo.)

For Y_2/Y_1 (exp.) $R^2 = 0.90$

For Y_2/Y_1 (Theo.) $R^2 = 0.89$

Figure no. 4.10 is based on the observations shown in Table no. 4, by which graph is plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio (exp. & Theo.) both also increases. By the plot, slight variation were found between experimental and theoretical values.

<u>Condition [4]</u> <u>– Block height 2.5 cm & Spacing 14 cm</u>

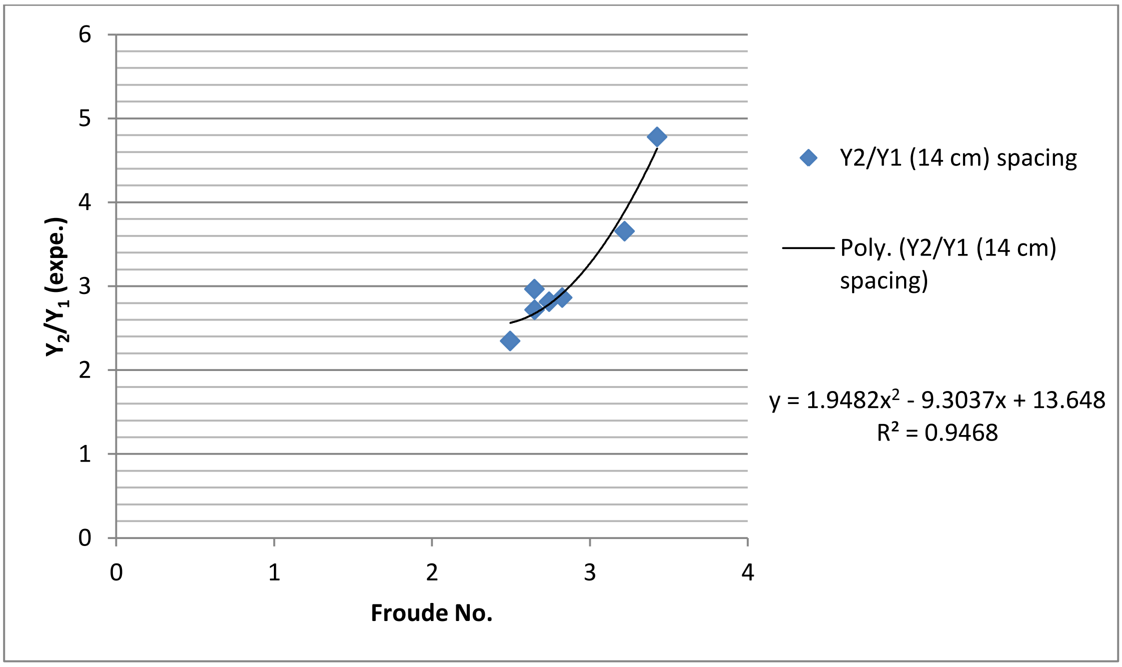


Figure 4.11 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.)

Figure no. 4.11 is based on the observations shown in Table no. 5, by which graph is plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio also increases rapidly.

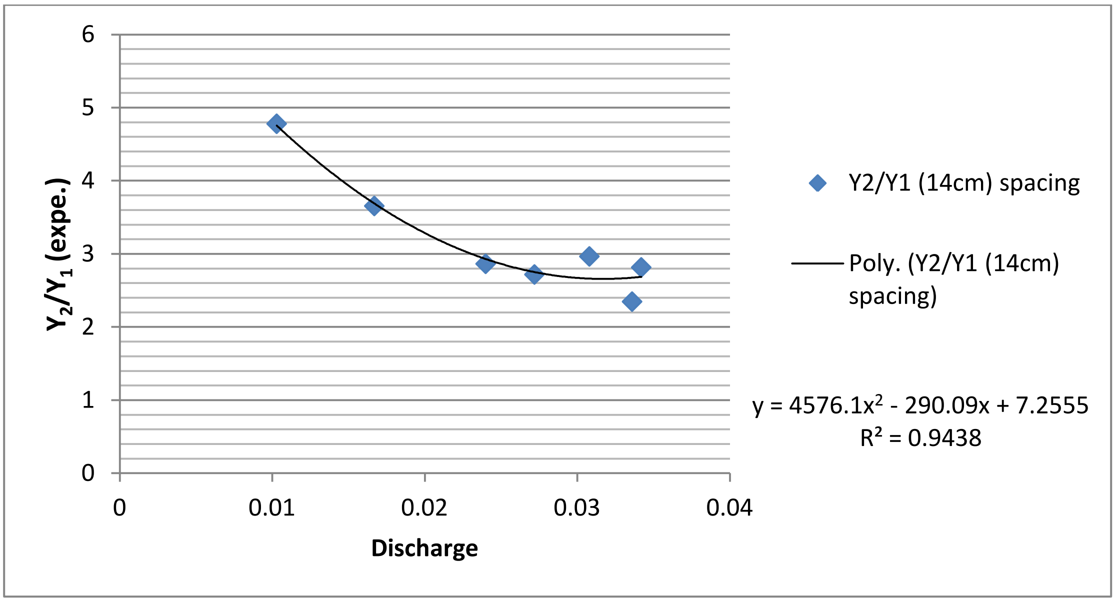


Figure 4.12 – Variation between Discharge (m^3/s) and Y_2/Y_1 (exp.)

Figure no. 4.12 is based on the observations shown in Table no. 5, by which graph is plotted between Discharge (m^3/s) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in discharge, sequent depth ratio decreases.

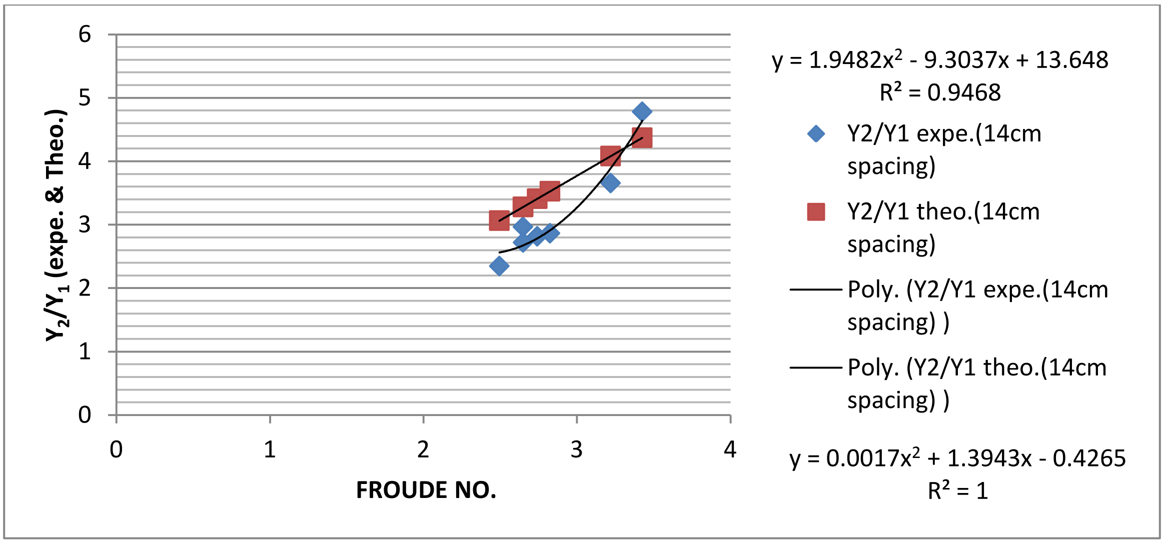


Figure 4.13 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp. & Theo.)

For Y_2/Y_1 (exp.) $R^2 = 0.9468$

For Y_2/Y_1 (Theo.) $R^2 = 1$

Figure no. 4.13 is based on the observations shown in Table no. 5, by which graph is plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio (exp. & Theo.) both also increases.

Condition [5] – Block height 2.5 cm & Spacing 17 cm

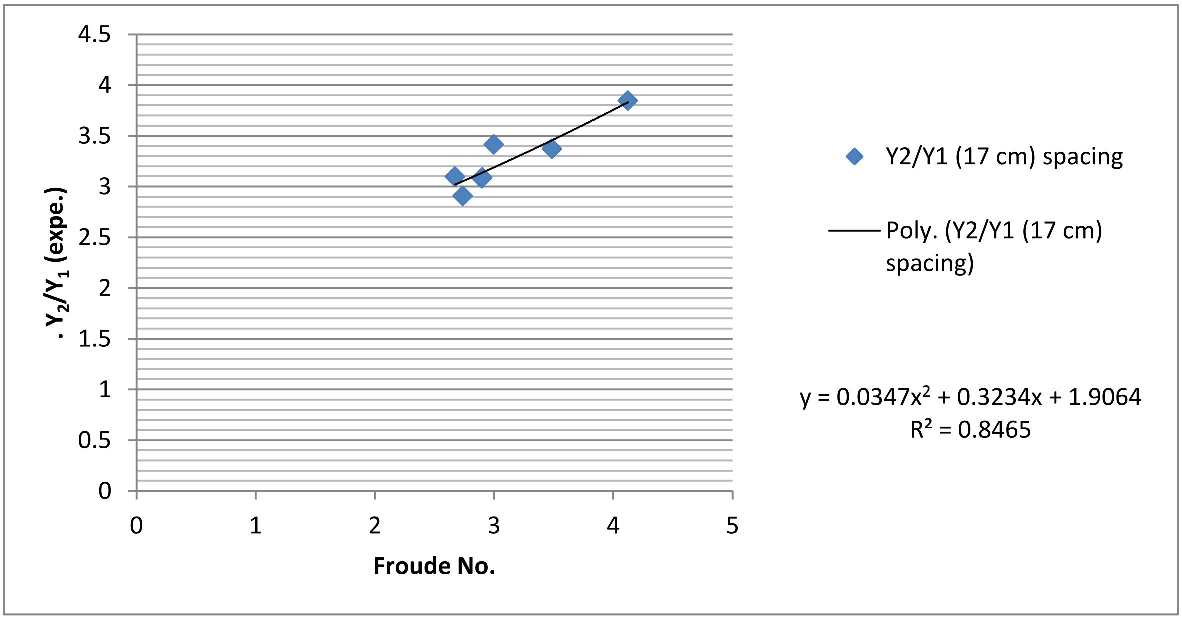


Figure 4.14 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.)

Figure no. 4.14 is based on the observations shown in Table no. 6, by which graph is plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio also increases rapidly.

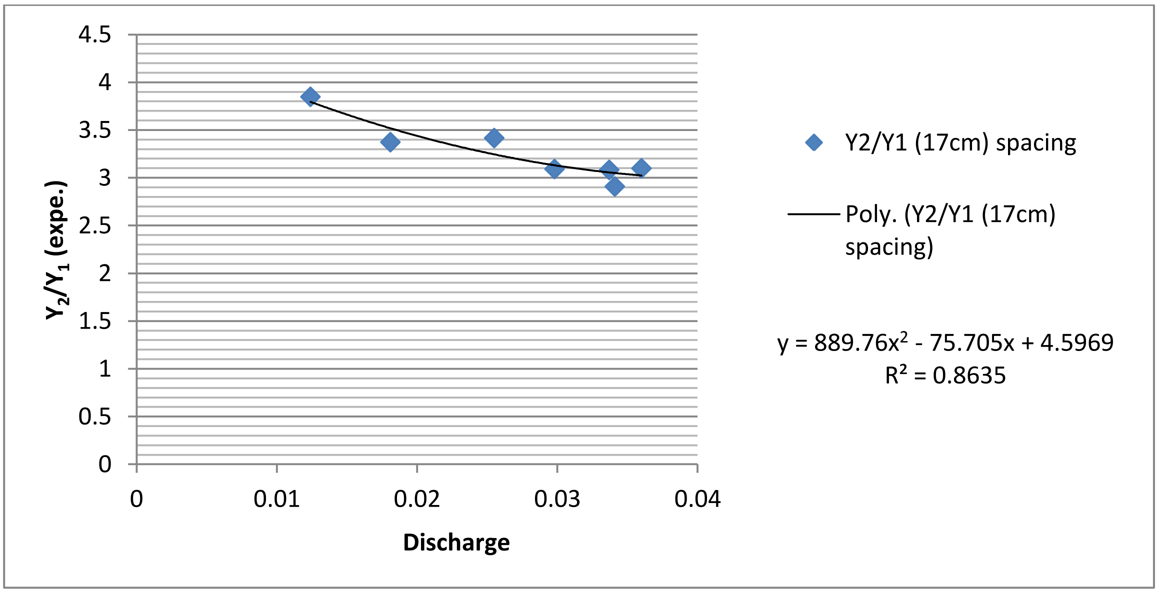


Figure 4.15 – Variation between Discharge (m^3/s) and Y_2/Y_1 (exp.)

Figure no. 4.15 is based on the observations shown in Table no. 6, by which graph is plotted between Discharge ($^{m^3}/_{s}$) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in discharge, sequent depth ratio decreases.

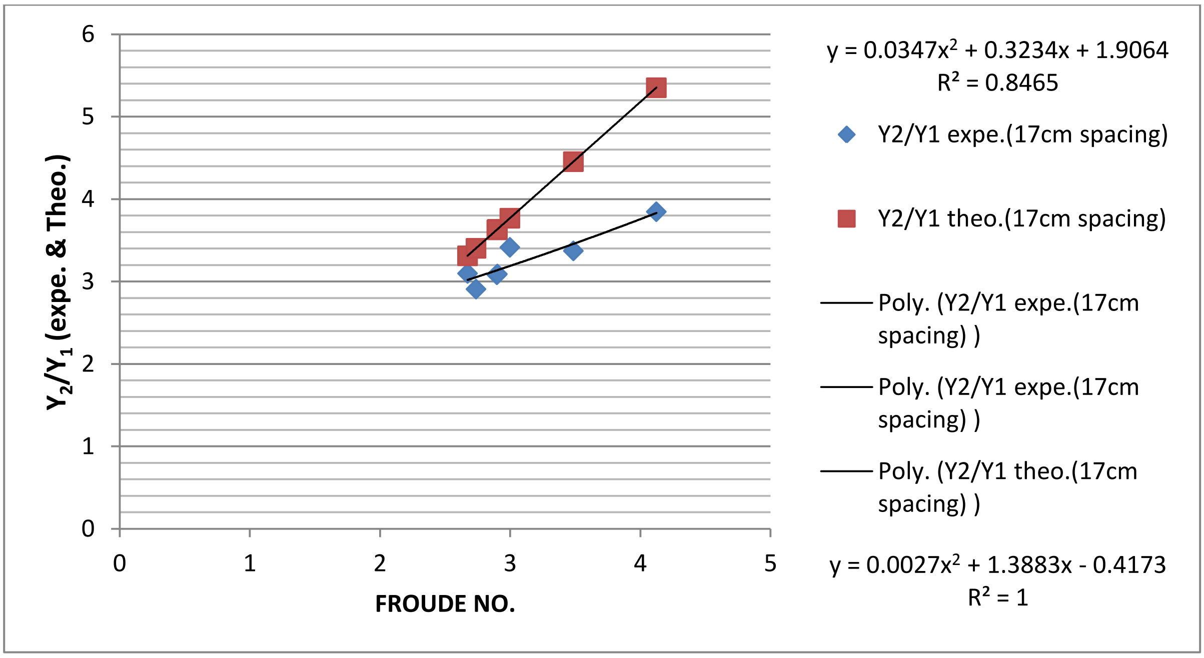


Figure 4.16 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp. & Theo.)

For Y_2/Y_1 (exp.) $R^2 = 0.846$

For Y_2/Y_1 (Theo.) $R^2 = 1$

Figure no. 4.16 is based on the observations shown in Table no. 6, by which graph is plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio (exp. & Theo.) both also increases.

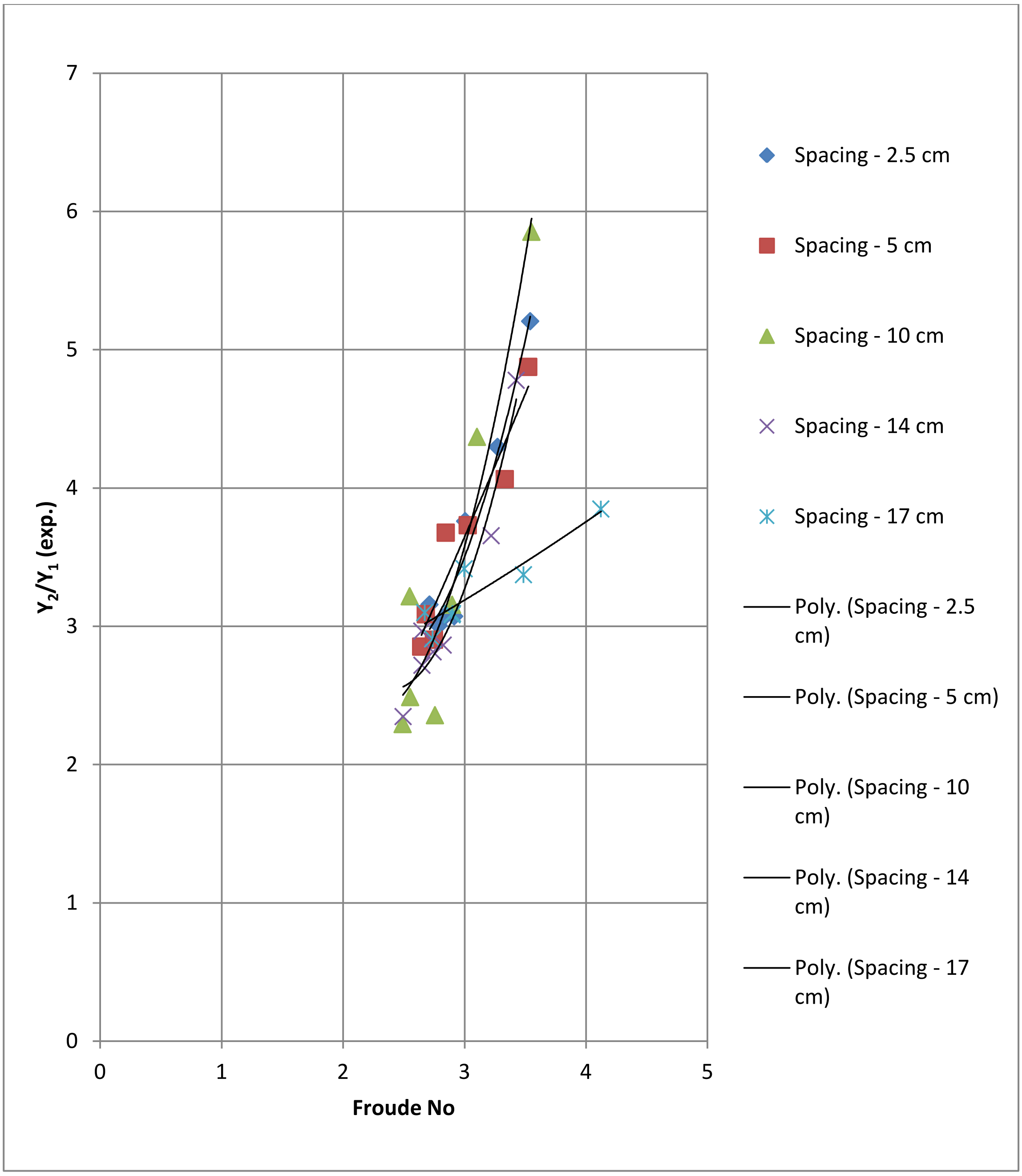


Figure 4.17 – Froude No. (F_{r_1}) and Y_2/Y_1 (exp.)

[Case (1) - Variation between Froude No. with sequent depth ratio with varying spacing at Block height 2.5 cm]

Figure no. 4.17 is based on the observations shown in all table of case 1, by which a graph plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.) of all the conditions of case 1. From the figure it was observed that with increase in Froude no., sequent depth ratio also increases rapidly with their relative spacing.

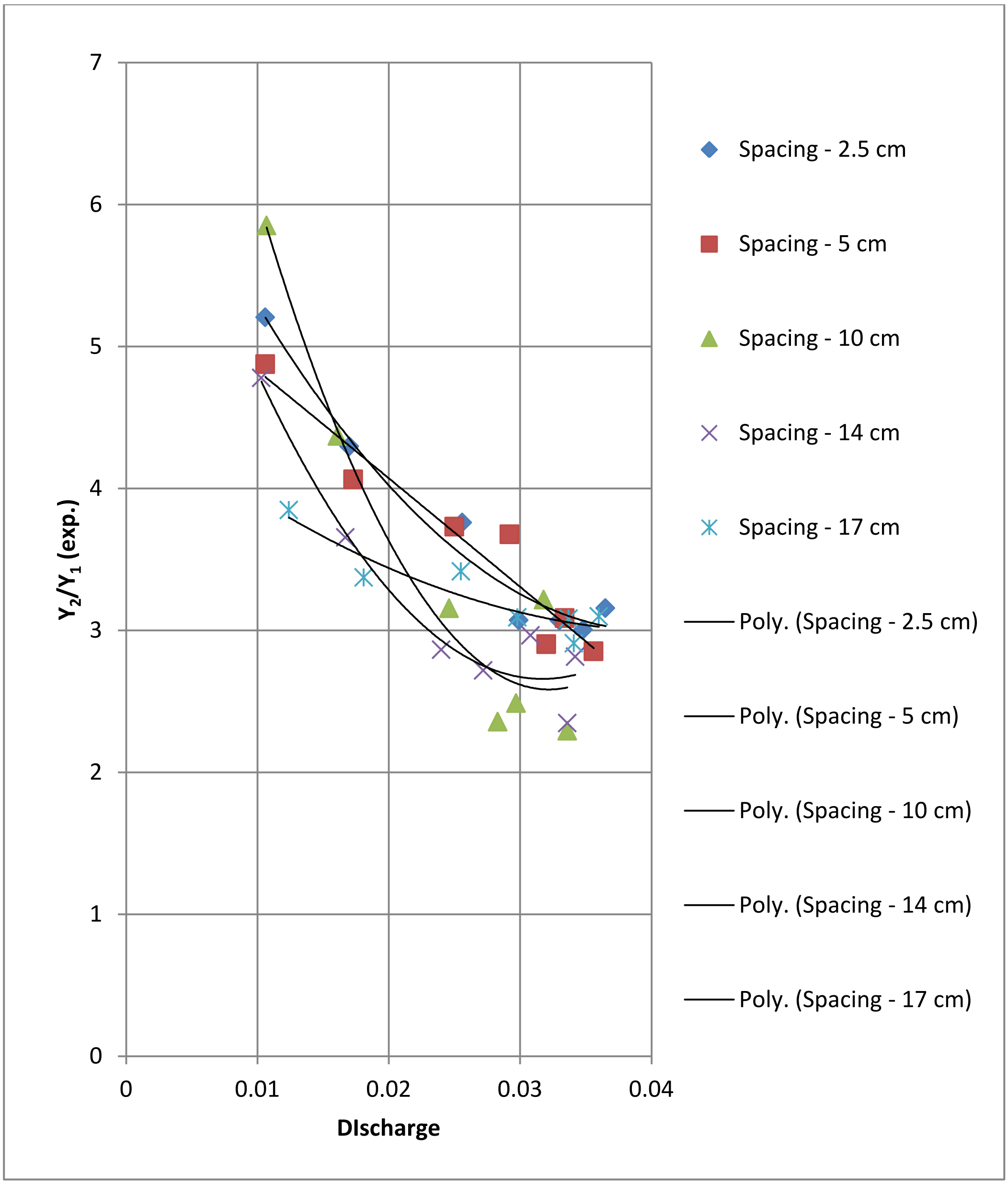


Figure 4.18 – Discharge and Y_2/Y_1 (exp.)

[Case – 1 Variation between Discharges with sequent depth ratio

with varying spacing at Block height 2.5 cm]

Figure no. 4.18 is based on the observations shown in all table of case 1, by which graph is plotted between discharge and Y_2/Y_1 (exp.) of all the conditions of case 1. From the figure it was observed that with increase in discharge, sequent depth ratio decreases with their relative spacing.

CASE - 2

For Rough Horizontal Bed (with block height 3.5 cm)

The roughness applied in case 2 by increases height of block 3.5 cm. with a change in their spacing.

Condition [1] - (Block height 3.5 cm & spacing 3.5 cm)

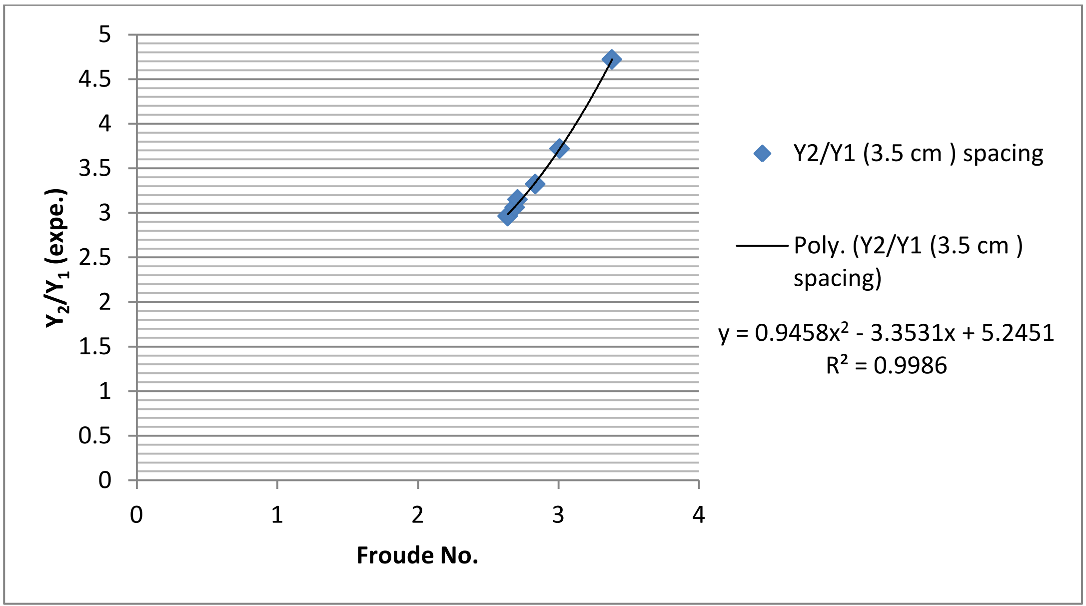


Figure 4.19 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.)

Figure no. 4.19 is based on the observations shown in Table no. 7, by which graph is plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio also increases rapidly.

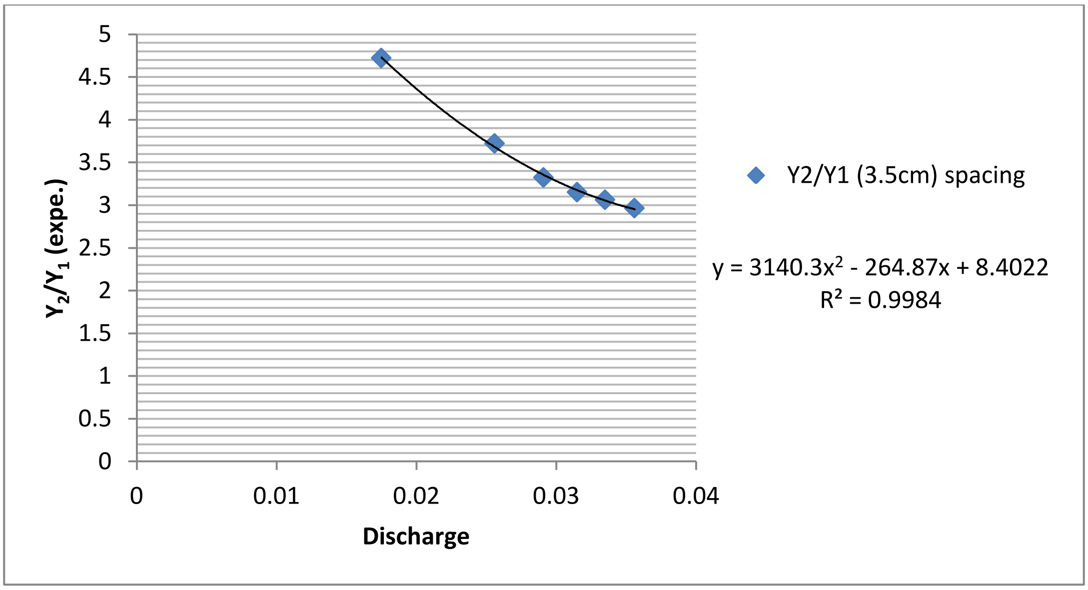


Figure 4.20 – Variation between Discharge (m^3/s) and Y_2/Y_1 (exp.)

Figure no. 4.20 is based on the observations shown in Table no. 7, by which graph is plotted between Discharge (m^3/s) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in discharge, sequent depth ratio decreases.

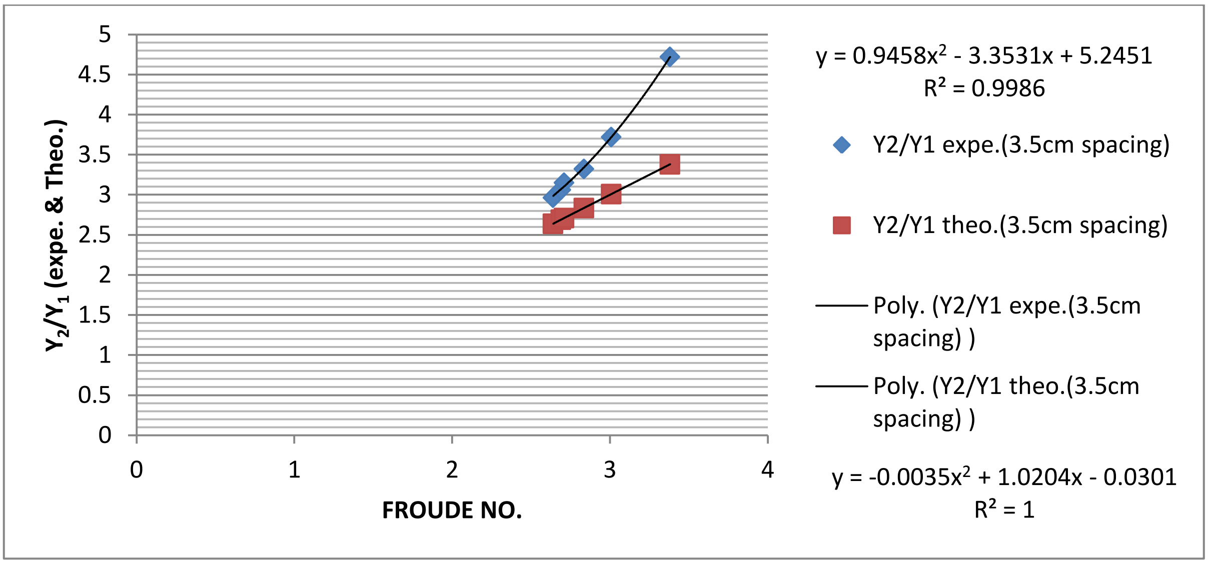


Figure 4.21– Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp. & Theo.)

For Y_2/Y_1 (exp.) $R^2 = 0.998$

For Y_2/Y_1 (Theo.) $R^2 = 1$

Figure no. 4.21 is based on the observations shown in Table no. 7, by which graph is plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio (exp. & Theo.) both also increases.

Condition [2] - (Block height 3.5 cm & spacing 7 cm)

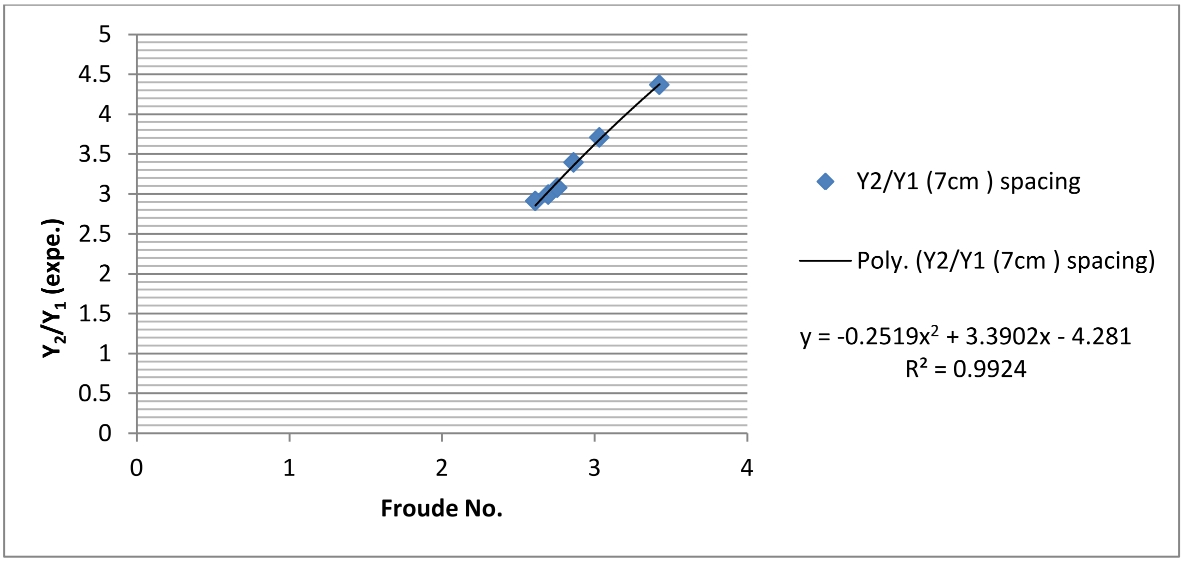


Figure 4.22 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.)

Figure no. 4.22 is based on the observations shown in Table no. 8, by which graph is plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio also increases rapidly.

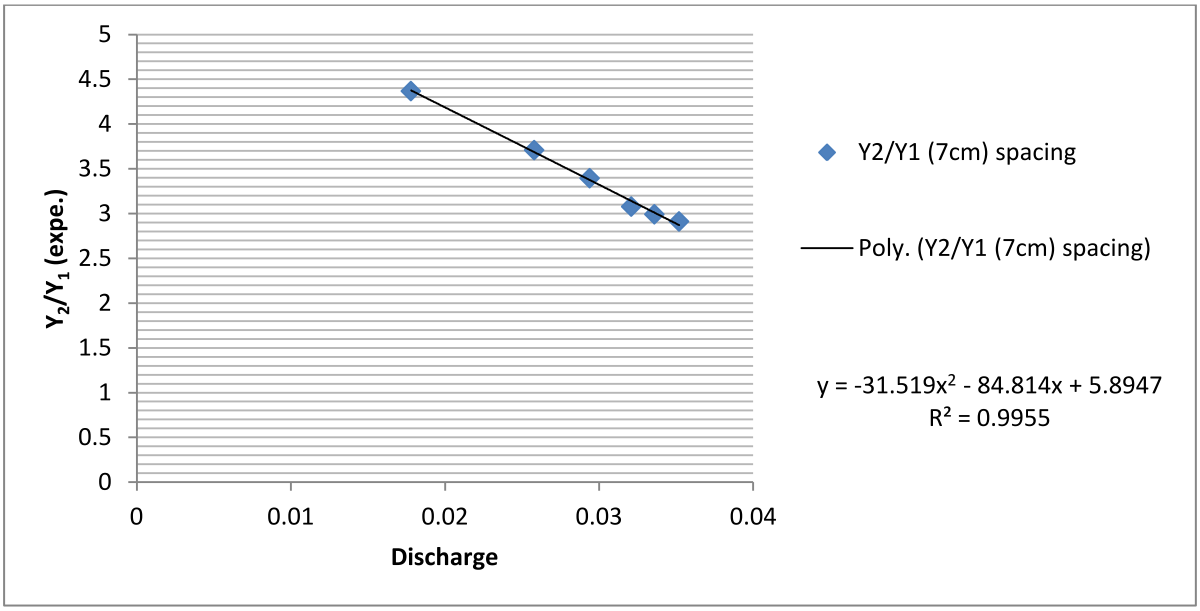


Figure 4.23 – Variation between Discharge ($^{m^3}/_{s}$) and Y_2/Y_1 (exp.)

Figure no. 4.23 is based on the observations shown in Table no. 8, by which graph is plotted between Discharge ($^{m^3}/_{s}$) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in discharge, sequent depth ratio decreases.

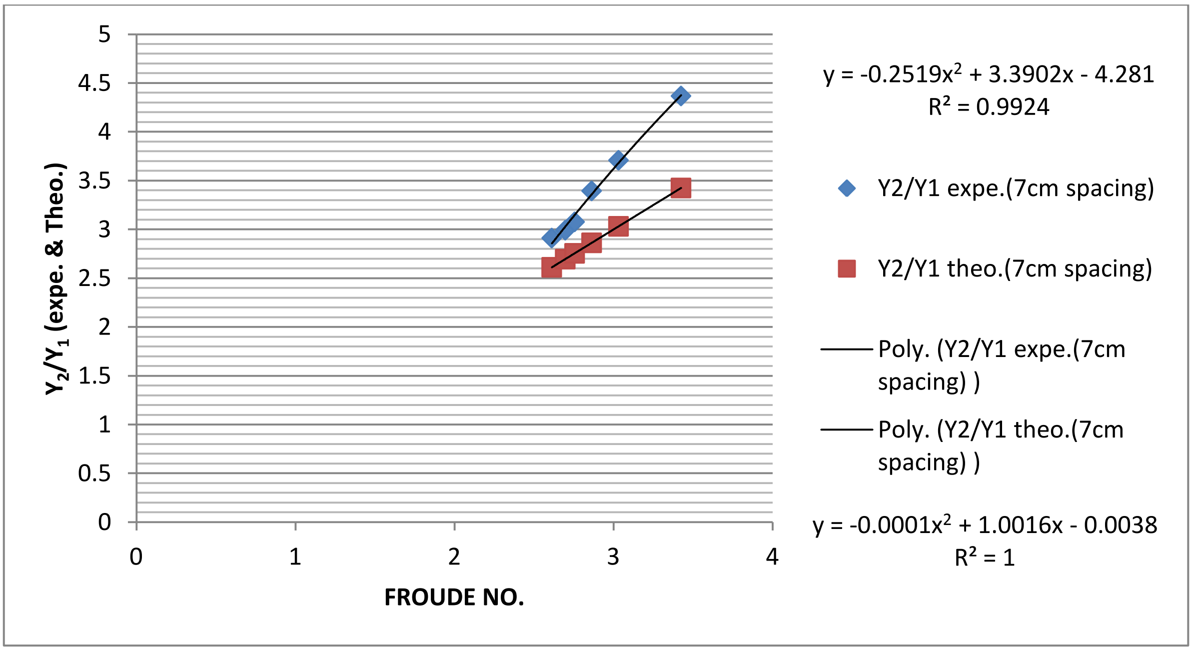


Figure 4.24 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp. & Theo.)

For Y_2/Y_1 (exp.) $R^2 = 0.9924$

For Y_2/Y_1 (Theo.) $R^2 = 1$

Figure no. 4.24 is based on the observations shown in Table no. 8, by which graph is plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio (exp. & Theo.) both also increases.

Condition [3] - (Block height 3.5 cm & spacing 10 cm)

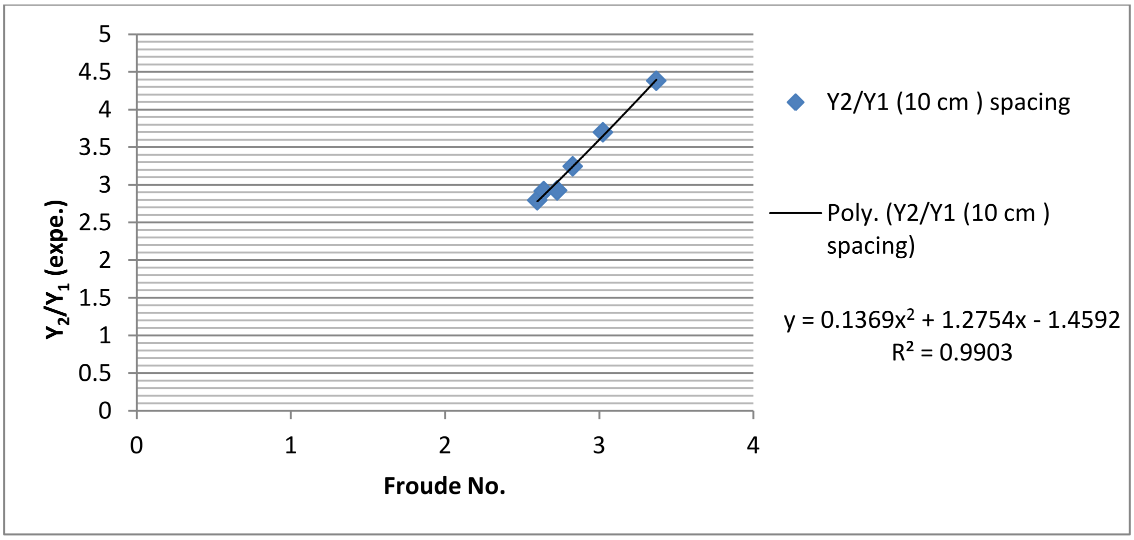


Figure 4.25 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.)

Figure no. 4.25 is based on the observations shown in Table no. 9, by which graph is plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio also increases rapidly.

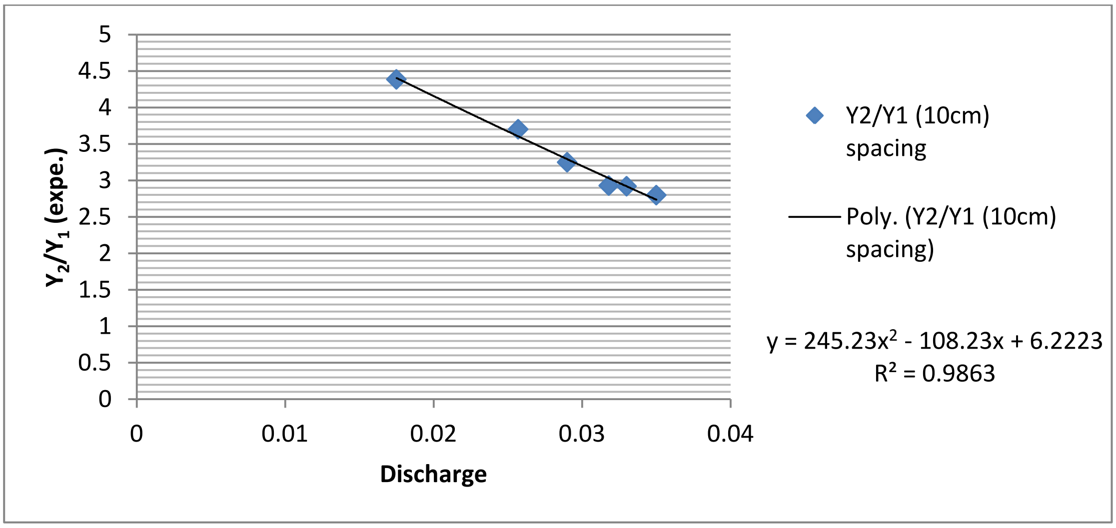


Figure 4.26 – Variation between Discharge (m^3/s) and Y_2/Y_1 (exp.)

Figure no. 4.26 is based on the observations shown in Table no. 9, by which graph is plotted between Discharge ($^{m^3}/_s$) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in discharge, sequent depth ratio decreases.

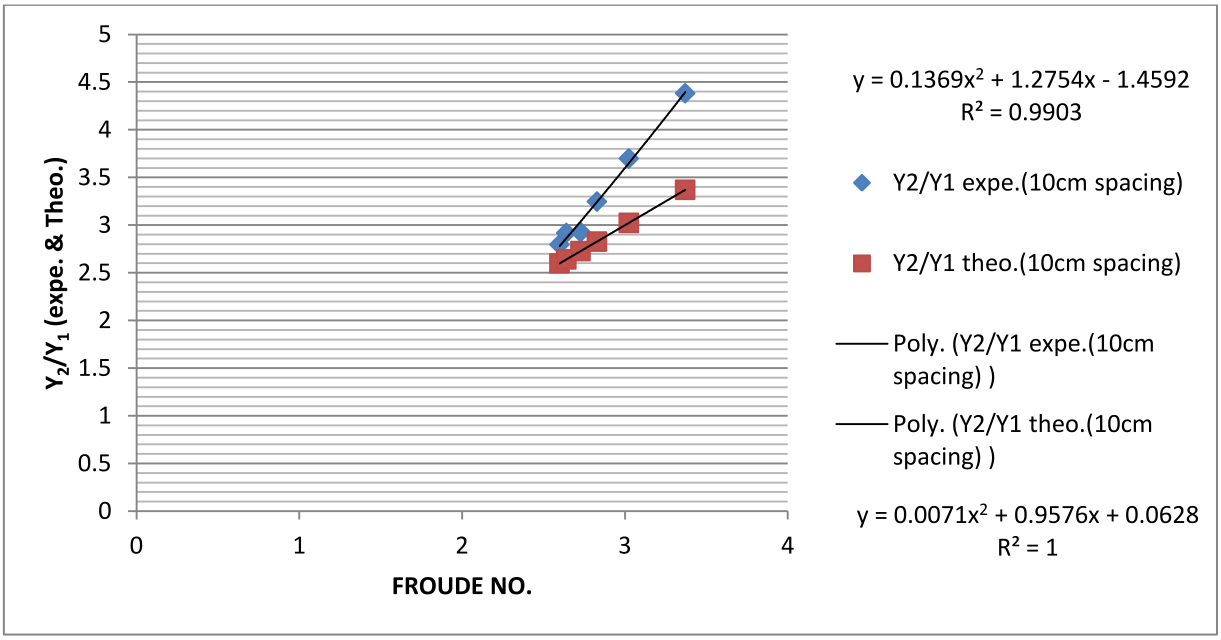


Figure 4.27 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp. & Theo.)

For Y_2/Y_1 (exp.) $R^2 = 0.9903$

For Y_2/Y_1 (Theo.) $R^2 = 1$

Figure no. 4.27is based on the observations shown in Table no. 9, by which graph is plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio (exp. & Theo.) both also increases.

Condition [4] - (Block height 3.5 cm & spacing 14 cm)

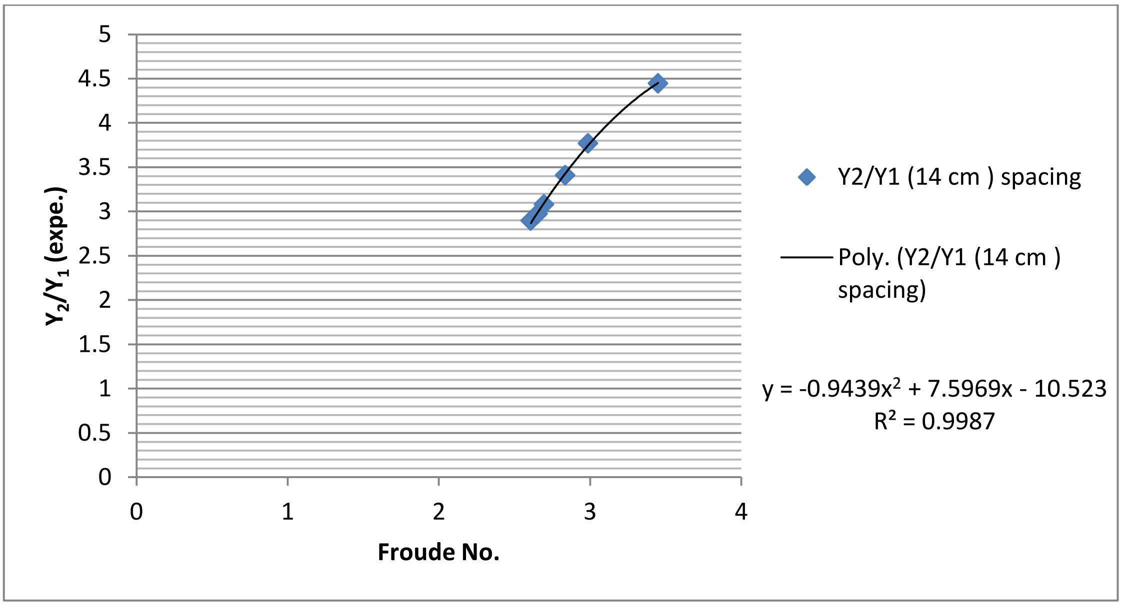


Figure 4.28 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.)

Figure no. 4.28 is based on the observations shown in Table no. 10, by which graph is plotted in between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio also increases rapidly.

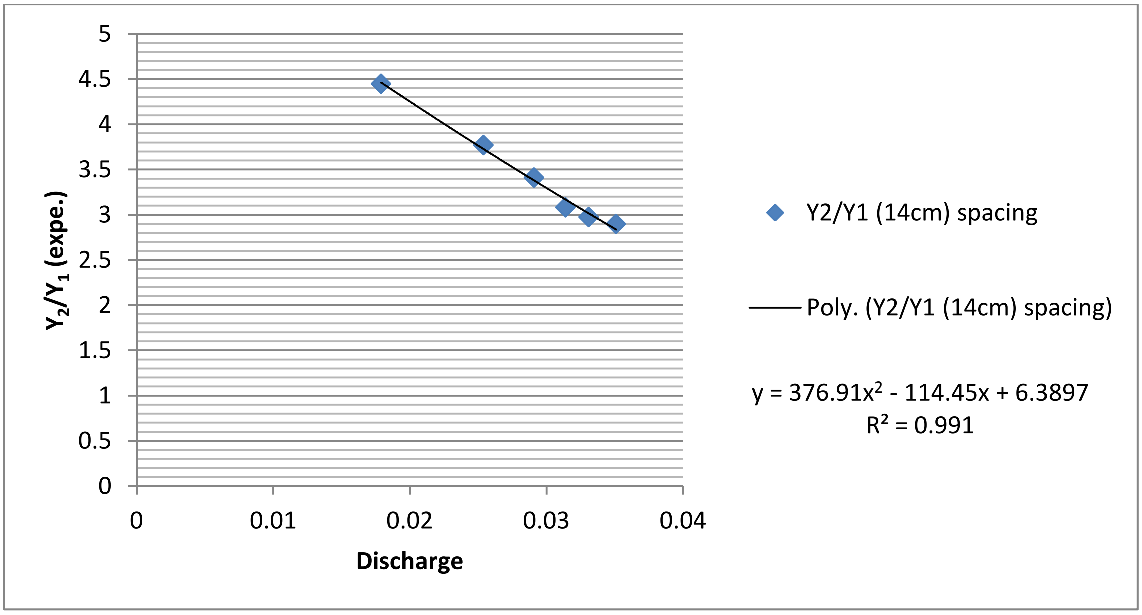


Figure 4.29 – Variation between Discharge ($^{m^3}/_{s}$) and Y_2/Y_1 (exp.)

Figure no. 4.29 is based on the observations shown in Table no. 10, by which graph is plotted in between Discharge ($^{m^3}/_{s}$) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in discharge sequent depth ratio decreases.

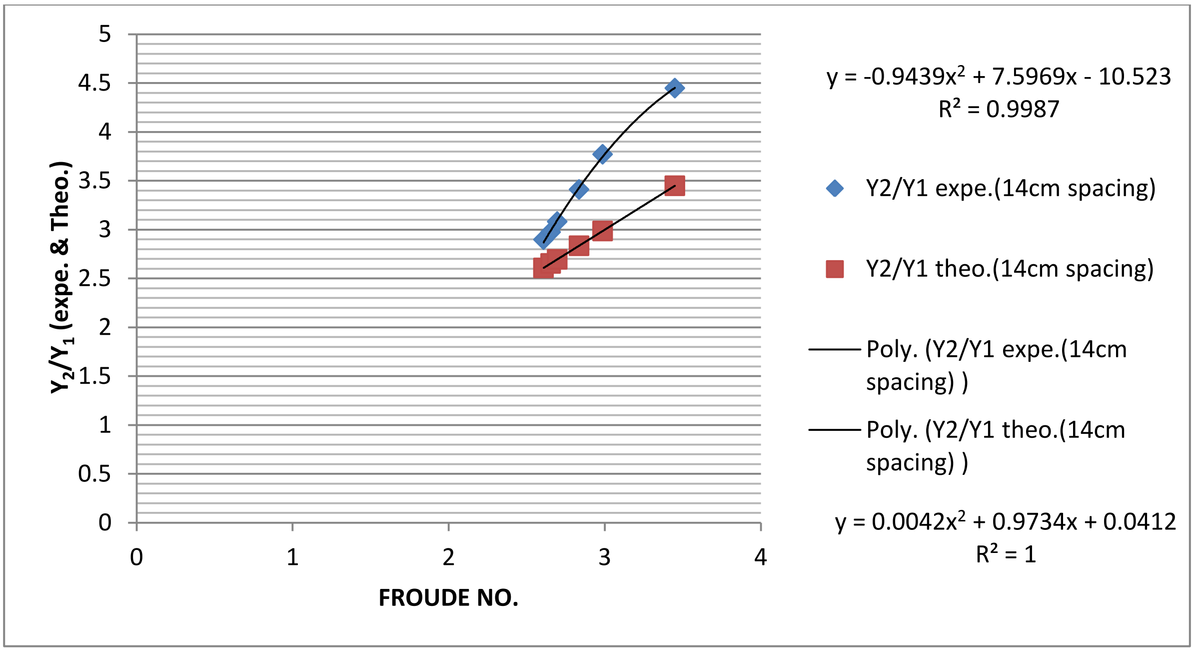


Figure 4.30 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp. & Theo.)

For Y_2/Y_1 (exp.) $R^2 = 0.998$

For Y_2/Y_1 (Theo.) $R^2 = 1$

Figure no. 4.30 is based on the observations shown in Table no. 10, by which graph is plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio (exp. & Theo.) both also increases.

<u>Condition [5]</u> - <u>(Block height 3.5 cm & spacing 17 cm)</u>

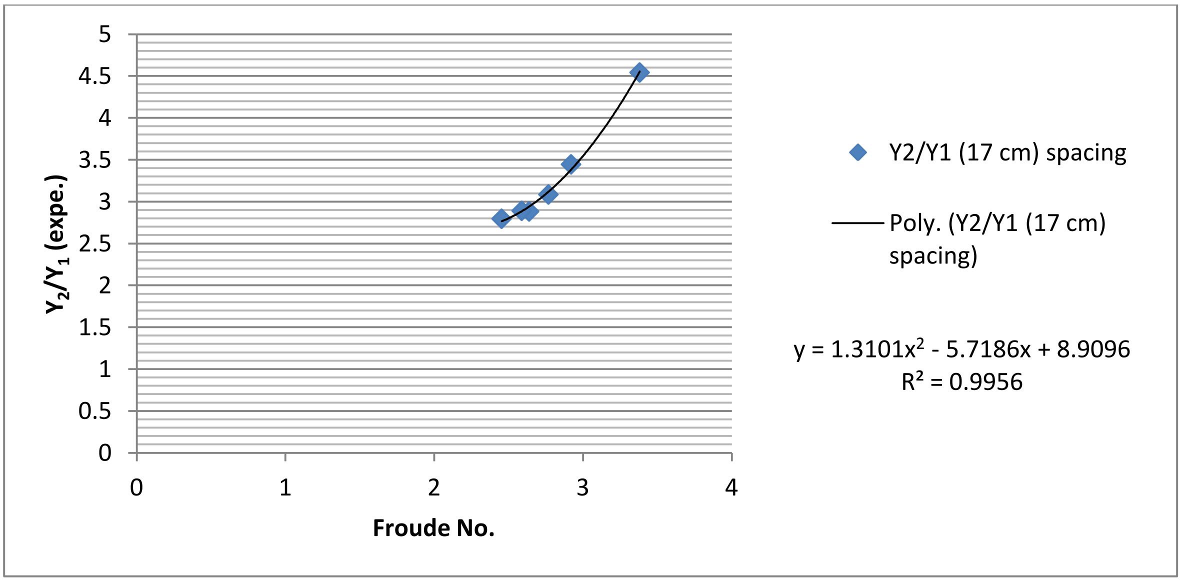


Figure 4.31 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.)

Figure no. 4.31 is based on the observations shown in Table no. 11, by which graph is plotted in between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio also increases rapidly.

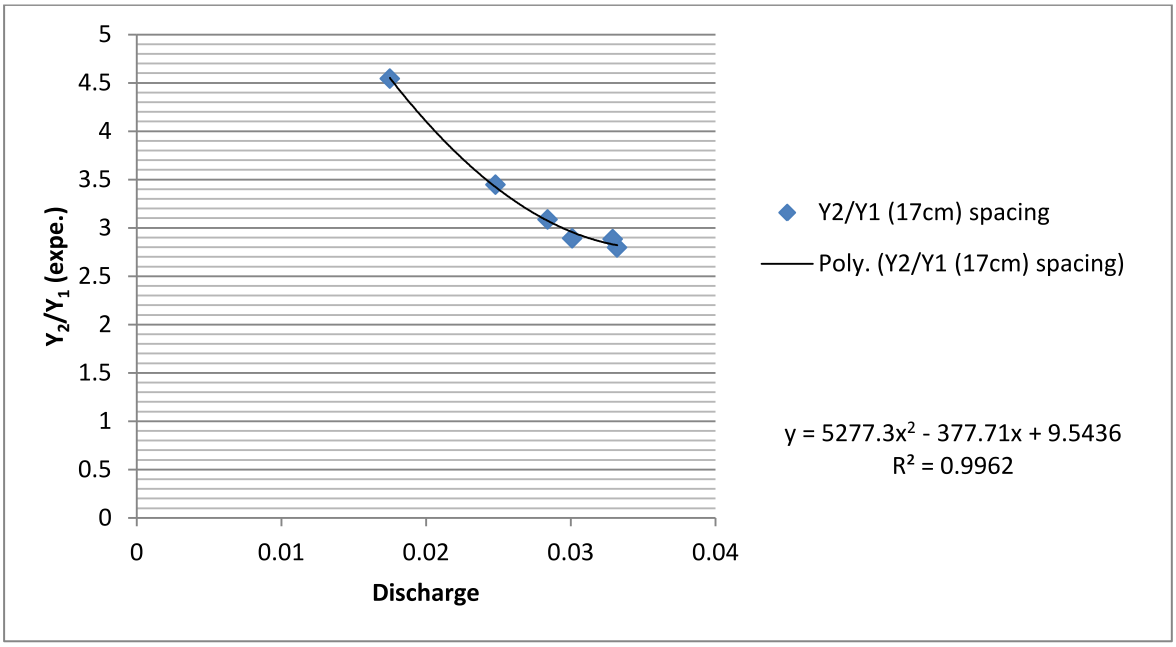


Figure 4.32 – Variation between Discharge (m^3/s) and Y_2/Y_1 (exp.)

Figure no. 4.32 is based on the observations shown in Table no. 11, by which graph is plotted in between Discharge (m^3/s) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in discharge, sequent depth ratio decreases.

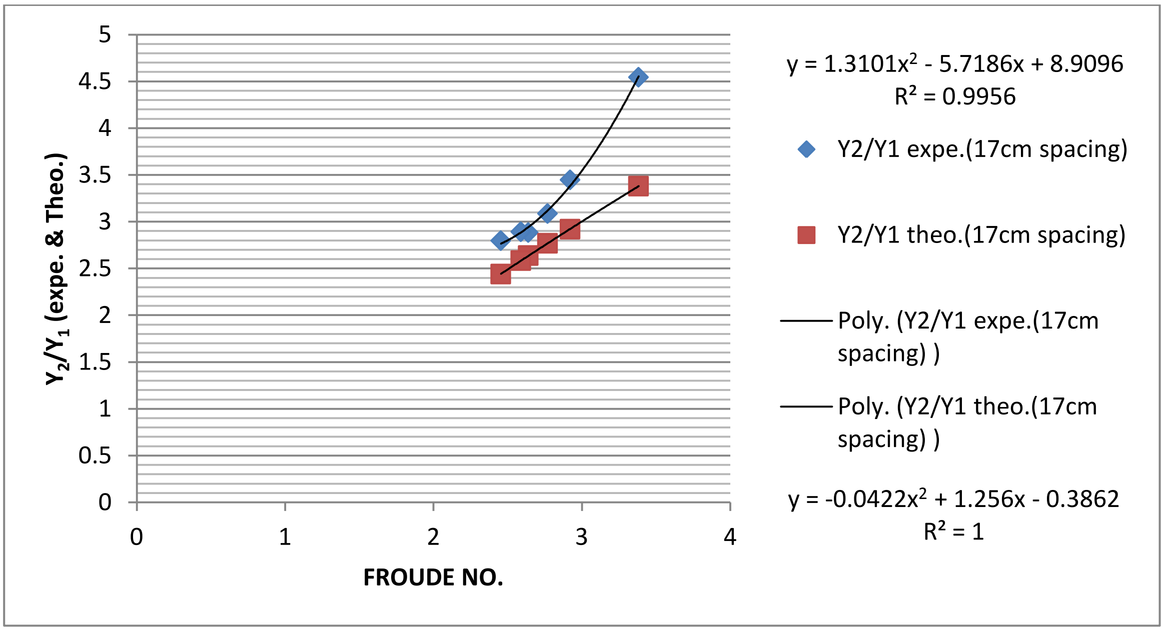


Figure 4.33 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp. & Theo.)

For Y_2/Y_1 (exp.) $R^2 = 0.9956$

For Y_2/Y_1 (Theo.) $R^2 = 1$

Figure no. 4.33 is based on the observations shown in Table no. 11, by which graph is plotted in between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio (exp. & Theo.) both also increases.

Condition [6] - (Block height 3.5 cm & spacing 20 cm)

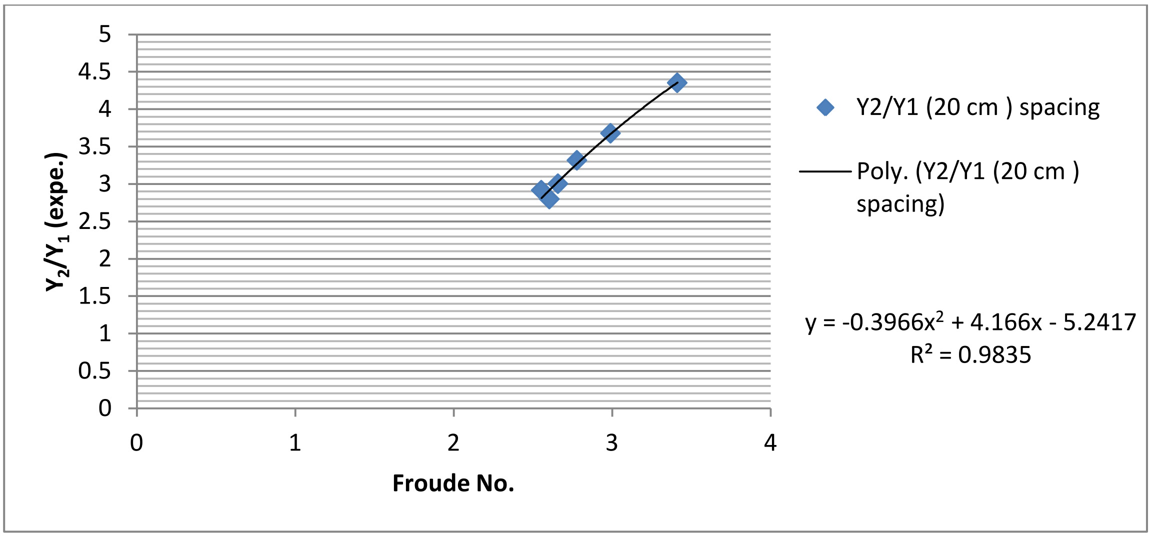


Figure 4.34 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.)

Figure no. 4.34 is based on the observations shown in Table no. 12, by which graph is plotted in between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio also increases rapidly.

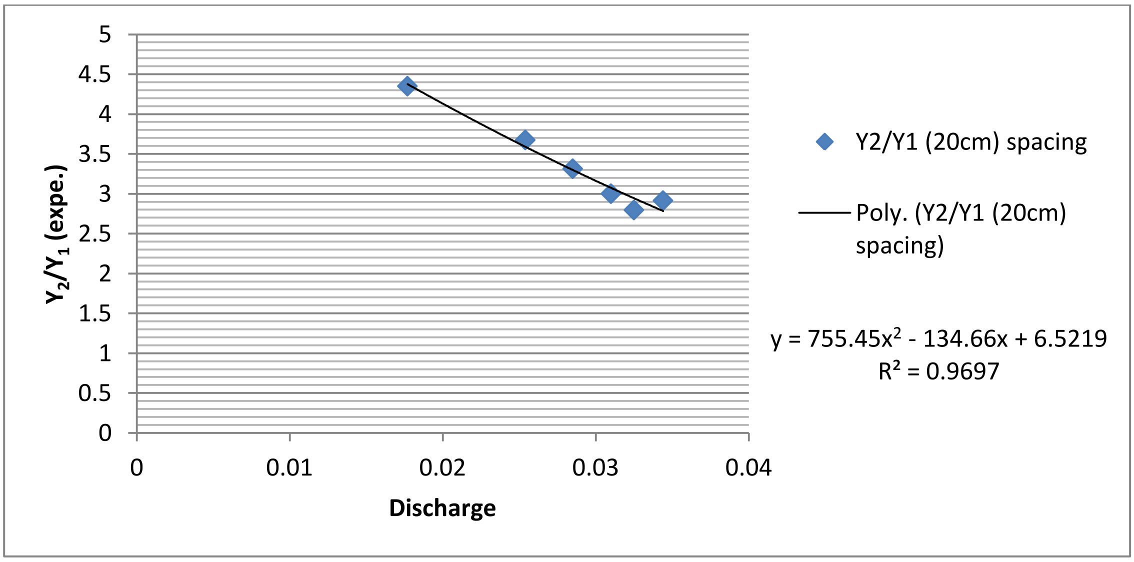


Figure 4.35 – Variation between Discharge (m^3/s) and Y_2/Y_1 (exp.)

Figure no. 4.35 is based on the observations shown in Table no. 12, by which graph is plotted in between Discharge (m^3/s) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in discharge, sequent depth ratio decreases.

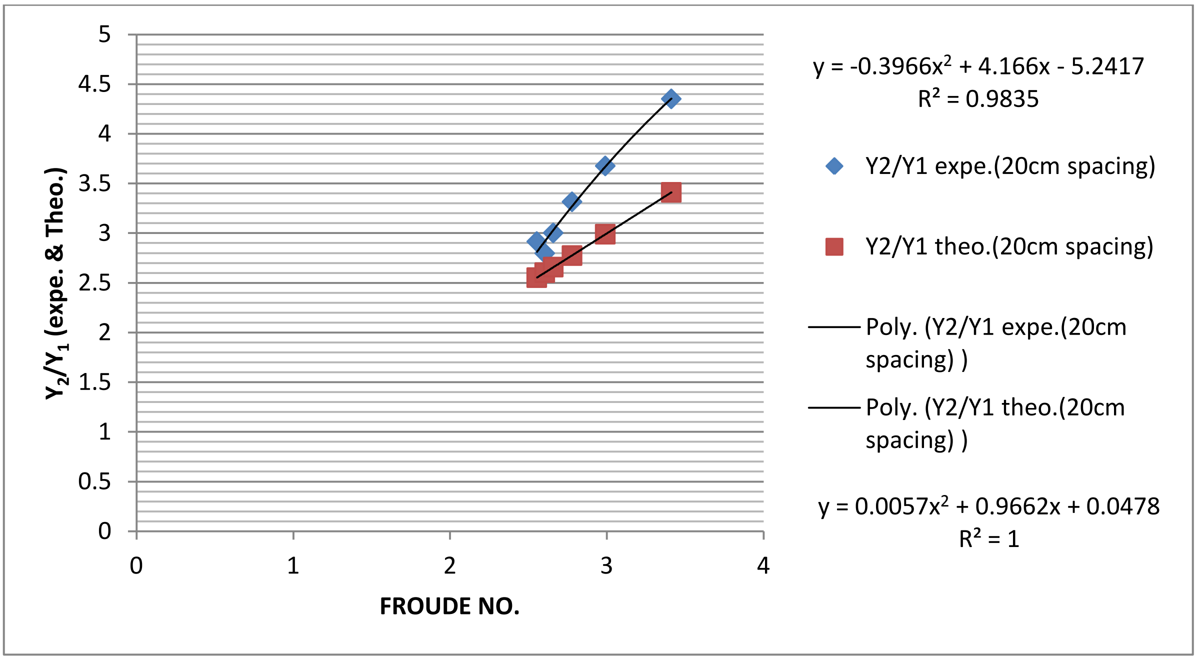


Figure 4.36 – Variation between Froude No. (F_{r_1}) and Y_2/Y_1 (exp. & Theo.)

For Y_2/Y_1 (exp.) $R^2 = 0.983$

For Y_2/Y_1 (Theo.) $R^2 = 1$

Figure no. 4.36 is based on the observations shown in Table no. 12, by which graph is plotted in between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.). From the figure it was observed that with increase in Froude no., sequent depth ratio (exp. & Theo.) both also increases.

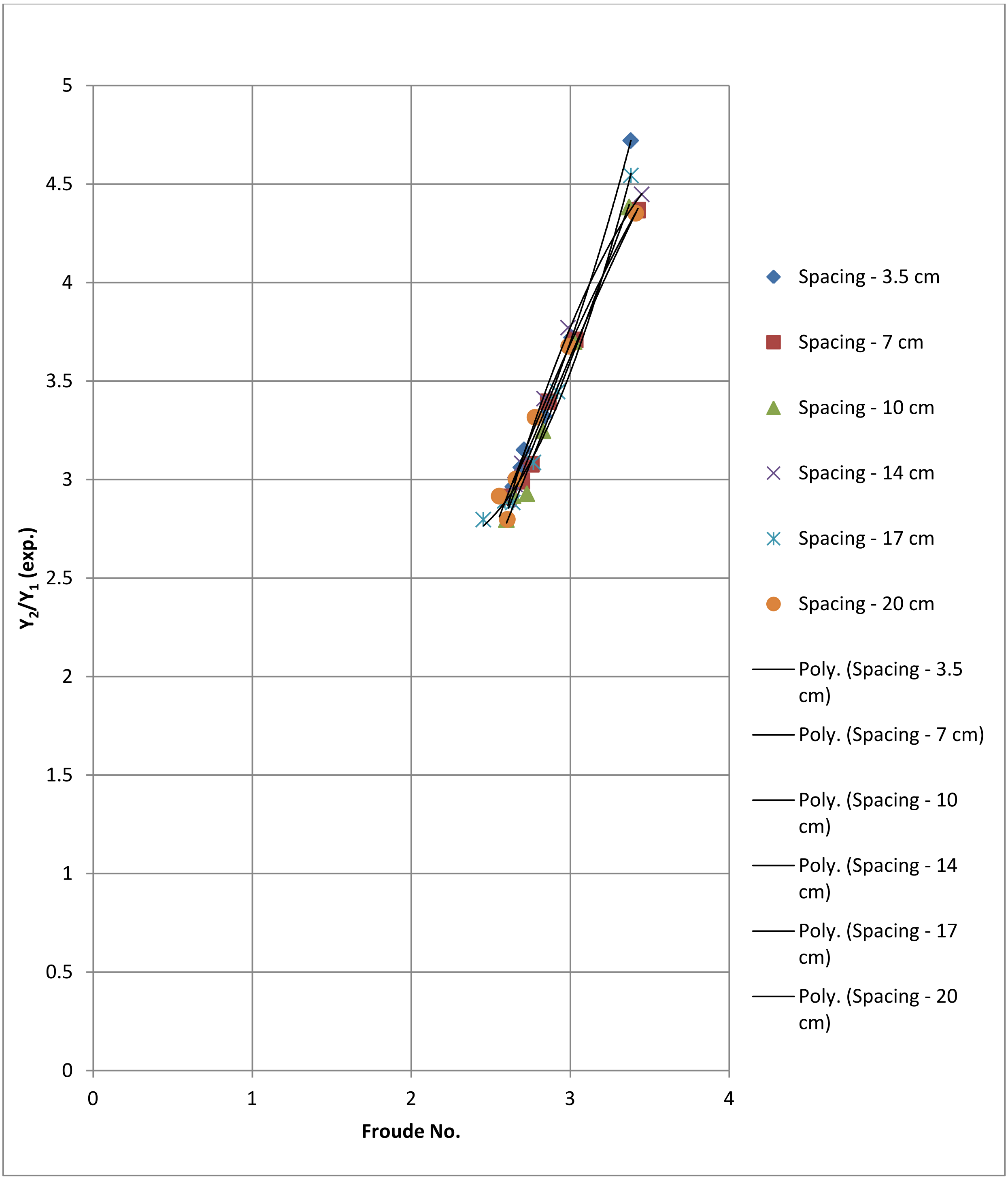


Figure 4.37 – Froude No. (F_{r_1}) and Y_2/Y_1 (exp.)

[Case – 2 Variation between Froude No. with sequent depth ratio

with varying spacing at Block height 3.5 cm]

Figure no. 4.37 is based on the observations shown in all table of case 2, by which a graph plotted between Froude No. (F_{r_1}) and Y_2/Y_1 (exp.) of all the conditions of case 2. From the figure it was observed that with increase in Froude no., sequent depth ratio also increases rapidly with their relative spacing.

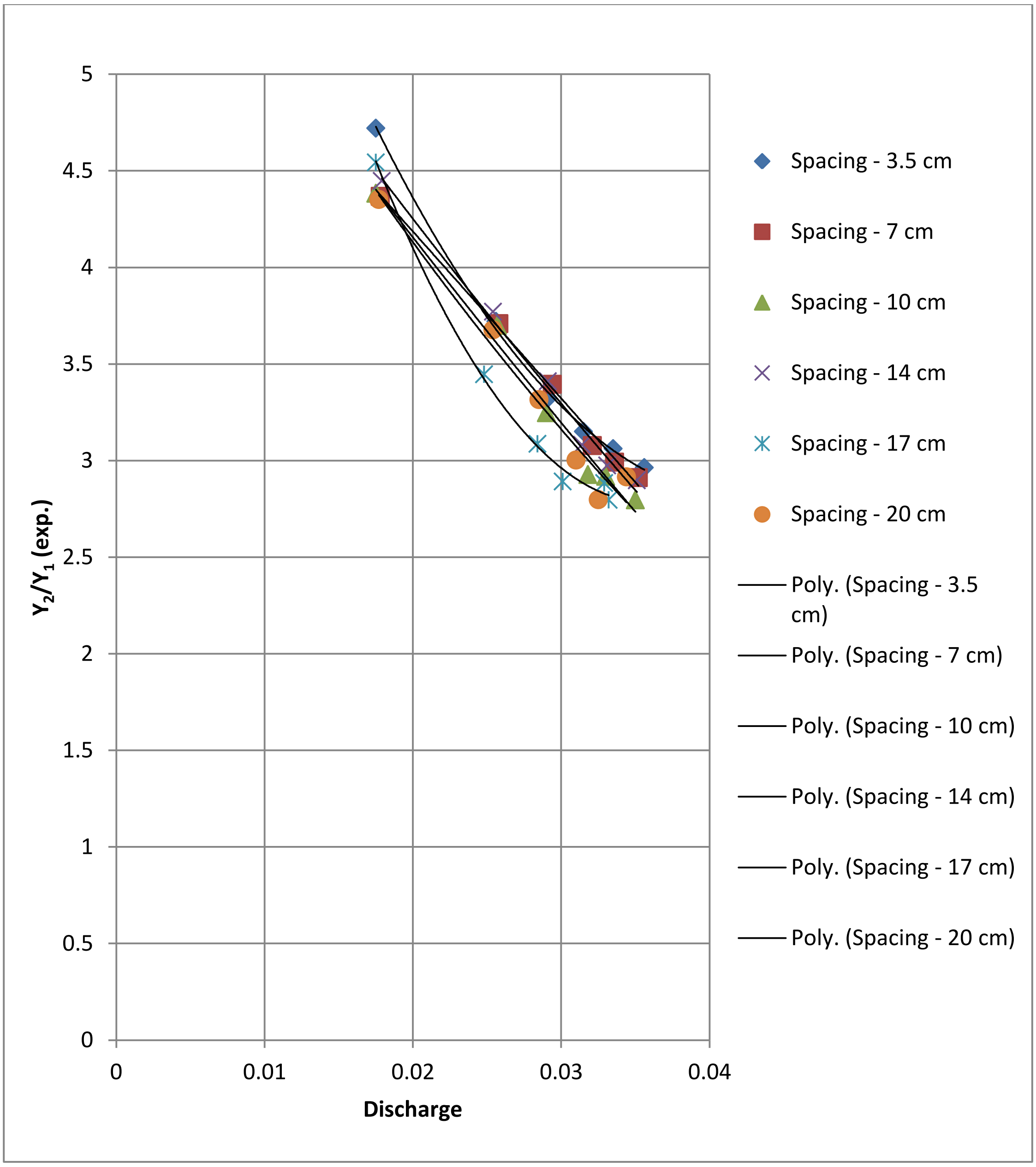


Figure 4.38 – Discharge and Y_2/Y_1 (exp.)

[Case – 2 Variation between Discharges with sequent depth ratio

with varying spacing at Block height 3.5 cm]

Figure no. 4.38 is based on the observations shown in all table of case 2, by which graph is plotted between discharge and Y_2/Y_1 (exp.) of all the conditions of case 2. From the figure it was observed that with increase in discharge, sequent depth ratio decreases with their relative spacing.

CONCLUSION

From the above results and discussions the following conclusion are drawn,

- As the height of block increased, the sequent depth ratio (exp.) is rapidly increases with increase in Froude No. in both the cases.
- With increase in discharge, the sequent depth ratio (exp.) decreases in both the cases.
- In condition 5 of case 1 when the spacing is increase (fig. 4.17), it was observed that the slope of line decreases when compared to the other conditions of case1.
- With increase in Froude no. the sequent depth ratio (Theo. & exp.) also increases in both the cases.
- Figure no. 4.37 show that the slope of curve also increases by increases height of roughness.
- When the combined graph (fig. 4.17) plotted between Froude no. the sequent depth ratio (exp.) showed a slight variation in slope of curve of different conditions of case1.
- When the plots of experimental observations of sequent depth ratio were compared with the theoretical values of all the conditions, it was found that the experimental results are more approximate to those obtained theoretically.

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