EFFECT OF CHANNEL SLOPE ON HYDRAULIC JUMP CHARACTERISTICS OVER ROUGH BED

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
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ROLL No. 2K14/HFE/09

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JUNE 2016

CERTIFICATE

This is to certify that thesis report entitled "**EFFECT OF CHANNEL SLOPE ON HYDRALIC JUMP CHARACTERISTICS OVER ROUGH BED**" 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.

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

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CANDIDATE DECLARATION

I hereby certify that the work that is being presented in this **MAJOR PROJECT REPORT**, entitled "EFFECT OF CHANNEL SLOPE ON HYDRAULICS JUMP CHARACTERISTICS OVER ROUGH BED" 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 Civil Engineering, Delhi Technological University India, is an authentic record of my work carried out till the month of June, 2016, 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 **KUNDAN KUMAR**

Date: JUN, 2016 ROLL NO. : **2K14/HFE/09**

ACKNOWLEDGEMENT

The culmination of this MAJOR PROJECT REPORT on the “EFFECT OF CHANNEL SLOPE ON HYDRAULICS JUMP CHARACTERISTICS OVER ROUGH BED“ 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.

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Place: Delhi **KUNDAN KUMAR**

Date: JUN, 2016 ROLL NO. 2K14/HFE/09

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NOTATIONS

The following symbols are used;

A = area of flume

B = width of flume

Fr1 = Froude number at super critical flow

Fr2 = 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 (Q/B)

Q = Discharge

v = velocity of flow

y = Depth of flow

ABSTRACT

Hydraulic jump mainly serves as an energy dissipater to dissipate excess energy of flowing water downstream of hydraulic structures, such as spillway, sluice gates etc. Present study investigate the effect of channel slope on the characteristics of free hydraulic jump and the energy dissipation downstream the gate. Study of jump has been done upon five different slopes -0.00175, -0.00349, -0.00419 and -0.00524 including horizontal bed in two cases of rough and smooth bed. The experimental program was conducted on a rectangular flume with 4.0 m long, 30 cm wide and 40 cm deep. A series of 80 experimental run were carried out in a rectangular flume which consists of artificially roughened beds formed by placing rectangular wooden strips in specific intervals. The hydraulic parameters such as, initial water depth, sequent water depth, and flow rate were measured for different bed roughness. The analysis of experimental data showed that the Sequent depth ratio and the length of jump upon smooth bed has been less than rough bed for the same slopes and Froude numbers which decreases with increase in the slope. Also comparison with energy loss, more energy loss has occurred upon rough bed than smooth bed.

CHAPTER - 1

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INTRODUCTION

1.1 Hydraulic Jump

Hydraulic jump in a rectangular channel is a natural phenomenon that occurs when the flow changes from supercritical to subcritical flow. 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.

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

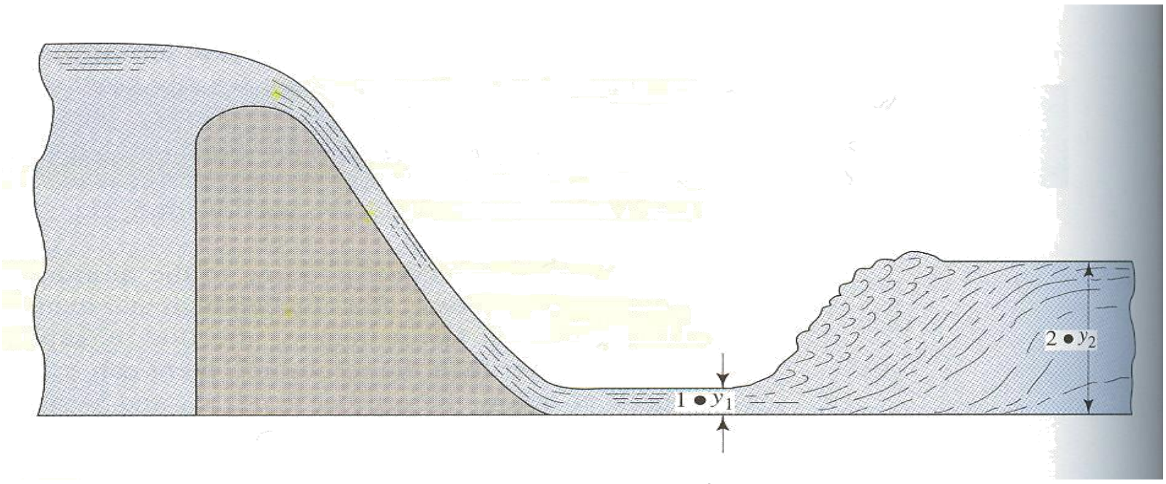
The occurrence of hydraulic jump is dependent upon the initially fluid speed .If the beginning speed of the fluid is below the critical speed, and then their no jump is possible. For beginning speed of flow which is not appreciably above the critical speed, the transition seems as an undulating wave.

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

Figure 1.2: Flow over a weir

At section 1(y1) flow – supercritical flow

At section 2 (y2) flow – subcritical flow

$$\frac{Y2}{Y1} = \frac{1}{2} \times \left[\sqrt{1+8F^2} - 1\right]$$

Where,

At section 1(Y_1) = sequent depth at section 1

At section 2(Y_2) = sequent depth at section 2

F_{r1}= 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;

$$Fr1 = \frac{V1}{\sqrt{gy1}}$$

1.4 (a) Undular jump ($1<F_{r1}<1.7$)

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

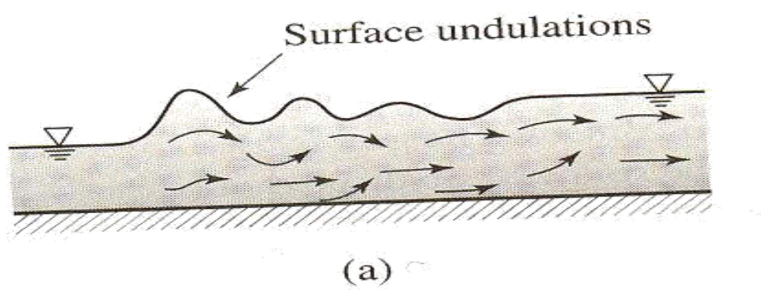


Figure 1.3: Undular jump

(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 ($1.7<F_{r1}<2.5$)

- 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.

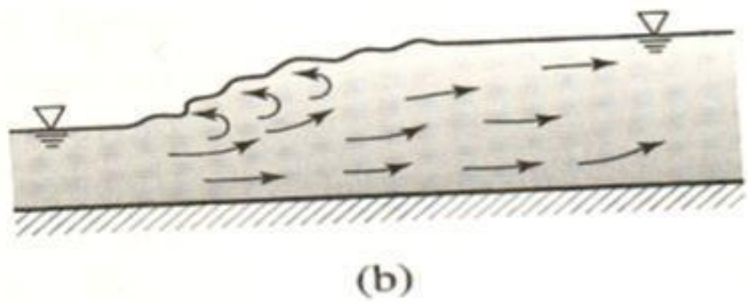


Figure 1.4: Weak jump

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 ($2.5 <F_{r1}<4.5$)

- 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.

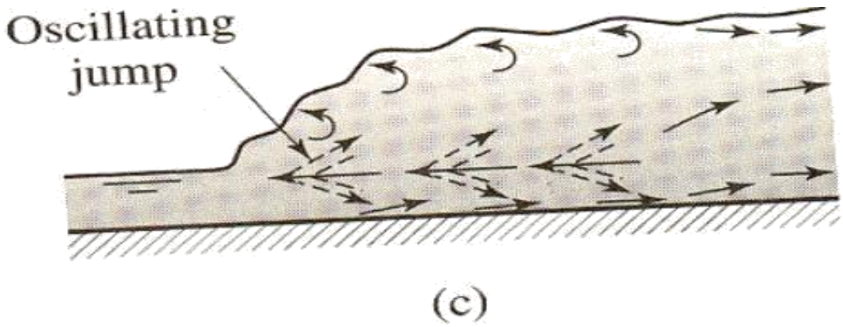


Figure 1.5: Oscillating jump

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 ($4.5<F_{r1}<9$)

- 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.

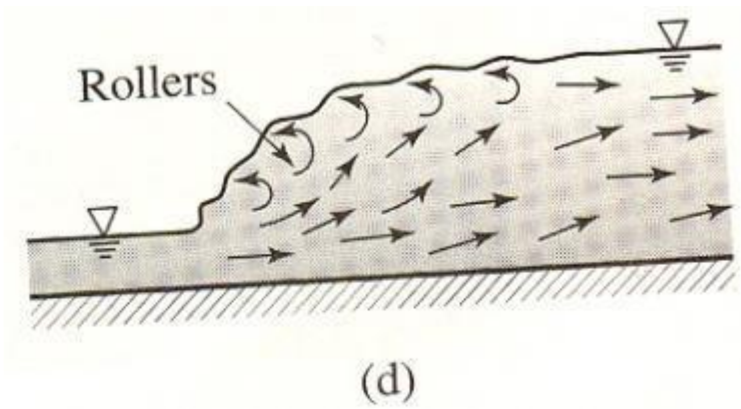


Figure 1.6: Stable jump

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 ($F_r > 9$)

- This type of Jump is become growingly rough.
- The value of Froude no. Fr1 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.

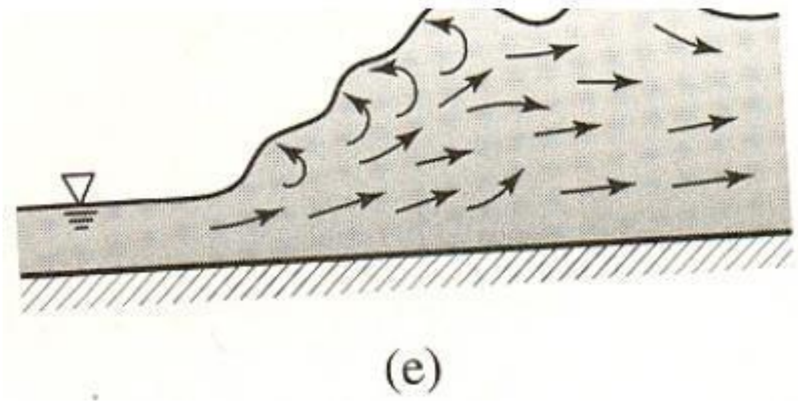


Figure 1.7: Strong jump

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

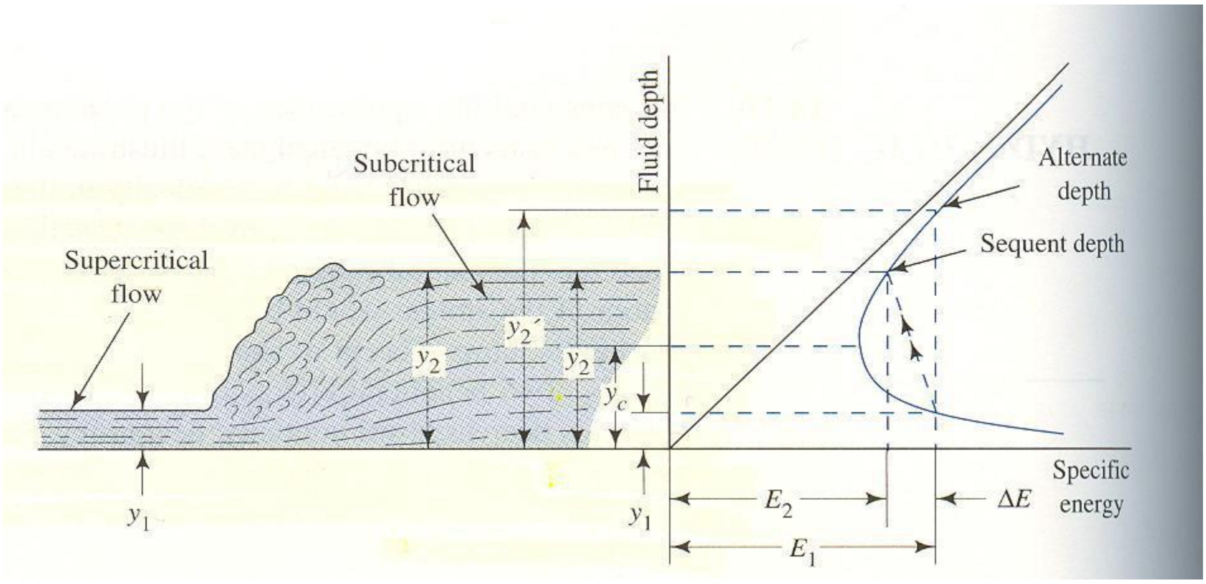


Figure 1.8: Specific energy diagram

Loss of energy :

$$E1 - E2 = \frac{(Y2 - Y1)^3}{4Y1 \times Y2}$$

Total energy of flow referred to datum head is given as

$$E = z + y + v^2/2g$$

Where, y = depth of flow liquid

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

z = datum head

- Theoretical depth after jump – alternate depth
- Actual depth after jump – sequent depth
- Length of jump – varies – but about 6.1 times the sub critical depth.

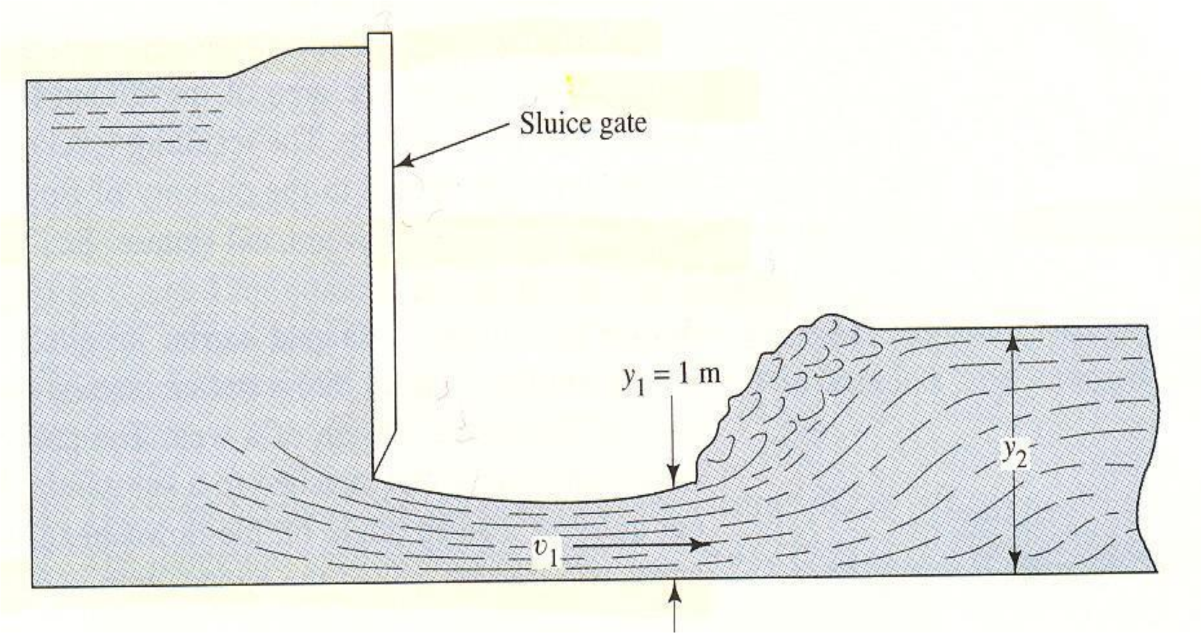


Figure 1.9: Sluice gate diagram

- **Height of jump**: Height of jump is the difference in between the pre jump depth and post jump depth.
- **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 or pre jump depth and depth of flow after the jump is known as post jump depth.

1.6 Objective of the work

Baffle blocks and sills are common accessory devices which are used in order to stabilize the location of a hydraulic jump and shorten the length of a stilling basin, so design of stilling basin becomes economical. On the other hand, strip roughness elements which cover the entire length of a basin may be an alternative. This study is to determine the effects of slope and roughness elements on the characteristics of hydraulic jumps such as conjugate depth ratio, jump length and energy dissipation.

For sake of safety of hydraulic structures such as dams and barrages, sluice-gates and draft tubes of hydraulic turbines, a considerable portion of the kinetic energy in supercritical flow must be dissipated to prevent scour.

The main objective of this work is to study out the effect of slope the on the characteristics of hydraulic jump for both smooth as well as rough 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 and slope 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.

1.7 Overview of the work

In this project I performed experiments in hydraulic flume in order to decrease the length of jump and increase the energy loss which leads to decrease length of stilling basin which make it economical. In first case experiment are performed on smooth bed for different discharges then increase the inclination of slope (adverse) and corresponding readings taken. Further bed is roughened by rectangular blocks and readings are taken for different discharges. Total 80 experimental run carried out and observed the different hydraulic jump properties such as sequent depth, length of jump, flow velocity, energy loss etc. Lastly graphs are plotted between initial Froude number and sequent depth ratio, length of jump and energy loss for both smooth and rough bed and all cases are compared.

CHAPTER - 2

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Literature review

Introduction

Hydraulic jump occurs when a high velocity supercritical flow drops to that of a subcritical flow, the rapid following flow is abruptly slowed and increases its height, converting some of the kinetic energy into potential energy. The condition of occurrence of a hydraulic jump is to change flow suddenly from supercritical flow (low depth with high velocity) to subcritical flow (high depth with a low velocity), Chow. It occurs in a canal below a regulating sluice, at the toe of a spillway or at the place where a steep channel slope suddenly turns flat. However, some of the recent work defines this change as a transitory process where the supercritical state transforms into the subcritical in a finite distance or a "transition zone."

The study of various papers represents the results of various studies in which the hydraulic jump characteristics were measured in different channel bed conditions, and suggests future research directions. Numerous studies have been conducted to investigate the hydraulic jump characteristics considering the different bed conditions some equations have been developed to establish the relationship between different parameters of hydraulic jump. The available literature on the characteristics of hydraulic jump on different types of roughened or corrugated beds is as follows.

Neveen B. Abdel Mageed (2015) performed a study on "Effect of Channel Slope on Hydraulic Jump Characteristics" This research paper investigates the effect of channel slope on the characteristics of free hydraulic jump and the energy dissipation downstream the gate. The experimental program was conducted on a re-circulating flume with 2.5 m long, 9 cm wide and 30 cm deep; with discharges range from The experiments were carried out mainly by using five different gate opening of 1, 1.5, 2, 2.5, and 3 cm. Five positive bottom slopes, So were used. Five slopes (0.0027, 0.004, 0.0054, 0.0081, and 0.011) were used in the experimental. Four different flow rates ranged from 90 to 150 LPM were used for each particular conduit height and bottom slope. The initial Froude number ranged from 1.2 to 4.6.

A total of 80 experiments were conducted. Statistical equation was developed to correlate the length, sequent depth ratio and distance of jump with the other independent parameters. It was found that the bottom slope "So", and the inlet Froude number Fr1, have major effect on the variations of the jump outlet characteristics. The sequent depth ratio increases with increase in approach Froude number and slope of the channel bed. The increase of Froude number by 100% the relative sequent depth increases by 85%. At same Froude number the increase of channel slope causes increase of the relative depth. The relative energy loss increases non-linear with increase Froude number and slope of the channel bed. The hydraulic jump length increases by 80% as increase of sequent depth by 100%. For same sequent length the hydraulic jump length increase by decreases the slope of the channel bed. The relative length of the jump increases with increase in approach Froude number and slope of the channel bed. The relative distance of the jump increases with increase in approach Froude number and slope of the channel bed.. The developed experimental computational models are applicable between Froude numbers from 1.2 to 4.6.

N.G.P.B. Neluwala, K.T.S. Karunanayake, K.B.G.M. Sandaruwan and K.P.P. Pathirana, (2013), This research attempts to investigate the “Characteristics of Hydraulic Jumps over Rough Beds, horizontal channel beds under different flow conditions using laboratory investigations. A series of experiments were carried out in a rectangular flume which consists of artificially roughened beds formed by placing rectangular wooden strips in specific intervals. 140 experimental runs were conducted for rough channel beds covering the flow rates from 8 to25 *l/s.* The hydraulic parameters such as, initial water depth, sequent water depth, and flow rate were measured for different bed roughness’s. The analysis of experimental data showed that the rough bed reduces the distance to the jump from the gate and the sequent depth ratio than those on smooth beds while creating a high energy loss. With the availability of a large number of experimental data on hydraulic jumps over rough channel beds, mathematical formulations were developed to express the hydraulic jump characteristics relating roughness parameters such as; roughness density and roughness height. A new parameter called ‘roughness density’ (*d* = width of roughness element /Spacing) was included into the analysis to represent the roughness spacing. Maximum effect of roughness elements occurred at a roughness density of 0.23. At this stage the sequent depth ratio reduced up to 34%.

Mainly focussed on the parameter roughness density in this paper and concluded that for artificially roughened beds jump characteristics are function of Froude number, roughness height and roughness density.

H.M. Imran, Shatirah Akib, (2013) present paper on “A review of hydraulic jump properties in different channel bed conditions”. The hydraulic jump properties including different types of corrugated and roughened beds. Hydraulic jumps are frequently used for excessive kinetic energy dissipation under hydraulic structures and the jumps are often generated with the assistant of baffle blocks and kept inside the stilling basin. Corrugated and roughened beds showed considerable energy dissipation at the downstream. The jump length and sequent depth also significantly reduced with respect to the smooth bed. Consequently, the use of corrugated and roughened beds reduced the scouring length and scouring depth as well as the stilling basin installation cost. This paper discusses the implications of corrugated and roughened beds, and highlights their findings in different installation systems by many researchers. Finally, it is found that the applications of corrugated and roughened beds are always showed better performance than that of the smooth bed.

Among the semi-circular, rectangular, trapezoidal and triangular corrugated beds, the most efficient corrugated bed was the triangular shaped for reducing the sequent depth and jump length. Conversely, it showed the best effectiveness for increasing the bed shear stress.

Generally, corrugated bed produced more eddies, and, consequently, increased the bed shear stress, which reduced the jump length and sequent depth. The hydraulic jump length and sequent depth are significantly reduced by bed shear stress, which is dependent on the interaction between the supercritical flow of liquid and the corrugations of the channel bed.

The effect of larger size boulders used as a roughened bed material can be investigated for hydraulic jump properties. Future studies can be carried out to evaluate the hydraulic jump characteristics on sloping bed conditions. A new circular shape corrugated bed channel is proposed for further study to investigate the hydraulic jump characteristics. More extensive investigations are recommended to determine the detailed information concerning the effects of boundary roughness on hydraulic jump.

Elnikhely (2014) performed a study on “Effect of staggered roughness element on flow characteristics in rectangular channel”. Flow characteristics are measured experimentally on an artificially roughened bed in a horizontal flume. The pattern; of roughness are staggered arrangements. The water surface profile is recorded at different sections. This paper investigated the effects of using fiberglass sheets as roughness elements for staggered arrangement, on different flow characteristics. Compared to the smooth bed, it is observed that the roughness bed decreases the relative jump depth by 22%, increases the relative energy loss by 14%, and reduces the relative jump length by 8.1%. The experimental results achieved promising results regarding each of dissipating energy; the relative jump length as well as the relative jump depth in addition to the coefficient of discharge.

The relations between the initial Froude number; and each of the relative jump depth y2/y1; the relative jump length Lj/y1 and the relative energy loss for different roughened depths (Hr=0.5, 0.75, 1.0, and 1.5cm) are plotted. The case of staggered roughness elements of roughened depth (Hr=1.5 cm) achieves minimum values of y2/y1, reducing the average relative depth of the jump by 22% in comparison with the case of the smooth bed, It gives also the minimum values of the relative jump length Lj/y1, reducing the average relative length of the jump by 8.1% in comparison with the smooth bed, In addition, it gives the maximum values of the relative energy loss $\Delta E/E1$, increasing the average relative energy loss of the jump by 14%. The derived formulas for relative depth and the relative energy loss that satisfactorily agree with the experimental data are proposed. Prediction equations were developed using the multiple linear regression (MLR) to model the hydraulic jump characteristics. The jump characteristics have been improved as the relative depth of the roughness elements, Hr increased.

Deshpande Madhura Mahesh and Talegaonkar S.D. (2015)

The paper presents a broad review of the available literature on the characteristics of hydraulic jump on different types of roughened or corrugated beds and effect of slope. The main objective of this study is to examine the potential use of roughened or corrugated beds for reducing the hydraulic jump length, sequent depth, to study the effectiveness of corrugated bed for energy dissipation below hydraulic structures and to study the bed shear stress.. Corrugated or roughened beds showed considerable energy dissipation at the downstream. The jump length and sequent depth also significantly reduced with respect to the smooth bed. Consequently, the use of corrugated and roughened beds reduced the scouring length and scouring depth as well as the stilling basin installation cost. The implementation of corrugated or roughened beds, and highlights their findings in different installation systems by many researchers are discussed. Comparison between different roughened shapes with different dimensions and spacing is also discussed. Finally, it is found that the applications of corrugated or roughened beds are always showed better performance than that of the smooth bed.

Nowadays jump study upon sloping beds, especially adverse slopes, is important because of the length of jump and the energy loss. The results showed that the Sequent depth ratio and the length of jump upon smooth bed has been more than rough bed for the same slopes and

Froude numbers. Also comparison with percentage of the energy loss, more energy loss has occurred upon rough bed than smooth bed. Beirami studied the hydraulic jumps in sloping channels and showed that the negative slope of the basin reduces the sequent depth ratio, while a positive slope increases the sequent depth ratio.

Fahmy S. Abdelhaleem, Amin A.M. and Helal Y. Esam,(2012) perform a study on " Effect of Corrugated Bed Shapes on Hydraulic Jump and Downstream Local Scour" this research, an experimental study was conducted to study the effect of using three different shapes of corrugated beds on the characteristics of a hydraulic jump and downstream local scour. Forty eight experimental runs were carried out considering wide range of Froude numbers ranging from 2.0 to 6.5. For each discharge, four values of initial depth of hydraulic jumps are used so, three types of hydraulic jumps (weak, oscillating and steady) were investigated. Five values of the relative roughness of corrugated shapes were investigated. A case of smooth bed is included to estimate the influence of corrugated beds on hydraulic jump parameters and the scour hole dimensions.

The required tail water depths for jumps over different semi-circular, trapezoidal and triangular corrugated beds is respectively, 86%, 85.5% and 82.6% of the same variable for jump over smooth bed. So, triangular shape of corrugation has highly decreased the required tail water depth. The semi-circular, trapezoidal and triangular corrugated beds reduce the length of jump by 10%, 11% and 14%, respectively, For jumps of $F_{r1} \leq 3$, the corrugated bed shapes have small influence on the length of jump, The relative energy loss for smooth bed ranges from 10% to 62%, while, for semi-circular, trapezoidal and triangular corrugated beds ranges from 14% to 64%, 15% to 65% and 16% to 66%, respectively, Corrugation beds reduce the maximum scour length by a range from 17% to 30% and reduce the maximum scour depth by a range from 22% to 36% in comparison with the smooth bed, Triangular shape is the best corrugated shape among the investigated shapes, Obtained results were analysed and graphically presented and also, simple formulae are developed to estimate the hydraulic jump parameters and the scour hole dimensions. The results of this study confirm the effectiveness of corrugated beds for energy dissipation downstream hydraulic structures and corrugating the stilling bed can decrease the cost of stilling basins.

Deniz Velioglu, Nuray Denli Tokyay & Ali Ersin Dincer (2015) perform a study on "A numerical and experimental study on the characteristics of hydraulic jumps on rough beds" The objective of this study is to determine the effects of this type of roughness elements on the characteristics of hydraulic jumps such as conjugate depth ratio, jump length and energy dissipation. Experimental and numerical investigations both show that when strip rectangular bars are introduced to the channel bed, they have a positive effect on the characteristics of a hydraulic jump. The tail water depth reduction compared to classical jump is 19% and jump length is reduced by 20%. These roughness elements induce 2% more energy dissipation than that of classical jump. It is clear that, if height of the strip bars is increased, the reduction in tail water depth and jump length will be much more than the ones that are obtained in this study. Similarly the gain in the amount of dissipated energy will increase. The reliability of a CFD model, Flow 3D, is also tested and it is seen that Flow 3D gives satisfactory results regarding free surface flows and turbulence models. In future studies, different arrangements of rectangular roughness elements may be investigated. It might also be useful to study the effects of roughness elements on hydraulic jumps formed in trapezoidal channels. The study is carried out using experimental data and a computational fluid dynamics (CFD) model, namely Flow 3D. In the first phase of the study, the experimental data are compared with Flow 3D results in order to assess the sensitivity of the code. In the second phase, several investigations are made to determine whether strip roughness elements are effective on the characteristics of hydraulic jumps or not. The results show that strip roughness elements have positive effects on the characteristics of hydraulic jumps. The tail water depth reduction compared to classical jump is 18-20%. The length of the jump is reduced about by 20-25%. This type of roughness elements induce 2-3% more energy dissipation than that of a classical jump. Therefore, strip bed roughness elements may be considered as an alternative for baffle blocks and sills.

Carollo, F.G., Ferro,V.and Pampalone (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. The grain-size distributions were characterized by D50=0.46, 0.82, 1.46, 2.39, and 3.20 cm, D50 being the diameter of the bed particles for which 50% are finer. The median diameter D50 was used as roughness height *ks*. Hydraulic jump characteristics were measured in a horizontal rectangular flume in which the bed was artificially roughened by closely packed crushed gravel particles cemented to the bottom and having five different

values of the roughness height. The measurements carried out for the smooth bed were in agreement with Bresse's equation. For the rough bed, the laboratory observations showed that boundary roughness reduces the sequent depth ratio. For a given approach flow Froude number F1, the sequent depth ratio $h2$ /$h1$ decreases as the bed roughness increases. For a given finite roughness height, the reduction of the sequent depth ratio increases with F1.
Using the present measurements 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.

Andrea Defina, Francesca Maria Susin and Daniele Pietro Viero,(2008) perform a experiment on "Bed friction effects on the stability of a stationary hydraulic jump in a rectangular upward sloping channel" The issue of the bed friction effect on the stability of a stationary hydraulic jump in a rectangular upward sloping channel is investigated through a combined theoretical and experimental approach. The slope of the ramp was tan ∅=0.04 with respect to the floor of the channel The theoretical stability criterion proposed generalized to include rough wall flows. The results of an extensive series of experiments are then presented. The adopted experimental procedure is detailed, and results are compared with theoretical predictions. It is shown that the proposed stability criterion successfully predicts both the stable and unstable behaviour of the jump for smooth and rough wall flow, at least in the range of small upward bottom slopes.

Firoz parvizyan Gange, Amirreza Bahrebar, Hossien Azarpayvand,Faride bahrebar, Farzane barati ,Moslem momeni (2004) carried out an experiment on "Effects of continuous triangular roughness's on the hydraulic jump characteristics in horizontal Stilling basin'' Since dimensions of these structures are directly dependent on characteristics of the hydraulic jump therefore to make them economical many wide surveys have been conducted on characteristics of hydraulic jump and how to control them or minimize their dimensions. For example in the recent years it has been suggested that continuous roughness of the Stilling basin could be effective in reducing jump dimensions. This study has been performed by considering this assumption and it is tried to determine level and type of this effect using laboratory experiments. triangular roughness's with a width of 35 cm were studied in three different spaces (t=4, 8, 12) and in each height four different spaces between blocks are considered for incoming supercritical flow. It was shown that compare to flat beds there is 15-fold shear force on rough beds so that generally 4 values were obtained for the roughness's space-height ratio. S/t=1, 0/5, 0.33). To achieve this aim various experiments were performed for input numbers ranging 5-12.5 in flume that is 35 cm wide. In these experiments triangular roughness's and their combination were installed and tested in the floor of flume in such a way that upper surface of roughness's and spillway crest are on the same level and some parameters like flow rate, roller length, first depth, secondary depth, jump length , water surface profile were measured. Analysis of data showed that roughness's decrease jump length to moderate size of 57% and provide about 20% decrease in secondary depth of jump than classic type. This decrease can be caused by increase in flow turbulences level between roughnesses that causes approximately 13-fold increase in shear stress.

CHAPTER - 3

CHAPTER – 3

Methodology

3.1 Method of work

In this work, we studied the effect of hydraulic jump on smooth horizontal bed without and with roughness for different slopes and observed all the required parameters. Then the observations are recorded at each set by changing the spacing of wooden blocks. Recorded observation are compared to know that which is more effective.

In this experimental work wooden blocks 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.

Size of wooden blocks is **30 × 0.5 × 2.5cm** with a spacing of **7.5 cm and 10 cm**.

3.2 Experimental set up

The set-up of the experiment includes:

- A 4 meter long flume.
- Current Meter for measurement of velocity.
- Wooden block of sizes (for roughness creation)
- Adhesive material for the fixing of wooden blocks.
- Water collecting tank.
- Bucket and measuring cylinder.
- 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 4 meter in length, 30cm width and 40cm 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.

The first set of observation on smooth bed is taken. For this flow of water allowed through the flume and sluice gate is adjusted in such a manner that the water level becomes steady at upstream side now the tail gate is adjusted to form the hydraulic jump in flume. Position of hydraulic jump can be changed by adjusting the tail gate and upstream sluice gate. The observations are recorded. In this firstly we have taken the flow depth at up-stream side before jump with point gauge by just touch the pointer at the surface of water. Bed readings at various points are 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 “Y1” and the sub-critical depth of flow is “Y2”.

In between super-critical flow depth i.e. “Y1” and sub-critical flow depth i.e. “Y2” a jump is formed, y_1 from where the jump is start forming to the 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 is measured by current meter which is pygmi type vertical axis current meter. Current meter gives the revolution per second reading for given velocity of flow for a particular depth of flow. Four readings are taken for different flow rate for a constant time interval of 60 seconds which is further used to find velocity for given flow by calibration chart of the current meter. Also approximate technique to estimate velocity by bucket collecting and paper float technique is used in each analysis. 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 and length of jump, current meter readings are recorded. Now again changed the discharge for the third set of observation, and noted down all the parameters which are mentioned above are recorded. The process is repeated by changing several different discharges and the relevant parameters are recorded for the smooth bed condition.

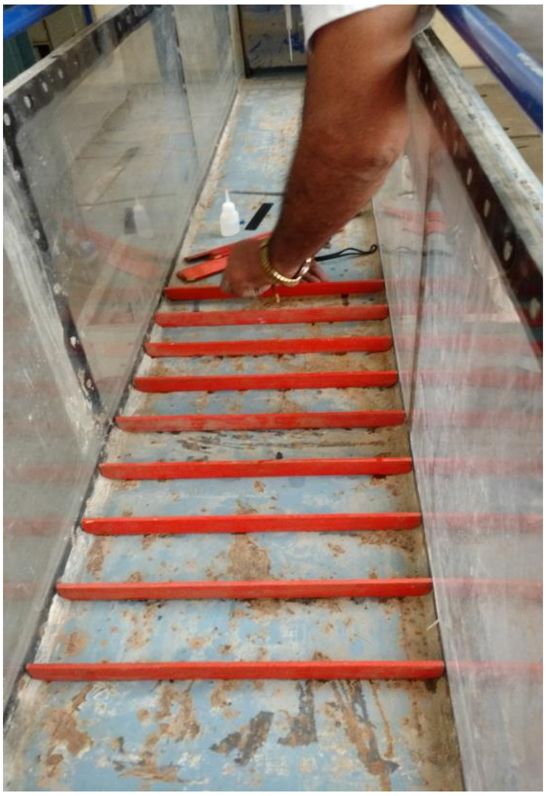
Fig. 3.1 Hydraulic Flume

Now for 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, and 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 adhesive material is used to fix these blocks.

The blocks are fixed at a spacing of 7.5cm. After its fixing finally checked all the blocks are fixed properly and arranged at the given spacing and no one is loose. 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.

Then all the important parameters i.e. sequent depth and at section 1 and 2, length of jump, velocity of flow by current meter 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 change the slope of horizontal bed and record all the parameters for different discharges. For five different slopes readings are taken.



<u>Fig. 3.2 Fixing of rectangular block</u>

Then for next set of reading the spacing are changed in between the wooden blocks. Then the above procedure is repeated for taken the observation at different discharges.

By the given procedure, the observations at different spacing in between the wooden blocks as 7.5 cm and 10 cm at the varying discharge are recorded for different slopes.

Fig. 3.3 Hydraulic Flume (Top view)

3.3 Calculation:

TOTAL DISCHARGE CALCULATION METHODS FOR CUURENT METER

GENERAL

There are three commonly used methods of calculating total discharge. The Velocity Curve method is the most accurate, the slowest and the most complicated. The Two-Point and the Six-Tenths methods are the most commonly used. Of the three, the Two-Point method should be used wherever possible because of its favourable balance of accuracy and speed.

VELOCITY CURVE METHOD

This method involves taking as many readings as possible at as many different depths as possible along the entire vertical cross-section and averaging all the readings to determine the mean velocity. This method can be quite complex and can require literally hundreds of readings for larger bodies of water. The Velocity Curve Method should only be used when absolute accuracy is required and time is no concern.

TWO-POINT METHOD

When using the Two-Point Method, measurements are taken at pre-determined points to find the mean velocity. Measurements are taken at 20% and 80% of water surface to bottom distance. The average of these two readings is taken as mean velocity of vertical cross-section. Experience has shown that this method renders more accurate results than any other method except the Velocity Curve Method.

Note: The Two-Point Method should not be used in water less than 2.5 feet (76.2cm) deep.

SIX-TENTHS METHOD

The velocity of water at a point six-tenths of the distance from the surface to the bottom very closely approximates the mean velocity of the entire vertical cross-section, making it possible to gather relatively accurate data by taking only one measurement in a particular vertical cross-section. Position the current meter at six-tenths of the water depth (four-tenths from bottom).

The Sixth-Tenths Method gives reliable results under several conditions:

- When the water depth less than 76.2cm.
- When large volume of slush, ice, debris is flotsam make the Two-Point Method impossible.

- When quick measurements are required.

CONVERTING CURRENT METER DATA TO FLOW VELOCITY

Use the English or Metric table furnished with the Current Meter to convert raw data to current velocity (See Rating Tables).

As an example:

- 100 pulses (revolutions of the bucket wheel) are counted in 60 seconds.
- Using the English Rating Table locate 100 (revolutions) on the top line and 60 (seconds) in the vertical column.
- These two values intercept at water velocity of 1.66fps.

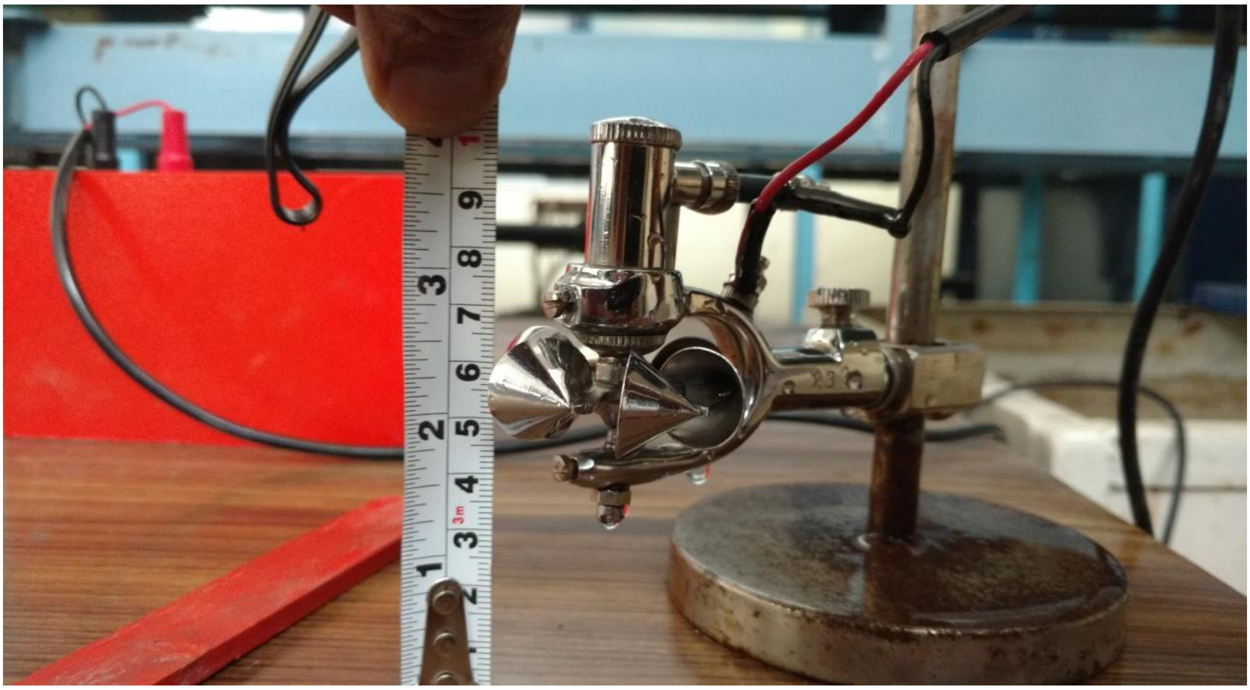


Fig. 3.4 Current meter

For current meter velocity V is given:

V= axN + b

Where V = velocity in metre per second

N = number of revolution in seconds

a, b= constant

for calibration chart of current meter a=.3042 and b= 0.0397

then V = 0.3024N+0.0397

HYDRAULIC RESEARCH STATION, MALAKPUR (PATHANKOT)
CURRENT METER RATING TABLE

Type Pygmy Cup ,Number J.N. 15 ,Spin. 40 Seconds, Calibrated on 26/12/77
= R.P.S.

Equation V= 0.3024 N+ 0.0397 Single/~~Penta~~

Time in Seconds	VELOCITY IN METRE PER SECOND Revolutions 3	5	7	10	15	20	25	30	40	Time in Seconds
40	0.0624	0.0775	0.0926	0.1053	0.1531	0.1909	·2287	·2665	·3421	40
41	0.0618	·0766	0.0913	·1135	·1503	·1872	·2241	·2610	·3347	41
42	0.0613	·0757	·0901	·1117	·1477	·1837	·2197	·2556	·3277	42
43	0.0608	·0749	·0889	·1100	·1452	·1803	·2155	·2507	·3210	43
44	0.0603	·0741	·0878	·1084	·1428	·1771	·2115	·2459	·3146	44
45	0.0599	·0733	·0868	·1069	·1405	·1741	·2077	·2413	·3085	45
46	0.0594	·0726	·0857	·1054	·1383	·1712	·2041	·2369	·3027	46
47	0.0590	·0719	·0847	·1041	·1362	·1684	·2005	·2327	·2971	47
48	0.0586	·0712	·0838	·1027	·1342	·1657	·1972	·2287	·2917	48
49	0.0582	·0705	·0829	·1014	·1323	·1631	·1940	·2248	·2865	49
50	0.0518	·0699	·0820	·1002	·1304	·1607	·1909	·2211	·2816	50
51	0.0575	·0693	·0812	·0990	·1286	·1583	·1879	·2176	·2769	51
52	·0571	·0688	·0804	·0979	·1269	·1560	·1851	·2142	·2723	52
53	·0568	·0682	·0796	·0968	·1253	·1538	·1823	·2109	·2679	53
54	·0565	·0677	·0789	·0957	·1237	·1517	·1797	·2077	·2637	54
55	·0562	·0672	·0782	·0947	·1222	·1497	·1772	·2047	·2596	55
56	·0559	·0667	·0775	·0937	·1207	·1477	·1747	·2017	·2557	56
57	·0556	·0662	·0768	·0927	·1193	·1458	·1723	·1989	·2519	57
58	·0553	·0658	·0762	·0918	·1179	·1440	·1700	·1961	·2482	58
59	·0551	·0653	·0756	·0910	·1166	·1422	·1678	·1935	·2447	59
60	·0548	·0649	·0750	·0901	·1153	·1405	·1657	·1909	·2413	
61	·0546	·0645	·0744	·0893	·1141	·1387	·1636	·1884	·2380	61
62	·0543	·0641	·0738	·0885	·1129	·1373	·1616	·1860	·2348	62
63	·0541	·0635	·0733	·0877	·1117	·1357	·1597	·1837	·2317	63
64	·0539	·0633	·0728	·0870	·1106	·1342	·1578	·1815	·2287	64
65	·0537	·0630	·0723	·0862	·1095	·1327	·1560	·1793	·2258	65
66	·0535	·0626	·0718	·0855	·1084	·1313	·1542	·1772	·2230	66
67	·0532	·0623	·0713	·0848	·1074	·1300	·1525	·1751	·2202	67
68	·0530	·0619	·0708	·0842	·1064	·1286	·1508	·1731	·2176	68
69	·0529	·0616	·0704	·0835	·1054	·1274	·1493	·1712	·2150	69
70	·0527	·0613	·0699	·0829	·1045	·1261	·1477	·1693	·2125	
	3	5	7	10	15	20	25	30	40	

Hydraulic Officer   Asstt Research Officer   Research Assistant

HYDRAULIC RESEARCH STATION, MALAKPUR (PATHANKOT)
CURRENT METER RATING TABLE

Type Pigmy Cup, Number J.N.15, Spin, 40 Seconds, Calibrated on 26/12/77

Equation V= 0.3024 N+ 0.0397 (a = 0.3024, b = 0.0397) Single/~~Penta~~

VELOCITY IN METRE PER SECOND.

Time in Seconds	Revolutions 3 / 50	5 / 60	7 / 70	10 / 80	15 / 90	20 / 100	25 / 150	30 / 200	40 / 250	Time in Seconds
40	.4177	.4933	.5689	.6445	.7201	.7957	1.1737	1.5517	1.9298	40
41	.4085	.4822	.5560	.6297	.7035	.7773	1.1460	1.5148	1.8836	41
42	.3997	.4717	.5437	.6157	.6877	.7597	1.1197	1.4797	1.8397	42
43	.3913	.4617	.5320	.6023	.6726	.7430	1.0946	1.4462	1.7978	43
44	.3833	.4521	.5208	.5895	.6282	.7270	1.0706	1.4142	1.7579	44
45	.3757	.4429	.5101	.5773	.6445	.7117	1.0477	1.3837	1.7197	45
46	.3684	.4341	.4999	.5656	.6313	.6971	1.0258	1.3545	1.6832	46
47	.3614	.4257	.4901	.5544	.6188	.6831	1.0048	1.3265	1.6482	47
48	.3547	.4177	.4807	.5437	.6067	.6697	0.9847	1.2997	1.6147	48
49	.3483	.4100	.4717	.5334	.5951	.6568	0.9654	1.2740	1.5826	49
50	.3421	.4026	.4631	.5235	.5840	.6445	0.9469	1.2493	1.5517	50
51	.3361	.3955	.4518	.5140	.5733	.6326	0.9291	1.2256	1.5221	51
52	.3305	.3856	.4468	.5049	.5631	.6212	0.9120	1.2028	1.4935	52
53	.3250	.3820	.4391	.4961	.5532	.6103	0.8955	1.1808	1.4661	53
54	.3197	.3757	.4317	.4877	.5437	.5997	0.8797	1.1597	1.4397	54
55	.3146	.3696	.4246	.4796	.5345	.5895	0.8644	1.1393	1.4142	55
56	.3097	.3637	.4177	.4717	.5257	.5797	0.8497	1.1197	1.3897	56
57	.3050	.3580	.4111	.4641	.5172	.5702	0.3355	1.1008	1.3660	57
58	.3004	.3525	.4047	.4568	.5089	.5611	0.8218	1.0825	1.3431	58
59	.2960	.3572	.3985	.4497	.5010	.5522	0.8085	1.0648	1.3211	59
60	.2917	.3421	.3925	.4429	.4933	.5437	0.7957	1.0477	1.2997	
61	.2876	.3371	.3867	.4363	.4859	.5354	0.7833	1.0312	1.2790	61
62	.2836	.3323	.3811	.4299	.4787	.5274	0.7713	1.0152	1.2591	62
63	.2797	.3277	.3757	.4237	.4717	.5197	0.7597	0.9997	1.2397	63
64	.2760	.3232	.3705	.4177	.4650	.5122	0.7485	0.9847	1.2210	64
65	.2723	.3188	.3654	.4119	.4584	.5049	0.7375	0.9702	1.2028	65
66	.2688	.3146	.3604	.4063	.4521	.4979	0.7270	0.9561	1.1852	66
67	.2654	.3105	.3556	.4008	.4459	.4910	0.7167	0.4424	1.1681	67
68	.2621	.3065	.3510	.3955	.4399	.4844	0.7068	0.9291	1.1515	68
69	.2588	.3027	.3465	.3903	.4342	.4780	0.6971	0.9162	1.1354	69
70	.2557	.2989	.3421	.3853	.4282	.4717	0.6877	0.9037	1.1197	
	3	5	7	10	15	20	25	30	40	

Hydraulic Officer   Asstt Research Officer   Research Assistant.

3.4 Observations Tables

If Y_1 and V_1 are, respectively, the depth and mean velocity of the supercritical stream just upstream of the jump, with a Froude number of

$$Fr1 = \frac{V1}{\sqrt{gy1}}$$

where g is the acceleration due to gravity, the supercritical depth Y1 is given by the well-known Belanger equation

$$\frac{Y2}{Y1} = \frac{\sqrt{1 + 8F^2 - 1}}{2}$$

Energy loss: The loss of energy in the hydraulic jump is equal to the difference in specific energies before and after the jump. It can be shown that the loss is $\Delta E = E1\text{-}E2$, for smooth bed

$$\frac{\Delta E}{E1} = \frac{\left(\sqrt{1 + 8F^2} - 3\right)^3}{8(F^2 + 2)\left(\sqrt{1 + 8F^2} - 1\right)}$$

or

$$\Delta E = Y1 + \frac{V^2}{2g} - Y2 - \frac{V^2}{2g}$$

$$E1 = Y1 + \frac{V^2}{2g}$$

CHOW(1959) $Lj = 6.1 \times Y_2$

The ratio of the specific energy after the jump to that before the jump is defined as the efficiency of the jump. It can be shown that the efficiency is:

$$\frac{\Delta E}{E1} = \frac{1 - \frac{D2}{D1} + \frac{v1^2 - v2^2}{2gD1cos\theta} - \frac{Lj \times tan\theta}{D1}}{1 + \frac{v1^2}{2gD1cos\theta}}$$

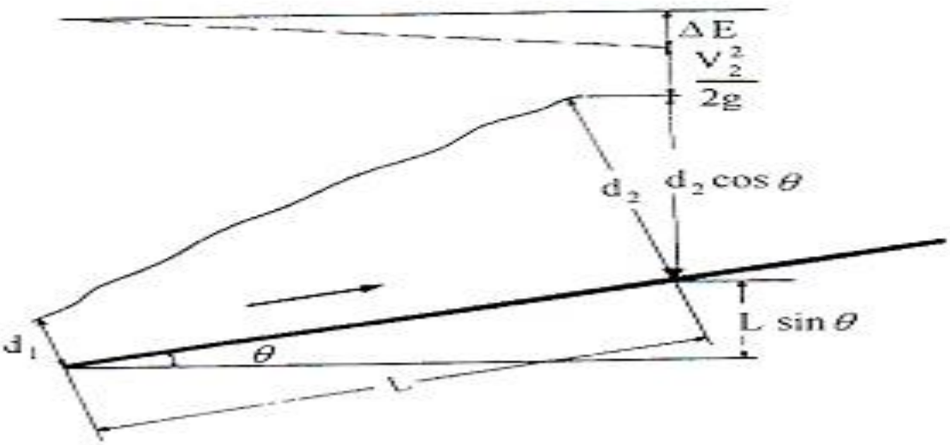


Fig. 3.5 Hydraulic jump in sloping channel

Where $D1 = Y_1\cos\Theta$, $D2 = Y_2\cos\Theta$ and *L*j is equal to length of jump. The ratio is known as the relative loss efficiency. This equation indicates that the efficiency of a jump is a dimensionless function, depending on the Froude number of the approaching flow.

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;

<u>For Smooth Horizontal Bed</u>

<u>CASE: 1 - 7.5 cm Spacing</u>

Table No. 1(A) – Jump on smooth horizontal bed

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.15	6.00	76	0.317	0.038	5.2	31.7	2.1	0.18
2.	1.21	7.50	67	0.246	0.030	6.2	37.8	2.4	0.24
3.	1.27	8.89	42	0.181	0.021	7.0	42.7	3.2	0.30
4.	1.34	11.3	36	0.156	0.018	8.4	51.2	3.8	0.33

Sample Calculation for S. No. (1)

$Y_1 = 1.15$ cm

$Y_2 = 6.00$ cm

V = 0.3024 x N+0.0397

V = .3024 x (35/60) +.0397

V = 0.216 m/s

Q = a x v = (b x y) x v

= 0.30 x 0.06 x 0.216

= 0.038 m3/s

q = Discharge per unit width = V x Y

$q = V_1 \times Y_1 = V_2 \times Y_2$

$V_1 = (Y_2/Y_2) \times V_2$

$Y_2/Y_1 = 6.00/1.15 = 5.2$

$V_1 = 0.216 \times 5.2 = 1.123$ m/s

$F_{r1} = V_1 / \sqrt{g}Y_1$

$= 1.123/\sqrt{(9.81 \times 0.15)}$

= 2.1

Lj/Y1 = 6.1 x Y2/Y1

= 6.1 x 5.2

= 31.7

$$\frac{\Delta E}{E1} = \frac{\left(\sqrt{1+8F^2}-3\right)^3}{8(F^2+2)\left(\sqrt{1+8F^2}-1\right)}$$

$\Delta E/E1 = (\sqrt{1+8 \times 2.1^2}-3)^3/8 \times (2.1^2+2) \times (\sqrt{1+8 \times 2.1^2}-1)$

= 0.18

Fig. 3.6 Hydraulic jump smooth bed

Table No. 1(B) – Jump on Rough horizontal bed

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.11	5.81	73	0.303	0.032	4.9	29.9	2.12	0.2
2.	1.21	6.25	57	0.223	0.026	5.2	31.7	2.44	0.26
3.	1.27	8.31	38	0.176	0.019	6.5	39.6	3.26	0.33
4.	1.34	10.05	31	0.145	0.016	7.5	45.7	3.85	0.38

Sample Calculation for S. No. (1)

Y_1 = 1.11 cm

Y_2 = 5.81 cm

V = 0.3024 x N+0.0397

V = .3024 x (73/60) +.0397

V = 0.303 m/s

~~Q = a~~ x v = (b x y) x v

= 0.30 x 0.0581 x 0.303

= 0.032 m3/s

q = Discharge per u~~nit w~~idth = V x Y

q = V_1 x Y_1 = V_2 x Y_2

V_1 = (Y_2/Y_2) x V_2

Y_2/Y_1 = 5.81/1.11 = 4.9

V_1 = 0.303 x 4.9= 1.485 m/s

F_{r1} = V_1 / $\sqrt{g}Y_1$

= 1.485/√(9.81 x 0.11)

= 2.12

Lj/Y1 = 6.1 x Y2/Y1

= 6.1 x 4.9

= 29.49

Table No. 2 (A) – Jump on smooth bed (Slope – 0.00175)

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.13	5.76	71	0.302	0.031	5.08	30.9	2.12	0.195
2.	1.19	8.33	54	0.220	0.025	5.8	35.4	2.44	0.22
3.	1.31	9.83	39	0.176	0.020	7.5	45.7	3.26	0.28
4.	1.35	10.8	34	0.148	0.018	8.0	48.8	3.85	0.35

Table No. 2 (B) – Jump on smooth bed (Slope – 0.00175)

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.03	4.91	70	0.300	0.031	4.75	28.9	2.1	0.22
2.	1.11	6.11	56	0.221	0.026	5.5	33.5	2.3	0.26
3.	1.27	8.14	35	0.172	0.018	6.4	39.0	3.2	0.35
4.	1.31	9.83	32	0.145	0.017	7.5	45.7	3.8	0.40

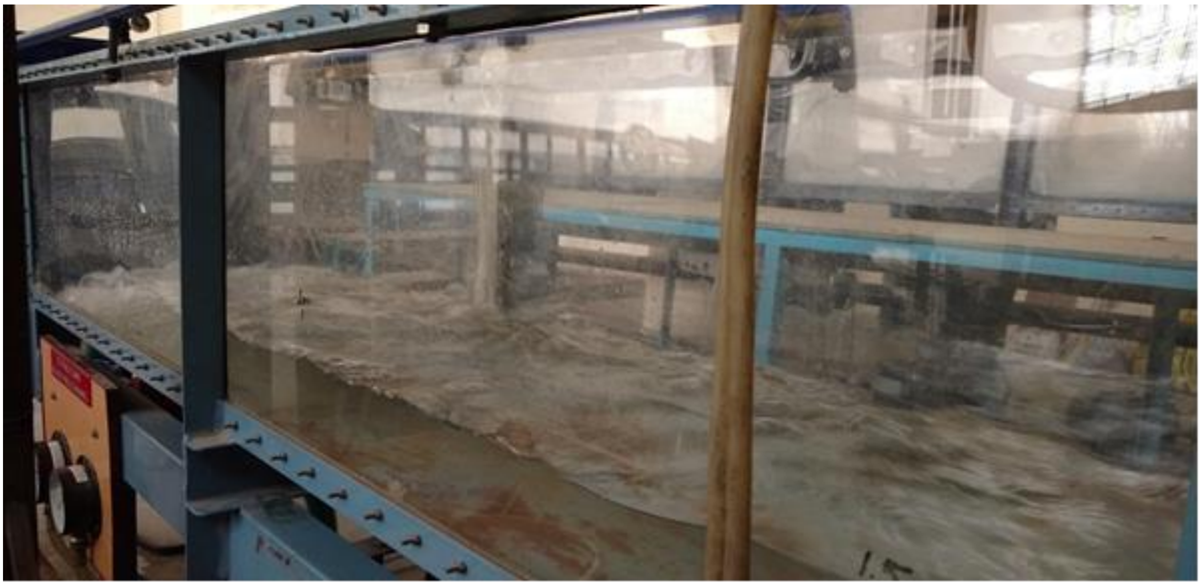


Fig. 3.7 Hydraulic jump post jump view

Table No. 3 (A) – Jump on smooth bed (Slope – 0.00349)

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.07	5.46	64	0.228	0.029	5.03	30.7	2.07	0.22
2.	1.20	6.91	50	0.198	0.021	5.76	35.1	2.35	0.24
3.	1.23	8.87	33	0.171	0.019	7.2	43.9	3.15	0.28
4.	1.34	10.45	33	0.171	0.017	7.8	47.6	3.78	0.35

Fig. 3.8 Hydraulic flume rough bed

Table No. 3 (B) – Jump on smooth bed (Slope – 0.00349)

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.04	4.87	62	0.227	0.028	4.67	28.5	2.10	0.24
2.	1.17	6.31	50	0.198	0.020	5.39	32.9	2.42	0.26
3.	1.23	7.69	32	0.170	0.019	6.25	38.1	3.25	0.31
4.	1.35	9.45	30	0.169	0.017	7.0	42.7	3.80	0.38

Table No. 4 (A) – Jump on smooth bed (Slope – 0.00419)

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.10	5.48	60	0.221	0.028	4.98	30.4	2.10	0.22
2.	1.23	7.14	50	0.198	0.021	5.80	35.4	2.30	0.26
3.	1.28	9.11	34	0.180	0.020	7.10	43.3	3.20	0.34
4.	1.37	10.30	36	0.181	0.021	7.5	45.7	3.75	0.36

Table No. 4 (B) – Jump on smooth bed (Slope – 0.00419)

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.05	4.20	56	0.218	0.025	4.0	24.4	2.12	0.28
2.	1.12	6.05	48	0.197	0.020	5.4	32.9	2.27	0.29
3.	1.26	7.56	30	0.178	0.019	6.0	36.6	3.3	0.37
4.	1.36	9.52	26	0.177	0.018	7.0	42.7	3.7	0.41

Fig. 3.9 Hydraulic jump rough bed

Table No. 5 (A) – Jump on smooth bed (Slope – 0.00524)

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.17	5.73	54	0.217	0.024	4.89	29.8	2.12	0.21
2.	1.22	6.84	44	0.195	0.021	5.6	34.1	2.44	0.27
3.	1.29	7.75	30	0.177	0.018	6.0	36.6	3.26	0.33
4.	1.34	10.05	24	0.175	0.016	7.5	45.75	3.85	0.38

Table No. 5 (B) – Jump on smooth bed (Slope – 0.00524)

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.09	4.57	52	0.216	0.023	4.1	25.0	2.12	0.22
2.	1.21	6.01	44	0.195	0.021	4.97	30.32	2.44	0.32
3.	1.23	8.61	32	0.179	0.019	7.0	42.7	3.26	0.37
4.	1.32	8.91	27	0.176	0.016	6.5	39.6	3.85	0.42

CASE: 2- 10 cm Spacing

Table No. 6 (A) – Jump on smooth horizontal bed

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.18	5.91	74	0.316	0.037	5.0	30.5	2.2	0.20
2.	1.21	7.02	66	0.244	0.029	5.8	35.4	2.6	0.25
3.	1.30	9.11	43	0.180	0.020	7.0	42.7	2.8	0.33
4.	1.41	11.3	33	0.155	0.017	8.0	48.8	3.5	0.38

Fig. 3.10 Hydraulic jump rough bed upstream and downstream view

Table No. 6 (B) – Jump on Rough horizontal bed

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.02	5.01	71	0.306	0.032	4.9	29.9	2.08	0.21
2.	1.13	6.33	56	0.223	0.026	5.6	34.2	2.65	0.28
3.	1.24	8.43	37	0.174	0.018	6.8	41.48	2.7	0.33
4.	1.35	10.26	31	0.146	0.016	7.6	46.4	3.55	0.36

Fig. 3.11 Hydraulic jump rough bed

Table No. 7 (A) – Jump on smooth bed (Slope – 0.00175)

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.06	5.23	69	0.299	0.030	4.9	29.9	2.17	0.22
2.	1.21	6.66	51	0.216	0.025	5.5	33.5	2.5	0.27
3.	1.29	8.39	38	0.175	0.019	6.5	39.6	2.8	0.29
4.	1.33	9.98	34	0.148	0.018	7.5	45.7	3.4	0.33

Table No. 7 (B) – Jump on smooth bed (Slope – 0.00175)

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.15	4.72	66	0.297	0.028	4.1	25.0	2.18	0.21
2.	1.24	6.45	49	0.215	0.026	5.2	31.7	2.49	0.28
3.	1.28	8.19	35	0.171	0.016	6.3	38.4	2.81	0.33
4.	1.33	9.92	31	0.142	0.016	7.4	45.1	3.35	0.36

Table No.8 (A) – Jump on smooth bed (Slope – 0.00349)

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.05	4.71	63	0.228	0.029	4.4	26.8	2.15	0.24
2.	1.22	6.48	50	0.198	0.021	5.3	32.3	2.48	0.28
3.	1.29	7.38	37	0.173	0.020	5.7	34.7	2.7	0.30
4.	1.40	8.98	35	0.172	0.019	6.4	39.0	3.2	0.32

Table No.8 (B) – Jump on smooth bed (Slope – 0.00349)

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.11	4.68	62	0.227	0.028	4.2	25.6	2.12	0.27
2.	1.25	6.25	52	0.199	0.020	5.0	30.5	2.48	0.33
3.	1.29	6.21	33	0.170	0.019	4.8	29.3	2.7	0.33
4.	1.34	6.98	32	0.169	0.017	5.2	31.7	3.19	0.37

Table No. 9 (A) – Jump on smooth bed (Slope – 0.00419)

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.12	5.16	56	0.217	0.028	4.6	28.1	2.10	0.25
2.	1.21	6.32	47	0.195	0.021	5.2	31.7	2.40	0.27
3.	1.23	7.79	38	0.183	0.020	6.3	38.4	2.7	0.30
4.	1.37	10.14	33	0.181	0.021	7.4	45.1	3.0	0.34

Fig. 3.12 Hydraulic jump huge intermixing

Table No. 9 (B) – Jump on smooth bed (Slope – 0.00419)

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.07	4.65	52	0.216	0.025	4.3	26.23	2.09	0.26
2.	1.19	5.96	46	0.194	0.020	5.0	30.5	2.42	0.32
3.	1.24	6.84	29	0.174	0.019	5.5	33.5	2.68	0.33
4.	1.31	7.88	26	0.172	0.018	6.0	36.6	3.03	0.37

Table No. 10 (A) – Jump on smooth bed (Slope – 0.00524)

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.03	4.63	51	0.215	0.024	4.5	27.4	2.0	0.23
2.	1.18	6.38	43	0.196	0.021	5.4	32.9	2.5	0.32
3.	1.25	7.91	37	0.171	0.018	6.3	38.4	2.6	0.35
4.	1.32	9.56	28	0.169	0.016	7.2	43.9	3.0	0.38

Table No. 10 (B) – Jump on smooth bed (Slope – 0.00524)

S.no.	Y1 (cm)	Y2 (cm)	N (for 60 sec)	V (m/s)	Q (m3/s)	Y2/Y1	Lj/Y1	Froude no.(F_{r1})	ΔE/E1
1.	1.16	4.65	52	0.214	0.023	4.0	24.4	2.02	0.24
2.	1.24	6.14	40	0.194	0.021	4.95	30.2	2.49	0.35
3.	1.29	7.11	26	0.168	0.019	5.5	33.5	2.59	0.4
4.	1.36	8.49	24	0.167	0.016	6.2	37.8	3.0	0.42

Fig. 3.13 Hydraulic flume experimental setup and jump formation

CHAPTER – 4

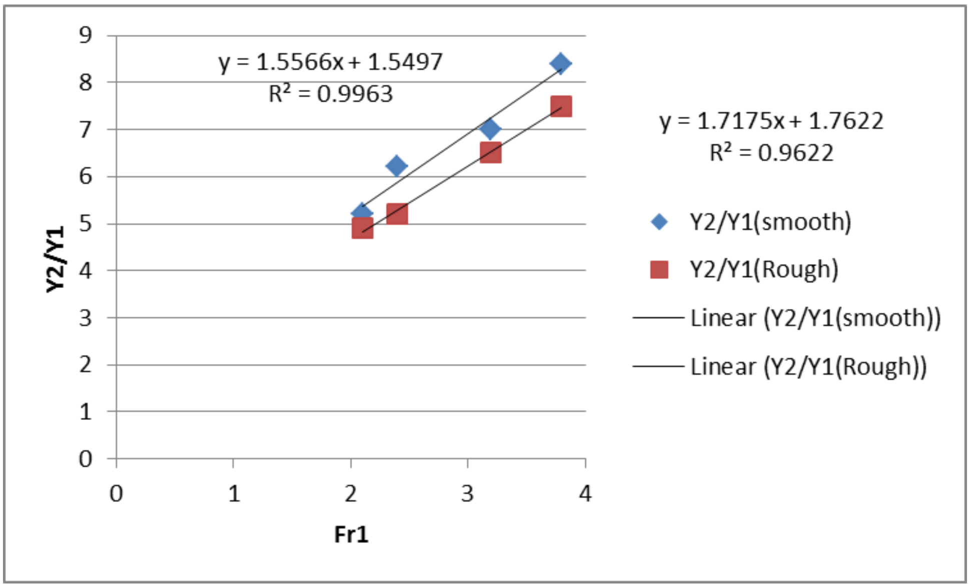
CHAPTER – 4

Results and Discussion

Case:1- 7.5 cm spacing

The experiment first performed on smooth bed then on rough bed.

Condition [1] - (Slope - 0 and spacing 7.5 cm)



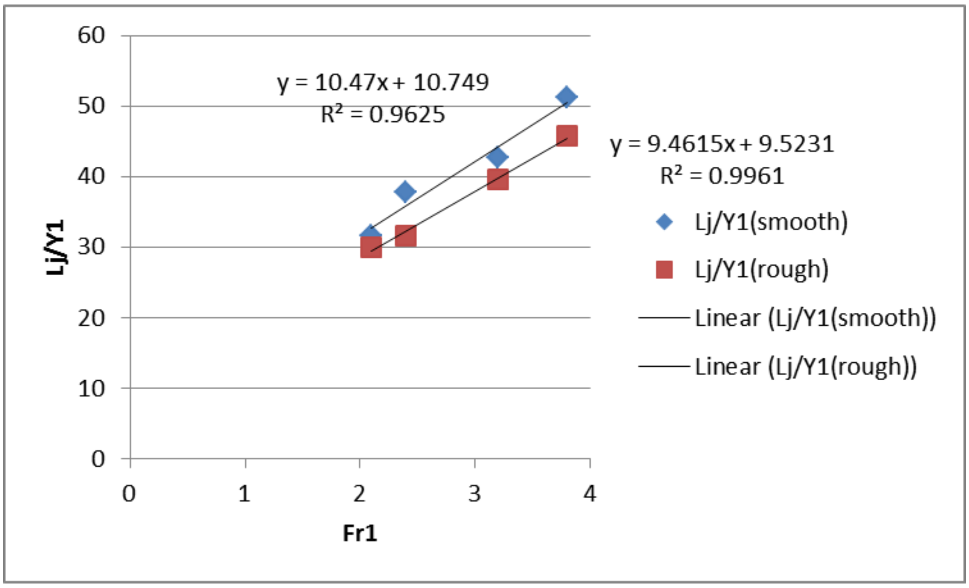
Graph 4.1 Variation between Initial Froude no. and Sequent depth ratio for horizontal bed

For Y2/Y1(Smooth) R2 =0.9963

For Y2/Y1(Rough) R2 = 0.9622

The experiment was performed on smooth bed and the observed data from Table No.-3.1 (A and B) was plotted between Froude no. and sequent depth ratio (smooth and rough bed), which is shown in figure 4.1. By the plot a slight variation were found between smooth and rough bed readings. Figure no. 4.1 is based on the observations shown in Table no. 3.1, by which graph is plotted between Froude No. (Fr1) and Y2/Y1. From the figure it was observed that with increase in Froude no., sequent depth ratio also increases.

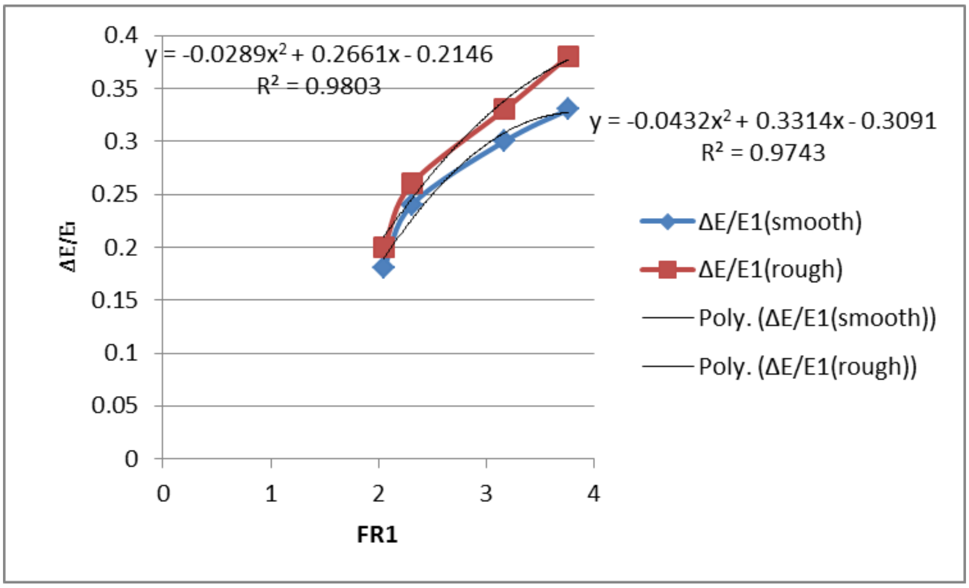
Condition [1] - (Slope - 0 and spacing 7.5 cm)



Graph 4.2 Variation between Initial Froude no. and Lj/Y1 for horizontal bed

Figure no. 4.2 is based on the observations shown in Table no. 1(A and B), by which graph is plotted between Fr1 and Lj/Y1. From the figure it was observed that with increase in Froude no. length of jump increases.

Condition [1] - (Slope - 0 and spacing 7.5 cm)

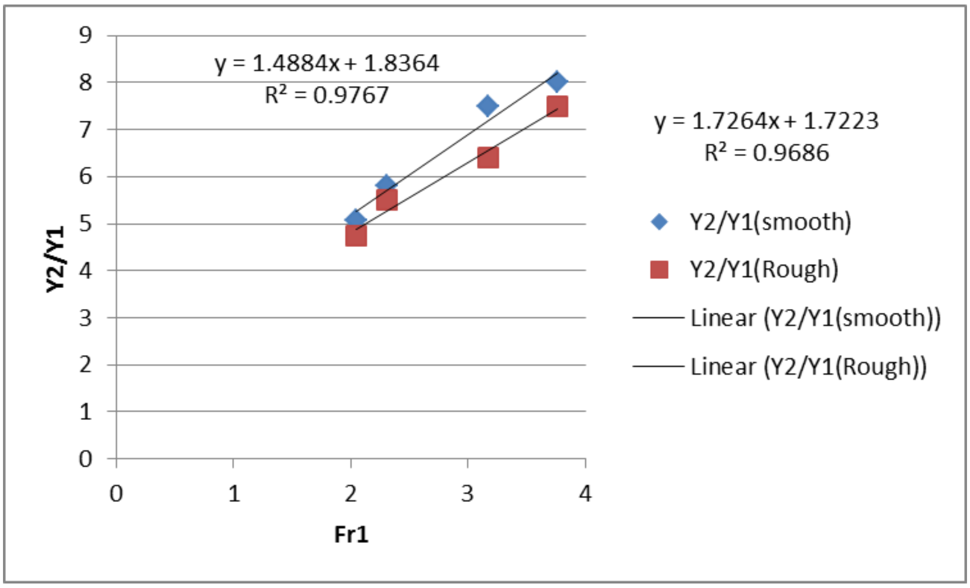


Graph 4.3 Variation between Initial Froude no. and ΔE/E1 for horizontal bed

Figure no. 4.3 is based on the observations shown in Table no. 3.1(A and B), by which graph is plotted between Fr1 and ΔE/E1. From the figure it was observed that with increase in Froude no., energy loss increases and for rough bed it is more than smooth.

It is clear from the graph in case of rough bed sequent depth ratio is smaller than smooth bed it means the sequent depth ratio decreases when bed turn smooth to rough. It is also true in case of length of jump which also decreases when bed turn smooth to rough but energy dissipation is more when bed turn smooth to rough.

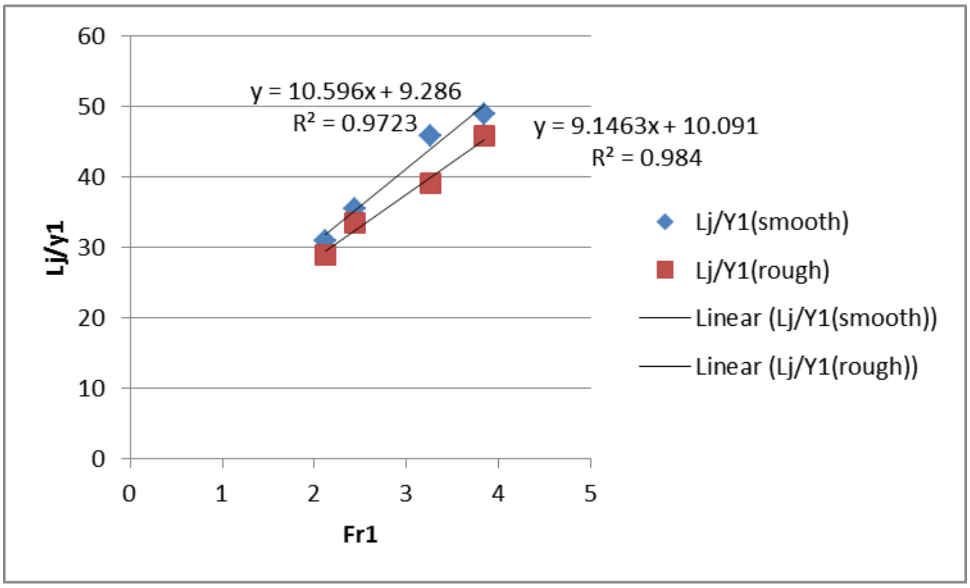
Condition [2] - (Slope – 0.00175 & spacing 7.5 cm)



Graph 4.4 Variation between Initial Froude no. and Sequent depth ratio (slope = 0.00175)

Table No.-3.2 (A and B) was plotted between Froude no. and sequent depth ratio for slope 0.00175 for (smooth and rough bed), which is shown in figure 4.4. By the plot a slight variation were found between smooth and rough bed readings. Graph is plotted between Froude No. (Fr1) and Y2/Y1. From the figure it was observed that with increase in Froude no., sequent depth ratio also increases for rough bed it is less than smooth.

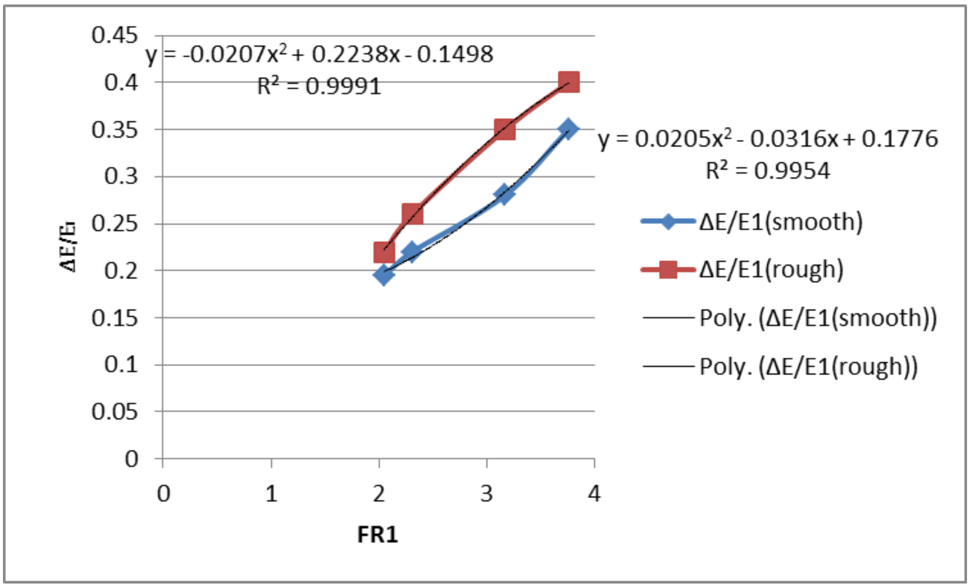
Condition [2] - (Slope – 0.00175 & spacing 7.5 cm)



Graph 4.5 Variation between Initial Froud no. and Lj/Y1 (slope= 0.00175)

Figure no. 4.5 is based on the observations shown in Table no. 3.2(A and B) for slope 0.00175, by which graph is plotted between Fr1 and Lj/Y1. From the figure it was observed that with increase in Froude no. length of jump increases but length of jump for rough bed it is less than smooth.

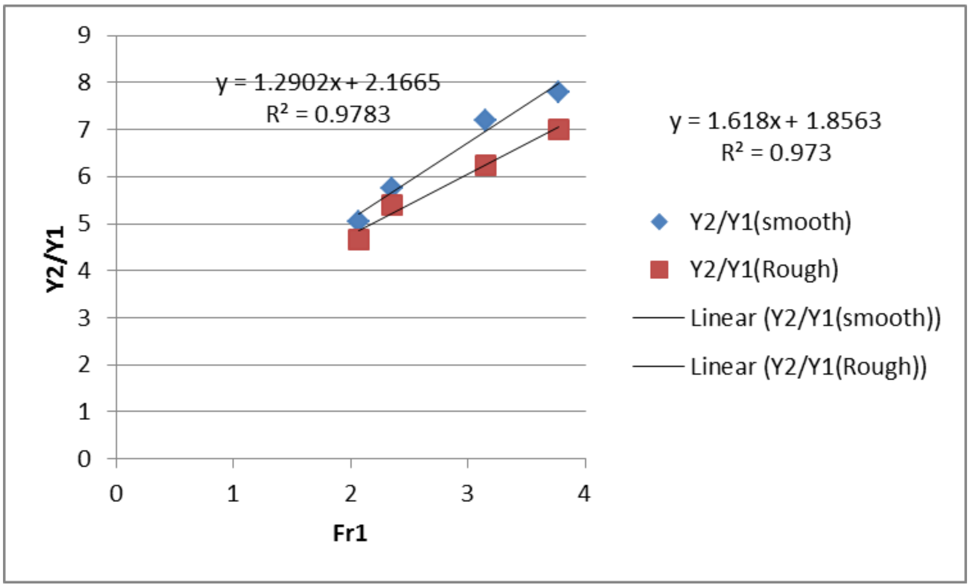
Condition [2] - (Slope – 0.00175 & spacing 7.5 cm)



Graph 4.6 Variation between Initial Froude no. and ΔE/E1 for (slope= 0.00175)

Figure no. 4.6 is based on the observations shown in Table no. 3.2(A and B) for slope 0.00175, by which graph is plotted between Fr1 and ΔE/E1. From the figure it was observed that with increase in Froude no., energy loss increases and for rough bed it is more than smooth.

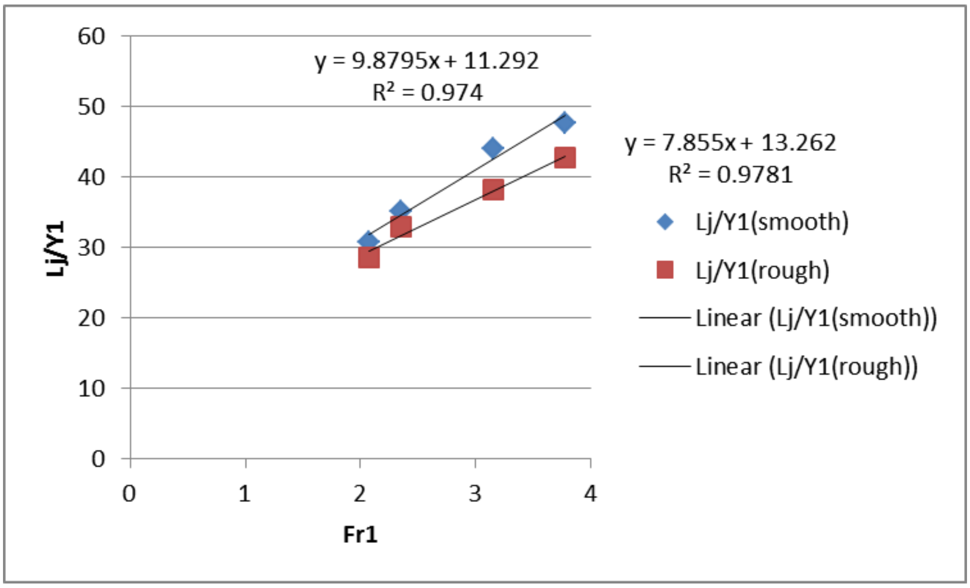
Condition [3] - (Slope – 0.00349 & spacing 7.5 cm)



Graph 4.7 Variation between Initial Froude no. and Sequent depth ratio (slope= 0.00349)

Table No.-3.3 (A and B) was plotted between Froude no. and sequent depth ratio for slope 0.00349 for (smooth and rough bed), which is shown in figure 4.7. By the plot a slight variation were found between smooth and rough bed readings. Graph is plotted between Froude No. (Fr1) and Y2/Y1. From the figure it was observed that with increase in Froude no., sequent depth ratio also increases but for rough bed it is less than smooth bed.

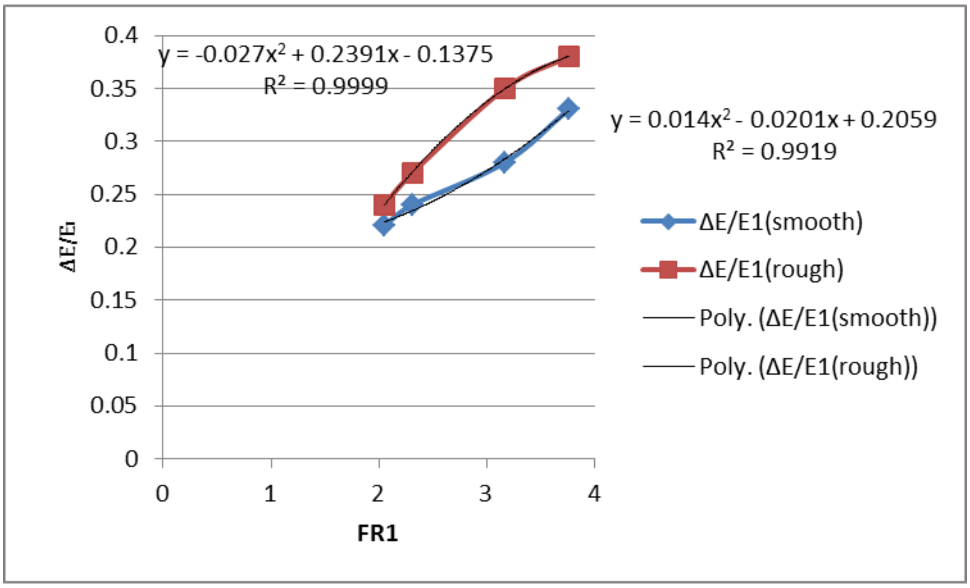
Condition [3] - (Slope – 0.00349 & spacing 7.5 cm)



Graph 4.8 Variation between Initial Froud no. and Lj/Y1 (slope = 0.00349)

Figure no. 4.8 is based on the observations shown in Table no. 3.3(A and B) for slope 0.00349, by which graph is plotted between Fr1 and Lj/Y1. From the figure it was observed that with increase in Froude no. length of jump increases but length of jump for rough bed it is less than that for smooth bed.

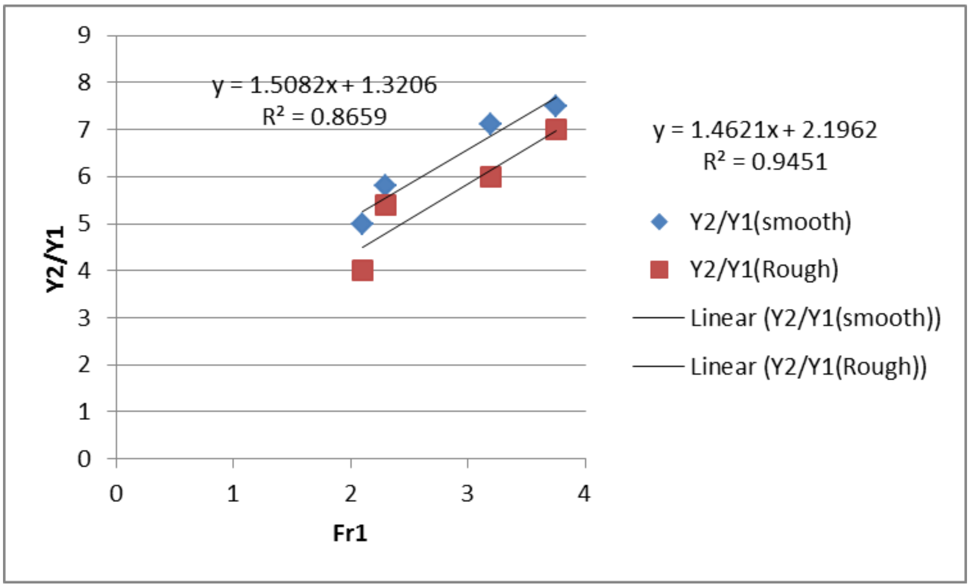
Condition [3] - <u>(Slope – 0.00349 & spacing 7.5 cm)</u>



Graph 4.9 Variation between Initial Froude no. and ΔE/E1 for (slope= 0.00349)

Figure no. 4.9 is based on the observations shown in Table no. 3.3(A and B) for slope 0.00349, by which graph is plotted between Fr1 and ΔE/E1. From the figure it was observed that with increase in Froude no., energy loss increases and for rough bed it is more than smooth.

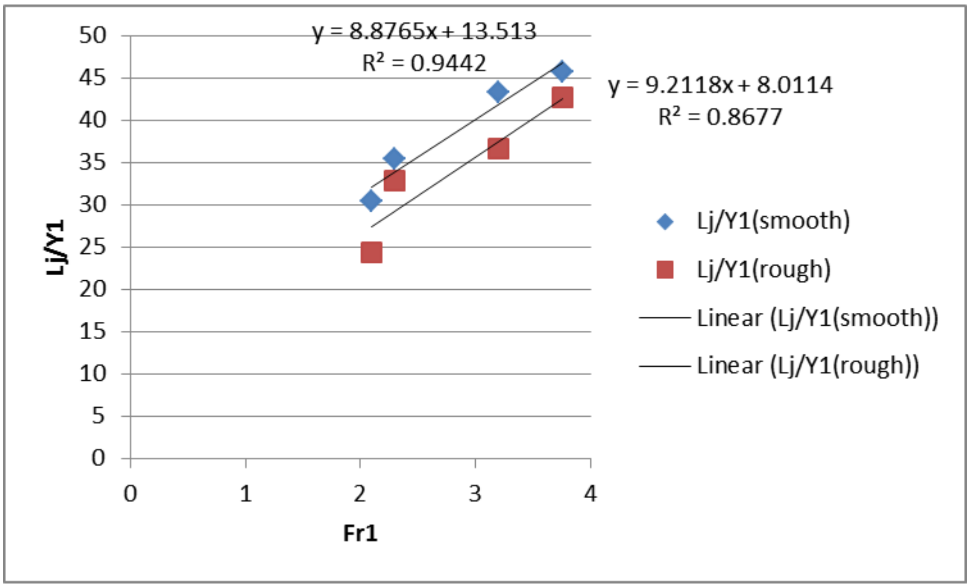
Condition [4] - (Slope – 0.00419 & spacing 7.5 cm)



Graph 4.10 Variation between Initial Froude no. and Sequent depth ratio (slope= 0.00419)

Table No.-3.4 (A and B) was plotted between Froude no. and sequent depth ratio for slope 0.00419 for (smooth and rough bed), which is shown in figure 4.10. By the plot a slight variation were found between smooth and rough bed readings. Graph is plotted between Froude No. (Fr1) and Y2/Y1. From the figure it was observed that with increase in Froude no., sequent depth ratio also increases but for rough bed it is less than smooth bed.

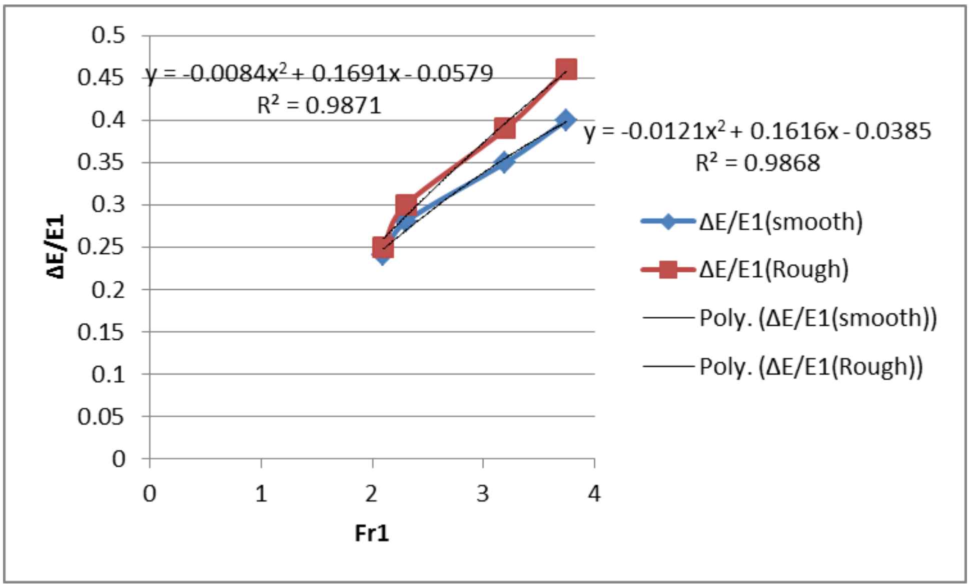
Condition [4] - (Slope – 0.00419 & spacing 7.5 cm)



Graph 4.11 Variation between Initial Froud no. and Lj/Y1 (slope = 0.00419)

Figure no. 4.11 is based on the observations shown in Table no. 3.4 (A and B) for slope 0.00419, by which graph is plotted between Fr1 and Lj/Y1. From the figure it was observed that with increase in Froude no. length of jump increases but length of jump for rough bed is less that for than smooth bed.

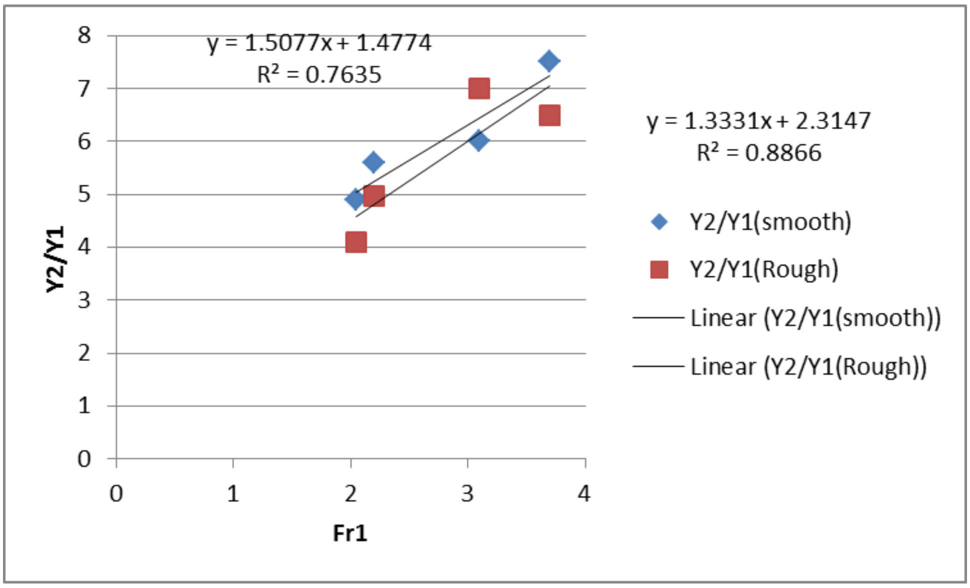
Condition [4] - (Slope – 0.00419 & spacing 7.5 cm)



Graph 4.12 Variation between Initial Froude no. and ΔE/E1 (slope= 0.00419)

Figure no. 4.12 is based on the observations shown in Table no. 3.4(A and B) for slope 0.00419, by which graph is plotted between Fr1 and ΔE/E1. From the figure it was observed that with increase in Froude no., energy loss increases and for rough bed it is more than smooth.

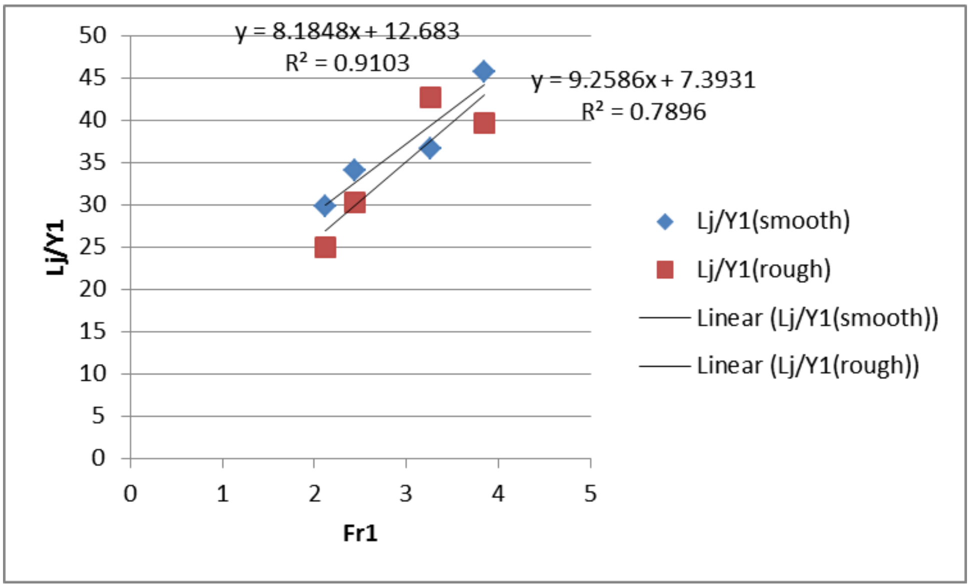
Condition [5] - (Slope – 0.00524 & spacing 7.5 cm)



Graph 4.13 Variation between Initial Froude no. and Sequent depth ratio (slope= 0.00524)

Table No.-3.5 (A and B) was plotted between Froude no. and sequent depth ratio for slope 0.00524 for (smooth and rough bed), which is shown in figure 4.13. By the plot a slight variation were found between smooth and rough bed readings. Graph is plotted between Froude No. (Fr1) and Y2/Y1. From the figure it was observed that with increase in Froude no., sequent depth ratio also increases but for rough bed it is less than smooth bed.

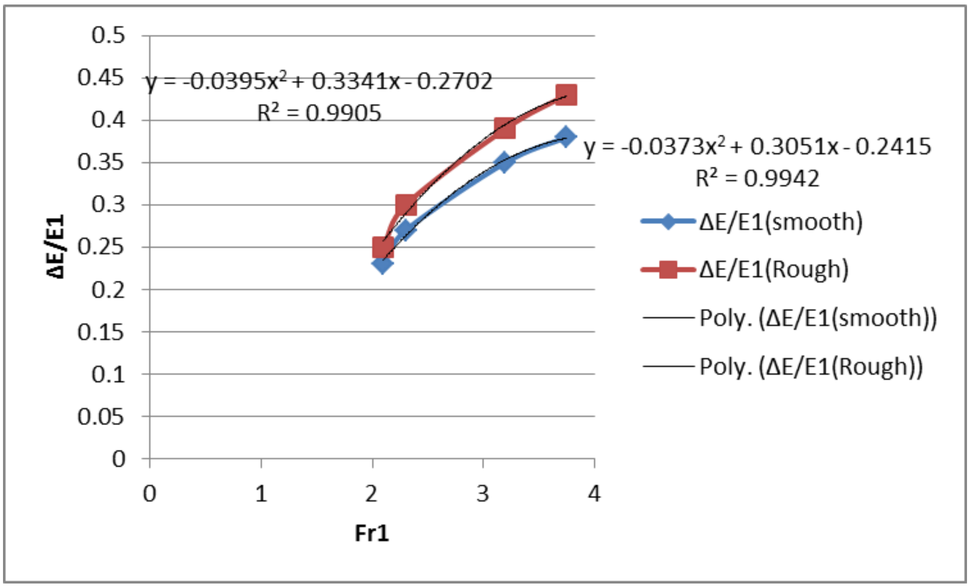
Condition [5] - (Slope – 0.00524 & spacing 7.5 cm)



Graph 4.14 Variation between Initial Froud no. and Lj/Y1 (slope= 0.00524)

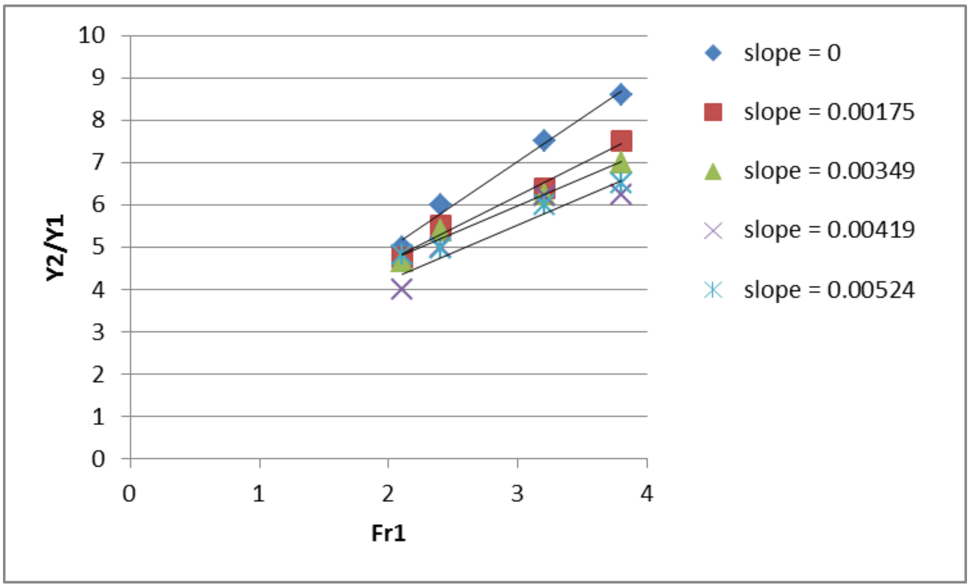
Figure no. 4.14 is based on the observations shown in Table no. 3.5 (A and B) for slope 0.00524, by which graph is plotted between Fr1 and Lj/Y1. From the figure it was observed that with increase in Froude no. length of jump increases but length of jump for rough bed is less that for than smooth bed.

Condition [5] - (Slope – 0.00524 & spacing 7.5 cm)



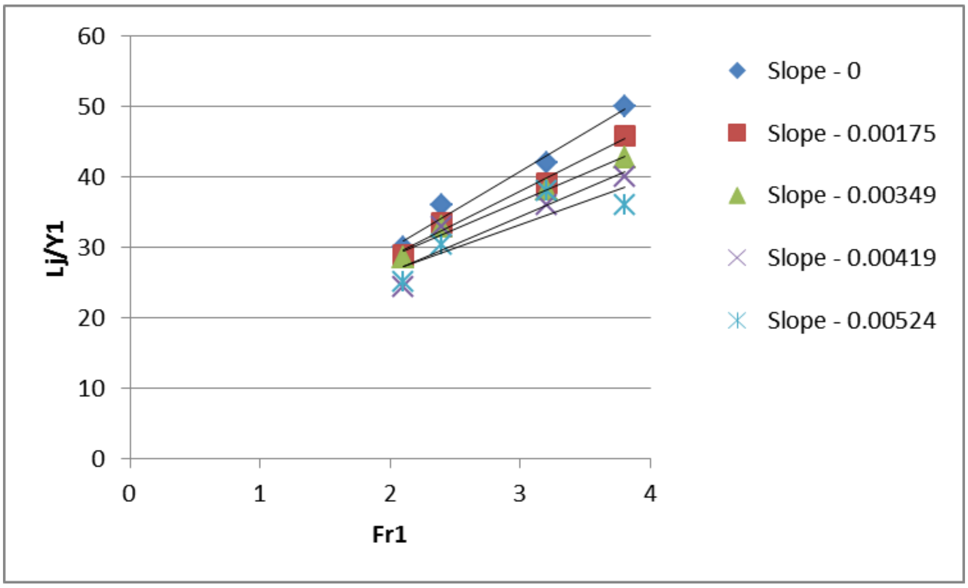
Graph 4.15 Variation between Initial Froude no. and ΔE/E1 for (slope= 0.00524)

Figure no. 4.15 is based on the observations shown in Table no. 3.5(A and B) for slope 0.00524, by which graph is plotted between Fr1 and ΔE/E1. From the figure it was observed that with increase in Froude no., energy loss increases and for rough bed it is more than smooth.



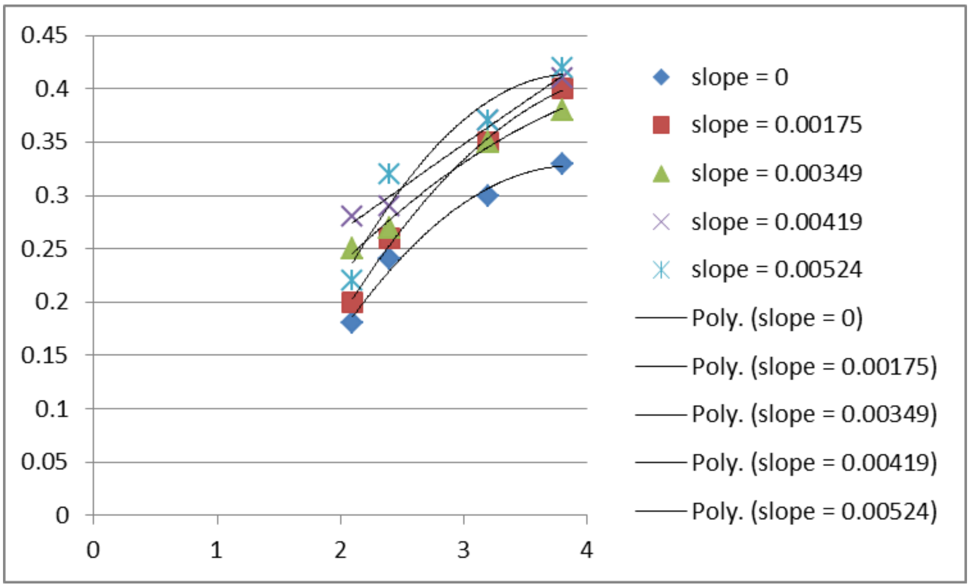
Graph 4.16 Variation between Initial Froude no. and Lj/Y1 ratio for different slope

Figure no. 4.16 is based on the observations shown in all table of case 1, by which a graph plotted between Froude No. and sequent depth ratio of all the conditions of case 1 (for rough bed). From the figure it was observed that with increase in Froude no., sequent depth ratio also increases. For small slope sequent depth ratio is higher which decreases with increases in slope.



Graph 4.17 Variation between Initial Froude no. and Lj/Y1 for different slopes (Rough bed)

Figure no. 4.17 is based on the observations shown in all table of case 1, by which a graph plotted between Froude No. and Lj/Y1 ratio of all the conditions of case 1 (for rough bed). From the figure it was observed that with increase in Froude no., length of jump also increases. For small slope length of jump is higher which decreases with increases in slope.



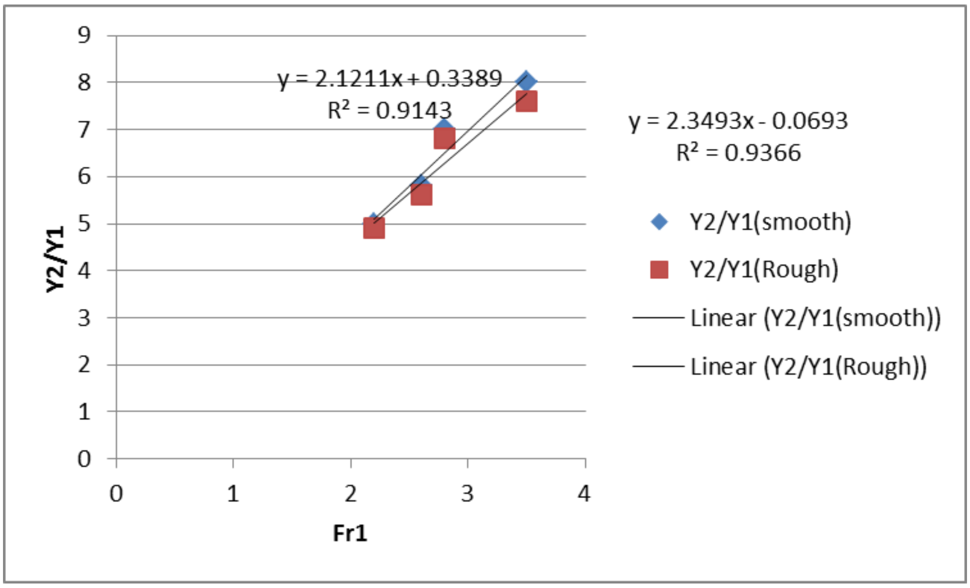
Graph 4.18 Variation between Initial Froude no. and ΔE/E1 for different slopes(Rough bed)

Figure no. 4.18 is based on the observations shown in all table of case 1, by which a graph plotted between Froude No. and ΔE/E1 ratio of all the conditions of case 1 (for rough bed). From the figure it was observed that with increase in Froude no., energy loss also increases.

For small slope energy loss is lesser which increase with increases in slope.

Case:2- 10 cm spacing

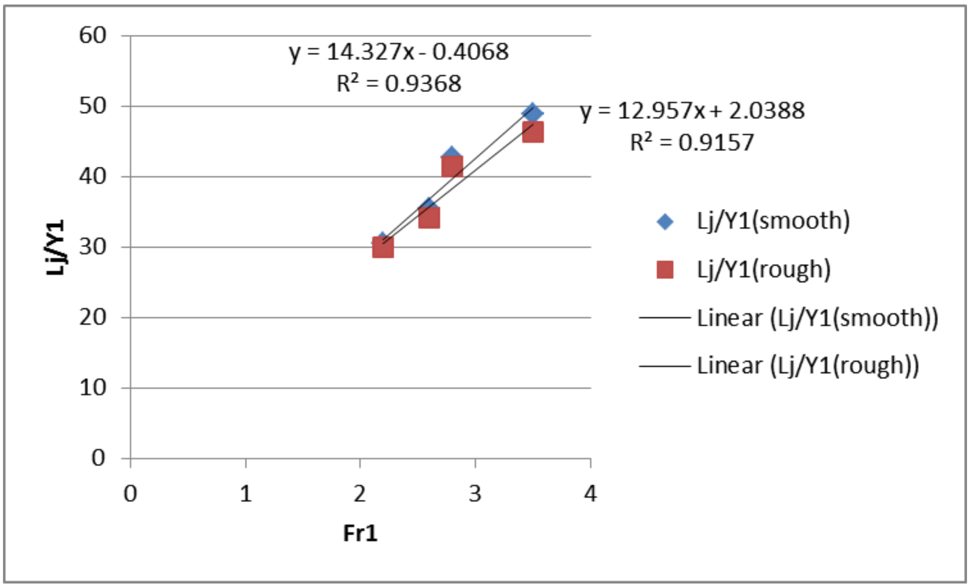
Condition [1] - (Slope – 0 & spacing 10cm)



Graph 4.19 Variation between Initial Froude no. and Sequent depth ratio for horizontal bed

The experiment was performed on smooth bed and the observed data from Table No.-3.6 (A and B) was plotted between Froude no. and sequent depth ratio (smooth and rough bed), which is shown in figure 4.19. By the plot a slight variation were found between smooth and rough bed readings. Figure no. 4.19 is based on the observations shown in Table no. 3.6, by which graph is plotted between Froude No. (Fr1) and Y2/Y1. From the figure it was observed that with increase in Froude no., sequent depth ratio also increases.

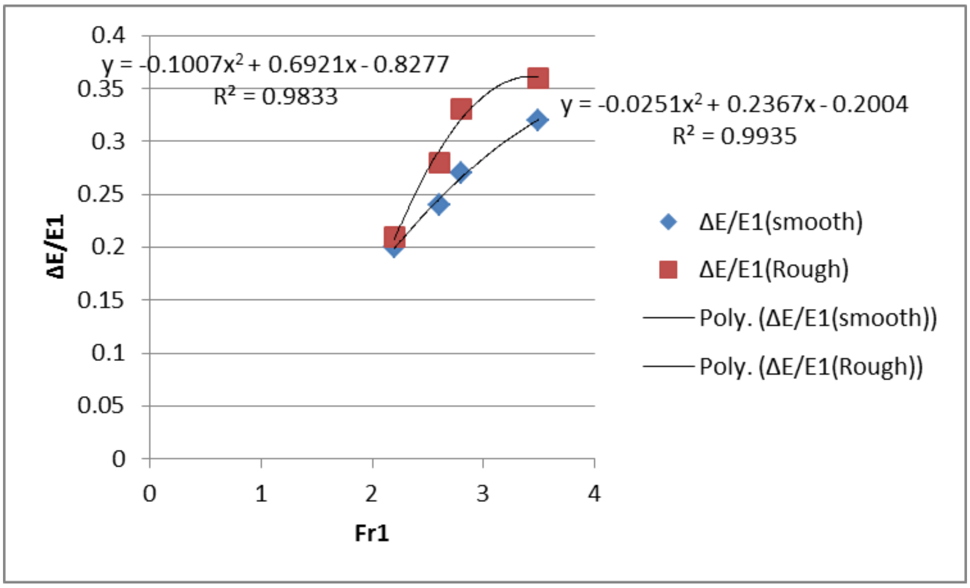
Condition [1] - (Slope – 0 & spacing 10cm)



Graph 4.20 Variation between Initial Froude no. and Lj/Y1 for Horizontal bed

Figure no. 4.20 is based on the observations shown in Table no. 6(A and B), by which graph is plotted between Fr1 and Lj/Y1. From the figure it was observed that with increase in Froude no. length of jump increases.

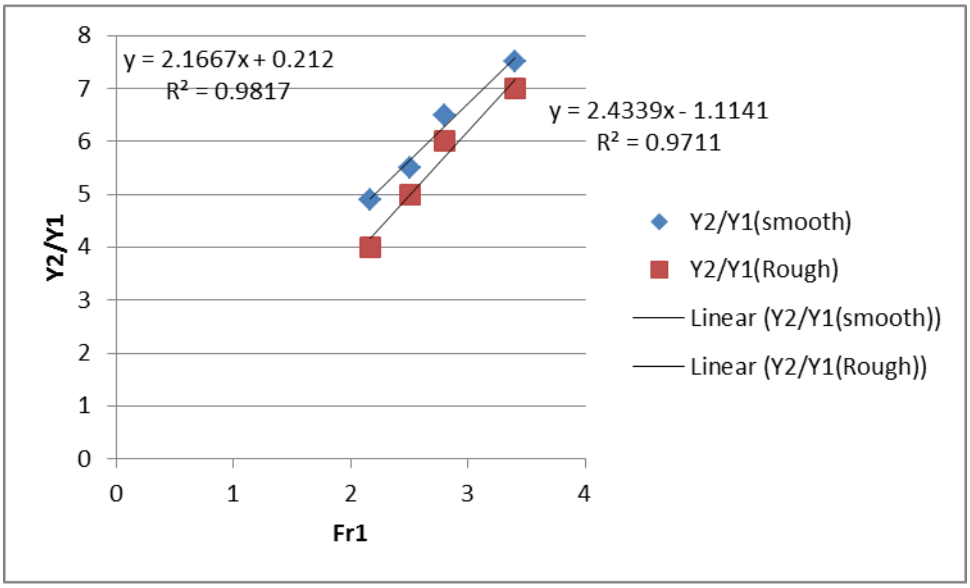
Condition [1] - (Slope – 0 & spacing 10cm)



Graph 4.21 Variation between Initial Froude no. and ΔE/E1 for Horizontal bed

Figure no. 4.21 is based on the observations shown in Table no. 3.6(A and B), by which graph is plotted between Fr1 and ΔE/E1. From the figure it was observed that with increase in Froude no., energy loss increases and for rough bed it is more than smooth.

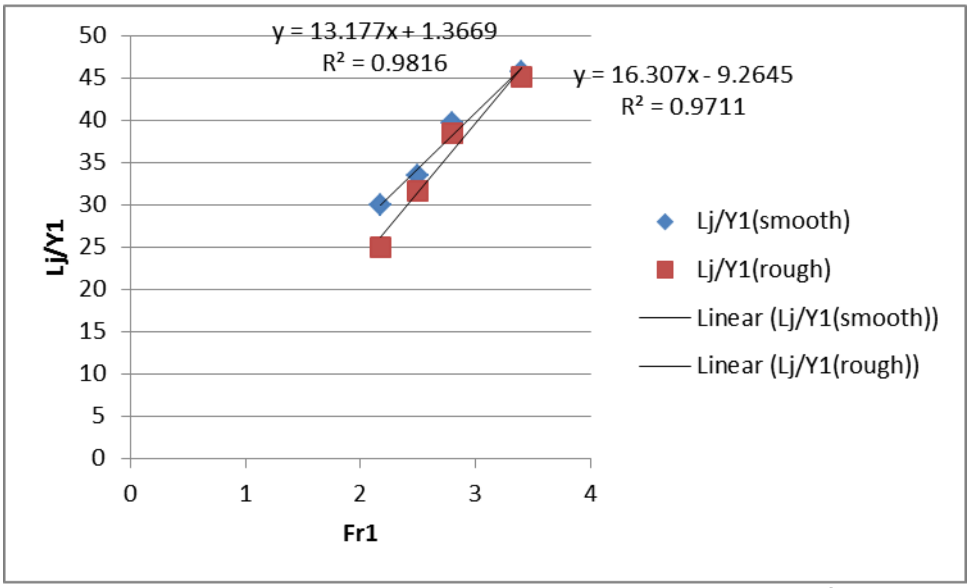
Condition [2] - (Slope – 0.00175 & spacing 10cm)



Graph 4.22 Variation between Initial Froude no. and Sequent depth ratio for (slope=0.00175)

Table No.-3.7 (A and B) was plotted between Froude no. and sequent depth ratio for slope 0.00175 for (smooth and rough bed), which is shown in figure 4.22 By the plot a slight variation were found between smooth and rough bed readings. Graph is plotted between Froude No. (Fr1) and Y2/Y1. From the figure it was observed that with increase in Froude no., sequent depth ratio also increases for rough bed it is less than smooth.

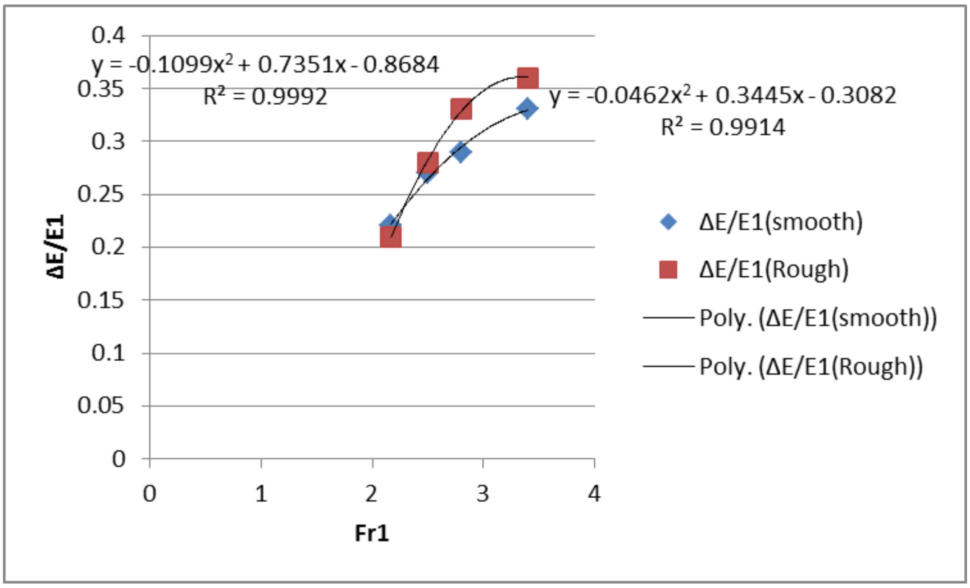
Condition [2] - (Slope – 0.00175 & spacing 10cm)



Graph 4.23 Variation between Initial Froude no. and Lj/Y1 for (slope=0.00175)

Figure no. 4.23 is based on the observations shown in Table no. 3.7(A and B) for slope 0.00175, by which graph is plotted between Fr1 and Lj/Y1. From the figure it was observed that with increase in Froude no. length of jump increases but length of jump for rough bed it is less than smooth.

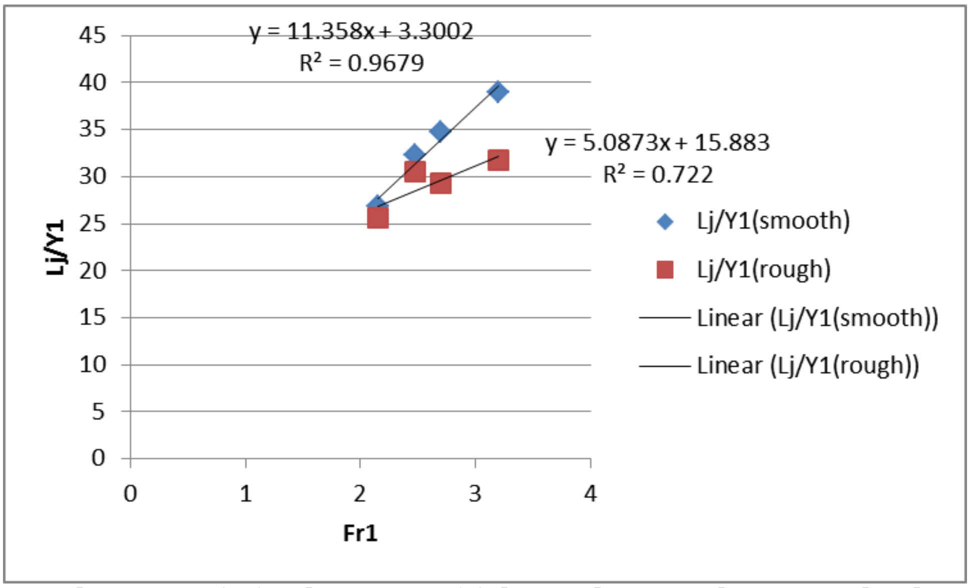
<u>Condition [2] -</u> <u>(Slope – 0.00175 & spacing 10cm)</u>



Graph 4.24 Variation between Initial Froude no. and ΔE/E1 for (slope=0.00175)

Figure no. 4.24 is based on the observations shown in Table no. 3.7(A and B) for slope 0.00175, by which graph is plotted between Fr1 and ΔE/E1. From the figure it was observed that with increase in Froude no., energy loss increases and for rough bed it is more than smooth.

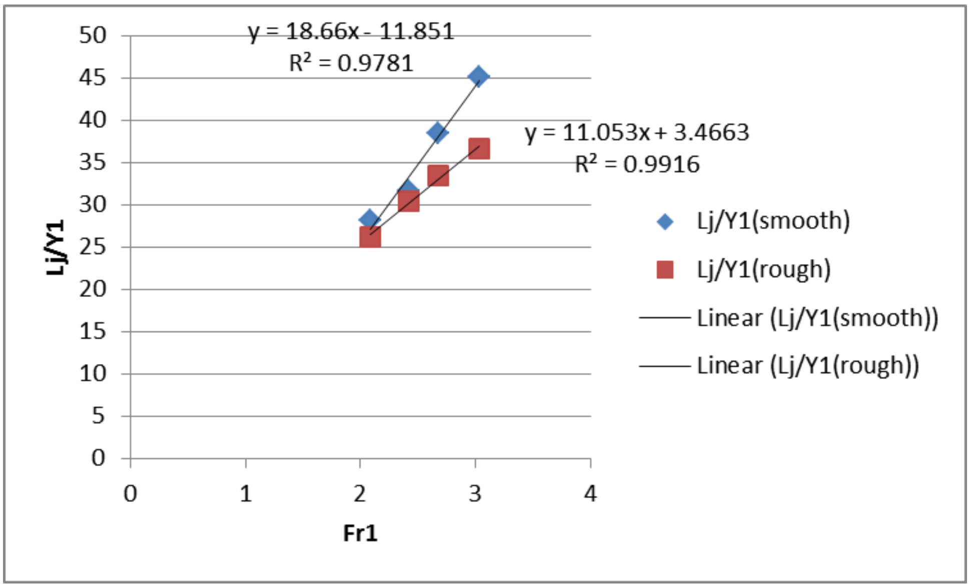
<u>Condition [3] -</u> <u>(Slope – 0.00349 & spacing 10cm)</u>



Graph 4.25 Variation between Initial Froude no. and Sequent depth ratio for (slope=0.00349)

Table No.-3.8 (A and B) was plotted between Froude no. and sequent depth ratio for slope 0.00349 for (smooth and rough bed), which is shown in figure 4.25. By the plot a slight variation were found between smooth and rough bed readings. Graph is plotted between Froude No. (Fr1) and Y2/Y1. From the figure it was observed that with increase in Froude no., sequent depth ratio also increases but for rough bed it is less than smooth bed.

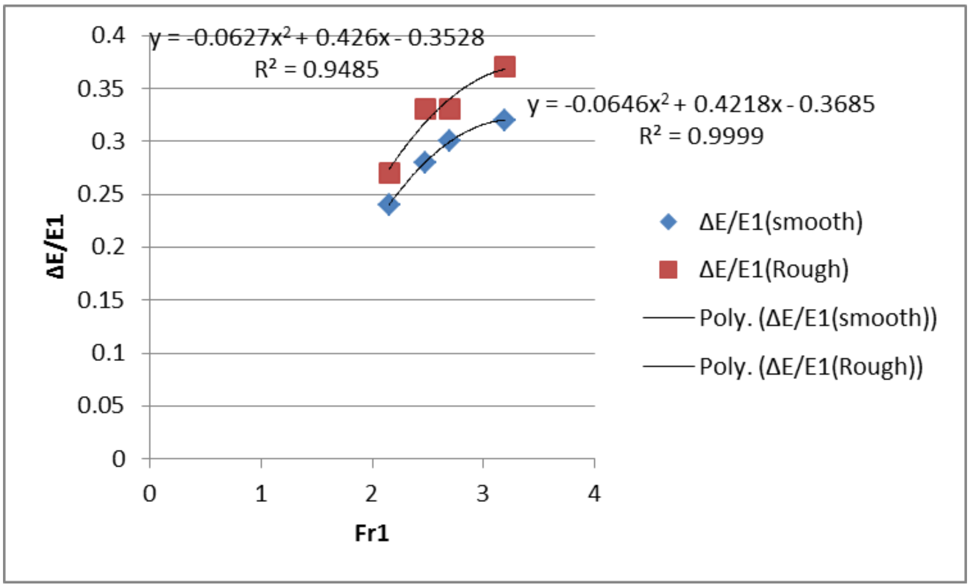
Condition [3] - (Slope – 0.00349 & spacing 10cm)



Graph 4.26 Variation between Initial Froude no. and Lj/Y1 for (slope=0.00349)

Figure no. 4.26 is based on the observations shown in Table no. 3.8(A and B) for slope 0.00349, by which graph is plotted between Fr1 and Lj/Y1. From the figure it was observed that with increase in Froude no. length of jump increases but length of jump for rough bed it is less than that for smooth bed.

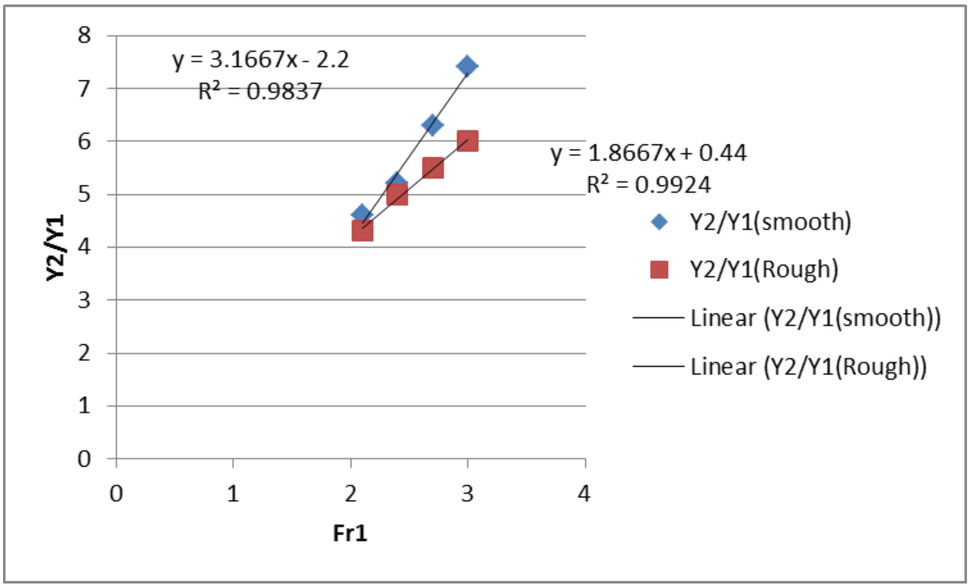
Condition [3] - (Slope – 0.00349 & spacing 10cm)



Graph 4.27 Variation between Initial Froude no. and ΔE/E1 for (slope=0.00349)

Figure no. 4.27 is based on the observations shown in Table no. 3.8(A and B) for slope 0.00349, by which graph is plotted between Fr1 and ΔE/E1. From the figure it was observed that with increase in Froude no., energy loss increases and for rough bed it is more than smooth.

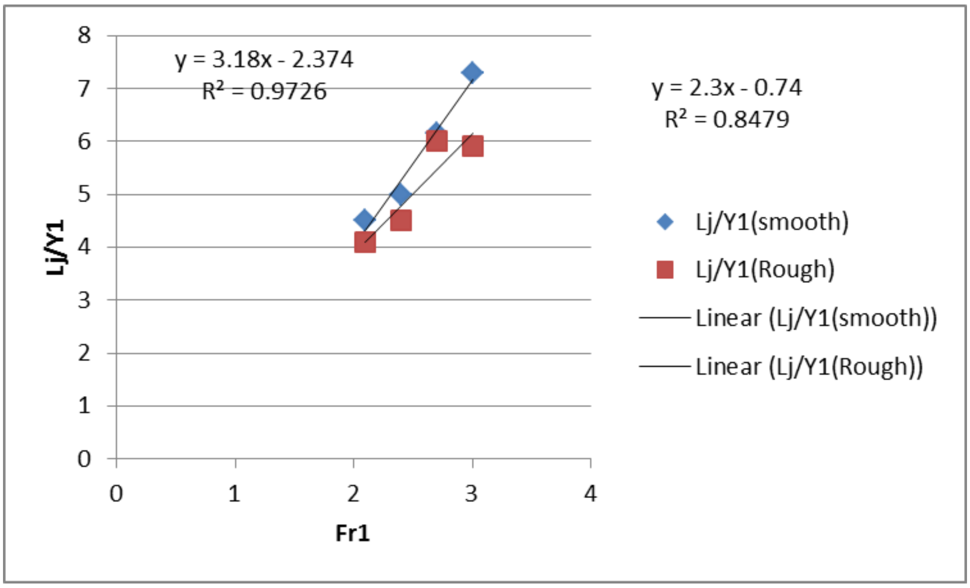
Condition [4] - (Slope – 0.00419 & spacing 10cm)



Graph 4.28 Variation between Initial Froude no. and Sequent depth ratio for (slope=0.00419)

Table No.-3.9 (A and B) was plotted between Froude no. and sequent depth ratio for slope 0.00419 for (smooth and rough bed), which is shown in figure 4.28 By the plot a slight variation were found between smooth and rough bed readings. Graph is plotted between Froude No. (Fr1) and Y2/Y1. From the figure it was observed that with increase in Froude no., sequent depth ratio also increases but for rough bed it is less than smooth bed.

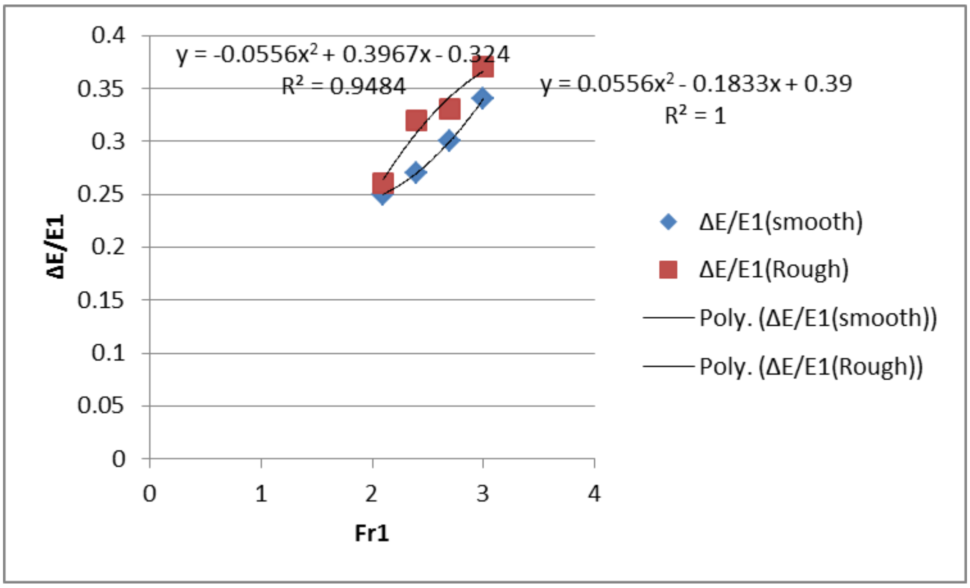
Condition [4] - <u>(Slope – 0.00419 & spacing 10cm)</u>



Graph 4.29 Variation between Initial Froude no. and Lj/Y1 for (slope=0.00419)

Figure no. 4.29 is based on the observations shown in Table no. 3.9 (A and B) for slope 0.00419, by which graph is plotted between Fr1 and Lj/Y1. From the figure it was observed that with increase in Froude no. length of jump increases but length of jump for rough bed is less that for than smooth bed.

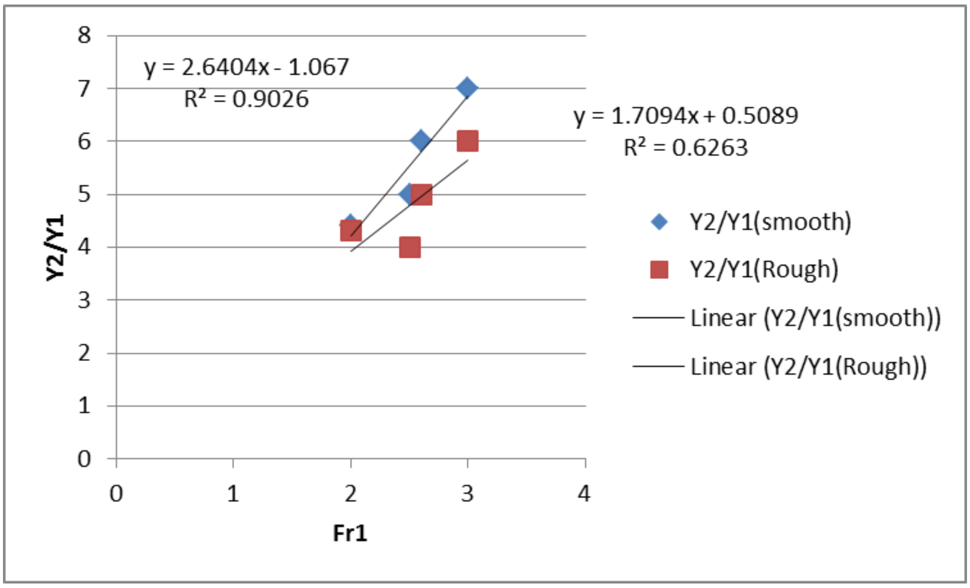
Condition [4] - <u>(Slope – 0.00419 & spacing 10cm)</u>



Graph 4.30 Variation between Initial Froude no. and ΔE/E1 for (slope=0.00419)

Figure no. 4.30 is based on the observations shown in Table no. 3.9(A and B) for slope 0.00419, by which graph is plotted between Fr1 and ΔE/E1. From the figure it was observed that with increase in Froude no., energy loss increases and for rough bed it is more than smooth.

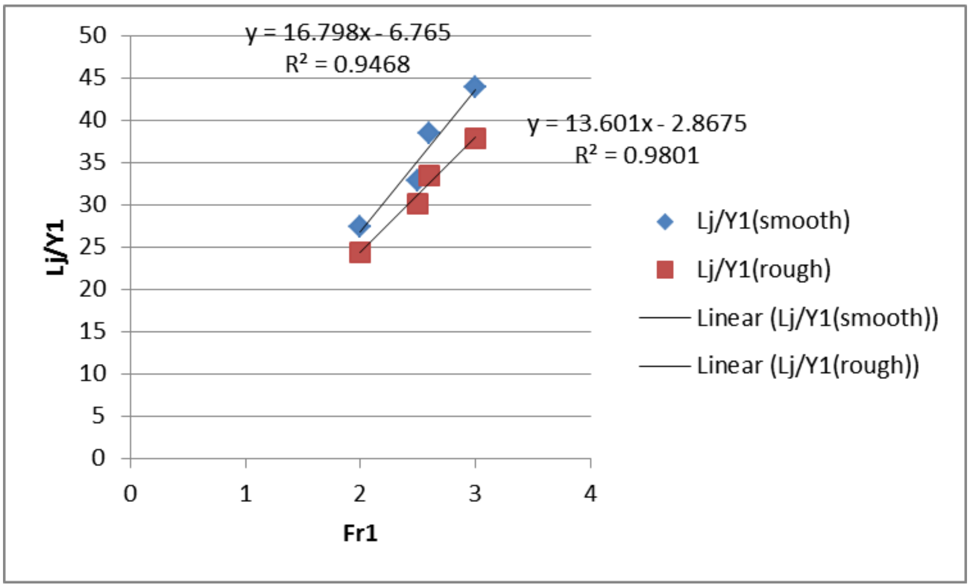
Condition [5] - (Slope – 0.00524 & spacing 10cm)



Graph 4.31 Variation between Initial Froude no. and Sequent depth ratio for (slope=0.00524)

Table No.-3.10 (A and B) was plotted between Froude no. and sequent depth ratio for slope 0.00524 for (smooth and rough bed), which is shown in figure 4.31. By the plot a slight variation were found between smooth and rough bed readings. Graph is plotted between Froude No. (Fr1) and Y2/Y1. From the figure it was observed that with increase in Froude no., sequent depth ratio also increases but for rough bed it is less than smooth bed.

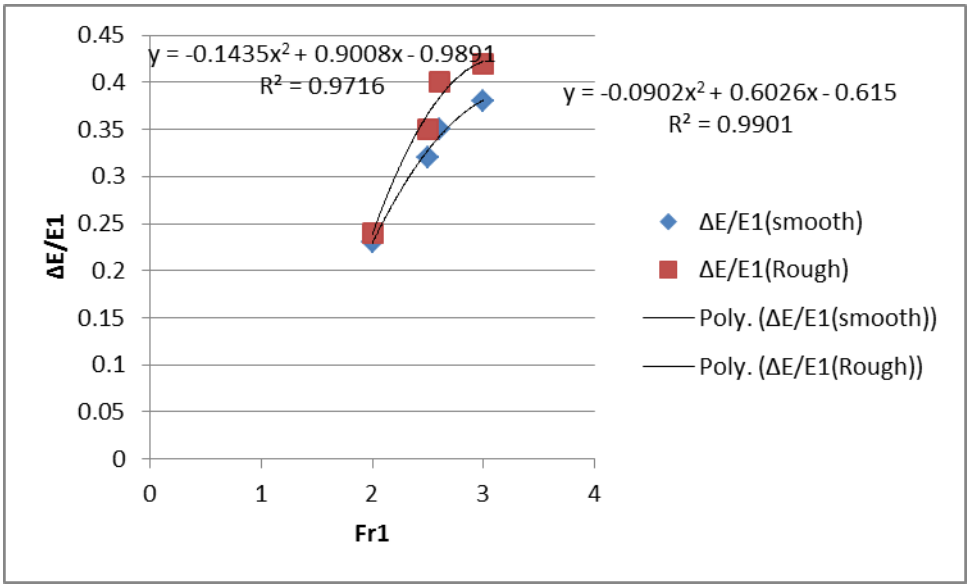
<u>Condition [5] - (Slope – 0.00524 & spacing 10cm)</u>



Graph 4.32 Variation between Initial Froude no. and Lj/Y1 for (slope=0.00524)

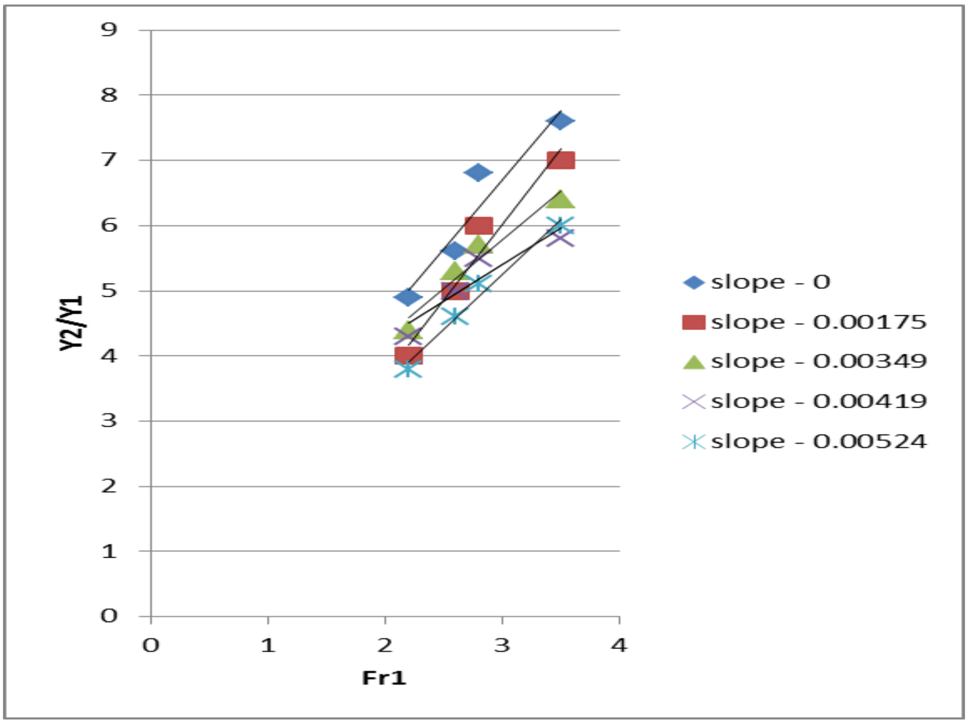
Figure no. 4.32 is based on the observations shown in Table no. 3.10 (A and B) for slope 0.00524, by which graph is plotted between Fr1 and Lj/Y1. From the figure it was observed that with increase in Froude no. length of jump increases but length of jump for rough bed is less that for than smooth bed.

<u>Condition [5] - (Slope – 0.00524 & spacing 10cm)</u>



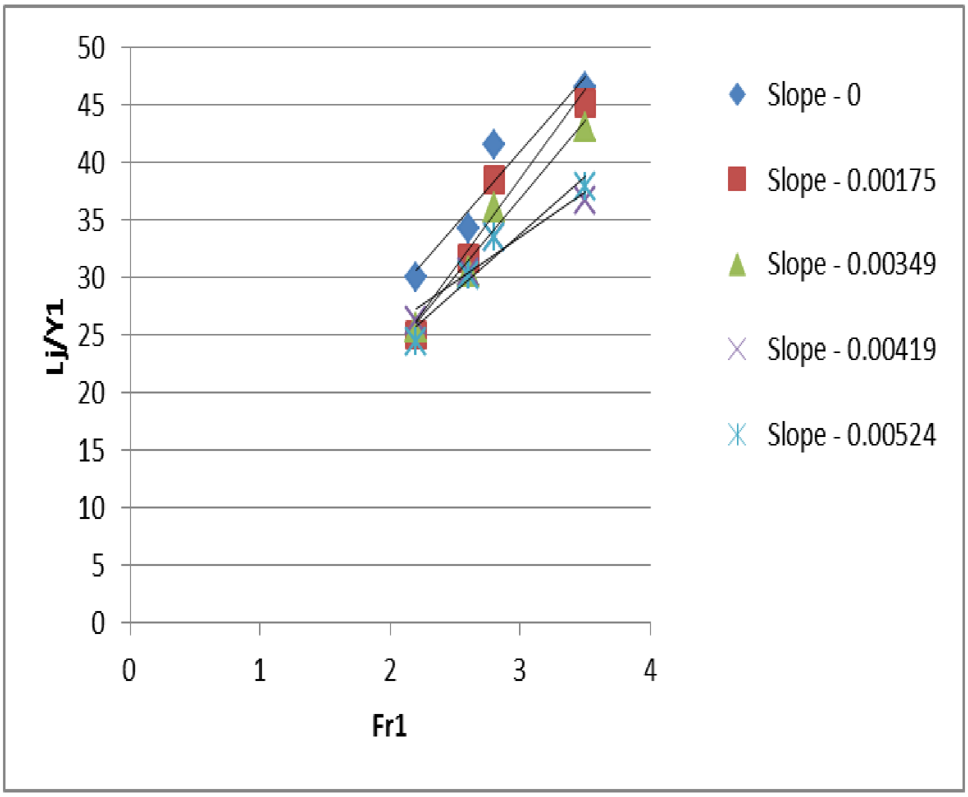
Graph 4.33 Variation between Initial Froude no. and ΔE/E1 for (slope=0.00524)

Figure no. 4.33 is based on the observations shown in Table no. 3.10(A and B) for slope 0.00524, by which graph is plotted between Fr1 and ΔE/E1. From the figure it was observed that with increase in Froude no., energy loss increases and for rough bed it is more than smooth.



Graph 4.34 Variation between Initial Froude no. and Y2/Y1 ratio for different slopes

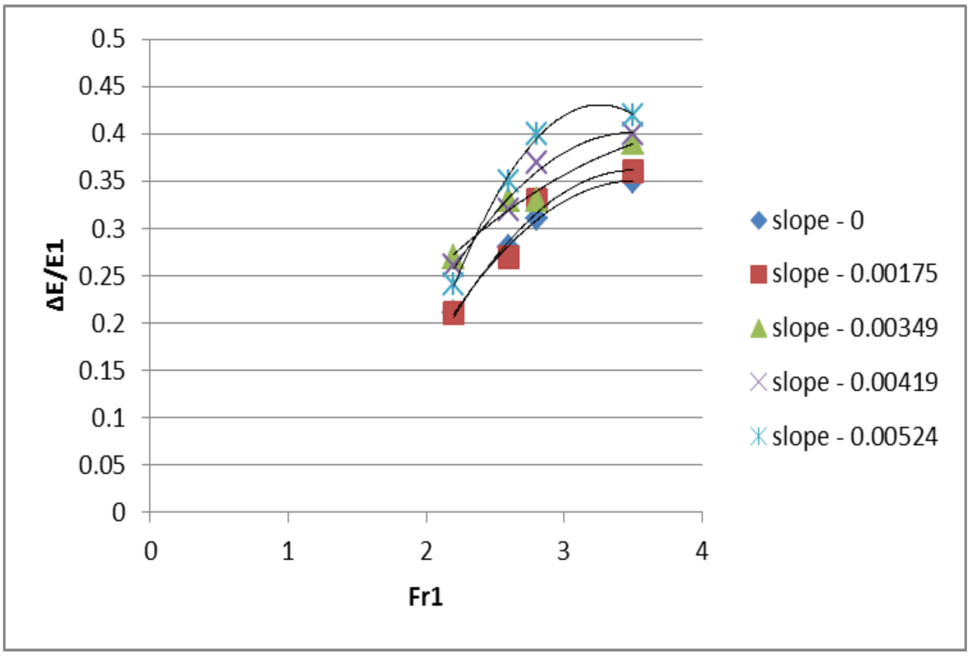
Figure no. 4.34 is based on the observations shown in all table of case 2, by which a graph plotted between Froude No. and sequent depth ratio of all the conditions of case 2 (for rough bed). From the figure it was observed that with increase in Froude no., sequent depth ratio also increases. For small slope sequent depth ratio is higher which decreases with increase in slope.



Graph 4.35 Variation between Initial Froude no. and Lj/Y1 ratio for different slopes(Rough bed)

Figure no. 4.35 is based on the observations shown in all table of case 2, by which a graph plotted between Froude No. and Lj/Y1 ratio of all the conditions of case 2 (for rough bed). From the figure it was observed that with increase in Froude no., length of jump also increases.

For small slope length of jump is higher which decreases with increases in slope.

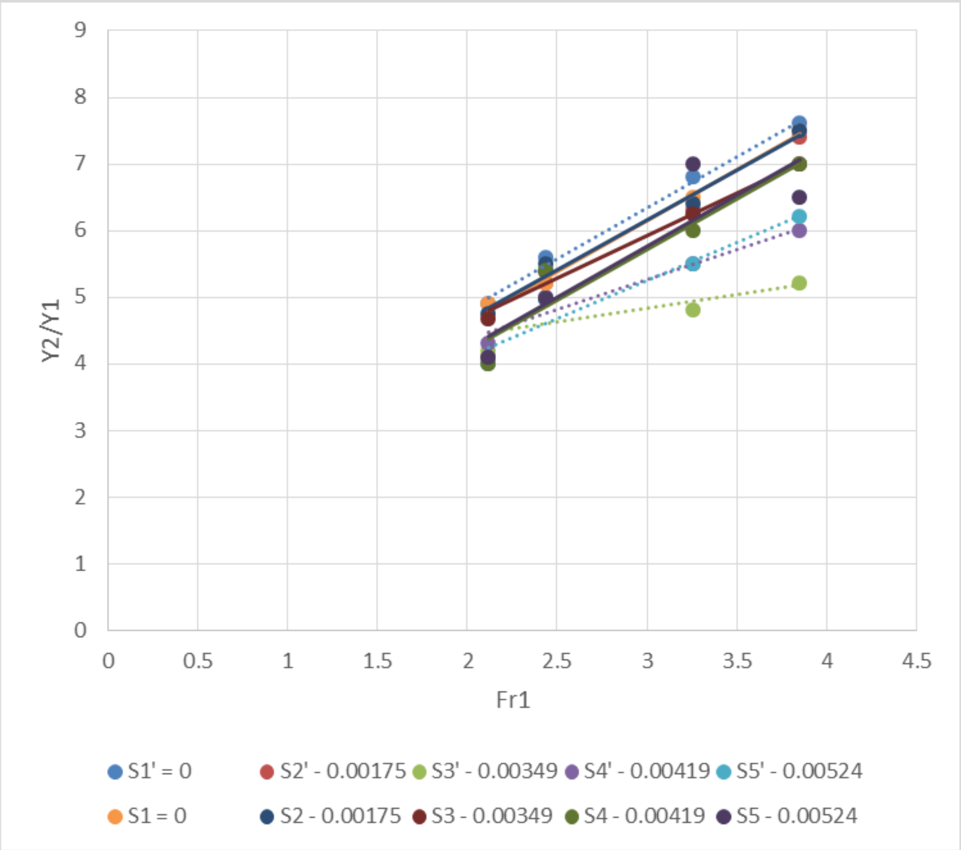


Graph 4.36 Variation between Initial Froude no. and ΔE/E1 for different slopes (Rough bed)

Figure no. 4.36 is based on the observations shown in all table of case 2, by which a graph plotted between Froude No. and ΔE/E1 ratio of all the conditions of case 1 (for rough bed). From the figure it was observed that with increase in Froude no., energy loss also increases.

For small slope energy loss is lesser which increase with increases in slope.

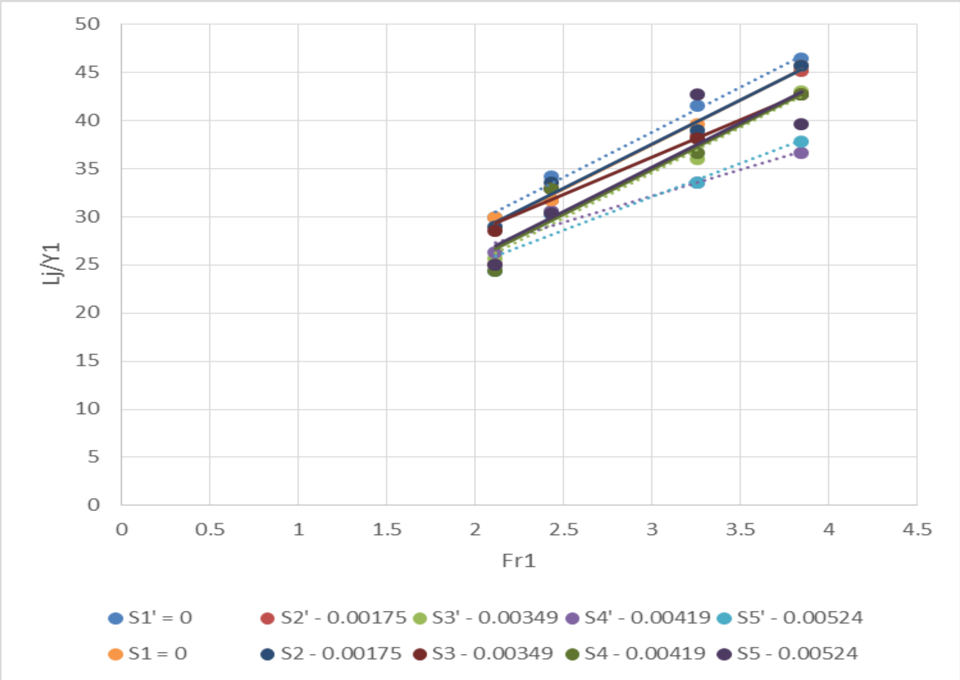
Variation of Fr1 and Y2/Y1 for different slope (Both case)



Graph 4.37 Variation between Initial Froude no. and Y2/Y1 ratio for different slopes (spacing 7.5 cm and 10 cm)

Graph no. 4.37 is based on the observations shown in all table of case 1 and 2 for rough bed,
For small slope sequent depth ratio is higher which decreases with increase in slope.
with increase in Froude no. the sequent depth ratio also increases in both the cases (smooth and rough) but higher values obtained for smooth bed compare to corresponding rough bed reading.
Spacing 10cm (case 2) shows better results than 7cm (case1) spacing with respect to sequent depth ratio, length of jump and energy loss for both smooth and rough bed.

Variation of Fr1 and Lj/Y1 for different slope (Both case)

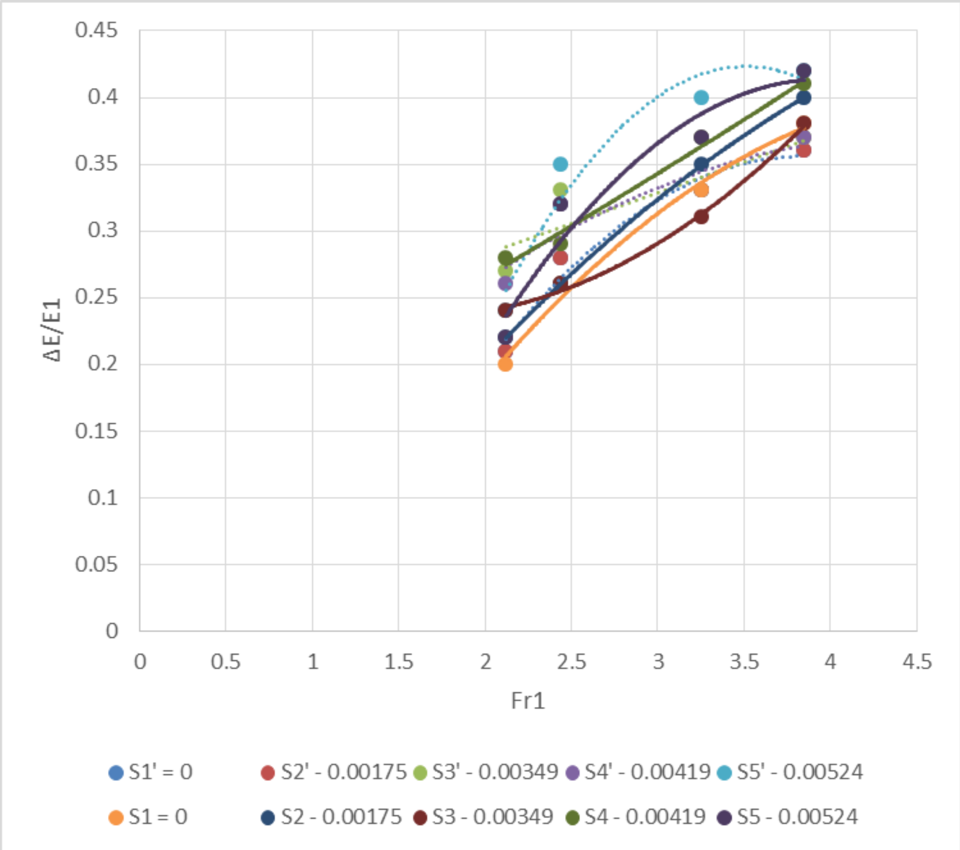


Graph 4.38 Variation between Initial Froude no. and Lj/Y1 ratio for different slopes (spacing 7.5 cm and 10 cm)

Graph no. 4.38 is based on the observations shown in all table of case 1 and 2 for rough bed, For small slope length of jump is higher which decreases with increase in slope. Further with increase in Froude no. the length of jump also increases in both the cases (smooth and rough) but higher values obtained for smooth bed compare to corresponding rough bed reading.

Spacing 10cm (case 2) shows better results than 7cm (case1) spacing with respect to sequent depth ratio, length of jump and energy loss for both smooth and rough bed.

Variation of Fr1 and ΔE/E1 for different slope (Both case)



Graph 4.39 Variation between Initial Froude no. and ΔE/E1 ratio for different slopes (spacing 7.5 cm and 10 cm)

Graph no. 4.39 is based on the observations shown in all table of case 1 and 2 for rough bed, For small slope energy loss is less which decreases with increase in slope. Further with increase in Froude no. the energy loss also increases in both the cases (smooth and rough) but higher values obtained for rough bed compare to corresponding smooth bed reading.

Spacing 10cm (case 2) shows better results than 7cm (case1) spacing with respect to sequent depth ratio, length of jump and energy loss for both smooth and rough bed.

CONCLUSION

A laboratory investigation evaluate the effect of channel slope over rough bed on the properties of hydraulic jump, namely the sequent depth ratio, Length of jump and Energy loss. Hydraulic jump characteristics were measured in a horizontal and inclined (adverse) rectangular flume in which the bed was artificially roughened. Both Sequent depth ratio and length of jump on rough bed was less than smooth bed. On the other hand the more energy loss occurred on rough bed than smooth bed. The following conclusion are drawn, from results

- In both smooth as well as rough bed increase in negative slope causes decrease in the sequent depth ratio and lesser values are obtained for inclined rough bed compare to smooth bed.
- As we increase the adverse slope causes decrease length of jump in both smooth as well as rough bed and lesser values are obtained for inclined rough bed compare to smooth bed.
- In both smooth as well as rough bed increase in adverse slope causes higher energy loss and higher values are obtained for inclined rough bed compare to smooth bed.
- Spacing 10cm (case 2) shows better results than 7cm (case1) spacing with respect to sequent depth ratio, length of jump and energy loss for both smooth and rough bed.
- The reduction in jump length and sequent depth greatly depended on the Froude number. For small Froude numbers the amount of reduction was low while large value Froude numbers showed a higher reduction.
- Corrugated beds confirmed the effectiveness for energy dissipation at downstream and reduce the cost of the stilling basin.
- With increase in Froude no. the sequent depth ratio also increases in both the cases (smooth and rough) but higher values obtained for smooth bed compare to corresponding rough bed reading.
- With increase in Froude no. the length of jump also increases in both the cases (smooth and rough) but higher values obtained for smooth bed compare to corresponding rough bed reading.
- With increase in Froude no. the length of jump also increases in both the cases (smooth and rough) but lesser values obtained for smooth bed compare to corresponding rough bed reading.

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