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# Investigation of the 2D flow model in the spillway with different geometries

Project Submitted to the department of environmental engineering of the University of Babylon in partial fulfillment of the requirements for the degree of B.Sc. of philosophy in environmental engineering.

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# <u>List of Samples</u>

| Sample | Definition |
|---|---|
| **A** | **Area (m2)** |
| **$E_0$** | **at the upstream end of spillway Energy** |
| **Ec** | **The critical energy over crest** |
| **Zo** | **The elevation of crest** |
| **Ed** | **The energy at the downstream end before the hydraulic jump** |
| **G** | **gravity ($m/s^2$).** |
| **H** | **Head of water on weir (m).** |
| **Zo** | **The invert elevation of the flume** |
| **A** | **The kinetic energy correction coefficient** |
| **Q** | **Discharge $(m^3 / s)$** |
| **V** | **Velocity (m/s)** |
| **Y1,Y2** | **Depth of flow** |

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# Abstract

The purpose of this study was to evaluate the hydraulic performance and efficiency in energy dissipation for proposed model to spillway. The proposed model contain six pipes interference through the body of spillway , pipes are regulated in the form of two columns and three rows, Pipe ends in the first row and the first column with elbow has $90^0$ introspective pipes the second column that mean corresponding to the pipes per row. This in turn leads to a collision of water mass Emerging from Pipe in the first row of the first column with the mass of water coming out of pipe in the first row of the second column, other words there are two forces opposing equal the amount of direction affect one point in each row of pipes.

Where the proposed model were manufacture and operate in the laboratory have been got a high percentage of dissipation of up to 78% to 84% through the operation of the model for 19 times.

From the above, the proposed model successful in terms of hydraulic energy dissipating in addition to reducing the costs required by some traditional treatments to traditional spillway.

# CHAPTER I

# INTRODUCTION

## 1.1 Background

Critical issues governing the performance of hydraulic structures such as spillways and chutes include the stability and safety of the structure itself. A stepped spillway aims to dissipate the energy of the water flow, thus decreasing the stilling basin volume and the risk of cavitation, and to enhance the aeration process, thus increasing the dissolved oxygen (DO) concentration. The energy dissipation is the main parameter affecting most hydraulic structural designs because the high kinetic energy of the water flow can cause scouring downstream (DS). Furthermore, hydraulic structures can improve aeration efficiency according to their geometry. One of the main purposes of aerating water is to raise the DO concentration. Hydraulic structures are of two common types: high-head flow systems and free-surface flow systems (Baylar et al. 2010). Stepped cascades have been used in hydraulic structures to dissipate energy and reduce scouring of the water channel. Stepped cascades are included in the spillways of dams, river weirs, irrigation channels and stormwater systems, and one example is the spillway of Gold Creek dam in Brisbane, Australia. Importantly, hydraulic structures must be designed to discharge water in a safe way and to prevent damage to the structure itself and the surrounding locations. Moreover, the flow over the stepped spillway has been characterised by free-surface aeration downstream of the inception point of air entrainment. While the energy dissipation overstepped spillway has been investigated in previous studies, the optimum design for stepped spillway regarding the aeration process is not known. Felder and Chanson (2009) described the energy losses and aeration processes of stepped cascades with moderate slopes and found that increases in the rate of reaeration are related to increases in the rate of energy loss. According to Aras and Berkun (2008), hydraulic structures affect the gas transfer dynamics of white-water. The DO is the most significant parameter related to water quality in rivers and streams. In addition, Baylar et al. (2007) stated that hydraulic structures can create turbulent conditions that increase DO levels as air bubbles, especially small ones, are transported into the bulk of the flow as chute aeration. Medhi et al. (2019) described the flow over the stepped spillway as a complex flow with different characteristics from other types of spillways. The flow being complex is also a reason to obtain better performance."

The high kinetic energy of water flowing over a spillway should be dissipated in stilling basins before reaching the downstream channel to reduce scour of downstream riverbed. Different common designs of stilling basins are available. These basins are usually equipped by a combination of chute blocks, baffle blocks, and end sills. Chute blocks furrow the incoming flow and lift a portion of it above the floor. These blocks stabilize the Baffle blocks installed on the stilling basin floor between chute blocks and the end sill. These blocks are used to stabilize the formation of the hydraulic jump, increase the turbulence to produce more energy dissipation. The hydraulic jump improves its performance, and decreases its length. End sills are used to reduce the length of the hydraulic jump and to control scour.

Spillways are one of the most important parts of dams. Dissipation of the energy of the high velocity flow becomes critical for the safety of the dam and downstream structures. Designers have looked for the most efficient methods to the dissipation of energy amounts generated because of difference in head between upstream and downstream of dams. Energy dissipation process can be accomplished in various techniques:

1. high velocity water nappe expelled from a flip bucket and impinging into downstream pool
2. forcing a hydraulic jump downstream by constructing a stilling basin with an artificial macro-roughness.
3. Construction of stepped spillway to dissipate energy through turbulence created over the spillway face..

Spillway surface was used to dissipate the energy in the ancient past by constructing a stepped spillway. The steps increase the rate of energy dissipation taking place along the chute and reduce the size of the required stilling basin. This study attempts to make use of the spillway length to fix energy dissipation blocks to reduce basin will be more efficient, shorter, and more economic.

## 1.2 Objectives of the Study

This study attempts to calculate and evaluate the energy dissipation by using a new model in spillway.

# CHAPTER II

# LITERATURE REVIEW

## 1.1 Introduction

This chapter presents a review of previous studies on energy dissipation structures by using physical models.

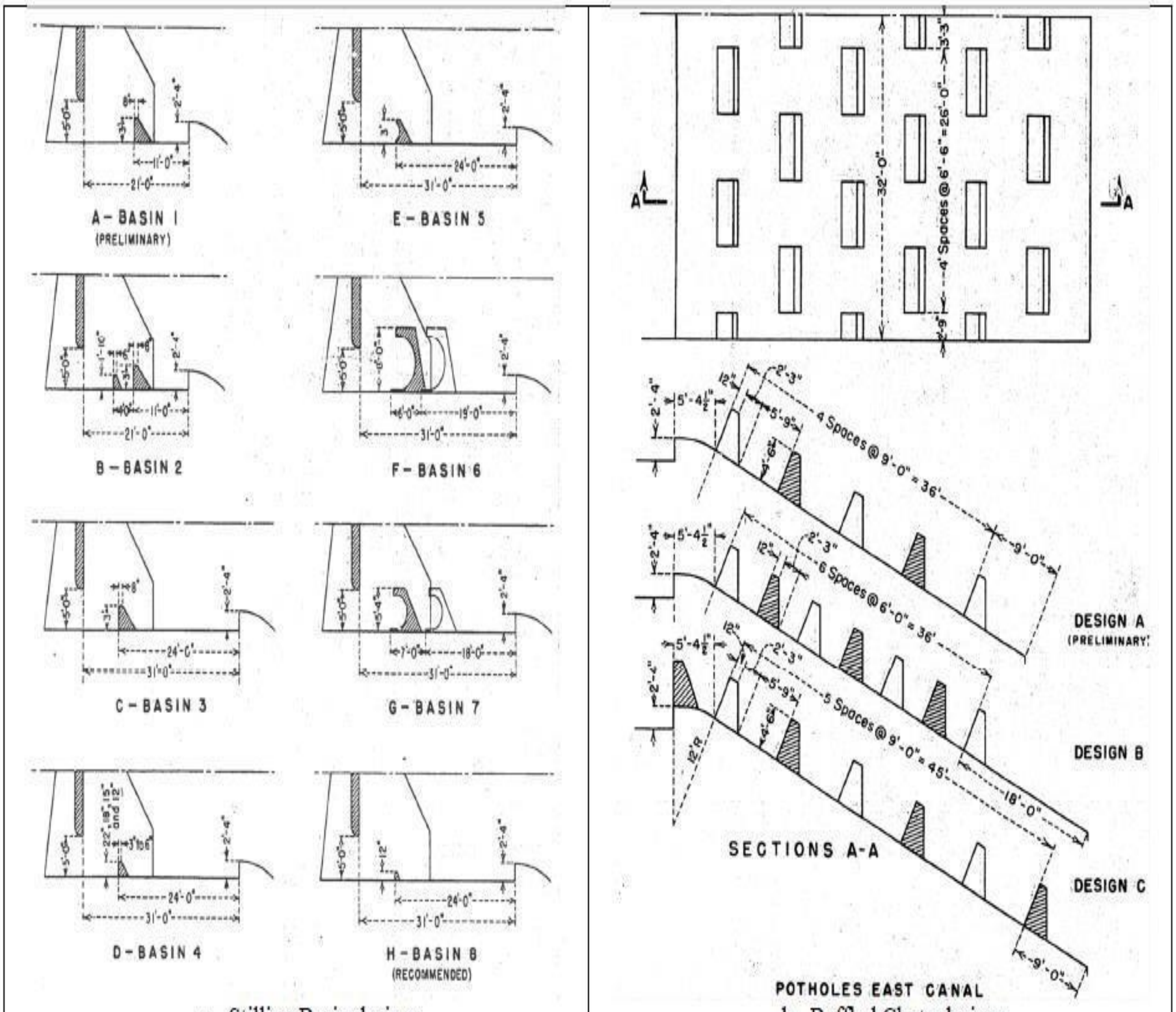
Spillways are very significant hydraulic structure utilised in rivers, channels and dams. The dissipation of the energy of high-velocity flow is critical for the safety of structures and downstream zones. Most studies have investigated the most efficient methods of dissipation of the energy generated by the changes in head values in the upstream (US) and downstream (DS) of the hydraulic structure (stepped spillway). Energy dissipation can be accomplished by various techniques, such as 1) expelling high-velocity water nappes from a flip pail that then plunge to the DS part, 2) forcing the hydraulic jump DS by constructing a stilling basin with artificial macro-roughness, and 3) building a stepped spillway to dissipate the energy through turbulence created by the flow on the spillway face.

Spillways were built by many ancient civilisations, and the remains of some of them still exist. The world's oldest stepped channels were possibly a group of stepped culverts built in Crete during 1500 BC (Chanson 2002). According to Chanson (1995), the presumed first creation stepped spillway in Arkanania, Greece, was constructed about 1300 BC. The Assyrian King Sennacherib built two dams over the Khoser River in Northern Iraq around 694 BC that included a stepped spillway arrangement. These dams (named Ajilah) were created to provide water to Nineveh (Assyrian city) in Iraq. In addition, Nabataeans, Romans and Sabaens built many stepped spillways. The remains of Roman spillways are still found in Syria and Tunisia. Furthermore, a stepped spillway was built over the Adheim Dam in Iraq (Chanson 2002). Even at the beginning of the 20th century, some stepped spillways (such as New Corton Dam, 1903) were constructed without following any definite design rules. The first contributions in stepped spillway research were by Essery and Horner (Horner 1969; Essery & Horner 1978). After the 1980s, the development of new creation techniques, such as the gabions and roller-compacted concrete, reduced costs and construction time. Since the 1990s, extensive research has been conducted on the main characteristics of stepped spillways (Chanson 1993). Stepped spillways are defined as a series of drops that provide artificial roughness on the spillway slope (Chanson, 1994a).

Flow over stepped spillway includes three flow regimes: 1) Nappe flow (NA) regime for the low flow rates, 2) Skimming flow (SK) for large flow rates and 3) Transition flow (TR) for intermediate flow rates. Compared with smooth spillways, flow oversteps are accompanied by large amounts of air entrainment because of greater boundary layer development from macro-roughness effects. The main advantage of stepped spillways is their high energy dissipation, which can reach 99% of the total available head (Chanson 1993), reducing the need for a DS stilling basin. In addition, the higher level of aeration and higher relative depth over the spillway reduces the risk of cavitation. Stepped spillways are used for low to moderate discharges; however, for large discharges, other types of spillways and energy dissipaters can be used. Stepped spillways have many applications.

Also, in the flow regimes, there are two classifications for the flow over stepped spillways. There are two flow regimes in the first classification: Nappe flow regime (NA) and Skimming flow regime (SK). Essery and Homer (1971) noted that the flow properties importantly affect the characteristics of flow regime on the stepped spillways. According to the relationship between the flow characteristics and flow regime, flow regimes are of two types: NA and SK. In NA regime, the water mass forms a series of plunges over the steps, and the flow is subcritical on most of the steps or part of it. In contrast, in the SK regime, water mass moves similar to a regular stream over all the steps and supercritical flow throughout. For the second classification, regimes of the flow are divided into three regimes. Regimes of the flow are NA (low discharges), SK (high discharges) and TR. Researchers in the hydraulic field consider the NA regime to be the highest efficiency regarding the energy dissipation and the efficiency of aeration (Pegram et al., 1999).

Wagner, W. E., 1956, carried out experiments on physical models of a check intake structure to determine the adequacy of the stilling basin and the effectiveness of the baffles piers in slowing the flow. This structure serves as a check to maintain the water surface elevation in the canal and to control the flow entering the Scooteney Reservoir. This structure was designed to pass a maximum discharge of 110$m_3/s$ controlled by three radial gates. After passing the gates, the flow enters a short stilling basin, then passes over a sill and flows down a baffled chute with a slope of 2:1. A physical model with a scale of 1:16 was constructed for this purpose. The model included about 52*m* length of the Potholes East Canal, gate structure, stilling basin, baffled apron, and approximately 24.5*m* of the outlet channel. For the erosion studies, the downstream channel of the baffled chute was molded in sand having a mean diameter of approximately 1*mm*. He carried tests on three designs of baffled chute with different arrangements and eight designs of stilling basins, as shown in Figure 2-1. The effectiveness of the baffled chute was evaluated by the amount of scour in the downstream channel and by the appearance of the flow on the chute. From investigation tests, the baffled chute design C with the stilling basin design 8 gave the best stilling basin performance with a least scour in the outlet channel. The stilling basin design 8 have a length of 9.5*m* and is equipped with 0.3*m* baffle piers were located immediately downstream the gates. The baffled chute was consisted of seven rows with a spacing of 2.75*m*, the upper row of piers was located on the top of the sill. The scour tests indicate that the excessive scour was due to the side eddies which formed at the end of training wall.



a- Stilling Basin designs
b- Baffled Chute designs

**Figure 2. 1 Potholes East Canal Intake structure, *Wagner, 1956*.**

Pillai, N. N., and Unny, T. E., 1964, carried out experimental studies to evaluate the effectiveness of the shapes of appurtenances in the stilling basins on energy dissipation. They used different shapes of baffle blocks with different apex angles of $60_o$, $90_o$, $120_o$, $150_o$, and $180_o$. These blocks have the same dimensions for all types with a width of $3y_1$ and a height of $2.5\ y_1$, in which $y_1$ is the pre jump depth.

Experimental results indicated that the baffle blocks with an apex angle of 120° are most effective in dissipation the excessive energy of flowing discharges. They found that the energy dissipation decreases as the baffle block width decreases to $2y_1$. Also they found the sequent depth is increases as block height increases.

Rand, W., 1966, carried out a laboratory tests on a physical model to evaluate the performance of each continuous and dentated end sill at the energy dissipation in the stilling basin. Many types of dentated end sill were tested in his study, with a constant thickness of 1.9*cm* in the model. The width and spacing of the blocks was varying but remain equal to each other. The ratio of the spacing to the sill height was 3/4. Results showed that the continuous sill is more efficient in stabilizing the forced hydraulic jump, reducing the required subcritical tailwater depth, and in producing a relatively short basin length. Rand was recommended to study and determine if the advantage of the continuous sill are sufficient to warrant the general replacement of the dentated of baffle sill by a continuous one. Basco, D. R., and Adams, J. R., 1971, tried to improve the design of the forced hydraulic jump energy dissipators by implementing model studies of specific stilling basins. Several baffle blocks shapes were used in their study with a standard-shape that recommended by United States Bureau of Reclamation. These baffle blocks were fixed with two rows. They proved that the ratio of drag force on the baffle blocks to free jump hydrostatic tailwater force for the same inlet Froude Number is most indicative of the effectiveness of baffle blocks in the forced jump. They indicated that the maximum value of the ratio of the total drag force on the baffle blocks to the free jump sequent depth hydrostatic pressure force is about 0.36. Their results enables designers to compute the drag force and 6 resulting tailwater depth for any block height and location combinations with an inlet Froude Number of a range between 3 and 10. Drag force increased when blockage ratio (w/w+s) increasing or by moving a second row nearer the first row, w is the block width and s is the spacing between the two adjacent blocks.

Bhowmik, N. G., 1971, conducted laboratory tests to investigate the possibilities of increasing the energy loss and shortening the required basin length for a particular range of Froude Number of 2.5 to 4.5. Tests were made in a glass walled tilting flume. The hydraulic jumps on the horizontal floor were developed with the aid of a sluice gate. Jumps were forced to form in a particular location by the addition of appurtenances, such as baffle blocks and end sills. The tail-water depth was simulated by controlling the downstream depth with a tail gate in the flume. Data were collected for both the ordinary hydraulic jump, jump in a horizontal rectangular basin, basin A, and the forced hydraulic jump. Out of the many different basins and arrangements utilized in the laboratory, basins B to K as shown by Figures 2-2 and 2-3, a set of appurtenances and geometrical arrangements designed for basin L was found to perform satisfactorily. Comparison of the basin L test data for the forced hydraulic jump with the data from an ordinary hydraulic jump for the same Froude Number shows that the energy loss can be increased, the required downstream depth of water can be about 5 percent less than the sequent depth, and the jump can be formed in a much shorter basin. Some wave activity was found to be present in the stilling basin, and the spill that might occur can be prevented by proper design of freeboard.

Rhone, T. J., 1977, noted that the presently used design standards were established with a maximum unit discharge of 60 *cfs/ft* width (5.6 $m_3/s/m$), and an approach velocity of less than the critical velocity of the design flow based on the design discharge. He tried to generalize the design criteria for higher unit discharges by using a hydraulic physical mode with a scale of 1:33 with a unit design discharge of 300 *cfs/ft* (28 $m_3/s/m$). The initial configuration was obtained by extrapolating the criteria used for canal structures.

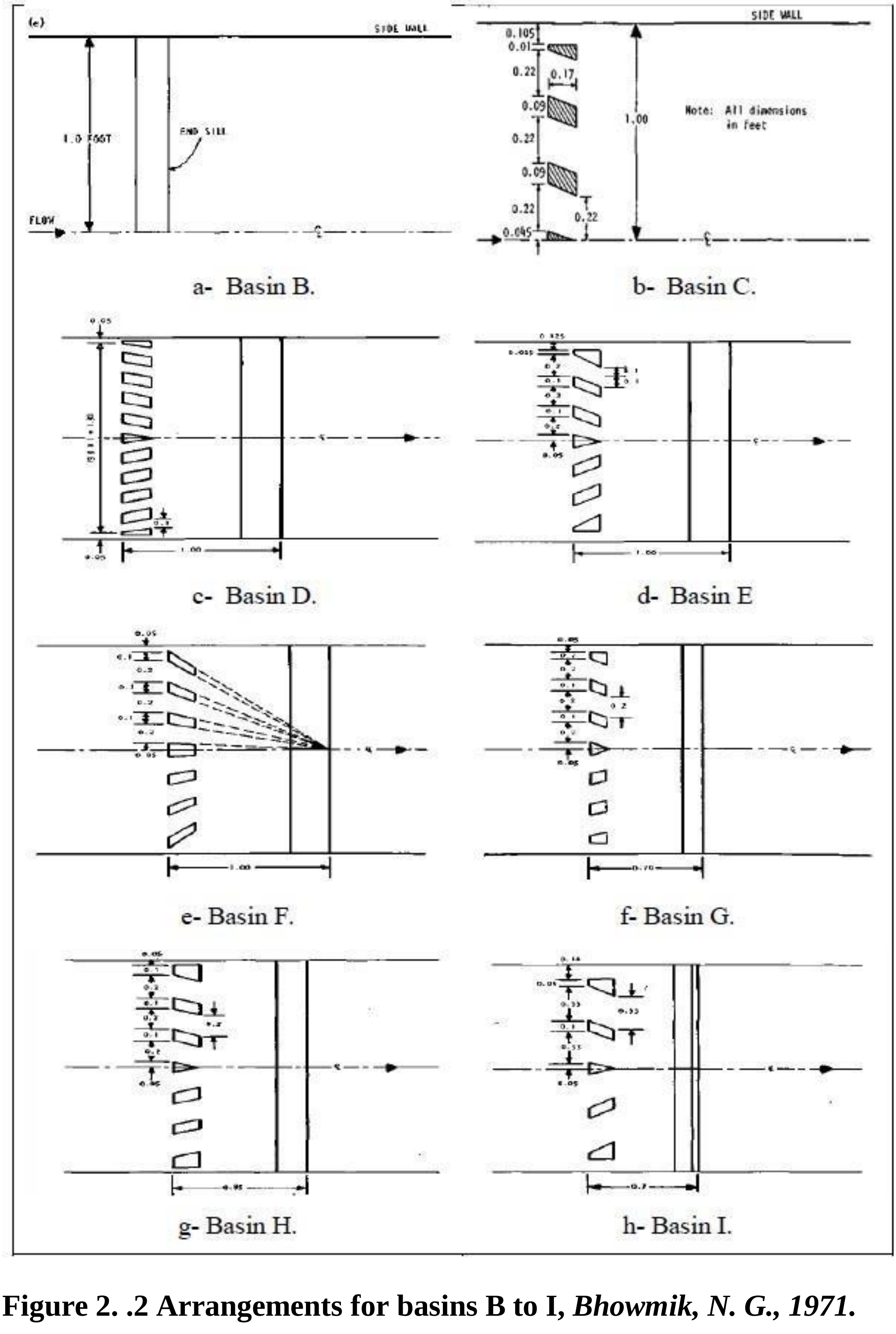



**Figure 2. .2 Arrangements for basins B to I,** ***Bhowmik, N. G., 1971.***

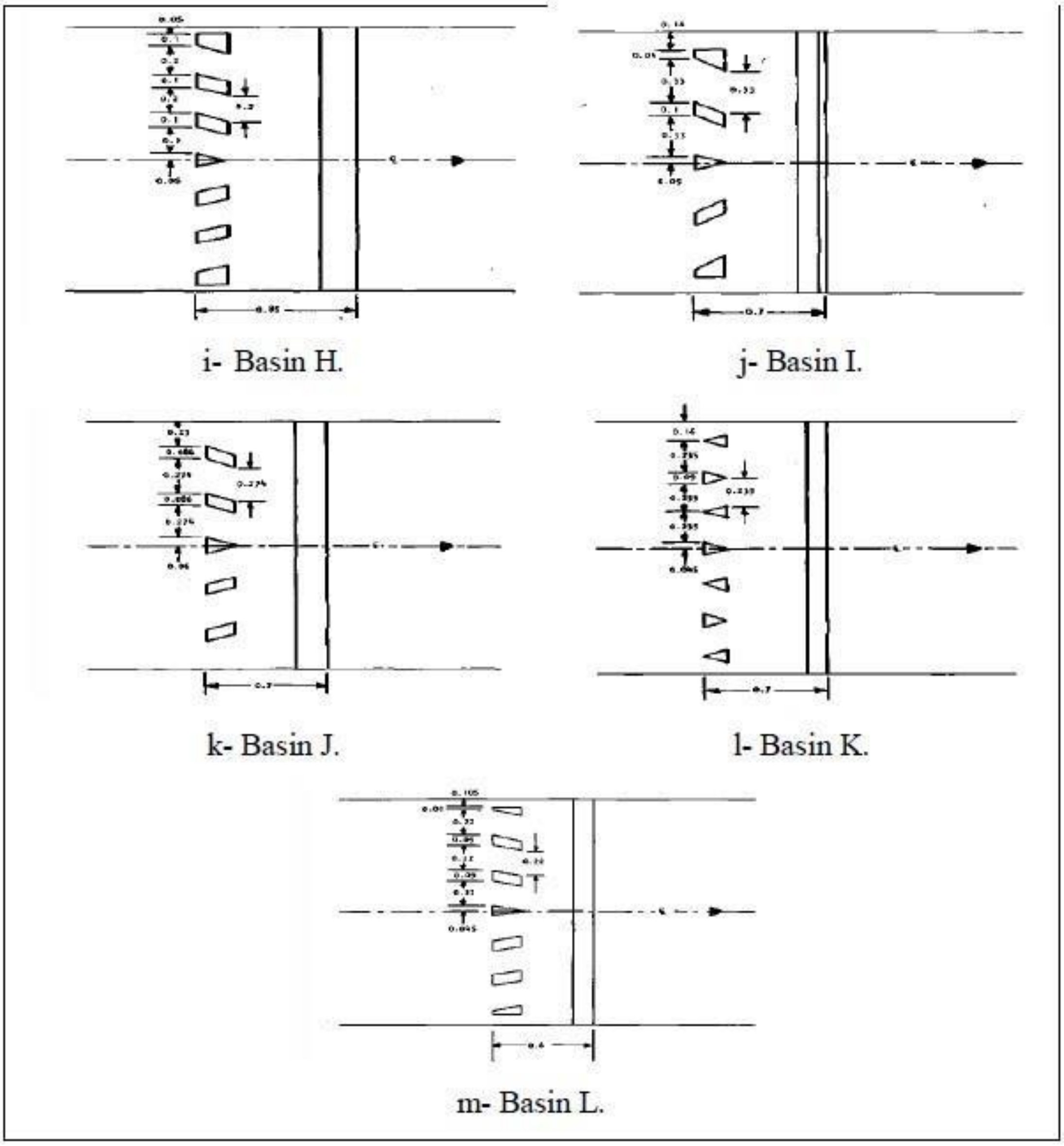



**Figure 2. .3 Arrangements for basins H to L*, Bhowmik, N. G., 1971.***

A sloping apron of 2:1 was used with a downstream erodible sand bed in a tail box. He tested standard blocks with different sizes and row spacing. Many piezometers were installed to measure the pressure at the side and the top of the sloping apron. The experimental tests were indicated that no changes in flow conditions compared with that at lower unit discharges. Also, there was no increase in the impact pressures after the third row of baffles. Comparing with lower discharge, the flow at the design discharge produced less splash, spray and an apparently smoother 9 water surface. Some test runs were made with discharges greater than design and in all cases the flow appearance was improved less splash, spray, and bottom erosion was moderately greater. The results show that the erosion at the base of the structure was moderate for all tests. The measured pressures were near the atmospheric pressure for all flows, this indicate a full aeration take place. The results were usually poorer flow conditions on the chute such as excessive splash or an increase in velocity down the chute. The row of blocks at the top entrance of the chute caused a significant increase in the water surface elevation at the upstream of the chute. Experimental results showed that the concept of a baffled apron could be used in lieu of spillway energy dissipaters at larger unit discharges. This study indicated that this type of structure was satisfactory for any discharge but structural and size-of-block limitations might control the quantity of the design unit discharge.

Peterka, A. J., 1983, studied the use of baffled apron for canals and spillway drops. He mentioned that the baffled aprons or chutes have been used on irrigation projects for many years, and many of these structures have performed satisfactory indicates that they are practical and that in many cases they are an economical answer to the problem of dissipating energy. Furthermore, he mentioned that the multiple rows on the chute prevent excessive acceleration of the flow and provide reasonable terminal velocity, regardless the height of the drop. Since the flow passes over, between, and around the baffle piers, it is not possible to define the flow condition in the chute in usual terms. The flow appears to slow down at each baffle pier and accelerate after passing the pier, the degree depending on the discharge and the height of baffle piers. He carried out filed and laboratory studies on different baffled aprons. Based on his hydraulic model tests made for a particular structure, some of the existing structures were modified. Other designs for existing structure were obtained by modifying model tested designs to the extend believe necessary to account for local changes in topography and flow conditions. He obtained a generalized design procedure based on tests results on several models of baffled chutes and from the model which was 10 modified as necessary to obtain information of value in designing a chute for any installation.

Eloubaidy, et. al., 1998, performed an experimental study on the effects of relative size, curvature, and location of curved baffle blocks at the energy dissipation and control the hydraulic jump. Fourteen types of baffle blocks were used with different sizes, curvatures, and arrangements under different flow conditions. The experimental results indicated that, for all flow conditions, the curved baffle blocks were more effective in lowering the downstream kinetic energy than the regular straight one. In addition, the curved blocks provided better stability to the hydraulic jump. Rageh, O. S., 1999, investigated and analyzed the effects of baffle blocks on a radial hydraulic jump to derive limiting design parameters for this type of jump in expanding channels. Laboratory experiments were carried out in a fixed-bed flume with a rectangular cross section and for a Froude Number ranged between 2 to 2.5. The results indicated that the energy loss and the sequent depth for a radial hydraulic jump were affected by baffle blocks. Ead, S. A., and Rajaratnam, N., 2002, carried out an experimental study on hydraulic jumps over a round shape corrugated bed under a Froude Numbers range of 4 to 10. A range of 0.25 to 0.5 of the relative roughness was considered. They concluded that the tailwater depth required for the hydraulic jump over corrugated bed is less than that required for jumps over smooth bed and the jump is approximately half of that which occurs over a smooth bed.

Chaudhry, Z. A., 2008, mentioned that statistics and studies made by International Commission on Large Dams showed that more than 20% of dam accidents occurred due to poor provision of energy dissipation arrangements. He studied and discussed the damage of Jinnah Barrage in Pakistan. He concluded that the hydraulic jump do not form over the glacis rather sweeps on the floor. He concluded that The un-dissipated energy is causing damage to the impact blocks, the adjacent concrete floor and downstream loose stone apron. Hayawi, H. A., and Mohammed A., Y., 2010, studied the properties of a hydraulic jump and energy dissipation downstream sluice gate in a rectangular channel. Three gate opening 2, 3, 4*cm* were used to carry out the experiments. They found that energy dissipation through the hydraulic jump is a function of Froude, Weber Numbers and gate openings. The energy dissipation decreases as Weber Number increases and increases as Froude Number increase. Edijatno, et. al., 2011, conducted a physical hydraulic model investigation to evaluate the performance of Dawuan weir at SitubondoEast Java. which is a standard spillway with $72_o$ slope and to compare the results with a stepped spillway design. It was found that for the stepped spillway with 32 steps could reduce the length of hydraulic jump by about 47.61%. The percentage of energy loss of stepped spillway was approximately 92.59%.

Negm, et. al., 2003, carried out theoretical and experimental studies on the relative depth and relative energy loss of submerged hydraulic jump formed in a sudden drop and radial stilling basin. properties of a hydraulic jump and energy dissipation downstream sluice gate in a rectangular channel. The model length was kept constant and the angle of the divergence was kept constant to 5.28°. A fixed height of the drop was used in different positions downstream from the gate opening were tested under the same flow conditions. The range of Froude Numbers was between 2.0 and 7.0. Each model was tested using five different gate openings and five discharges for each gate opening. The measurements were recorded for several submergence ratios for each discharge. Results show that the relative depth and long of the submerged hydraulic jump was increased and the relative energy loss was decreased, when the submergence ratio, height of vertical drop and the position of the drop measured from the beginning of the basin increasing. Froude Number has the same effect at the free and the submerged hydraulic jump there occurs at a stilling basin without vertical drop. The water surface profiles for submerged jump in radial basin with drop have a similar nature to those obtained for a basin without drop. Due to the effect of the drop height, the 15 water surface profiles considering a drop are higher than the corresponding one for basins without drop. From results, the increasing in the water surface depth depends on the height of the drop and the rate of energy loss through the jump. Also, the energy loss by the submerged radial jump is more than that of the corresponding one in rectangular basin and similar observation is valid for the free jumps. The lesser energy loss is associated with the greater submergence. Results indicated that at a particular relative location of the drop, the relative water depth, relative energy loss, and relative length of jump increase by increasing Froude Number keeping the submergence unchanged. Also, it is proved that the relative water depth and relative length of jump increase by increasing the submergence ratio at a specific Froude Number. The increasing of the submergence will reduces the relative energy loss with a keeping other factors unchanged. Also, by moving the drop away from the gate, within the basin, the relative water depth and relative length of the submerged jump will be increases and the energy loss ratio will be decreases. They indicated that equations obtained by the theoretical analyzed is in good agreement with the experimental results.

# CHAPTER III

# LABORATORY WORK

## 3.1 General

This chapter presents the shapes and dimensions of the used proposed case, details of the weir and stilling basin physical model, which were used to test the effectiveness in the energy dissipation, Froude Number, and the hydraulic jump characteristics. Moreover, this chapter summarizes the laboratory tests that were carried out on the proposed model and configurations.

## 3.2 Model Scale Factors

The model must behave as a prototype, so that the model results can represent the actual scale by a proportionality factors. To achieve the same behavior, the model must be geometrically, kinematically, and dynamically similar to the prototype, Hauke, 2008. There are a number of phenomena that might be important in hydraulic flow such as viscous effects, surface tension, and gravity effect. The use of the same fluid on both prototype and model prohibits simultaneously satisfying the Froude, Reynolds, and Weber Numbers scaling criteria. The Froude Number similarity requires that $V_r=\sqrt{L_r}$, the Reynolds Number scaling implies that $V_r=1/L_r$, and the Weber Number similarity requires $V_r=1/\sqrt{L_r}$. In most cases, only the most dominant effect is modeled. In free surface flow, gravity effects are always important and Froude Number modeling is used, Singh, B., 1973. When this equality is maintained and the same fluid is used in the model as in the prototype, a certain distortion occurs in the Reynolds number which defines whether the flow is laminar or turbulent. This is easily can be solved when the Reynolds Number on the model is always greater than the critical Reynolds Number denoting the transition from laminar to turbulent flow, Novak and Cabelka, 1981. In this study, minimum Reynolds Number that was adopted equal to 2000, above this value either viscous effect

becomes insignificant at high Reynolds numbers or becomes independent of the Reynolds number, Vennard and Street, 1976. Moreover, surface tension, the vortex and entrainment effects in model studies can be neglected when the Weber Number is higher than a value of 11, Yazdandoost and Attari, 2004.

Physical model used in pressure distribution around on the proposed model were constructed with dimensions that accomplish a turbulent flow and a high Froude Number. Physical model that represent existing structures were constructed with a geometric scale of 1:50, that is $L_r = L_p/L_m = 50$. With this geometrical scale, scale factors for other quantities were calculated and are listed in Table 3-1.

**Table 3. 1 Physical models scale factors.**

| **Parameter** | **Relations** |
|---|---|
| **Discharge** | $Q_r = V_r L_r^2 = L_r^{2.5}$ |
| **Energy** | $E_r = L_r^4$ |
| **Force** | $F_r = L_r$ |
| **Pressure** | $P_r = F_r / L_{r2}$ |
| **Reynolds number** | $R_r = L_{r\ 1.5}$ |
| **Time** | $T_r = \sqrt{L_r}$ |
| **Velocity** | $V_r = \sqrt{L_r}$ |

### 3.3 Proposed Model

The proposed model was made from wood with plastic pipes passing through the wooden body, the pipes have 2 inches diameter with elbows have angel =900 in the ends of the pipes and length was 30cm, Wooden body measurements were right-angled triangle a height of 30cm the base 30cm and width of 30cm and figures (31),(3-2)and (3-3) shows the proposed model .

**Figure 3. 1 Proposed Model.**


**Figure 3.  2 Side view of the proposed Model.**

**Figure 3.  3 Front view of the  proposed Model.**

## 3.4 Discharge and its Calibration

Before conducting any laboratory run, two issues forefront. First, at what range of discharges should models operate? Second, how discharges will be measured, and how accurate this measurement is?

Different flow regimes exist in the proposed spillways and these regimes vary for a given geometry with discharge; thus discharges must be selected such as to cover these regimes, specifically the skimming flow regime, as it is the one most adopted for design purposes. Typical case dimensions are used to define the boundaries of these regimes.

Thirteen runs were conducted for all models and Table 3.2 shows the discharges and their regimes. Due to the limited capacity of the flume larger discharges could not be tested. Discharges were computed using critical depth measurements over broad crested weir. A movable point gauge, with accuracy of 0.1 mm, on a trolley mounted on the flume side rails, allowing longitudinal and transverse movement, was used to measure water depths .The positioning accuracy of trolley is (1 mm). Figure (3.4) show the flow over the spillway when measuring the discharge and Figure (3.5) shows a view of installed point gauge .

**Table 3. 2** Obtained rating curve of the traditional model.

| **Run no.** | **Head above weir crest, H *cm*** | **Discharge *l/s*** |
|---|---|---|
| **1** | **4.78** | **7.4** |
| **2** | **4.54** | **6.88** |
| **3** | **4.32** | **6.1** |
| **4** | **4.05** | **5.4** |
| **5** | **3.57** | **4.3** |
| **6** | **3.07** | **3.4** |
| **7** | **2.67** | **2.7** |
| **8** | **2.25** | **2.2** |
| **9** | **2.08** | **1.9** |
| **10** | **1.85** | **1.5** |
| **11** | **1.58** | **1.2** |
| **12** | **1.39** | **1.0** |
| **13** | **1.16** | **0.8** |

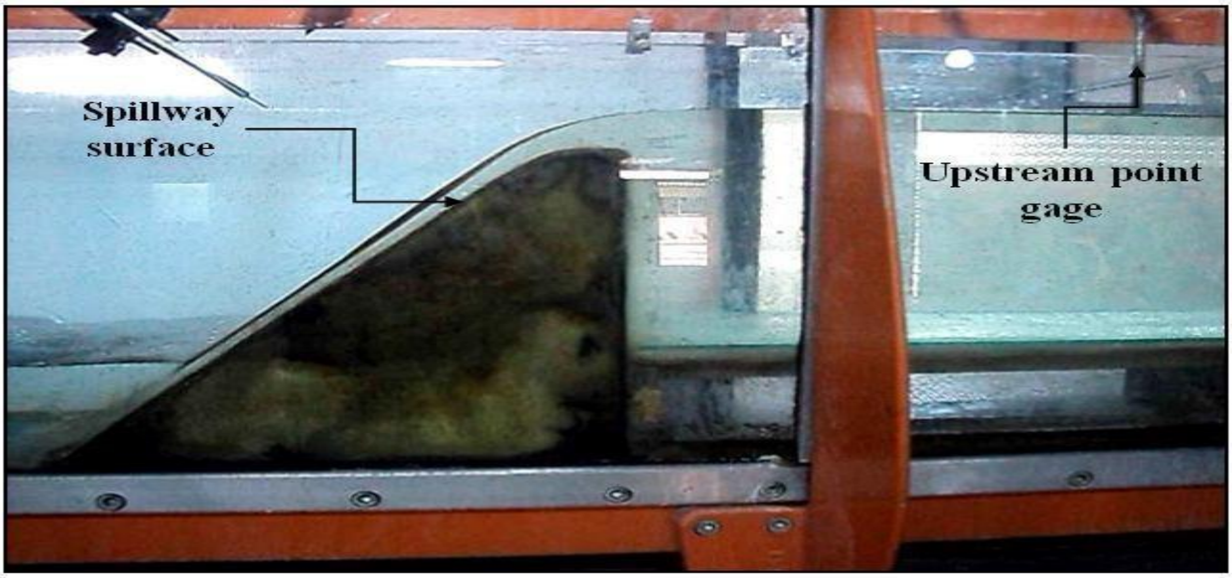



**Figure 3. 4 Flow over the spillway when measuring the discharge.**

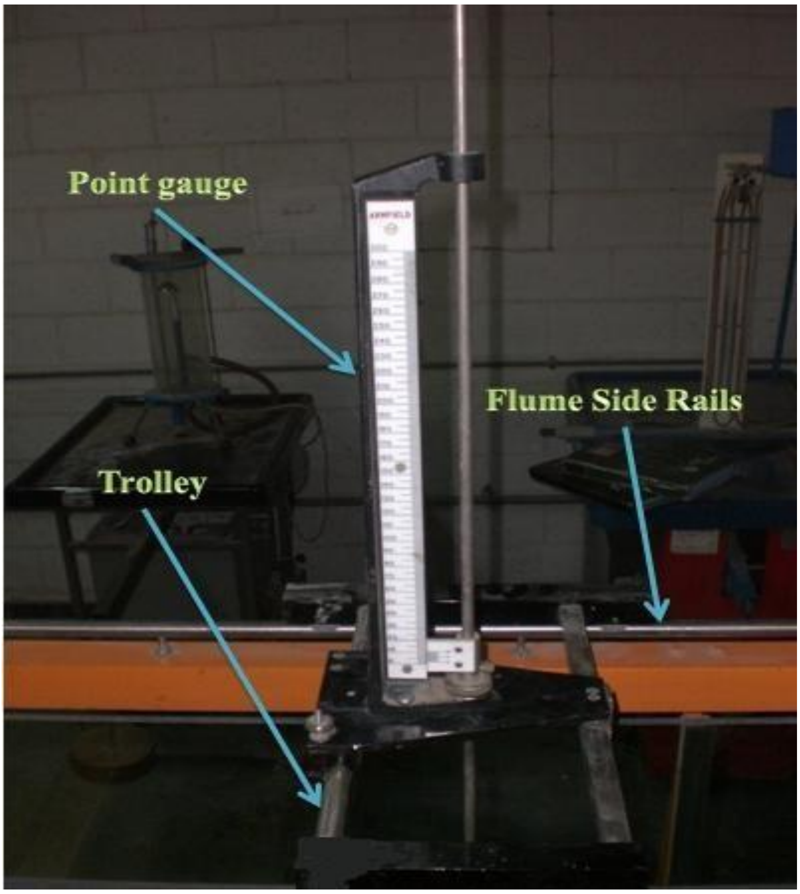



**Figure 3. 5 Point gauge, trolley, and flume side rails**

### 3.5 Measuring of Energy

The main objectives of this work is to find out energy dissipation efficiency for each case; Energy, Eo, at the upstream end of spillway is computed by

$E_0=Z_0+E_C$ ....................................................................3.1

$E_c$ is the critical energy over crest, $Z_o$ is the elevation of crest and equal to spillway height considering the invert of the flume as datum, $g$ is the gravitational acceleration and equal to 9.81 m/s$^2$. The energy, $E_d$, at the downstream end, before the hydraulic jump, is expressed in the following formula,

$Ed= Z_0+P/\gamma+\alpha\ V^2/2g$ ....................... 3.2

$Z_o$ is the invert elevation of the flume and is equal to zero, $\alpha$ is the kinetic energy correction coefficient. Boes and Hager (2003b) observed that $\alpha$ =1.1. The velocity head is calculated from discharge and water depth at downstream end of spillway. The depth at this section, or clear water depth, is back calculated from the sequent depth of the hydraulic jump at the downstream end of spillway. This method is widely used by many researchers Peyras et al. (1992). The principle behind it is to measure, $Y_2$ the sequent depth of hydraulic jump at the toe of spillway, where $Y_2$ is the clear, non-aerated, water depth, then calculating $Y_1$ the upstream initial depth entering the jump, by the hydraulic jump formula (Chow 1959):

$$\boldsymbol{Y_1 = \frac{Y_2}{2}\left(\sqrt{1+8(Fr_2^2)} - 1\right)} \quad \text{……………..3.3}$$

This method avoids the need to measure the clear water depth at the spillway toe, as the flow at this section is characterized with a two phase flow nature. It is necessary that the hydraulic jump is located such that $Y_1$

of the jump represents the clear water depth at the toe of spillway. If measurements are precisely made, the energy at the toe of the spillway could be very accurate; For instance, Pegram et al. (1999) discovered 2% error in his range of reported flows.

Andre' (2004) carried out a sensitivity analysis to study the effect of the jump position on the computation of residual energy at the toe. She discovered that the residual energy will be overestimated if the jump submerges the last steps (about 13% for the last two drowned steps); and will be underestimated about 3% if jump is far from the base of the last step. She concluded that the optimum position is when the front of hydraulic jump is located at the point where the plunging flow reaches the basin bottom. $Y_2$ depth is measured using point gauge installed 1.0 m downstream of the end of spillway. The energy dissipation efficiency is calculated using the following formula:

$$\frac{\Delta E}{E_0} = \left(\frac{E0-Ed}{E_0}\right) \times \mathbf{100} \qquad \ldots\ldots\ldots\ldots 3.4$$

$\Delta E$ is the difference in the energy between upstream and downstream of spillway.

# CHAPTER IV

# RESULTS AND ANALYSES

This chapter presents the results and analysis of the laboratory tests that were carried out on the efficiency in dissipating energy and controlling the hydraulic jump.

## 4.1 Weir Rating Curve

Laboratory results of thirteen runs with different discharges are presented in table 3.2. These results were used to determine the rating curve weir. It is clear from table3.2, that the discharge coefficient at low flows, less than 60$m^3/s$, is about 2.05and at high discharges, which exceed the design discharge, the discharge coefficient is about 2.3. Figure 4-1 show the rating curve analysis for measuring the discharge.

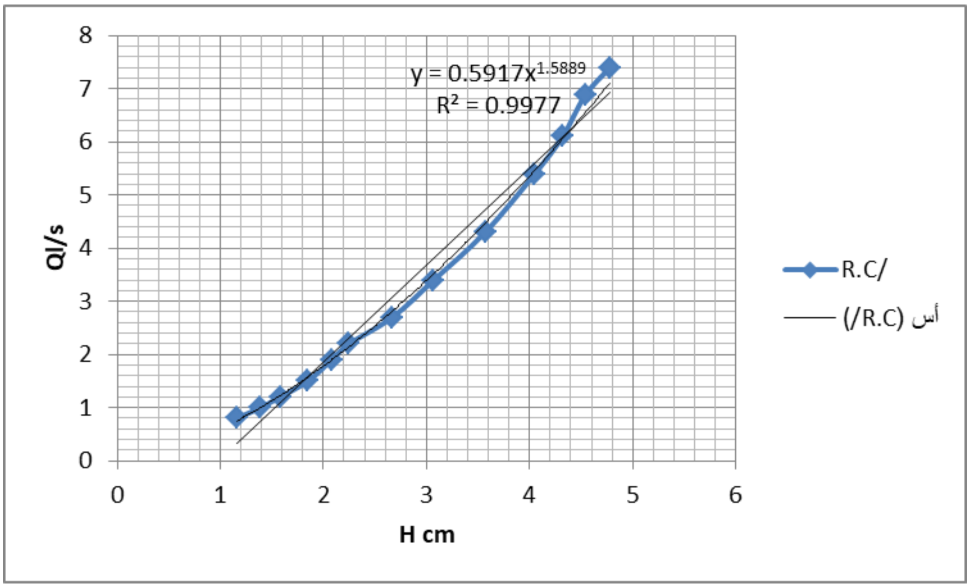



**Figure 4. 1 Rating curve analysis**

## 4.2 Energy Dissipation Tests

The variation of relative energy loss and Froude Number with discharge for

the standard design of the weir. To show the effectiveness of the pipes in dissipation of energy, the energy dissipation of the standard design of proposal case was investigated.

To see the calculation of the energy dissipation in the proposal case take an example to that run NO1:

$Q1=0.007143\ m^3/s$

q=Q/B.............................4.1

where:

q:discharge for flume per unit width $m^3/s/m$

Q: discharge for flume m3/s

B:Wide of the flume m

B=0.3m

q= 0.02381 m3/s/m

measured up stream depth $Y_{up}$= 0.289 m

energy in upstream $E_0 = Y_0+( q^2/2gY^2{}_0)$= 0.289 m

measured up stream depth in the hydraulic jump$Y_1$= 0.032 m

energy in upstream $E_d= Y_d+( q2/2gY^2{}_d)$= 0.060m

then calculate the energy dissipation  by equation 3.4

$\frac{\Delta E}{E_0} = (\frac{E_0-E_d}{E_0}) \times 100 = 79\ \%$

All the results can be shown in table 4.1

## Table 4. 1 The results of the energy dissipation

| vol l | vol m3 | time sec | Q m3/s | q m2/s | yd cm | yd m | Ed m | y2 cm | y2 m | E2 m | ΔE | Y0 CM | Y0 M | E0 M | ΔE2 | R ED |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 0.02 | 40.5 | 0.0005 | 0.002 | 0.3 | 0.003 | 0.018 | 1.8 | 0.018 | 0.018 | 0.0001 | 9 | 0.09 | 0.09 | 0.07 | 0.80 |
| 20 | 0.02 | 36.3 | 0.0006 | 0.002 | 0.4 | 0.004 | 0.015 | 1.4 | 0.014 | 0.015 | 0.0001 | 9.3 | 0.09 | 0.09 | 0.08 | 0.84 |
| 20 | 0.02 | 26.7 | 0.0007 | 0.002 | 0.5 | 0.005 | 0.018 | 2.1 | 0.021 | 0.022 | 0.0040 | 9.5 | 0.10 | 0.10 | 0.08 | 0.81 |
| 20 | 0.02 | 19.5 | 0.0010 | 0.003 | 0.6 | 0.006 | 0.023 | 2.2 | 0.022 | 0.023 | 0.0007 | 10.1 | 0.10 | 0.10 | 0.08 | 0.78 |
| 20 | 0.02 | 16.8 | 0.0012 | 0.004 | 0.7 | 0.007 | 0.023 | 2.4 | 0.024 | 0.025 | 0.0020 | 10.6 | 0.11 | 0.11 | 0.08 | 0.78 |
| 20 | 0.02 | 15.6 | 0.0013 | 0.004 | 0.9 | 0.009 | 0.020 | 2.6 | 0.026 | 0.027 | 0.0069 | 11.1 | 0.11 | 0.11 | 0.09 | 0.82 |
| 20 | 0.02 | 9.1 | 0.0022 | 0.007 | 1.6 | 0.016 | 0.027 | 3.4 | 0.034 | 0.036 | 0.0097 | 16.9 | 0.17 | 0.17 | 0.14 | 0.84 |
| 20 | 0.02 | 7.1 | 0.0028 | 0.009 | 1.9 | 0.019 | 0.031 | 3.6 | 0.036 | 0.039 | 0.0080 | 19.2 | 0.19 | 0.19 | 0.16 | 0.84 |
| 20 | 0.02 | 7 | 0.0029 | 0.010 | 2 | 0.02 | 0.032 | 3.7 | 0.037 | 0.040 | 0.0088 | 19.3 | 0.19 | 0.19 | 0.16 | 0.84 |
| 20 | 0.02 | 6.13 | 0.0033 | 0.011 | 2 | 0.02 | 0.035 | 3.7 | 0.037 | 0.041 | 0.0063 | 19.8 | 0.20 | 0.20 | 0.16 | 0.82 |
| 20 | 0.02 | 5.06 | 0.0040 | 0.013 | 2.1 | 0.021 | 0.041 | 4.1 | 0.041 | 0.046 | 0.0052 | 20.5 | 0.21 | 0.21 | 0.16 | 0.80 |
| 20 | 0.02 | 4.5 | 0.0044 | 0.015 | 2.2 | 0.022 | 0.045 | 4.3 | 0.043 | 0.049 | 0.0039 | 21.9 | 0.22 | 0.22 | 0.17 | 0.79 |
| 20 | 0.02 | 4.15 | 0.0048 | 0.016 | 2.2 | 0.022 | 0.049 | 4.5 | 0.045 | 0.051 | 0.0023 | 24 | 0.24 | 0.24 | 0.19 | 0.80 |
| 20 | 0.02 | 3.81 | 0.0052 | 0.017 | 2.8 | 0.028 | 0.048 | 5 | 0.05 | 0.056 | 0.0083 | 27.2 | 0.27 | 0.27 | 0.22 | 0.82 |
| 20 | 0.02 | 3.6 | 0.0056 | 0.019 | 2.4 | 0.024 | 0.054 | 4.7 | 0.047 | 0.055 | 0.0006 | 26.4 | 0.26 | 0.26 | 0.21 | 0.79 |
| 20 | 0.02 | 3.4 | 0.0059 | 0.020 | 2.5 | 0.025 | 0.056 | 4.8 | 0.048 | 0.057 | 0.0002 | 26.6 | 0.27 | 0.27 | 0.21 | 0.79 |
| 20 | 0.02 | 3.25 | 0.0062 | 0.021 | 2.65 | 0.0265 | 0.057 | 4.8 | 0.048 | 0.057 | 0.0003 | 26.9 | 0.27 | 0.27 | 0.21 | 0.79 |
| 20 | 0.02 | 3.1 | 0.0065 | 0.022 | 2.7 | 0.027 | 0.059 | 5.1 | 0.051 | 0.060 | 0.0007 | 27.6 | 0.28 | 0.28 | 0.22 | 0.79 |
| 20 | 0.02 | 2.8 | 0.0071 | 0.024 | 3.2 | 0.032 | 0.060 | 5.4 | 0.054 | 0.064 | 0.0037 | 28.9 | 0.29 | 0.29 | 0.23 | 0.79 |

# CHAPTER V

# Conclusions and Recommendations

## 5.1 Conclusions

From the results obtained from the laboratory can be the inclusion of the following conclusions:

1. Traditional Model that has been used was within the specifications of the traditional models used in previous research.
2. The proposed model, which used a new model being a non-thoughtful previously.
3. The proposed model gave a ratio of dispersing in energy up to the limits of 83%.
4. The proposed model better than the hydraulic because it does not need to buffers or basins because of the weakness of the hydraulic jump in it.
5. Reservoir capacity is same at the two models.

## 5.2 Recommendations

From the work and results can be gat the following recommendations:

1. Applying and using the proposed model in practice.
2. Improve the proposed model through some additions to the design.
3. Re-work by increasing the number of the attempts.

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**الخالصه**

**إن الغاية ألأساسية من هذه ألدراسة هي لاختبار كفاءة كتل تغيير الاتجاه في تشتيت الطاقة ألحركية للمياه الجارية خلال ألمسيل ألمائي. تم اختبار نموذج مقترح يتمثل بمد 6 انابيب خلال جسم المسيل المائي موضوعه على شكل عمودين وبثلاثة صفوف وينتهي الانابيب بالعمود الاول بعكس بزاويه 900 متجهه نحو الانابيب بالعمود الثاني اي ان هناك تقابل في كل صف من الانابيب وهذا بدوره يؤدي الى ارتطام الكتلة المائية الخارجة من الانبوب في الصف الاول من العمود الاول مع الكتلة المائية الخارجة من الانبوب في الصف الاول من العمود الثاني اي ان هناك قوتين متساويتين بالمقدار متعاكستين بالاتجاه يؤثران بنقطه واحده في كل صف من الأنابيب .**

**حيث تم تصنيع النموذج المقترح وتشغيله في المختبر وقد تم الحصول على نسبة تشتيت عاليه وصلت الى 78% الى84% من خلال تشغيل النموذج 19 مره من اعلاه فان النموذج المقترح ناجح من الناحية الهيدروليكية في تشتيت الطاقة اضافه الى تقليل الكلف التي تتطلبها بعض المعالجات التقليدية للمسيل التقليدي.**