ENERGY DISSIPATION LOSSES IN DIFFERENT GEOMETRIES OF STEPPED SPILLWAY

BY

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M.Sc/ENG/10898/2011-2012

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ZARIA

FEBRUARY, 2015

DECLARATION

I hereby declare that the dissertation entitled “**Energy Dissipation Losses In Different Geometries Of Stepped Spillway”** was done by me in the Department of Water Resources and Environmental Engineering under the supervision of Professor Abubakar Ismail and Dr Ajibola Morufu Ajibike. It has not been previously presented for the award of any degree. All sources of information which are not originally mine are specially acknowledge by reference.

Bashir TANIMU		
Name of student	Signature	Date

CERTIFICATION

The dissertation entitle **“ENERGY DISSIPATION LOSSES IN DIFFERENT GEOMETRIES OF STEPPED SPILLWAY”** by Bashir TANIMU meet the requirements of the school of post graduate studies, Ahmadu Bello University, Zaria for the award of degree of Masters of Science (M.Sc) in Water Resources and Environmental Engineering.

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DEDICATION

I dedicated this work to the memory of my late father Mallam Jibril Muhammad, my late sister Hauwa'u Tanimu and my late grand mother Hajiya Salamatu Abdullahi (Maikoko), May their soul rest in peace (Ameen).

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ABSTRACT

This research study the rate of energy dissipation losses taking place in various types of stepped spillway geometries (end sill at all steps, inclined at all steps, inclined between two steps, end sill between two steps, combination of inclined and end sill on the stepped spillway starting with end sill and combination of inclined and end sill on the stepped spillway starting with inclined). The models were made from wooden materials each having a chute angle of 45°, model height of 24cm, step height 4cm and number of steps 6. Variable flow discharges were applied on each model geometry and the hydraulic parameters were measure and energy dissipation rates were calculated and compared. The result shows that the effect of steps geometry on energy dissipation on stepped chute is significant as the ratio of energy losses to the upstream energy varies from 49% to 70%. The result also indicated that the energy dissipation rate on model C (inclined between two steps) is highest among all the test models. Equations were developed for predicting energy dissipated over the spillway and for calculating the flow rate in stepped chute. Results of the modelled equation were compared with that of experimental studied. The percentage difference between between the values predicted by the modelled equation and that of actual experimental values range 1.10% to 5.12%. this shows that there is a good agreement between the predicted values and experimental values

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NOTATIONS

A	Area of cross-section
a	Constant coefficient
b	Constant coefficient
C_d	Coefficient of discharge
E_1	Energy at section 1
E_2	Energy at section 2
f	Friction factor
F_r	Froude number
g	Acceleration due to gravity
h	Height of step
h_w	Equivalent clear water depth
H_{dam}	Height of the stepped chute model
H_0	Drop height , maximum energy with respect to the model base
H_n	Head loss of the onset of the uniform flow
H	Model step height
k	Constant coefficient
k_s	Roughness coefficient of spillway surface
L	Effective length of the crest
L_s	Cavity length
l_s	Length of stepped chute
L_j	Length of jump
L_i	Non aerated water length
m `	Increament in step height either due to end sill or inclined

M	Mass of water
n	Exponential constant
n	Mannings constant
n	Exponential of the head above the crest of stepped spillway models
N_s	Number of steps
P	Hydrostatic pressure
p_1	The proportion of the energy loss
q	Discharge per unit width
Q	Discharge over the stepped spillway
R^2	Coefficient of correlation
Re	Reynolds number
$S_{h\,,}$	Step height
t_1, t_2	Time
t_{avg}	Average time
$t_g\theta$	Slope of the model
v_c	Critical velocity
v_1	Velocity of flow at the downstream section
y_1	Depth at section 1
y_2	Depth at section 2
ΔE	Energy lost in jump , Energy loss
θ	Inclination angle or slope of step chute spillway
α	Weighing factor

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Recent advances in technology have led to the construction of large dams, reservoirs and channels. This progress has necessitated the provision of adequate flood disposal facilities and safe dissipation of the energy of the flow, which may be achieved by providing steps on the spillway face. Stepped Spillways are been used more than 3000 years ago. Stepped spillway is generally a modification on the downstream face of a standard profile for an uncontrolled ogee spillway. At some distance in the downstream of the spillway crest, steps are fitted into the spillway profile such that the envelope of their tips follows the standard profile down to the toe of the spillway. A stepped chute design increases higher energy dissipation and thus reduces greatly the need for a large energy dissipator at the toe of the spillway or chute (Thandaveswara, 2005).

A spillway is usually the most important appurtenant facility to a dam. The function of dam spillway is to provide an efficient and safe means of conveying flood discharges to the downstream channel. The spillway design primarily depends on the dam type and location, reservoir size and operation. Spillways can be classified based on (i)their function (main, emergency, and auxiliary), (ii) their hydraulic type {free over fall,overflow,chute,siphon etc.}, and (iii) their mode of control (ungated and gated). While the number of new dams under construction in the world is declining, the Number of existing dams that have had to be upgraded to meet current hydraulic and seismic criteria are increasing. This is especially true for smaller embankment dams that have been judged to have inadequate spillway capacity and are unable to store or pass safely floods in accordance with the current criteria of at least one half the theoretical Probable Maximum Flood (PMF). Many failures of dams have been caused by improperly designed spillways or by spillways with insufficient capacity. Several embankment dams have been identified as unable to pass their design flows without failure due to overtopping (Frizell, 1991). In addition to providing sufficient capacity, the spillway must be hydraulically and structurally adequate. For a typical overflow spillway the flow accelerates along the downstream face and high velocities are attained at the spillway's toe. The spillway's outlet structure must be designed to ensure that the spillway discharges will not erode the downstream channel bed, or undermine the toe of the dam itself.

Therefore, the spillway's surface must be erosion resistant to withstand the high scouring velocities created by the drop from the reservoir surface to the tail water.

In dam design the traditional approach to handling the excessively high kinetic energies associated with large flows is through some form of stilling basin structure located at the foot of the spillway. Depending on the expected Froude Number range of the incoming flow, the form of the stilling basin can range from a simple concrete apron to a complex structure that may include rows of chute blocks, baffle piers and a plain or dentate end sill (Peterka 1958, USBR 1977). If the basin requires all three features this can add substantially to the overall costs,

Consequently alternative solutions to the problem merit investigation. One possible Solution is to consider a stepped-spillway instead of the traditional smooth ogee profile spillway.

The stepped spillway is a spillway whose face is provided with a series of steps from near the crest to the toe. The steps significantly increase the rate of energy dissipation taking place on the spillway face. They also reduce the size of the required downstream energy dissipation basin. A stepped spillway offers a number of advantages over an equivalent smooth spillway:

1. Compatibility with Roller Compacted Concrete(RCC) and gabion hydraulic structures;
2. Reduction of dissipation basin size;
3. Reduction of the risk of cavitation;
4. In the case of an auxiliary spillway the construction programme is much shortened;
5. An increase in the discharge capacity; and
6. Low cost.

1.2 STATEMENT OF PROBLEM

Uncontrolled over topping during floods events can endanger embankments safety. In fact, this high energy and velocity of the overflows are able to create dramatic damages such as erosion on the downstream slope and scouring of its base at the toe which could lead to complete failure of the dam itself. This fact considers that the more energy dissipated on the spillway, the more the dimension of the stilling basin reduces and construction cost becomes more economical.

Researchers have been concentrating on increasing the efficiency of stepped spillway and due to this fact; different approaches are used for reducing the energy. Recently an end sill and inclined steps were suggested for maximum energy dissipation and were found to achieve greater energy dissipation (Al-shukur et al,2014).

Although several researchers have studies stepped spillway in the past, there remain considerable gaps in knowledge in the design of these structures. For example we are still unable to predict energy dissipated on structure without building a model.

1.3 AIM AND OBJECTIVES

The aim of this work is to study energy dissipation losses in different geometries of Stepped spillway.

The specific objectives are as follows, to:

1. Develop a mathematical equation that can be used to determine the flow rate over stepped spillway models.
2. Examine the performance characteristics of each model on energy dissipation.
3. Compare the level of energy dissipation (%) among the stepped chute geometry models in order to get most efficient geometry.
4. Develop a mathematical equation that can be used to predict energy dissipated over stepped spillway.

1.4 JUSTIFICATION

From practical point of view, information about the percentage amount of energy dissipated over the spillway is very vital because it plays a vital role in choosing energy dissipated device and also has direct implication on the downstream energy dissipation (Munta, 2010).

This study will provide data that can be used to predict and ascertain the efficiency of stepped chute in energy dissipation.

The mathematical equations develop will serve as a guideline to assist the Engineers in hydraulic design of the stepped chute and location of the stilling basin.

Finally, the different chute geometries used in this study will give engineers various options that they may considered in their design.

1.5 SCOPE

The stepped chute experiments were performed in the hydraulic laboratory of Water Resources and Environmental Engineering A.B.U Zaria. Skimming flow regime was considered.

The flow over the model head was restricted to a head of 3cm to 6.3cm.This study examined and compared the hydraulic performance of various stepped chute spillway having different geometry in terms of energy dissipation.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Stepped spillway is a kind of structure that has been used for energy dissipating and reducing water erosion at the river domain (length) and on steep slope. Practically, this structure is more powerful than ogee spillway in controlling flood and energy monitoring at downstream of dams. (When water has been pouring from spillway; potential energy has been transformed to the kinetic energy). This sort of energy occurred with very high velocity and it may caused many problem at downstream of river. In order to control and govern these sorts of catastrophic events, it's necessary that some kind of protecting structure such as: steeped spillway has been used to predict energy loss and decreased kinetic energy (Abbasi and Kamanbedast, 2012).

The stepped spillway is a spillway whose face is provided with a series of steps from near the crest to the toe. The steps significantly increase the rate of energy dissipation taking place on the spillway face. They also reduce the size of the required downstream energy dissipation basin.
The step geometry of stepped spillway can be horizontal, inclined (upward or down ward) and pooled step. For a given chute geometry, the flow pattern may be either nappe flow at low
flow rates, transition flow for intermediate discharges or skimming flow at larger flow rates.

The design of stepped spillways has been known for at least 3,500 years, but at the beginning of the 20th century, breakthroughs in the design of hydraulic jump-stilling basins led to the disuse of stepped spillways (Chanson, 1994). With the development of new, more efficient construction techniques [(e.g., roller-compacted concrete (RCC)], the design of stepped spillways regained interest in the 1980s (Chanson, 1994). This was associated with a substantial amount of physical modeling research (Chamani, and Rajaratnam ,1999)

Most experiments were conducted on stepped spillways with uniform flat steps to quantify the energy dissipation and to provide some design guidelines. But some prototype spillways are equipped with non uniform step heights (Malmsburry and Upper Coliban,) and their long operation indicates that the design is sound (Chanson, 1994). However, some flow instabilities and shock waves might occur for the non uniform step heights (Chanson and Toombes , 2002) in the napped flow regime and for pooled stepped spillways.

In recent years, the design flows of many dams were re-evaluated, often resulting in discharges larger than the original design. In many cases, the occurrence of the revised discharges would result in dam overtopping because of insufficient storage and spillway capacity. The embankment dams are more prone to overtopping failure than other types of dams because of breaching or erosion of the downstream face of the embankment. Despite the catastrophic effects of failure, dam overtopping constitutes the majority of identified dam failures. Before the 1980s, (Chason,1993) overtopping counter-measures consisted mainly of increasing the reservoir storage or spillway capacity. Lately overtopping protection systems have gained acceptance because they safely allow controlled flows over the dam wall during large flood events. There are several techniques to armour embankment slopes, including paving, rip-rap gabions, reinforced earth, pre-cast concrete slabs and roller compacted concrete (RCC). RCC protection and gabion placement techniques increase embankment protections in a stepped fashion. While most modern stepped spillways are designed as prismatic rectangular chutes with horizontal steps, recent studies suggested different step configurations that might enhance the rate of energy dissipation.

Some older structures were equipped with devices to enhance energy dissipation: some had pooled steps with vertical walls or rounded end sills. Macro roughness systems consisting of concrete blocks were studied also (Chanson and Gonzalez, 2006).

To propose a composite design for a spillway, it is necessary to consider the various factors influencing spillway size and type, and to correlate alternatively selected components. The components of a spillway are: (i) the control structure; (ii) the discharge channel; (iii) the terminal structure; and (iv) the entrance and/ or outlet channels.

After the hydraulic size and outflow characteristics of the spillway are determined by routing of the design flood, the general dimensions of the control structure can be selected. A specific spillway layout can be developed by considering (i) the type of dam; (ii) the topography;(iii) the foundation conditions;(iv) the hydraulic condition of the control structure; and(v) the overall economy.

Site conditions greatly influence the selection of location, type and components of a spillway. In the design of a spillway the following considerations are also necessary:

1. The steepness of the terrain traversed by the spillway control and discharge Channel.
2. The class and amount of excavation material and the possibility for its use as Embankment material;
3. The potential to scour the spillway and downstream channel surfaces and the need for lining; and
4. The stability of the excavated slopes.

2.2 SPILLWAY TYPES

A spillway can be constructed in several locations: within the body of the dam, at one end of the dam or independently in a saddle. Spillways are ordinarily classified according to their most prominent features, either as they relate to the control the discharge channel, or to some other component. The following are common types:

1. A free-over fall (straight drop) Spillway is one in which the flow drops freely from the crest.
2. An Ogee (overflow) Spillway has an ogee- or S-shaped profile. The upper curve of the ogee is generally made to conform closely to the profile of the lower nappe of a ventilated sheet falling from an equivalent sharp-crested weir.
3. A side-channel Spillway is one in which the control weir is placed along the side of and approximately parallel to the upper portion of the spillway discharge channel.
4. An open-channel (trough or chute) Spillway is a spillway whose discharge is Conveyed from the reservoir to the downstream river level through an open channel, placed either along a dam abutment or through a saddle.
5. A conduit or tunnel Spillway is a closed channel used to convey the discharge around or under a dam.
6. A shaft (morning glory or drop inlet) Spillway is one in which the water enters over a horizontal-positioned lip, drops through a vertical or sloping shaft, and then flows to the downstream river channel through a horizontal or near horizontal conduit or tunnel.
7. A siphon Spillway is a closed conduit system formed in the shape of a U, and Positioned so that the inside of the bend of the upper passageway is at normal reservoir storage level.

Siphonic action takes place after the air in the bend over the crest has been expelled from the conduit.

2.3 ENERGY DISSIPATORS

To prevent scour and erosion of the toe of a dam, as well as the downstream channel, energy dissipaters are provided to dissipate sufficient amount of energy before water enters the downstream channel. The flow velocity at the toe of a high-head spillway is usually around 32-35 m/sec. This high velocity may cause serious scour and erosion of the downstream channel if proper precautions are not taken. The common types of energy dissipators which are used as outlet structures in spillway design are:

(a) **Straight drop:** This kind of energy dissipater is commonly used in small drainage structures, and low head spillways. The aerated free-falling nappe at the straight drop usually produces supercritical flow on the apron. Therefore, a hydraulic jump may be formed downstream.

(b) **Stilling basin:** The stilling basin structure comes in several forms and is designed to dissipate the energy of the flow by utilizing the development and enhancement of the hydraulic jump within the basin. This is a solution for dams up to 60-70 m high. The location of the hydraulic jump is important for determining the length of channel requiring protection. Energy loss in a hydraulic jump is expressed as:

$$\Delta E = E_1 - E_2 = \frac{(y_1 - y_2)^3}{4y_1y_2} \tag{2.1}$$

where,

E_1 = energy at section 1;

E_2= energy at section 2;

y_1 = depth at section 1;

y_2= depth at section 2; and

ΔE = energy lost in the jump

Depending upon the range of Froude number of the upstream flow, the following devices may be incorporated, either singularly or in combination, in stilling basin design:

i. **Paved apron:** A simple paved apron may be used in the case of low-head structures. The length of the paved apron depends on the maximum length of the anticipated range of hydraulic jumps.

ii. **Chute blocks:** These devices are placed at the entrance of the stilling basin to corrugate the jet, and lift a portion of it from the basin floor. This creates a greater number of energy dissipating eddies, which results in a shorter length of jump than would be possible without them. These blocks also reduce the tendency of the jump to sweep off the apron at the tail water elevations below the conjugate depth.

iii. **Baffle blocks:** These structures are located in the stilling basin at a certain distance downstream from the chute blocks. Their function is to dissipate energy mostly by impact action. In certain circumstances, they must be designed to withstand impact from ice or floating debris and or damage due to cavitation.

iv. **End sill:** This device is located at the exit of the stilling basin. It can either be solid or dentated. Its function is to reduce further the length of the jump and to control scour immediately downstream from the structure. For large basins that are designed for high incoming velocities, the sill is usually dentated to perform the additional function of diffusing the residual portion of the high-velocity jets that may reach the end of the basin.

v. **Flip buckets:** When the downstream channel bed is relatively stable, the flip-bucket or ski-jump spillway can be considered, this form of dissipater structure projects the high velocity jet away from the base of the dam into the downstream channel. This is achieved via a concave section at the bottom of the chute section. The spillway overflow is discharged into the atmosphere completely above the tail water level. Under ideal conditions, these kinds of energy dissipaters have been found to be very efficient in dissipating the excess energy.

vi. **Roller buckets:** When the discharge channel has appreciable natural erosion resistance, the roller bucket can be used. This kind of dissipater requires substantially higher tail water levels than conventional hydraulic jump basins. Scour will occur in the streambed at the point of impingement when the jet dives, but will be filled in by the ground roller when the jet rides.

vii. **Stepped spillways:** Another possible energy dissipater option is to dissipate part of the kinetic energy of the spillway flow on the spillway face itself. An ogee stepped spillway is a spillway containing a series of drops or steps in the invert at a point just downstream of the spillway crest, steps are introduced into the profile so that the envelope of their tips follows the standard profile down to the toe of the spillway, the total fall is divided into a number of smaller falls. At each fall, retarding forces are derived from reaction of the steps to the descending flow. The steps significantly increase the rate of energy dissipation taking place on the spillway face and eliminate or greatly reduce the need for a large energy dissipation basin at the toe of the spillway. Step geometries are either horizontal, inclined, or end sill. Frizell (1992) examined the hydraulic performance of different step slopes and showed that horizontal steps would have the greatest energy dissipation.

2.3.1 Types of stepped spillways

Stepped spillways can be classified into 3 groups:

a. Stepped spillway with simple steps
b. Stepped spillway with end sills
c. Stepped spillway with inclined steps

Fig 2.1 depicts all these types and different parameters such as height of steps (s_h), Length of steps (l) and the increment in step's height due to end sills or inclined steps (m) were showed.

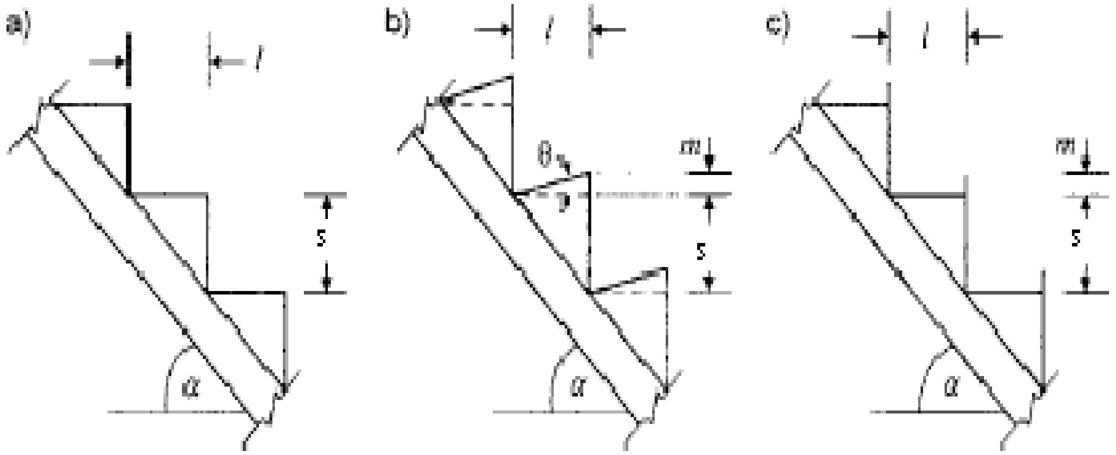


Figure 2.1: Different types of stepped spillways

(Chinnarasis and Wongwisess, 2006)

2.3.2 Suitability

Energy dissipation below hydraulic structures is accomplished generally by single fall hydraulic jump type stilling basins, roller buckets or trajectory buckets. However, when the kinetic energy at the toe of the spillway is high, the tail water depths in the river are often inadequate. Then first two devices cannot be used as in the case of high head dams.

In narrow curved gorges consisting of fractured rocks, buckets cannot be used. In such situations, a system of cascading falls down the side of a valley, with a stilling basin in the downstream, can be used as an alternative spillway. Cascade spillways can be used for any type of dam irrespective of the material used for construction.

The only disadvantage with stepped spillway is that of large discharges, as the jet is not aerated for some distance downstream of the spillway, low pressure may occur and lead to cavitation damage.

2.3.3 Physical Modeling of Stepped Spillway

Free surface flows are commonly modeled using Froude similitude. The various flow elements are;

i. The role of the steps in enhancing turbulent dissipation as well as their interaction with other adjacent steps and,
ii. The effect of aerated flow makes it difficult to model.

2.4 BASIC FLOW PATTERNS AND FLOW REGIMES

The flow over a stepped cascade may be divided into three distinct flow regimes depending upon the flow rate for a given stepped chute geometry: napped, transition and skimming flow regimes with increasing flow rates. The napped flows are observed for small dimensionless discharge dc/h where d_c is the critical flow depth and h is the step height. They are characterised by a succession of free-falling nappe at each step edge, followed by napped impact on the downstream step. The transition flows are observed for intermediate discharges. Strong hydrodynamic fluctuations, splashing and spray near the free surface are the main features of this flow regime. Different sized air cavities alternating with fluid-filled recirculation vortices were observed between step edges below the mainstream of the flow. To date, the transition flow properties cannot be predicted accurately as very little information is available (Chanson and Toombes 2004). The skimming flow regime is observed for their large discharges. The water skims over the pseudo-bottom formed by the step edges as a coherent stream. Beneath the pseudo-bottom intense recirculation vortices fill the cavities between all step edges (Chamani and Rajaratnam 1999). These recirculation eddies are maintained by the transmission of shear stress from the mainstream and contribute significantly to the energy dissipation.

2.4.1 Napped flow region

This type of flow occurs for small discharges. The flow cascades over the steps, falls in a series of plunges from one step to another in a thin layer that clings to the face of each step, with the energy dissipation occurring by breaking of the jet in the air, impact of jet on the step and mixing on the step, with or without the formation of a partial hydraulic jump on the step. The step height s_h must be relatively large for nappe flow. This situation may apply to relatively flat stepped channels or at low flow rates. Rajaratnam (1990) propose that values of $\frac{y_c}{h}0.8$ will produce skimming flow while the napped flow region is produce when $\frac{y_c}{h} \leq 0.8$. A number of dams have been built in South Africa with stepped spillways. From this experience Stephenson (1991) suggested that the most suitable conditions for nappe flow situations are : $\tan\alpha = \frac{h}{l} < 0.2$. and $\frac{y_c}{h} < \frac{1}{3}$

Chanson and Toombes (2002) proposes that the boundary for napped flow given $y_c = 0.9174 - 0.381\frac{h}{l}$ for range $0 \leq \frac{h}{l} \leq 1.7$

2.4.2 Transition flow regime

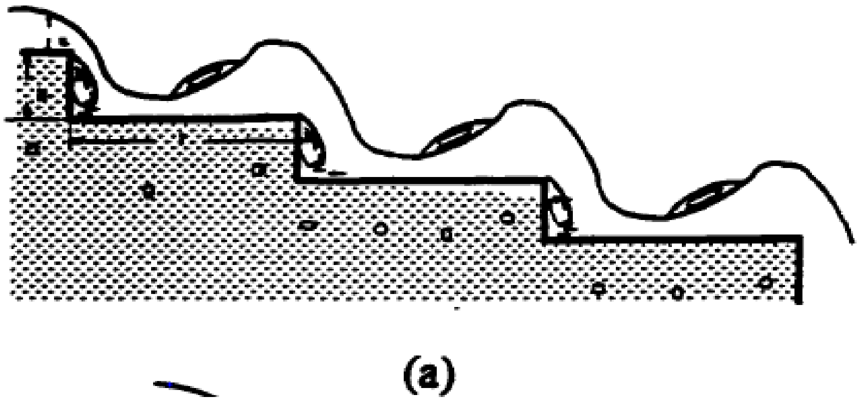
In this type of flow, the nappe does not fully impinge on the step surface and it is dispersed with considerable turbulence. Flow is super - critical down the length of the spillway. For a given step geometry, an increase in flow rate may lead to intermediate flow pattern between nappe and skimming flow. The transition flow regime also called a partial nappe flow. The transition flow is characterised by a pool of circulating water often accompanied by a small air bubble (cavity), and significant water spray at the deflection of water jet immediately downstream of the stagnation point. At the Downstream of the spray region, the supercritical flow decelerates up to the downstream step edge. The transition flow pattern exhibits significant longitudinal variations of the flow properties on each step and does not present the coherent appearance of skimming flows.

2.4.3 Skimming flow regime

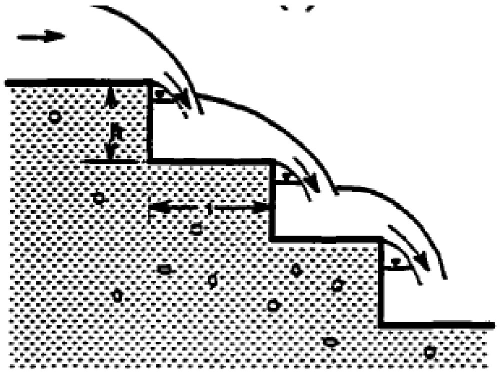
In skimming flow regimes, the water flows down the stepped face as a coherent stream, skimming over the steps and cushioned by recirculating fluid trapped between them. The external edges of the steps form a pseudo bottom over which the flow skims.

Beneath this, recirculating vortices are form and are sustained through the transmission of shear stress from the water flowing past the edge of the steps. At the upstream end, the flow is transparent and has a glossy appearance with no air entrainment taking place. After a few steps the flow is characterised by air entrainment similar to a self -aerated flow down a smooth invert spillway. In case of the skimming flow, at each step, whether air entrainment occurs or otherwise, a stable vortex develops and the overlying flow moves down the spillway supported by these vortices, which behave as a solid boundary for the skimming flow, and the tips of the steps. There is a continuous exchange of flow between the top layer and vortices formed on the steps. The flow rotates in the vortex for a brief period and then returns to the main flow to proceed on down the spillway face. Similarly, air bubbles penetrate and rotate with the vortex flow, when aeration takes place.

Figure 2.2 shows the different types of flow characteristics over a stepped spillway

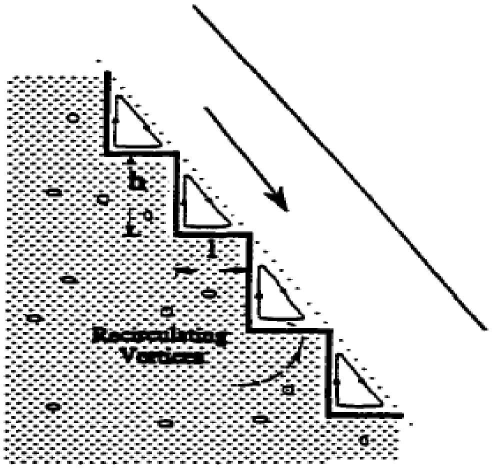


Nappe flow with fully developed hydraulic jump (Azdary ,1997)



(b)

Nappe flow with partially developed hydraulic jump (Azdary ,1997)



(c)

Figure 2.2 Characteristic flows over a stepped spillway: (a) Nappe flow with fully developed hydraulic jump, (b) Nappe flow with partially developed hydraulic jump, (c) Skimming flow (Azdary ,1997)

2.5 PREDICTION OF FLOW

The type of stepped flow regime is a function of the discharge and step geometry.

Chanson has analyzed a large number of experimental data related to change in flow regimes. Most of the data were obtained from flat horizontal steps.

The result suggest that the upper limit of nappe flow may be approximated as:

$$\frac{y_c}{s_h} = 0.89 - 0.4\frac{s_h}{l_s} \tag{2.3}$$

Where y_c is the critical depth, s_h is the step height, and l_s the step length. The above equation indicates the transition of flow from nappe to transition flow regime.

While the lower limits of skimming flow may be estimated as.

$$\frac{y_c}{s_h} = 1.2 - 0.325\frac{s_h}{l_s} \tag{2.4}$$

on set of skimming flow is given by

$$\frac{y_c}{s_h} > 1.057 - 0.465\frac{s_h}{l_s} \tag{2.5}$$

Tatewar and Ingle (1999) studied the energy dissipation capacity of an inclined spillway and developed the following regression equation using available datawith range of S_h /l_s from 0.4 to 0.85 and θ from 0^o to 20^o to distinguish between nappe and skimming flow

$$\frac{y_c}{s_h} = 0.888 - 0.00385\theta_o - 0.1195\left(\frac{s_h}{l_s}\right) \tag{2.6}$$

They found that for slopes steeper than 0.9, the possibility of nappe flow reduces considerably**.**

2.6 ENERGY DISSIPATION

Although the mechanisms of energy loss are quite different between the nappe flow and skimming flow regimes, both flows can dissipate a major proportion of the flow energy. A stepped spillway with a nappe flow can be considered as a succession of step structures. The energy dissipation occurs by jet breakup in the air jet impact and jet mixing on the steps, with the formation of fully-developed or partially-developed hydraulic jumps on the steps. In a skimming flow regime, the steps act as large roughness elements. Most of the energy is dissipated to maintain stable horizontal vortices beneath the pseudo-bottom formed by the external edges of the steps. The vortices are maintained through the transmission of turbulent shear stress between the skimming stream and the recirculating fluid underneath. The hydraulic features of the cascade spillway as compared to chute flow are:

i. The flow depth is much larger than in a chute due to the highly turbulent cascade flow, and higher sidewalls are required,
ii. More air is entrained and the spray action may become an important issue.
iii. Abrasion can be a serious problem for flows with sediment or with floating debris.

In cascade spillways two flow types may occur as

a. Nappe flow: is the flow from each step hits the next step as a falling jet;
b. Skimming flow: the flow remains coherent over the individual steps.
c. The onset of skimming flow occurs for $\frac{y_c}{s_h} > 0.8$, where y_c is the critical depth and s_h is the height of the step. When uniform cascade flow occurs in longchannels, skimming flow dissipates more energy than nappe flow. However, nappe flow is more efficient for a short cascade than skimming flow (Chanson,1994), the energy dissipated ΔE relative to the drop height H_0 depends on the drop Froude number and the slope of the spillway.

Stephenson (1991)expressed the relative energy loss as

$$\frac{\Delta E}{H_O} = \left(\frac{0.84}{\theta^{0.25}}\right) F_O{}^{-0.33} \tag{2.7}$$

In which **ΔH** is the energy loss over a height H_0, F_0 is the

$$\text{Froude Number} = [\frac{q}{gH_0{}^3}]^{0.5} \tag{2.8}$$

and θ is expressed in degrees in the above equation.

The energy dissipated **ΔH** relative to the drop height H_0 depends on the drop Froude number

$$F_0 = \frac{q}{\sqrt{gH_0 3}} \tag{2.9}$$

and θ slope of the spillway.

Chanson (1993) assumed that the head loss at any intermediary steps equals the steps height. He expressed the total head loss for fully-developed hydraulic jump as:

$$\frac{\Delta E}{Eo} = 1 - \frac{0.54(\frac{y_c}{h})^{0.275} + 1.72(\frac{y_c}{h})^{-0.55}}{1.5 + \frac{H_{dam}}{y_c}} \tag{2.10}$$

Christodoulou (1993) studied the effect of number of steps on energy dissipation in case of skimming flow. Using his own data for $S_{h1} / l_s = 0.7$ and for N = 15 (number of steps) as well as the available data for $h_c < 25$, where $h_c = (y_c / NS_h)$ with $y_c = (q^2/g)^{1/3}$ as critical depth, he showed for the same discharge the energy dissipation increases with the increase in the number of steps.

$$\frac{\Delta H}{Ho} = \exp(-30h_c^2) \tag{2.11}$$

By Increasing the number of steps the energy dissipation can be increased and hence the performance of the stepped spillway.

Chanson (1994) developed the following expression valid for free flow spillways and napped flow with fully developed hydraulic jump (Chanson, 1994):

$$\frac{\Delta E}{\Delta U} = \frac{0.54(\frac{y_c}{h})^{0.275} + 1.715(\frac{y_c}{h})^{-0.55}}{1.5 + \frac{p}{y_c}} \tag{2.12}$$

Chamani and Rajaratnam (1994) presented a method to estimate the energy loss on a stepped spillway with nappe flow. Analyzing the data obtained by Homer (1969), they introduced the concept of average relative energy loss per step. The found the following equation:

$$\frac{\Delta E}{Eo} = 1 - \frac{\left((1-p_1)^{N_s}\left[1+1.5\frac{y_c}{h}\right]+\sum_{i=1}^{N_s-1} -(1-p)^i\right)}{N_s+1.5(\frac{y_c}{h})} \qquad (2.13)$$

Where,

p = The proportion of the energy loss per step p=a-blog $\left(\frac{y_c}{h}\right)$

a,b are coefficients described by the following equations:

a=0.30-0.35$(\frac{h}{l})$

b=0.54+0.27$(\frac{h}{l})$

All these equations are valid for $\frac{y}{h} < 0.8$

. They found that the relative energy loss could be up to 0.97.

Tatewar and Ingle (1999) derived a simplified expression for energy loss (upper limit of energy dissipation) using the equation for the discharge over the weir and is given by

$$\frac{\Delta E}{Eo} = \frac{1}{1+\frac{9}{8}{C_d}^2\left(\frac{y_c}{H_{dam}+h}\right)} \qquad (2.14)$$

Tatewar and Ingle based on regression analysis fitted an equation for the proportion of energy per step for the range of θ from **5** to 20 S_{h1} /$1_s$from 0.421 to 0.842 and

$\frac{y_c}{s_{h1}}$ $from$ 0.05 to 0.833

They concluded that energy dissipation is more in case of inclined steps.

Boes and Minor (2000) suggest the following equation for the non-uniform flow in skimming regime:

$$\frac{\Delta E}{Eu} = \exp\left[(-0.045(\frac{k}{D_h})^{0.1} \sin\theta^{-0.8})\, \frac{p}{y_c}\right] \qquad (2.15)$$

Yashuda et al (2001) have derived a general expression for the energy loss at the base of a stepped spillway with skimming flow, regardless of whether the flow is uniform or not:

$$\frac{\Delta E}{E_0} = 104.33\left(\frac{p}{h\cos\theta}\right)C_D^{0.054} \tag{2.16}$$

$$C_D = \frac{2.02}{\left(\frac{D_h}{h\cos\theta}\right)Fr^{1.968}} \tag{2.17}$$

Boes and Hager (2003) introduced a relationship for the rate of energy dissipation in skimming regime as following:

$$\frac{\Delta E}{Eu} = 1 - \frac{(\frac{y}{y_c})^{-2} + (\frac{y}{y_c})\cos\theta}{3+2(\frac{p}{y_c})} \tag{2.18}$$

Barani et al, (2005) studied the energy loss on stepped spillway at different slopes and indicated that the spillways with bigger steps and more discharge have more effect on energy losses

Kavianpour and Masoumi (2008) developed an expression to determine the rate of energy dissipation for non-uniform flow regime as follow:

$$\frac{\Delta E}{\Delta U} = 0.2047\left(\frac{k_s}{D}\right)R^{0.2115}Fr^{-0.4970} \times (\tan\theta)^{0.1615} \tag{2.19}$$

Fuladipanah and Jafarinia(2011) developed the following equation to estimate energy dissipation on an adverse-sloped stepped spillway:

$$\frac{\Delta \mathrm{E}}{\Delta \mathrm{U}}=0.83n^{0.05}\phi^{0.0027}\alpha^{0.088}(\frac{y_c}{h})^{0.024}(\frac{h}{l})^{-0.016} \tag{2.20}$$

Fuladipanah and Jafarinia (2014) studied The effect of adverse-slope stepped spillway on energy dissipation. Using the regression equations with coefficients, predicted values of relative energy dissipation were calculated. The results showed that the effect of adverse-slope steps on energy dissipation is significant as the ratio of energy loss to upstream energy varies from 0.83 to 0.983.

Munta (2010) studied Evaluation of energy dissipation over stepped spillway model using charts by varying the angle of the stepped chute, He concluded that the length of hydraulic jump increased with increase in the angle of the chute and the length of aerated portion of the steps increased as the discharge per unit width decreases. He developed an equation for energy dissipation as

$$\frac{H_n}{H_0} = 25.29(Re)^{0.054}\,(\mathrm{Fr})^{-0.130}\,\left(\frac{K_s}{h_w}\right)^{-0.338}\left(\frac{L_i}{L_s}\right)^{0.448}\mathrm{t_g}(\theta)^{-0.084} \qquad (2.21)$$

Al-Shukur,et al (2014) Studied Optimum Safe hydraulic design of stepped spillway by physical models. They based their study on laboratory experiments aimed to determine the optimum slope and step height of stepped spillway models, by investigating the flow characteristics and energy dissipation rate on a twelve physical models on conventional step at angles (α= 30, 40, 45 and 55^0). Each angle was modeled with three different heights of steps (h=3, 6 and 10 cm) under different flow regimes (skimming, transition and nappe flow regime). The experiments were done and the hydraulic parameters of flow over the models were measured and energy dissipation was calculated. The Results showed that, the optimal height of steps in skimming flow regime was (h=6cm, number of step N=5) at high discharge but with reduction the discharge and tendency toward the nappe flow regime, the optimal height shows decrease (h=3cm, N=10). Also the results of the investigations indicated that, the optimum slopes of stepped spillway models at (h=3cm) was ($\alpha=30^0$) at all runs, but with increasing the height of steps to (h=6cm and h=10cm), the optimum slope increasing to ($\alpha=45^0$ and 55^0) according to the ratio of critical depth to the height of steps (y_c/h).

Naderi (2014) studied Investigation of Energy Dissipation in Various Types of Stepped Spillways including Inclined Steps and Steps with End Sills by Numerical Model, taking into accounts parameters such as; characteristic height of step, flow discharge per unit width and overall slope of steps stepped spillway by numerical method. He concluded that in spillways with end sills and fixed dam height, number of steps, length of steps, steps height and spillway's slope, increasing the sills height increase the efficiency of spillway in dissipating energy and In the case that stepped spillway is inclined stepped spillway and the slope is fixed increasing the sills height or inclining the steps are highly efficient in energy dissipation. Finally, in inclined stepped spillways and variable steps inclination, increasing the inclination increases the amount of dissipated energy. In addition stepped spillways with end sills provide better situation from aeration points of view.

CHAPTER THREE

MATERIALS AND METHODS

3.1 INTRODUCTION

Physical models of hydraulic structures are probably the most common type of hydraulic model studied. They are cheap, generally easy to operate, and easy to interpret. Physical model studies are used to investigate the anticipated performance of hydraulic structures. The model is usually a reduced-size representation of the proposed hydraulic structure and is designed to investigate specific areas of concern related to the hydrodynamic performance of the waterways. Modelling laws based to the theoretical analysis and laboratory experience have been developed which permit correct simulation of the particular hydrodynamic phenomena under investigation.

Once the model laws are understood and proper consideration is given to their limiting range of application, successful laboratory investigations can be completed which will in fact simulate the performance of the full scale structure.

The hydraulic model plays a key role in the development of final design concepts for hydraulic structures (Azhdary,1997)

3.2 MATERIALS

3.2.1 Description of the equipment used in the study (Flume)

A rectangular recirculating tilting flume of working length 6m and cross section 0.3m wide by 0.3m deep was used. The flume basically consist of 3parts,the inlet, testing part and outlet. The flume sidewalls are made from perplex glass material while its bed is made of steel rolled sheet welded to each other.

A pair of adjustable rail was fitted on top of the perplex on which the pointer guage trolley can move for vertical elevation measurement of water depth. Water was circulating through the flume by an electrically driven centrifugal pump.

A feeding pipe of 150mm diameter introduces water into the flume via the inlet part and leaves through a gate where it is collected into a container which measures the flow discharge.

Plate 3.1 Pictorial view of the flume used for the study

3.2.2 Stop watch: A digital stop watch was used to ascertain the time to collect the mass of the water in a container mounted on a flat form of the weighing tank to determine the discharge.

3.2.3 Weighing scale: This was located at the end of the flume so as to measure the mass of water that passes over the stepped chute at a specific time.

Plate 3.2 Pictorial view of weighing scale for measuring the discharge

Description of the models: Six configurations on different types of steps geometry were use in the experimental laboratory as shown in figure 3.3,which are: (inclined and end sills which were fixed on the downstream of the horizontal face of all steps, inclined between two horizontal steps and end sill between two horizontal steps, steps combine with end sill and inclined with inclined started and steps combined with inclined and end sill but started with end sill. The main angle of the chutes is 45^o which represented the ratio of H:V of 1:1

All configurations have the same spillway slope, spillway height, number of steps (i.e. 45^0, 24cms, and 6 respectively).

These pieces were made of wood with a smooth surface and they were painted with varnish to avoid swelling and to reduce the roughness coefficient of the models in agreement with concrete roughness coefficient.

The physical models have a ratio of height to length of step($\frac{h}{l}$=1) and h=4cm at skimming flow.

i. **Inclined group:** It consists of inclined pieces which have a triangular-shape with (30cm) length and thickness (4cm) as shown in figure (3.1), to produce adverse bottom slope ($\theta=45^0$), it was fixed on the downstream of the horizontal face of all steps (Model A) and of alternative steps (Model C).

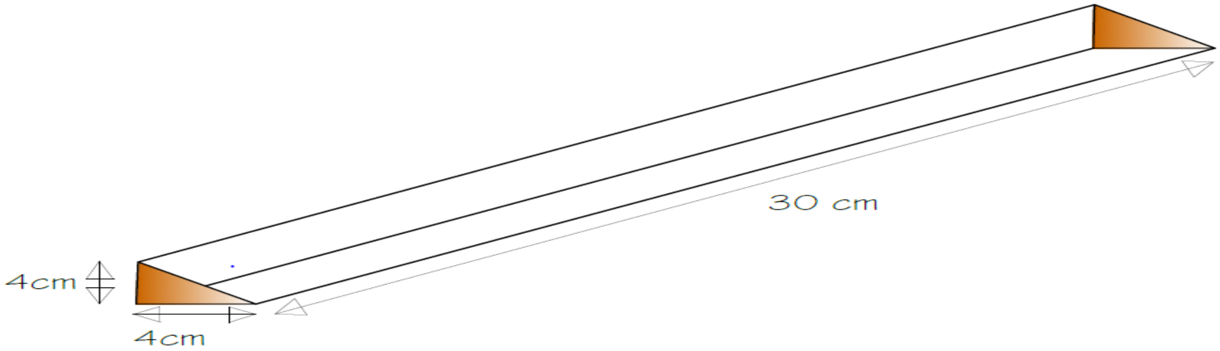


Figure 3.1 Inclined accessory triangular-shape (Al-shukur et al, 2014)

ii. **End sills group:** It consists of rectangular shape of endsills with length, width and thickness (30cm, 2cm and4cm) respectively as shown in figure (3.2). It is attached the downstream of horizontal face of all steps (Model B) and on alternative steps (ModelD) as shown in figure

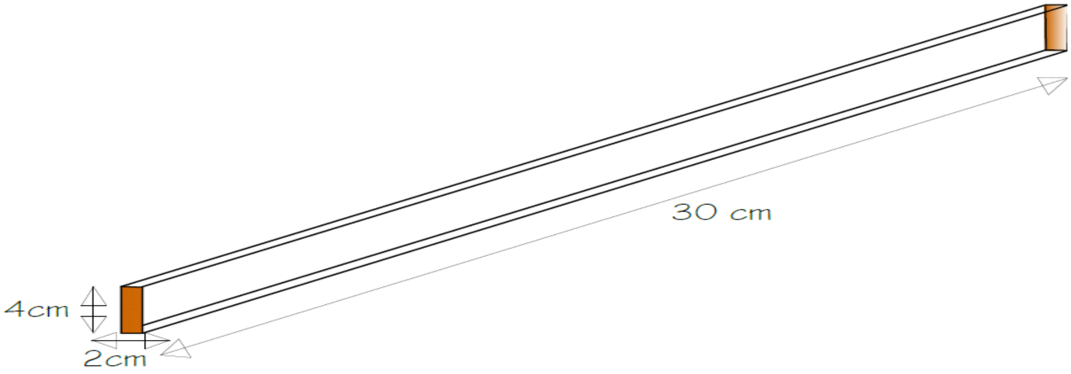
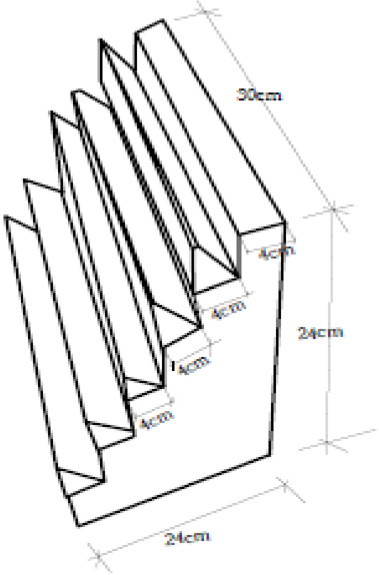
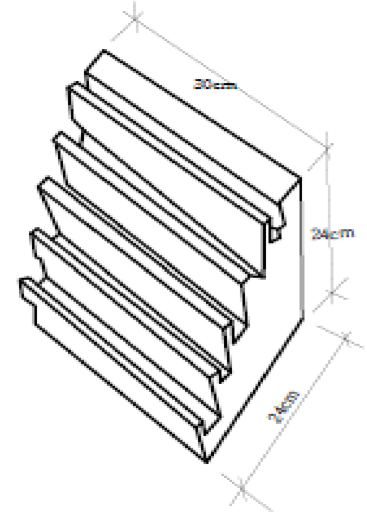


Figure 3.2 End sill accessory rectangular-shape (Al-shukur et al, 2014)

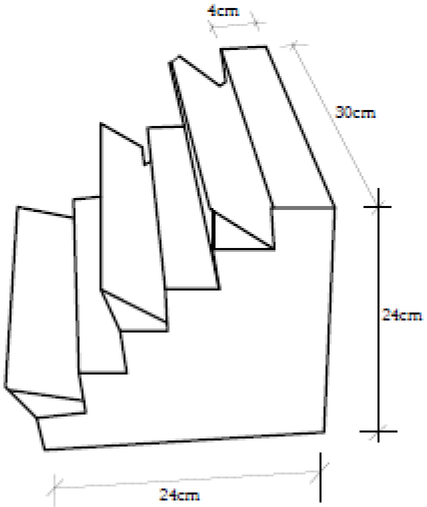
iii. Combined group: It consists of alternative end sills and inclined started with inclined (Model E), and alternative end sills and inclined but started with end sills (Model F) as shown in plate (3). Alls the end sills and inclined have the same dimensions as first and second groups above.



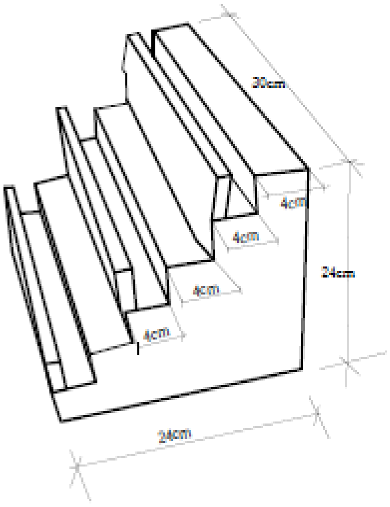
Model A (inclined at all steps)



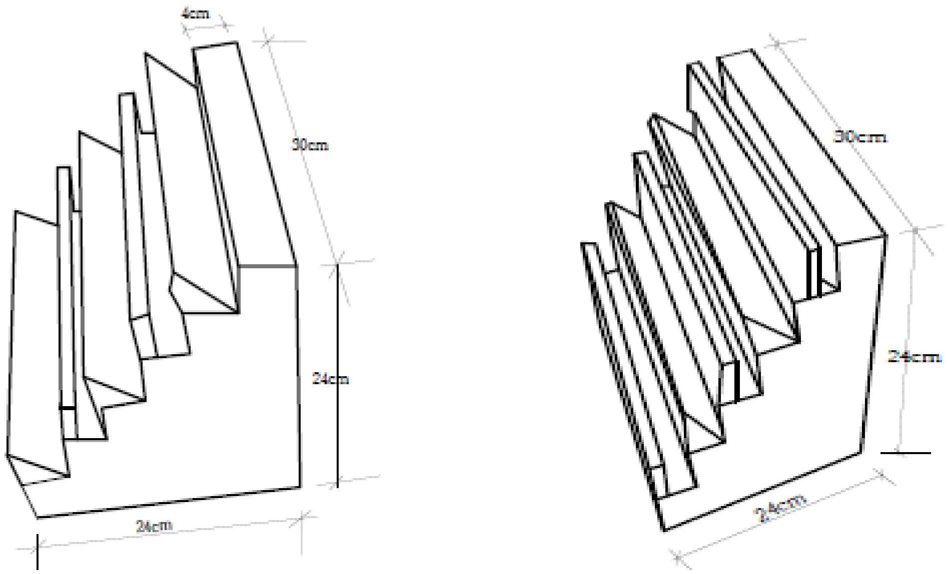
Model B (endsill at all steps)



Model C (inclined between two steps)



Model D (end sill between two steps)



Model E (Combine steps) starting with inclined

Model F (Combined steps) starting with end sill

Figure 3.3: Experimental models

3.3.1. Experimental set up

The experiment was conducted in the hydraulic laboratory of Department of Water Resources And Environmental Engineering A.B.U Zaria.

The flume was first set to be horizontal, then the model was set at right angle to the direction of flow in the flume at 3m from the inlet channel as suggested by (Munta ,2010).The pointer gauge was then set such that the height of the nodal crest will be subtracted from the total depth to give the depth of water above the model's crest.

Water was then pumped by a centrifugal pump from the water storage through a pipe of 150mm which was regulated by a valve.

The head H above the crest of the model's upstream was measured using the point gauge with 0.05 accuracy at a distance $3H_{dam}$ from the models upstream as suggested by

(Muhammad,2012). The depth of flow was also measured after the jump was fixed at a distance in non-aerated tail of water to be jump at a distance of 125cm downstream of the toe of the models (Al-Shukur etal, 2014)

Plate 3.4 Flow over the stepped spillway laboratory model in the flume.

3.3.2 Spillway discharge equation

The spillway discharge equation can be determined based on the experiment conducted by gravimetric method. In this method the mass of the water can be determined directly from the weighing machine in which a container that collected water from the flume is mounted.

In this method, the volume is calculated by dividing the mass of the water collected by the density of water. Then discharge is determined using the equation.

$Q=\frac{M}{t_{av}\rho}$ (3.1)

Where Q = flow rate (m^3/s) M = mass of water measured using weighing machine (kg)

t_{av}= average time (s) ρ=density of water=1000kg/m^3

Basically, the general form of the discharge equation for spillways is given as

$Q = C_d L\sqrt{2g}H^{3/2}$ (3.2)

This can be in the form

$Q = KH^n$ (3.3)

Where Q is the actual discharge; H is the measured head; K and n are parameters to be determined by regression analysis.

3.4 CALCULATION OF RELATIVE ENERGY LOSSES

The energy losses (ΔE) means difference between upstream energy of spillway structure (E_0) and downstream (toe) of hydraulic jump location (E_1) , the upstream energy (E_0) depend on critical depth (y_c) and height of the spillway (H_{dam}), while the downstream energy (E_1) depend on the depth at the toe of stepped spillway (y_1) and the velocity on this depth (v_1) as well as the gravitational acceleration (g= 9.81 m/s^2)

shown below:

$\Delta E= E_0-E_1$ (3.4)

Where:

$E_0=1.5y_c + H_{dam}$, $E_1=y_1+(V_1)^2/2g$

And none dimensioned energy loss has been defined as below:

$(\Delta E)/E_0 = (E_0-E_1)/E_0$ (3.5)

3.5 DIMENSIONAL ANALYSIS OF PARAMETERS AFFECTING ENERGY DISSIPATION IN STEPPED SPILLWAY

The main parameters influence on energy flow dissipation in spillway are the number of steps(N) step height(s_h),length of step(L),model slope(θ),velocity of flow at downstream(v),discharge per unit width(q), acceleration due to gravity(g),initial flow of energy at upstream(E_0), increament step height due to step inclination(φ),due to endsill(m)

.The dependant variable is $\Delta E/E_o$ which is the ratio of energy loss between upstream and downstream of the spillway model to energy amount in the upstream of the spillway. The equation which indicates the mention parameters is written as

$\Delta E = E(E_o,q,L,h,g,m,N,\theta,\phi,v)$

By dimensional analysis, we have

$$\Delta E/E_0 = E/E_0(y_c/s_h,\ s_h/l,\ m/s_h,\ N,\ Fr,) \qquad (3.6)$$

Which are non dimensional.

As shown in the above eqn(3.6), Critical depth flow(y_c) in a rectangular flume.

$y_c = (q^2/g)^{1/3}$,N, h, L, q, L, m, g, E, ϕ as the main parameters

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 DISCHARGE MEASUREMENT

Six experiments were conducted at the hydraulic laboratory of Department of Water Resources and Environmental Engineering to determine the Flow rate. The values in table 4.1 were analyzed using regression analysis to develop an equation for head discharge. The head H was measured at a point $3H_{dam}$ away from the model crest using a point gauge.

Table 4.1: Measured head and Flow Rate

S/N	1	2	3	4	5	6
Head(cm)	6.10	5.72	5.08	4.10	3.81	3.30
Discharge(l/s)	7.549	6.804	5.74	5.065	3.725	3.011

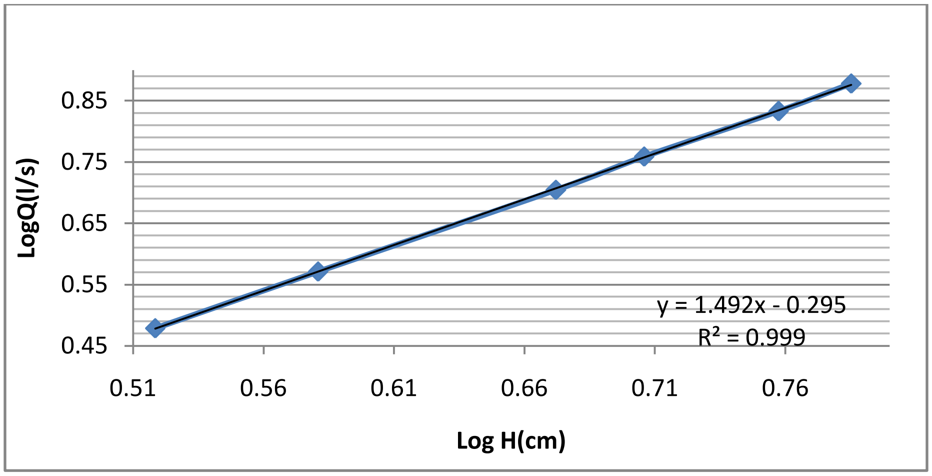


Figure 4.1 Head-Discharge Relationship

The figure above shows the head – discharge relationship for the models. It shows that the head of water over the crest increases with increase in discharge value. The rating curve for these models take the form

$$Q = KH^n \qquad (4.1)$$

It was also observed that the discharge coefficient depend on the height of the dam not the downstream slope of the dam.

The models whose geometries are related were compared were compared below.

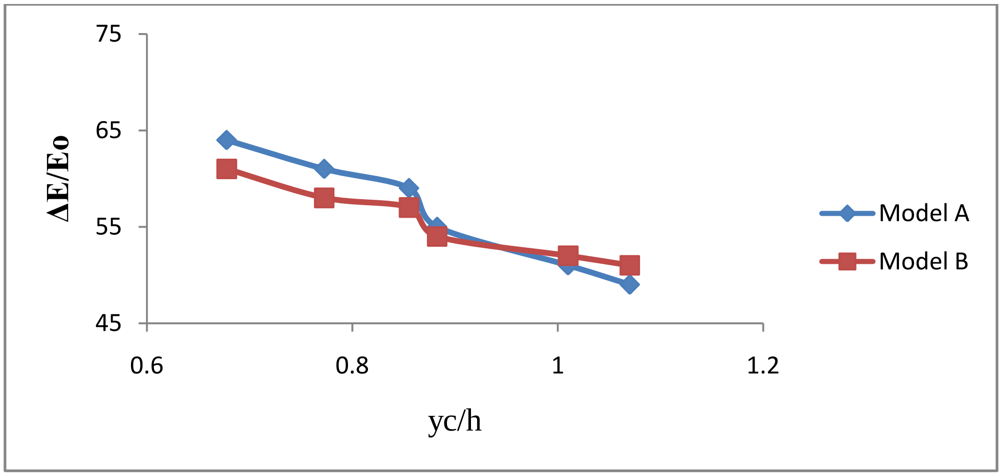


Figure 4.2 percentage of energy dissipation for model A and model B

The figure above shows the percentage of energy dissipation for model A (inclined at all steps) and model B (end sills at all steps).The result shows that model A dissipate more energy than model B. It also shows that energy dissipation are inversely proportional to the flow discharge or critical depths. The inclined steps are more efficient in energy dissipation at lower limit of skimming flow regime than end sill.

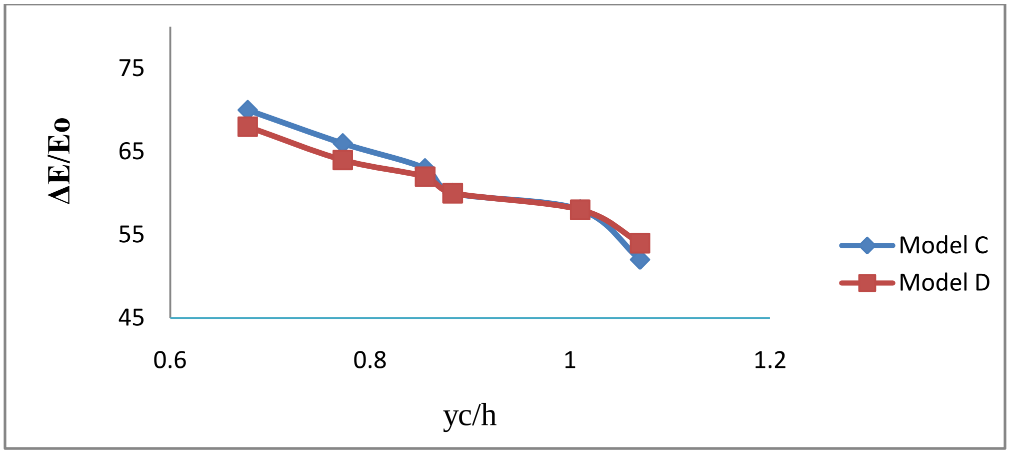


Figure 4.3 percentage of energy dissipation for model C and model D

Figure 4.3 shows the percentage of energy dissipation for model C (inclined between two steps) and model D (end sill between two steps). The result shows that model C dissipate more energy than model D. It is adjudge that air cavities are continuously filled with water of the free space to circulate between the two steps in inclined between two steps while in end sill between two steps the flow is subjected to a higher acceleration before hitting the next steps so air pocket in the step remain in the cavity.

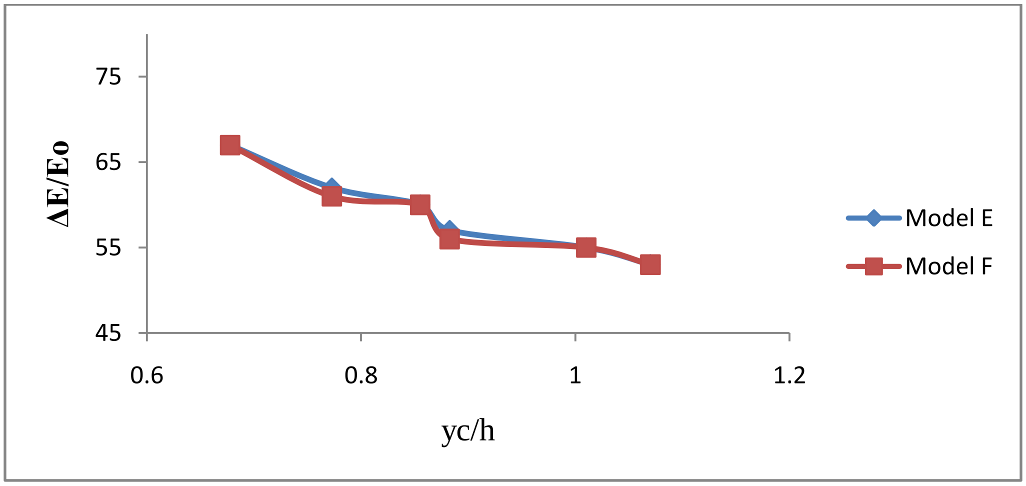


Figure 4.4 percentage of energy dissipation for model E and model F

In the above figure there is a small difference in percentage of energy dissipation between the two models.

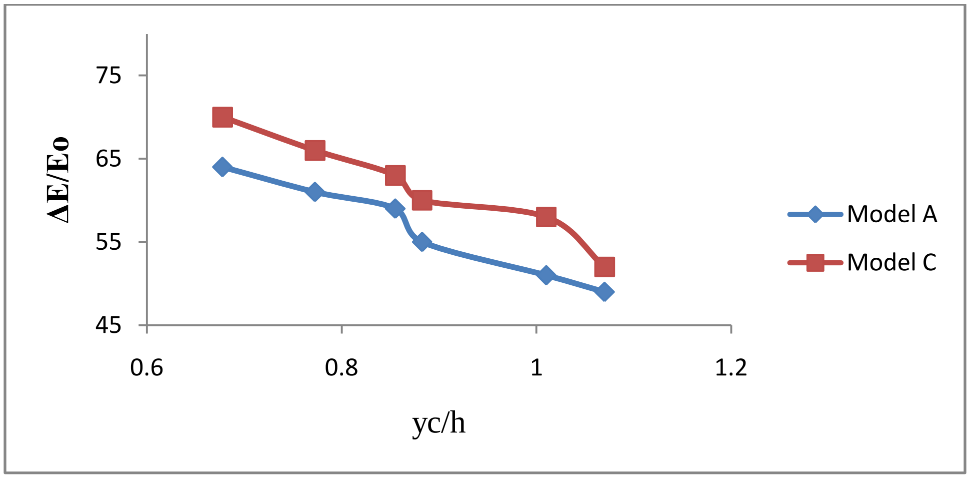


Figure 4.4 percentage of energy dissipation for model A and model C

Figure 4.4 shows the percentage of energy dissipation for model A and model C, it can be seen that model C dissipate more amount of energy than model A at both higher and lower discharge. This occurs due to the free circulation the two steps.

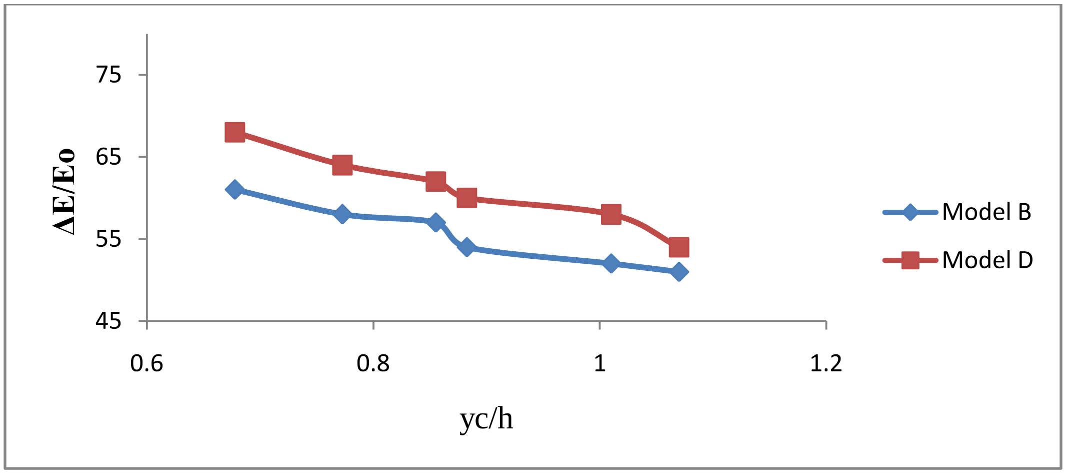


Figure 4.5 percentage of energy dissipation for model B and model D

Figure 4.5 shows the percentage of energy dissipation for model B and model D. it can be seen that model D dissipate more energy than model D. This is because end sill slightly increase energy dissipation since the internal transverse jets on the end sill outer edges are shorter and are broken by the end sill itself while end sill between two steps causes less energy dissipation until when all the steps are filled with water and recirculation cells.

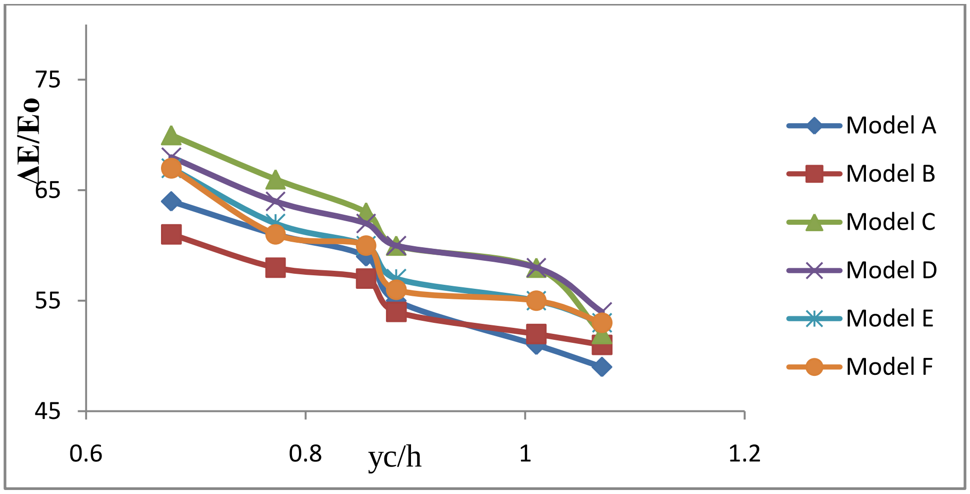


Figure 4.5; Percentage of Energy Dissipation for Model A,B,C,D,E and F.

Figure 4.5 shows the percentage of energy dissipation of the different stepped spillway models. It can be seen that overall, the model C provide highest energy dissipation rate among all the models studied.

The mathematical equation that can be used to predict energy dissipated over the stepped spillway with most efficient geometry take the form

$$\frac{\Delta E}{E_0} = \beta_1 (\frac{y_c}{h})^{\beta_2} \qquad (4.2)$$

4.2 MEASURED FLOW PARAMETERS ON THE STEPPED CHUTE MODELS

Thirty six experiments were conducted in the hydraulics laboratory to determined the flow parameters namely, head of water over the crest(H),water depth at a point upstream and downstream of the model(y),discharge(Q),Energy dissipation rate $(\frac{\Delta E}{E_0})$,critical depth y_c. The depth H and y were measured using a point gauge. The upstream head on the crest of each of the models are the same, the flow rate are also the same for each of the model while the depth of water at the downstream for each of the models are different.

Table 4.1 shows the various values of H and the corresponding value of the Q.

Table 4.4 to 4.9 shows the various values of y_c and $(\frac{\Delta E}{E_0})$ based on different geometries of the models. See Appendix. The values in table 4.4 to 4.9 were obtained according to the explanation given earlier. The values in these tables were used in plotting the variation of $\left(\frac{\Delta E}{E_0}\right)$ with ${}^{y_c}/_{h}$ for various geometry models. Also the values in the same table were analysed using regression analysis to developed Equation 4.1 for head-discharge relationship and Equation 4.2 for energy dissipation rate.

4.3 MATHEMATICAL EQUATIONS DEVELOPED FOR FLOW RATE AND RATE OF ENERGY DISSIPATION OVER THE STEPPED CHUTE SPILLWAY

The following expressions were developed using the experimental result

$$Q=0.5061H^{1.492} \tag{4.3}$$

Equation (4.1) is the discharge-head relationship which can be used to calculate the flow rate over the crest for the stepped chute models.

$$\frac{\Delta E}{E_0} = 0.5482\left(\frac{Y_c}{h}\right)^{-0.520} \qquad (4.4)$$

Equation 4.2 is the relationship for percentage of energy dissipation with the ratio of critical depth to height of steps.

The parameters of the above expressions were determined using SPSS regression analysis. At the end of the regression analysis, the values of these parameters were found as listed below

Table 4.2 Values of Parameters As A Result Of Regression Analysis

Equation	**parameter**	**value**	**R^2**	**Error**	**Significance**
4.1	K	0.5061	0.999	0.06	0.10
	n	1.492			
4.2	β_1	0.5482	0.951	0.015	0.30
	β_2	-0.520			

From Table 4.2, the value n=1.492 obtained for the stepped spillway models is less than that of normal weir equation by 0.008 as that of normal weir is 1.5 (Chow,1959). The percentage error will be

$$\%error = \frac{Theoretical - actual}{Theoretical} \times 100\% = \frac{1.500 - 1.492}{1.500} \times 100 = 0.511\%$$

This shows that the developed model equation was adequate to be employed in running this experiment.

The parameters of the Equations (4.3) and (4.4) have been obtained by regression analysis as indicated in Table 4.2

From this table, Correlation coefficient R_2 is an indicator of reliability or performance level of each of these relationships. For instance, the equation (4.3) has R^2 of 0.99, the means that 99.9% of the variation in the dependent variable (Q) is explained by the independent variable (H). Equation (4.4) has R^2 of 0.979, this means that 95.1% of the variation in the dependent variable $(\frac{\Delta E}{E_0})$ is explain by the independent variable (y_c/h) and the higher the value of R^2 the better the model.

Also from the above table the significance value in the both equation is < 0.005 which means that the regression equation is significant otherwise not and the smaller the standard error the better the estimate.

The parameters values for each of the developed relationships are shown in Table 4.2. In addition, the values of the dependent parameters predicted in equations 4.3 were compared with their respective experimental values calculated directly from values obtained from experiments. The results of the comparative analysis are respectively shown in Tables 4.4.

$$\text{Error} = \left(\frac{\frac{\Delta E}{E_0}_{experiment} - \frac{\Delta E}{E_0}_{theoritical}}{\frac{\Delta E}{E_0}_{experiment}} \right)$$

Table 4.3 Comparison of the range of values obtained for Energy Dissipation

S/NO	q(l/sm)	y_c/h	$\frac{\Delta E}{E_0}\%$ Experimental	$\frac{\Delta E}{E_0}\%$ Theoretical	Error %
1	0.0277	1.07	52.320	52.920	1.11
2	0.0252	1.01	55.510	54.540	1.71
3	0.0208	0.8825	59.6510	58.705	1.58
4	0.0198	0.855	62.870	59.470	5.39
5	0.0170	0.7725	65.740	62.690	4.64

The table above shows the result of experimental analysis of flow compared with results obtained from theoretical equation developed. The results are in terms of the amount of energy dissipated over the stepped chute. For calculating the error between the results, the following relationship was used.

Comparing the result of experimental analysis of this study with that of theoretical equation developed reveals that for discharge per unit width of 0.0277 the error was about 1.11 percent while for discharge per unit width of 0.0252 and 0.0170 errors were within 1.71 to 4.64 percent. So it signifies that there is good agreement between the measured and predicted values of energy dissipated over the spillway model.

From the graphs, it shows that at lower discharge more energy is dissipated over the steps which agree with Barani et al (2005) that increase in discharge decreases energy dissipation. Also the Eqn 4.4 for energy dissipation over the chute has a regression of 0.979 which is better than that of Kavianpour and Masoumi (2008) with regression of 0.92.

The percentage of energy dissipation over the steps models was found to be 69-70% which is more than that of Munta (2010) which is 40.20-64%.

The inclined steps are highly efficient in energy dissipation than end sills which also agree with Naderi (2014) study.

Finally the result of this study conform with that of Al-shukur et al (2014) which shows that among all the models studied, Inclined between two steps dissipate highest energy at lower discharge than other models. Also the range of energy dissipated for this study is between 49% to 70% which is less than that of Al-shukur et al (2014) which is between 60% to 90%.This shows that the smaller the angle of the chute the higher the energy dissipated over the chute, this is in good agreement with Munta (2010) .

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CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSIONS

Based on the results obtained in this investigation, The following conclusions were drawn

1 An Equation was developed for head-discharge relationship.

2 The downstream slope of the model does not affect the discharge coefficient.

3 An Equation was developed for energy dissipation rate for skimming flow.

4 The results indicated that among the test models, the highest energy losses is in model C (inclined every two steps).

5 The energy dissipation is inversely proportional to the flow discharge i.e when the discharge increase the energy dissipating rate decreases

6 Stepped spillway dissipates the flow energy better than those of smooth profile Because of the steps present in the spillway.

7 The inclined step has effects to an extent on skimming flow regime in comparison with end sills steps. It increases to a small extent at some lower discharge but the effect on higher discharge value is negligible.

The study has therefore been able to achieve the following,

1. Developed a model equation used to determine the flow rate over a stepped chute models.

2. Developed a mathematical equation for predicting percentage of energy dissipation over a stepped chute for the most efficient model i.e. model C.

5.2 RECOMMENDATION

Future research investigations should be carried out to provide information in the following areas:

i. Reduction of flow velocity also reduces the risk of cavitation as cavitation index increases; further research is required to examine the efficiency of the stepped spillways models in reducing cavitation.

ii. Stepped spillways can increase dissolved oxygen levels by creating turbulent conditions where small air bubbles are carried into the bulk of the flow so they are used in water treatment plants to enhance air water transfer of gases, so there is need to study aeration efficiency rate among the stepped spillway models.

iii. Study of flow characteristics and pressure fluctuations at stepped spillways with slope changes need to be carried out since there is gap knowledge in understanding flow characteristics over slope changes and its influence on design criteria.

iv. More research is required in the determination of length of hydraulic jump since no analytical solution has been developed as yet.

v Since flow conditions above stepped spillways are affected by air entrainment so measurement of air concentration and velocity in aerated flows above stepped spillway are also required to be investigated.

vi Stepped spillway chutes are characterized by intense turbulent and strong flow aeration and most studies did not investigate the turbulence characteristics so highly turbulent air water flows down a stepped chute need to be investigated.

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APPENDIX

MEASURED AND CALCULATED FLOW PARAMETERS ON THE STEPPED SPILLWAY MODELS

Table 4.1b Measured head and calculated flow rate

Run	Water head H(cm)	Mass,M(kg)	Time,t_1(s)	Time,$t_2(s)$	Flow rate,Q(l/s)
1	6.10	174	23.0	23.1	7.549
2	5.72	182	26.7	26.8	6.804
3	5.08	190	33.1	33.1	5.72
4	4.70	194	38.3	38.3	5.065
5	3.81	203	54.6	54.4	3.725
6	3.30	212	71.0	69.8	3.011
7	2.60	220	104	104	2.115

Table 4.4 Flow characteristics for the Model A

S/N	Q(l/s)	q(l/sm)	y_c(m)	1.5y_c(m)	H_d(m)	E_0(m)	$E_1(m)$	$\frac{E_0 - E_1}{E_0}$ (%)	y_C/h
S	8.36	0.0277	0.0428	0.0642	0.24	0.3042	0.1551	49	1.07
2	7.56	0.0252	0.0408	0.0603	0.24	0.3003	0.1471	51	1.01
3	6.25	0.0208	0.0353	0.0530	0.24	0.2930	0.1436	55	0.8825
4	5.95	0.0198	0.0342	0.0513	0.24	0.2913	0.1194	59	0.855
5	5.10	0.0170	0.0309	0.0464	0.24	0.2884	0.1125	61	0.7725
6	4.24	0.014	0.0271	0.0407	0.24	0.2807	0.1011	64	0.6775

Table 4.5 Flow characteristics for the Model B

S/N	Q(l/s)	q(l/sm)	y_c(m)	1.5y_c(m)	H_d(m)	E_0 (m)	E_1 (m)	$\frac{E_0 - E_1}{E_0}$ (%)
1	8.36	0.0277	0.0428	0.0642	0.24	0.3042	0.1491	51
2	7.56	0.0252	0.0408	0.0603	0.24	0.3003	0.1441	52
3	6.25	0.0208	0.0353	0.0530	0.24	0.2930	0.1348	54
4	5.95	0.0198	0.0342	0.0513	0.24	0.2913	0.1253	57
5	5.10	0.0170	0.0309	0.0464	0.24	0.2884	0.1211	58
6	4.24	0.014	0.0271	0.0407	0.24	0.2807	0.1095	61

Table 4.6 Flow characteristics for the Model C

S/N	Q(l/s)	q(l/sm)	y_c(m)	1.5y_c(m)	H_d(m)	E_0 (m)	E_1 (m)	$\frac{E_0 - E_1}{E_0}$ (%)
1	8.36	0.0277	0.0428	0.0642	0.24	0.3042	0.1460	52
2	7.56	0.0252	0.0408	0.0603	0.24	0.3003	0.1321	56
3	6.25	0.0208	0.0353	0.0530	0.24	0.2930	0.1172	60
4	5.95	0.0198	0.0342	0.0513	0.24	0.2913	0.1078	63
5	5.10	0.0170	0.0309	0.0464	0.24	0.2884	0.0981	66
6	4.24	0.014	0.0271	0.0407	0.24	0.2807	0.0842	70

Table 4.7 Flow characteristics for the Model D

S/N	Q(l/s)	q(l/sm)	y_c(m)	1.5y_c(m)	H_d(m)	E_0 (m)	$E_1 (m)$	$\frac{E_0 - E_1}{E_0}$ (%)
1	8.36	0.0277	0.0428	0.0642	0.24	0.3042	0.1399	54
2	7.56	0.0252	0.0408	0.0603	0.24	0.3003	0.1351	55
3	6.25	0.0208	0.0353	0.0530	0.24	0.2930	0.1172	60
4	5.95	0.0198	0.0342	0.0513	0.24	0.2913	0.1107	62
5	5.10	0.0170	0.0309	0.0464	0.24	0.2884	0.1038	64
6	4.24	0.014	0.0271	0.0407	0.24	0.2807	0.0898	68

Table 4.8 Flow characteristics for the Model E

S/N	Q(l/s)	q(l/sm)	y_c(m)	1.5y_c(m)	H_d(m)	$E_0(m)$	$E_1(m)$	$\frac{E_0 - E_1}{E_0}$ (%)
1	8.36	0.0277	0.0428	0.0642	0.24	0.3042	0.1430	53
2	7.56	0.0252	0.0408	0.0603	0.24	0.3003	0.1351	55
3	6.25	0.0208	0.0353	0.0530	0.24	0.2930	0.1260	57
4	5.95	0.0198	0.0342	0.0513	0.24	0.2913	0.1165	60
5	5.10	0.0170	0.0309	0.0464	0.24	0.2884	0.1096	62
6	4.24	0.014	0.0271	0.0407	0.24	0.2807	0.0926	67

Table 4.9 Flow characteristics for the Model F

S/N	Q(l/s)	q(l/sm)	y_c(m)	1.5y_c(m)	H_d(m)	$E_0\ (m)$	$E_1(m)$	$\frac{E_0 - E_1}{E_0}$ (%)
1	8.36	0.0277	0.0428	0.0642	0.24	0.3042	0.1430	53
2	7.56	0.0252	0.0408	0.0603	0.24	0.3003	0.1351	55
3	6.25	0.0208	0.0353	0.0530	0.24	0.2930	0.1289	56
4	5.95	0.0198	0.0342	0.0513	0.24	0.2913	0.1165	60
5	5.10	0.0170	0.0309	0.0464	0.24	0.2884	0.1125	61
6	4.24	0.014	0.0271	0.0407	0.24	0.2807	0.0926	67