Republic of Iraq

Ministry of Higher

Education and Scientific Research

University of Technology

Stilling Basin for Selected Hydraulic Conditions

Annual Project Submitted to Department of Building and Construction Engineering of the University of Technology in Partial Fulfillment of Requirements for the Degree of B.SC. In Building and Construction Engineering

Submitted by

Aulla Thammer

Nusaibah Abdullah

Supervised By

Numa Imara

Prof. Numa H.Imara

١٣

2010 ***1431***

بسم الله الرحمن الرحيم

و علمك ما لم تكن تعلم

و كان فضل الله عليك عظيما

صدق الله العظيم

النساء 113

Acknowledgement

Praise is to Allah for his grace on we to finish this project. We wish to express our deep sense of gratitude to our supervisor, Prof.Numa Hamad Imara for his valuable guidance, advice and cooperation during the work on this project. To him we owe the most. Finally, we thank our families, especially our mothers, fathers, sisters and brothers for their forbearance and support.

Dedication

To Mohammed

Messenger of

Allah

To

Our families especially

Our parents

To

Our friends

CONTENTS

Details Page No.

CHAPTER ONE: INTRODUCTION

CHAPTER TWO: THE HYDRAULIC JUMP

CHAPTER THREE: HYDRAULIC STRUCTURES WITH STILLING BASINS

Details Page No.

3.3 Standard Stilling Basins (S.S.B)

CHAPTER FOURE: STILLING BASIN DESIGN

CHAPTER FIVE: SUMMARY AND CONCLUSIONS

List of figures Page No.

List of figures Page NO.

List of Tables

List of Symbol

B	Width
D	Drop number
D.L.	Datum level
E_1	Total energy upstream
E_2	Total energy downstream
E_j	Energy loss in the hydraulic jump
E_l	Energy loss in the over fall
E_S	Specific energy
E.L.	Energy line
F_1	Froude number
Hd	Design head of the spillway
He	Energy loss in the hydraulic jump
Lb	Length of the stilling basin
Ld	Length of the drop
Lj	Length of the jump
n	Manning roughness coefficient
P	Pier
Q	Discharge
R	The hydraulic radius
S	Slope of the channel

List of symbols

T.W.	Tailwater
V_1	Velocity in the upstream
V_2	Velocity in the downstream
V_C	Centerline velocity
$\frac{V^2}{2g}$	Velocity head
y_1	Incoming depth
y_2	Sequent or (conjugate) depth
y_c	The upstream critical depth
y_n	Normal depth in the upstream
Z	The height of the fall

CHAPTER ONE

INTRODUCTION

1.1 General

A stilling basin is a channel structure which usually has a rectangular cross-section with mild slope. It is used for the structures or pipes which have high velocity flow or large change in their slopes .So, there must be an energy dissipator to dissipate some of the high kinetic energy of the flow by using the hydraulic jump in the basin. The stilling basin is also necessary for the hydraulic structures to save some of them from high velocity stream when discharged into the downstream channel. This may cause dangerous erosion and saved from danger of cavitation due to changes in channel or bed geometry. The stilling basin may also face bed scour. Stilling basin always placed at the outlet of the hydraulic structures such as side escape, drops or falls, chutes, spillways and pipe outlets. The flow at these structures is usually supercritical with high velocity. The side escape is usually needed before the cross- Regulator in the irrigation system. It is useful to release the excess water from the channel under any circumstances. Drops or falls, and chutes are required at suitable intervals in channels which must have a gentler slope than that of the adjacent land, so as to reduce the water level downstream and reduce the velocity of flow. They also provide for the safe dissipation of surplus energy when combined with a stilling basin. When this is achieved over a short distance such a structure is called a drop; when the water is conveyed over a long distance but at slopes steep enough to maintain supercritical flow, the structure is called a chute (or inclined drop). Chutes may also be used on sloping land where a single drop or series of drops would be more expensive. The choice between vertical drops and chutes is governed mainly by the difference in water level to be controlled by the structure, in other words, the energy to be dissipated. However, generalization of the criteria for the choice is not possible but the following points should be considered:-

- The necessary drop in level and dissipation of energy can be achieved either by one or a few large drops or by several small drops over the same distance, depending on cost.

- The chute unlike the vertical drop offers the possibility of dissipating energy through the hydraulic jump. Where the fall is considerable, the whole structure of the chute requires less material and labor input than the wall and stilling basin of the vertical drop.
- Drops can be used as measuring devices by incorporating a calibrated weir section and chutes may be designed to include a calibrated flume section.
- In main and branch canals , drops are sometimes provided with a low crest wall or check gate upstream to prevent excessive drawdown of flow in the upstream channel. Thus in the design of drops, chutes, spillways and stilling basins, it is necessary to have some knowledge of the hydraulic jump which shall be explained in chapter two and may be utilized with these structures.

1.2 Objectives

The objectives of this last year project are:

1. To investigate the hydraulic structures that has high energy flow which needs to be dissipated in a basin.

2. Establish the flow condition in a given hydraulic structure and design the required stilling basin to dissipate the excess energy of the flow.

1.3 Outline of the Project

This last year project consists of five chapters. Chapter one cover the hydraulic structures with flow of high velocity. These structures need a stilling basin to dissipate the excess energy of the flow. Six types of structures were mentioned in this chapter. Since the hydraulic jump is used as a mean for dissipating the excess energy, chapter two was devoted to explain the basic of this phenomena. Brief explanation of the hydraulic structures that need a stilling basin as part of their appurtenances is included in chapter three. The design of the stilling basin for a given hydraulic conditions and type of structure is illustrated in chapter four. Chapter five will cover the summary, conclusions and recommendations.

CHAPTER TWO

THE HYDRAULIC JUMP

2.1 Introduction

In many hydraulic structures where the flow has high energy, the hydraulic jump is usually used to dissipate this excess energy. Therefore, it is necessary to have full understanding of this phenomena.

2.2 The Hydraulic Jump

It is a device of excessive energy dissipation in some hydraulic structures which has a steep slope such as chute, spillway, drops... etc. The flow changing from supercritical to subcritical is associated with the hydraulic jump, figure (2.1).

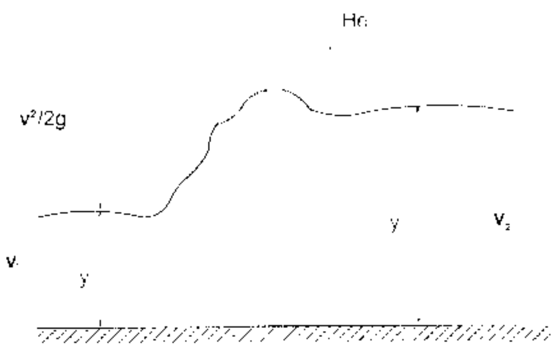


Fig. (2.1) Notation for the hydraulic jump

The appropriate relationship between incoming and outgoing flow is given by the following equation:-

$$y_2 / y_1 = \frac{1}{2}[\sqrt{1 + 8F_1^2} - 1], \text{ H.J.E} \qquad (2\text{-}1)$$

Where $F_1^2 = q^2 / gy_1^3$ or $F_1 = \frac{q}{y_1\sqrt{gy_1}} = \frac{V_1}{\sqrt{gy_1}}$ (2-2)

The depth y_2 is called conjugate or sequent to the incoming depth y_1.Figure (2.2) shows the relation of equation (2.1)

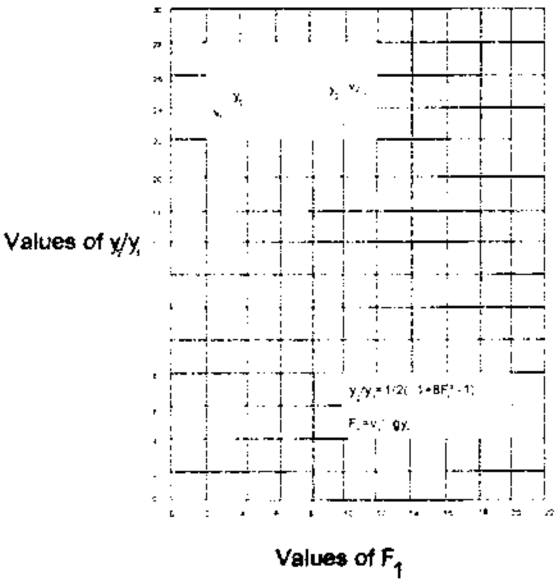


Fig.(2.2) Versus y/y_1 for the hydraulic jump equation

The energy loss in the jump is given by:

$$He = \frac{(y_2 - y_1)^3}{4y_1y_2} \qquad (2.3)$$

He is shown in figure (2.1). The important aspect of using the hydraulic jump as an energy dissipator is to keep the jump at a known location. If the downstream water level rises the jump is forced upstream and may submerge the control causing subcritical flow and therefore reduce the discharge. If the tailwater drops, the jump can travel downstream and in an unlined canal, this is not tolerable. The hydraulic jump and modification to it for use as an energy dissipator are discussed in many literatures(10)*.

2.2.1 Types of Jump

Hydraulic jumps on horizontal floor are of several distinct types. According to the studies of the U.S. Bureau of Reclamation (11), these types can be conveniently classified according to the Froude number F_1 of the incoming flow, Figure (2.3), as follows: -

F_1=1-1.7 Undular jump

F_1=1.7-2.5 Weak jump

F_1=2.5-4.5 Oscillating jump

F_1=4.5-9.0 Steady jump

F_1>9.0 Strong jump

Fig.(2.3) various types of hydraulic jump

*Number between parentheses refers to the reference number in the reference list.

For F_1=1, the flow is critical, and hence no jump can form. For F_1 =1 to 1.7, the water surface shows undulations, and the jump is called an undelay jump. For F_1=1.7 to 2.3, a series of small rollers develop on the surface of the jump, but the downstream water surface remains smooth .The velocity throughout is fairly uniform, and the Energy loss is low. This jump may be called a weak jump. ForF_1 =2.5 to 4.5, There is an oscillating jet entering theJump bottom to surface and back again with no periodicity. Each oscillation produces a large wave of irregular period which, very common in canals, can travel for a long distance doing unlimited damage to earth banks and ripraps. This jump may be called an oscillating jump. For F_1 =4.5 to 9.0, the downstream extremity of the Surface roller and the point at which the high-velocity Jet tends to have the flow occur at practically the same vertical section. The action and position of this jump are least sensitive to variation in tail water depth. This jump is well-balanced and the performance is at its best. The energy dissipation ranges from (45to70) %. This jump may be called a steady jump. For F_1≥9.o, the high-velocity jet grabs intermittent kilograms of water rolling down the front face of the jump, generating waves downstream, and a rough surface can prevail. The jump action is rough but effective since the energy dissipation may reach 85%. This jump may be called a strong jump.

3.1 Hydraulic Structures

There are many hydraulic structures with high energy flow .Such structures need a stilling basin to reduce the energy of the flow to save the downstream part of the channel. Below is a list of such structures. The design of their stilling basin shall be made in chapter four.

3.1.1 Spillway Structure

The spillway is one of the appurtenances of the dam; figure (3.1).It is built on one side of the dam to release the flood water. As the water falls through the spillway with height(h),high velocity(V_1)is expected at the bottom of the spillway. Therefore, a stilling basin is needed at the bottom of this spillway. In figure (3.1) Hd is called the design head.

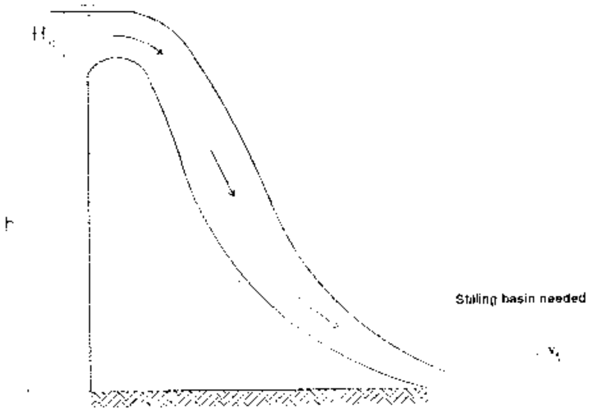


Fig.(3.1) The spillway structure

3.1.2 Vertical Drop Structure

The vertical drop structure is a convenient and simple device with which to dispose excess energy and produce a small change in channel invert in areas where natural ground slopes are steep, figure (3.2).

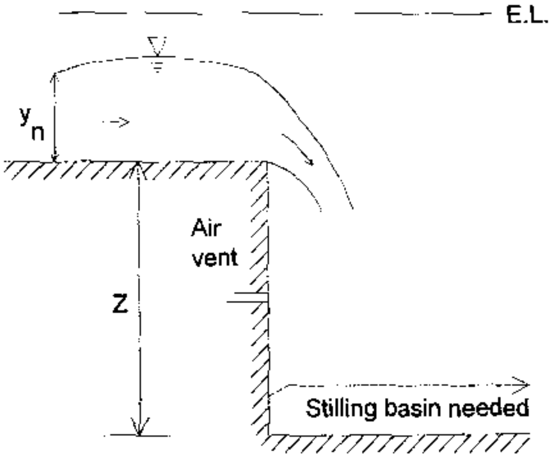


Fig.(3.2) Vertical drop structure

In general their use should be limited to change in bed level (z) of about 1.0 m in unlined channels and 2.0 m in lined canals. y_n in figure (3.2) is called the normal depth or the depth which is obtained by using the manning's equation.

3.1.3 Bottom Outlet

Bottom outlets (one or more) are usually used at the bottom of the dam to release the water for any purpose .This water is controlled by a valve. It is released for the purpose of drinking, cultivation, industrial use or release of sediment behind the dam. At the outlet a stilling basin is needed, figure (3.3).

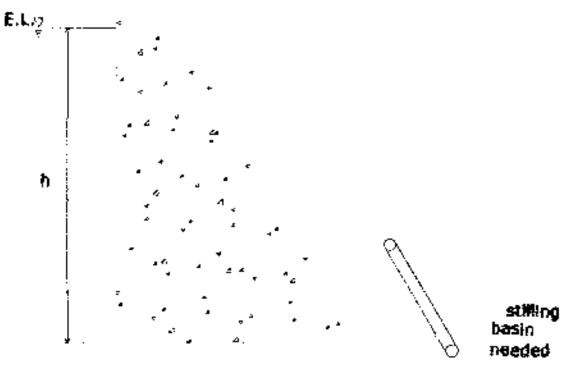


Fig.(3.3) Bottom outlet

3.1.4 Chute

The energy dissipation in inclined drops or chutes is usually achieved by the creation of a hydraulic jump at the toe or downstream end of the sloping section and may be supplemented by impact blocks and other energy dissipation devices, Figure (3.4). The slope of inclined channel section is steep, usually between 2:1and 6:1. The chute may be used to drop the water from high level to low level. This chute may be used as side escape before the cross regulator. At the end of it a stilling basin is needed.

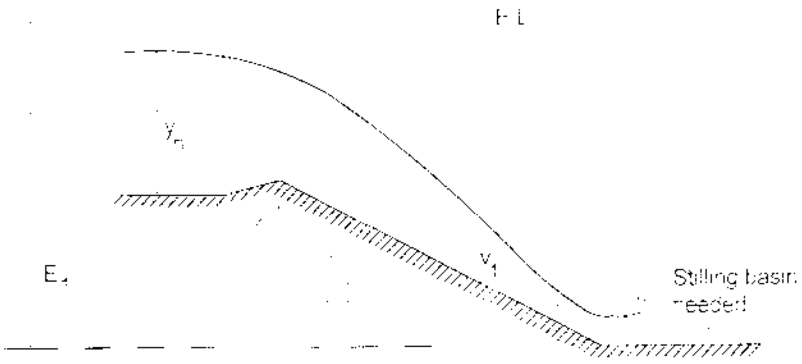


Fig.(3.4) Typical chute

3.1.5 Open Channel Outlet

At the end of any irrigation canal, the excess water needs to be released to some canals to avoid damaging the agricultural land. Usually a pipe is used to quid the excess water to the drainage canal as shown in Figure (3.5). A stilling basin is needed at the end of the pipe. Since this pipe is short, it is called a culvert.

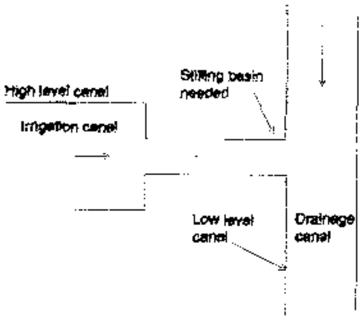


Fig.(3.5) Pipe outlet from irrigation

3.1.6 High Velocity Pipe Flow

When the flow in a pipe has very high velocity and needs to be discharged, its jet may be divided in to two gets by a tee junction to face each other. The result is strong impact of the two jets. This impact will dissipate most of the kinetic energy of the flow (12). Many other methods are available in the literatures to solve the case of pipe flow with very high velocity, another last year project needs to cover the design of different stilling for such pipe flow. For this project, only the four cases listed in this chapter will be illustrated. The design of a stilling basin for one type of stilling for the high velocity of pipe flow is considered in the next chapter.

3.2 Generalized Design of Stilling Basins

Generalized designs of stilling basins are often necessary for economy and to meet specific requirements in important structures. The design can be developed through years of experience and observations on existing structures or by investigations or from both. When the basins are designed then they are provided with special appurtenances, which include chute blocks, sills, and baffle piers, figure (3.6). These appurtenances have special shape and function with particular location in the basin. The following is the required details about these appurtenances.

3.2.1 Chute Blocks

They are used to form a serrated device at the entrance to the stilling basin. Their function is to furrow the incoming jet and lift a portion of it from the floor, producing shorter length of jump than would be possible without them. In addition, these blocks also tend to stabilize the jump and thus improve its performance.

3.2.2 Sills

They are either dentate or solid, sills usually located at the end of the stilling basin. The function of sills is to reduce further the length of the jump and to control scour. For large basins that are designed for high incoming velocities, the sill is usually dentated to create the additional function of diffusing the residual portion of the high-velocity jet that may reach the end of the basin.

3.2.3 Baffle Piers

These types of blocks are placed in intermediate positions across the basin floor. Their function is to dissipate energy mostly by impact action. The baffle piers are very useful in small structures with low incoming velocities, but they are unsuitable where there are high velocities because they possibly make cavitations. The baffle piers must be designed to withstand impact from ice or floating debris.

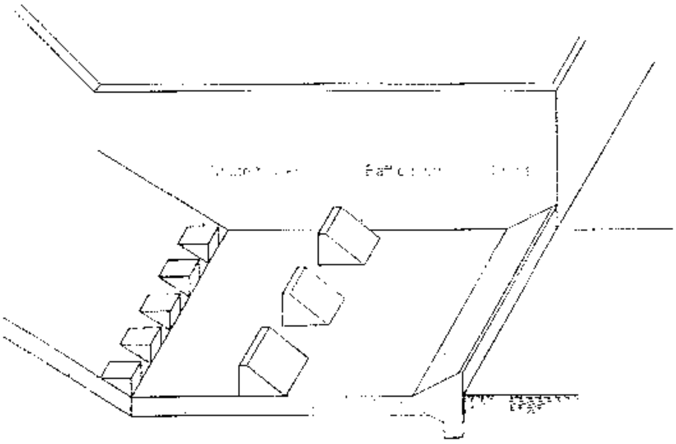


Fig.(3.6) Appurtenances of stilling basin

3.3 Standard Stilling Basins (S.S.B)

3.3.1 (S.S.B) With Hydraulic Jump

There are many types of stilling basin that use a hydraulic jump as the means of energy dissipation:-

1-The SAF stilling basin

This type of basin is used for small structures such as small spillway, outlet Works, and small canal structures. Where F1 = 1.7 to 17.

The reduction in basin length is achieved through the use of appurtenances designed for the basin is about 80% (70 to 90 %).

2- USBR stilling basins

There are many types of these basins:

A-USBR stilling basin I

This is a basin created by jump accuring on a flat floor with no appurtenances, but this type of basin usually is not very practical because of its expensive length and its lack of control.

B-USRB stilling basin II

This type of basin was developed for stilling basins in common use for high – dam and earth – dam spillways and for large canal structures. Where F1>4.5. The jump and basin length is reduced about 33% with use of appurtenances.

C- USBR stilling basin III

This type of basin is used for similar purpose to that of the SAF basin, but it has a higher factor of safety, which is necessary for Bureau use. The jump and basin length is reduced about 60% with the appurtenances; it is low compared with 80% for SAF basin. Therefore, the SAF basin is shorter and more economical, but it has a lower safety factor.

D-USBR stilling basin v

This type of basin is used for high-dam spillways where structural economies dictate the use of a sloping apron.

E-USBR stilling basin IV

This type of basin is used for canal structures and diversion dams. Where F1 = 2.5 to 4.5. This type of basin design to reduce excessive waves created in imperfect jumps.

Since stilling basins usually accomplish the dissipation of excess Energy by the hydraulic jump, it becomes necessary to review chapter two before any step for the design of the stilling basin.

3.3.2 Stilling Basin with No Hydraulic Jump

When high velocity flow ends facing body of water, the stilling basin may become a simple pool. In this case, there is no need to separate the stilling basin from the water body. This will help to eliminate the detail design of the stilling basin which is usually contains most of the appurtenances of the basin. All excess energy is usually dissipated in this pool. Example is shown in figure (4.11) where the pipe outlet canal ends in the water. Many of these pool basins were used in the Hilla-Kifil irrigation project south of Baghdad. Another case is the flow of water from bottom outlet in dams, figure (3.3). The jets of water may discharge above the pool and dissipates its energy by impact with the water in the pool. This practice was used in Rutba dam on Huron valley near Rutba city.

3.4. Types of the Energy Dissipators

There are many types of energy dissipators which have been built, and usually the design of each has been varied to solve the problem at hand. They are classified as one or a combination of the following types

1- Roughened channel lining.
2- Drop structure basin.
3- Free fall basin.
4- Hydraulic jump basin.
5- Diffusion structure.
6- Impact structure.
7- Roller bucket.
8- Flip bucket.

Some of these basins are provided with special appurtenances such as chute blocks, baffle piers, and end sills to help improve their performance. In addition, they help stabilize the flow, increase the turbulence, and distribute the velocities more evenly throughout the basin. They usually help in reducing the required tail water depth and length of the basin. The above listed types of dissipators can be utilized as stilling basin transitions from open channels to open channels or from pipes to open channels.

3.5. Types of the Dissipators for the High-Velocity Pipe Flow

The following are some of the devices which were developed to expend part of the energy of the high- velocity pipe flow before it issues to an open channel

1- Manifold stilling basin dissipator.
2- Contra Costa energy dissipator.
3- Plate energy dissipator.
4- Pipe energy dissipator.
5- Bradly-peterka energy dissipator.

The general design rules are presented in each corresponding reference (12) so that the necessary dimensions for the particular basin may be obtained. The following is a brief discussion and description of the first two types of basins.

3.5.1 The Manifold Stilling Basin Dissipator

Study of the manifold stilling basin dissipator was made by G.R. Fiala and M.L. Albertson (12). It is a diffusion-type energy dissipator. It consists of along box-like structure with cross bars on the top and slots through which the water enters the open channel, figure (3.7).The manifold had a constant width but the depth decreased linearly to zero at the downstream end. The model was constructed with a length of 8 feet, width of 1 foot, and a depth of 1 foot at the inlet end. The outside channel had 2:1 side slope. Piezometers were used to study the pressure along the manifold. Different size and shapes of cross bars were used to study their effect on the water surface. It was found that a 1-foot square inlet with an 8-foot long manifold gave satisfactory velocity distribution, and the flow from the manifold was reasonably uniform. Energy dissipation is initiated by shear resistance and pressure resistance, with the turbulence associated with them, as well as the diffusion action of numerous jets issuing from the manifold through the tail water. Protection against erosion is required on the bank and bed of the open channel downstream due to the remaining kinetic energy in the jets.

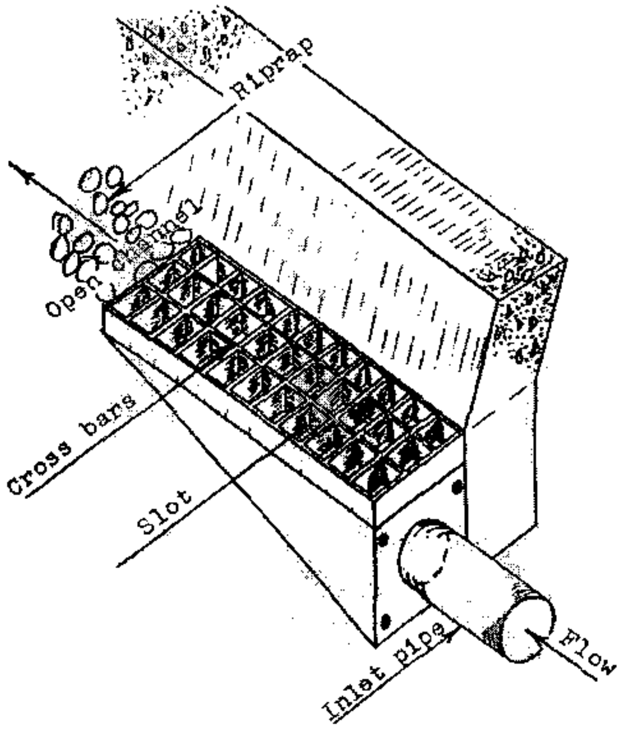


Fig. (3.7) the manifold stilling basin

3.5.2. The Contra Costa Energy Dissipator

The contra costa energy dissipator was investigated by S.Russell keim (12). The basin consists of the first and second baffles which were built inside a trapezoidal channel with a sill downstream from the second baffle. A typical model of the final design is shown in figure (3.8).

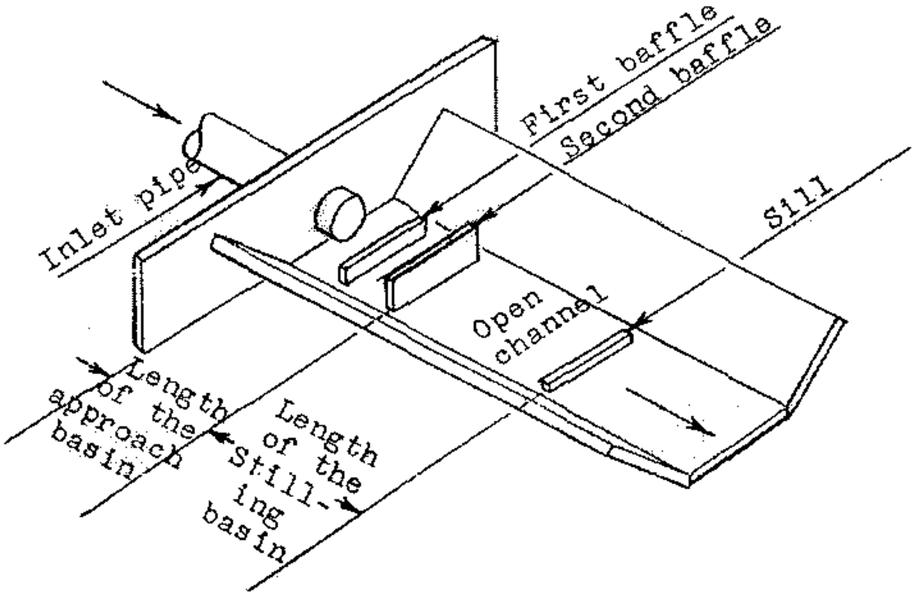


Figure (3.8)

The contra costa energy dissipater

For this model the height of the first baffle was one- half the height of the second baffle and was placed at the midpoint of the approach basin. The open channel had an 8-inch bottom width and 1:1 side slopes. The ratio of the approach basin to the height of the second baffle is 1to 3.5. To protect against local material deposition a small sill at the end of the stilling basin was installed to provide a reverse roller near the bed. It was proved through model investigation that the depth of inlet flow must be less than one- half of the inlet pipe diameter for desirable performance. Energy dissipation is due to the diffusion, impact of the flow with the first and second baffle, and the hydraulic jump. Dissipators of this design are in use.

CHAPTER FOUR

STILLING BASIN DESIGN

4.1 Introduction

In chapter one, structures were mentioned that need a stilling basin to dissipate the excess energy of the flow. It was also mentioned that most of these basins use a hydraulic jump as a mean for dissipating the excess energy. Then chapter two was devoted to explain this phenomena. In chapter three, six cases were mentioned of hydraulic structures which need stilling basin as part of their appurtenances. Four cases shall be considered for design of the stilling basin. The fourth case is a special pipe flow with very high velocity.

4.2 Case 1

Stilling Basin for Straight or (Vertical) Drop

For a canal with B=2.4m, Z=1.5,lined i.e. n=o.o15 and bed slope =17.7cm/km with normal supply discharge of 5m^3/s coming along 800m of some steeply terrain. This canal needs vertical drop design to change the upstream to downstream water level by 2m.The same depth of flow in the channel should be maintained in the channel reaches upstream and downstream of the drop structure. Fixed weir may be necessary.

Design

1- Basic Information

The notation for straight drop is shown in figure (4.1)

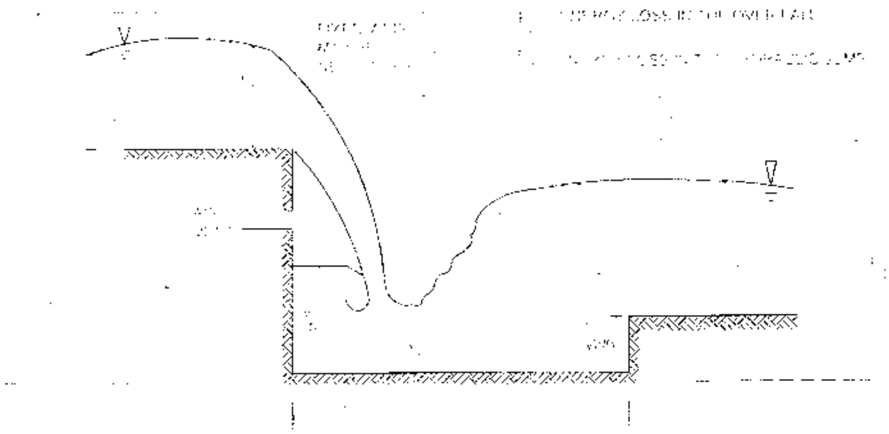


Fig.(4.1) Notation for straight drop

The equations governing the geometry of this type of fall have been derived from experiments. The pertinent equations are:-

Drop number=D= $(y_c/Z)^3$ (4-1)

Ld =4.3*Z*$D^{0.27}$ (4-2)

y_p =Z*$D^{0.22}$ (4-3)

y_1 =0.54*Z*$D^{0.425}$ (4-4)

y_2 =1.66*Z*$D^{0.27}$ (4-5)

Lj =6.9(y_2-y_1) (4-6)

E_2=2.5y_c (4-7)

All the above variables are shown in figure (4-1) with y_c representing the critical depth. An additional diagram. Figure (4-2) may be useful for enabling the stilling basin to be dimensioned completely.

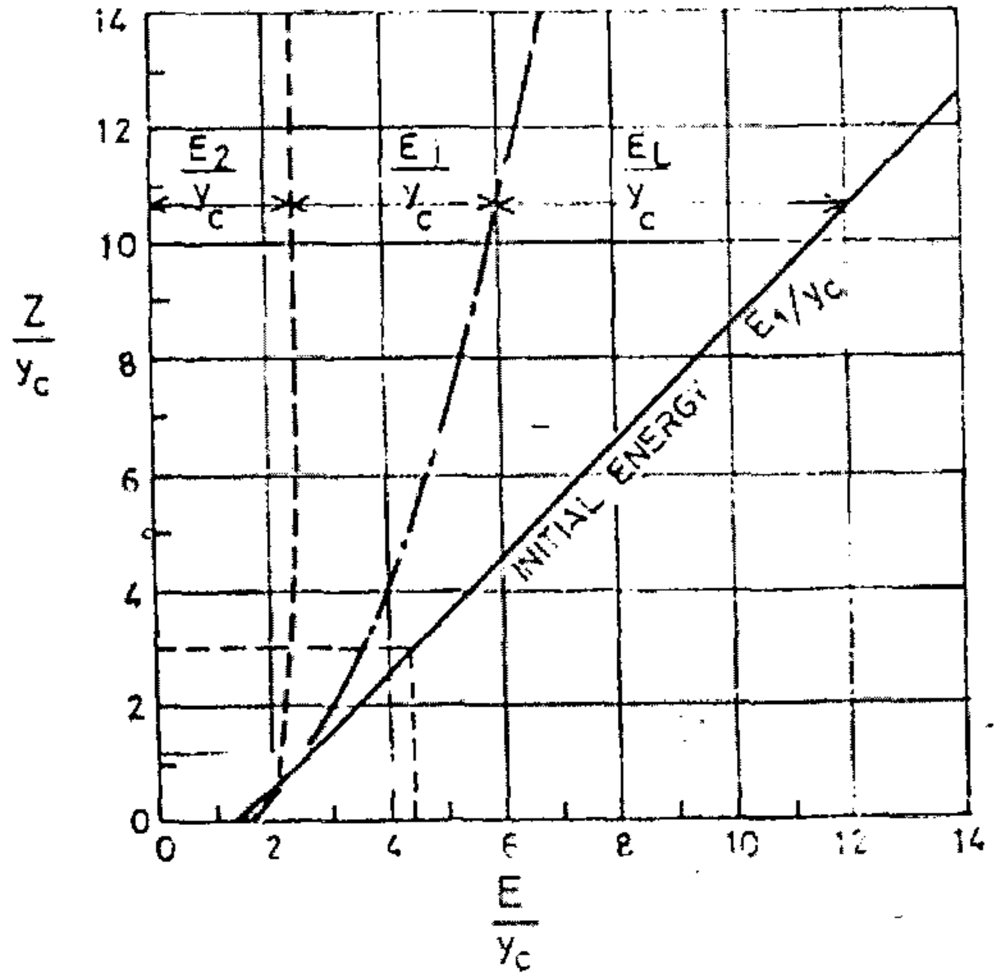


Fig. (4.2) Energy losses in a straight drop structure

2-Appropriate Discharge Equations

The manning's equation for uniform flow in open channel is:

$$Q = \frac{A}{n} R^{2/3} S^{1/2} \qquad (4\text{-}8)$$

The sharp crested rectangular weir equation is

$$Q = 3.13\ B y_c^{3/2} \qquad (4\text{-}9)$$

Where n is manning roughness coefficient, B is width of the drop (m), R is the hydraulic radius (m), S is the slope of the channel, Q is the discharge (m^3/sec.), and y_c is the critical depth.

The critical depth is given by:

$$y_c = \left(\frac{q^2}{g}\right)^{1/3} \qquad (4\text{-}10)$$

Where q is the discharge per unit width i.e. $(\frac{Q}{B})$. All above three equations are written in SI units. The critical depth is also equal to (2/3) of the specific energy (Es) i.e.

$$y_c = 2/3\ \text{Es} \qquad (4\text{-}11)$$

The specific energy is equal to the depth plus the velocity head

$$\text{Es} = y + \frac{V^2}{2g} \qquad (4\text{-}12)$$

3- Calculations

Since the design discharge, Q =$5m^3/s$, the calculations should include three discharges, the design discharge of $5m^3/s$, 1.2 Q = $6m^3/s$ and 0.7Q =$3.5m^3/s$.

- Normal Flow Calculations

A) Q = 5m^3 /s

The normal depth for Q =5m^3/s using the information in figure (4.3) for trapezoidal channel and manning's equation, equation (4-8), the result is:

$$Q = \frac{A}{n} R^{2/3} S^{1/2}$$

$$5 = \frac{(2.4+1.5y_n)y_n}{0.015} \left[\frac{(2.4+1.5y_n)y_n}{2.4+3.61\, y_n}\right]^{2/3} [0.000177]^{½}$$

By trial and error y_n = 1.4m

$$\therefore 5 = \left(\frac{6.3}{0.015}\right)\left(\frac{6.3}{7.454}\right)^{2/3} (0.0133) = 4.9934 \approx 5.0$$

y_n =1.4 m, $V_n = \frac{Q}{A}$

$\therefore\ V_n = \frac{5}{6.3} = 0.794$ m/s, $\frac{V_n^2}{2g} = 0.032$m

The specific force $= y_n + \frac{V_n^2}{2g}$

$\therefore\ E_s = 1.40 + 0.032 = 1.432$m

$y_c = \frac{2}{3}$ Es

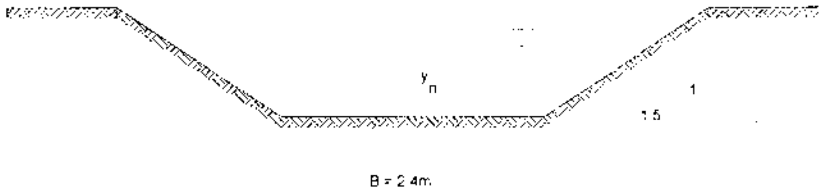


Fig.(4.3) The trapezoidal channel

$\therefore\ y_c = \frac{2}{3}(1.432) = 0.955\text{m}$

B- Q =6 m^3/s

$$6 = \frac{(2.4+1.5\,y_n)y_n}{0.015}\left[\frac{(2.4+1.5\,y_n)y_n}{2.4+3.61\,y_n}\right]^{2/3}[0.000177]^{½}$$

By trial and error $y_n = 1.53\text{m}$, A =7.183m^2,

$V = \frac{6}{7.183} = 0.835, \frac{V^2}{2g} = 0.036\text{m}.$

Specific energy upstream $= y_n + \frac{V^2}{2g} = 1.566\text{m}$

When no raised crest is used to maintain the upstream depth;

$y_c = \frac{2}{3}\,\text{Es}$

$= \frac{2}{3}(1.566) = 1.044\text{m}$

And from equation (4-10)

$y_c = (\frac{q^2}{g})^{1/3}$ or $1.044 = (\frac{q^2}{9.81})^{1/3}$ from which q =3.341 m^2/s

Therefore the width of the fall $=\frac{Q}{q}=\frac{6}{3.341}=1.80$m.

Using the pertinent equations of the drop, one can find:-

With z =2m as assumed first (with no weir) the drop number

From equation (4-1):-

D = $(y_c/Z)^3=(1.044/2)^3=0.142$

Ld = (4.3) (z)$D^{0.27}$ = (4.3) (2) $(0.142)^{0.27}$ = 5.1m

y_1 = (0.54) (z)$D^{0.425}$ = (0.54) (2) $(0.142)^{0.425}$ =0.471m

y_2 = (1.66) (z) $D^{0.27}$ = (1.66) (2) $(0.142)^{0.27}$ =1.96m

Lj = (6.9) (y_2-y_1) = (6.9) (1.96-0.471) =10.3m

The sequent depth (y_2) is greater than the tail water which is (1.53m) so the jump would not form near the base of the over fall.

Considering the upstream channel with ($5m^3/s$) in the canal, the above equation shows that ($y_n = 1.40m$) and the velocity (v=0.794m/s)

And the specific energy (Es $=y_n+\frac{V^2}{2g}$ = 1.432 m), but with width (B) of the fall (1.8m).

$\frac{Q}{B}=q=\left(\frac{5}{1.8}\right)=2.778$ m^2/s

$y_c=\left(\frac{q^2}{g}\right)^{1/3}=0.923$m

So the specific energy = $y_c+\frac{V_c^2}{2g}$

Es $=0.923+\frac{3.01^2}{2*9.81}$

$\therefore$ Es =0.923 +0.462 =1.385 m

This will cause some drawdown of the normal depth upstream which is not good.

Considering the upstream channel with (Q =3.5 m^3/ sec), using manning equation:-

$$Q = \frac{A}{n} R^{2/3} S^{1/2} \text{ or}$$

$$3.5 = \frac{(2.4+1.5\,y_n)\,y_n}{0.015}\left[\frac{(2.4+1.5\,y_n)y_n}{2.4+3.61\,y_n}\right]^{2/3}[0.000177]^{½}$$

By trial and error y_n =1.17m, v =0.72m/s, so the specific energy $= y_n + \frac{V_n^2}{2g}$

$$Es = 1.17 + \frac{(0.72)^2}{2*9.81} = 1.196\text{m.}$$

However, at the drop, $q = \left(\frac{3.5}{1.8}\right) = 1.944\text{m}^2/\text{s}$

$$y_c = \left[\frac{q^2}{g}\right]^{1/3} = \left[\frac{1.944^2}{9.81}\right]^{1/3} = 0.728\text{m}$$

And the specific energy $= y_c + \frac{V_c^2}{2g}$ with

$$V_c = \frac{3.5}{(0.728)(1.8)} = 2.671 \text{ m/s.}$$

$$\therefore Es = 0.728 + \frac{2.671^2}{2*9.81} = 1.092\text{m}$$

This will cause more drawdown upstream for the low flow case and this may affect off takes. To overcome these problems, the width of the drop approach Channel can be increased and at the same time a raised weir is placed at the drop. If the width of this channel is made the same as the channel bed width so that (b =B = 2.4m)

$q = \frac{6}{2.4} = 2.5\ \text{m}^2/\text{s}$, $y_c = \left(\frac{q^2}{g}\right)^{1/3}$

$y_c = \left[\frac{2.5^2}{9.81}\right]^{1/3} = 0.86\ \text{m}$

And specific energy at the drop = 1.29 m

$V_c = \frac{Q}{B\,y_c} = \frac{6}{(2.4)(0.86)} = 2.91\ \text{m/s}$ so,

$0.86 + \frac{(2.91)^2}{2*9.81} = 1.29\ \text{m}$

The weir height is given by (1.566 -1.29 =0.28 m) with 5m^3/sec. in the canal, y_c at the drop,

$q = \frac{5}{2.4} = 2.083\ \text{m}^2/\text{s}$

$y_c = \left(\frac{q^2}{g}\right)^{1/3} = \left(\frac{2.083^2}{9.81}\right)^{1/3}$

$\therefore\ y_c = 0.762$ m and

$V_c = \frac{5}{(0.762)(2.4)} = 2.734\ \text{m/s}$ so,

The specific energy = $0.762 + \frac{(2.734)^2}{2*9.81} = 1.143$ m,

With the weir height getting total energy of:-

(1.143 +0.28 = 1.423m) compared with the total upstream energy

Of (1.432) .... (o.k.).

Since there is little drawdown.

With (3.5m^3/sec.), ($y_c = 0.6m$) by same procedure with (5m^3/sec) and

(Total energy = $\frac{3}{2} y_c + 0.28 = 1.18$m) compared with (1.196m) from above so there is little drawdown. Returning to design discharge of (6m^3/s)

Assume (z) (from the top of the crest weir to the stilling basin floor), z = 2.0 +0.28 = 2.28 m, so the drop number becomes:

$D = \left[\frac{y_c}{z}\right]^3 = \left[\frac{0.86}{2.28}\right]^3$ =0.054, using the drop pertinent equations

Ld = (4.3) (z) $D^{0.27}$ = (4.3) (2.28) $(0.054)^{0.27}$ =4.46m

y_1 = (0.54) (z) $D^{0.425}$ = (0.54) (2.28) $(0.054)^{0.425}$ =0.36m

y_2 = (1.66) (z) $D^{0.27}$ = (1.66) (2.28) $(0.054)^{0.27}$ = 1.72m

Lj = (6-9) $(y_2 - y_1)$ = 6.9 (1.72 -0.36) = 9.4m

Again the sequent depth (y_2 = 1.72m) is greater than the normal depth ($y_n = 1.53m$). Therefore the basin floor must be depressed.

Assume a lowering of (0.30m), the drop number will become

z = 2.0 +0.28 + 0.3= 2.58m

$D = \left[\frac{0.86}{2.0+0.28+0.30}\right]^3 = \left[\frac{0.86}{2.58}\right]^3 = 0.037m$

By the same equation:-

Ld = 4.55m, y_1 = 0.343m, y_2 = 1.76m,L j =9.8m.

This will ensure that the jump is contained within the stilling basin.

By using figure (4.2), $\frac{z}{y_c} = \frac{2.58}{0.86} = 3$

$\frac{E_1}{y_c}$ = 4.5 so the energy lost

$\frac{E_L}{y_c}$ = 0.95, E_L = 0.82m

$\frac{E_2}{y_c}$ = 2.15, E_2 =1.85m

The energy lost in the jump is given by

$E_j = \frac{(y_2 - y_1)^3}{4y_1\, y_2} = \frac{(1.76-0.34)^3}{(4)(1.76)(0.34)} = 1.2\text{m}$, so

The energy lost in the basin = $E_j + E_l$ = 1.2m + 0.82m =2.02m

∴ Energy lost in the basin = 2.02m.

Which is what was required.

The final design of the basin with the obtained dimensions

Is shown in figure (4.4).

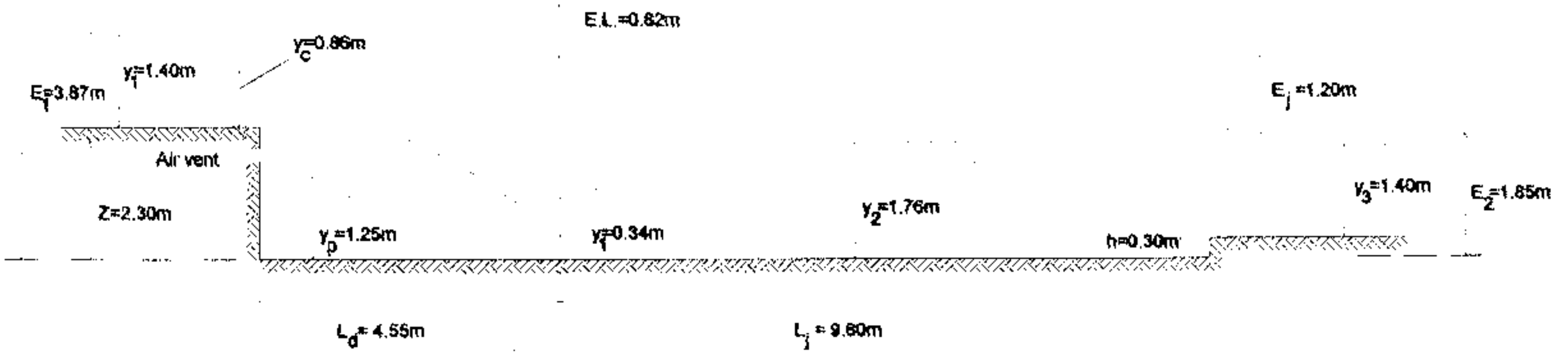


Fig.(4.4) Dimensions for a straight drop

4.3 Case 2

Stilling Basin for the Chute

Figure (4.5) shows common chute notation. The usual slope of inclined channel section is steep and takes a value between 2:1 and 6:1.This means that the control is at inlet. Therefore the design entails calculation of the water surface profile from the inlet to the bottom of the structure and dimensioning of the energy dissipation system.

Fig.(4.5) Common chute notation

The depth of flow at the toe of the glacis can be calculated sufficiently accurately for design purpose when the length of the sloping glacis is less than 10m by considering the energy equation between the upstream channel and the toe of the glacis. From figure (4.5), one can write:

$$E_1 = y_1 + q^2/2g\, y_1^2 \qquad (4.13)$$

Where q is the discharge per unit width, E_1 the total energy upstream and y_1 the depth at the toe of the glacis. The hydraulic jump equation can be used to find the sequent depth of the hydraulic jump y_2 and the energy lost can be found from equation (2.3). Comparison can be made between the sequent depth and tailwater depth to indicate whether or not the basin floor needs to be lowered.

The parameters for flow at case 1 (vertical drop) are used to determine the suitable chute dimensions to lower the upstream and downstream water levels by 2m. The procedure shall be carried out as follows:

a) From case1: upstream normal depth y_n=1.53m, bed width in the trapezoidal channel b= 2.4m and upstream specific energy E_s= 1.566m.

b) At the chutes approach: The critical depth y_c = 0.86m, B= 2.4m, q=$\frac{6}{2.4}$ =2.5m^2/s, p (which should equal to the weir height) = 0.28m.

It was mentioned in case 1 that these dimensions ensure that there will be no serious drawdown in the canal upstream at flows lower than 6m^3/s. As in case 1, the design discharge is equal to 5m^3/s. The upstream and downstream canal conditions are similar. So, the energy lost can be equated to the difference in water levels. Therefore, the head loss in the chute and the hydraulic jump, He, in figure (4.5) should equal to 2m. Table (4.1) shows the procedure which should be followed.

Table (4.1) calculation of the chute

End step h (m)	**Z (m)**	**E_1 (m)**	**y_1 (m)**	**V_1=q/y_1 (m/s)**	**F_1**	**y_2 (m)**	**He (m)**
0	2.00	3.566	0.313	7.99	4.56	1.87	1.61
0.10	2.10	3.666	0.308	8.12	4.67	1.89	1.70
0.20	2.20	3.766	0.303	8.25	4.79	1.90	1.77
0.30	2.30	3.866	0.299	8.36	4.88	1.92	1.85
0.40	2.40	3.966	0.295	8.47	4.98	1.94	1.94
0.50	2.50	4.066	0.290	8.62	5.11	1.96	2.05

The procedure in table (4.1) is based on assuming a value of the end steep h (the value of lowering the basin) as shown in figure (4.5) and find the corresponding value of the head lost in the chute He so,

Z =2.0+h, E_1 = z+y_n, y_1 (from equation (4.13)) = E_1 - $q^2/2gy^2{}_1$

$V_1 = q/y_1$, $F_1 = \frac{V_1}{\sqrt{g y_1}}$, $y_2 = \frac{y_1}{2}(\sqrt{1+8F^2{}_1}-1)$ and He =Ej (the loss in the hydraulic jump). This means that the loss in sloping glacis is neglected. Following the above equations, the procedure is for h=o

Z= 2.0+h = 2m, E_1 = z + y_n = 2+ 1.566 = 3.566 m,

$$y_1 = E_1 - \frac{q^2}{2g\,y_1^2},\ q = 2.5\text{m}^2/\text{s so } y_1 = 3.566 - \frac{(2.5)^2}{(2)(9.8y_1^2)} \text{ or}$$

$$y_1 + \frac{(2.5)^2}{(19.62)(y_1^2)} = 3.566 \text{ by trial \&error } y_1 = 0.313\text{m}$$

$$V_1 = \frac{q}{y_1} = \frac{2.5}{0.313} = 7.99 \text{ m/s}$$

$$F_1 = \frac{V_1}{\sqrt{g y_1}} = \frac{7.99}{\sqrt{(9.81)(0.313)}} = 4.56$$

$$y_2 = \frac{y_1}{2}(\sqrt{1 + 8\,F^2{}_1} - 1) = \frac{0.313}{2}(\sqrt{1 + (8)\,(4.56)^2}\,-1) = 1.87$$

$$E_j = \frac{(y_2 - y_1)^3}{4\,(y_1)(y_2)} \text{ or } \frac{(1.87 - 0.313)^3}{(4)(0.313)(1.87)} = 1.61\text{m}$$

He = E_j = 1.61m.

The value of h is 0.45m and He = 2.0 by interpolation from the above table. With h = 0.45m y_1 = 0.293m, y_2 = 1.95m and for jump controlled by abrupt rise, the length of the jump is given by L_b= 5(h +y_3) and since $\frac{h}{y_1} = \frac{0.45}{0.293} =$ 1.54, with F =F_1 = 4.56, figure (4.6) gives y_3/y_1 = 3.8 or y_3 = 1.113

L_b =5 (0.45 + 1.113) =7.82m.

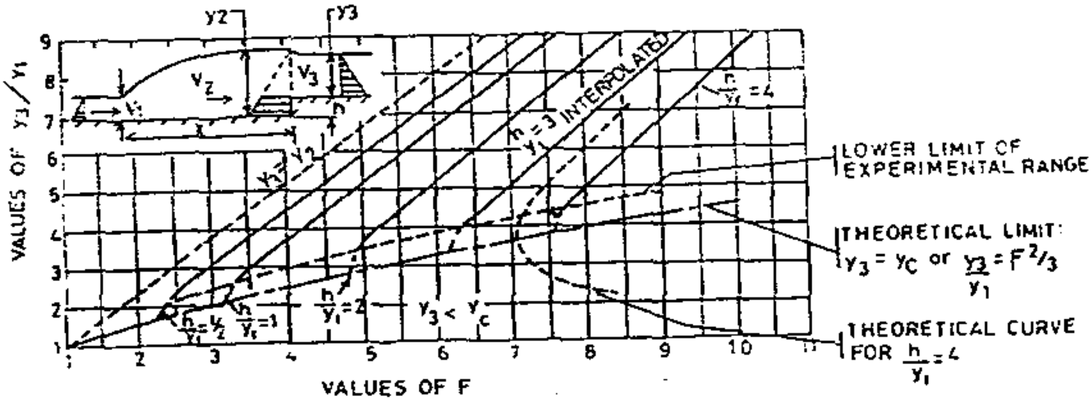


Fig. (4.6) Jump controlled by abrupt rise for L_b =5 (h +y_3)

The horizontal length of the chute assuming a slope of 2:1 (normally used) =L_d = 2 (z +h +p) = 2 (2+0.45 + 0.28) = 5.5m.The final dimensions of the chute are shown in figure (4.7).

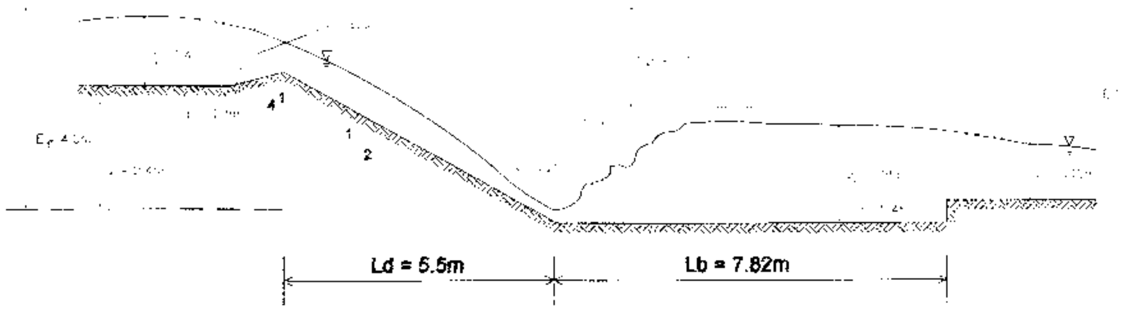


Fig.(4.7) Final dimensions of the chute

4.4 Case 3

Stilling Basin Design for Spillway

USBR Stilling basin II shall be used, figure (4.9) a

At the toe of spillway, the flow has high velocity and to avoid damage of erosion a stilling basin is suggested to achieve this purpose. Figure (4.8) was prepared to show the actual velocity at the toe of spillways under various heads, falls, and slopes from 1on 0.6 to 1on 0.8.

The design head for the spillway Hd = H in figure (4.8) is equal to 14.11 ft.

water surface El. = 920 m = 30185 ft.

Tail water El. = 895 m = 2936.5 ft.

Floor El. = 885 m = 2904 ft.

L=15m=49.22 ft.

Z=920- 885

Z = 35m= 115 ft.

Q = 300 m^3/s = 10594.5 ft^3/sec.

=10601 ft^3/sec.

With these values of Hd and Z, the velocity at the toe of spillway is equal to 70 ft. /s or V_1 =70 ft. /s.

Therefore, the depth of flow y_1=Q/LV_1 or

y_1 = 10601/ (49.22 *70) = 3.08 ft. and

Q=10601/49.22 = 215.4 $ft^3/s/ft$.

The Froude number $F_1 = V_1/(gy_1)^{½}$ =70/(32.2 ∗ 3.08 $)^{½}$

=70/9.96 = 7.03 use 7.0

The entering Froude number F_1 is considered equal to 7; the flow is super-critical flow with high Froude number. Since the fall of the water z =115 ft. < 200 ft. and the discharge per unit width q =215.4 $ft^3/s/ft$. < 500 $ft^3/s/ft$.

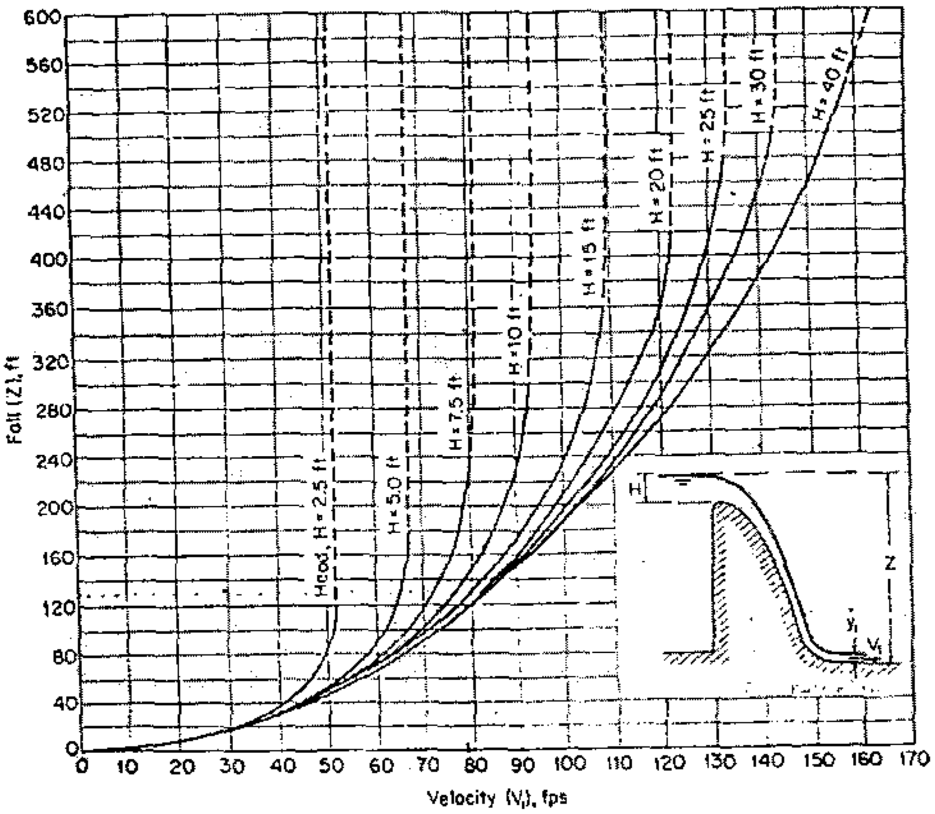


Fig. (4.8) curves for determination of velocity at the toe of spillway with slopes 1 on o.6 to 0.8

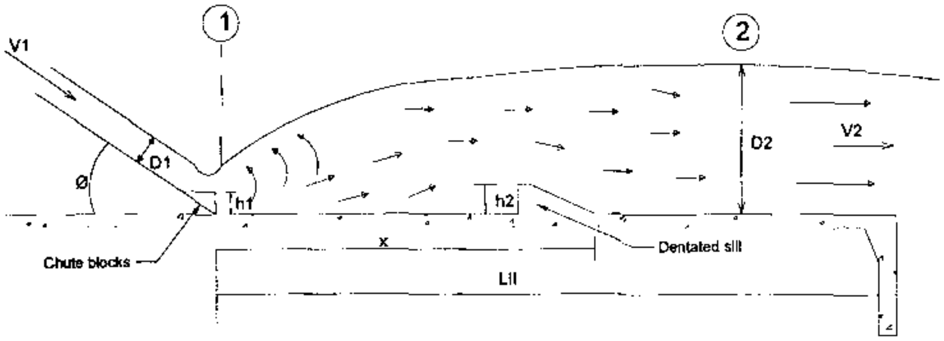


Fig. (4.9) a Definition of symbols for stilling basin USBR II

And the entering Froude number F_1 =7 > 4, a stilling basin II figure (4.9) of USBR is recommended to be used.

USBR basin II was developed for stilling basin in common use for high-dam and earth-dam spillways and for large canal structures.

The basin contains chute blocks at the upstream end and a dentate sill near the downstream end. No baffle piers are used because the relatively high velocities entering the jump might cause cavitation on piers. The detailed design and the data for computations are shown in figure (4.9).

The rules recommended for the design are as follow:

1- Set apron elevation to utilize full sequent tailwater depth, plus an added factor of safety if needed. The dashed lines in figure (4.9) b are guides drawn for several of actual tailwater depth to sequent depth. Studies of existing design indicate that most of the basins were designed for sequent tailwater depth or less. However, there is a limit, which is governed by the curve labeled "Minimum TW depth." This curve indicates the point at which the front of the jump moves away from the chute blocks. In other words, any additional lowering of the tailwater depth would cause the jump to leave the basin, that is, would produce a "Sweep-out". For design purposes, the basin should not be designed for less than sequent depth. For additional safety, in fact, the Bureau recommends that a minimum safety margin of 5% of D_2 be added to the sequent depth.

2- Basin II may be effective down to a Froude number of 4, but the lower values should not be taken for granted. For lower values, design considering wave suppression are recommended.

3- The length of basin can be obtained from the length-of -jump curve Figure (4.9) C.

4- The height of chute blocks is equal to the depth D_1 of flow entering the basin.

5- The width and spacing should be approximately equal to D_1; however, this may be varied to eliminate the need for fraction blocks. A space equal to 0.5 D_1 is preferable along each wall to reduce spray and maintain desirable pressure.

6- The height of the dentate sill is equal to $0.2D_2$, and the maximum width and spacing recommended is approximately $0.15D_2$. In this design a block is recommended adjacent to each side wall. The slope of the continuous portion of the end sill is 2:1. In the case of narrow basin, which would involve only a few dentate according to the above rule, it is advisable to reduce the width and the spacing, provided this is done proportionally. Reducing the width and spacing actually improves the performance in narrow basins, thus, the minimum width and spacing of the dentate is governed only by structural considerations.

7- It is not necessary to stagger the chute blocks and the sill dentate. in fact this practice is usually inadvisable from a construction stand point.

8- The verification tests on basin II indicated no perceptible change in the stilling-basin action with the slope of the chute preceding the basin. The slope of chute varied from 0.6:1 to 2:1 in these test. Actually, the slope of the chute does have an effect on the hydraulic jump in some cases. It is recommended that the sharp intersection between chute and basin apron be replaced with a curve of reasonable radius (R $\geq 4D_1$) when the slope of the chute is 1:1 or greater. Chute blocks can be incorporated on the curved faces as readily as on the plane surfaces. On steep chutes the length of the top surface on the chute blocks should be made sufficiently long to deflect the jet.

The above rules will result in a safe, conservation stilling basin for spillways with fall up to 200 ft. and for flows up to 500 cfs. per foot of basin width, provided the jet entering the basin is reasonably uniform both in velocity and in depth. For greater falls, larger unit discharges, or possible asymmetry, a model study of the specific design is recommended. The approximate water- surface and pressure profiles of a jump in the basin are shown in figure (4.9) d.

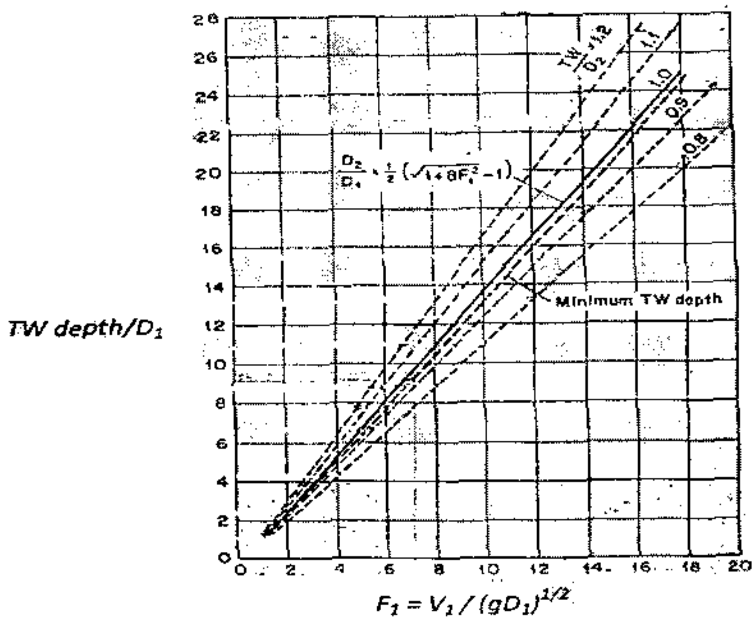
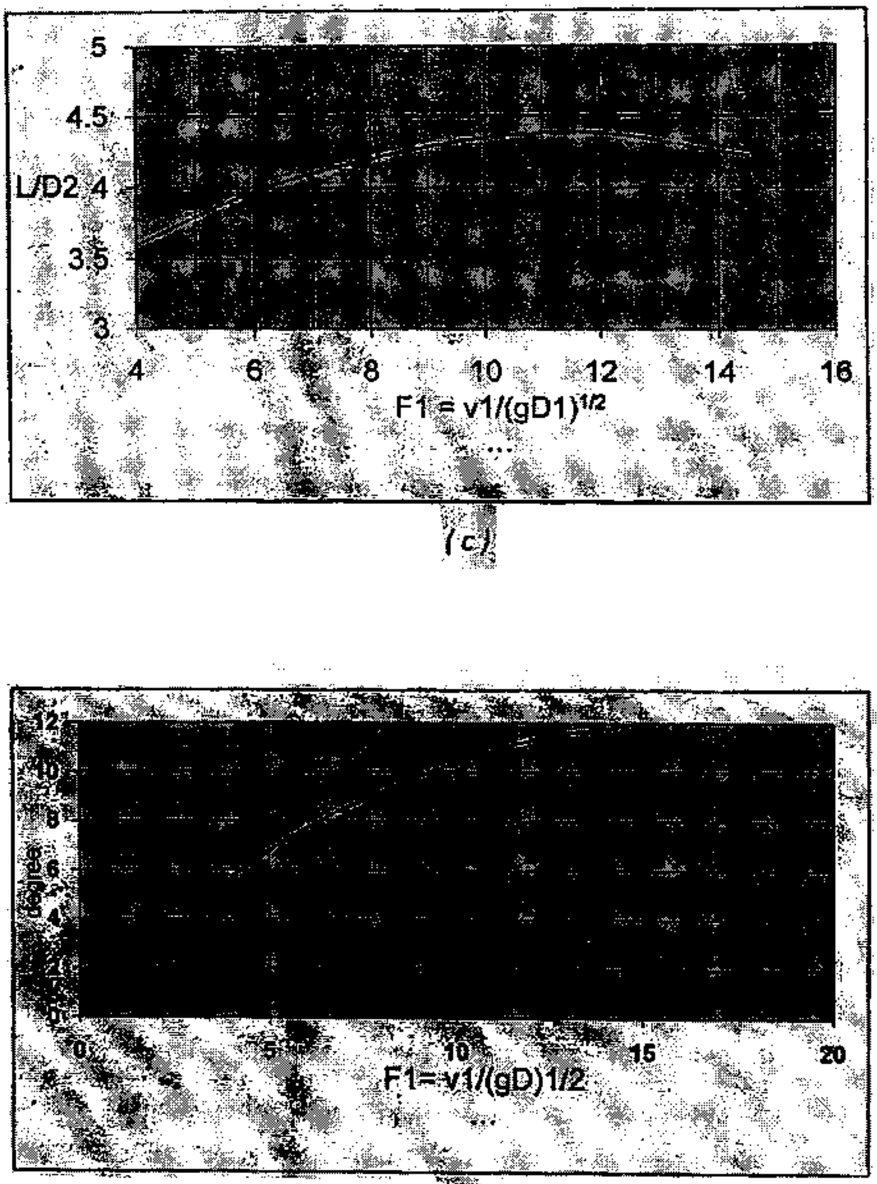


Fig. (4.9) b Minimum tail water depths for stilling basin USBR II



(c)

(d)

Fig. (4.9) c, d (C) Length of hydraulic jump; (d) approximate water surface and pressure profiles (conjugate depth = sequent depth)

Following the above eight steps, the design of the stilling basin will be accomplished.

Using the hydraulic jump equation:

$$D_2/D_1 = \frac{1}{2}(\sqrt{1+8F_1^2} - 1\ ) \tag{2.1}$$

On figure (4.9) b (solid line) with F_1=7 and D_1 = 3.08ft,

Then by using figure (4.9) b (the solid line) or the hydraulic jump equation:

$$D_2/D_1 = \frac{1}{2}(\sqrt{1+8F^2{}_1}\ \text{-}1)$$

$$\therefore D_2/D_1 = \frac{1}{2}(\sqrt{1+8\,(7)^2}\ \text{-}1) = 9.41$$

∴ Then tailwater TW= D_2=9.41D_1= (9.41 *3.08)

=28.983ft=8.83m

For the downstream condition, the tail water is existing at 895m

The solid line in the above figure considers TW =D_2.

The floor elevation should be set equal to 895-8.83m = 886.17m instead of 885m

The minimum TW depth reads 9.2

TW = (9.2 * 3.08) =28.336 ft. = 8.64m

Difference 28.983 – 28.336 = 0.647 ft.

∴ Margin of safety = (0.647/28.983) * 100 = 2.23%.

Now the total fall is 920 – 886.17 = 33.83m.

$h_2 = 0.2D_2 = 0.2 * 8.83$

= 1.77m =177 cm use 180 cm

Crest of the dentate sill = 0.02 D_2 = 0.177 m

= 17.7 cm use 20 cm

$W_2 = 0.15\ D_2 = 0.15 * 8.83$

= 1.32 m = 132 cm use 130 cm.

Number of Chute Blocks:

Width of the stilling basin L =15 m =1500 cm

n = number of chute blocks (SB)

(n - 1) = number of space between them (s)

n (SB) + (n - 1) s = 1500 – 50 = 1450 cm

n (95) + (n – 1) 95 = 1450 cm

95 n + 95n – 95 = 1450 cm

180 n = 1545

∴ n = 8.43 use 8 chute blocks

∴ Number of space = 8-1 = 7 spaces

Distance between last block and the wall equal

1500 - (8 + 7) 95

= 1500 – 1425 = 75 cm

Using figure (4.9) d the angle$\propto = 8.4^{\circ}$

Use S_1 = 100 cm, i.e. increase the distance between chute blocks 5 cm to become 1oo cm. Therefore, the distance between last chute block and the wall becomes 75 – (7*5) = 40 cm.

The final design of the stilling basin is shown in figure (4.10).

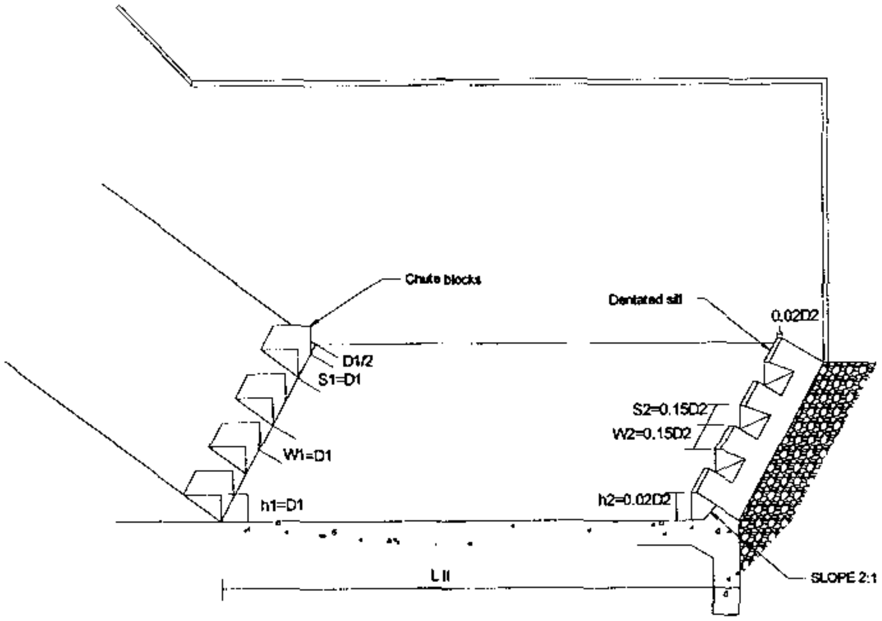


Fig.(4.9) e Recommended proportions

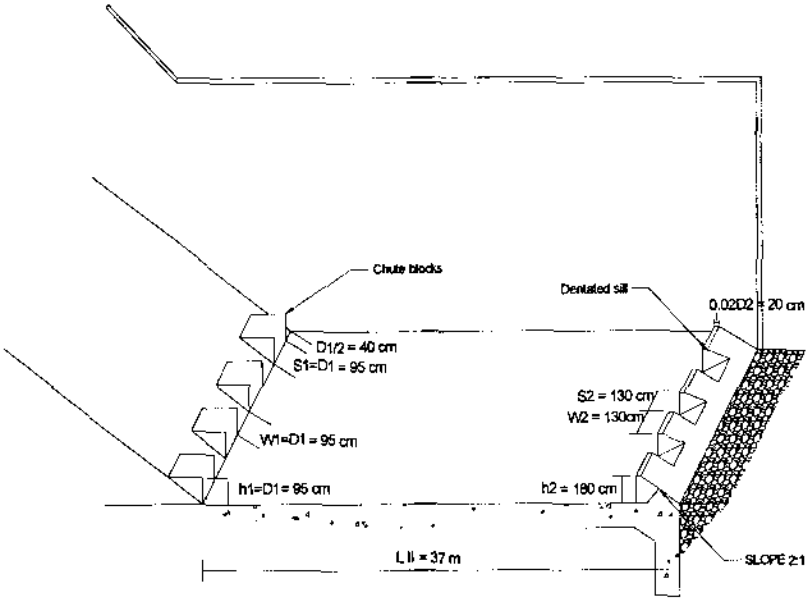


Fig.(4.10) Final design of the stilling basin

4.5 Case 4

Stilling Basin for High Velocity Pipe Flow

1- Jet Mechanics in Infinite Field

Extensive study has been made of the mechanics of a submerged jet entering a static fluid of the same properties.

Figure (4.11) is schematic representation of a round jet entering on infinite field.

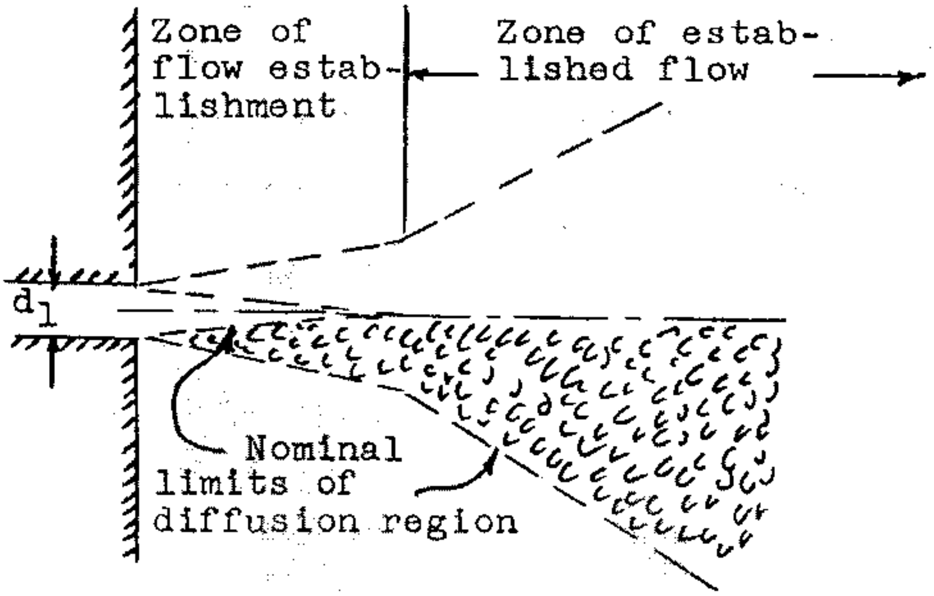


Fig. (4.11) schematic representation of a round jet issuing at infinite field of water

The kinetic energy of the oncoming flow from the jet will be converted in to kinetic energy of turbulence which will decay through viscous shear. As the jet penetrates the fluid, it will decelerate while the surrounding fluid accelerates, and the total rate of flow past successive sections of each jet will increase with distance from the outlet (efflux section). However, momentum flux past successive section will be constant. The jet also will expand as the distance from the efflux sections increases.

At a large distance from the efflux section the longitudinal velocities approach zero and the only kinetic energy remaining, if any, will be the kinetic energy of turbulence. The two zones of flow considered are the zone of flow establishment and the zone of established flow. The zone of flow establishment is the first zone adjacent to the efflux section of either a two-dimensional or a three- dimensional submerged jet. It is a zone where the effect of the surrounding fluid is not felt throughout the jet and the maximum velocity is equal to the efflux velocity V_1 . This is a zone of high shear and the eddies generated in this region will immediately result in a lateral mixing process which progresses in word and outward with distance from efflux section. This mixing process, the fluid within the jet gradually decelerates while surrounding fluid is gradually accelerated or entrained. The limit of this initial zone of flow establishment is reached when mixing has penetrated to the centerline of the jet and the flow is considered to be fully established. The reduction in the centerline velocity is balanced by the expanding eddy region, and the diffusion process continues there after without essential change in character. The boundaries of the two zones of flow and the diffusion region are accepted as convenient nominal designations. Previous study (12) indicates the variation of the center line velocity with distance from outlet as shown in Figure (4.12). Figure (4.13) shows variation of energy flux downstream from orifice. A three- dimensional jet discharging in to a basin which enlarges from orifice diameter to a maximum of (24) times the orifice diameter. The horizontal line in Figure (4.12) is for the zone of flow establishment and ends at $\frac{X}{d_1} = 6.2$ where X is the distance from the efflux section and d_1 is the diameter of the outlet. The sloping line for the zone of established flow has 1:1 slope. According to these experimental results, the centerline velocity V_c in the zone of established flow ($6.2 \leq \frac{X}{d_1} \leq 600$) is given by

$$V_c = 6.2\, V_1 \frac{d_1}{X} \qquad (4.13)$$

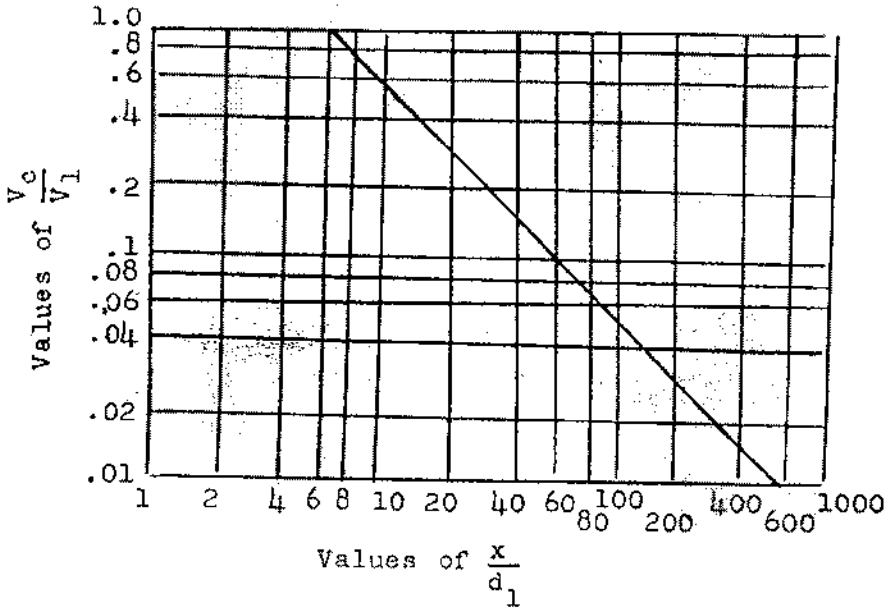


Fig. (4.12) variation of centerline velocity for flow from orifice (12)

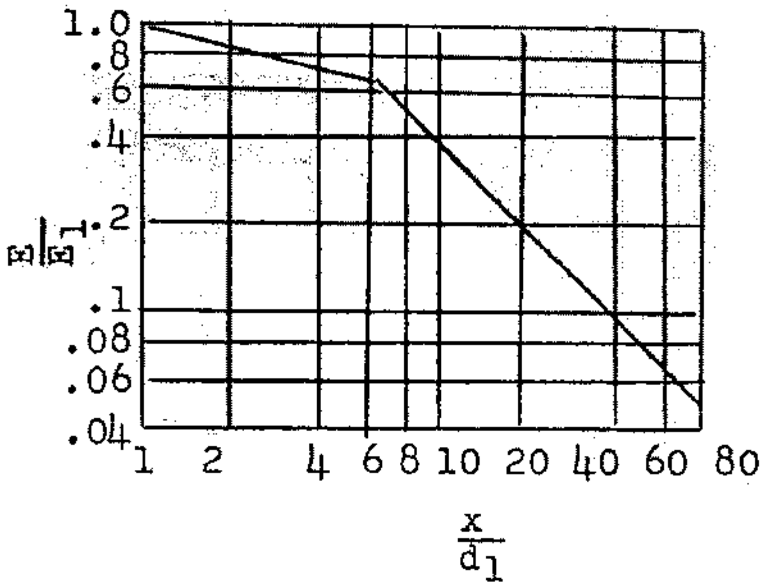


Fig. (4.13) variation of energy flux downstream from orifice (12)

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Design

For full flow water within the pipe with 200 mm diameter, with normal supply discharge of 157L/s. This pipe needs a stilling basin design to dissipate the excess energy of the flow.

Calculations

Q =157 L/S = 0.157 m^3/S.

d =200 mm = 0.2 m.

V = Q/A

$= 0.157/\frac{\pi(0.2)^2}{4}$

$\therefore\ V = 5$ m/s.

$E_1 = \frac{V_1^2}{2g} = \frac{5^2}{2*9.81}$

$\therefore\ E_1 = 1.27$ m

1- When $\frac{V_c}{V_1} = 1, \frac{X}{d_1} = 6.2$ and from figure (4.12)

$\therefore$ X = 6.2 *0.2 = 1.24 m,

$\frac{E}{E_1} = 0.68$, from figure (4.13)

$\therefore$ E = 0.68 * 1.27 = 0.864 m

The efficiency = $\frac{E1-E}{E1} = \frac{1.27-0.864}{1.27}$

$\therefore$The efficiency = 0.32 or 32%.

2 – When $\frac{V_c}{V1} = 0.2, \frac{X}{d1} = 30$ and from figure (4.12)

$\therefore x = 30 * 0.2 = 6$ m

The required to total length = 6m +1.24 = 7.24m

$\frac{E}{E1} = 0.15$, from figure (4.13)

$\therefore E = 0.15 * 1.27 = 0.191$ m

The efficiency $= \frac{E1 - E}{E1} = \frac{1.27 - 0.191}{1.27}$

$\therefore$The efficiency = 0.85 or 85%.

Figure (4.14) shows the dimensions for the stilling basin of the high velocity pipe flow. As shown in this figure the width of the basin is taken 3 m and its height is 2 m.

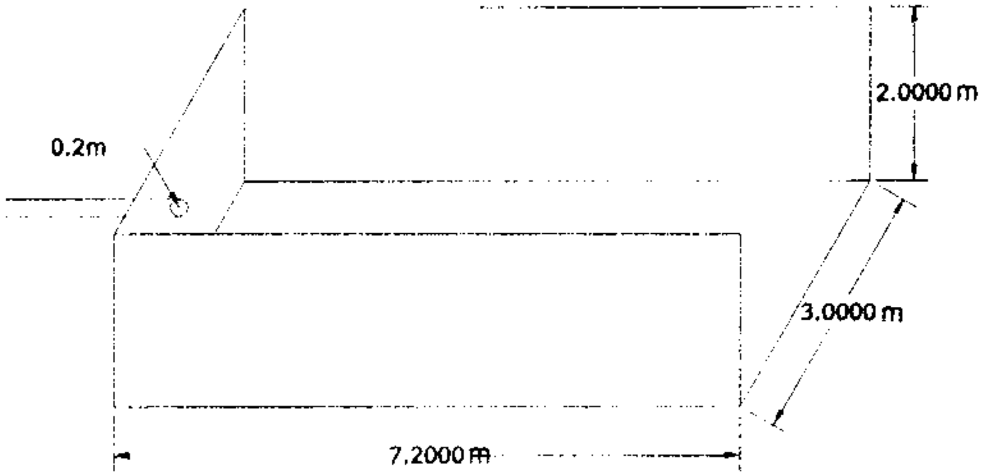


Fig. (4.14) Final dimensions of stilling basin for the high velocity pipe flow

5.1 Summary

The hydraulic structures are very important in the control and management of the water resources. When the flow in these structures is high, a stilling basin is used to dissipate the excess energy. Established experimental curves are used for the design of these basins. In this last year project, four types of stilling basins were analyzed and designed for the vertical drop structure, the chute, spillway structure, and for high velocity pipe flow. Other stilling basins for high velocity pipe flow were just illustrated in figures and explanation without design. The required experimental curves were placed with the design in order to follow the hydraulic design procedure.

5.2 Conclusions

The stilling basins are important hydraulic structures which are used to dissipate the excess energy of flow. The hydraulic jump as device to achieve this purpose is usually used in these basins. The design considerations are used in designing the stilling basin to simplified the difficulties which are usually result different design information's. The design problems can be followed for the selection of suitable dimensions due to the availability of hydraulic information's as it was in the case of the drop, chute, spillway and high velocity pipe flow. The use of appurtenances in the stilling basin such as chute blocks, sills and dentated sills are very useful excess for stabilization of the flow performance of the basin.

5.3 Recommendation

It is recommended to design stilling basin for the taken structures for different discharges.

References

1- Study of Rutba dam on Horan valley- institution of improving Tharthar project 1969.

2- Final drawings of Rutba dam- general directorate of dams and reservoirs 1970.

3- Study of Abila dam/General directorate of dams and reservoirs 1971.

4- Primary report on establishing small dams/Gen. Direct. Of dams and reservoirs 1973.

5- Study of Aghry dam on Aghry valley/Gen. Direct. Of dams and reservoirs 1974.

6- Report of geological studies of Hussainia dam/Gen. Direct. Of dams and reservoirs 1974.

7- Study of Great dam of Rutba/Gen. Direct. of dams and reservoirs 1974.

8- Report of evaluation of small dams in Iraq (western desert) - ministry of planning 1980.

9- Instituting of the resident engineer for establishing small dams in western dessert/ Rutba 1994.

10- Open channel Hydraulics by ven Te chow, McGraw – Hill, 1959.

11- Research studies on stilling basins, energy dissipators and associated appurtenances, U.S. Bureau of Reclamation, Hydraulic laboratory Report No. Hyd – 399 June, 1955.

12- Imara, N.H., Jet to Jet energy dissipator, master thesis, submitted to university of Utah 1967.

13- Design manual for irrigation and drainage, pencol engineering consultants organization for land reclamation general establishment for design and research.